Computer Vision System Toolbox™
Reference

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2-D Autocorrelation
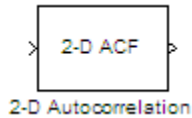
Library

Statistics

`visionstatistics`

Description

The 2-D Autocorrelation block computes the two-dimensional autocorrelation of the input matrix. Assume that input matrix A has dimensions (Ma, Na). The equation for the two-dimensional discrete autocorrelation is

$$C(i, j) = \sum_{m=0}^{(Ma-1)} \sum_{n=0}^{(Na-1)} A(m,n) \cdot conj(A(m+i, n+j))$$

where $0 \le i < 2Ma - 1$ and $0 \le j < 2Na - 1$.

The output of this block has dimensions $(2Ma - 1, 2Na - 1)$.

Port	Input/Output	Supported Data Types	Complex Values Supported
Input	Vector or matrix of intensity values or a scalar, vector, or matrix that represents one plane of the RGB video stream	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes–
Output	Autocorrelation of the input matrix	Same as Input port	Yes

If the data type of the input is floating point, the output of the block has the same data type.

Fixed-Point Data Types

The following diagram shows the data types used in the 2-D Autocorrelation block for fixed-point signals.
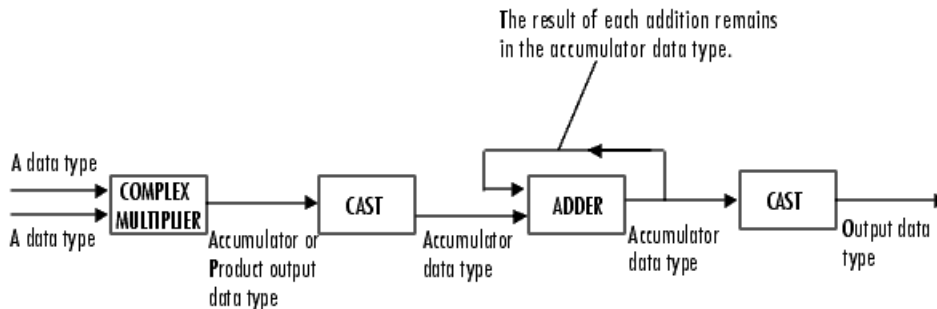
You can set the product output, accumulator, and output data types in the block mask as discussed in "Parameters" on page 1-4.

The output of the multiplier is in the product output data type if at least one of the inputs to the multiplier is real. If both of the inputs to the multiplier are complex, the result of the multiplication is in the accumulator data type. For details on the complex multiplication performed, refer to "Multiplication Data Types".

Parameters

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range".

Product output

Specify the product output data type. See "Fixed-Point Data Types" on page 1-3 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block:

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Accumulator

Use this parameter to specify how to designate the accumulator word and fraction lengths. Refer to "Fixed-Point Data Types" on page 1-3 and "Multiplication Data Types" for illustrations depicting the use of the accumulator data type in this block. The accumulator data type is only used when both inputs to the multiplier are complex.

- When you select `Same as product output`, these characteristics match those of the product output.

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox software is 0.

Output

Choose how to specify the output word length and fraction length.

- When you select `Same as input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox software is `0`.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink® documentation.

See Also

2-D Correlation	Computer Vision System Toolbox
2-D Histogram	Computer Vision System Toolbox
2-D Mean	Computer Vision System Toolbox
2-D Median	Computer Vision System Toolbox
2-D Standard Deviation	Computer Vision System Toolbox
2-D Variance	Computer Vision System Toolbox
2-D Maximum	Computer Vision System Toolbox
2-D Minimum	Computer Vision System Toolbox

Introduced before R2006a

2-D Convolution

Compute 2-D discrete convolution of two input matrices
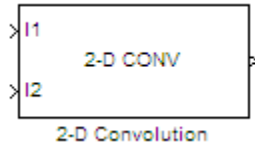
Library

Filtering

`visionfilter`

Description

The 2-D Convolution block computes the two-dimensional convolution of two input matrices. Assume that matrix A has dimensions (*Ma*, *Na*) and matrix B has dimensions (*Mb*, *Nb*). When the block calculates the full output size, the equation for the 2-D discrete convolution is

$$C(i, j) = \sum_{m=0}^{(Ma-1)} \sum_{n=0}^{(Na-1)} A(m, n) * B(i - m, j - n)$$

where $0 \le i < Ma + Mb - 1$ and $0 \le j < Na + Nb - 1$.

Port	Input/Output	Supported Data Types	Complex Values Supported
I1	Matrix of intensity values or a matrix that represents one plane of the RGB video stream	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes
I2	Matrix of intensity values or a matrix that represents one plane of the RGB video stream	Same as I1 port	Yes
Output	Convolution of the input matrices	Same as I1 port	Yes

If the data type of the input is floating point, the output of the block has the same data type.

The dimensions of the output are dictated by the **Output size** parameter. Assume that the input at port I1 has dimensions (Ma, Na) and the input at port I2 has dimensions (Mb, Nb). If, for the **Output size** parameter, you choose `Full`, the output is the full two-dimensional convolution with dimensions ($Ma+Mb$-1, $Na+Nb$-1). If, for the **Output size** parameter, you choose `Same as input port I1`, the output is the central part of the convolution with the same dimensions as the input at port I1. If, for the **Output size** parameter, you choose `Valid`, the output is only those parts of the convolution that are computed without the zero-padded edges of any input. This output has dimensions (Ma-Mb+1, Na-Nb+1). However, if `all(size(I1)<size(I2))`, the block errors out.

If you select the **Normalized output** check box, the block's output is divided by `sqrt(sum(dot(I1p,I1p))*sum(dot(I2,I2)))`, where `I1p` is the portion of the I1 matrix that aligns with the I2 matrix. See "Example 2" on page 1-10 for more information.

Note When you select the **Normalized output** check box, the block input cannot be fixed point.

Fixed-Point Data Types

The following diagram shows the data types used in the 2-D Convolution block for fixed-point signals.
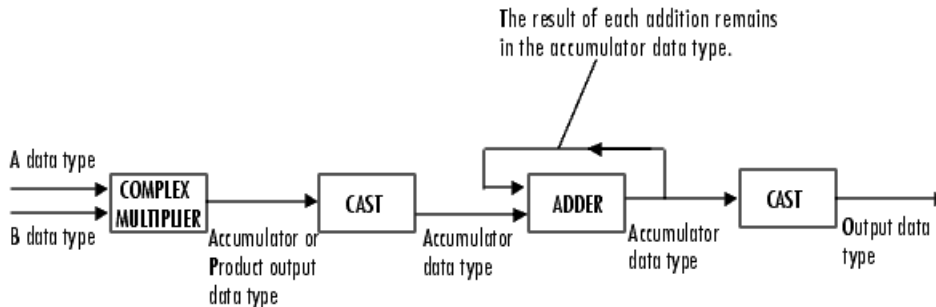
You can set the product output, accumulator, and output data types in the block mask as discussed in "Parameters" on page 1-13.

The output of the multiplier is in the product output data type if at least one of the inputs to the multiplier is real. If both of the inputs to the multiplier are complex, the result of the multiplication is in the accumulator data type. For details on the complex multiplication performed, refer to "Multiplication Data Types".

Examples

Example 1

Suppose I1, the first input matrix, has dimensions (4,3) and I2, the second input matrix, has dimensions (2,2). If, for the **Output size** parameter, you choose Full, the block uses the following equations to determine the number of rows and columns of the output matrix:

$$C_{\text{full}_{\text{rows}}} = I1_{\text{rows}} + I2_{\text{rows}} - 1 = 5$$

$$C_{full_{columns}} = I1_{columns} + I2_{columns} - 1 = 4$$

The resulting matrix is

$$C_{full} = \begin{bmatrix} c_{00} & c_{01} & c_{02} & c_{03} \\ c_{10} & c_{11} & c_{12} & c_{13} \\ c_{20} & c_{21} & c_{22} & c_{23} \\ c_{30} & c_{31} & c_{32} & c_{33} \\ c_{40} & c_{41} & c_{42} & c_{43} \end{bmatrix}$$

If, for the **Output size** parameter, you choose `Same as input port I1`, the output is the central part of C_{full} with the same dimensions as the input at port I1, (4,3). However, since a 4-by-3 matrix cannot be extracted from the exact center of C_{full}, the block leaves more rows and columns on the top and left side of the C_{full} matrix and outputs:

$$C_{same} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \\ c_{41} & c_{42} & c_{43} \end{bmatrix}$$

If, for the **Output size** parameter, you choose `Valid`, the block uses the following equations to determine the number of rows and columns of the output matrix:

$$C_{valid_{rows}} = I1_{rows} - I2_{rows} + 1 = 3$$

$$C_{\text{valid}_{\text{columns}}} = I1_{\text{columns}} - I2_{\text{columns}} + 1 = 2$$

In this case, it is always possible to extract the exact center of C_{full}. Therefore, the block outputs

$$C_{\text{full}} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \\ c_{31} & c_{32} \end{bmatrix}$$

Example 2

In convolution, the value of an output element is computed as a weighted sum of neighboring elements.

For example, suppose the first input matrix represents an image and is defined as

```
I1 = [17   24    1    8   15
      23    5    7   14   16
       4    6   13   20   22
      10   12   19   21    3
      11   18   25    2    9]
```

The second input matrix also represents an image and is defined as

```
I2 = [8    1    6
      3    5    7
      4    9    2]
```

The following figure shows how to compute the (1,1) output element (zero-based indexing) using these steps:

1 Rotate the second input matrix, I2, 180 degrees about its center element.

2 Slide the center element of I2 so that it lies on top of the (0,0) element of I1.

3 Multiply each element of the rotated I2 matrix by the element of I1 underneath.

4 Sum the individual products from step 3.

Hence the (1,1) output element is

$$0 \cdot 2 + 0 \cdot 9 + 0 \cdot 4 + 0 \cdot 7 + 17 \cdot 5 + 24 \cdot 3 + 0 \cdot 6 + 23 \cdot 1 + 5 \cdot 8 = 220 \ .$$

Values of rotated I2 matrix

2	9	4
7	5	3
6	1	8

Alignment of center element of I2

17	24	1	8	15
23	5	7	14	16
4	6	13	20	22
10	12	19	21	3
11	18	25	2	9

Image pixel values

Alignment of I2 matrix
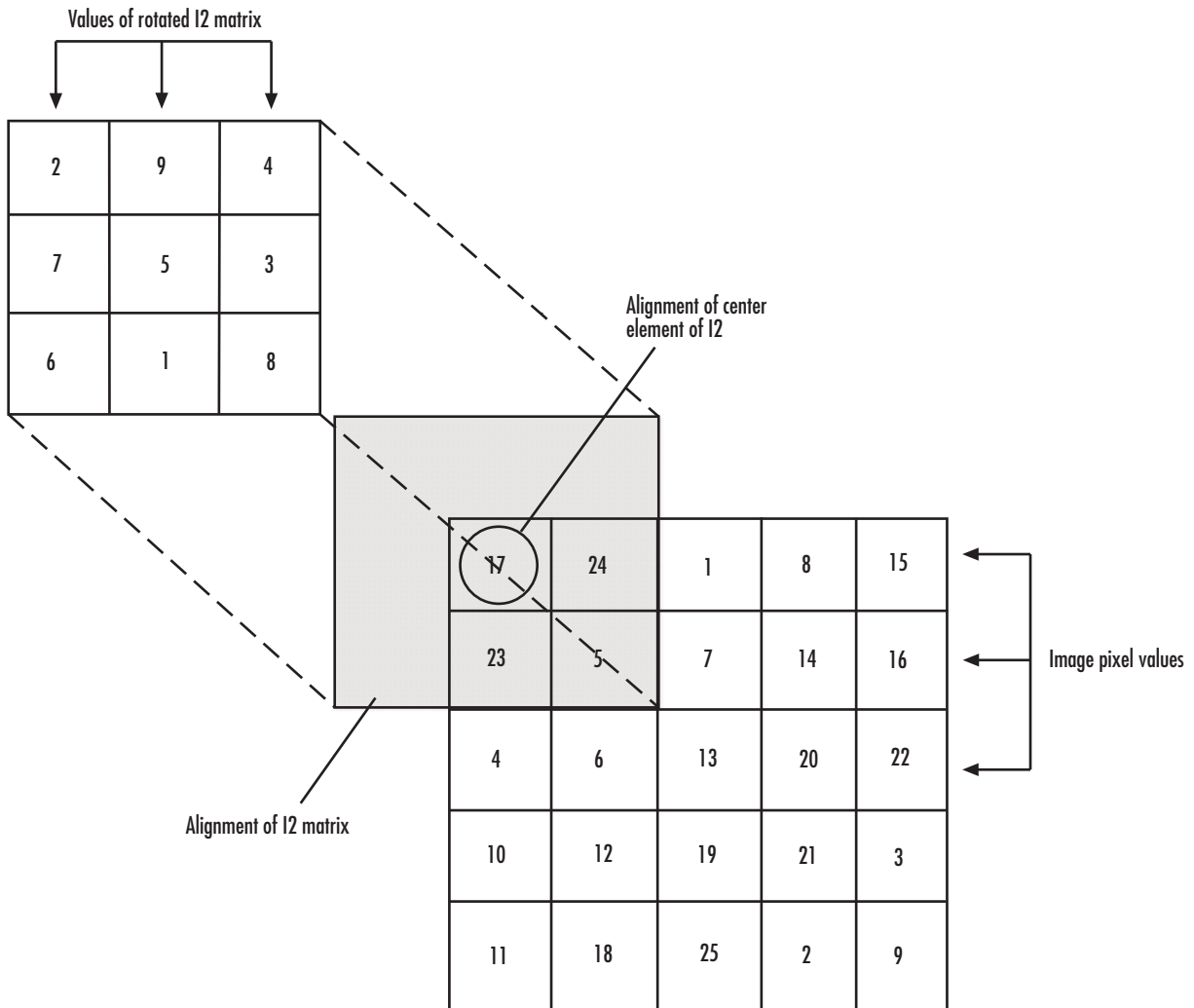
Computing the (1,1) Output of Convolution

The normalized convolution of the (1,1) output element is `220/ sqrt(sum(dot(I1p,I1p))*sum(dot(I2,I2)))` = 0.3459, where `I1p = [0 0 0; 0 17 24; 0 23 5]`.

Parameters

Output size

This parameter controls the size of the output scalar, vector, or matrix produced as a result of the convolution between the two inputs. If you choose `Full`, the output has dimensions ($Ma+Mb$-1, $Na+Nb$-1). If you choose `Same as input port I1`, the output has the same dimensions as the input at port I1. If you choose `Valid`, output has dimensions ($Ma-Mb$+1, $Na-Nb$+1).

Normalized output

If you select this check box, the block's output is normalized.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the Overflow mode for fixed-point operations.

Product output

Use this parameter to specify how to designate the product output word and fraction lengths. Refer to "Fixed-Point Data Types" on page 1-8 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block:

- When you select `Same as first input`, these characteristics match those of the first input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

The Product Output inherits its sign according to the inputs. If either or both input **I1** and **I2** are signed, the Product Output will be signed. Otherwise, the Product Output is unsigned. The following table shows all cases.

Sign of Input I1	Sign of Input I2	Sign of Product Output
unsigned	unsigned	unsigned
unsigned	signed	signed

Sign of Input I1	Sign of Input I2	Sign of Product Output
signed	unsigned	signed
signed	signed	signed

Accumulator

Use this parameter to specify how to designate the accumulator word and fraction lengths. Refer to "Fixed-Point Data Types" on page 1-8 and "Multiplication Data Types" for illustrations depicting the use of the accumulator data type in this block. The accumulator data type is only used when both inputs to the multiplier are complex:

- When you select `Same as product output`, these characteristics match those of the product output.

- When you select `Same as first input`, these characteristics match those of the first input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox software is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as first input`, these characteristics match those of the first input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

See Also

2-D FIR Filter	Computer Vision System Toolbox software

Introduced before R2006a

2-D Correlation

Compute 2-D cross-correlation of two input matrices
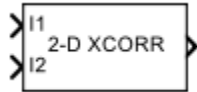
Library

Statistics

`visionstatistics`

Description

The 2-D Correlation block computes the two-dimensional cross-correlation of two input matrices. Assume that matrix A has dimensions (Ma, Na) and matrix B has dimensions (Mb, Nb). When the block calculates the full output size, the equation for the two-dimensional discrete cross-correlation is

$$C(i, j) = \sum_{m=0}^{(Ma-1)} \sum_{n=0}^{(Na-1)} A(m, n) \cdot conj(B(m + i, n + j))$$

where $0 \le i < Ma + Mb - 1$ and $0 \le j < Na + Nb - 1$.

Port	Input/Output	Supported Data Types	Complex Values Supported
I1	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes
I2	Scalar, vector, or matrix of intensity values or a scalar, vector, or matrix that represents one plane of the RGB video stream	Same as I1 port	Yes
Output	Convolution of the input matrices	Same as I1 port	Yes

If the data type of the input is floating point, the output of the block is the same data type.

The dimensions of the output are dictated by the **Output size** parameter and the sizes of the inputs at ports I1 and I2. For example, assume that the input at port I1 has dimensions (Ma, Na) and the input at port I2 has dimensions (Mb, Nb). If, for the **Output size** parameter, you choose Full, the output is the full two-dimensional cross-correlation with dimensions ($Ma+Mb$-1, $Na+Nb$-1). If, for the **Output size** parameter, you choose Same as input port I1, the output is the central part of the cross-correlation with the same dimensions as the input at port I1. If, for the **Output size** parameter, you choose Valid, the output is only those parts of the cross-correlation that are computed without the zero-padded edges of any input. This output has dimensions (Ma-Mb+1, Na-Nb+1). However, if all(size(I1)<size(I2)), the block errors out.

If you select the **Normalized output** check box, the block's output is divided by sqrt(sum(dot(I1p,I1p))*sum(dot(I2,I2))), where I1p is the portion of the I1 matrix that aligns with the I2 matrix. See "Example 2" on page 1-20 for more information.

Note When you select the **Normalized output** check box, the block input cannot be fixed point.

Fixed-Point Data Types

The following diagram shows the data types used in the 2-D Correlation block for fixed-point signals.
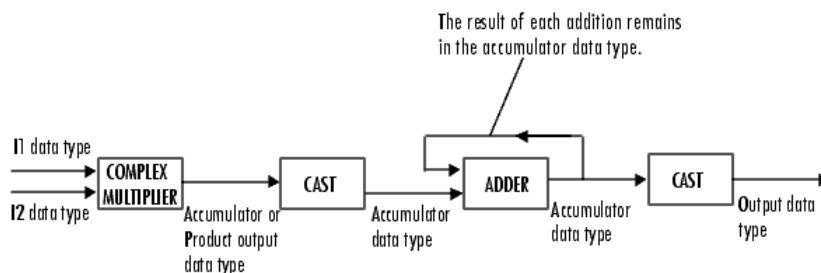
The result of each addition remains in the accumulator data type.

You can set the product output, accumulator, and output data types in the block mask as discussed in "Parameters" on page 1-22.

The output of the multiplier is in the product output data type if at least one of the inputs to the multiplier is real. If both of the inputs to the multiplier are complex, the result of the multiplication is in the accumulator data type. For details on the complex multiplication performed, refer to "Multiplication Data Types".

Examples

Example 1

Suppose I1, the first input matrix, has dimensions (4,3). I2, the second input matrix, has dimensions (2,2). If, for the **Output size** parameter, you choose Full, the block uses the following equations to determine the number of rows and columns of the output matrix:

$$C_{\text{full}_{\text{rows}}} = I1_{\text{rows}} + I2_{\text{rows}} - 1 = 4 + 2 - 1 = 5$$

$$C_{\text{full}_{\text{columns}}} = I1_{\text{columns}} + I2_{\text{columns}} - 1 = 3 + 2 - 1 = 4$$

The resulting matrix is

$$C_{\text{full}} = \begin{bmatrix} c_{00} & c_{01} & c_{02} & c_{03} \\ c_{10} & c_{11} & c_{12} & c_{13} \\ c_{20} & c_{21} & c_{22} & c_{23} \\ c_{30} & c_{31} & c_{32} & c_{33} \\ c_{40} & c_{41} & c_{42} & c_{43} \end{bmatrix}$$

If, for the **Output size** parameter, you choose `Same as input port I1`, the output is the central part of C_{full} with the same dimensions as the input at port I1, (4,3). However, since a 4-by-3 matrix cannot be extracted from the exact center of C_{full}, the block leaves more rows and columns on the top and left side of the C_{full} matrix and outputs:

$$C_{\text{same}} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \\ c_{41} & c_{42} & c_{43} \end{bmatrix}$$

If, for the **Output size** parameter, you choose `Valid`, the block uses the following equations to determine the number of rows and columns of the output matrix:

$$C_{\text{valid}_{\text{rows}}} = I1_{\text{rows}} - I2_{\text{rows}} + 1 = 3$$

$$C_{\text{valid}_{\text{columns}}} = I1_{\text{columns}} - I2_{\text{columns}} + 1 = 2$$

In this case, it is always possible to extract the exact center of C_{full}. Therefore, the block outputs

$$C_{\text{full}} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \\ c_{31} & c_{32} \end{bmatrix}$$

Example 2

In cross-correlation, the value of an output element is computed as a weighted sum of neighboring elements.

For example, suppose the first input matrix represents an image and is defined as

```
I1 = [17   24    1    8   15
      23    5    7   14   16
       4    6   13   20   22
      10   12   19   21    3
      11   18   25    2    9]
```

The second input matrix also represents an image and is defined as

```
I2 = [8    1    6
      3    5    7
      4    9    2]
```

The following figure shows how to compute the (2,4) output element (zero-based indexing) using these steps:

1   Slide the center element of I2 so that lies on top of the (1,3) element of I1.

2   Multiply each weight in I2 by the element of I1 underneath.

3   Sum the individual products from step 2.

The (2,4) output element from the cross-correlation is

$$1 \cdot 8 + 8 \cdot 1 + 15 \cdot 6 + 7 \cdot 3 + 14 \cdot 5 + 16 \cdot 7 + 13 \cdot 4 + 20 \cdot 9 + 22 \cdot 2 = 585 \ .$$
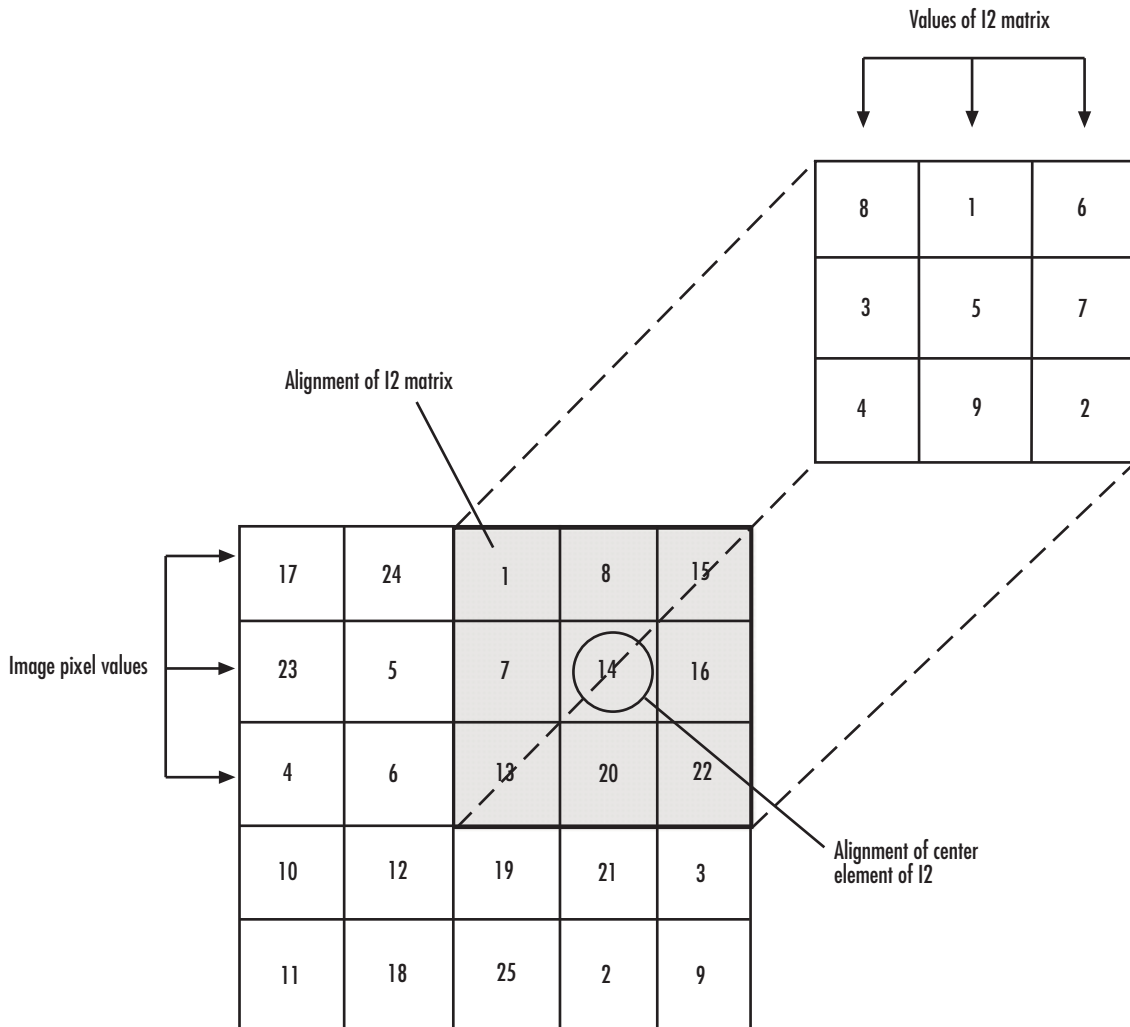
Computing the (2,4) Output of Cross-Correlation

The normalized cross-correlation of the (2,4) output element is 585/ sqrt(sum(dot(I1p,I1p))*sum(dot(I2,I2))) = 0.8070, where I1p = [1 8 15; 7 14 16; 13 20 22].

Parameters

Output size

This parameter controls the size of the output scalar, vector, or matrix produced as a result of the cross-correlation between the two inputs. If you choose Full, the output has dimensions ($Ma+Mb$-1, $Na+Nb$-1). If you choose Same as input port I1, the output has the same dimensions as the input at port I1. If you choose Valid, output has dimensions ($Ma-Mb$+1, $Na-Nb$+1).

Normalized output

If you select this check box, the block's output is normalized.

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Overflow mode

Select the Overflow mode for fixed-point operations.

Product output

Specify the product output data type. See "Fixed-Point Data Types" on page 1-18 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block:

- When you select Same as first input, these characteristics match those of the first input to the block.

- When you select Binary point scaling, you can enter the word length and the fraction length of the product output, in bits.

- When you select Slope and bias scaling, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

The Product Output inherits its sign according to the inputs. If either or both input **I1** and **I2** are signed, the Product Output will be signed. Otherwise, the Product Output is unsigned. The table below show all cases.

Sign of Input I1	Sign of Input I2	Sign of Product Output
unsigned	unsigned	unsigned
unsigned	signed	signed
signed	unsigned	signed
signed	signed	signed

Accumulator

Use this parameter to specify how to designate the accumulator word and fraction lengths. Refer to "Fixed-Point Data Types" on page 1-18 and "Multiplication Data Types" for illustrations depicting the use of the accumulator data type in this block. The accumulator data type is only used when both inputs to the multiplier are complex:

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox software is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

See Also

2-D Autocorrelation	Computer Vision System Toolbox
2-D Histogram	Computer Vision System Toolbox
2-D Mean	Computer Vision System Toolbox
2-D Median	Computer Vision System Toolbox
2-D Standard Deviation	Computer Vision System Toolbox
2-D Variance	Computer Vision System Toolbox
2-D Maximum	Computer Vision System Toolbox
2-D Minimum	Computer Vision System Toolbox

Introduced before R2006a

2-D DCT

Compute 2-D discrete cosine transform (DCT)
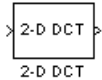
2-D DCT

2-D DCT

Library

Transforms

`visiontransforms`

Description

The 2-D DCT block calculates the two-dimensional discrete cosine transform of the input signal. The equation for the two-dimensional DCT is

$$F(m,n) = \frac{2}{\sqrt{MN}} C(m)C(n) \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \cos \frac{(2x+1)m\pi}{2M} \cos \frac{(2y+1)n\pi}{2N}$$

where $C(m), C(n) = 1/\sqrt{2}$ for $m,n = 0$ and $C(m), C(n) = 1$ otherwise.

The number of rows and columns of the input signal must be powers of two. The output of this block has dimensions the same dimensions as the input.

Port	Input/Output	Supported Data Types	Complex Values Supported
Input	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Output	2-D DCT of the input	Same as Input port	No

If the data type of the input signal is floating point, the output of the block is the same data type.

Use the **Sine and cosine computation** parameter to specify how the block computes the sine and cosine terms in the DCT algorithm. If you select `Trigonometric fcn`, the block computes the sine and cosine values during the simulation. If you select `Table lookup`, the block computes and stores the trigonometric values before the simulation starts. In this case, the block requires extra memory.

Fixed-Point Data Types

The following diagram shows the data types used in the 2-D DCT block for fixed-point signals. Inputs are first cast to the output data type and stored in the output buffer. Each butterfly stage processes signals in the accumulator data type, with the final output of the butterfly being cast back into the output data type.

butterfly stage

OR

butterfly stage — twiddle multiplication

W1 and W2 are twiddle table constants

OR

butterfly stage

Butterfly Stage Data Types

Inputs to butterfly - output data type

Accumulator data type

Accumulator data type

Output data type

Twiddle Multiplication Data Types

Input to twiddle multiplication - output data type

Sine table data type

Accumulator or Product output data type
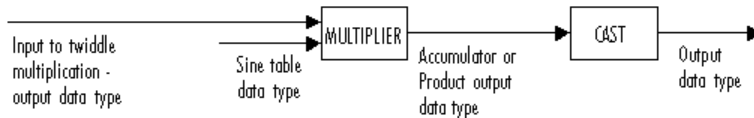
Output data type

The output of the multiplier is in the product output data type when at least one of the inputs to the multiplier is real. When both inputs to the multiplier are complex, the result of the multiplication is in the accumulator data type. For details on the complex multiplication performed, refer to "Multiplication Data Types". You can set the sine table,

product output, accumulator, and output data types in the block mask as discussed in the next section.

Parameters

Sine and cosine computation

Specify how the block computes the sine and cosine terms in the DCT algorithm. If you select `Trigonometric fcn`, the block computes the sine and cosine values during the simulation. If you select `Table lookup`, the block computes and stores the trigonometric values before the simulation starts. In this case, the block requires extra memory.

Rounding mode

Select the "Rounding Modes" for fixed-point operations. The sine table values do not obey this parameter; they always round to `Nearest`.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range". The sine table values do not obey this parameter; instead, they are always saturated.

Sine table data type

Choose how you specify the word length of the values of the sine table. The fraction length of the sine table values always equals the word length minus one. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same word length as input`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16)`

The sine table values do not obey the **Rounding mode** and **Saturate on integer overflow** parameters; instead, they are always saturated and rounded to `Nearest`.

Product output data type

Specify the product output data type. See "Fixed-Point Data Types" on page 1-26 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. See "Fixed-Point Data Types" on page 1-26 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Output data type

Specify the output data type. See "Fixed-Point Data Types" on page 1-26 for illustrations depicting the use of the output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`.

  When you select `Inherit: Inherit via internal rule`, the block calculates the output word length and fraction length automatically. The internal rule first calculates an ideal output word length and fraction length using the following equations:

$$WL_{ideal\,output} = WL_{input} + floor(\log_2(DCT\,length - 1)) + 1$$

$$FL_{ideal\,output} = FL_{input}$$

Using these ideal results, the internal rule then selects word lengths and fraction lengths that are appropriate for your hardware. For more information, see "Inherit via Internal Rule".

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Lock scaling against changes by the autoscaling tool

Select this parameter to prevent any fixed-point scaling you specify in this block mask from being overridden by the autoscaling tool in the Fixed-Point Tool. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Chen, W.H, C.H. Smith, and S.C. Fralick, "A fast computational algorithm for the discrete cosine transform," *IEEE Trans. Commun.*, vol. COM-25, pp. 1004-1009. 1977.

[2] Wang, Z. "Fast algorithms for the discrete W transform and for the discrete Fourier transform," *IEEE Trans. Acoust., Speech, Signal Processing*, vol. ASSP-32, pp. 803-816, Aug. 1984.

See Also

2-D IDCT	Computer Vision System Toolbox software
2-D FFT	Computer Vision System Toolbox software
2-D IFFT	Computer Vision System Toolbox software

Introduced before R2006a

2-D FFT

Compute two-dimensional fast Fourier transform of input

Library

Transforms

`visiontransforms`

Description

The 2-D FFT block computes the fast Fourier transform (FFT). The block does the computation of a two-dimensional *M*-by-*N* input matrix in two steps. First it computes the one-dimensional FFT along one dimension (row or column). Then it computes the FFT of the output of the first step along the other dimension (column or row).

The output of the 2-D FFT block is equivalent to the MATLAB® `fft2` function:

```
y = fft2(A)    % Equivalent MATLAB code
```

Computing the FFT of each dimension of the input matrix is equivalent to calculating the two-dimensional discrete Fourier transform (DFT), which is defined by the following equation:

$$F(m,n) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) e^{-j\frac{2\pi nx}{M}} e^{-j\frac{2\pi ny}{N}}$$

where $0 \le m \le M-1$ and $0 \le n \le N-1$.

The output of this block has the same dimensions as the input. If the input signal has a floating-point data type, the data type of the output signal uses the same floating-point

data type. Otherwise, the output can be any fixed-point data type. The block computes scaled and unscaled versions of the FFT.

The input to this block can be floating-point or fixed-point, real or complex, and conjugate symmetric. The block uses one of two possible FFT implementations. You can select an implementation based on the FFTW library [1], [2], or an implementation based on a collection of Radix-2 algorithms. You can select Auto to allow the block to choose the implementation.

Port Description

Port	Description	Supported Data Types	Complex Values Supported
Input	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes
Output	2-D FFT of the input	Same as Input port	Yes

FFTW Implementation

The FFTW implementation provides an optimized FFT calculation including support for power-of-two and non-power-of-two transform lengths in both simulation and code generation. Generated code using the FFTW implementation will be restricted to those computers which are capable of running MATLAB. The input data type must be floating-point.

Radix-2 Implementation

The Radix-2 implementation supports bit-reversed processing, fixed or floating-point data, and allows the block to provide portable C-code generation using the "Simulink Coder". The dimensions of the input matrix, M and N, must be powers of two. To work with other

input sizes, use the Image Pad block to pad or truncate these dimensions to powers of two, or if possible choose the FFTW implementation.

With Radix-2 selected, the block implements one or more of the following algorithms:

- Butterfly operation
- Double-signal algorithm
- Half-length algorithm
- Radix-2 decimation-in-time (DIT) algorithm
- Radix-2 decimation-in-frequency (DIF) algorithm

Other Parameter Settings	Algorithms Used for IFFT Computation
☐ Input is in bit-reversed order ☐ Input is conjugate symmetric	Butterfly operation and radix-2 DIT
☑ Input is in bit-reversed order ☐ Input is conjugate symmetric	Radix-2 DIF
☐ Input is in bit-reversed order ☑ Input is conjugate symmetric	Butterfly operation and radix-2 DIT in conjunction with the half-length and double-signal algorithms
☑ Input is in bit-reversed order ☑ Input is conjugate symmetric	Radix-2 DIF in conjunction with the half-length and double-signal algorithms

Other Parameter Settings	Algorithms Used for IFFT Computation
☐ Input is in bit-reversed order ☐ Input is conjugate symmetric	Butterfly operation and radix-2 DIT
☑ Input is in bit-reversed order ☐ Input is conjugate symmetric	Radix-2 DIF

Note The **Input is conjugate symmetric** parameter cannot be used for fixed-point signals.

In certain situations, the block's Radix–2 algorithm computes all the possible trigonometric values of the twiddle factor

$$e^{j\frac{2\pi k}{K}}$$

where K is the greater value of either M or N and $k = 0, \cdots, K-1$. The block stores these values in a table and retrieves them during simulation. The number of table entries for fixed-point and floating-point is summarized in the following table:

Number of Table Entries for N-Point FFT	
floating-point	3 $N/4$
fixed-point	N

The following diagrams show the data types used in the FFT block for fixed-point signals. You can set the sine table, accumulator, product output, and output data types displayed in the diagrams in the FFT dialog box as discussed in "Parameters" on page 1-37.

Inputs to the FFT block are first cast to the output data type and stored in the output buffer. Each butterfly stage then processes signals in the accumulator data type, with the final output of the butterfly being cast back into the output data type. The block multiplies in a twiddle factor before each butterfly stage in a decimation-in-time FFT and after each butterfly stage in a decimation-in-frequency FFT.
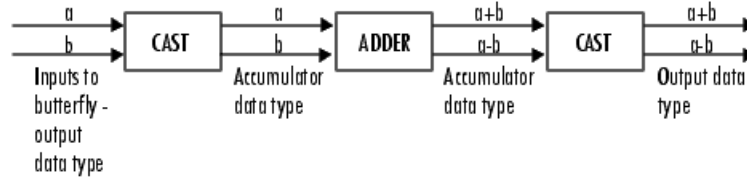
Decimation-in-time IFFT
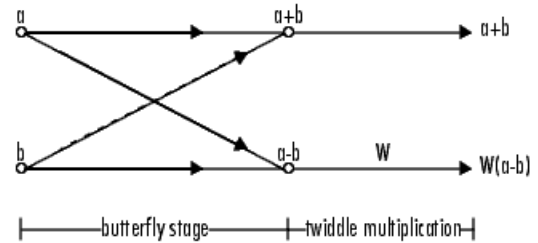
Decimation-in-frequency IFFT

Butterfly stage data types

Twiddle multiplication data types

The multiplier output appears in the accumulator data type because both of the inputs to the multiplier are complex. For details on the complex multiplication performed, refer to "Multiplication Data Types".

Parameters

FFT implementation

Set this parameter to `FFTW` [1], [2] to support an arbitrary length input signal. The block restricts generated code with FFTW implementation to host computers capable of running MATLAB.

Set this parameter to `Radix-2` for bit-reversed processing, fixed or floating-point data, or for portable C-code generation using the "Simulink Coder". The dimensions of the input matrix, *M* and *N*, must be powers of two. To work with other input sizes, use the Image Pad block to pad or truncate these dimensions to powers of two, or if possible choose the FFTW implementation. See "Radix-2 Implementation" on page 1-33.

Set this parameter to `Auto` to let the block choose the FFT implementation. For non-power-of-two transform lengths, the block restricts generated code to MATLAB host computers.

Output in bit-reversed order

Designate the order of the output channel elements relative to the ordering of the input elements. When you select this check box, the output channel elements appear in bit-reversed order relative to the input ordering. If you clear this check box, the output channel elements appear in linear order relative to the input ordering.

Linearly ordering the output requires extra data sorting manipulation. For more information, see "Bit-Reversed Order" on page 1-40.

Scale result by FFT length

When you select this parameter, the block divides the output of the FFT by the FFT length. This option is useful when you want the output of the FFT to stay in the same amplitude range as its input. This is particularly useful when working with fixed-point data types.

Rounding mode

Select the "Rounding Modes" for fixed-point operations. The sine table values do not obey this parameter; instead, they always round to `Nearest`.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range". The sine table values do not obey this parameter; instead, they are always saturated.

Sine table data type

Choose how you specify the word length of the values of the sine table. The fraction length of the sine table values always equals the word length minus one. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same word length as input`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16)`

The sine table values do not obey the **Rounding mode** and **Saturate on integer overflow** parameters; instead, they are always saturated and rounded to `Nearest`.

Product output data type

Specify the product output data type. See "Fixed-Point Data Types" on page 1-35 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. See "Fixed-Point Data Types" on page 1-35 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Output data type

Specify the output data type. See "Fixed-Point Data Types" on page 1-35 for illustrations depicting the use of the output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`.

  When you select `Inherit: Inherit via internal rule`, the block calculates the output word length and fraction length automatically. The internal rule first calculates an ideal output word length and fraction length using the following equations:

  - When you select the **Divide butterfly outputs by two** check box, the ideal output word and fraction lengths are the same as the input word and fraction lengths.
  - When you clear the **Divide butterfly outputs by two** check box, the block computes the ideal output word and fraction lengths according to the following equations:

$$WL_{ideal\ output} = WL_{input} + floor(\log_2(FFT\ length - 1)) + 1$$

$$FL_{ideal\ output} = FL_{input}$$

  Using these ideal results, the internal rule then selects word lengths and fraction lengths that are appropriate for your hardware. For more information, see "Inherit via Internal Rule".

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button $\boxed{>>}$ to display the **Data Type Assistant**, which helps you set the **Output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Example

Bit-Reversed Order

Two numbers are bit-reversed values of each other when the binary representation of one is the mirror image of the binary representation of the other. For example, in a three-bit system, one and four are bit-reversed values of each other because the three-bit binary representation of one, 001, is the mirror image of the three-bit binary representation of four, 100. The following diagram shows the row indices in linear order. To put them in bit-reversed order

1   Translate the indices into their binary representation with the minimum number of bits. In this example, the minimum number of bits is three because the binary representation of 7 is 111.

2   Find the mirror image of each binary entry, and write it beside the original binary representation.

3   Translate the indices back to their decimal representation.

    The row indices now appear in bit-reversed order.
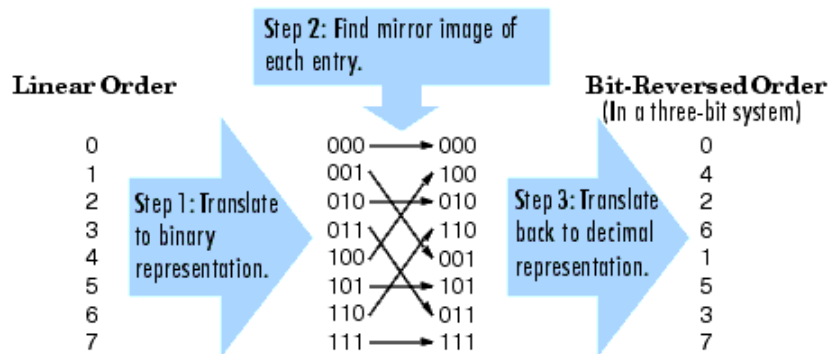
If, on the 2-D FFT block parameters dialog box, you select the **Output in bit-reversed order** check box, the block bit-reverses the order of both the columns and the rows. The next diagram illustrates the linear and bit-reversed outputs of the 2-D FFT block. The output values are the same, but they appear in different order.

$$\begin{bmatrix} 245 & -13 & 10-5i & 10+5i & 13.9-0.4i & -15.9-21.6i & -15.9+21.6i & 13.9 \\ -9 & 1 & 14-31i & 14+31i & 16.3+5.9i & 17.7-23.9i & 17.7+23.9i & 16.3-5.9i \\ 18-5i & 6-3i & 19-24i & 5+4i & -4.3-10.4i & -5.7+16.4i & 12.4-11.4i & 5.5+1.4i \\ 18+5i & 6+3i & 5-4i & 19+24i & 5.5-1.4i & 12.5+11.3i & -5.7-16.4i & 34+0.5i \\ -4.3-10.3i & 1.1-i & -5.6+13.1i & -11.5-11i & -27.6-6.6i & -2.6i & -3.4+8.7i & 6.2+13i \\ 8.4+2.4i & 11+9i & -18.4-25.1i & -4.5-1.1i & 3.4-5.4i & 17.6-9.4i & -2.2+13i & -1-2.7i \\ 8.4-2.4i & 11-9i & -4.5+1.1i & -18.4+25.1i & -0.6+2.7i & -2.2-13i & 17.6+9.4i & 34+0.5i \\ -4.4+10.3i & 1.1+i & -11.5+11i & -5.6-13.1 & 6.2-13i & -3.4-8.7i & 2.6i & -27.6+6.6i \end{bmatrix}$$

References

[1] FFTW (http://www.fftw.org)

[2] Frigo, M. and S. G. Johnson, "FFTW: An Adaptive Software Architecture for the FFT,"*Proceedings of the International Conference on Acoustics, Speech, and Signal Processing*, Vol. 3, 1998, pp. 1381-1384.

See Also

2-D DCT	Computer Vision System Toolbox software
2-D IDCT	Computer Vision System Toolbox software
2-D IFFT	Computer Vision System Toolbox software
2-D IFFT	Computer Vision System Toolbox software
bitrevorder	Signal Processing Toolbox software
fft	MATLAB
ifft	MATLAB
"Simulink Coder"	Simulink Coder™

Introduced before R2006a

2-D FIR Filter

Perform 2-D FIR filtering on input matrix
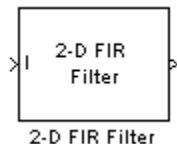
Library

Filtering

`visionfilter`

Description

The 2-D Finite Impulse Response (FIR) filter block filters the input matrix I using the coefficient matrix H or the coefficient vectors HH and HV.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes
H	Matrix of filter coefficients	Same as I port.	Yes
HH	Vector of filter coefficients	Same as I port. The input to ports HH and HV must be the same data type.	Yes
HV	Vector of filter coefficients	Same as I port. The input to ports HH and HV must be the same data type.	Yes

Port	Input/Output	Supported Data Types	Complex Values Supported
PVal	Scalar value that represents the constant pad value	Input must have the same data type as the input to I port.	Yes
Output	Scalar, vector, or matrix of filtered values	Same as I port.	Yes

If the input has a floating-point data type, then the output uses the same data type. Otherwise, the output can be any fixed-point data type.

Select the **Separable filter coefficients** check box if your filter coefficients are separable. Using separable filter coefficients reduces the amount of calculations the block must perform to compute the output. For example, suppose your input image is M-by-N and your filter coefficient matrix is x-by-y. For a nonseparable filter with the **Output size** parameter set to Same as input port I, it would take

$$x \cdot y \cdot M \cdot N$$

multiply-accumulate (MAC) operations for the block to calculate the output. For a separable filter, it would only take

$$(x + y) \cdot M \cdot N$$

MAC operations. If you do not know whether or not your filter coefficients are separable, use the isfilterseparable function.

Here is an example of the function syntax, [S, HCOL, HROW] = isfilterseparable(H). The isfilterseparable function takes the filter kernel, H, and returns S, HCOL and HROW. Here, S is a Boolean variable that is 1 if the filter is separable and 0 if it is not. HCOL is a vector of vertical filter coefficients, and HROW is a vector of horizontal filter coefficients.

Use the **Coefficient source** parameter to specify how to define your filter coefficients. If you select the **Separable filter coefficients** check box and then select a **Coefficient source** of Specify via dialog, the **Vertical coefficients (across height)** and **Horizontal coefficients (across width)** parameters appear in the dialog box. You can use these parameters to enter vectors of vertical and horizontal filter coefficients, respectively.

You can also use the variables HCOL and HROW, the output of the `isfilterseparable` function, for these parameters. If you select the **Separable filter coefficients** check box and then select a **Coefficient source** of `Input port`, ports HV and HH appear on the block. Use these ports to specify vectors of vertical and horizontal filter coefficients.

If you clear the **Separable filter coefficients** check box and select a **Coefficient source** of `Specify via dialog`, the **Coefficients** parameter appears in the dialog box. Use this parameter to enter your matrix of filter coefficients.

If you clear the **Separable filter coefficients** check box and select a **Coefficient source** of `Input port`, port **H** appears on the block. Use this port to specify your filter coefficient matrix.

The block outputs the result of the filtering operation at the Output port. The **Output size** parameter and the sizes of the inputs at ports **I** and **H** dictate the dimensions of the output. For example, assume that the input at port I has dimensions (*Mi*, *Ni*) and the input at port H has dimensions (*Mh*, *Nh*). If you select an **Output size** of `Full`, the output has dimensions (*Mi+Mh*-1, *Ni+Nh*-1). If you select an **Output size** of `Same as input port I`, the output has the same dimensions as the input at port I. If you select an **Output size** of `Valid`, the block filters the input image only where the coefficient matrix fits entirely within it, so no padding is required. The output has dimensions (*Mi-Mh*+1, *Ni-Nh*+1). However, if `all(size(I)<size(H))`, the block errors out.

Use the **Padding options** parameter to specify how to pad the boundary of your input matrix. To pad your matrix with a constant value, select `Constant`. To pad your input matrix by repeating its border values, select `Replicate`. To pad your input matrix with its mirror image, select `Symmetric`. To pad your input matrix using a circular repetition of its elements, select `Circular`. For more information on padding, see the Image Pad block reference page.

If, for the **Padding options** parameter, you select `Constant`, the **Pad value source** parameter appears in the dialog box. If you select `Specify via dialog`, the **Pad value** parameter appears in the dialog box. Use this parameter to enter the constant value with which to pad your matrix. If you select **Pad value source** of `Input port`, the PVal port appears on the block. Use this port to specify the constant value with which to pad your matrix. The pad value must be real if the input image is real. You will get an error message if the pad value is complex when the input image is real.

Use the **Filtering based on** parameter to specify the algorithm by which the block filters the input matrix. If you select `Convolution` and set the **Output size** parameter to `Full`, the block filters your input using the following algorithm

$$C(i,j) = \sum_{m=0}^{(Ma-1)} \sum_{n=0}^{(Na-1)} A(m,n) * H(i-m, j-n)$$

where $0 \le i < Ma + Mh - 1$ and $0 \le j < Na + Nh - 1$. If you select `Correlation` and set the **Output size** parameter to `Full`, the block filters your input using the following algorithm

$$C(i,j) = \sum_{m=0}^{(Ma-1)} \sum_{n=0}^{(Na-1)} A(m,n) \cdot conj(H(m+i, n+j))$$

where $0 \le i < Ma + Mh - 1$ and $0 \le j < Na + Nh - 1$.

TThe `imfilter` function from the Image Processing Toolbox™ product similarly performs N-D filtering of multidimensional images.

Fixed-Point Data Types

The following diagram shows the data types used in the 2-D FIR Filter block for fixed-point signals.

The result of each addition remains
in the accumulator data type

| Input (A) data type | COMPLEX MULTIPLIER | | CAST | | ADDER | | CAST | | Output (C) data type |

Filter coefficient (H) data type

Accumulator or Product output data type

Accumulator data type

Accumulator data type
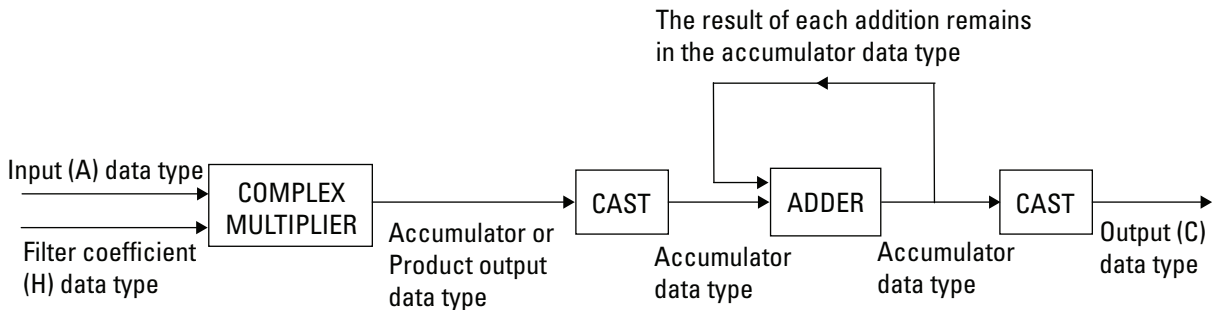
You can set the coefficient, product output, accumulator, and output data types in the block mask as discussed in "Parameters" on page 1-46.

The output of the multiplier is in the product output data type if at least one of the inputs to the multiplier is real. If both of the inputs to the multiplier are complex, the result of

the multiplication is in the accumulator data type. For details on the complex multiplication performed, refer to "Multiplication Data Types".

Parameters

Separable filter coefficients

Select this check box if your filter coefficients are separable. Using separable filter coefficients reduces the amount of calculations the block must perform to compute the output.

Coefficient source

Specify how to define your filter coefficients. Select `Specify via dialog` to enter your coefficients in the block parameters dialog box. Select `Input port` to specify your filter coefficient matrix using port H or ports HH and HV.

Coefficients

Enter your real or complex-valued filter coefficient matrix. This parameter appears if you clear the **Separable filter coefficients** check box and then select a **Coefficient source** of `Specify via dialog`. Tunable.

Vertical coefficients (across height)

Enter the vector of vertical filter coefficients for your separable filter. This parameter appears if you select the **Separable filter coefficients** check box and then select a**Coefficient source** of `Specify via dialog`.

Horizontal coefficients (across width)

Enter the vector of horizontal filter coefficients for your separable filter. This parameter appears if you select the **Separable filter coefficients** check box and then select a**Coefficient source** of `Specify via dialog`.

Output size

This parameter controls the size of the filtered output. If you choose `Full`, the output has dimensions ($Ma+Mh$-1, $Na+Nh$-1). If you choose `Same as input port I`, the output has the same dimensions as the input at port I If you choose `Valid`, output has dimensions (Ma-Mh+1, Na-Nh+1).

Padding options

Specify how to pad the boundary of your input matrix. Select `Constant` to pad your matrix with a constant value. Select `Replicate` to pad your input matrix by repeating its border values. Select `Symmetric`to pad your input matrix with its mirror image. Select `Circular` to pad your input matrix using a circular repetition of its

elements. This parameter appears if you select an **Output size** of `Full` or `Same as input port I`.

Pad value source

Use this parameter to specify how to define your constant boundary value. Select `Specify via dialog` to enter your value in the block parameters dialog box. Select `Input port` to specify your constant value using the PVal port. This parameter appears if you select a **Padding options** of `Constant`.

Pad value

Enter the constant value with which to pad your matrix. This parameter is visible if, for the **Pad value source** parameter, you select `Specify via dialog`. Tunable. The pad value must be real if the input image is real. You will get an error message if the pad value is complex when the input image is real.

Filtering based on

Specify the algorithm by which the block filters the input matrix. You can select `Convolution` or `Correlation`.

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range".

Coefficients

Choose how to specify the word length and the fraction length of the filter coefficients.

- When you select `Inherit: Same word length as input`, the word length of the filter coefficients match that of the input to the block. In this mode, the block automatically sets the fraction length of the coefficients to the binary-point only scaling that provides you with the best precision possible given the value and word length of the coefficients.

- When you select `fixdt(1,16)`, you can enter the word length of the coefficients, in bits. In this mode, the block automatically sets the fraction length of the coefficients to the binary-point only scaling that provides you with the best precision possible given the value and word length of the coefficients.

- When you select `fixdt(1,16,0)`, you can enter the word length and the fraction length of the coefficients, in bits.

- When you select `<data type expression>`, you can enter the data type expression.

The filter coefficients do not obey the **Rounding mode** and the **Saturate on integer overflow** parameters; instead, they are always saturated and rounded to `Nearest`.

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Product output

Use this parameter to specify how to designate the product output word and fraction lengths. Refer to "Fixed-Point Data Types" on page 1-45 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block:

- When you select `Inherit: Same as input`, these characteristics match those of the input to the block.
- When you select `fixdt([],16,0)`, you can enter the word length and the fraction length of the product output, in bits.
- When you select `<data type expression>`, you can enter the data type expression.

If you set the **Coefficient source** (on the **Main** tab) to `Input port` the Product Output will inherit its sign according to the inputs. If either or both input **I1** and **I2** are signed, the Product Output will be signed. Otherwise, the Product Output is unsigned. The following table shows all cases.

Sign of Input I1	Sign of Input I2	Sign of Product Output
unsigned	unsigned	unsigned
unsigned	signed	signed
signed	unsigned	signed
signed	signed	signed

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator

Use this parameter to specify how to designate the accumulator word and fraction lengths. Refer to "Fixed-Point Data Types" on page 1-45 and "Multiplication Data

Types" for illustrations depicting the use of the accumulator data type in this block. The accumulator data type is only used when both inputs to the multiplier are complex:

- When you select `Inherit: Same as input`, these characteristics match those of the input to the block.
- When you select `Inherit: Same as product output`, these characteristics match those of the product output.
- When you select `fixdt([],16,0)`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. All signals in the Computer Vision System Toolbox software have a bias of 0.

Click the **Show data type assistant** button ⟩⟩ to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Inherit: Same as input`, these characteristics match those of the input to the block.
- When you select `fixdt([],16,0)`, you can enter the word length and the fraction length of the output, in bits.

  You can choose to set signedness of the output to `Auto`, `Signed` or `Unsigned`.
- When you select `<data type expression>`, you can enter the a data type expression.

Click the **Show data type assistant** button ⟩⟩ to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

See Also

imfilter	Image Processing Toolbox

Introduced before R2006a

2-D Histogram

Generate histogram of input or sequence of inputs
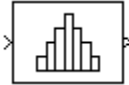
Library

Statistics

`visionstatistics`

Description

The 2-D Histogram block computes the frequency distribution of the elements in the input. You must use the **Find the histogram over** parameter to specify whether the block computes the histogram for `Each column` of the input or of the `Entire input`. The **Running histogram** check box allows you to select between basic operation and running operation, as described below.

The block distributes the elements of the input into the number of discrete bins specified by the **Number of bins** parameter, `n`.

```
y = hist(u,n)                    % Equivalent MATLAB code
```

The 2-D Histogram block sorts all complex input values into bins according to their magnitude.

The histogram value for a given bin represents the frequency of occurrence of the input values bracketed by that bin. You specify the upper boundary of the highest-valued bin in the **Upper limit of histogram** parameter, B_M, and the lower boundary of the lowest-valued bin in the **Lower limit of histogram** parameter, B_m. The bins have equal width of

$$\Delta = \frac{B_M - B_m}{n}$$

and centers located at

$$B_m + \left(k + \frac{1}{2} \right) \Delta \qquad k = 0, 1, 2, ..., n - 1$$

Input values that fall on the border between two bins are placed into the lower valued bin; that is, each bin includes its upper boundary. For example, a bin of width 4 centered on the value 5 contains the input value 7, but not the input value 3. Input values greater than the **Upper limit of histogram** parameter or less than **Lower limit of histogram** parameter are placed into the highest valued or lowest valued bin, respectively.

The values you enter for the **Upper limit of histogram** and **Lower limit of histogram** parameters must be real-valued scalars. NaN and inf are not valid values for the **Upper limit of histogram** and **Lower limit of histogram** parameters.

Basic Operation

When the **Running histogram** check box is not selected, the 2-D Histogram block computes the frequency distribution of the current input.

When you set the **Find the histogram over** parameter to Each column, the 2-D Histogram block computes a histogram for each column of the *M*-by-*N* matrix independently. The block outputs an *n*-by-*N* matrix, where *n* is the **Number of bins** you specify. The *j*th column of the output matrix contains the histogram for the data in the *j*th column of the *M*-by-*N* input matrix.

When you set the **Find the histogram over** parameter to Entire input, the 2-D Histogram block computes the frequency distribution for the entire input vector, matrix or N-D array. The block outputs an *n*-by-1 vector, where *n* is the **Number of bins** you specify.

Running Operation

When you select the **Running histogram** check box, the 2–D Histogram block computes the frequency distribution of both the past and present data for successive inputs. The block resets the histogram (by emptying all of the bins) when it detects a reset event at the optional Rst port. See "Resetting the Running Histogram" on page 1-53 for more information on how to trigger a reset.

When you set the **Find the histogram over** parameter to Each column, the 2-D Histogram block computes a running histogram for each column of the *M*-by-*N* matrix.

The block outputs an *n*-by-*N* matrix, where *n* is the **Number of bins** you specify. The *j*th column of the output matrix contains the running histogram for the *j*th column of the *M*-by-*N* input matrix.

When you set the **Find the histogram over** parameter to `Entire input`, the 2-D Histogram block computes a running histogram for the data in the first dimension of the input. The block outputs an *n*-by-1 vector, where *n* is the **Number of bins** you specify.

Note When the 2-D Histogram block is used in running mode and the input data type is non-floating point, the output of the histogram is stored as a `uint32` data type. The largest number that can be represented by this data type is 2^{32}-`1`. If the range of the `uint32` data type is exceeded, the output data will wrap back to 0.

Resetting the Running Histogram

The block resets the running histogram whenever a reset event is detected at the optional Rst port. The reset signal and the input data signal must be the same rate.

You specify the reset event using the **Reset port** menu:

- `None` — Disables the Rst port

- `Rising edge` — Triggers a reset operation when the Rst input does one of the following:

  - Rises from a negative value to a positive value or zero
  - Rises from zero to a positive value, where the rise is not a continuation of a rise from a negative value to zero (see the following figure)

- `Falling edge` — Triggers a reset operation when the `Rst` input does one of the following:

    - Falls from a positive value to a negative value or zero

    - Falls from zero to a negative value, where the fall is not a continuation of a fall from a positive value to zero (see the following figure)

- `Either edge` — Triggers a reset operation when the `Rst` input is a `Rising edge` or `Falling edge` (as described earlier)

- `Non-zero sample` — Triggers a reset operation at each sample time that the `Rst` input is not zero

Parameters

Lower limit of histogram

Enter a real-valued scalar for the lower boundary, B_m, of the lowest-valued bin. `NaN` and `inf` are not valid values for B_m. Tunable (Simulink).

Upper limit of histogram

Enter a real-valued scalar for the upper boundary, B_M, of the highest-valued bin. `NaN` and `inf` are not valid values for B_M. Tunable (Simulink).

Number of bins

The number of bins, n, in the histogram.

Find the histogram over

Specify whether the block finds the histogram over the entire input or along each column of the input.

Note The option will be removed in a future release.

Normalized

When selected, the output vector, v, is normalized such that `sum(v) = 1`.

Use of this parameter is not supported for fixed-point signals.

Running histogram

Set to enable the running histogram operation, and clear to enable basic histogram operation. For more information, see "Basic Operation" on page 1-52 and "Running Operation" on page 1-52.

Reset port

The type of event that resets the running histogram. For more information, see "Resetting the Running Histogram" on page 1-53. The reset signal and the input data signal must be the same rate. This parameter is enabled only when you select the **Running histogram** check box. For more information, see "Running Operation" on page 1-52.

Note The fixed-point parameters listed are only used for fixed-point complex inputs, which are distributed by squared magnitude.

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range".

Product output data type

Specify the product output data type. See "Multiplication Data Types" for illustrations depicting the use of the product output data type. You can set it to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`
- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button `>>` to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`
- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button `>>` to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Supported Data Types

Port	Supported Data Types
In	• Double-precision floating point
	• Single-precision floating point
	• Fixed point (signed and unsigned)
	• 8-, 16-, and 32-bit signed integers
	• 8-, 16-, and 32-bit unsigned integers
Output	• Double-precision floating point
	• Single-precision floating point
	• 32-bit unsigned integers
Rst	• Double-precision floating point
	• Single-precision floating point
	• Boolean
	• 8-, 16-, and 32-bit signed integers
	• 8-, 16-, and 32-bit unsigned integers

See Also

histogram   MATLAB

2-D IDCT

Compute 2-D inverse discrete cosine transform (IDCT)

```
2-D IDCT
```
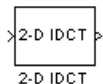
2-D IDCT

Library

Transforms

`visiontransforms`

Description

The 2-D IDCT block calculates the two-dimensional inverse discrete cosine transform of the input signal. The equation for the two-dimensional IDCT is

$$f(x,y) = \frac{2}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} C(m)C(n)F(m,n) \cos\frac{(2x+1)m\pi}{2M} \cos\frac{(2y+1)n\pi}{2N}$$

where $F(m,n)$ is the DCT of the signal $f(x,y)$ and $C(m), C(n) = \dfrac{1}{\sqrt{2}}$ for $m, n = 0$ and $C(m), C(n) = 1$ otherwise.

The number of rows and columns of the input signal must be powers of two. The output of this block has dimensions the same dimensions as the input.

Port	Input/Output	Supported Data Types	Complex Values Supported
Input	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Output	2-D IDCT of the input	Same as Input port	No

If the data type of the input signal is floating point, the output of the block is the same data type.

Use the **Sine and cosine computation** parameter to specify how the block computes the sine and cosine terms in the IDCT algorithm. If you select `Trigonometric fcn`, the block computes the sine and cosine values during the simulation. If you select `Table lookup`, the block computes and stores the trigonometric values before the simulation starts. In this case, the block requires extra memory.

Fixed-Point Data Types

The following diagram shows the data types used in the 2-D IDCT block for fixed-point signals. Inputs are first cast to the output data type and stored in the output buffer. Each butterfly stage processes signals in the accumulator data type, with the final output of the butterfly being cast back into the output data type.
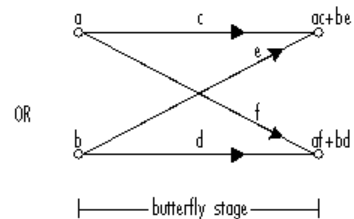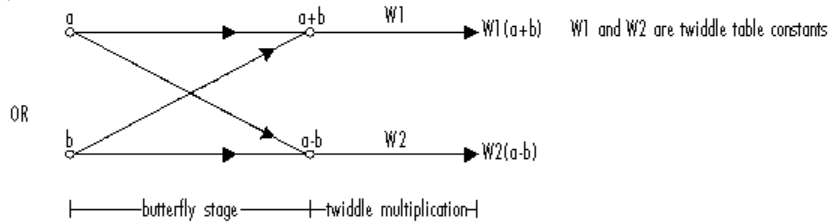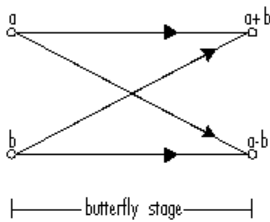
Butterfly Stage Data Types
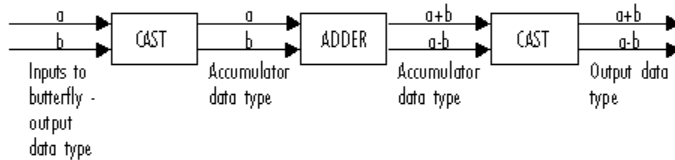
Twiddle Multiplication Data Types
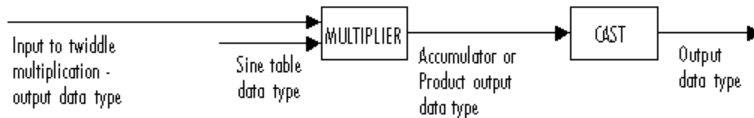
The output of the multiplier is in the product output data type when at least one of the inputs to the multiplier is real. When both of the inputs to the multiplier are complex, the result of the multiplication is in the accumulator data type. For details on the complex multiplication performed, refer to "Multiplication Data Types". You can set the sine table,

product output, accumulator, and output data types in the block mask as discussed in the next section.

Parameters

Sine and cosine computation

Specify how the block computes the sine and cosine terms in the IDCT algorithm. If you select `Trigonometric fcn`, the block computes the sine and cosine values during the simulation. If you select `Table lookup`, the block computes and stores the trigonometric values before the simulation starts. In this case, the block requires extra memory.

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range". The sine table values do not obey this parameter; instead, they are always saturated.

Sine table data type

Choose how you specify the word length of the values of the sine table. The fraction length of the sine table values always equals the word length minus one. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same word length as input`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16)`

The sine table values do not obey the **Rounding mode** and **Saturate on integer overflow** parameters; instead, they are always saturated and rounded to `Nearest`.

Product output data type

Specify the product output data type. See "Fixed-Point Data Types" on page 1-59 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. See "Fixed-Point Data Types" on page 1-59 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Output data type

Specify the output data type. See "Fixed-Point Data Types" on page 1-59 for illustrations depicting the use of the output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`.

  When you select `Inherit: Inherit via internal rule`, the block calculates the output word length and fraction length automatically. The internal rule first calculates an ideal output word length and fraction length using the following equations:

$$WL_{ideal\ output} = WL_{input} + floor(\log_2(DCT\ length - 1)) + 1$$

$$FL_{ideal\ output} = FL_{input}$$

  Using these ideal results, the internal rule then selects word lengths and fraction lengths that are appropriate for your hardware. For more information, see "Inherit via Internal Rule".

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button ![>>] to display the **Data Type Assistant**, which helps you set the **Output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Lock scaling against changes by the autoscaling tool

Select this parameter to prevent any fixed-point scaling you specify in this block mask from being overridden by the autoscaling tool in the Fixed-Point Tool. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Chen, W.H, C.H. Smith, and S.C. Fralick, "A fast computational algorithm for the discrete cosine transform,"*IEEE Trans. Commun.*, vol. COM-25, pp. 1004-1009. 1977.

[2] Wang, Z. "Fast algorithms for the discrete W transform and for the discrete Fourier transform," *IEEE Trans. Acoust., Speech, Signal Processing*, vol. ASSP-32, pp. 803-816, Aug. 1984.

See Also

2-D DCT	Computer Vision System Toolbox software
2-D FFT	Computer Vision System Toolbox software
2-D IFFT	Computer Vision System Toolbox software

Introduced before R2006a

2-D IFFT

2-D Inverse fast Fourier transform of input

Library

Transforms

visiontransforms

Description

The 2-D IFFT block computes the inverse fast Fourier transform (IFFT) of an *M*-by-*N* input matrix in two steps. First, it computes the one-dimensional IFFT along one dimension (row or column). Next, it computes the IFFT of the output of the first step along the other dimension (column or row).

The output of the IFFT block is equivalent to the MATLAB `ifft2` function:

```
y = ifft2(A)                    % Equivalent MATLAB code
```

Computing the IFFT of each dimension of the input matrix is equivalent to calculating the two-dimensional inverse discrete Fourier transform (IDFT), which is defined by the following equation:

$$f(x,y) = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} F(m,n) e^{j\frac{2\pi mx}{M}} e^{j\frac{2\pi ny}{N}}$$

where $0 \le x \le M-1$ and $0 \le y \le N-1$.

The output of this block has the same dimensions as the input. If the input signal has a floating-point data type, the data type of the output signal uses the same floating-point

data type. Otherwise, the output can be any fixed-point data type. The block computes scaled and unscaled versions of the IFFT.

The input to this block can be floating-point or fixed-point, real or complex, and conjugate symmetric. The block uses one of two possible FFT implementations. You can select an implementation based on the FFTW library [1], [2], or an implementation based on a collection of Radix-2 algorithms. You can select `Auto` to allow the block to choose the implementation.

Port Description

Port	Description	Supported Data Types	Complex Values Supported
Input	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes
Output	2-D IFFT of the input	Same as Input port	Yes

FFTW Implementation

The FFTW implementation provides an optimized FFT calculation including support for power-of-two and non-power-of-two transform lengths in both simulation and code generation. Generated code using the FFTW implementation will be restricted to MATLAB host computers. The data type must be floating-point. Refer to "Simulink Coder" for more details on generating code.

Radix-2 Implementation

The Radix-2 implementation supports bit-reversed processing, fixed or floating-point data, and allows the block to provide portable C-code generation using the "Simulink Coder". The dimensions of the input matrix, M and N, must be powers of two. To work with other

input sizes, use the Image Pad block to pad or truncate these dimensions to powers of two, or if possible choose the FFTW implementation.

With Radix-2 selected, the block implements one or more of the following algorithms:

- Butterfly operation
- Double-signal algorithm
- Half-length algorithm
- Radix-2 decimation-in-time (DIT) algorithm
- Radix-2 decimation-in-frequency (DIF) algorithm

Parameter Settings	Algorithms Used for IFFT Computation
☐ Input is in bit-reversed order ☐ Input is conjugate symmetric	Butterfly operation and radix-2 DIT
☑ Input is in bit-reversed order ☐ Input is conjugate symmetric	Radix-2 DIF
☐ Input is in bit-reversed order ☑ Input is conjugate symmetric	Butterfly operation and radix-2 DIT in conjunction with the half-length and double-signal algorithms
☑ Input is in bit-reversed order ☑ Input is conjugate symmetric	Radix-2 DIF in conjunction with the half-length and double-signal algorithms

Other Parameter Settings	Algorithms Used for IFFT Computation
☐ Input is in bit-reversed order ☐ Input is conjugate symmetric	Butterfly operation and radix-2 DIT
☑ Input is in bit-reversed order ☐ Input is conjugate symmetric	Radix-2 DIF

Note The **Input is conjugate symmetric** parameter cannot be used for fixed-point signals.

In certain situations, the block's Radix–2 algorithm computes all the possible trigonometric values of the twiddle factor

$$e^{j\frac{2\pi k}{K}}$$

where K is the greater value of either M or N and $k = 0, \cdots, K - 1$. The block stores these values in a table and retrieves them during simulation. The number of table entries for fixed-point and floating-point is summarized in the following table:

Number of Table Entries for N-Point FFT	
floating-point	3 N/4
fixed-point	N

The following diagrams show the data types used in the IFFT block for fixed-point signals. You can set the sine table, accumulator, product output, and output data types displayed in the diagrams in the IFFT dialog box as discussed in "Parameters" on page 1-69.

Inputs to the IFFT block are first cast to the output data type and stored in the output buffer. Each butterfly stage then processes signals in the accumulator data type, with the final output of the butterfly being cast back into the output data type. The block multiplies in a twiddle factor before each butterfly stage in a decimation-in-time IFFT and after each butterfly stage in a decimation-in-frequency IFFT.

Decimation-in-time IFFT
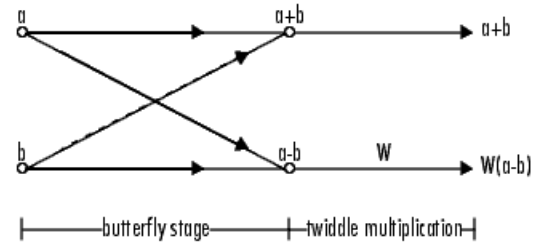
Decimation-in-frequency IFFT

Butterfly stage data types

Twiddle multiplication data types

The multiplier output appears in the accumulator data type because both of the inputs to the multiplier are complex. For details on the complex multiplication performed, refer to "Multiplication Data Types".

Parameters

FFT implementation

Set this parameter to `FFTW` [1], [2] to support an arbitrary length input signal. The block restricts generated code with FFTW implementation to MATLAB host computers.

Set this parameter to `Radix-2` for bit-reversed processing, fixed or floating-point data, or for portable C-code generation using the "Simulink Coder". The dimensions of the input matrix, M and N, must be powers of two. To work with other input sizes, use the Image Pad block to pad or truncate these dimensions to powers of two, or if possible choose the FFTW implementation. See "Radix-2 Implementation" on page 1-65.

Set this parameter to `Auto` to let the block choose the FFT implementation. For non-power-of-two transform lengths, the block restricts generated code to MATLAB host computers.

Input is in bit-reversed order

Select or clear this check box to designate the order of the input channel elements. Select this check box when the input should appear in reversed order, and clear it when the input should appear in linear order. The block yields invalid outputs when you do not set this parameter correctly. This check box only appears when you set the **FFT implementation** parameter to `Radix-2` or `Auto`.

For more information ordering of the output, see "Bit-Reversed Order" on page 1-40. The 2-D FFT block bit-reverses the order of both the columns and the rows.

Input is conjugate symmetric

Select this option when the block inputs both floating point and conjugate symmetric, and you want real-valued outputs. This parameter cannot be used for fixed-point signals. Selecting this check box optimizes the block's computation method.

The FFT block yields conjugate symmetric output when you input real-valued data. Taking the IFFT of a conjugate symmetric input matrix produces real-valued output. Therefore, if the input to the block is both floating point and conjugate symmetric, and you select this check box, the block produces real-valued outputs.

If the IFFT block inputs conjugate symmetric data and you do not select this check box, the IFFT block outputs a complex-valued signal with small imaginary parts. The block outputs invalid data if you select this option with non conjugate symmetric input data.

Divide output by product of FFT length in each input dimension

Select this check box to compute the scaled IFFT. The block computes scaled and unscaled versions of the IFFT. If you select this option, the block computes the scaled version of the IFFT. The unscaled IFFT is defined by the following equation:

$$f(x,y) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} F(m,n) e^{j\frac{2\pi mx}{M}} e^{j\frac{2\pi ny}{N}}$$

where $0 \leq x \leq M-1$ and $0 \leq y \leq N-1$.

The scaled version of the IFFT multiplies the above unscaled version by $\frac{1}{MN}$.

Rounding mode

Select the "Rounding Modes" for fixed-point operations. The sine table values do not obey this parameter; instead, they always round to `Nearest`.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range". The sine table values do not obey this parameter; instead, they are always saturated.

Sine table data type

Choose how you specify the word length of the values of the sine table. The fraction length of the sine table values always equals the word length minus one. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same word length as input`
- An expression that evaluates to a valid data type, for example, `fixdt(1,16)`

The sine table values do not obey the **Rounding mode** and **Saturate on integer overflow** parameters; instead, they are always saturated and rounded to `Nearest`.

Product output data type

Specify the product output data type. See "Fixed-Point Data Types" on page 1-67 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. See"Fixed-Point Data Types" on page 1-67 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Output data type

Specify the output data type. See "Fixed-Point Data Types" on page 1-67 for illustrations depicting the use of the output data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Inherit via internal rule`.

  When you select `Inherit: Inherit via internal rule`, the block calculates the output word length and fraction length automatically. The internal rule first calculates an ideal output word length and fraction length using the following equations:

  - When you select the **Divide butterfly outputs by two** check box, the ideal output word and fraction lengths are the same as the input word and fraction lengths.

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- When you clear the **Divide butterfly outputs by two** check box, the block computes the ideal output word and fraction lengths according to the following equations:

$$WL_{ideal\,output} = WL_{input} + floor(\log_2(FFT\ length - 1)) + 1$$

$$FL_{ideal\,output} = FL_{input}$$

  Using these ideal results, the internal rule then selects word lengths and fraction lengths that are appropriate for your hardware. For more information, see "Inherit via Internal Rule".

- An expression that evaluates to a valid data type, for example, `fixdt(1,16,0)`

Click the **Show data type assistant** button `>>` to display the **Data Type Assistant**, which helps you set the **Output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] FFTW (`http://www.fftw.org`)

[2] Frigo, M. and S. G. Johnson, "FFTW: An Adaptive Software Architecture for the FFT,"*Proceedings of the International Conference on Acoustics, Speech, and Signal Processing*, Vol. 3, 1998, pp. 1381-1384.

See Also

2-D DCT	Computer Vision System Toolbox software
2-D FFT	Computer Vision System Toolbox software

2-D IDCT	Computer Vision System Toolbox software
2-D FFT	Computer Vision System Toolbox software
2-D IFFT	Computer Vision System Toolbox software
bitrevorder	Signal Processing Toolbox software
fft	MATLAB
ifft	MATLAB
"Simulink Coder"	Simulink

Introduced before R2006a

2-D Maximum

Find maximum values in input or sequence of inputs
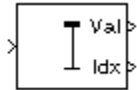
Library

Statistics

`visionstatistics`

Description

The 2-D Maximum block identifies the value and/or position of the smallest element in each row or column of the input, or along a specified dimension of the input. The 2-D Maximum block can also track the maximum values in a sequence of inputs over a period of time.

The 2-D Maximum block supports real and complex floating-point, fixed-point, and Boolean inputs. Real fixed-point inputs can be either signed or unsigned, while complex fixed-point inputs must be signed. The output data type of the maximum values match the data type of the input. The block outputs `double` index values, when the input is `double`, and `uint32` otherwise.

Port Descriptions

Port	Input/Output	Supported Data Types
Input	Scalar, vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point (signed and unsigned) • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers
Rst	Scalar value	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers
Val	Maximum value output based on the "Value Mode" on page 1-76	• Double-precision floating point • Single-precision floating point • Fixed point (signed and unsigned) • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers
Idx	One-based output location of the maximum value based on the "Index Mode" on page 1-77	• Double-precision floating point • 32-bit unsigned integers

Value Mode

When you set the **Mode** parameter to `Value`, the block computes the maximum value in each row or column of the input, along vectors of a specified dimension of the input, or of the entire input at each sample time, and outputs the array *y*. Each element in *y* is the maximum value in the corresponding column, row, vector, or entire input. The output *y* depends on the setting of the **Find the maximum value over** parameter. For example, consider a 3-dimensional input signal of size *M*-by-*N*-by-*P*:

- `Each row` — The output at each sample time consists of an *M*-by-1-by-*P* array, where each element contains the maximum value of each vector over the second dimension of the input. For an *M*-by-*N* input matrix, the block outputs an *M*-by-1 column vector at each sample time.

- `Each column` — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the maximum value of each vector over the first dimension of the input. For an *M*-by-*N* input matrix, the block outputs a 1-by-*N* row vector at each sample time.

  In this mode, the block treats length-*M* unoriented vector inputs as *M*-by-1 column vectors.

- `Entire input` — The output at each sample time is a scalar that contains the maximum value in the *M*-by-*N*-by-*P* input matrix.

- `Specified dimension` — The output at each sample time depends on **Dimension**. When you set **Dimension** to 1, the block output is the same as when you select `Each column`. When you set **Dimension** to 2, the block output is the same as when you select `Each row`. When you set **Dimension** to 3, the block outputs an *M*-by-*N* matrix containing the maximum value of each vector over the third dimension of the input, at each sample time.

For complex inputs, the block selects the value in each row or column of the input, along vectors of a specified dimension of the input, or of the entire input that has the maximum magnitude squared as shown below. For complex value $u = a + bi$, the magnitude squared is $a^2 + b^2$.
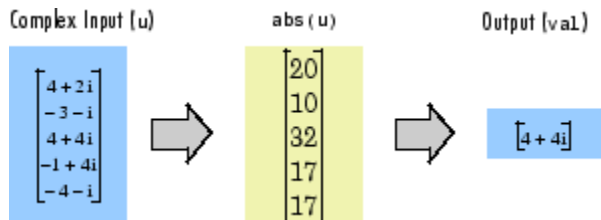
Index Mode

When you set the **Mode** parameter to `Index`, the block computes the maximum value in each row or column of the input, along vectors of a specified dimension of the input, or of the entire input, and outputs the index array *I*. Each element in *I* is an integer indexing the maximum value in the corresponding column, row, vector, or entire input. The output *I* depends on the setting of the **Find the maximum value over** parameter. For example, consider a 3-dimensional input signal of size *M*-by-*N*-by-*P*:

- `Each row` — The output at each sample time consists of an *M*-by-1-by-*P* array, where each element contains the index of the maximum value of each vector over the second dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is an *M*-by-1 column vector.

- `Each column` — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the index of the maximum value of each vector over the first dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is a 1-by-*N* row vector.

  In this mode, the block treats length-*M* unoriented vector inputs as *M*-by-1 column vectors.

- `Entire input` — The output at each sample time is a 1-by-3 vector that contains the location of the maximum value in the *M*-by-*N*-by-*P* input matrix. For an input that is an *M*-by-*N* matrix, the output will be a 1-by-2 vector of one-based [x y] location coordinates for the maximum value.

- `Specified dimension` — The output at each sample time depends on **Dimension**. If **Dimension** is set to 1, the output is the same as when you select `Each column`. If **Dimension** is set to 2, the output is the same as when you select `Each row`. If **Dimension** is set to 3, the output at each sample time is an *M*-by-*N* matrix containing the indices of the maximum values of each vector over the third dimension of the input.

When a maximum value occurs more than once, the computed index corresponds to the first occurrence. For example, when the input is the column vector `[3 2 1 2 3]'`, the computed one-based index of the maximum value is `1` rather than `5` when `Each column` is selected.

When inputs to the block are double-precision values, the index values are double-precision values. Otherwise, the index values are 32-bit unsigned integer values.

Value and Index Mode

When you set the **Mode** parameter to `Value and Index`, the block outputs both the maxima and the indices.

Running Mode

When you set the **Mode** parameter to `Running`, the block tracks the maximum value of each channel in a time sequence of M-by-N inputs. In this mode, the block treats each element as a channel.

Resetting the Running Maximum

The block resets the running maximum whenever a reset event is detected at the optional Rst port. The reset sample time must be a positive integer multiple of the input sample time.

You specify the reset event in the **Reset port** menu:

- `None` — Disables the Rst port.
- `Rising edge` — Triggers a reset operation when the Rst input does one of the following:

    - Rises from a negative value to a positive value or zero
    - Rises from zero to a positive value, where the rise is not a continuation of a rise from a negative value to zero (see the following figure)

- `Falling edge` — Triggers a reset operation when the `Rst` input does one of the following:

  - Falls from a positive value to a negative value or zero

  - Falls from zero to a negative value, where the fall is not a continuation of a fall from a positive value to zero (see the following figure)

- `Either edge` — Triggers a reset operation when the `Rst` input is a `Rising edge` or `Falling edge` (as described above)

- `Non-zero sample` — Triggers a reset operation at each sample time that the `Rst` input is not zero

Note When running simulations in the Simulink `MultiTasking` mode, reset signals have a one-sample latency. Therefore, when the block detects a reset event, there is a one-sample delay at the reset port rate before the block applies the reset.

ROI Processing

To calculate the statistical value within a particular region of interest (ROI) of the input, select the **Enable ROI processing** check box. This applies to any mode other than running mode and when you set the **Find the maximum value over** parameter to `Entire input` and you select the **Enable ROI processing** check box. ROI processing applies only for 2-D inputs.

You can specify a rectangle, line, label matrix, or binary mask ROI type.

Use the binary mask to specify which pixels to highlight or select.

Use the label matrix to label regions. Pixels set to `0` represent the background. Pixels set to `1` represent the first object, pixels set to `2`, represent the second object, and so on. Use the **Label Numbers** port to specify the objects in the label matrix for which the block calculates statistics. The input to this port must be a vector of scalar values that correspond to the labeled regions in the label matrix.

For rectangular ROIs, use the **ROI portion to process** parameter to specify whether to calculate the statistical value for the entire ROI or just the ROI perimeter. For more information about the format of the input to the ROI port when you set the ROI to a rectangle or a line, see the Draw Shapes block reference page.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	ROI is completely outside the input image.
1	ROI is completely or partially inside the input image.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	All ROIs are completely outside the input image.
1	At least one ROI is completely or partially inside the input image.

If the ROI is partially outside the image, the block only computes the statistical values for the portion of the ROI that is within the image.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	Label number is not in the label matrix.
1	Label number is in the label matrix.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	None of the label numbers are in the label matrix.
1	At least one of the label numbers is in the label matrix.

Fixed-Point Data Types

The parameters on the **Data Types** pane of the block dialog are only used for complex fixed-point inputs. The sum of the squares of the real and imaginary parts of such an input are formed before a comparison is made, as described in "Value Mode" on page 1-76. The results of the squares of the real and imaginary parts are placed into the product output data type. The result of the sum of the squares is placed into the accumulator data type. These parameters are ignored for other types of inputs.

Parameters

Mode

Specify the block's mode of operation:

- `Value and Index` — Output both the value and the index location.
- `Value` — Output the maximum value of each input matrix. For more information, see "Value Mode" on page 1-76.
- `Index`— Output the one-based index location of the maximum value. For more information, see "Index Mode" on page 1-77.
- `Running` — Track the maximum value of the input sequence over time. For more information, see "Running Mode" on page 1-78.

For the `Value`, `Index`, and `Value and Index` modes, the 2-D Maximum block produces identical results as the MATLAB `max` function when it is called as `[y I] =`

`max(u,[],D)`, where *u* and *y* are the input and output, respectively, *D* is the dimension, and *I* is the index.

Find the maximum value over

Specify whether the block should find the maximum of the entire input each row, each column, or dimensions specified by the **Dimension** parameter.

Reset port

Specify the reset event that causes the block to reset the running maximum. The rate of the reset signal must be a positive integer multiple of the rate of the data signal input. This parameter appears only when you set the **Mode** parameter to `Running`. For information about the possible values of this parameter, see "Resetting the Running Maximum" on page 1-78.

Dimension

Specify the dimension (one-based value) of the input signal, over which the maximum is computed. The value of this parameter cannot exceed the number of dimensions in the input signal. This parameter applies only when you set the **Find the maximum value over** parameter to `Specified dimension`.

Enable ROI processing

Select this check box to calculate the statistical value within a particular region of each image. This parameter applies only when you set the **Find the maximum value over** parameter to `Entire input`, and the block is not in running mode.

ROI type

Specify the type of ROI you want to use. Your choices are `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`.

When you set this parameter to `Rectangles` or `Lines`, the **Output flag indicating if ROI is within image bounds** check box appears in the dialog box. If you select this check box, the **Flag** port appears on the block.

When you set this parameter to `Label matrix`, the **Label** and **Label Numbers** ports appear on the block and the **Output flag indicating if input label numbers are valid** check box appears in the dialog box. If you select this check box, the Flag port appears on the block.

See "ROI Output Statistics" on page 1-80 for details.

ROI portion to process

> Specify whether you want to calculate the statistical value for the entire ROI or just the ROI perimeter. This parameter applies only when you set the **ROI type** parameter to `Rectangles`.

Output

> Specify the block output. The block can output a vector of separate statistical values for each ROI or a scalar value that represents the statistical value for all the specified ROIs. This parameter does not apply when you set the **ROI type** parameter, to `Binary mask`.

Output flag indicating if ROI is within image bounds

> When you select this check box, the **Flag** port appears on the block. This check box applies only when you set the **ROI type** parameter to `Rectangles` or `Lines`. For a description of the **Flag** port output, see the tables in "ROI Processing" on page 1-80.

Output flag indicating if label numbers are valid

> When you select this check box, the **Flag** port appears on the block. This check box applies only when you set the **ROI type** parameter to `Label matrix`. For a description of the **Flag** port output, see the tables in "ROI Processing" on page 1-80.

Note The parameters on the **Data Types** pane are only used for complex fixed-point inputs. The sum of the squares of the real and imaginary parts of such an input are formed before a comparison is made, as described in "Value Mode" on page 1-76. The results of the squares of the real and imaginary parts are placed into the product output data type. The result of the sum of the squares is placed into the accumulator data type. These parameters are ignored for other types of inputs.

Rounding mode

> Select the "Rounding Modes" for fixed-point operations.

Saturate on integer overflow

> Select the overflow mode for fixed-point operations. See "Precision and Range".

Product output data type

> Specify the product output data type. See "Fixed-Point Data Types" on page 1-81 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block. You can set it to:
>
> • A rule that inherits a data type, for example, `Inherit: Same as input`

- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button `>>` to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. See "Fixed-Point Data Types" on page 1-81 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same as product output`
- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button `>>` to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Lock data type settings against changes by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask.

Examples

The ex_vision_2dmaximum example finds the maximum value within two ROIs. The model outputs the maximum values and their one-based [x y] coordinate locations.

See Also

2-D Mean	Computer Vision System Toolbox
2-D Minimum	Computer Vision System Toolbox
MinMax	Simulink
`max`	MATLAB

2-D Mean

Find mean value of each input matrix
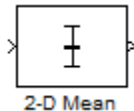
Library

Statistics

`visionstatistics`

Description

The 2-D Mean block computes the mean of each row or column of the input, along vectors of a specified dimension of the input, or of the entire input. The 2-D Mean block can also track the mean value in a sequence of inputs over a period of time. To track the mean value in a sequence of inputs, select the **Running mean** check box.

Port Description

Port	Supported Data Types
Input	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers

Port	Supported Data Types
Reset	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers
ROI	Rectangles and lines: • Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers Binary Mask: • Boolean
Label	• 8-, 16-, and 32-bit unsigned integers
Label Numbers	• 8-, 16-, and 32-bit unsigned integers
Output	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers
Flag	• Boolean

Basic Operation

When you do not select the **Running mean** check box, the block computes the mean value in each row or column of the input, along vectors of a specified dimension of the input, or of the entire input at each individual sample time. Each element in the output array y is the mean value of the corresponding column, row, vector, or entire input. The

output array, y, depends on the setting of the **Find the mean value over** parameter. For example, consider a 3-dimensional input signal of size *M*-by-*N*-by-*P*:

- `Entire input` — The output at each sample time is a scalar that contains the mean value of the *M*-by-*N*-by-*P* input matrix.

  ```
  y = mean(u(:))                 % Equivalent MATLAB code
  ```
- `Each row` — The output at each sample time consists of an *M*-by-1-by-*P* array, where each element contains the mean value of each vector over the second dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is an *M*-by-1 column vector.

  ```
  y = mean(u,2)                 % Equivalent MATLAB code
  ```
- `Each column` — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the mean value of each vector over the first dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is a 1-by-*N* row vector.

  ```
  y = mean(u)                 % Equivalent MATLAB code
  ```

  In this mode, the block treats length-*M* unoriented vector inputs as *M*-by-1 column vectors.
- `Specified dimension` — The output at each sample time depends on the value of the **Dimension** parameter. If you set the **Dimension** to 1, the output is the same as when you select `Each column`. If you set the **Dimension** to 2, the output is the same as when you select `Each row`. If you set the **Dimension** to 3, the output at each sample time is an *M*-by-*N* matrix containing the mean value of each vector over the third dimension of the input.

  ```
  y = mean(u,Dimension)                 % Equivalent MATLAB code
  ```

The mean of a complex input is computed independently for the real and imaginary components, as shown in the following figure.
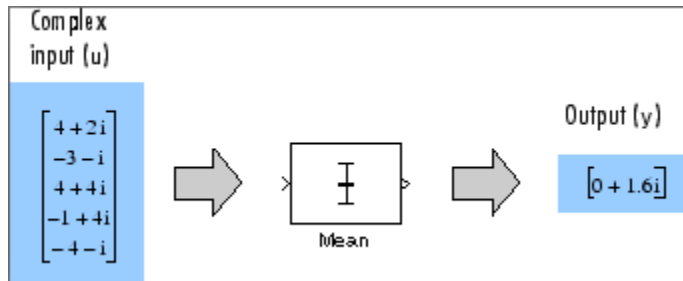
Running Operation

When you select the **Running mean** check box, the block tracks the mean value of each channel in a time sequence of inputs. In this mode, the block treats each element as a channel.

Resetting the Running Mean

The block resets the running mean whenever a reset event is detected at the optional Rst port. The reset sample time must be a positive integer multiple of the input sample time.

When a reset event occurs, the running mean for each channel is initialized to the value in the corresponding channel of the current input.

You specify the reset event by the **Reset port** parameter:

- None disables the Rst port.
- Rising edge — Triggers a reset operation when the Rst input does one of the following:

   - Rises from a negative value to a positive value or zero
   - Rises from zero to a positive value, where the rise is not a continuation of a rise from a negative value to zero (see the following figure)

- `Falling edge` — Triggers a reset operation when the `Rst` input does one of the following:

  - Falls from a positive value to a negative value or zero

  - Falls from zero to a negative value, where the fall is not a continuation of a fall from a positive value to zero (see the following figure)

- `Either edge` — Triggers a reset operation when the `Rst` input is a `Rising edge` or `Falling edge` (as described earlier)

- `Non-zero sample` — Triggers a reset operation at each sample time that the `Rst` input is not zero

Note When running simulations in the Simulink MultiTasking mode, reset signals have a one-sample latency. Therefore, when the block detects a reset event, there is a one-sample delay at the reset port rate before the block applies the reset.

ROI Processing

To calculate the statistical value within a particular region of interest (ROI) of the input, select the **Enable ROI processing** check box. This option is only available when the **Find the mean value over** parameter is set to `Entire input` and the **Running mean** check box is not selected. ROI processing is only supported for 2-D inputs.

- A binary mask is a binary image that enables you to specify which pixels to highlight, or select.

- In a label matrix, pixels equal to 0 represent the background, pixels equal to 1 represent the first object, pixels equal to 2 represent the second object, and so on. When the **ROI type** parameter is set to `Label matrix`, the Label and Label Numbers ports appear on the block. Use the Label Numbers port to specify the objects in the label matrix for which the block calculates statistics. The input to this port must be a vector of scalar values that correspond to the labeled regions in the label matrix.

- For more information about the format of the input to the ROI port when the ROI is a rectangle or a line, see the Draw Shapes reference page.

For more information about the format of the input to the ROI port when the ROI is a rectangle or a line, see the Draw Shapes block reference page.

Note For rectangular ROIs, use the **ROI portion to process** parameter to specify whether to calculate the statistical value for the entire ROI or just the ROI perimeter.

Use the **Output** parameter to specify the block output. The block can output separate statistical values for each ROI or the statistical value for all specified ROIs. This parameter is not available if, for the **ROI type** parameter, you select `Binary mask`.

If, for the **ROI type** parameter, you select `Rectangles` or `Lines`, the **Output flag indicating if ROI is within image bounds** check box appears in the dialog box. If you select this check box, the Flag port appears on the block. The following tables describe the Flag port output based on the block parameters.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	ROI is completely outside the input image.
1	ROI is completely or partially inside the input image.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	All ROIs are completely outside the input image.
1	At least one ROI is completely or partially inside the input image.

If the ROI is partially outside the image, the block only computes the statistical values for the portion of the ROI that is within the image.

If, for the **ROI type** parameter, you select `Label matrix`, the **Output flag indicating if input label numbers are valid** check box appears in the dialog box. If you select this check box, the Flag port appears on the block. The following tables describe the Flag port output based on the block parameters.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	Label number is not in the label matrix.
1	Label number is in the label matrix.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	None of the label numbers are in the label matrix.
1	At least one of the label numbers is in the label matrix.

Fixed-Point Data Types

The following diagram shows the data types used within the Mean block for fixed-point signals.
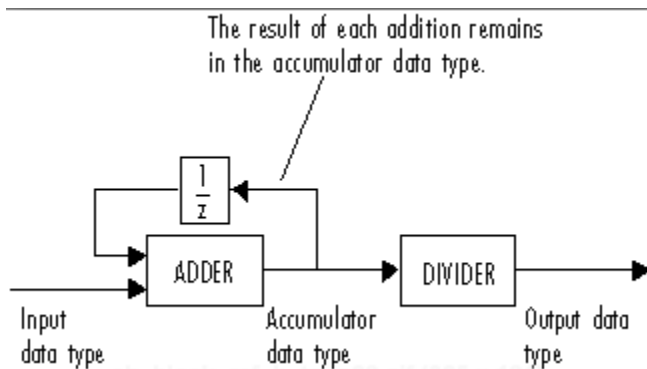
You can set the accumulator and output data types in the block dialog, as discussed in "Parameters" on page 1-93.

Parameters

Running mean

Enables running operation when selected.

Reset port

Specify the reset event that causes the block to reset the running mean. The sample time of the input to the Rst port must be a positive integer multiple of the input sample time. This parameter appears only when you select the **Running mean** check box. For more information, see "Resetting the Running Mean" on page 1-89.

Find the mean value over

Specify whether to find the mean value along rows, columns, entire input, or the dimension specified in the **Dimension** parameter. For more information, see "Basic Operation" on page 1-87.

Dimension

Specify the dimension (one-based value) of the input signal, over which the mean is computed. The value of this parameter cannot exceed the number of dimensions in

the input signal. This parameter is only visible when the **Find the mean value over** parameter is set to `Specified dimension`.

Enable ROI Processing

Select this check box to calculate the statistical value within a particular region of each image. This parameter is only available when the **Find the mean value over** parameter is set to `Entire input`, and the block is not in running mode.

ROI type

Specify the type of ROI you want to use. Your choices are `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`.

ROI portion to process

Specify whether you want to calculate the statistical value for the entire ROI or just the ROI perimeter. This parameter is only visible if, for the **ROI type** parameter, you specify `Rectangles`.

Output

Specify the block output. The block can output a vector of separate statistical values for each ROI or a scalar value that represents the statistical value for all the specified ROIs. This parameter is not available if, for the **ROI type** parameter, you select `Binary mask`.

Output flag indicating if ROI is within image bounds

When you select this check box, a Flag port appears on the block. For a description of the Flag port output, see the tables in "ROI Processing" on page 1-91.

Output flag indicating if label numbers are valid

When you select this check box, a Flag port appears on the block. This check box is visible only when you select `Label matrix` for the **ROI type** parameter. For a description of the Flag port output, see the tables in "ROI Processing" on page 1-91.

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range".

Accumulator data type

Specify the accumulator data type. See "Fixed-Point Data Types" on page 1-93 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same as input`
- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Output data type

Specify the output data type. See "Fixed-Point Data Types" on page 1-93 for illustrations depicting the use of the output data type in this block. You can set it to:

- A rule that inherits a data type, for example, `Inherit: Same as accumulator`
- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Minimum

Specify the minimum value that the block should output. The default value, `[]`, is equivalent to `-Inf`. Simulink software uses this value to perform:

- Simulation range checking (see "Signal Ranges" (Simulink))
- Automatic scaling of fixed-point data types

Maximum

Specify the maximum value that the block should output. The default value, `[]`, is equivalent to `Inf`. Simulink software uses this value to perform:

- Simulation range checking (see "Signal Ranges" (Simulink))
- Automatic scaling of fixed-point data types

Example

The ex_vision_2dmean calculates the mean value within two ROIs.

See Also

2-D Maximum	Computer Vision System Toolbox
2D-Median	Computer Vision System Toolbox
2-D Minimum	Computer Vision System Toolbox
2-D Standard Deviation	Computer Vision System Toolbox
mean	MATLAB

2-D Median

Find 2-D Median value of each input matrix

Library

Statistics

`visionstatistics`

Description

The 2-D Median block computes the median value of each row or column of the input, along vectors of a specified dimension of the input, or of the entire input. The median of a set of input values is calculated as follows:

1   The values are sorted.

2   If the number of values is odd, the median is the middle value.

3   If the number of values is even, the median is the average of the two middle values.

For a given input u, the size of the output array y depends on the setting of the **Find the median value over** parameter. For example, consider a 3-dimensional input signal of size M-by-N-by-P:

- `Entire input` — The output at each sample time is a scalar that contains the median value of the M-by-N-by-P input matrix.

  `y = median(u(:))    % Equivalent MATLAB code`

- `Each row` — The output at each sample time consists of an M-by-1-by-P array, where each element contains the median value of each vector over the second dimension of the input. For an input that is an M-by-N matrix, the output is an M-by-1 column vector.

```
y = median(u,2)        % Equivalent MATLAB code
```
- `Each column` — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the median value of each vector over the first dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is a 1-by-*N* row vector.

```
y = median(u)          % Equivalent MATLAB code
```

For convenience, length-*M* 1-D vector inputs are treated as *M*-by-1 column vectors when the block is in this mode. Sample-based length-*M* row vector inputs are also treated as *M*-by-1 column vectors.

- `Specified dimension` — The output at each sample time depends on **Dimension**. If **Dimension** is set to 1, the output is the same as when you select `Each column`. If **Dimension** is set to 2, the output is the same as when you select `Each row`. If **Dimension** is set to 3, the output at each sample time is an *M*-by-*N* matrix containing the median value of each vector over the third dimension of the input.

```
y = median(u,Dimension)        % Equivalent MATLAB code
```

The block sorts complex inputs according to their magnitude.

Fixed-Point Data Types

For fixed-point inputs, you can specify accumulator, product output, and output data types as discussed in "Parameters" on page 1-99. Not all these fixed-point parameters are applicable for all types of fixed-point inputs. The following table shows when each kind of data type and scaling is used.

	Output data type	Accumulator data type	Product output data type
Even *M*	X	X	
Odd *M*	X		
Odd *M* and complex	X	X	X
Even *M* and complex	X	X	X

The accumulator and output data types and scalings are used for fixed-point signals when *M* is even. The result of the sum performed while calculating the average of the two central rows of the input matrix is stored in the accumulator data type and scaling. The total result of the average is then put into the output data type and scaling.

The accumulator and product output parameters are used for complex fixed-point inputs. The sum of the squares of the real and imaginary parts of such an input are formed before the input elements are sorted, as described in Description on page 1-97. The results of the squares of the real and imaginary parts are placed into the product output data type and scaling. The result of the sum of the squares is placed into the accumulator data type and scaling.

For fixed-point inputs that are both complex and have even *M*, the data types are used in all of the ways described. Therefore, in such cases, the accumulator type is used in two different ways.

Parameters

Sort algorithm

Specify whether to sort the elements of the input using a `Quick sort` or an `Insertion sort` algorithm.

Find the median value over

Specify whether to find the median value along rows, columns, entire input, or the dimension specified in the **Dimension** parameter. For more information, see Description on page 1-97.

Dimension

Specify the dimension (one-based value) of the input signal, over which the median is computed. The value of this parameter cannot exceed the number of dimensions in the input signal. This parameter is only visible when the **Find the median value over** parameter is set to `Specified dimension`.

Note Floating-point inheritance takes precedence over the data type settings defined on this pane. When inputs are floating point, the block ignores these settings, and all internal data types are floating point.

Rounding mode

Select the Rounding mode for fixed-point operations.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range".

Product output data type

Specify the product output data type. See "Fixed-Point Data Types" on page 1-98 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block. You can set it to:

- A rule that inherits a data type, for example, `Inherit: Same as input`

- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. See "Fixed-Point Data Types" on page 1-98 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same as product output`

- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Output data type

Specify the output data type. See "Fixed-Point Data Types" on page 1-98 for illustrations depicting the use of the output data type in this block. You can set it to:

- A rule that inherits a data type, for example, `Inherit: Same as accumulator`

- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button [>>] to display the **Data Type Assistant**, which helps you set the **Output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Minimum

Specify the minimum value that the block should output. The default value, [], is equivalent to -Inf. Simulink software uses this value to perform:
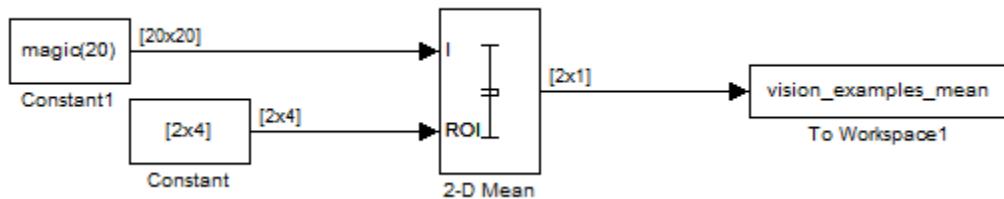
- Simulation range checking (see "Signal Ranges" (Simulink))
- Automatic scaling of fixed-point data types

Maximum

Specify the maximum value that the block should output. The default value, [], is equivalent to Inf. Simulink software uses this value to perform:

- Simulation range checking (see "Signal Ranges" (Simulink))
- Automatic scaling of fixed-point data types

Supported Data Types

Port	Supported Data Types
Input	• Double-precision floating point • Single-precision floating point • Fixed point (signed and unsigned) • 8-, 16-, 32-, and 128-bit signed integers • 8-, 16-, 32-, and 128-bit unsigned integers
Output	• Double-precision floating point • Single-precision floating point • Fixed point (signed and unsigned) • 8-, 16-, 32-, and 128-bit signed integers • 8-, 16-, 32-, and 128-bit unsigned integers

Examples

Calculate Median Value Over Entire Input
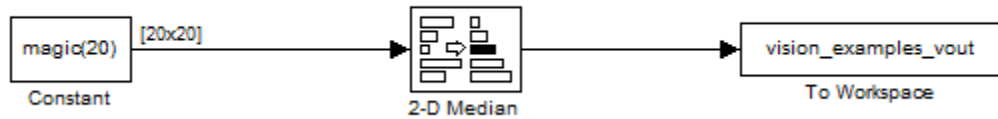
The ex_vision_2dmedian calculates the median value over the entire input.

See Also

2-D Maximum	Computer Vision System Toolbox
2-D Mean	Computer Vision System Toolbox
2-D Minimum	Computer Vision System Toolbox
2-D Standard Deviation	Computer Vision System Toolbox
2-D Variance	Computer Vision System Toolbox
median	MATLAB

2-D Minimum

Find minimum values in input or sequence of inputs
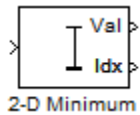
2-D Minimum

Library

Statistics

`visionstatistics`

Description

The 2-D Minimum block identifies the value and/or position of the smallest element in each row or column of the input, or along a specified dimension of the input. The 2-D Minimum block can also track the minimum values in a sequence of inputs over a period of time.

The 2-D Minimum block supports real and complex floating-point, fixed-point, and Boolean inputs. Real fixed-point inputs can be either signed or unsigned, while complex fixed-point inputs must be signed. The output data type of the minimum values match the data type of the input. The block outputs `double` index values, when the input is `double`, and `uint32` otherwise.

Port Description

Port	Input/Output	Supported Data Types	Complex Values Supported
Input	Scalar, vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes
Rst	Scalar value	Boolean	No
Val	Minimum value output based on the "Value Mode" on page 1-104	Same as Input port	Yes
Idx	One-based output location of the minimum value based on the "Index Mode" on page 1-105	Same as Input port	No

Length-*M* 1-D vector inputs are treated as *M*-by-1 column vectors.

Value Mode

When you set the **Mode** parameter to `Value`, the block computes the minimum value in each row, column, entire input, or over a specified dimension. The block outputs each element as the minimum value in the corresponding column, row, vector, or entire input. The output depends on the setting of the **Find the minimum value over** parameter. For example, consider a 3-dimensional input signal of size *M*-by-*N*-by-*P*:

- `Each row` — The output at each sample time consists of an *M*-by-1-by-*P* array, where each element contains the minimum value of each vector over the second dimension of the input. For an *M*-by-*N* input matrix, the block outputs an *M*-by-1 column vector at each sample time.

- `Each column` — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the minimum value of each vector over the first dimension of the input. For an *M*-by-*N* input matrix, the block outputs a 1-by-*N* row vector at each sample time.

In this mode, the block treats length-*M* unoriented vector inputs as *M*-by-1 column vectors.

- `Entire input` — The output at each sample time is a scalar that contains the minimum value in the *M*-by-*N*-by-*P* input matrix.

- `Specified dimension` — The output at each sample time depends on **Dimension**. When you set **Dimension** to 1, the block output is the same as when you select `Each column`. When you set **Dimension** to 2, the block output is the same as when you select `Each row`. When you set **Dimension** to 3, the block outputs an *M*-by-*N* matrix containing the minimum value of each vector over the third dimension of the input, at each sample time.

For complex inputs, the block selects the value in each row or column of the input, along vectors of a specified dimension of the input, or of the entire input that has the minimum magnitude squared as shown below. For complex value $u = a + bi$, the magnitude squared is $a^2 + b^2$.
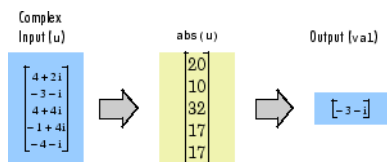
Index Mode

When you set the **Mode** parameter to `Index`, the block computes the minimum value in each row or column of the input, along vectors of a specified dimension of the input, or of the entire input, and outputs the index array *I*. Each element in *I* is an integer indexing the minimum value in the corresponding column, row, vector, or entire input. The output *I* depends on the setting of the **Find the minimum value over** parameter. For example, consider a 3-dimensional input signal of size *M*-by-*N*-by-*P*:

- `Each row` — The output at each sample time consists of an *M*-by-1-by-*P* array, where each element contains the index of the minimum value of each vector over the second dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is an *M*-by-1 column vector.

- `Each column` — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the index of the minimum value of each vector over the first dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is a 1-by-*N* row vector.

In this mode, the block treats length-*M* unoriented vector inputs as *M*-by-1 column vectors.

- `Entire input` — The output at each sample time is a 1-by-3 vector that contains the location of the minimum value in the *M*-by-*N*-by-*P* input matrix. For an input that is an *M*-by-*N* matrix, the output will be a 1-by-2 vector of one-based [x y] location coordinates for the minimum value.

- `Specified dimension` — The output at each sample time depends on **Dimension**. If **Dimension** is set to 1, the output is the same as when you select `Each column`. If **Dimension** is set to 2, the output is the same as when you select `Each row`. If **Dimension** is set to 3, the output at each sample time is an *M*-by-*N* matrix containing the indices of the minimum values of each vector over the third dimension of the input.

When a minimum value occurs more than once, the computed index corresponds to the first occurrence. For example, when the input is the column vector `[-1 2 3 2 -1]'`, the computed one-based index of the minimum value is `1` rather than `5` when `Each column` is selected.

Value and Index Mode

When you set the **Mode** parameter to `Value and Index`, the block outputs both the minima, and the indices.

Running Mode

When you set the **Mode** parameter to `Running`, the block tracks the minimum value of each channel in a time sequence of *M*-by-*N* inputs. In this mode, the block treats each element as a channel.

Resetting the Running Minimum

The block resets the running minimum whenever a reset event is detected at the optional Rst port. The reset sample time must be a positive integer multiple of the input sample time.

You specify the reset event by the **Reset port** parameter:

- `None` — Disables the Rst port
- `Rising edge` — Triggers a reset operation when the Rst input does one of the following:

- Rises from a negative value to a positive value or zero
- Rises from zero to a positive value, where the rise is not a continuation of a rise from a negative value to zero (see the following figure)

- `Falling edge` — Triggers a reset operation when the `Rst` input does one of the following:

  - Falls from a positive value to a negative value or zero
  - Falls from zero to a negative value, where the fall is not a continuation of a fall from a positive value to zero (see the following figure)

- `Either edge` — Triggers a reset operation when the `Rst` input is a `Rising edge` or `Falling edge` (as described above)
- `Non-zero sample` — Triggers a reset operation at each sample time that the `Rst` input is not zero

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Note When running simulations in the Simulink `MultiTasking` mode, reset signals have a one-sample latency. Therefore, when the block detects a reset event, there is a one-sample delay at the reset port rate before the block applies the reset.

ROI Processing

To calculate the statistical value within a particular region of interest (ROI) of the input, select the **Enable ROI processing** check box. This applies to any mode other than the running mode and when you set the **Find the minimum value over** parameter to `Entire input` and you select the **Enable ROI processing** check box. ROI processing applies only for 2-D inputs.

You can specify a rectangle, line, label matrix, or binary mask ROI type.

Use the binary mask to specify which pixels to highlight or select.

Use the label matrix to label regions. Pixels set to `0` represent the background. Pixels set to `1` represent the first object, pixels set to `2`, represent the second object, and so on. Use the **Label Numbers** port to specify the objects in the label matrix for which the block calculates statistics. The input to this port must be a vector of scalar values that correspond to the labeled regions in the label matrix.

For rectangular ROIs, use the **ROI portion to process** parameter to specify whether to calculate the statistical value for the entire ROI or just the ROI perimeter. For more information about the format of the input to the ROI port when you set the ROI to a rectangle or a line, see the Draw Shapes block reference page.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	ROI is completely outside the input image.
1	ROI is completely or partially inside the input image.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	All ROIs are completely outside the input image.
1	At least one ROI is completely or partially inside the input image.

If the ROI is partially outside the image, the block only computes the statistical values for the portion of the ROI that is within the image.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	Label number is not in the label matrix.
1	Label number is in the label matrix.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	None of the label numbers are in the label matrix.
1	At least one of the label numbers is in the label matrix.

Fixed-Point Data Types

The parameters on the **Fixed-point** pane of the dialog box are only used for complex fixed-point inputs. The sum of the squares of the real and imaginary parts of such an input are formed before a comparison is made, as described in "Value Mode" on page 1-104. The results of the squares of the real and imaginary parts are placed into the product output data type. The result of the sum of the squares is placed into the accumulator data type. These parameters are ignored for other types of inputs.

Parameters

Mode

Specify the block's mode of operation:

- `Value and Index` — Output both the value and the index location.
- `Value` — Output the minimum value of each input matrix. For more information, see "Value Mode" on page 1-104
- `Index`— Output the one-based index location of the minimum value. For more information, see "Index Mode" on page 1-105
- `Running` — Track the minimum value of the input sequence over time. For more information, see "Running Mode" on page 1-106.

For the `Value`, `Index`, and `Value and Index` modes, the 2-D Minimum block produces identical results as the MATLAB `min` function when it is called as $[y\ I]$ = $\min(u,[],D)$, where u and y are the input and output, respectively, D is the dimension, and I is the index.

Find the minimum value over

Specify whether the block should find the minimum of the entire input each row, each column, or dimensions specified by the **Dimension** parameter.

Reset port

Specify the reset event that causes the block to reset the running minimum. The rate of the reset signal must be a positive integer multiple of the rate of the data signal input. This parameter appears only when you set the **Mode** parameter to `Running`. For information about the possible values of this parameter, see "Resetting the Running Minimum" on page 1-106.

Dimension

Specify the dimension (one-based value) of the input signal, over which the minimum is computed. The value of this parameter cannot exceed the number of dimensions in the input signal. This parameter applies only when you set the **Find the minimum value over** parameter to `Specified dimension`.

Enable ROI processing

Select this check box to calculate the statistical value within a particular region of each image. This parameter applies only when you set the **Find the minimum value over** parameter to `Entire input`, and the block is not in running mode.

ROI type

Specify the type of ROI you want to use. Your choices are `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`.

When you set this parameter to `Rectangles` or `Lines`, the **Output flag indicating if ROI is within image bounds** check box appears in the dialog box. If you select this check box, the **Flag** port appears on the block.

When you set this parameter to `Label matrix`, the **Label** and **Label Numbers** ports appear on the block and the **Output flag indicating if input label numbers are valid** check box appears in the dialog box. If you select this check box, the Flag port appears on the block.

See Output = Individual statistics for each ROI for details.

ROI portion to process

Specify whether you want to calculate the statistical value for the entire ROI or just the ROI perimeter. This parameter applies only when you set the **ROI type** parameter to `Rectangles`.

Output

Specify the block output. The block can output a vector of separate statistical values for each ROI or a scalar value that represents the statistical value for all the specified ROIs. This parameter does not apply when you set the **ROI type** parameter, to `Binary mask`.

Output flag indicating if ROI is within image bounds

When you select this check box, the **Flag** port appears on the block. This check box applies only when you set the **ROI type** parameter to `Rectangles` or `Lines`. For a description of the **Flag** port output, see the tables in "ROI Processing" on page 1-108.

Output flag indicating if label numbers are valid

When you select this check box, the **Flag** port appears on the block. This check box applies only when you set the **ROI type** parameter to `Label matrix`. For a description of the **Flag** port output, see the tables in "ROI Processing" on page 1-108.

Note The parameters on the **Data Types** pane are only used for complex fixed-point inputs. The sum of the squares of the real and imaginary parts of such an input are formed before a comparison is made, as described in "Value Mode" on page 1-104. The results of the squares of the real and imaginary parts are placed into the product output data type. The result of the sum of the squares is placed into the accumulator data type. These parameters are ignored for other types of inputs.

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Saturate on integer overflow

Select the overflow mode for fixed-point operations. See "Precision and Range".

Product output data type

Specify the product output data type. See "Fixed-Point Data Types" on page 1-109 and "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block. You can set it to:

- A rule that inherits a data type, for example, `Inherit: Same as input`
- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Product output data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Accumulator data type

Specify the accumulator data type. See "Fixed-Point Data Types" on page 1-109 for illustrations depicting the use of the accumulator data type in this block. You can set this parameter to:

- A rule that inherits a data type, for example, `Inherit: Same as input`
- An expression that evaluates to a valid data type, for example, `fixdt([],16,0)`

Click the **Show data type assistant** button >> to display the **Data Type Assistant**, which helps you set the **Accumulator data type** parameter.

See "Specify Data Types Using Data Type Assistant" (Simulink) for more information.

Examples
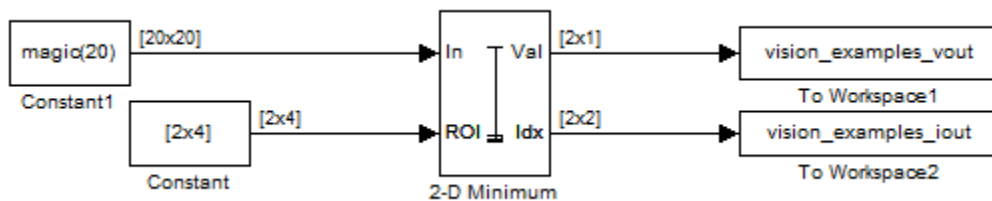
The ex_vision_2dminimum example finds the minimum value within two ROIs. The model outputs the minimum values and their one-based [x y] coordinate locations.

See Also

2-D Maximum	Computer Vision System Toolbox
2-D Mean	Computer Vision System Toolbox
MinMax	Simulink
2D-Histogram	Computer Vision System Toolbox
min	MATLAB

2-D Standard Deviation

Find standard deviation of each input matrix

2-D Standard
Deviation
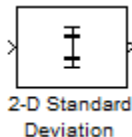
Library

Statistics

`visionstatistics`

Description

The Standard Deviation block computes the standard deviation of each row or column of the input, along vectors of a specified dimension of the input, or of the entire input. The Standard Deviation block can also track the standard deviation of a sequence of inputs over a period of time. The **Running standard deviation** parameter selects between basic operation and running operation.

Port Description

Port	Supported Data Types
Input	• Double-precision floating point • Single-precision floating point
Reset	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers

Port	Supported Data Types
ROI	Rectangles and lines: • Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers Binary Mask: • Boolean
Label	• 8-, 16-, and 32-bit unsigned integers
Label Numbers	• 8-, 16-, and 32-bit unsigned integers
Output	• Double-precision floating point • Single-precision floating point
Flag	• Boolean

Basic Operation

When you do not select the **Running standard deviation** check box, the block computes the standard deviation of each row or column of the input, along vectors of a specified dimension of the input, or of the entire input at each individual sample time, and outputs the array y. Each element in y contains the standard deviation of the corresponding column, row, vector, or entire input. The output y depends on the setting of the **Find the standard deviation value over** parameter. For example, consider a 3-dimensional input signal of size M-by-N-by-P:

• `Entire input` — The output at each sample time is a scalar that contains the standard deviation of the entire input.

```
y = std(u(:))                    % Equivalent MATLAB code
```
• `Each Row` — The output at each sample time consists of an M-by-1-by-P array, where each element contains the standard deviation of each vector over the second dimension of the input. For an input that is an M-by-N matrix, the output at each sample time is an M-by-1 column vector.

```
y = std(u,0,2)                          % Equivalent MATLAB code
```

- Each Column — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the standard deviation of each vector over the first dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is a 1-by-*N* row vector.

```
y = std(u,0,1)                          % Equivalent MATLAB code
```

In this mode, the block treats length-*M* unoriented vector inputs as *M*-by-1 column vectors.

- Specified Dimension — The output at each sample time depends on **Dimension**. If **Dimension** is set to 1, the output is the same as when you select Each column. If **Dimension** is set to 2, the output is the same as when you select Each row. If **Dimension** is set to 3, the output at each sample time is an *M*-by-*N* matrix containing the standard deviation of each vector over the third dimension of the input.

```
y = std(u,0,Dimension)                  % Equivalent MATLAB code
```

For purely real or purely imaginary inputs, the standard deviation of the *j*th column of an *M*-by-*N* input matrix is the square root of its variance:

$$y_j = \sigma_j = \sqrt{\frac{\sum_{i=1}^{M}\left|u_{ij} - \mu_j\right|^2}{M-1}} \qquad 1 \le j \le N$$

For complex inputs, the output is the *total standard deviation*, which equals the square root of the *total variance*, or the square root of the sum of the variances of the real and imaginary parts. The standard deviation of each column in an *M*-by-*N* input matrix is given by:

$$\sigma_j = \sqrt{\sigma_{j,\mathrm{Re}}^2 + \sigma_{j,\mathrm{Im}}^2}$$

Note The total standard deviation does *not* equal the sum of the real and imaginary standard deviations.

Running Operation

When you select the **Running standard deviation** check box, the block tracks the standard deviation of successive inputs to the block. In this mode, the block treats each element as a channel.

Resetting the Running Standard Deviation

The block resets the running standard deviation whenever a reset event is detected at the optional `Rst` port. The reset sample time must be a positive integer multiple of the input sample time.

You specify the reset event in the **Reset port** parameter:

- `None` disables the `Rst` port.
- `Rising edge` — Triggers a reset operation when the `Rst` input does one of the following:

  - Rises from a negative value to a positive value or zero
  - Rises from zero to a positive value, where the rise is not a continuation of a rise from a negative value to zero (see the following figure)

- `Falling edge` — Triggers a reset operation when the `Rst` input does one of the following:

  - Falls from a positive value to a negative value or zero
  - Falls from zero to a negative value, where the fall is not a continuation of a fall from a positive value to zero (see the following figure)

- `Either edge` — Triggers a reset operation when the `Rst` input is a `Rising edge` or `Falling edge` (as described earlier)

- `Non-zero sample` — Triggers a reset operation at each sample time that the `Rst` input is not zero

> **Note** When running simulations in the Simulink MultiTasking mode, reset signals have a one-sample latency. Therefore, when the block detects a reset event, there is a one-sample delay at the reset port rate before the block applies the reset.

ROI Processing

To calculate the statistical value within a particular region of interest (ROI) of the input, select the **Enable ROI processing** check box. This option is only available when the **Find the standard deviation value over** parameter is set to `Entire input` and the **Running standard deviation** check box is not selected. ROI processing is only supported for 2-D inputs.

Use the **ROI type** parameter to specify whether the ROI is a rectangle, line, label matrix, or binary mask. A binary mask is a binary image that enables you to specify which pixels to highlight, or select. In a label matrix, pixels equal to 0 represent the background, pixels equal to 1 represent the first object, pixels equal to 2 represent the second object, and so on. When the **ROI type** parameter is set to `Label matrix`, the Label and Label Numbers ports appear on the block. Use the Label Numbers port to specify the objects in the label matrix for which the block calculates statistics. The input to this port must be a vector of scalar values that correspond to the labeled regions in the label matrix. For

more information about the format of the input to the ROI port when the ROI is a rectangle or a line, see the Draw Shapes block reference page.

For rectangular ROIs, use the **ROI portion to process** parameter to specify whether to calculate the statistical value for the entire ROI or just the ROI perimeter.

Use the **Output** parameter to specify the block output. The block can output separate statistical values for each ROI or the statistical value for all specified ROIs. This parameter is not available if, for the **ROI type** parameter, you select `Binary mask`.

If, for the **ROI type** parameter, you select `Rectangles` or `Lines`, the **Output flag indicating if ROI is within image bounds** check box appears in the dialog box. If you select this check box, the Flag port appears on the block. The following tables describe the Flag port output based on the block parameters.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	ROI is completely outside the input image.
1	ROI is completely or partially inside the input image.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	All ROIs are completely outside the input image.
1	At least one ROI is completely or partially inside the input image.

If the ROI is partially outside the image, the block only computes the statistical values for the portion of the ROI that is within the image.

If, for the **ROI type** parameter, you select `Label matrix`, the **Output flag indicating if input label numbers are valid** check box appears in the dialog box. If you select this check box, the Flag port appears on the block. The following tables describe the Flag port output based on the block parameters.

Output = Individual statistics for each ROI

Flag Port Output	Description
0	Label number is not in the label matrix.
1	Label number is in the label matrix.

Output = Single statistic for all ROIs

Flag Port Output	Description
0	None of the label numbers are in the label matrix.
1	At least one of the label numbers is in the label matrix.

Parameters

Running standard deviation

Enables running operation when selected.

Reset port

Specify the reset event that causes the block to reset the running standard deviation. The sample time of the input to the Rst port must be a positive integer multiple of the input sample time. This parameter appears only when you select the **Running standard deviation** check box. For more information, see "Resetting the Running Standard Deviation" on page 1-117.

Find the standard deviation value over

Specify whether to find the standard deviation value along rows, columns, entire input, or the dimension specified in the **Dimension** parameter. For more information, see "Basic Operation" on page 1-115.

Dimension

Specify the dimension (one-based value) of the input signal, over which the standard deviation is computed. The value of this parameter cannot exceed the number of dimensions in the input signal. This parameter is only visible when the **Find the standard deviation value over** parameter is set to `Specified dimension`.

Enable ROI Processing

Select this check box to calculate the statistical value within a particular region of each image. This parameter is only available when the **Find the standard deviation value over** parameter is set to `Entire input`, and the block is not in running mode.

ROI type

Specify the type of ROI you want to use. Your choices are `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`.

ROI portion to process

Specify whether you want to calculate the statistical value for the entire ROI or just the ROI perimeter. This parameter is only visible if, for the **ROI type** parameter, you specify `Rectangles`.

Output

Specify the block output. The block can output a vector of separate statistical values for each ROI or a scalar value that represents the statistical value for all the specified ROIs. This parameter is not available if, for the **ROI type** parameter, you select `Binary mask`.

Output flag indicating if ROI is within image bounds

When you select this check box, a Flag port appears on the block. For a description of the Flag port output, see the tables in "ROI Processing" on page 1-118.

Output flag indicating if label numbers are valid

When you select this check box, a Flag port appears on the block. This check box is visible only when you select `Label matrix` for the **ROI type** parameter. For a description of the Flag port output, see the tables in "ROI Processing" on page 1-118.

Example
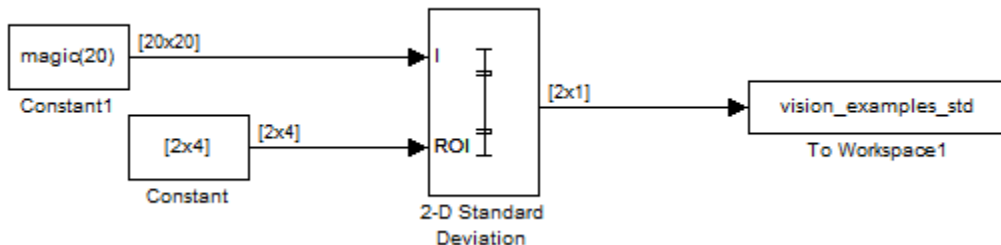
The ex_vision_2dstd calculates the standard deviation value within two ROIs.

See Also

2-D Mean	Computer Vision System Toolbox
2-D Variance	Computer Vision System Toolbox
std	MATLAB

2-D Variance

Compute variance of input or sequence of inputs
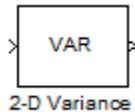
2-D Variance

Library

Statistics

`visionstatistics`

Description

The 2-D Variance block computes the unbiased variance of each row or column of the input, along vectors of a specified dimension of the input, or of the entire input. The 2-D Variance block can also track the variance of a sequence of inputs over a period of time. The **Running variance** parameter selects between basic operation and running operation.

Port Description

Port	Supported Data Types
Input	• Double-precision floating point
	• Single-precision floating point
	• Fixed point
	• 8-, 16-, and 32-bit signed integers
	• 8-, 16-, and 32-bit unsigned integers

Port	Supported Data Types
Reset	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers
ROI	Rectangles and lines: • Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers Binary Mask: • Boolean
Label	• 8-, 16-, and 32-bit unsigned integers
Label Numbers	• 8-, 16-, and 32-bit unsigned integers
Output	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers
Flag	• Boolean

Basic Operation

When you do not select the **Running variance** check box, the block computes the variance of each row or column of the input, along vectors of a specified dimension of the input, or of the entire input at each individual sample time, and outputs the array *y*. Each element in *y* is the variance of the corresponding column, row, vector, or entire input. The

output *y* depends on the setting of the **Find the variance value over** parameter. For example, consider a 3-dimensional input signal of size *M*-by-*N*-by-*P*:

- `Entire input` — The output at each sample time is a scalar that contains the variance of the entire input.

  ```
  y = var(u(:))                    % Equivalent MATLAB code
  ```

- `Each row` — The output at each sample time consists of an *M*-by-1-by-*P* array, where each element contains the variance of each vector over the second dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is an *M*-by-1 column vector.

  ```
  y = var(u,0,2)                   % Equivalent MATLAB code
  ```

- `Each column` — The output at each sample time consists of a 1-by-*N*-by-*P* array, where each element contains the variance of each vector over the first dimension of the input. For an input that is an *M*-by-*N* matrix, the output at each sample time is a 1-by-*N* row vector.

  ```
  y = var(u,0,1)                   % Equivalent MATLAB code
  ```

  In this mode, the block treats length-*M* unoriented vector inputs as *M*-by-1 column vectors.

- `Specified dimension` — The output at each sample time depends on **Dimension**. If **Dimension** is set to 1, the output is the same as that when you select `Each column`. If **Dimension** is set to 2, the output is the same as when you select `Each row`. If **Dimension** is set to 3, the output at each sample time is an *M*-by-*N* matrix containing the variance of each vector over the third dimension of the input.

  ```
  y = var(u,0,Dimension)                   % Equivalent MATLAB code
  ```

For purely real or purely imaginary inputs, the variance of an M-by-N matrix is the square of the standard deviation:

$$y = \sigma^2 = \frac{\displaystyle\sum_{i=1}^{M}\sum_{j=1}^{N}\left|u_{ij}\right|^2 - \dfrac{\left|\displaystyle\sum_{i=1}^{M}\sum_{j=1}^{N}u_{ij}\right|^2}{M*N}}{M*N-1}$$

For complex inputs, the variance is given by the following equation:

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$$\sigma^2 = \sigma_{Re}{}^2 + \sigma_{Im}{}^2$$

Running Operation

When you select the **Running variance** check box, the block tracks the variance of successive inputs to the block. In this mode, the block treats each element as a channel.

Resetting the Running Variance

The block resets the running variance whenever a reset event is detected at the optional Rst port. The reset sample time must be a positive integer multiple of the input sample time.

You specify the reset event in the **Reset port** parameter:

- None disables the Rst port.
- Rising edge — Triggers a reset operation when the Rst input does one of the following:

  - Rises from a negative value to a positive value or zero
  - Rises from zero to a positive value, where the rise is not a continuation of a rise from a negative value to zero (see the following figure)

- Falling edge — Triggers a reset operation when the Rst input does one of the following:

  - Falls from a positive value to a negative value or zero

- Falls from zero to a negative value, where the fall is not a continuation of a fall from a positive value to zero (see the following figure)

- `Either edge` — Triggers a reset operation when the Rst input is a `Rising edge` or `Falling edge` (as described earlier)
- `Non-zero sample` — Triggers a reset operation at each sample time that the Rst input is not zero

Note When running simulations in the Simulink MultiTasking mode, reset signals have a one-sample latency. Therefore, when the block detects a reset event, there is a one-sample delay at the reset port rate before the block applies the reset.

ROI Processing

To calculate the statistical value within a particular region of interest (ROI) of the input, select the **Enable ROI processing** check box. This option is only available when the **Find the variance value over** parameter is set to `Entire input` and the **Running variance** check box is not selected. ROI processing is only supported for 2-D inputs.

Use the **ROI type** parameter to specify whether the ROI is a binary mask, label matrix, rectangle, or line. ROI processing is only supported for 2-D inputs.

- A binary mask is a binary image that enables you to specify which pixels to highlight, or select.
- In a label matrix, pixels equal to 0 represent the background, pixels equal to 1 represent the first object, pixels equal to 2 represent the second object, and so on. When the **ROI type** parameter is set to `Label matrix`, the Label and Label Numbers

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ports appear on the block. Use the Label Numbers port to specify the objects in the label matrix for which the block calculates statistics. The input to this port must be a vector of scalar values that correspond to the labeled regions in the label matrix.

- For more information about the format of the input to the ROI port when the ROI is a rectangle or a line, see the Draw Shapes reference page.

Note For rectangular ROIs, use the **ROI portion to process** parameter to specify whether to calculate the statistical value for the entire ROI or just the ROI perimeter.

Use the **Output** parameter to specify the block output. The block can output separate statistical values for each ROI or the statistical value for all specified ROIs. This parameter is not available if, for the **ROI type** parameter, you select `Binary mask`.

If, for the **ROI type** parameter, you select `Rectangles` or `Lines`, the **Output flag indicating if ROI is within image bounds** check box appears in the dialog box. If you select this check box, the Flag port appears on the block. The following tables describe the Flag port output based on the block parameters.

Output = Individual Statistics for Each ROI

Flag Port Output	Description
0	ROI is completely outside the input image.
1	ROI is completely or partially inside the input image.

Output = Single Statistic for All ROIs

Flag Port Output	Description
0	All ROIs are completely outside the input image.
1	At least one ROI is completely or partially inside the input image.

If the ROI is partially outside the image, the block only computes the statistical values for the portion of the ROI that is within the image.

If, for the **ROI type** parameter, you select `Label matrix`, the **Output flag indicating if input label numbers are valid** check box appears in the dialog box. If you select this check box, the Flag port appears on the block. The following tables describe the Flag port output based on the block parameters.

Output = Individual Statistics for Each ROI

Flag Port Output	Description
0	Label number is not in the label matrix.
1	Label number is in the label matrix.

Output = Single Statistic for All ROIs

Flag Port Output	Description
0	None of the label numbers are in the label matrix.
1	At least one of the label numbers is in the label matrix.

Fixed-Point Data Types

The parameters on the **Data Types** pane of the block dialog are only used for fixed-point inputs. For purely real or purely imaginary inputs, the variance of the input is the square of its standard deviation. For complex inputs, the output is the sum of the variance of the real and imaginary parts of the input.

The following diagram shows the data types used within the Variance block for fixed-point signals.

u_{ij}

The results of the magnitude-squared calculations in the figure are in the product output data type. You can set the accumulator, product output, and output data types in the block dialog as discussed in "Parameters" on page 1-129.

Parameters

Running variance

Enables running operation when selected.

Reset port

Specify the reset event that causes the block to reset the running variance. The sample time of the input to the Rst port must be a positive integer multiple of the

input sample time. This parameter appears only when you select the **Running variance** check box. For more information, see "Resetting the Running Variance" on page 1-126

Find the variance value over

Specify whether to find the variance along rows, columns, entire input, or the dimension specified in the **Dimension** parameter. For more information, see "Basic Operation" on page 1-124.

Dimension

Specify the dimension (one-based value) of the input signal, over which the variance is computed. The value of this parameter cannot exceed the number of dimensions in the input signal. This parameter is only visible when the **Find the variance value over** parameter is set to `Specified dimension`.

Enable ROI Processing

Select this check box to calculate the statistical value within a particular region of each image. This parameter is only available when the **Find the variance value over** parameter is set to `Entire input`, and the block is not in running mode.

Note Full ROI processing is available only if you have a Computer Vision System Toolbox license. If you do not have a Computer Vision System Toolbox license, you can still use ROI processing, but are limited to the **ROI type** `Rectangles`.

ROI type

Specify the type of ROI you want to use. Your choices are `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`.

ROI portion to process

Specify whether you want to calculate the statistical value for the entire ROI or just the ROI perimeter. This parameter is only visible if, for the **ROI type** parameter, you specify `Rectangles`.

Output

Specify the block output. The block can output a vector of separate statistical values for each ROI or a scalar value that represents the statistical value for all the specified ROIs. This parameter is not available if, for the **ROI type** parameter, you select `Binary mask`.

Output flag indicating if ROI is within image bounds

When you select this check box, a Flag port appears on the block. For a description of the Flag port output, see the tables in "ROI Processing" on page 1-127.

Output flag indicating if label numbers are valid

When you select this check box, a Flag port appears on the block. This check box is visible only when you select `Label matrix` for the **ROI type** parameter. For a description of the Flag port output, see the tables in "ROI Processing" on page 1-127.

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Overflow mode

Select the Overflow mode for fixed-point operations.

Note See "Fixed-Point Data Types" on page 1-129 for more information on how the product output, accumulator, and output data types are used in this block.

Input-squared product

Use this parameter to specify how to designate the input-squared product word and fraction lengths:

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the input-squared product, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the input-squared product. This block requires power-of-two slope and a bias of zero.

Input-sum-squared product

Use this parameter to specify how to designate the input-sum-squared product word and fraction lengths:

- When you select `Same as input-squared product`, these characteristics match those of the input-squared product.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the input-sum-squared product, in bits.

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- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the input-sum-squared product. This block requires power-of-two slope and a bias of zero.

Accumulator

Use this parameter to specify the accumulator word and fraction lengths resulting from a complex-complex multiplication in the block:

- When you select `Same as input-squared product`, these characteristics match those of the input-squared product.

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. This block requires power-of-two slope and a bias of zero.

Output

Choose how you specify the output word length and fraction length:

- When you select `Same as accumulator`, these characteristics match those of the accumulator.

- When you select `Same as input-squared product`, these characteristics match those of the input-squared product.

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. This block requires power-of-two slope and a bias of zero.

Lock data type settings against changes by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask.

Example
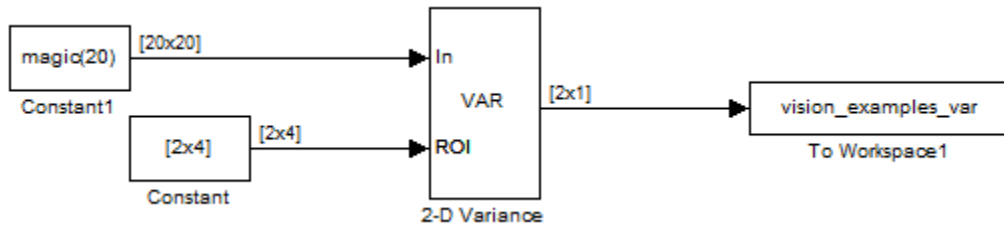
The ex_vision_2dvar calculates the variance value within two ROIs.

See Also

2-D Mean	Computer Vision System Toolbox
2-D Standard Deviation	Computer Vision System Toolbox
var	MATLAB

Autothreshold

Convert intensity image to binary image
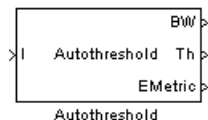
Library

Conversions

`visionconversions`

Description

The Autothreshold block converts an intensity image to a binary image using a threshold value computed using Otsu's method.

This block computes this threshold value by splitting the histogram of the input image such that the variance of each pixel group is minimized.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
BW	Scalar, vector, or matrix that represents a binary image	Boolean	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Th	Threshold value	Same as I port	No
EMetric	Effectiveness metric	Same as I port	No

Use the **Thresholding operator** parameter to specify the condition the block places on the input values. If you select > and the input value is greater than the threshold value, the block outputs 1 at the BW port; otherwise, it outputs 0. If you select <= and the input value is less than or equal to the threshold value, the block outputs 1; otherwise, it outputs 0.

Select the **Output threshold** check box to output the calculated threshold values at the Th port.

Select the **Output effectiveness metric** check box to output values that represent the effectiveness of the thresholding at the EMetric port. This metric ranges from 0 to 1. If every pixel has the same value, the effectiveness metric is 0. If the image has two pixel values or the histogram of the image pixels is symmetric, the effectiveness metric is 1.

If you clear the **Specify data range** check box, the block assumes that floating-point input values range from 0 to 1. To specify a different data range, select this check box. The **Minimum value of input** and **Maximum value of input** parameters appear in the dialog box. Use these parameters to enter the minimum and maximum values of your input signal.

Use the **When data range is exceeded** parameter to specify the block's behavior when the input values are outside the expected range. The following options are available:

- Ignore — Proceed with the computation and do not issue a warning message. If you choose this option, the block performs the most efficient computation. However, if the input values exceed the expected range, the block produces incorrect results.
- Saturate — Change any input values outside the range to the minimum or maximum value of the range and proceed with the computation.
- Warn and saturate — Display a warning message in the MATLAB Command Window, saturate values, and proceed with the computation.
- Error — Display an error dialog box and terminate the simulation.

If you clear the **Scale threshold** check box, the block uses the threshold value computed by Otsu's method to convert intensity images into binary images. If you select the **Scale**

threshold check box, the **Threshold scaling factor** appears in the dialog box. Enter a scalar value. The block multiplies this scalar value with the threshold value computed by Otsu's method and uses the result as the new threshold value.

Fixed-Point Data Types

The following diagram shows the data types used in the Autothreshold block for fixed-point signals. You can use the default fixed-point parameters if your input has a word length less than or equal to 16.
In this diagram, DT means data type. You can set the product, accumulator, quotient, and effectiveness metric data types in the block mask.
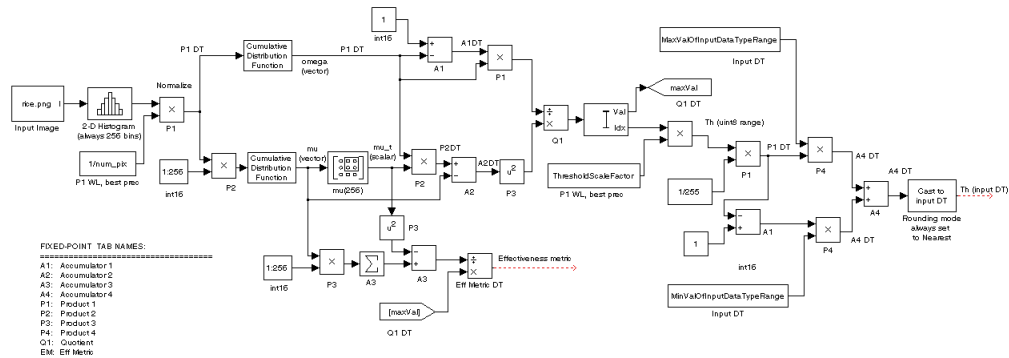
Parameters

Thresholding operator

Specify the condition the block places on the input matrix values. If you select > or <=, the block outputs 0 or 1 depending on whether the input matrix values are above, below, or equal to the threshold value.

Output threshold

Select this check box to output the calculated threshold values at the Th port.

Output effectiveness metric

Select this check box to output values that represent the effectiveness of the thresholding at the EMetric port.

Specify data range

If you clear this check box, the block assumes that floating-point input values range from 0 to 1. To specify a different data range, select this check box.

Minimum value of input

Enter the minimum value of your input data. This parameter is visible if you select the **Specify data range** check box.

Maximum value of input

Enter the maximum value of your input data. This parameter is visible if you select the **Specify data range** check box.

When data range is exceeded

Specify the block's behavior when the input values are outside the expected range. Your options are `Ignore`, `Saturate`, `Warn and saturate`, or `Error`. This parameter is visible if you select the **Specify data range** check box.

Scale threshold

Select this check box to scale the threshold value computed by Otsu's method.

Threshold scaling factor

Enter a scalar value. The block multiplies this scalar value with the threshold value computed by Otsu's method and uses the result as the new threshold value. This parameter is visible if you select the **Scale threshold** check box.

Rounding mode

Select the rounding mode for fixed-point operations. This parameter does not apply to the Cast to input DT step shown in "Fixed-Point Data Types" on page 1-136. For this step, **Rounding mode** is always set to `Nearest`.

Overflow mode

Select the overflow mode for fixed-point operations.

Product 1, 2, 3, 4

As shown previously, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate the product output word and fraction lengths.

- When you select `Specify word length`, you can enter the word length of the product values in bits. The block sets the fraction length to give you the best precision.
- When you select `Same as input`, the characteristics match those of the input to the block. This choice is only available for the **Product 4** parameter.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output in bits.
- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Accumulator 1, 2, 3, 4
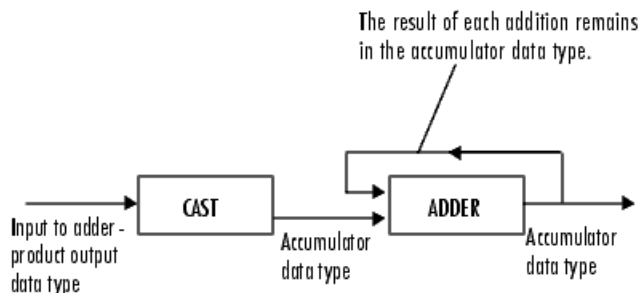
As shown previously, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate the accumulator word and fraction lengths.

- When you select `Same as Product`, these characteristics match those of the product output.
- When you select `Specify word length`, you can enter the word length of the accumulator values in bits. The block sets the fraction length to give you the best precision. This choice is not available for the **Accumulator 4** parameter because it is dependent on the input data type.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator in bits.
- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox software is 0.

The **Accumulator 3** parameter is only visible if, on the **Main** pane, you select the **Output effectiveness metric** check box.

Quotient

Choose how to specify the word length and fraction length of the quotient data type:

- When you select `Specify word length`, you can enter the word length of the quotient values in bits. The block sets the fraction length to give you the best precision.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the quotient, in bits.
- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the quotient. The bias of all signals in the Computer Vision System Toolbox software is 0.

Eff Metric

Choose how to specify the word length and fraction length of the effectiveness metric data type. This parameter is only visible if, on the **Main** tab, you select the **Output effectiveness metric** check box.

- When you select `Specify word length`, you can enter the word length of the effectiveness metric values, in bits. The block sets the fraction length to give you the best precision.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the effectiveness metric in bits.
- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the effectiveness metric. The bias of all signals in the Computer Vision System Toolbox software is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Example

Example 1.1. Thresholding Intensity Images Using the Autothreshold Block

Convert an intensity image into a binary image. Use the Autothreshold block when lighting conditions vary and the threshold needs to change for each video frame.

You can open the example model by typing

`ex_vision_autothreshold`

on the MATLAB command line.

See Also

Compare To Constant	Simulink
Relational Operator	Simulink
graythresh	Image Processing Toolbox

Introduced before R2006a

Blob Analysis

Compute statistics for labeled regions
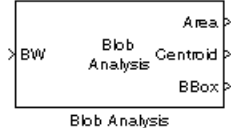
Library

Statistics

`visionstatistics`

Description

Use the Blob Analysis block to calculate statistics for labeled regions in a binary image. The block returns quantities such as the centroid, bounding box, label matrix, and blob count. The Blob Analysis block supports input and output variable size signals. You can also use the Selector block from Simulink, to select certain blobs based on their statistics.

For information on pixel and spatial coordinate system definitions, see "Image Coordinate Systems" (Image Processing Toolbox) and "Coordinate Systems".

Port Descriptions

Port	Input/Output	Supported Data Types
BW	Vector or matrix that represents a binary image	Boolean
Area	Vector that represents the number of pixels in labeled regions	32-bit signed integer

Port	Input/Output	Supported Data Types
Centroid	*M*-by-2 matrix of centroid coordinates, where *M* represents the number of blobs	• Double-precision floating point • Single-precision floating point • Fixed point
BBox	*M*-by-4 matrix of [x y width height] bounding box coordinates, where *M* represents the number of blobs and [x y] represents the upper left corner of the bounding box.	32-bit signed integer
MajorAxis	Vector that represents the lengths of major axes of ellipses	• Double-precision floating point • Single-precision floating point
MinorAxis	Vector that represents the lengths of minor axes of ellipses	Same as MajorAxis port
Orientation	Vector that represents the angles between the major axes of the ellipses and the *x*-axis.	Same as MajorAxis port
Eccentricity	Vector that represents the eccentricities of the ellipses	Same as MajorAxis port
Diameter ^2	Vector that represents the equivalent diameters squared	Same as Centroid port
Extent	Vector that represents the results of dividing the areas of the blobs by the area of their bounding boxes	Same as Centroid port
Perimeter	Vector containing an estimate of the perimeter length, in pixels, for each blob	Same as Centroid port
Label	Label matrix	8-, 16-, or 32-bit unsigned integer
Count	Scalar value that represents the actual number of labeled regions in each image	Same as Label port

Dialog Box

The **Main** pane of the Blob Analysis dialog box appears as shown in the following figure. Use the check boxes to specify the statistics values you want the block to output. For a full description of each of these statistics, see the `regionprops` function reference page in the Image Processing Toolbox documentation.
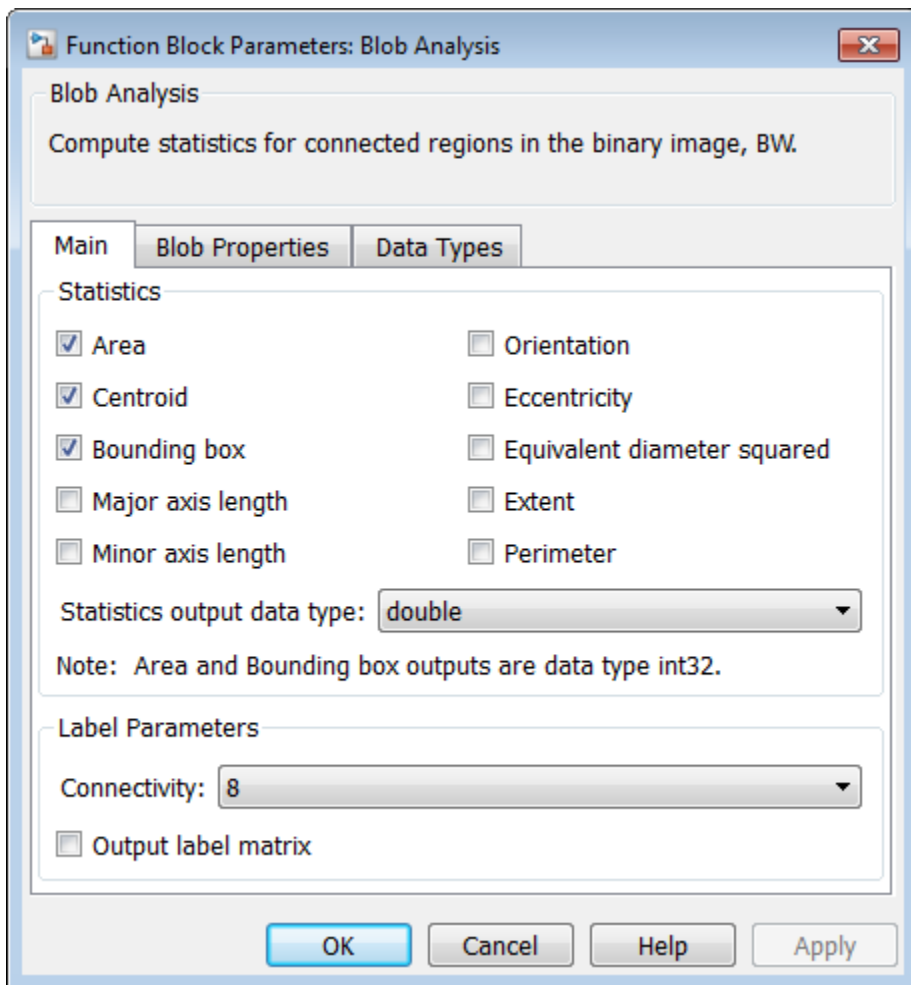
Area

Select this check box to output a vector that represents the number of pixels in labeled regions

Centroid

Select this check box to output an *M*-by-2 matrix of [x y] centroid coordinates. The rows represent the coordinates of the centroid of each region, where *M* represents the number of blobs.

Example: Suppose there are two blobs, where the row and column coordinates of their centroids are x_1, y_1 and x_2, y_2, respectively. The block outputs:

$$\begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \end{bmatrix}$$

at the Centroid port.

Bounding box

Select this check box to output an *M*-by-4 matrix of [x y width height] bounding boxes. The rows represent the coordinates of each bounding box, where *M* represents the number of blobs.

Example: Suppose there are two blobs, where *x* and *y* define the location of the upper-left corner of the bounding box, and *w*, *h* define the width and height of the bounding box. The block outputs

$$\begin{bmatrix} x_1 & y_1 & w_1 & h_1 \\ x_2 & y_2 & w_2 & h_2 \end{bmatrix}$$

at the BBox port.

Major axis length

Select this check box to output a vector with the following characteristics:

- Represents the lengths of the major axes of ellipses
- Has the same normalized second central moments as the labeled regions

Minor axis length

Select this check box to output a vector with the following characteristics:

- Represents the lengths of the minor axes of ellipses

- Has the same normalized second central moments as the labeled regions

Orientation

Select this check box to output a vector that represents the angles between the major axes of the ellipses and the *x*-axis. The angle values are in radians and range between:

$$-\frac{\pi}{2} \text{ and } \frac{\pi}{2}$$

Eccentricity

Select this check box to output a vector that represents the eccentricities of ellipses that have the same second moments as the region

Equivalent diameter squared

Select this check box to output a vector that represents the equivalent diameters squared

Extent

Select this check box to output a vector that represents the results of dividing the areas of the blobs by the area of their bounding boxes

Perimeter

Select this check box to output an *N-by-1* vector of the perimeter lengths, in pixels, of each blob, where *N* is the number of blobs.

Statistics output data type

Specify the data type of the outputs as `double`, `single`, or to `Specify via Data Types tab`. The fields on the **Data Types** tab appear when you set the output data type to `Specify via Data Types tab`.

Connectivity

Define which pixels connect to each other. If you want to connect pixels located on the top, bottom, left, and right, select 4. If you want to connect pixels to the other pixels on the top, bottom, left, right, and diagonally, select 8. For more information about this parameter, see the Label block reference page.

The **Connectivity** parameter also affects how the block calculates the perimeter of a blob. For example:

The following figure illustrates how the block calculates the perimeter when you set the **Connectivity** parameter to 4.

1-145
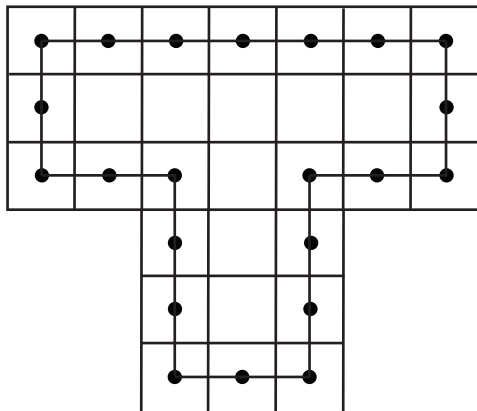
The block calculates the distance between the center of each pixel (marked by the black dots) and estimates the perimeter to be 22.

The next figure illustrates how the block calculates the perimeter of a blob when you set the **Connectivity** parameter to 8.
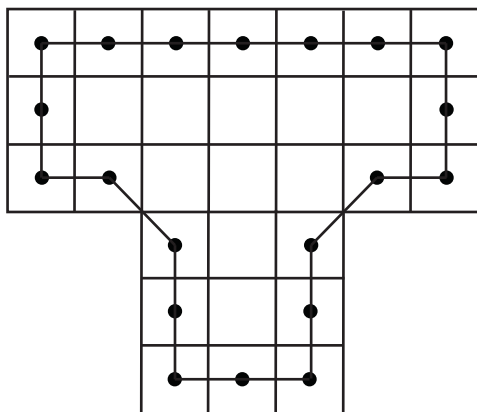
The block takes a different path around the blob and estimates the perimeter to be

$18 + 2\sqrt{2}$.

Output label matrix

Select this check box, to output the label matrix at the **Label** port. The pixels equal to 0 represent the background. The pixels equal to 1 represent the first object. The pixels equal to 2 represent the second object, and so on.

The **Blob Properties** pane of the Blob Analysis dialog box appears as shown in the following figure.
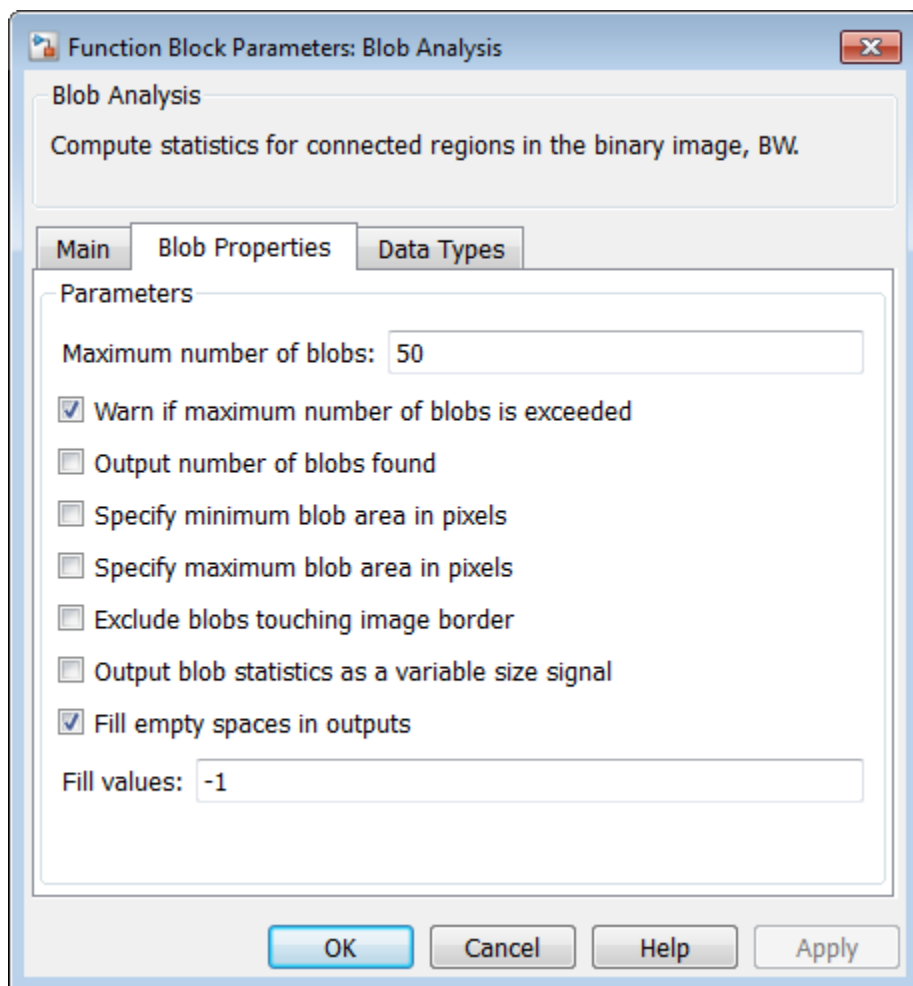
Maximum number of blobs

Specify the maximum number of labeled regions in each input image. The block uses this value to preallocate vectors and matrices to ensure that they are long enough to hold the statistical values. The maximum number of blobs the block outputs depends on both the value of this parameter, and on the size of the input image. The number of blobs the block outputs may be limited by the input image size.

Warn if maximum number of blobs is exceeded

Select this check box to output a warning when the number of blobs in an image is greater than the value of **Maximum number of blobs** parameter.

Output number of blobs found

Select this check box to output a scalar value that represents the actual number of connected regions in each image at the **Count** port.

Specify minimum blob area in pixels

Select this check box to enter the minimum blob area in the edit box that appears beside the check box. The blob gets a label if the number of pixels meets the minimum size specified. This parameter is tunable.

Specify maximum blob area in pixels

Select this check box to enter the maximum blob area in the edit box that appears beside the check box. The blob gets a label if the number of pixels meets the minimum size specified. The maximum allowable value is the maximum of `uint32` data type. This parameter is tunable.

Exclude blobs touching image border

Select this check box to exclude a labeled blob that contains at least one border pixel.

Output blob statistics as a variable-size signal

Select this check box to output blob statistics as a variable-size signal. Selecting this check box means that you do not need to specify fill values.

Fill empty spaces in outputs

Select this check box to fill empty spaces in the statistical vectors with the values you specify in the **Fill values** parameter.

The **Fill empty spaces in outputs** check box does not appear when you select the **Output blob statistics as a variable-size signal** check box.

Fill values

If you enter a scalar value, the block fills all the empty spaces in the statistical vectors with this value. If you enter a vector, it must have the same length as the number of

selected statistics. The block uses each vector element to fill a different statistics vector. If the empty spaces do not affect your computation, you can deselect the **Fill empty spaces in outputs** check box. As a best practice, leave this check box selected.

The **Fill values** parameter is not visible when you select the **Output blob statistics as a variable-size signal** check box.

The **Data Types** pane of the Blob Analysis dialog box appears as shown in the following figure.
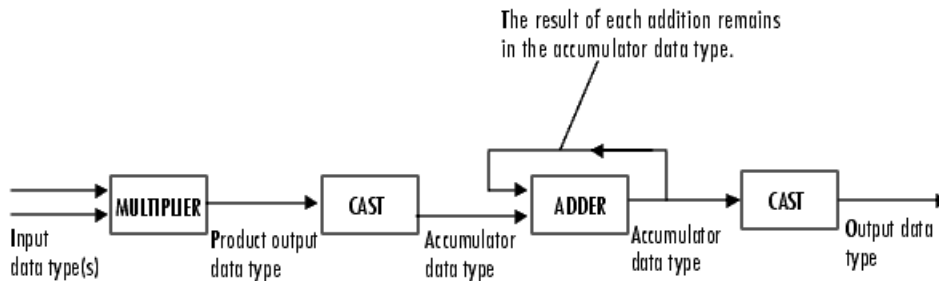
The parameters on the **Data Types** tab apply only when you set the **Statistics output data type** parameter to `Specify via Data Types tab`.
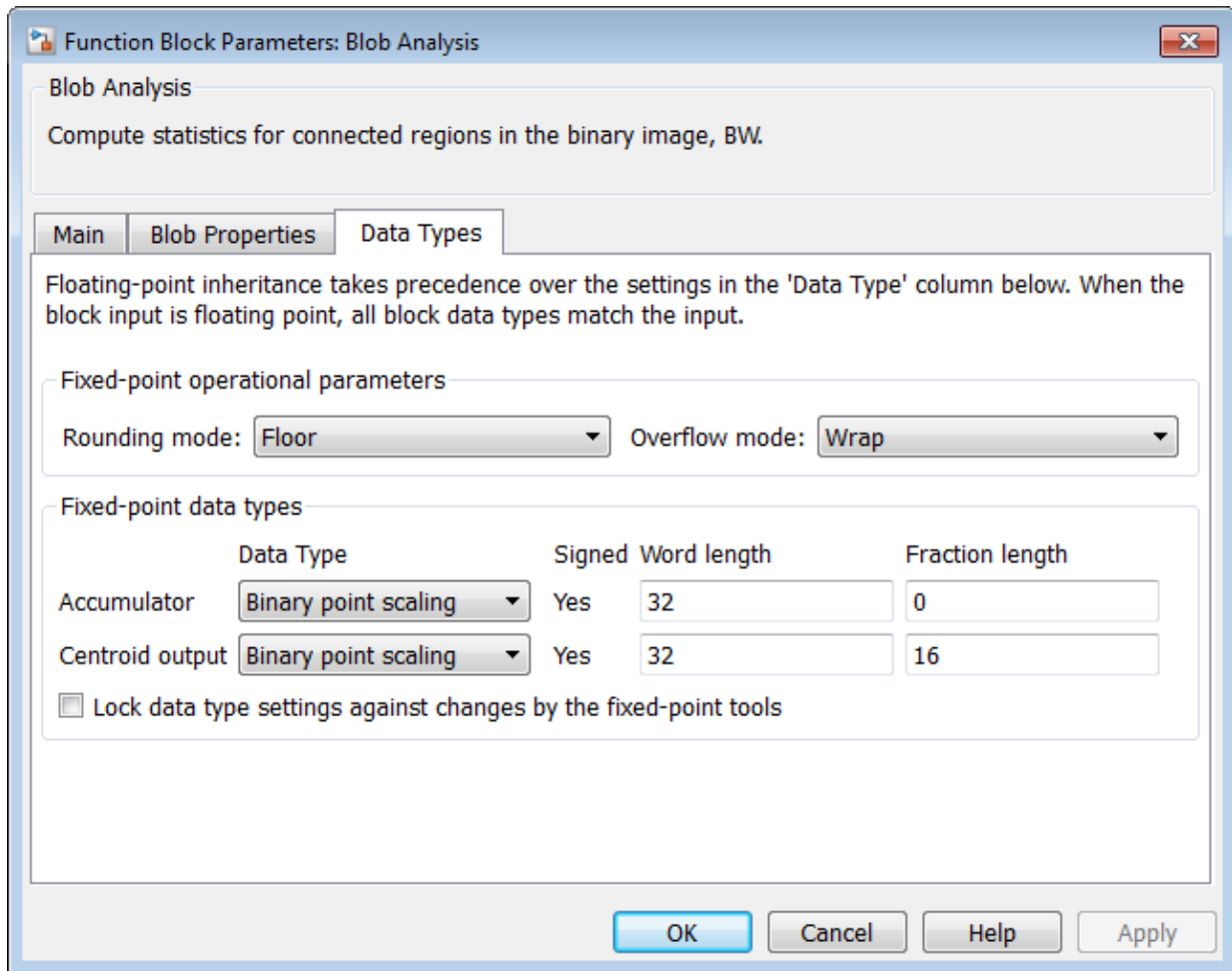
Rounding mode

> Select the rounding mode `Floor`, `Ceiling`, `Nearest` or `Zero` for fixed-point operations.

Overflow mode

> Select the overflow mode, `Wrap` or `Saturate` for fixed-point operations.

Product output

When you select `Binary point scaling`, you can enter the **Word length** and the **Fraction length** of the product output, in bits.

When you select `Slope and bias scaling`, you can enter the **Word length** in bits, and the **Slope** of the product output. All signals in the Computer Vision System Toolbox software have a bias of `0`.

Accumulator data type

MULTIPLIER Product output data type

4/pi data type

The block places the output of the multiplier into the **Product output** data type and scaling. The computation of the equivalent diameter squared uses the product output data type. During this computation, the block multiplies the blob area (stored in the accumulator) by the 4/pi factor. This factor has a word length that equals the value of **Equivalent diameter squared** output data type **Word length**. The value of the **Fraction length** equals its word length minus two. Use this parameter to specify how to designate this product output word and fraction lengths.

Accumulator

When you select `Same as product output` the characteristics match the characteristics of the product output.

When you select `Binary point scaling`, you can enter the **Word length** and the **Fraction length** of the accumulator, in bits.

When you select `Slope and bias scaling`, you can enter the **Word length**, in bits, and the **Slope** of the **Accumulator**. All signals in the Computer Vision System Toolbox software have a bias of 0.
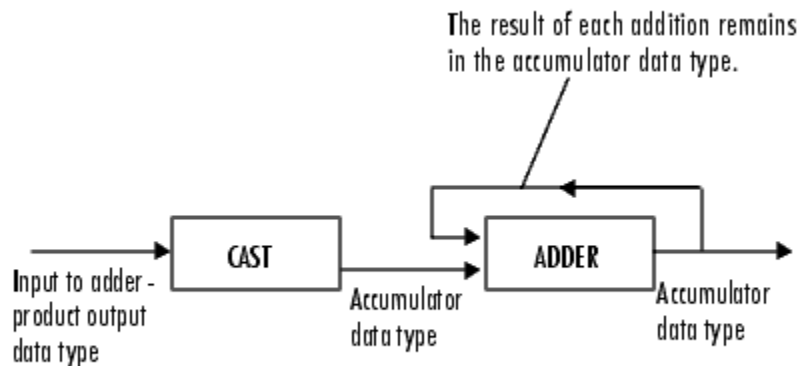
Inputs to the **Accumulator** get cast to the accumulator data type. Each element of the input gets added to the output of the adder, which remains in the accumulator data type. Use this parameter to specify how to designate this accumulator word and fraction lengths.

Centroid output

Choose how to specify the **Word length** and **Fraction length** of the output at the **Centroid** port:

- When you select `Same as accumulator`, these characteristics match the characteristics of the accumulator.
- When you select `Binary point scaling`, you can enter the **Word length** and **Fraction length** of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the **Word length**, in bits, and the **Slope** of the output. All signals in the Computer Vision System Toolbox software have a bias of 0.

Equiv Diam^2 output

Choose how to specify the **Word length** and **Fraction length** of the output at the **Diameter ^2** port:

- When you select `Same as accumulator`, these characteristics match the characteristics of the **Accumulator**.
- When you select `Same as product output`, these characteristics match the characteristics of the **Product output**.

- When you select `Binary point scaling`, you can enter the **Word length** and **Fraction length** of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the **Word length**, in bits, and the **Slope** of the output. All signals in the Computer Vision System Toolbox software have a bias of 0.

Extent output

Choose how to specify the **Word length** and **Fraction length** of the output at the **Extent** port:

- When you select `Same as accumulator`, these characteristics match the characteristics of the accumulator.
- When you select `Binary point scaling`, you can enter the **Word length** and **Fraction length** of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the **Word length**, in bits, and the **Slope** of the output. All signals in the Computer Vision System Toolbox software have a bias of 0.

Perimeter output

Choose how to specify the **Word length** and **Fraction length** of the output at the **Perimeter** port:

- When you select `Same as accumulator`, these characteristics match the characteristics of the accumulator.
- When you select `Binary point scaling`, you can enter the **Word length** and **Fraction length** of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the **Slope** of the output. All signals in the Computer Vision System Toolbox software have a bias of 0.

Lock data type settings against changes by the fixed–point tools

Select this parameter to prevent the autoscaling tool in the Fixed-Point Tool from overriding any fixed-point scaling you specify in this block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

See Also

Label	Computer Vision System Toolbox
`regionprops`	Image Processing Toolbox

Introduced before R2006a

Block Matching

Estimate motion between images or video frames
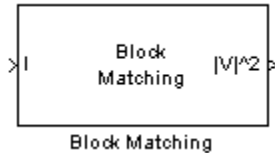
Library

Analysis & Enhancement

`visionanalysis`

Description

The Block Matching block estimates motion between two images or two video frames using "blocks" of pixels. The Block Matching block matches the block of pixels in frame k to a block of pixels in frame k+1 by moving the block of pixels over a search region.

Suppose the input to the block is frame k. The Block Matching block performs the following steps:

1   The block subdivides this frame using the values you enter for the **Block size [height width]** and **Overlap [r c]** parameters. In the following example, the **Overlap [r c]** parameter is [0 0].

2   For each subdivision or block in frame k+1, the Block Matching block establishes a search region based on the value you enter for the **Maximum displacement [r c]** parameter.

3   The block searches for the new block location using either the `Exhaustive` or `Three-step` search method.

Input image = frame k

STEP 1: Subdivide the image in frame k.

Center pixel
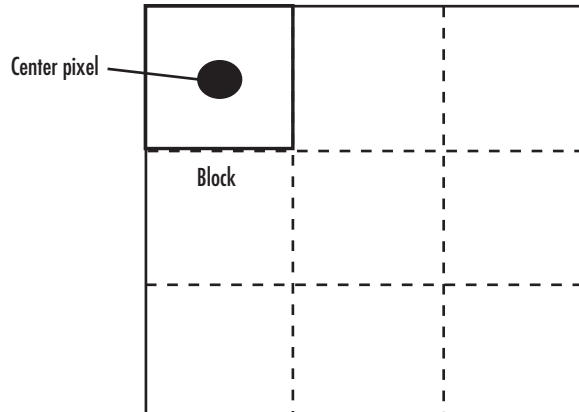
Block

STEP 2: Establish the search region in frame k+1.
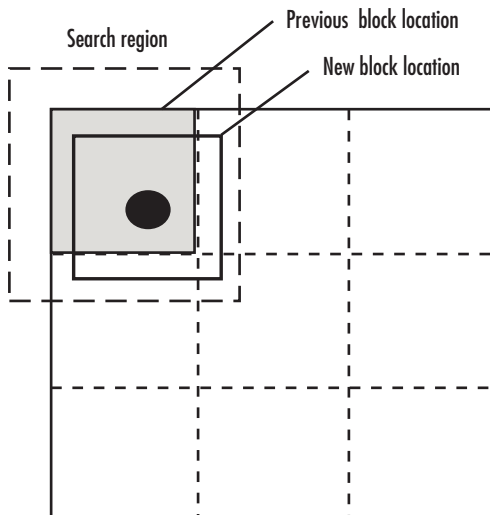
STEP 3: Search for the new block location in frame k+1.

Search region

Previous block location

New block location

Search region

Port	Output	Supported Data Types	Complex Values Supported
I/I1	Scalar, vector, or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
I2	Scalar, vector, or matrix of intensity values	Same as I port	No
|V|^2	Matrix of velocity magnitudes	Same as I port	No
V	Matrix of velocity components in complex form	Same as I port	Yes

Use the **Estimate motion between** parameter to specify whether to estimate the motion between two images or two video frames. If you select `Current frame and N-th frame back`, the **N** parameter appears in the dialog box. Enter a scalar value that represents the number of frames between the reference frame and the current frame.

Use the **Search method** parameter to specify how the block locates the block of pixels in frame k+1 that best matches the block of pixels in frame k.

- If you select `Exhaustive`, the block selects the location of the block of pixels in frame k+1 by moving the block over the search region 1 pixel at a time. This process is computationally expensive.
- If you select `Three-step`, the block searches for the block of pixels in frame k+1 that best matches the block of pixels in frame k using a steadily decreasing step size. The block begins with a step size approximately equal to half the maximum search range. In each step, the block compares the central point of the search region to eight search points located on the boundaries of the region and moves the central point to the search point whose values is the closest to that of the central point. The block then reduces the step size by half, and begins the process again. This option is less computationally expensive, though it might not find the optimal solution.

Use the **Block matching criteria** parameter to specify how the block measures the similarity of the block of pixels in frame k to the block of pixels in frame k+1. If you select

Mean square error (MSE), the Block Matching block estimates the displacement of the center pixel of the block as the (d_1, d_2) values that minimize the following MSE equation:

$$MSE(d_1, d_2) = \frac{1}{N_1 \times N_2} \sum_{(n_1, n_2), \in B} \sum [s(n_1, n_2, k) - s(n_1 + d_1, n_2 + d_2, k + 1)]^2$$

In the previous equation, B is an $N_1 \times N_2$ block of pixels, and $s(x, y, k)$ denotes a pixel location at (x, y) in frame k. If you select Mean absolute difference (MAD), the Block Matching block estimates the displacement of the center pixel of the block as the (d_1, d_2) values that minimize the following MAD equation:

$$MAD(d_1, d_2) = \frac{1}{N_1 \times N_2} \sum_{(n_1, n_2), \in B} \sum | s(n_1, n_2, k) - s(n_1 + d_1, n_2 + d_2, k + 1) |$$

Use the **Block size [height width]** and **Overlap [r c]** parameters to specify how the block subdivides the input image. For a graphical description of these parameters, see the first figure in this reference page. If the **Overlap [r c]** parameter is not [0 0], the blocks would overlap each other by the number of pixels you specify.

Use the **Maximum displacement [r c]** parameter to specify the maximum number of pixels any center pixel in a block of pixels might move from image to image or frame to frame. The block uses this value to determine the size of the search region.

Use the **Velocity output** parameter to specify the block's output. If you select Magnitude-squared, the block outputs the optical flow matrix where each element is of the form $u^2 + v^2$. If you select Horizontal and vertical components in complex form, the block outputs the optical flow matrix where each element is of the form $u + jv$. The real part of each value is the horizontal velocity component and the imaginary part of each value is the vertical velocity component.

Fixed-Point Data Types

The following diagram shows the data types used in the Block Matching block for fixed-point signals.
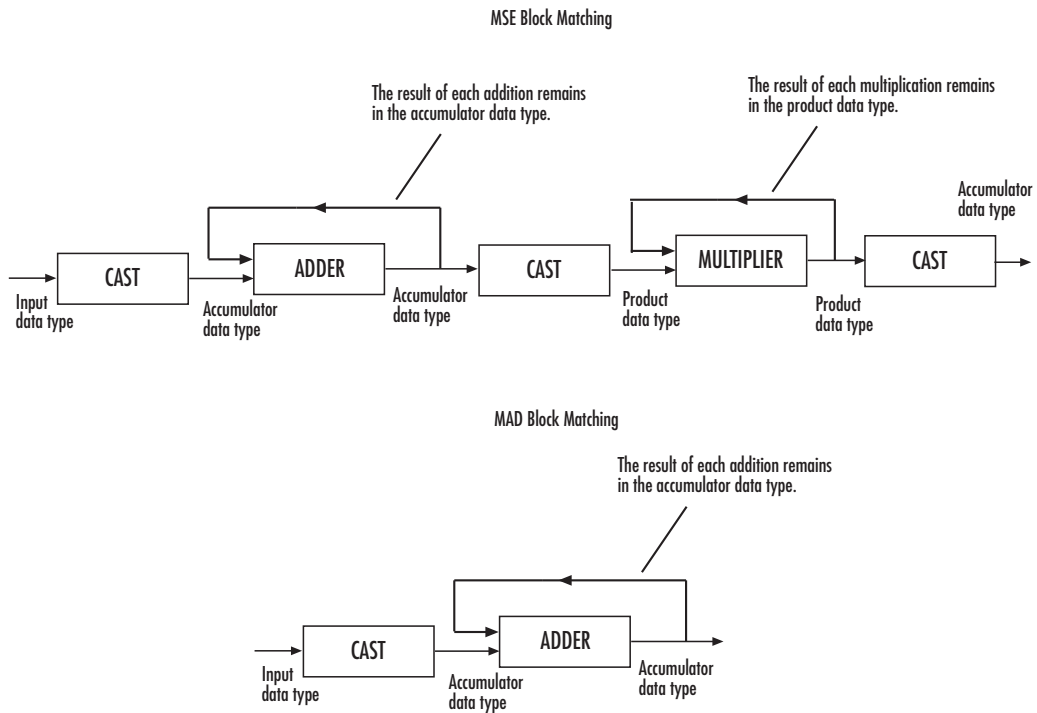
MSE Block Matching

The result of each addition remains
in the accumulator data type.

The result of each multiplication remains
in the product data type.

Accumulator
data type

Input
data type

CAST

Accumulator
data type

ADDER

Accumulator
data type

CAST

Product
data type

MULTIPLIER

Product
data type

CAST

MAD Block Matching

The result of each addition remains
in the accumulator data type.

Input
data type

CAST

Accumulator
data type

ADDER

Accumulator
data type

You can set the accumulator and output data types in the block mask as discussed in the next section.

Parameters

Estimate motion between

> Select `Two images` to estimate the motion between two images. Select `Current frame and N-th frame back` to estimate the motion between two video frames that are N frames apart.

N

> Enter a scalar value that represents the number of frames between the reference frame and the current frame. This parameter is only visible if, for the **Estimate motion between** parameter, you select `Current frame and N-th frame back`.

Search method

Specify how the block searches for the block of pixels in the next image or frame. Your choices are `Exhaustive` or `Three-step`.

Block matching criteria

Specify how the block measures the similarity of the block of pixels in frame k to the block of pixels in frame k+1. Your choices are `Mean square error (MSE)` or `Mean absolute difference (MAD)`.

Block size [height width]

Specify the size of the block of pixels.

Overlap [r c]

Specify the overlap (in pixels) of two subdivisions of the input image.

Maximum displacement [r c]

Specify the maximum number of pixels any center pixel in a block of pixels might move from image to image or frame to frame. The block uses this value to determine the size of the search region.

Velocity output

If you select `Magnitude-squared`, the block outputs the optical flow matrix where each element is of the form $u^2 + v^2$. If you select `Horizontal and vertical components in complex form`, the block outputs the optical flow matrix where each element is of the form $u + jv$.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Product output

As shown previously, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate the product output word and fraction lengths.

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Accumulator

The result of each addition remains in the accumulator data type.
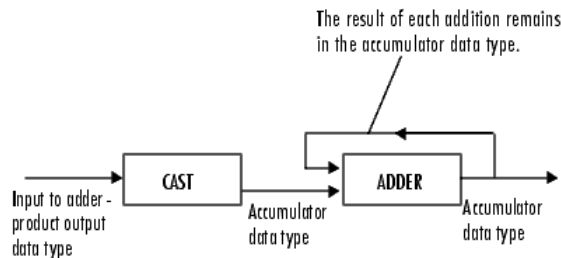
As depicted previously, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox software is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Binary point scaling`, you can enter the word length of the output, in bits. The fractional length is always 0.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, of the output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

See Also

Optical Flow	Computer Vision System Toolbox software

Introduced before R2006a

Block Processing

Repeat user-specified operation on submatrices of input matrix
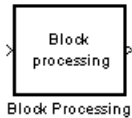
Block Processing

Library

Utilities

visionutilities

Description

The Block Processing block extracts submatrices of a user-specified size from each input matrix. It sends each submatrix to a subsystem for processing, and then reassembles each subsystem output into the output matrix.
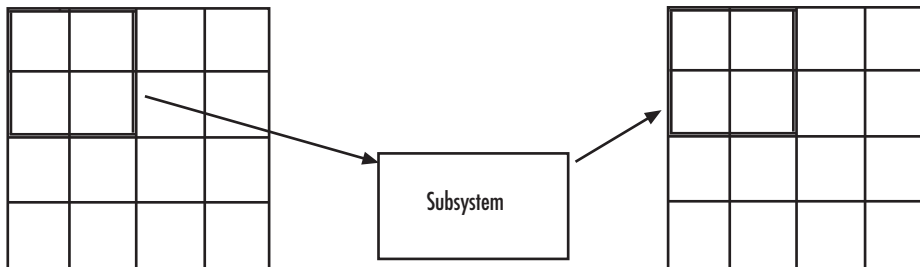
Note Because you modify the Block Processing block's subsystem, the link between this block and the block library is broken when you click-and-drag a Block Processing block into your model. As a result, this block will not be automatically updated if you upgrade to a newer version of the Computer Vision System Toolbox software. If you right-click on the block and select **Mask>Look Under Mask**, you can delete blocks from this subsystem

without triggering a warning. Lastly, if you search for library blocks in a model, this block will not be part of the results.

The blocks inside the subsystem dictate the frame status of the input and output signals, whether single channel or multichannel signals are supported, and which data types are supported by this block.

Use the **Number of inputs** and **Number of outputs** parameters to specify the number of input and output ports on the Block Processing block.

Use the **Block size** parameter to specify the size of each submatrix in cell array format. Each vector in the cell array corresponds to one input; the block uses the vectors in the order you enter them. If you have one input port, enter one vector. If you have more than one input port, you can enter one vector that is used for all inputs or you can specify a different vector for each input. For example, if you want each submatrix to be 2-by-3, enter `{[2 3]}`.

Use the **Overlap** parameter to specify the overlap of each submatrix in cell array format. Each vector in the cell array corresponds to the overlap of one input; the block uses the vectors in the order they are specified. If you enter one vector, each overlap is the same size. For example, if you want each 3-by-3 submatrix to overlap by 1 row and 2 columns, enter `{[1 2]}`.

The **Traverse order** parameter determines how the block extracts submatrices from the input matrix. If you select `Row-wise`, the block extracts submatrices by moving across the rows. If you select `Column-wise`, the block extracts submatrices by moving down the columns.

Click the **Open Subsystem** button to open the block's subsystem. Click-and-drag blocks into this subsystem to define the processing operation(s) the block performs on the submatrices. The input to this subsystem are the submatrices whose size is determined by the **Block size** parameter.

Note When you place an Assignment block inside a Block Processing block's subsystem, the Assignment block behaves as though it is inside a For Iterator block. For a description of this behavior, see the "Iterated Assignment" section of the Assignment block reference page.

Parameters

Number of inputs

Enter the number of input ports on the Block Processing block.

Add port to supply subsystem parameters

Add an input port to the block to supply subsystem parameters. When you check this option, a port (**P**) is added to the block.

Number of outputs

Enter the number of output ports on the Block Processing block.

Block size

Specify the size of each submatrix in cell array format. Each vector in the cell array corresponds to one input.

Overlap

Specify the overlap of each submatrix in cell array format. Each vector in the cell array corresponds to the overlap of one input.

Traverse order

Determines how the block extracts submatrices from the input matrix. If you select `Row-wise`, the block extracts submatrices by moving across the rows. If you select `Column-wise`, the block extracts submatrices by moving down the columns.

Open Subsystem

Click this button to open the block's subsystem. Click-and-drag blocks into this subsystem to define the processing operation(s) the block performs on the submatrices.

See Also

For Iterator	Simulink
blockproc	Image Processing Toolbox

Introduced before R2006a

Bottom-hat

Perform bottom-hat filtering on intensity or binary images
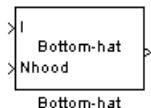
Library

Morphological Operations

visionmorphops

Description

Use the Bottom-hat block to perform bottom-hat filtering on an intensity or binary image using a predefined neighborhood or structuring element. Bottom-hat filtering is the equivalent of subtracting the input image from the result of performing a morphological closing operation on the input image. This block uses flat structuring elements only.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Nhood	Matrix or vector of ones and zeros that represents the neighborhood values	Boolean	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Output	Scalar, vector, or matrix that represents the filtered image	Same as I port	No

If your input image is a binary image, for the **Input image type** parameter, select `Binary`. If your input image is an intensity image, select `Intensity`.

Use the **Neighborhood or structuring element source** parameter to specify how to enter your neighborhood or structuring element values. If you select `Specify via dialog`, the **Neighborhood or structuring element** parameter appears in the dialog box. If you select `Input port`, the Nhood port appears on the block. Use this port to enter your neighborhood values as a matrix or vector of 1s and 0s. You can only specify a structuring element using the dialog box.

Use the **Neighborhood or structuring element** parameter to define the region the block moves throughout the image. Specify a neighborhood by entering a matrix or vector of 1s and 0s. Specify a structuring element with the `strel` function from the Image Processing Toolbox. If the structuring element is decomposable into smaller elements, the block executes at higher speeds due to the use of a more efficient algorithm.

Parameters

Input image type

If your input image is a binary image, select `Binary`. If your input image is an intensity image, select `Intensity`.

Neighborhood or structuring element source

Specify how to enter your neighborhood or structuring element values. Select `Specify via dialog` to enter the values in the dialog box. Select `Input port` to use the Nhood port to specify the neighborhood values. You can only specify a structuring element using the dialog box.

Neighborhood or structuring element

If you are specifying a neighborhood, this parameter must be a matrix or vector of 1s and 0s. If you are specifying a structuring element, use the `strel` function from the Image Processing Toolbox. This parameter is visible if, for the **Neighborhood or structuring element source** parameter, you select `Specify via dialog`.

See Also

Closing	Computer Vision System Toolbox software
Dilation	Computer Vision System Toolbox software
Erosion	Video and Image Processing Blockset software
Label	Computer Vision System Toolbox software
Opening	Computer Vision System Toolbox software
Top-hat	Computer Vision System Toolbox software
`imbothat`	Image Processing Toolbox software
`strel`	Image Processing Toolbox software

Introduced before R2006a

Chroma Resampling

Downsample or upsample chrominance components of images
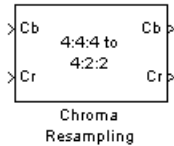
Library

Conversions

visionconversions

Description

The Chroma Resampling block downsamples or upsamples chrominance components of pixels to reduce the bandwidth required for transmission or storage of a signal.

Port	Input/Output	Supported Data Types	Complex Values Supported
Cb	Matrix that represents one chrominance component of an image	• Double-precision floating point • Single-precision floating point • 8-bit unsigned integer	No
Cr	Matrix that represents one chrominance component of an image	Same as Cb port	No

The data type of the output signals is the same as the data type of the input signals.

Chroma Resampling Formats

The Chroma Resampling block supports the formats shown in the following diagram.

4:4:4

4:2:2

4:1:1

4:2:0 MPEG1

4:2:0 MPEG2

○ Y pixel

△ Cb and Cr pixel
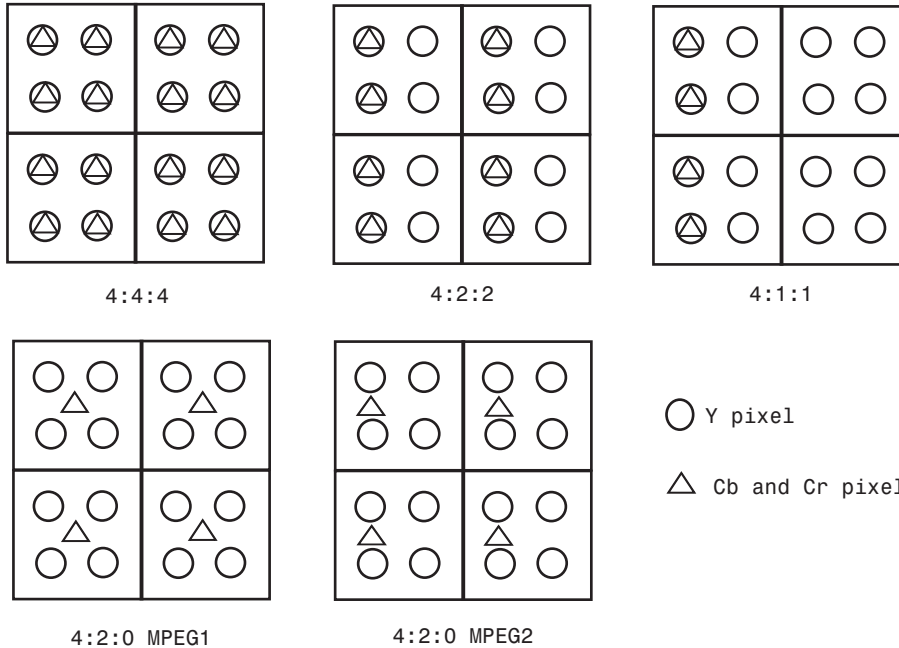
Downsampling

If, for the **Resampling** parameter, you select `4:4:4 to 4:2:2`, `4:4:4 to 4:2:0 (MPEG1)`, `4:4:4 to 4:2:0 (MPEG2)`, `4:4:4 to 4:1:1`, `4:2:2 to 4:2:0 (MPEG1)`, or `4:2:2 to 4:2:0 (MPEG2)`, the block performs a downsampling operation. When the block downsamples from one format to another, it can bandlimit the input signal by applying a lowpass filter to prevent aliasing.

If, for the **Antialiasing filter** parameter, you select `Default`, the block uses a built-in lowpass filter to prevent aliasing.

If, for the **Resampling** parameter, you select `4:4:4 to 4:2:2`, `4:4:4 to 4:2:0 (MPEG1)`, `4:4:4 to 4:2:0 (MPEG2)`, or `4:4:4 to 4:1:1` and, for the **Antialiasing filter** parameter, you select `User-defined`, the **Horizontal filter**

coefficients parameter appears on the dialog box. Enter the filter coefficients to apply to your input.

If, for the **Resampling** parameter, you select `4:4:4 to 4:2:0 (MPEG1)`, `4:4:4 to 4:2:0 (MPEG2)`, `4:2:2 to 4:2:0 (MPEG1)`, or `4:2:2 to 4:2:0 (MPEG2)` and, for the **Antialiasing filter** parameter, you select `User-defined`. **Vertical filter coefficients** parameters appear on the dialog box. Enter an even number of filter coefficients to apply to your input signal.

If, for the **Antialiasing filter** parameter, you select `None`, the block does not filter the input signal.

Upsampling

If, for the **Resampling** parameter, you select `4:2:2 to 4:4:4`, `4:2:0 (MPEG1) to 4:2:2`, `4:2:0 (MPEG1) to 4:4:4`, `4:2:0 (MPEG2) to 4:2:2`, `4:2:0 (MPEG2) to 4:4:4`, or `4:1:1 to 4:4:4`, the block performs an upsampling operation.

When the block upsamples from one format to another, it uses interpolation to approximate the missing chrominance values. If, for the **Interpolation** parameter, you select `Linear`, the block uses linear interpolation to calculate the missing values. If, for the **Interpolation** parameter, you select `Pixel replication`, the block replicates the chrominance values of the neighboring pixels to create the upsampled image.

Row-Major Data Format

The MATLAB environment and the Computer Vision System Toolbox software use column-major data organization. However, the Chroma Resampling block gives you the option to process data that is stored in row-major format. When you select the **Input image is transposed (data order is row major)** check box, the block assumes that the input buffer contains contiguous data elements from the first row first, then data elements from the second row second, and so on through the last row. Use this functionality only when you meet all the following criteria:

- You are developing algorithms to run on an embedded target that uses the row-major format.

- You want to limit the additional processing required to take the transpose of signals at the interfaces of the row-major and column-major systems.

When you use the row-major functionality, you must consider the following issues:

- When you select this check box, the signal dimensions of the Chroma Resampling block's input are swapped.

- All the Computer Vision System Toolbox blocks can be used to process data that is in the row-major format, but you need to know the image dimensions when you develop your algorithms.

  For example, if you use the 2-D FIR Filter block, you need to verify that your filter coefficients are transposed. If you are using the Rotate block, you need to use negative rotation angles, etc.

- Only three blocks have the **Input image is transposed (data order is row major)** check box. They are the Chroma Resampling, Deinterlacing, and Insert Text blocks. You need to select this check box to enable row-major functionality in these blocks. All other blocks must be properly configured to process data in row-major format.

Use the following two-step workflow to develop algorithms in row-major format to run on an embedded target.

Parameters

Resampling

Specify the resampling format.

Antialiasing filter

Specify the lowpass filter that the block uses to prevent aliasing. If you select `Default`, the block uses a built-in lowpass filter. If you select `User-defined`, the **Horizontal filter coefficients** and/or **Vertical filter coefficients** parameters appear on the dialog box. If you select `None`, the block does not filter the input signal. This parameter is visible when you are downsampling the chrominance values.

Horizontal filter coefficients

Enter the filter coefficients to apply to your input signal. This parameter is visible if, for the **Resampling** parameter, you select `4:4:4 to 4:2:2`, `4:4:4 to 4:2:0 (MPEG1)`, `4:4:4 to 4:2:0 (MPEG2)`, or `4:4:4 to 4:1:1` and, for the **Antialiasing filter** parameter, you select `User-defined`.

Vertical filter coefficients

Enter the filter coefficients to apply to your input signal. This parameter is visible if, for the **Resampling** parameter, you select `4:4:4 to 4:2:0 (MPEG1)`, `4:4:4 to 4:2:0 (MPEG2)`, `4:2:2 to 4:2:0 (MPEG1)`, or `4:2:2 to 4:2:0 (MPEG2)` and, for the **Antialiasing filter** parameter, you select `User-defined`.

Interpolation

Specify the interpolation method that the block uses to approximate the missing chrominance values. If you select `Linear`, the block uses linear interpolation to calculate the missing values. If you select `Pixel replication`, the block replicates the chrominance values of the neighboring pixels to create the upsampled image. This parameter is visible when you are upsampling the chrominance values. This parameter is visible if the **Resampling** parameter is set to `4:2:2 to 4:4:4`, `4:2:0 (MPEG1) to 4:4:4`, `4:2:0 (MPEG2) to 4:4:4`, `4:1:1 to 4:4:4`, `4:2:0 (MPEG1) to 4:2:2`, or `4:2:0 (MPEG2) to 4:2:2`.

Input image is transposed (data order is row major)

When you select this check box, the block assumes that the input buffer contains data elements from the first row first, then data elements from the second row second, and so on through the last row.

References

[1] Haskell, Barry G., Atul Puri, and Arun N. Netravali. *Digital Video: An Introduction to MPEG-2*. New York: Chapman & Hall, 1996.

[2] Recommendation ITU-R BT.601-5, Studio Encoding Parameters of Digital Television for Standard 4:3 and Wide Screen 16:9 Aspect Ratios.

[3] Wang, Yao, Jorn Ostermann, Ya-Qin Zhang. *Video Processing and Communications*. Upper Saddle River, NJ: Prentice Hall, 2002.

See Also

Autothreshold	Computer Vision System Toolbox software
Color Space Conversion	Computer Vision System Toolbox software
Image Complement	Computer Vision System Toolbox software

Introduced before R2006a

Closing

Perform morphological closing on binary or intensity images
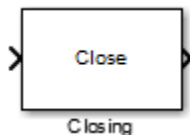
Library

Morphological Operations

`visionmorphops`

Description

The Closing block performs a dilation operation followed by an erosion operation using a predefined neighborhood or structuring element. This block uses flat structuring elements only.

Port	Input/Output	Supported Data Types	Complex Values Supported
	Vector or matrix of intensity values	- Double-precision floating point - Single-precision floating point - Fixed point - Boolean 8-, 16-, and 32-bit signed integer 8-, 16-, and 32-bit unsigned integer	No
Nhood	Matrix or vector of ones and zeros that represents the neighborhood values	Boolean	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Output	Vector or matrix of intensity values that represents the closed image	Same as I port	No

The output signal has the same data type as the input to the I port.

Use the **Neighborhood or structuring element source** parameter to specify how to enter your neighborhood or structuring element values. If you select Specify via dialog, the **Neighborhood or structuring element** parameter appears in the dialog box. If you select Input port, the Nhood port appears on the block. Use this port to enter your neighborhood values as a matrix or vector of 1s and 0s. You can only specify a structuring element using the dialog box.

Use the **Neighborhood or structuring element** parameter to define the region the block moves throughout the image. Specify a neighborhood by entering a matrix or vector of 1s and 0s. Specify a structuring element with the strel function from the Image Processing Toolbox. If the structuring element is decomposable into smaller elements, the block executes at higher speeds due to the use of a more efficient algorithm.

Parameters

Neighborhood or structuring element source

Specify how to enter your neighborhood or structuring element values. Select Specify via dialog to enter the values in the dialog box. Select Input port to use the Nhood port to specify the neighborhood values. You can only specify a structuring element using the dialog box.

Neighborhood or structuring element

If you are specifying a neighborhood, this parameter must be a matrix or vector of 1s and 0s. If you are specifying a structuring element, use the strel function from the Image Processing Toolbox. This parameter is visible if, for the **Neighborhood or structuring element source** parameter, you select Specify via dialog.

References

[1] Soille, Pierre. *Morphological Image Analysis*. 2nd ed. New York: Springer, 2003.

See Also

Bottom-hat	Computer Vision System Toolbox software
Dilation	Computer Vision System Toolbox software
Erosion	Computer Vision System Toolbox software
Label	Computer Vision System Toolbox software
Opening	Computer Vision System Toolbox software
Top-hat	Computer Vision System Toolbox software
imclose	Image Processing Toolbox software
strel	Image Processing Toolbox software

Introduced before R2006a

Color Space Conversion

Convert color information between color spaces

Library

Conversions

`visionconversions`

Description

The Color Space Conversion block converts color information between color spaces. Use the **Conversion** parameter to specify the color spaces you are converting between. Your choices are `R'G'B' to Y'CbCr`, `Y'CbCr to R'G'B'`, `R'G'B' to intensity`, `R'G'B' to HSV`, `HSV to R'G'B'`, `sR'G'B' to XYZ`, `XYZ to sR'G'B'`, `sR'G'B' to L*a*b*`, and `L*a*b* to sR'G'B'`.

- If the input is `uint8`, YCBCR is `uint8`, where Y is in the range `[16 235]`, and Cb and Cr are in the range `[16 240]`.
- If the input is a `double`, Y is in the range `[16/255 235/255]` and Cb and Cr are in the range `[16/255 240/255]`.

Port	Input/Output	Supported Data Types	Complex Values Supported
Input / Output	M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • 8-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
R'	Matrix that represents one plane of the input RGB video stream	Same as the Input port	No
G'	Matrix that represents one plane of the input RGB video stream	Same as the Input port	No
B'	Matrix that represents one plane of the input RGB video stream	Same as the Input port	No
Y'	Matrix that represents the luma portion of an image	Same as the Input port	No
Cb	Matrix that represents one chrominance component of an image	Same as the Input port	No
Cr	Matrix that represents one chrominance component of an image	Same as the Input port	No
I'	Matrix of intensity values	Same as the Input port	No
H	Matrix that represents the hue component of an image	• Double-precision floating point • Single-precision floating point	No
S	Matrix that represents represent the saturation component of an image	Same as the H port	No
V	Matrix that represents the value (brightness) component of an image	Same as the H port	No
X	Matrix that represents the X component of an image	Same as the H port	No
Y	Matrix that represents the Y component of an image	Same as the H port	No
Z	Matrix that represents the Z component of an image	Same as the H port	No
L*	Matrix that represents the luminance portion of an image	Same as the H port	No

Port	Input/Output	Supported Data Types	Complex Values Supported
a*	Matrix that represents the a* component of an image	Same as the H port	No
b*	Matrix that represents the b* component of an image	Same as the H port	No

The data type of the output signal is the same as the data type of the input signal.

Use the **Image signal** parameter to specify how to input and output a color video signal. If you select `One multidimensional signal`, the block accepts an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port accepts one M-by-N plane of an RGB video stream.

Note The prime notation indicates that the signals are gamma corrected.

Conversion Between R'G'B' and Y'CbCr Color Spaces

The following equations define R'G'B' to Y'CbCr conversion and Y'CbCr to R'G'B' conversion:

$$\begin{bmatrix} Y' \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \text{A} \times \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \text{B} \times \left(\begin{bmatrix} Y' \\ Cb \\ Cr \end{bmatrix} - \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} \right)$$

The values in matrices A and B are based on your choices for the **Use conversion specified by** and **Scanning standard** parameters.

Matrix	Use conversion specified by = Rec. 601 (SDTV)	Use conversion specified by = Rec. 709 (HDTV)	
		Scanning standard = 1125/60/2:1	Scanning standard = 1250/50/2:1
A	$\begin{bmatrix} 0.25678824 & 0.50412941 & 0.09790588 \\ -0.1482229 & -0.29099279 & 0.43921569 \\ 0.43921569 & -0.36778831 & -0.07142737 \end{bmatrix}$	$\begin{bmatrix} 0.18258588 & 0.61423059 & 0.06200706 \\ -0.10064373 & -0.33857195 & 0.43921569 \\ 0.43921569 & -0.39894216 & -0.04027352 \end{bmatrix}$	$\begin{bmatrix} 0.25678824 & 0.50412941 & 0.09790588 \\ -0.1482229 & -0.29099279 & 0.43921569 \\ 0.43921569 & -0.36778831 & -0.07142737 \end{bmatrix}$
B	$\begin{bmatrix} 1.1643836 & 0 & 1.5960268 \\ 1.1643836 & -0.39176229 & -0.81296765 \\ 1.1643836 & 2.0172321 & 0 \end{bmatrix}$	$\begin{bmatrix} 1.16438356 & 0 & 1.79274107 \\ 1.16438356 & -0.21324861 & -0.53290933 \\ 1.16438356 & 2.11240179 & 0 \end{bmatrix}$	$\begin{bmatrix} 1.1643836 & 0 & 1.5960268 \\ 1.1643836 & -0.39176229 & -0.81296765 \\ 1.1643836 & 2.0172321 & 0 \end{bmatrix}$

Conversion from R'G'B' to Intensity

The following equation defines conversion from the R'G'B' color space to intensity:

$$\text{intensity} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

Conversion Between R'G'B' and HSV Color Spaces

The R'G'B' to HSV conversion is defined by the following equations. In these equations, *MAX* and *MIN* represent the maximum and minimum values of each R'G'B' triplet, respectively. *H*, *S*, and *V* vary from 0 to 1, where 1 represents the greatest saturation and value.

$$H = \begin{cases} \left(\dfrac{G' - B'}{MAX - MIN} \right) / 6, & \text{if} \quad R' = MAX \\ \left(2 + \dfrac{B' - R'}{MAX - MIN} \right) / 6, & \text{if} \quad G' = MAX \\ \left(4 + \dfrac{R' - G'}{MAX - MIN} \right) / 6, & \text{if} \quad B' = MAX \end{cases}$$

$$S = \frac{MAX - MIN}{MAX}$$

$$V = MAX$$

The HSV to R'G'B' conversion is defined by the following equations:

$$H_i = \lfloor 6H \rfloor$$

$$f = 6H - H_i$$

$$p = 1 - S$$

$$q = 1 - fS$$

$$t = 1 - (1 - f)S$$

$$\text{if} \quad H_i = 0, \quad R_{tmp} = 1, \quad G_{tmp} = t, \quad B_{tmp} = p$$

$$\text{if} \quad H_i = 1, \quad R_{tmp} = q, \quad G_{tmp} = 1, \quad B_{tmp} = p$$

$$\text{if} \quad H_i = 2, \quad R_{tmp} = p, \quad G_{tmp} = 1, \quad B_{tmp} = t$$

$$\text{if} \quad H_i = 3, \quad R_{tmp} = p, \quad G_{tmp} = q, \quad B_{tmp} = 1$$

$$\text{if} \quad H_i = 4, \quad R_{tmp} = t, \quad G_{tmp} = p, \quad B_{tmp} = 1$$

$$\text{if} \quad H_i = 5, \quad R_{tmp} = 1, \quad G_{tmp} = p, \quad B_{tmp} = q$$

$$u = V / \max(R_{tmp}, G_{tmp}, B_{tmp})$$

$$R' = uR_{tmp}$$

$$G' = uG_{tmp}$$

$$B' = uB_{tmp}$$

Conversion Between sR'G'B' and XYZ Color Spaces

The sR'G'B' to XYZ conversion is a two-step process. First, the block converts the gamma-corrected sR'G'B' values to linear sRGB values using the following equations:

If $\quad R'_{sRGB}, G'_{sRGB}, B'_{sRGB} \leq 0.03928$

$R_{sRGB} = R'_{sRGB} / 12.92$

$G_{sRGB} = G'_{sRGB} / 12.92$

$B_{sRGB} = B'_{sRGB} / 12.92$

otherwise, $\quad$ if $\quad R'_{sRGB}, G'_{sRGB}, B'_{sRGB} > 0.03928$

$$R_{sRGB} = \left[\left(R'_{sRGB} + 0.055 \right) \Big/ 1.055 \right]^{2.4}$$

$$G_{sRGB} = \left[\left(G'_{sRGB} + 0.055 \right) \Big/ 1.055 \right]^{2.4}$$

$$B_{sRGB} = \left[\left(B'_{sRGB} + 0.055 \right) \Big/ 1.055 \right]^{2.4}$$

Then the block converts the sRGB values to XYZ values using the following equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.41239079926596 & 0.35758433938388 & 0.18048078840183 \\ 0.21263900587151 & 0.71516867876776 & 0.07219231536073 \\ 0.01933081871559 & 0.11919477979463 & 0.95053215224966 \end{bmatrix} \times \begin{bmatrix} R_{sRGB} \\ G_{sRGB} \\ B_{sRGB} \end{bmatrix}$$

The XYZ to sR'G'B' conversion is also a two-step process. First, the block converts the XYZ values to linear sRGB values using the following equation:

$$\begin{bmatrix} R_{sRGB} \\ G_{sRGB} \\ B_{sRGB} \end{bmatrix} = \begin{bmatrix} 0.41239079926596 & 0.35758433938388 & 0.18048078840183 \\ 0.21263900587151 & 0.71516867876776 & 0.07219231536073 \\ 0.01933081871559 & 0.11919477979463 & 0.95053215224966 \end{bmatrix}^{-1} \times \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Then the block applies gamma correction to obtain the sR'G'B' values. This process is described by the following equations:

If $\quad R_{sRGB}, G_{sRGB}, B_{sRGB} \leq 0.00304$

$R'_{sRGB} = 12.92 R_{sRGB}$

$G'_{sRGB} = 12.92 G_{sRGB}$

$B'_{sRGB} = 12.92 B_{sRGB}$

otherwise, $\quad$ if $\quad R_{sRGB}, G_{sRGB}, B_{sRGB} > 0.00304$

$R'_{sRGB} = 1.055 R_{sRGB}^{(1.0/2.4)} - 0.055$

$G'_{sRGB} = 1.055 G_{sRGB}^{(1.0/2.4)} - 0.055$

$B'_{sRGB} = 1.055 B_{sRGB}^{(1.0/2.4)} - 0.055$

Note Computer Vision System Toolbox software uses a D65 white point, which is specified in Recommendation ITU-R BT.709, for this conversion. In contrast, the Image Processing Toolbox conversion is based on ICC profiles, and it uses a D65 to D50 Bradford adaptation transformation to the D50 white point. If you are using these two products and comparing results, you must account for this difference.

Conversion Between sR'G'B' and L*a*b* Color Spaces

The Color Space Conversion block converts sR'G'B' values to L*a*b* values in two steps. First it converts sR'G'B' to XYZ values using the equations described in "Conversion Between sR'G'B' and XYZ Color Spaces" on page 1-182. Then it uses the following

equations to transform the XYZ values to L*a*b* values. Here, X_n, Y_n, and Z_n are the tristimulus values of the reference white point you specify using the **White point** parameter:

$L* = 116(Y/Y_n)^{1/3} - 16, for \quad Y/Y_n > 0.008856$

$L* = 903.3 \, Y/Y_n, \quad$ otherwise

$a* = 500(f(X/X_n) - f(Y/Y_n))$

$b* = 200(f(Y/Y_n) - f(Z/Z_n)),$

where $\quad f(t) = t^{1/3}, for \quad t > 0.008856$

$f(t) = 7.787t + 16/166, \quad$ otherwise

The block converts L*a*b* values to sR'G'B' values in two steps as well. The block transforms the L*a*b* values to XYZ values using these equations:

For $\quad Y/Y_n > 0.008856$

$$X = X_n (P + a* / 500)^3$$
$$Y = Y_n P^3$$
$$Z = Z_n (P - b* / 200)^3,$$

where $\quad P = (L* + 16)/116$

Parameters

Conversion

Specify the color spaces you are converting between. Your choices are `R'G'B' to Y'CbCr`, `Y'CbCr to R'G'B'`, `R'G'B' to intensity`, `R'G'B' to HSV`, `HSV to R'G'B'`, `sR'G'B' to XYZ`, `XYZ to sR'G'B'`, `sR'G'B' to L*a*b*`, and `L*a*b* to sR'G'B'`.

Use conversion specified by

Specify the standard to use to convert your values between the R'G'B' and Y'CbCr color spaces. Your choices are `Rec. 601 (SDTV)` or `Rec. 709 (HDTV)`. This parameter is only available if, for the **Conversion** parameter, you select `R'G'B' to Y'CbCr` or `Y'CbCr to R'G'B'`.

Scanning standard

Specify the scanning standard to use to convert your values between the R'G'B' and Y'CbCr color spaces. Your choices are `1125/60/2:1` or `1250/50/2:1`. This parameter is only available if, for the **Use conversion specified by** parameter, you select `Rec. 709 (HDTV)`.

White point

Specify the reference white point. This parameter is visible if, for the **Conversion** parameter, you select `sR'G'B' to L*a*b*` or `L*a*b* to sR'G'B'`.

Image signal

Specify how to input and output a color video signal. If you select `One multidimensional signal`, the block accepts an M-by-N-by-P color video signal,

where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port accepts one M-by-N plane of an RGB video stream.

References

[1] Poynton, Charles A. *A Technical Introduction to Digital Video*. New York: John Wiley & Sons, 1996.

[2] Recommendation ITU-R BT.601-5, Studio Encoding Parameters of Digital Television for Standard 4:3 and Wide Screen 16:9 Aspect Ratios.

[3] Recommendation ITU-R BT.709-5. Parameter values for the HDTV standards for production and international programme exchange.

[4] Stokes, Michael, Matthew Anderson, Srinivasan Chandrasekar, and Ricardo Motta, "A Standard Default Color Space for the Internet - sRGB." November 5, 1996.

[5] Berns, Roy S. *Principles of Color Technology, 3rd ed*. New York: John Wiley & Sons, 2000.

See Also

Chroma Resampling	Computer Vision System Toolbox software
`rgb2hsv`	MATLAB software
`hsv2rgb`	MATLAB software
`rgb2ycbcr`	Image Processing Toolbox software
`ycbcr2rgb`	Image Processing Toolbox software
`rgb2gray`	Image Processing Toolbox software
`makecform`	Image Processing Toolbox software
`applycform`	Image Processing Toolbox software

Introduced before R2006a

Compositing

Combine pixel values of two images, overlay one image over another, or highlight selected pixels

Library

Text & Graphics

`visiontextngfix`

Description

You can use the Compositing block to combine two images. Each pixel of the output image is a linear combination of the pixels in each input image. This process is defined by the following equation:

$$O(i,j) = (1 - X) * I1(i,j) + X * I2(i,j)$$

You can define the amount by which to scale each pixel value before combining them using the opacity factor, X, where , $0 \leq X \leq 1$.

You can use the Compositing block to overlay one image over another image. The masking factor and the location determine which pixels are overwritten. Masking factors can be `0` or `1`, where `0` corresponds to not overwriting pixels and `1` corresponds to overwriting pixels.

You can also use this block to highlight selected pixels in the input image. The block uses a binary input image at the **Mask** port, to specify which pixels to highlight.

Note This block supports intensity and color images.

Fixed-Point Data Types

The following diagram shows the data types used in the Compositing block for fixed-point signals. These data types applies when the **Operation** parameter is set to `Blend`.
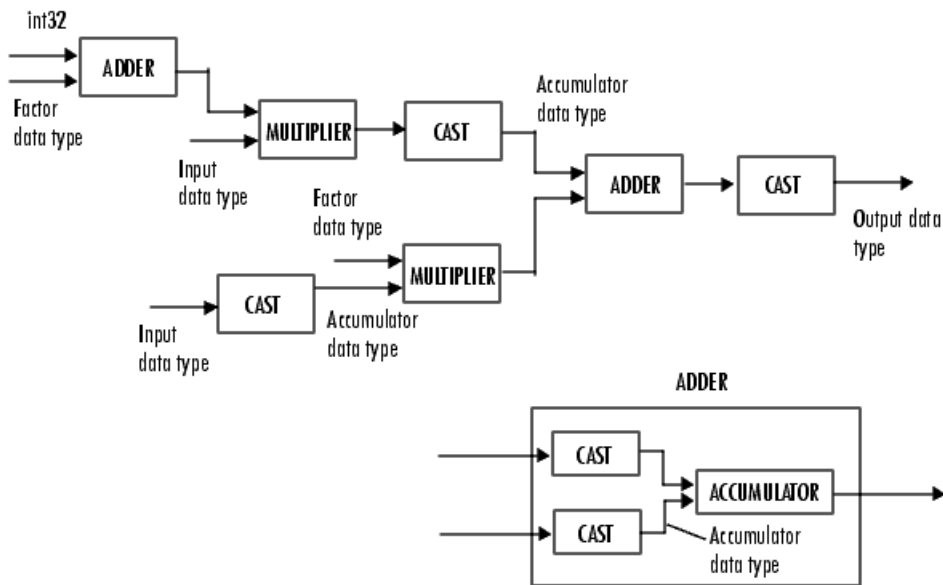
You can set the product output, accumulator, and output data types in the block mask as discussed in the next section.

Parameters

Operation

Specify the operation you want the block to perform. If you choose `Blend`, the block linearly combines the pixels of one image with another image. If you choose `Binary mask`, the block overwrites the pixel values of one image with the pixel values of

another image. If you choose `Highlight selected pixels`, the block uses the binary image input at the **Mask** port. Using this image, the block then determines which pixels are set to the maximum value supported by their data type.

Blend

If, for the **Operation** parameter, you choose `Blend`, the **Opacity factor(s) source** parameter appears on the dialog box. Use this parameter to indicate where to specify the opacity factor(s).

- If you choose `Specify via dialog`, the **Opacity factor(s)** parameter appears on the dialog box. Use this parameter to define the amount by which the block scales each pixel values for input image at the **Image2** port before combining them with the pixel values of the input image at **Image1** port. You can enter a scalar value used for all pixels or a matrix of values that is the same size as the input image at the **Image2** port.

- If you choose `Input port`, the **Factor** port appears on the block. The input to this port must be a scalar or matrix of values as described for the **Opacity factor(s)** parameter. If the input to the **Image1** and **Image2** ports is floating point, the input to this port must be the same floating-point data type.

Binary mask

If, for the **Operation** parameter, you choose `Binary mask`, the **Mask source** parameter appears on the dialog box. Use this parameter to indicate where to specify the masking factor(s).

- If you choose `Specify via dialog`, the **Mask** parameter appears on the dialog box. Use this parameter and the location source of the image to define which pixels are overwritten. You can enter 0 or 1 to use for all pixels in the image, or a matrix of 0s and 1s that defines the factor for each pixel.

- If you choose `Input port`, the **Factor** port appears on the block. The input to this port must be a 0 or 1 whose data type is Boolean. Or, a matrix of 0s or 1s whose data type is Boolean, as described for the **Mask** parameter.

Highlight selected pixels

If, for the **Operation** parameter, you choose `Highlight selected pixels`, the block uses the binary image input at the **Mask** port to determine which pixels are set to the maximum value supported by their data type. For example, for every pixel value set to 1 in the binary image, the block sets the corresponding pixel in the input image

to the maximum value supported by its data type. For every `0` in the binary image, the block leaves the corresponding pixel value alone.

Opacity factor(s) source

Indicate where to specify any opacity factors. Your choices are `Specify via dialog` and `Input port`. This parameter is visible if, for the **Operation** parameter, you choose `Blend`.

Opacity factor(s)

Define the amount by which the block scales each pixel value before combining them. You can enter a scalar value used for all pixels or a matrix of values that defines the factor for each pixel. This parameter is visible if, for the **Opacity factor(s) source** parameter, you choose `Specify via dialog`. Tunable.

Mask source

Indicate where to specify any masking factors. Your choices are `Specify via dialog` and `Input port`. This parameter is visible if, for the **Operation** parameter, you choose `Binary mask`.

Mask

Define which pixels are overwritten. You can enter 0 or 1, which is used for all pixels, or a matrix of 0s and 1s that defines the factor for each pixel. This parameter is visible if, for the **Mask source** parameter, you choose `Specify via dialog`. Tunable.

Location source

Use this parameter to specify where to enter the location of the upper-left corner of the image input at input port **Image2**. You can choose either `Specify via dialog` or `Input port`.

When you choose `Specify via dialog`, you can set the **Location [x y]** parameter.

When you choose `Input port`, the **Location** port appears on the block. The input to this port must be a two-element vector as described for the **Location [x y]** parameter.

Location [x y]

Enter a two-element vector that specifies the row and column position of the upper-left corner of the image input at **Image2** port. The position is relative to the upper-left corner of the image input at **Image1** port. This parameter is visible if, for the **Location source** parameter, you choose `Specify via dialog`. Tunable.

Positive values move the image down and to the right; negative values move the image up and to the left. If the first element is greater than the number of rows in the

Image1 matrix, the value is clipped to the total number of rows. If the second element is greater than the number of columns in the input **Image1** matrix, the value is clipped to the total number of columns.

These parameters apply only when the **Operation** parameter is set to `Blend`.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Opacity factor

Choose how to specify the word length and fraction length of the opacity factor:

- When you select `Same word length as input`, these characteristics match those of the input to the block.

- When you select `Specify word length`, enter the word length of the opacity factor.

- When you select `Binary point scaling`, you can enter the word length of the opacity factor, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, of the opacity factor. The bias of all signals in the Computer Vision System Toolbox software is 0.

Product output

As the previous figure shows, the block places the output of the multiplier into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths.

- When you select `Same as first input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Accumulator

The result of each addition remains in the accumulator data type.
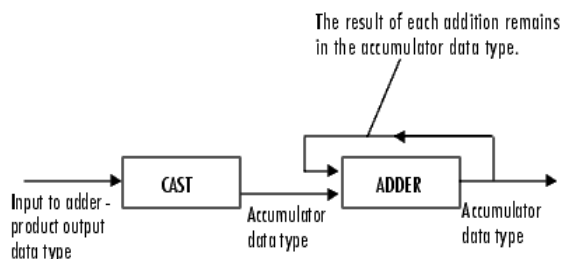
As the previous figure shows, the block takes inputs to the accumulator and casts them to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it.

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as first input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox software software is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as first input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Supported Data Types

Port	Input/Output	Supported Data Types	Complex Values Supported
Image 1	*M*-by-*N* matrix of intensity values or an *M*-by-*N*-by-*P* color video signal where *P* is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Image 2	*M*-by-*N* matrix of intensity values or an *M*-by-*N*-by-*P* color video signal where *P* is the number of color planes	Same as Image 1 port	No
Factor	Scalar or matrix of opacity or masking factor	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Mask	Binary image that specifies which pixels to highlight	Same as Factor port When the **Operation** parameter is set to `Highlight selected pixel`, the input to the Mask port must be a Boolean data type.	No
Location	Two-element vector [*x y*], that specifies the position of the upper-left corner of the image input at port I2	• Double-precision floating point. (Only supported if the input to the Image 1 and Image 2 ports is a floating-point data type.) • Single-precision floating point. (Only supported if the input to the Image 1 and Image 2 ports is a floating-point data type.) • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Output	Vector or matrix of intensity or color values	Same as Image 1 port	No

See Also

Insert Text	Computer Vision System Toolbox
Draw Markers	Computer Vision System Toolbox
Draw Shapes	Computer Vision System Toolbox

Introduced before R2006a

Contrast Adjustment

Adjust image contrast by linearly scaling pixel values

Contrast Adjustment

Library

Analysis & Enhancement

`visionanalysis`

Description

The Contrast Adjustment block adjusts the contrast of an image by linearly scaling the pixel values between upper and lower limits. Pixel values that are above or below this range are saturated to the upper or lower limit value, respectively.
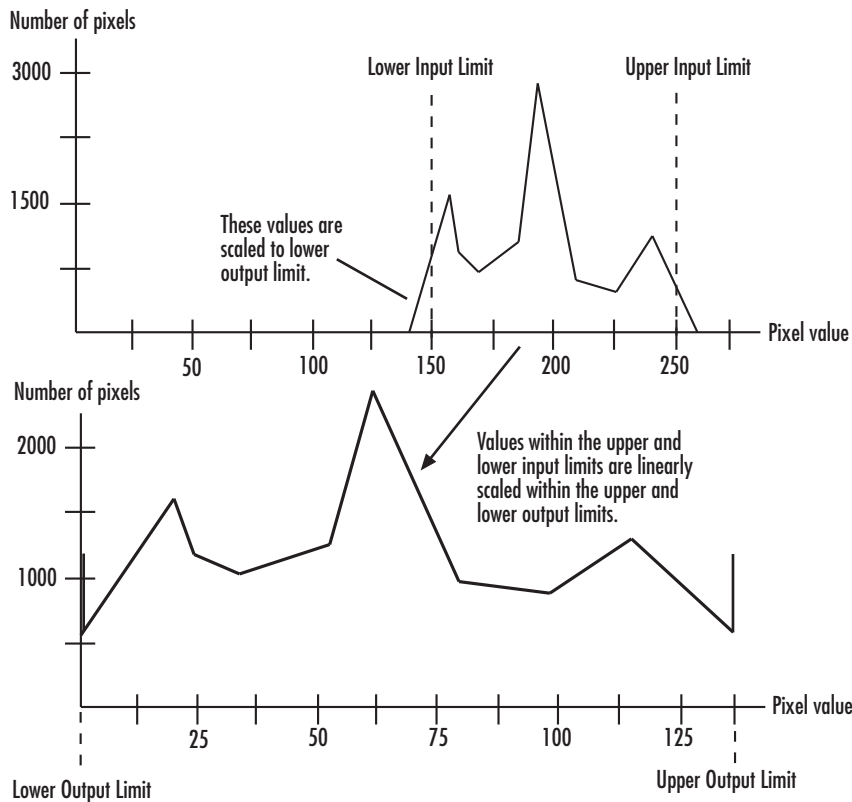
Mathematically, the contrast adjustment operation is described by the following equation, where the input limits are [*low_in high_in*] and the output limits are [*low_out high_out*]:

$$Output = \begin{cases} low\_out, & Input \le low\_in \\ low\_out + (Input - low\_in)\dfrac{high\_out - low\_out}{high\_in - low\_in}, & low\_in < Input < high\_in \\ high\_out, & Input \ge high\_in \end{cases}$$

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Output	Scalar, vector, or matrix of intensity values or a scalar, vector, or matrix that represents one plane of the RGB video stream	Same as I port	No

Specifying upper and lower limits

Use the **Adjust pixel values from** and **Adjust pixel values to** parameters to specify the upper and lower input and output limits. All options are described below.

Use the **Adjust pixel values from** parameter to specify the upper and lower input limits. If you select `Full input data range [min max]`, uses the minimum input value as the lower input limit and the maximum input value as the upper input limit.
If you select `User-defined`, the **Range [low high]** parameter associated with this option appears. Enter a two-element vector of scalar values, where the first element corresponds to the lower input limit and the second element corresponds to the upper input limit.
If you select `Range determined by saturating outlier pixels`, the **Percentage of pixels to saturate [low high] (in %)**, **Specify number of histogram bins (used to calculate the range when outliers are eliminated)**, and **Number of histogram bins** parameters appear on the block. The block uses these parameter values to calculate the input limits in this three-step process:

1. Find the minimum and maximum input values, [*min_in max_in*].

2. Scale the pixel values from [**min_in max_in**] to [0 *num_bins*-1], where *num_bins* is the scalar value you specify in the **Number of histogram bins** parameter. This parameter always displays the value used by the block. Then the block calculates the

histogram of the scaled input. For additional information about histograms, see the 2D-Histogram block reference page.

3 Find the lower input limit such that the percentage of pixels with values smaller than the lower limit is at most the value of the first element of the **Percentage of pixels to saturate [low high] (in %)** parameter. Similarly, find the upper input limit such that the percentage of pixels with values greater than the upper limit is at least the value of the second element of the parameter.

Use the **Adjust pixel values to** parameter to specify the upper and lower output limits. If you select `Full data type range`, the block uses the minimum value of the input data type as the lower output limit and the maximum value of the input data type as the upper out
If you select `User-defined range`, the **Range [low high]** parameter appears on the block. Enter a two-element vector of scalar values, where the first element corresponds to the lower output limit and the second element corresponds to the upper output limit.

If any input pixel value is either `INF` or `-INF`, the Contrast Adjustment block will change the pixel value according to how the parameters are set. The following table shows how the block handles these pixel values.

If Adjust pixel values from parameter is set to...	Contrast Adjustment block will:
Full data range [min,max]	Set the entire output image to the lower limit of the **Adjust pixel values to** parameter setting.
Range determined by saturating outlier pixels	
User defined range	Lower and higher limits of the **Adjust pixel values to** parameter set to `-INF` and `INF`, respectively.

If any input pixel has a `NAN` value, the block maps the pixels with valid numerical values according to the user-specified method. It maps the `NAN` pixels to the lower limit of the **Adjust pixels values to** parameter.

Examples

See "Adjust the Contrast of Intensity Images" in the *Computer Vision System Toolbox User's Guide*.

Fixed-Point Data Types

The following diagram shows the data types used in the Contrast Adjustment block for fixed-point signals:
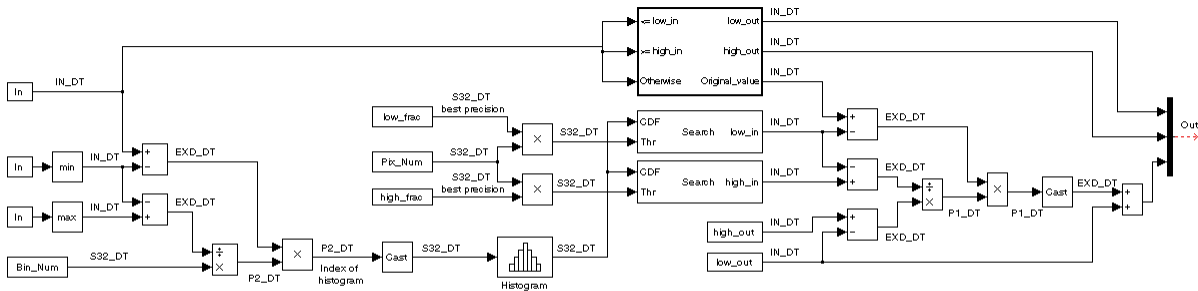
FIXED-POINT TAB NAMES:
=====================================
IN_DT: Datatype of the input image
EXD_DT: IN_DT with extra bit for sign
P1_DT: Datatype of product 1
P2_DT: Datatype of product 2

SUB-SYSTEMS:
=====================================
Search:
Calculate the pixel value that corresponds
to Thr in the cumulative histogram (CDF).

Parameters

Adjust pixel values from

> Specify how to enter the upper and lower input limits. Your choices are `Full input data range [min max]`, `User-defined`, and `Range determined by saturating outlier pixels`.

Range [low high]

> Enter a two-element vector of scalar values. The first element corresponds to the lower input limit, and the second element corresponds to the upper input limit. This parameter is visible if, for the **Adjust pixel values from** parameter, you select `User-defined`.

Percentage of pixels to saturate [low high] (in %)

> Enter a two-element vector. The block calculates the lower input limit such that the percentage of pixels with values smaller than the lower limit is at most the value of the first element. It calculates the upper input limit similarly. This parameter is visible if, for the **Adjust pixel values from** parameter, you select `Range determined by saturating outlier pixels`.

Specify number of histogram bins (used to calculate the range when outliers are eliminated)

Select this check box to change the number of histogram bins. This parameter is editable if, for the **Adjust pixel values from** parameter, you select `Range determined by saturating outlier pixels`.

Number of histogram bins

Enter the number of histogram bins to use to calculate the scaled input values. This parameter is available if you select the **Specify number of histogram bins (used to calculate the range when outliers are eliminated)** check box.

Adjust pixel values to

Specify the upper and lower output limits. If you select `Full data type range`, the block uses the minimum value of the input data type as the lower output limit and the maximum value of the input data type as the upper output limit. If you select `User-defined range`, the **Range [low high]** parameter appears on the block.

Range [low high]

Enter a two-element vector of scalar values. The first element corresponds to the lower output limit and the second element corresponds to the upper output limit. This parameter is visible if, for the **Adjust pixel values to** parameter, you select `User-defined range`

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Product 1

The product output type when the block calculates the ratio between the input data range and the number of histogram bins.

As shown in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths:

When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Product 2

The product output type when the block calculates the bin location of each input value.

As shown in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths:

When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

This parameter is visible if, for the **Adjust pixel values from** parameter, you select `Range determined by saturating outlier pixels`.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

See Also

| 2D-Histogram | Computer Vision System Toolbox software |

Histogram Equalization	Computer Vision System Toolbox software

Introduced in R2006b

Corner Detection

Calculate corner metric matrix and find corners in images
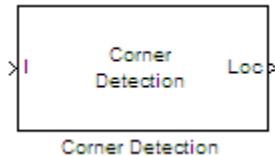
Corner Detection

Library

Analysis & Enhancement

`visionanalysis`

Description

The Corner Detection block finds corners in an image using the Harris corner detection (by Harris & Stephens), minimum eigenvalue (by Shi & Tomasi), or local intensity comparison (Features from Accelerated Segment Test, FAST by Rosten & Drummond) method. The block finds the corners in the image based on the pixels that have the largest corner metric values.

For the most accurate results, use the "Minimum Eigenvalue Method" on page 1-204. For the fastest computation, use the "Local Intensity Comparison" on page 1-205. For the trade-off between accuracy and computation, use the "Harris Corner Detection Method" on page 1-205.

Port Description

Port	Description	Supported Data Types
I	Matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer
Loc	*M*-by-2 matrix of [x y] coordinates, that represents the locations of the corners. *M* represents the number of corners and is less than or equal to the **Maximum number of corners** parameter	32-bit unsigned integer
Count	Scalar value that represents the number of detected corners	32-bit unsigned integer
Metric	Matrix of corner metric values that is the same size as the input image	Same as I port

Minimum Eigenvalue Method

This method is more computationally expensive than the Harris corner detection algorithm because it directly calculates the eigenvalues of the sum of the squared difference matrix, *M*.

The sum of the squared difference matrix, *M*, is defined as follows:

$$M = \begin{bmatrix} A & C \\ C & B \end{bmatrix}$$

The previous equation is based on the following values:

$$A = (I_x)^2 \otimes w$$
$$B = (I_y)^2 \otimes w$$
$$C = (I_x I_y)^2 \otimes w$$

where I_x and I_y are the gradients of the input image, I, in the x and y direction, respectively. The $\otimes$ symbol denotes a convolution operation.

Use the **Coefficients for separable smoothing filter** parameter to define a vector of filter coefficients. The block multiplies this vector of coefficients by its transpose to create a matrix of filter coefficients, w.

The block calculates the smaller eigenvalue of the sum of the squared difference matrix. This minimum eigenvalue corresponds to the corner metric matrix.

Harris Corner Detection Method

The Harris corner detection method avoids the explicit computation of the eigenvalues of the sum of squared differences matrix by solving for the following corner metric matrix, R:

$$R = AB - C^2 - k(A + B)^2$$

A, B, C are defined in the previous section, "Minimum Eigenvalue Method" on page 1-204.

The variable k corresponds to the sensitivity factor. You can specify its value using the **Sensitivity factor (0<k<0.25)** parameter. The smaller the value of k, the more likely it is that the algorithm can detect sharp corners.

Use the **Coefficients for separable smoothing filter** parameter to define a vector of filter coefficients. The block multiplies this vector of coefficients by its transpose to create a matrix of filter coefficients, w.

Local Intensity Comparison

This method determines that a pixel is a possible corner if it has either, N contiguous valid bright surrounding pixels, or N contiguous dark surrounding pixels. Specifying the

value of *N* is discussed later in this section. The next section explains how the block finds these surrounding pixels.

Suppose that *p* is the pixel under consideration and *j* is one of the pixels surrounding *p*. The locations of the other surrounding pixels are denoted by the shaded areas in the following figure.
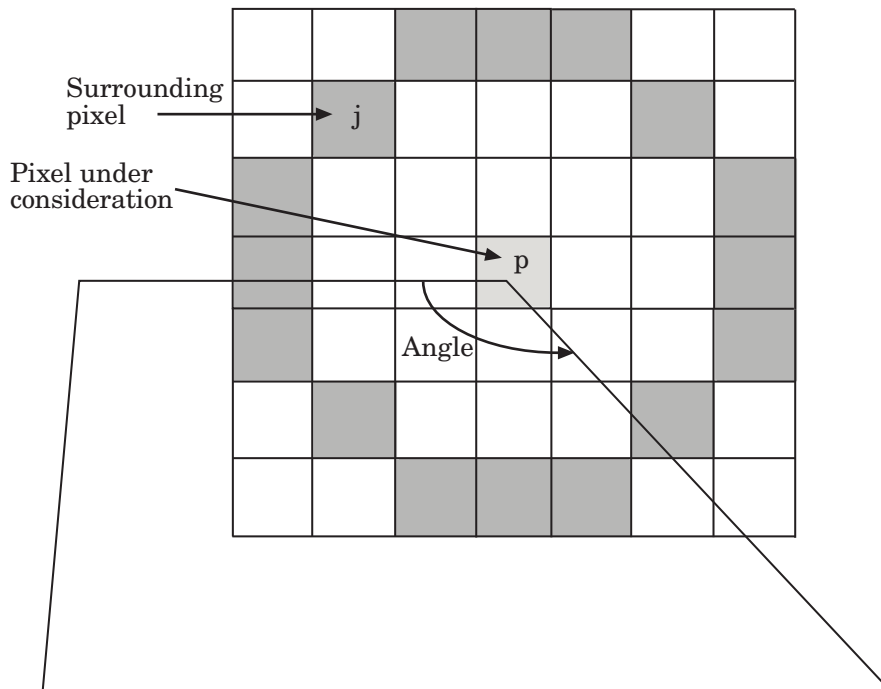
I_p and I_j are the intensities of pixels *p* and *j*, respectively. Pixel *j* is a valid bright

surrounding pixel if $I_j - I_p \geq T$. Similarly, pixel *j* is a valid dark surrounding pixel if

$I_p - I_j \geq T$. In these equations, *T* is the value you specified for the **Intensity comparison threshold** parameter.

The block repeats this process to determine whether the block has *N* contiguous valid surrounding pixels. The value of *N* is related to the value you specify for the **Maximum angle to be considered a corner (in degrees)**, as shown in the following table.

Number of Valid Surrounding Pixels, N	Angle (degrees)
15	22.5
14	45
13	67.5
12	90
11	112.5
10	135
9	157.5

After the block determines that a pixel is a possible corner, it computes its corner metric using the following equation:

$$R = \max\left(\sum_{j:I_j \geq I_p + T} \left|I_p - I_j\right| - T, \sum_{j:I_j \leq I_p - T} \left|I_p - I_j\right| - T, \right)$$

Fixed-Point Data Types

The following diagram shows the data types used in the Corner Detection block for fixed-point signals. These diagrams apply to the Harris corner detection and minimum eigenvalue methods only.
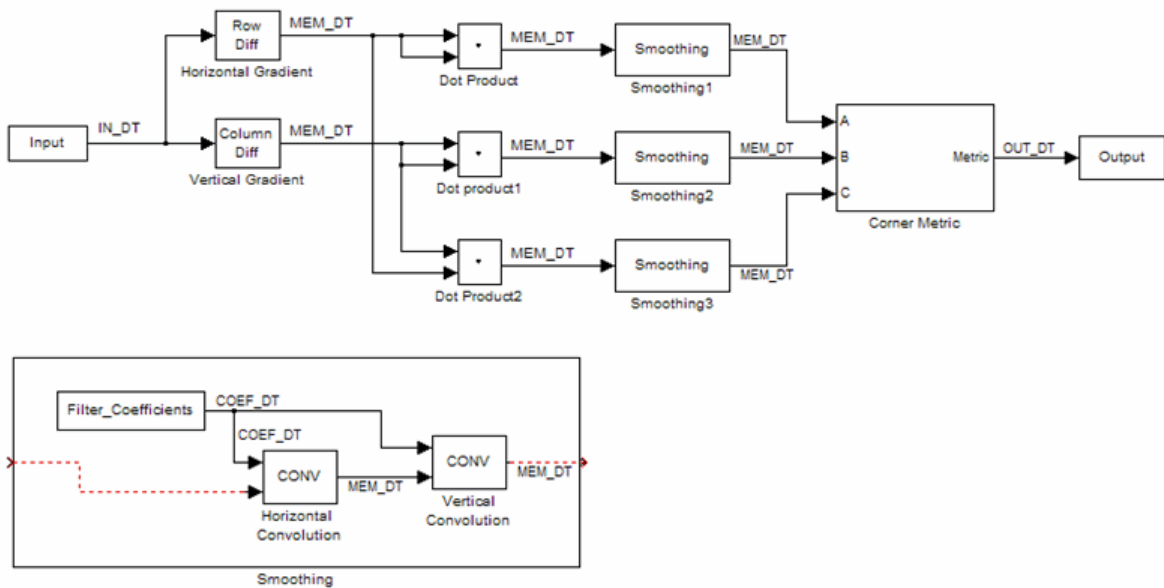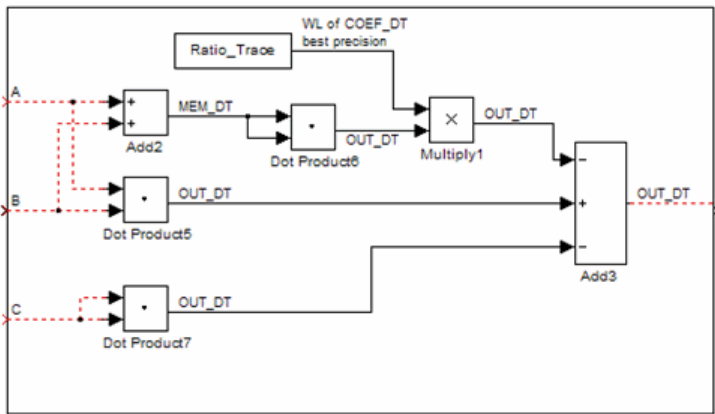
Corner Metric by Harris Algorithm
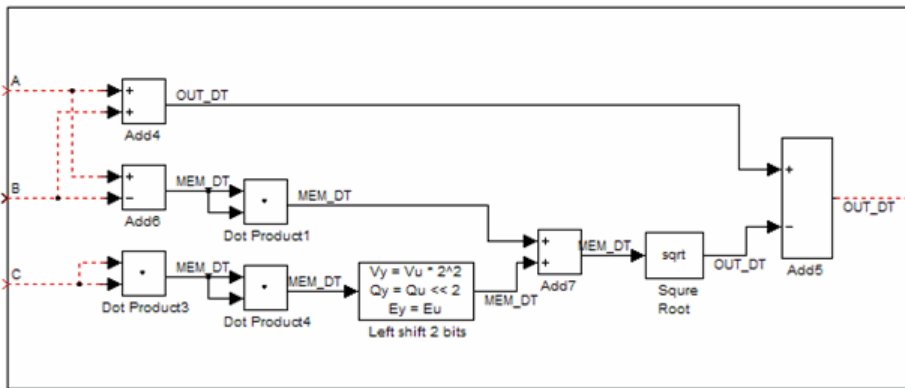
Corner Metric by Minimum Eigenvalue Algorithm

The following table summarizes the variables used in the previous diagrams.

Variable Name	Definition
IN_DT	Input data type
MEM_DT	Memory data type
OUT_DT	Metric output data type
COEF_DT	Coefficients data type

Parameters

Method

Specify the method to use to find the corner values. Your choices are `Harris corner detection (Harris & Stephens)`, `Minimum eigenvalue (Shi & Tomasi)`, and `Local intensity comparison (Rosten & Drummond)`.

Sensitivity factor (0<k<0.25)

Specify the sensitivity factor, k. The smaller the value of k the more likely the algorithm is to detect sharp corners. This parameter is visible if you set the **Method** parameter to `Harris corner detection (Harris & Stephens)`. This parameter is tunable.

Coefficients for separable smoothing filter

Specify a vector of filter coefficients for the smoothing filter. This parameter is visible if you set the **Method** parameter to `Harris corner detection (Harris & Stephens)` or `Minimum eigenvalue (Shi & Tomasi)`.

Intensity comparison threshold

Specify the threshold value used to find valid surrounding pixels. This parameter is visible if you set the **Method** parameter to `Local intensity comparison (Rosten & Drummond)`. This parameter is tunable.

Maximum angle to be considered a corner (in degrees)

Specify the maximum corner angle. This parameter is visible if you set the **Method** parameter to `Local intensity comparison (Rosten & Drummond)`. This parameter is tunable for Simulation only.

Output

Specify the block output. Your choices are `Corner location`, `Corner location and metric matrix`, and `Metric matrix`. The block outputs the corner locations in an M-by-2 matrix of [x y] coordinates, where M represents the number of corners. The block outputs the corner metric value in a matrix, the same size as the input image.

When you set this parameter to `Corner location` or `Corner location and metric matrix`, the **Maximum number of corners**, **Minimum metric value that indicates a corner**, and **Neighborhood size (suppress region around detected corners)** parameters appear on the block.

To determine the final corner values, the block follows this process:

1 Find the pixel with the largest corner metric value.

2 Verify that the metric value is greater than or equal to the value you specified for the **Minimum metric value that indicates a corner** parameter.

3 Suppress the region around the corner value by the size defined in the **Neighborhood size (suppress region around detected corners)** parameter.

The block repeats this process until it finds all the corners in the image or it finds the number of corners you specified in the **Maximum number of corners** parameter.

The corner metric values computed by the `Minimum eigenvalue` and `Local intensity comparison` methods are always non-negative. The corner metric values computed by the `Harris corner detection` method can be negative.

Maximum number of corners

Enter the maximum number of corners you want the block to find. This parameter is visible if you set the **Output** parameter to `Corner location` or `Corner location and metric matrix`.

Minimum metric value that indicates a corner

Specify the minimum corner metric value. This parameter is visible if you set the **Output** parameter to `Corner location` or `Corner location and metric matrix`. This parameter is tunable.

Neighborhood size (suppress region around detected corners)

Specify the size of the neighborhood around the corner metric value over which the block zeros out the values. Enter a two-element vector of positive odd integers, [r c]. Here, r is the number of rows in the neighborhood and c is the number of columns. This parameter is visible if you set the **Output** parameter to `Corner location` or `Corner location and metric matrix`.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Coefficients

Choose how to specify the word length and the fraction length of the coefficients:

• When you select `Same word length as input`, the word length of the coefficients match that of the input to the block. In this mode, the fraction length of the coefficients is automatically set to the binary-point only scaling that

provides you with the best precision possible given the value and word length of the coefficients.

- When you select `Specify word length`, you can enter the word length of the coefficients, in bits. The block automatically sets the fraction length to give you the best precision.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the coefficients, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the coefficients. The bias of all signals in the Computer Vision System Toolbox software is 0.

Product output

As shown in the following figure, the output of the multiplier is placed into the product output data type and scaling.

Use this parameter to specify how to designate the product output word and fraction lengths.

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox software is 0.

Accumulator

As shown in the following figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it.

The result of each addition remains
in the accumulator data type.

```
                    ┌─────────┐      ┌─────────────┐
 ────────────────▶  │  CAST   │ ───▶ │    ADDER    │ ──────▶
 Input to adder -   └─────────┘      └─────────────┘ ──────▶
 input data type               Accumulator         Accumulator
                               data type           data type
```

Use this parameter to specify how to designate this accumulator word and fraction lengths:

- When you select `Same as input`, these characteristics match those of the input.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox software is 0.

Memory

Choose how to specify the memory word length and fraction length:

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. This block requires power-of-two slope and a bias of 0.

Metric output

Choose how to specify the metric output word length and fraction length:

- When you select `Same as accumulator`, these characteristics match those of the accumulator.

- When you select `Same as input`, these characteristics match those of the input to the block.

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- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. This block requires power-of-two slope and a bias of 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] C. Harris and M. Stephens. "A Combined Corner and Edge Detector." *Proceedings of the 4th Alvey Vision Conference.* August 1988, pp. 147-151.

[2] J. Shi and C. Tomasi. "Good Features to Track." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition.* June 1994, pp. 593–600.

[3] E. Rosten and T. Drummond. "Fusing Points and Lines for High Performance Tracking." *Proceedings of the IEEE International Conference on Computer Vision* Vol. 2 (October 2005): pp. 1508–1511.

See Also

Find Local Maxima	Computer Vision System Toolbox software
Estimate Geometric Transformation	Computer Vision System Toolbox software
matchFeatures	Computer Vision System Toolbox software
extractFeatures	Computer Vision System Toolbox software
detectSURFFeatures	Computer Vision System Toolbox software

Introduced in R2007b

Deinterlacing

Remove motion artifacts by deinterlacing input video signal

Deinterlacing

Library

Analysis & Enhancement

`visionanalysis`

Description

The Deinterlacing block takes the input signal, which is the combination of the top and bottom fields of the interlaced video, and converts it into deinterlaced video using line repetition, linear interpolation, or vertical temporal median filtering.

Note This block supports intensity and color images on its ports.

Port	Input/Output	Supported Data Types	Complex Values Supported
Input	Combination of top and bottom fields of interlaced video	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Output	Frames of deinterlaced video	Same as Input port	No

Use the **Deinterlacing method** parameter to specify how the block deinterlaces the video.

The following figure illustrates the block's behavior if you select Line repetition.

Line Repetition

Original Interlaced Video

	Top Field				Bottom Field		
Row 1	A	B	C	Row 1			
Row 2				Row 2	D	E	F
Row 3	G	H	I	Row 3			
Row 4				Row 4	J	K	L
Row 5	M	N	O	Row 5			
Row 6				Row 6	P	Q	R

	Block Input				Block Output - Deinterlaced Video		
Row 1	A	B	C	Row 1	A	B	C
Row 2	D	E	F	Row 2	A	B	C
Row 3	G	H	I	Row 3	G	H	I
Row 4	J	K	L	Row 4	G	H	I
Row 5	M	N	O	Row 5	M	N	O
Row 6	P	Q	R	Row 6	M	N	O

The following figure illustrates the block's behavior if you select `Linear interpolation`.

Linear Interpolation

Original Interlaced Video

	Top Field				Bottom Field		
Row 1	A	B	C	Row 1			
Row 2				Row 2	D	E	F
Row 3	G	H	I	Row 3			
Row 4				Row 4	J	K	L
Row 5	M	N	O	Row 5			
Row 6				Row 6	P	Q	R

	Block Input				Block Output - Deinterlaced Video		
Row 1	A	B	C	Row 1	A	B	C
Row 2	D	E	F	Row 2	(A+G)/2	(B+H)/2	(C+I)/2
Row 3	G	H	I	Row 3	G	H	I
Row 4	J	K	L	Row 4	(G+M)/2	(H+N)/2	(I+O)/2
Row 5	M	N	O	Row 5	M	N	O
Row 6	P	Q	R	Row 6	M	N	O

The following figure illustrates the block's behavior if you select `Vertical temporal median filtering`.

Vertical Temporal Median Filtering

Original Interlaced Video

	Top Field				Bottom Field		
Row 1	A	B	C	Row 1			
Row 2				Row 2	D	E	F
Row 3	G	H	I	Row 3			
Row 4				Row 4	J	K	L
Row 5	M	N	O	Row 5			
Row 6				Row 6	P	Q	R

	Block Input				Block Output - Deinterlaced Video		
Row 1	A	B	C	Row 1	A	B	C
Row 2	D	E	F	Row 2	median([A,D,G])	median([B,E,H])	median([C,F,I])
Row 3	G	H	I	Row 3	G	H	I
Row 4	J	K	L	Row 4	median([G,J,M])	median([H,K,N])	median([I,L,O])
Row 5	M	N	O	Row 5	M	N	O
Row 6	P	Q	R	Row 6	M	N	O

Row-Major Data Format

The MATLAB environment and the Computer Vision System Toolbox software use column-major data organization. However, the Deinterlacing block gives you the option to process data that is stored in row-major format. When you select the **Input image is transposed (data order is row major)** check box, the block assumes that the input buffer contains contiguous data elements from the first row first, then data elements from the second row

second, and so on through the last row. Use this functionality only when you meet all the following criteria:

- You are developing algorithms to run on an embedded target that uses the row-major format.
- You want to limit the additional processing required to take the transpose of signals at the interfaces of the row-major and column-major systems.

When you use the row-major functionality, you must consider the following issues:

- When you select this check box, the first two signal dimensions of the Deinterlacing block's input are swapped.
- All the Computer Vision System Toolbox blocks can be used to process data that is in the row-major format, but you need to know the image dimensions when you develop your algorithms.

  For example, if you use the 2-D FIR Filter block, you need to verify that your filter coefficients are transposed. If you are using the Rotate block, you need to use negative rotation angles, etc.

- Only three blocks have the **Input image is transposed (data order is row major)** check box. They are the Chroma Resampling, Deinterlacing, and Insert Text blocks. You need to select this check box to enable row-major functionality in these blocks. All other blocks must be properly configured to process data in row-major format.

Use the following two-step workflow to develop algorithms in row-major format to run on an embedded target.

Step 1:
Create block diagram

Algorithm
blocks

Video
source
block

Transpose
block

Transpose
block

Video
sink
block

Embedded
target source
block

Step 2:
Replace source, transpose, and
sink blocks with target source
and sink blocks that produce
data in row-major format

Embedded
target sink
block

Example

The following example shows you how to use the Deinterlacing block to remove motion
artifacts from an image.

1   Open the example model by typing

```
ex_deinterlace
```

at the MATLAB command prompt.

2   Double-click the Deinterlacing block. The model uses this block to remove the motion
artifacts from the input image. The **Deinterlacing method** parameter is set to
`Vertical temporal median filtering`.
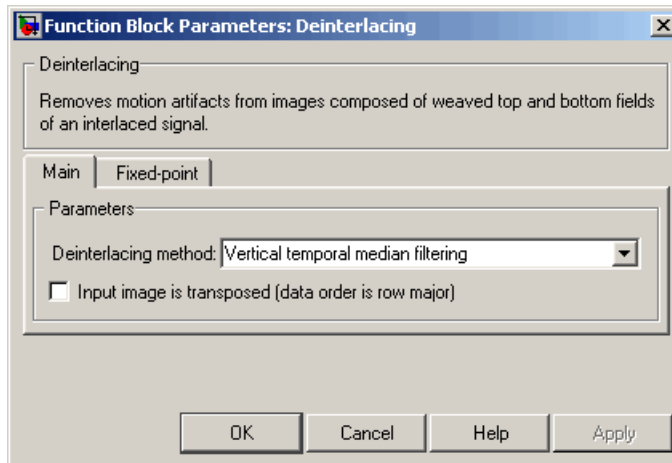
3 Run the model.

The original image that contains the motion artifacts appears in the Input Image window.
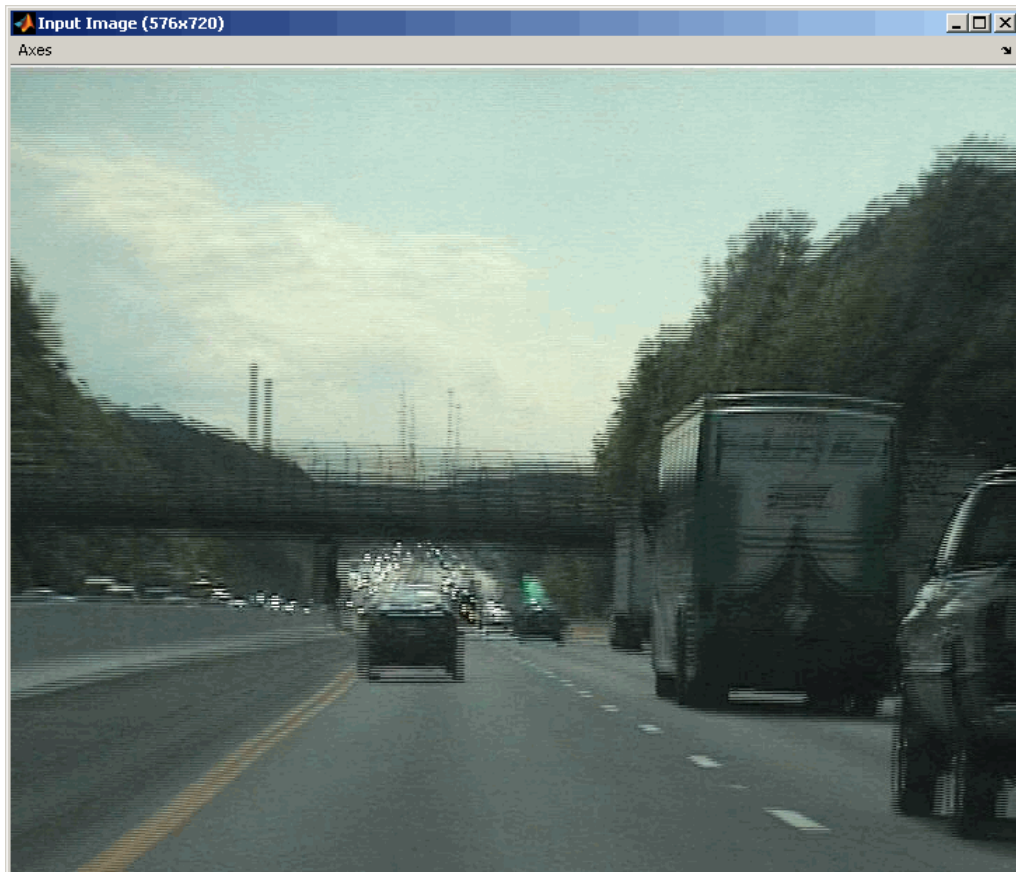
The clearer output image appears in the Output Image window.
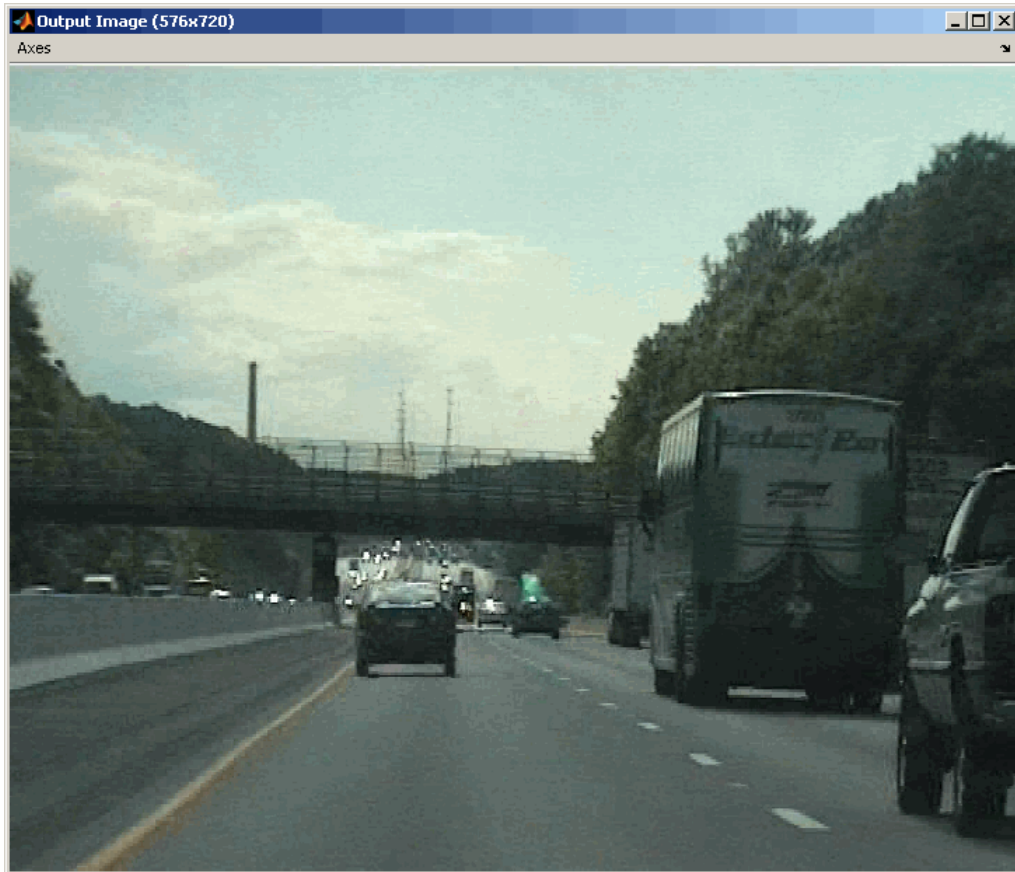
Fixed-Point Data Types

The following diagram shows the data types used in the Deinterlacing block for fixed-point signals.
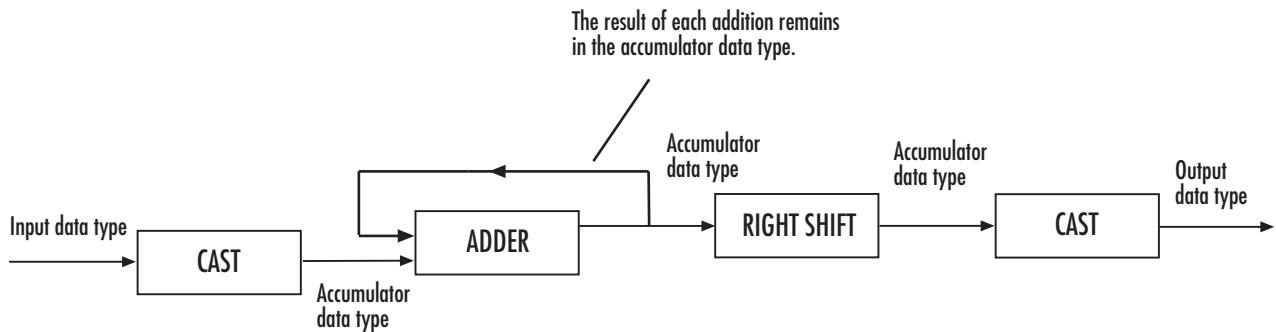
The result of each addition remains
in the accumulator data type.

Input data type → CAST → Accumulator data type → ADDER → Accumulator data type → RIGHT SHIFT → Accumulator data type → CAST → Output data type

You can set the product output, accumulator, and output data types in the block mask as discussed in the next section.

Parameters

Deinterlacing method

Specify how the block deinterlaces the video. Your choices are `Line repetition`, `Linear interpolation`, or `Vertical temporal median filtering`.

Input image is transposed (data order is row major)

When you select this check box, the block assumes that the input buffer contains data elements from the first row first, then data elements from the second row second, and so on through the last row.

Note The parameters on the **Data Types** pane are only available if, for the **Deinterlacing method**, you select `Linear interpolation`.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Accumulator

The result of each addition remains in the accumulator data type.

Input to adder - input data type → CAST → Accumulator data type → ADDER → Accumulator data type

As depicted in the previous figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths:

- When you select `Same as product output`, these characteristics match those of the product output.

- When you select `Same as input`, these characteristics match those of the input.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Output

Choose how to specify the output word length and fraction length:

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. This block requires power-of-two slope and a bias of 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Introduced before R2006a

Demosaic

Demosaic Bayer's format images
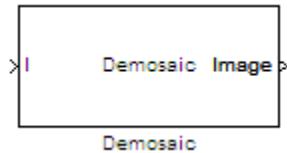
Demosaic

Library

Conversions

visionconversions

Description

The following figure illustrates a 4-by-4 image in Bayer's format with each pixel labeled R, G, or B.

B	G	B	G
G	R	G	R
B	G	B	G
G	R	G	R

The Demosaic block takes in images in Bayer's format and outputs RGB images. The block performs this operation using a gradient-corrected linear interpolation algorithm or a bilinear interpolation algorithm.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Matrix of intensity values • If, for the **Interpolation algorithm** parameter, you select `Bilinear`, the number of rows and columns must be greater than or equal to 3. • If, for the **Interpolation algorithm** parameter, you select `Gradient-corrected linear`, the number of rows and columns must be greater than or equal to 5.	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
R, G, B	Matrix that represents one plane of the input RGB video stream. Outputs from the R, G, or B ports have the same data type.	Same as I port	No
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes.	Same as I port	No

Use the **Interpolation algorithm** parameter to specify the algorithm the block uses to calculate the missing color information. If you select `Bilinear`, the block spatially averages neighboring pixels to calculate the color information. If you select `Gradient-corrected linear`, the block uses a Weiner approach to minimize the mean-squared error in the interpolation. This method performs well on the edges of objects in the image. For more information, see [1].

Use the **Sensor alignment** parameter to specify the alignment of the input image. Select the sequence of R, G and B pixels that correspond to the 2-by-2 block of pixels in the top-

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left corner of the image. You specify the sequence in left-to-right, top-to-bottom order. For example, for the image at the beginning of this reference page, you would select BGGR.

Both methods use symmetric padding at the image boundaries. For more information, see the Image Pad block reference page.

Use the **Output image signal** parameter to specify how to output a color video signal. If you select One multidimensional signal, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select Separate color signals, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.

Fixed-Point Data Types

The following diagram shows the data types used in the Demosaic block for fixed-point signals.
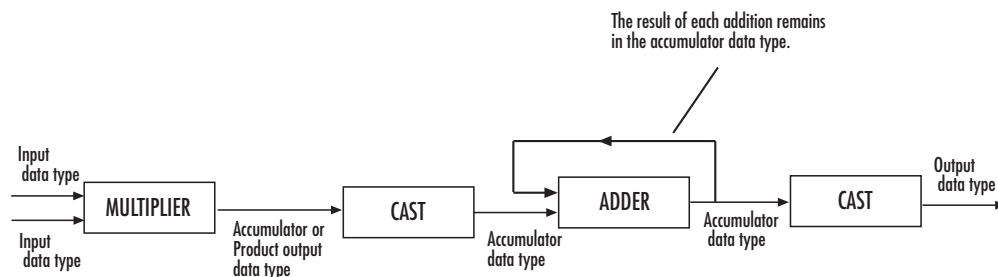
You can set the product output and accumulator data types in the block mask as discussed in the next section.

Parameters

Interpolation algorithm

Specify the algorithm the block uses to calculate the missing color information. Your choices are Bilinear or Gradient-corrected linear.

Sensor alignment

Select the sequence of R, G and B pixels that correspond to the 2-by-2 block of pixels in the top left corner of the image. You specify the sequence in left-to-right, top-to-bottom order.

Output image signal

Specify how to output a color video signal. If you select `One multidimensional signal`, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.
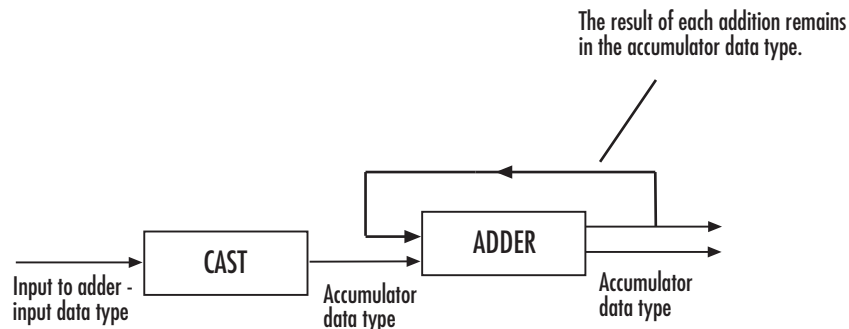
Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Product output

As depicted in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths:

When you select `Same as input`, these characteristics match those of the input to the block.

When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Accumulator

The result of each addition remains
in the accumulator data type.

As depicted in the previous figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths:

- When you select `Same as product output`, these characteristics match those of the product output.

- When you select `Same as input`, these characteristics match those of the input.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Malvar, Henrique S., Li-wei He, and Ross Cutler. "High-Quality Linear Interpolation for Demosaicing of Bayer-Patterned Color Images." *Microsoft Research*, May 2004. http://research.microsoft.com/pubs/102068/Demosaicing_ICASSP04.pdf.

[2] Gunturk, Bahadir K., John Glotzbach, Yucel Altunbasak, Ronald W. Schafer, and Russel M. Mersereau, "Demosaicking: Color Filter Array Interpolation," *IEEE Signal Processing Magazine*, Vol. 22, Number 1, January 2005.

Introduced in R2006b

Dilation

Find local maxima in binary or intensity image

Library

Morphological Operations

`visionmorphops`

Description

The Dilation block rotates the neighborhood or structuring element 180 degrees. Then it slides the neighborhood or structuring element over an image, finds the local maxima, and creates the output matrix from these maximum values. If the neighborhood or structuring element has a center element, the block places the maxima there, as illustrated in the following figure.
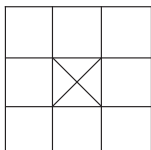
If the neighborhood or structuring element does not have an exact center, the block has a bias toward the lower-right corner, as a result of the rotation. The block places the maxima there, as illustrated in the following figure.

This block uses flat structuring elements only.

Port	Input/Output	Supported Data Types	Complex Values Supported
	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Nhood	Matrix or vector of ones and zeros that represents the neighborhood values	Boolean	No
Output	Vector or matrix of intensity values that represents the dilated image	Same as I port	No

The output signal has the same data type as the input to the I port.

Use the **Neighborhood or structuring element source** parameter to specify how to enter your neighborhood or structuring element values. If you select Specify via dialog, the **Neighborhood or structuring element** parameter appears in the dialog box. If you select Input port, the Nhood port appears on the block. Use this port to enter your neighborhood values as a matrix or vector of 1s and 0s. You can only specify a structuring element using the dialog box.

Use the **Neighborhood or structuring element** parameter to define the neighborhood or structuring element that the block applies to the image. Specify a neighborhood by entering a matrix or vector of 1s and 0s. Specify a structuring element with the strel

function from the Image Processing Toolbox. If the structuring element is decomposable into smaller elements, the block executes at higher speeds due to the use of a more efficient algorithm. If you enter an array of STREL objects, the block applies each object to the entire matrix in turn.

Parameters

Neighborhood or structuring element source

Specify how to enter your neighborhood or structuring element values. Select `Specify via dialog` to enter the values in the dialog box. Select `Input port` to use the Nhood port to specify the neighborhood values. You can only specify a structuring element using the dialog box.

Neighborhood or structuring element

If you are specifying a neighborhood, this parameter must be a matrix or vector of 1s and 0s. If you are specifying a structuring element, use the `strel` function from the Image Processing Toolbox. This parameter is visible if, for the **Neighborhood or structuring element source** parameter, you select `Specify via dialog`.

References

[1] Soille, Pierre. *Morphological Image Analysis. 2nd ed*. New York: Springer, 2003.

See Also

Bottom-hat	Computer Vision System Toolbox software
Closing	Computer Vision System Toolbox software
Erosion	Computer Vision System Toolbox software
Label	Computer Vision System Toolbox software
Opening	Computer Vision System Toolbox software
Top-hat	Computer Vision System Toolbox software
imdilate	Image Processing Toolbox software
strel	Image Processing Toolbox software

Introduced before R2006a

Draw Markers

Draw markers by embedding predefined shapes on output image
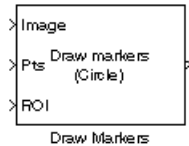
Library

Text & Graphics

`visiontextngfix`

Description

The Draw Markers block can draw multiple circles, x-marks, plus signs, stars, or squares on images by overwriting pixel values. Overwriting the pixel values embeds the shapes.

This block uses Bresenham's circle drawing algorithm to draw circles and Bresenham's line drawing algorithm to draw all other markers.

Port Description

Port	Input/Output	Supported Data Types	Complex Values Supported
Image	*M*-by-*N* matrix of intensity values or an *M*-by-*N*-by-*P* color values where *P* is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
R, G, B	Scalar, vector, or matrix that represents one plane of the input RGB video stream. Inputs to the R, G, and B ports must have the same dimensions and data type.	Same as Image port	No
Pts	*M*-by-2 matrix of [x y] coordinates, $$\begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \\ \vdots & \vdots \\ x_M & y_M \end{bmatrix}$$ where *M* is the total number of markers and each [x y] pair defines the center of a marker.	• Double-precision floating point • Single-precision floating point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer If the input to the Image port is an integer, fixed point, or boolean data type, the input to the Pts port must also be an integer data type.	No
ROI	Four-element vector of integers [x y width height] that define a rectangular area in which to draw the markers. The first two elements represent the one-based [x y] coordinates of the upper-left corner of the area. The second two elements represent the width and height of the area.	• Double-precision floating point • Single-precision floating point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Clr	*P*-element vector or *M*-by-*P* matrix where *P* is the number of color planes.	Same as Image port	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Output	Scalar, vector, or matrix of pixel values that contain the marker(s)	Same as Image port	No

The output signal is the same size and data type as the inputs to the Image, R, G, and B ports.

Parameters

Marker shape

Specify the type of marker(s) to draw. Your choices are `Circle`, `X-mark`, `Plus`, `Star`, or `Square`.

When you select `Circle`, `X-mark`, or `Star`, and you select the **Use antialiasing** check box, the block performs a smoothing algorithm. The algorithm is similar to the `poly2mask` function to determine which subpixels to draw.

Marker size

Enter a scalar value that represents the size of the marker, in pixels.

Enter a scalar value, M, that defines a $(2M+1)$-by-$(2M+1)$ pixel square into which the marker fits. M must be greater than or equal to 1.

Filled

Select this check box to fill the marker with an intensity value or a color. This parameter is visible if, for the **Marker shape** parameter, you choose `Circle` or `Square`.

When you select the **Filled** check box, the **Fill color source**, **Fill color** and **Opacity factor (between 0 and 1)** parameters appear in the dialog box.

Fill color source

Specify source for fill color value. You can select `Specify via dialog` or `Input port`. This parameter appears when you select the **Filled** check box. When you select `Input port`, the color input port **clr** appears on the block.

Fill color

If you select `Black`, the marker is black. If you select `White`, the marker is white. If you select `User-specified value`, the **Color value(s)** parameter appears in the dialog box. This parameter is visible if you select the **Filled** check box.

Border color source

Specify source for the border color value to either `Specify via dialog` or `Input port`. Border color options are visible when the fill shapes options are not selected. This parameter is visible if you select the **Filled** check box. When you select `Input port`, the color input port **clr** appears on the block.

Border color

Specify the appearance of the shape's border. If you select `Black`, the border is black. If you select `White`, the border is white. If you select `User-specified value`, the **Color value(s)** parameter appears in the dialog box. This parameter is visible if you clear the **Fill shapes** check box.

Color value(s)

Specify an intensity or color value for the marker's border or fill. This parameter appears when you set the **Border color** or **Fill color** parameters, to `User-specified value`. Tunable.

The following table describes what to enter for the color value based on the block input and the number of shapes you are drawing.

Block Input	Color Value(s) for Drawing One Marker or Multiple Markers with the Same Color	Color Value(s) for Drawing Multiple Markers with Unique Color
Intensity image	Scalar intensity value	R-element vector where R is the number of markers
Color image	P-element vector where P is the number of color planes	P-by-R matrix where P is the number of color planes and R is the number of markers

For each value in the parameter, enter a number between the minimum and maximum values that can be represented by the data type of the input image. If you enter a value outside this range, the block produces an error message.

Opacity factor (between 0 and 1)

Specify the opacity of the shading inside the marker, where `0` indicates transparent and `1` indicates opaque. This parameter appears when you select the **Filled** check box. This parameter is tunable.

The following table describes what to enter for the **Opacity factor(s) (between 0 and 1)** parameter based on the block input and the number of markers you are drawing.

Opacity Factor value for Drawing One Marker or Multiple Markers with the Same Color	Oopacity Factor value for Drawing Multiple Marker with Unique Color
Scalar intensity value	R-element vector where R is the number of markers

Draw markers in

Specify the area in which to draw the markers. When you select `Entire image`, you can draw markers in the entire image. When you select `Specify region of interest via port`, the ROI port appears on the block. Enter a four-element vector, `[x y width height]`, where `[x y]` are the coordinates of the upper-left corner of the area.

Use antialiasing

Perform a smoothing algorithm on the marker. This parameter is visible if, for the **Marker shape** parameter, you select `Circle`, `X-mark`, or `Star`.

Image signal

Specify how to input and output a color video signal. When you select `One multidimensional signal`, the block accepts an M-by-N-by-P color video signal, where P is the number of color planes, at one port. When you select `Separate color signals`, additional ports appear on the block. Each port accepts one M-by-N plane of an RGB video stream.

See Also

Draw Shapes	Computer Vision System Toolbox software
Insert Text	Computer Vision System Toolbox software

Introduced before R2006a

Draw Shapes

Draw rectangles, lines, polygons, or circles on images

Draw Shapes

Library

Text & Graphics

```
visiontextngfix
```
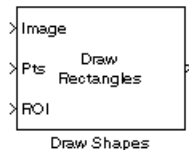
Description

The Draw Shapes block draws multiple rectangles, lines, polygons, or circles on images by overwriting pixel values. As a result, the shapes are embedded on the output image.

This block uses Bresenham's line drawing algorithm to draw lines, polygons, and rectangles. It uses Bresenham's circle drawing algorithm to draw circles.

The output signal is the same size and data type as the inputs to the Image, R, G, and B ports.

You can set the shape fill or border color via the input port or via the input dialog. Use the color input or color parameter to determine the appearance of the rectangle(s), line(s), polygon(s), or circle(s).

Port Description

Port	Input/Output	Supported Data Types	Complex Values Supported
Image	M-by-N matrix of intensity values or an M-by-N-by-P color values where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
R, G, B	Scalar, vector, or matrix that is one plane of the input RGB video stream. Inputs to the R, G, and B ports must have the same dimensions and data type.	Same as Image port	No
Pts	Use integer values to define one-based shape coordinates. If you enter noninteger values, the block rounds them to the nearest integer.	• Double-precision floating point (only supported if the input to the I or R, G, and B ports is floating point) • Single-precision floating point (only supported if the input to the I or R, G, and B ports is floating point) • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
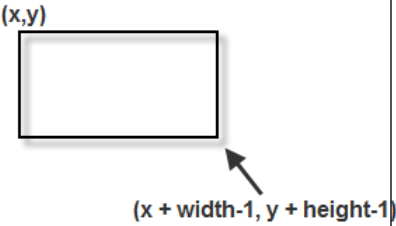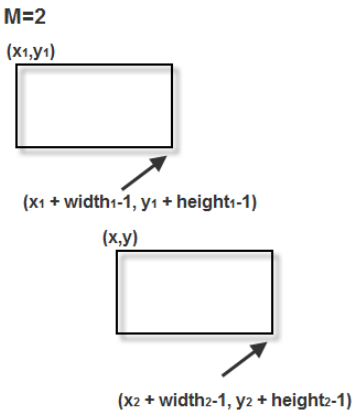
Port	Input/Output	Supported Data Types	Complex Values Supported
ROI	*4*-element vector of integers [x y width height], that define a rectangular area in which to draw the shapes. The first two elements represent the one-based coordinates of the upper-left corner of the area. The second two elements represent the width and height of the area.	• Double-precision floating point • Single-precision floating point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Clr	This port can be used to dynamically specify shape color. *P*-element vector or an *M*-by-*P* matrix, where *M* is the number of shapes, and *P*, the number of color planes. You can specify a color (RGB), for each shape, or specify one color for all shapes.	Same as Image port	No
Output	Scalar, vector, or matrix of pixel values that contain the shape(s)	Same as Image port	No

Drawing Shapes and Lines
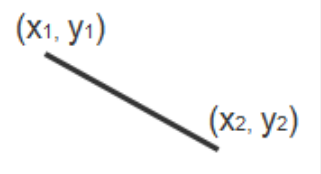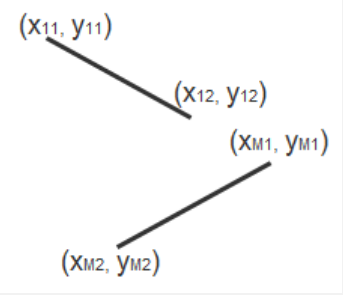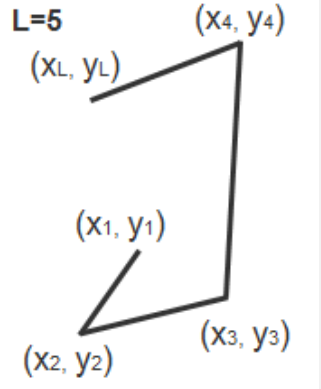
Use the **Shape** parameter and **Pts** port to draw the following shapes or lines:
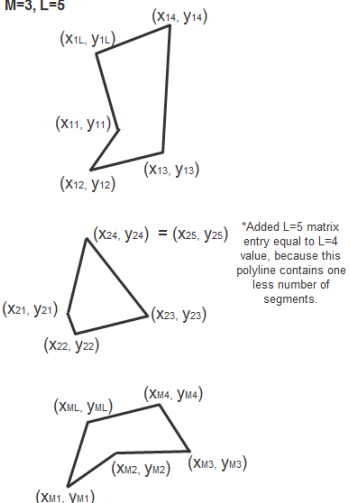
- "Drawing Rectangles" on page 1-246
- "Drawing Lines and Polylines" on page 1-247
- "Drawing Polygons" on page 1-249
- "Drawing Circles" on page 1-251

The Draw Shapes block lets you draw one or more rectangles. Set the **Shape** parameter to Rectangles, and then follow the instructions in the table to specify the input to the Pts port to obtain the desired number of rectangles.

Shape	Input to the Pts Port	Drawn Shape
Single Rectangle	Four-element row vector `[x y width height]` where • `x` and `y` are the one-based coordinates of the upper-left corner of the rectangle. • `width` and `height` are the width, in pixels, and height, in pixels, of the rectangle. The values of `width` and `height` must be greater than 0.	
M Rectangles	M-by-4 matrix $$\begin{bmatrix} x_1 & y_1 & width_1 & height_1 \\ x_2 & y_2 & width_2 & height_2 \\ \vdots & \vdots & \vdots & \vdots \\ x_M & y_M & width_M & height_M \end{bmatrix}$$ where each row of the matrix corresponds to a different rectangle and is of the same form as the vector for a single rectangle.	

The Draw Shapes block lets you draw either a single line, or one or more polylines. You can draw a polyline with a series of connected line segments. Set the **Shape** parameter to `Lines`, and then follow the instructions in the table to specify the input to the Pts port to obtain the desired shape.
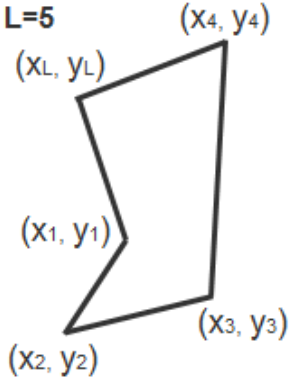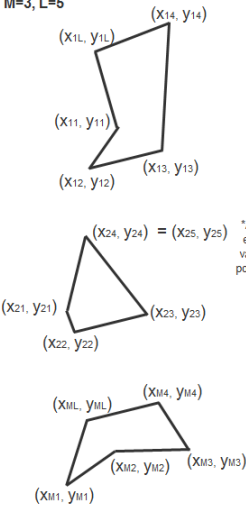
Shape	Input to the Pts Port	Drawn Shape
Single Line	Four-element row vector $[x_1 \ y_1 \ x_2 \ y_2]$ where • x_1 and y_1 are the coordinates of the beginning of the line. • x_2 and y_2 are the coordinates of the end of the line.	(x_1, y_1) (x_2, y_2)
M Lines	M-by-4 matrix $$\begin{bmatrix} x_{11} & y_{11} & x_{12} & y_{12} \\ x_{21} & y_{21} & x_{22} & y_{22} \\ \vdots & \vdots & \vdots & \vdots \\ x_{M1} & y_{M1} & x_{M2} & y_{M2} \end{bmatrix}$$ where each row of the matrix corresponds to a different line and is of the same form as the vector for a single line.	(x_{11}, y_{11}) (x_{12}, y_{12}) (x_{M1}, y_{M1}) (x_{M2}, y_{M2})
Single Polyline with $(L-1)$ Segments	Vector of size $2L$, where L is the number of vertices, with format, $[x_1, \ y_1, \ x_2, \ y_2, \ \ldots, \ x_L, \ y_L]$. • x_1 and y_1 are the coordinates of the beginning of the first line segment. • x_2 and y_2 are the coordinates of the end of the first line segment and the beginning of the second line segment. • x_L and y_L are the coordinates of the end of the $(L-1)^{th}$ line segment. The polyline always contains $(L-1)$ number of segments because the first and last vertex points do not connect. The block produces an error message when the number of rows is less than two or not a multiple of two.	**L=5** (x_4, y_4) (x_L, y_L) (x_1, y_1) (x_3, y_3) (x_2, y_2)

Shape	Input to the Pts Port	Drawn Shape
M Polylines with $(L\text{-}1)$ Segments	M-by-$2L$ matrix where each row of the matrix corresponds to a different polyline and is of the same form as the vector for a single polyline. When you require one polyline to contain less than $(L\text{–}1)$ number of segments, fill the matrix by repeating the coordinates of the last vertex. The block produces an error message if the number of rows is less than two or not a multiple of two.	

If you select the **Use antialiasing** check box, the block applies an edge smoothing algorithm.
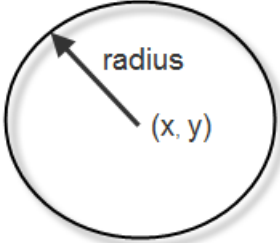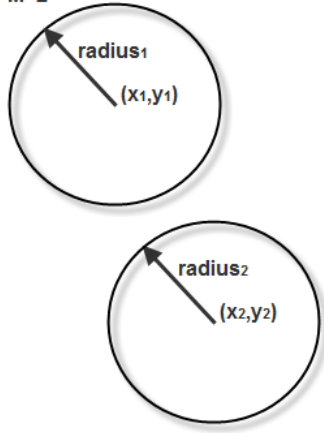
For an example of how to use the Draw Shapes block to draw a line, see "Detect Lines in Images".

The Draw Shapes block lets you draw one or more polygons. Set the **Shape** parameter to `Polygons`, and then follow the instructions in the table to specify the input to the Pts port to obtain the desired number of polygons.

Shape	Input to the Pts Port	Drawn Shape
Single Polygon with L line segments	Row vector of size $2L$, where L is the number of vertices, with format, $[x_1 \ y_1 \ x_2 \ y_2 \ \dots \ x_L \ y_L]$ where • x_1 and y_1 are the coordinates of the beginning of the first line segment. • x_2 and y_2 are the coordinates of the end of the first line segment and the beginning of the second line segment. • x_L and y_L are the coordinates of the end of the $(L\text{-}1)^{\text{th}}$ line segment and the beginning of the Lth line segment. The block connects $[x_1 \ y_1]$ to $[x_L \ y_L]$ to complete the polygon. The block produces an error if the number of rows is negative or not a multiple of two.	
M Polygons with the largest number of line segments in any line being L	M-by-$2L$ matrix where each row of the matrix corresponds to a different polygon and is of the same form as the vector for a single polygon. If some polygons are shorter than others, repeat the ending coordinates to fill the polygon matrix. The block produces an error message if the number of rows is less than two or is not a multiple of two.	

The Draw Shapes block lets you draw one or more circles. Set the **Shape** parameter to `Circles`, and then follow the instructions in the table to specify the input to the Pts port to obtain the desired number of circles.

Shape	Input to the Pts Port	Drawn Shape
Single Circle	Three-element row vector `[x y radius]` where • `x` and `y` are coordinates for the center of the circle. • `radius` is the radius of the circle, which must be greater than 0.	
M Circles	*M-by-3* matrix $$\begin{bmatrix} x_1 & y_1 & radius_1 \\ x_2 & y_2 & radius_2 \\ \vdots & \vdots & \vdots \\ x_M & y_M & radius_M \end{bmatrix}$$ where each row of the matrix corresponds to a different circle and is of the same form as the vector for a single circle.	

Parameters

Shape

Specify the type of shape(s) to draw. Your choices are `Rectangles`, `Lines`, `Polygons`, or `Circles`.

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The block performs a smoothing algorithm when you select the **Use antialiasing** check box with either `Lines`, `Polygons`, or `Circles`. The block uses an algorithm similar to the `poly2mask` function to determine which subpixels to draw.

Fill shapes

Fill the shape with an intensity value or a color.

When you select this check box, the **Fill color source**, **Fill color** and **Opacity factor (between 0 and 1)** parameters appear in the dialog box.

Note If you are generating code and you select the **Fill shapes** check box, the word length of the block input(s) cannot exceed 16 bits.

When you do not select the **Fill shapes** check box, the **Border color source**, and **Border color** parameters are available.

Fill color source

Specify source for fill color value to either `Specify via dialog` or `Input port`. This parameter appears when you select the **Fill shapes** check box. When you select `Input port`, the color input port **clr** appears on the block.

Fill color

Specify the fill color for shape. You can specify either `Black`, `White`, or `User-specified value`. When you select `User-specified value`, the **Color value(s)** parameter appears in the dialog box. This parameter is visible if you select the **Fill shapes** check box.

Border color source

Specify source for the border color value to either `Specify via dialog` or `Input port`. Border color options are visible when the fill shapes options are not selected. **Border color source** appears when you select the **Fill shapes** check box. When you select `Input port`, the color input port **clr** appears on the block.

Border color

Specify the appearance of the shape's border. You can specify either `Black`, `White`, or `User-specified value`. If you select `User-specified value`, the **Color value(s)** parameter appears in the dialog box. This parameter appears when you clear the **Fill shapes** check box.

Color value(s)

Specify an intensity or color value for the shape's border or fill. This parameter applies when you set the **Border color** or **Fill color** parameter to `User-specified value`. This parameter is tunable.

The following table describes what to enter for the color value based on the block input and the number of shapes you are drawing.

Block Input	Color Value(s) for Drawing One Shape or Multiple Shapes with the Same Color	Color Value(s) for Drawing Multiple Shapes with Unique Color
Intensity image	Scalar intensity value	*R*-element vector where *R* is the number of shapes
Color image	*P*-element vector where *P* is the number of color planes	*R*-by-*P* matrix where *P* is the number of color planes and *R* is the number of shapes

For each value in the **Color Value(s)** parameter, enter a number between the minimum and maximum values that can be represented by the data type of the input image. If you enter a value outside this range, the block produces an error message.

Opacity factor (between 0 and 1)

Specify the opacity of the shading inside the shape, where 0 is transparent and 1 is opaque. This parameter is visible if you select the **Fill shapes** check box.

The following table describes what to enter for this parameter based on the block input and the number of shapes you are drawing. This parameter applies when you select the `Filled` check box.

Opacity Factor value for Drawing One Shape or Multiple Shapes with the Same Color	Opacity Factor value for Drawing Multiple Shapes with Unique Color
Scalar intensity value	*R*-element vector where *R* is the number of shapes

Draw shapes in

Specify the type of area in which to draw shapes. You can define one of the following:

- `Entire image`, enables you to draw shapes in the entire image.
- `Specify region of interest via port`. When you select this option, the ROI port appears on the block. Enter a four-element vector of integer values, `[x y width height]`, where `[x y]` are the coordinates of the upper-left corner of the area.

> **Note** If you specify values that are outside the image, the block sets the values to the image boundaries.

Use antialiasing

Perform a smoothing algorithm on the line, polygon, or circle. This parameter is visible if, for the **Shape** parameter, you select `Lines`, `Polygons`, or `Circles`.

Image signal

Specify how to input and output a color video signal. Select one of the following:

- `One multidimensional signal`, the block accepts an M-by-N-by-P color video signal, where P is the number of color planes, at one port.
- `Separate color signals`, additional ports appear on the block. Each port accepts one M-by-N plane of an RGB video stream.

See Also

Draw Markers	Computer Vision System Toolbox software
Insert Text	Computer Vision System Toolbox software

Introduced before R2006a

Edge Detection

Find edges of objects in images using Sobel, Prewitt, Roberts, or Canny method

```
>I    Sobel  Edge >

Edge Detection
```

Library

Analysis & Enhancement

`visionanalysis`

Description

If, for the **Method** parameter, you select `Sobel`, `Prewitt`, or `Roberts`, the Edge Detection block finds the edges in an input image by approximating the gradient magnitude of the image. The block convolves the input matrix with the Sobel, Prewitt, or Roberts kernel. The block outputs two gradient components of the image, which are the result of this convolution operation. Alternatively, the block can perform a thresholding operation on the gradient magnitudes and output a binary image, which is a matrix of Boolean values. If a pixel value is 1, it is an edge.

If, for the **Method** parameter, you select `Canny`, the Edge Detection block finds edges by looking for the local maxima of the gradient of the input image. It calculates the gradient using the derivative of the Gaussian filter. The Canny method uses two thresholds to detect strong and weak edges. It includes the weak edges in the output only if they are connected to strong edges. As a result, the method is more robust to noise, and more likely to detect true weak edges.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point (not supported for the Canny method) • 8-, 16-, 32-bit signed integer (not supported for the Canny method) • 8-, 16-, 32-bit unsigned integer (not supported for the Canny method)	No
Th	Matrix of intensity values	Same as I port	No
Edge	Matrix that represents a binary image	Boolean	No
Gv	Matrix of gradient responses to the vertical edges	Same as I port	No
Gh	Matrix of gradient responses to the horizontal edges	Same as I port	No
G45	Matrix of gradient responses to edges at 45 degrees	Same as I port	No
G135	Matrix of gradient responses to edges at 135 degrees	Same as I port	No

The output of the Gv, Gh, G45, and G135 ports is the same data type as the input to the I port. The input to the Th port must be the same data type as the input to the I port.

Use the **Method** parameter to specify which algorithm to use to find edges. You can select `Sobel`, `Prewitt`, `Roberts`, or `Canny` to find edges using the Sobel, Prewitt, Roberts, or Canny method.

Sobel, Prewitt, and Roberts Methods

Use the **Output type** parameter to select the format of the output. If you select `Binary image`, the block outputs a Boolean matrix at the Edge port. The nonzero elements of this matrix correspond to the edge pixels and the zero elements correspond to the background pixels. If you select `Gradient components` and, for the **Method** parameter, you select `Sobel` or `Prewitt`, the block outputs the gradient components that correspond to the horizontal and vertical edge responses at the Gh and Gv ports, respectively. If you select `Gradient components` and, for the **Method** parameter, you select `Roberts`, the block outputs the gradient components that correspond to the 45 and 135 degree edge responses at the G45 and G135 ports, respectively. If you select `Binary image and gradient components`, the block outputs both the binary image and the gradient components of the image.

Select the **User-defined threshold** check box to define a threshold values or values. If you clear this check box, the block computes the threshold for you.

Use the **Threshold source** parameter to specify how to enter your threshold value. If you select `Specify via dialog`, the **Threshold** parameter appears in the dialog box. Enter a threshold value that is within the range of your input data. If you choose `Input port`, use input port Th to specify a threshold value. This value must have the same data type as the input data. Gradient magnitudes above the threshold value correspond to edges.

The Edge Detection block computes the automatic threshold using the mean of the gradient magnitude squared image. However, you can adjust this threshold using the **Threshold scale factor (used to automatically calculate threshold value)** parameter. The block multiplies the value you enter with the automatic threshold value to determine a new threshold value.

Select the **Edge thinning** check box to reduce the thickness of the edges in your output image. This option requires additional processing time and memory resources.

Note This block is most efficient in terms of memory usage and processing time when you clear the **Edge thinning** check box and use the **Threshold** parameter to specify a threshold value.

Canny Method

Select the **User-defined threshold** check box to define the low and high threshold values. If you clear this check box, the block computes the threshold values for you.

Use the **Threshold source** parameter to specify how to enter your threshold values. If you select `Specify via dialog`, the **Threshold [low high]** parameter appears in the dialog box. Enter the threshold values. If a pixel's magnitude in the gradient image, which is formed by convolving the input image with the derivative of the Gaussian filter, exceeds the high threshold, then the pixel corresponds to a strong edge. Any pixel connected to a strong edge and having a magnitude greater than the low threshold corresponds to a weak edge. If, for the **Threshold source** parameter, you choose `Input port`, use input port Th to specify a two-element vector of threshold values. These values must have the same data type as the input data.

The Edge Detection block computes the automatic threshold values using an approximation of the number of weak and nonedge image pixels. Enter this approximation for the **Approximate percentage of weak edge and nonedge pixels (used to automatically calculate threshold values)** parameter.

Use the **Standard deviation of Gaussian filter** parameter to define the Gaussian filter whose derivative is convolved with the input image.

Fixed-Point Data Types

The following diagram shows the data types used in the Edge Detection block for fixed-point signals.
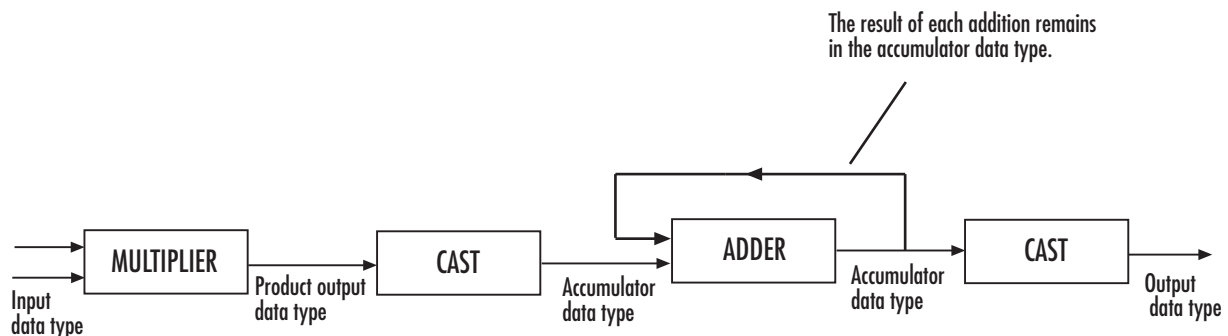
The block squares the threshold and compares it to the sum of the squared gradients to avoid using square roots.

Threshold:
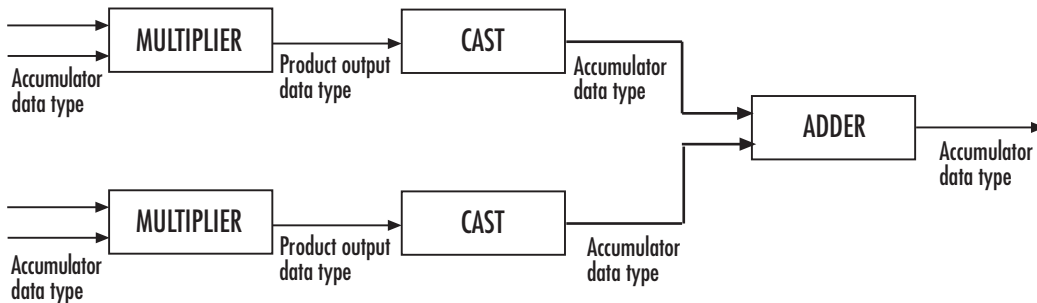
```
              MULTIPLIER                CAST
Input                  Product output          Accumulator
data type              data type               data type
```

Gradients:

```
              MULTIPLIER                CAST
Accumulator            Product output          Accumulator
data type              data type               data type
                                                            ADDER
                                                                    Accumulator
                                                                    data type
              MULTIPLIER                CAST
Accumulator            Product output          Accumulator
data type              data type               data type
```

You can set the product output and accumulator data types in the block mask as discussed in the next section.

Parameters

Method

Select the method by which to perform edge detection. Your choices are `Sobel`, `Prewitt`, `Roberts`, or `Canny`.

Output type

Select the desired form of the output. If you select `Binary image`, the block outputs a matrix that is filled with ones, which correspond to edges, and zeros, which correspond to the background. If you select `Gradient components` and, for the **Method** parameter, you select `Sobel` or `Prewitt`, the block outputs the gradient components that correspond to the horizontal and vertical edge responses. If you select `Gradient components` and, for the **Method** parameter, you select `Roberts`, the block outputs the gradient components that correspond to the 45 and 135 degree

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edge responses. If you select `Binary image and gradient components`, the block outputs both the binary image and the gradient components of the image. This parameter is visible if, for the **Method** parameter, you select `Sobel`, `Prewitt`, or `Roberts`.

User-defined threshold

If you select this check box, you can enter a desired threshold value. If you clear this check box, the block computes the threshold for you. This parameter is visible if, for the **Method** parameter, you select `Sobel`, `Prewitt`, or `Roberts`, and, for the **Output type** parameter, you select `Binary image` or `Binary image and gradient components`. This parameter is also visible if, for the **Method** parameter, you select `Canny`.

Threshold source

If you select `Specify via dialog`, enter your threshold value in the dialog box. If you choose `Input port`, use the Th input port to specify a threshold value that is the same data type as the input data. This parameter is visible if you select the **User-defined threshold** check box.

Threshold

Enter a threshold value that is within the range of your input data. This parameter is visible if, for the **Method** parameter, you select `Sobel`, `Prewitt`, or `Roberts`, you select the **User-defined threshold** check box, and, for **Threshold source** parameter, you select `Specify via dialog.`.

Threshold [low high]

Enter the low and high threshold values that define the weak and strong edges. This parameter is visible if, for the **Method** parameter, you select `Canny`. Then you select the **User-defined threshold** check box, and, for **Threshold source** parameter, you select `Specify via dialog`. Tunable.

Threshold scale factor (used to automatically calculate threshold value)

Enter a multiplier that is used to adjust the calculation of the automatic threshold. This parameter is visible if, for the **Method** parameter, you select `Sobel`, `Prewitt`, or `Roberts`, and you clear the **User-defined threshold** check box. Tunable.

Edge thinning

Select this check box if you want the block to perform edge thinning. This option requires additional processing time and memory resources. This parameter is visible if, for the **Method** parameter, you select `Sobel`, `Prewitt`, or `Roberts`, and for the **Output type** parameter, you select `Binary image` or `Binary image and gradient components`.

Approximate percentage of weak edge and nonedge pixels (used to automatically calculate threshold values)

Enter the approximate percentage of weak edge and nonedge image pixels. The block computes the automatic threshold values using this approximation. This parameter is visible if, for the **Method** parameter, you select `Canny`. Tunable.

Standard deviation of Gaussian filter

Enter the standard deviation of the Gaussian filter whose derivative is convolved with the input image. This parameter is visible if, for the **Method** parameter, you select `Canny`.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.
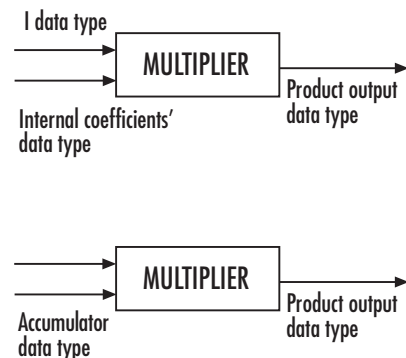
Product output

Here, the internal coefficients are the Sobel, Prewitt, or Roberts masks. As depicted in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths.

- When you select `Same as first input`, these characteristics match those of the first input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Accumulator

The result of each addition remains in the accumulator data type.

CAST

Input to adder - product output data type

Accumulator data type

ADDER

Accumulator data type

As depicted in the previous figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths.

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Gradients

Choose how to specify the word length and fraction length of the outputs of the Gv and Gh ports. This parameter is visible if, for the **Output type** parameter, you choose `Gradient components` or `Binary image and gradient components`:

- When you select `Same as accumulator`, these characteristics match those of the accumulator.

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Gonzales, Rafael C. and Richard E. Woods. *Digital Image Processing. 2nd ed*. Englewood Cliffs, NJ: Prentice-Hall, 2002.

[2] Pratt, William K. *Digital Image Processing, 2nd ed*. New York: John Wiley & Sons, 1991.

See Also

| edge | Image Processing Toolbox |

Introduced before R2006a

Erosion

Find local minima in binary or intensity images
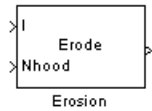
Library

Morphological Operations

`visionmorphops`

Description

The Erosion block slides the neighborhood or structuring element over an image, finds the local minima, and creates the output matrix from these minimum values. If the neighborhood or structuring element has a center element, the block places the minima there, as illustrated in the following figure.
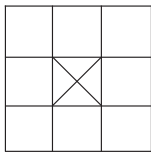
If the neighborhood or structuring element does not have an exact center, the block has a bias toward the upper-left corner and places the minima there, as illustrated in the following figure.

This block uses flat structuring elements only.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Nhood	Matrix or vector of 1s and 0s that represents the neighborhood values	Boolean	No
Output	Vector or matrix of intensity values that represents the eroded image	Same as I port	No

The output signal is the same data type as the input to the I port.

Use the **Neighborhood or structuring element source** parameter to specify how to enter your neighborhood or structuring element values. If you select `Specify via dialog`, the **Neighborhood or structuring element** parameter appears in the dialog box. If you select `Input port`, the Nhood port appears on the block. Use this port to enter your neighborhood values as a matrix or vector of 1s and 0s. You can only specify a structuring element using the dialog box.

Use the **Neighborhood or structuring element** parameter to define the neighborhood or structuring element that the block applies to the image. Specify a neighborhood by entering a matrix or vector of 1s and 0s. Specify a structuring element with the `strel` function from the Image Processing Toolbox. If the structuring element is decomposable into smaller elements, the block executes at higher speeds due to the use of a more efficient algorithm. If you enter an array of STREL objects, the block applies each object to the entire matrix in turn.

Parameters

Neighborhood or structuring element source

Specify how to enter your neighborhood or structuring element values. Select `Specify via dialog` to enter the values in the dialog box. Select `Input port` to use the Nhood port to specify the neighborhood values. You can only specify a structuring element using the dialog box.

Neighborhood or structuring element

If you are specifying a neighborhood, this parameter must be a matrix or vector of 1s and 0s. If you are specifying a structuring element, use the `strel` function from the Image Processing Toolbox. This parameter is visible if, for the **Neighborhood or structuring element source** parameter, you select `Specify via dialog`.

References

[1] Soille, Pierre. *Morphological Image Analysis. 2nd ed*. New York: Springer, 2003.

See Also

Bottom-hat	Computer Vision System Toolbox software
Closing	Computer Vision System Toolbox software
Dilation	Computer Vision System Toolbox software
Label	Computer Vision System Toolbox software
Opening	Computer Vision System Toolbox software
Top-hat	Computer Vision System Toolbox software
imerode	Image Processing Toolbox software
strel	Image Processing Toolbox software

Introduced before R2006a

Estimate Geometric Transformation

Estimate geometric transformation from matching point pairs
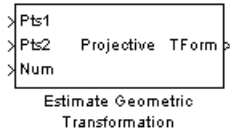
Library

Geometric Transformations

visiongeotforms

Description

Use the Estimate Geometric Transformation block to find the transformation matrix which maps the greatest number of point pairs between two images. A *point pair* refers to a point in the input image and its related point on the image created using the transformation matrix. You can select to use the RANdom SAmple Consensus (RANSAC) or the Least Median Squares algorithm to exclude outliers and to calculate the transformation matrix. You can also use all input points to calculate the transformation matrix.

Port	Input/Output	Supported Data Types	Complex Values Supported
Pts1/Pts2	*M*-by-2 Matrix of one-based [x y] point coordinates, where *M* represents the number of points.	• Double • Single • 8, 16, 32-bit signed integer • 8, 16, 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Num	Scalar value that represents the number of valid points in **Pts1** and **Pts 2**.	• 8, 16, 32-bit signed integer • 8, 16, 32-bit unsigned integer	No
TForm	3-by-2 or 3-by-3 transformation matrix.	• Double • Single	No
Inlier	*M*-by-1 vector indicating which points have been used to calculate `TForm`.	Boolean	No

Ports `Pts1` and `Pts2` are the points on two images that have the same data type. The block outputs the same data type for the transformation matrix

When `Pts1` and `Pts2` are single or double, the output transformation matrix will also have single or double data type. When `Pts1` and `Pts2` images are built-in integers, the option is available to set the transformation matrix data type to either `Single` or `Double`. The `TForm` output provides the transformation matrix. The `Inlier` output port provides the Inlier points on which the transformation matrix is based. This output appears when you select the **Output Boolean signal indicating which point pairs are inliers** checkbox.

RANSAC and Least Median Squares Algorithms

The *RANSAC* algorithm relies on a distance threshold. A pair of points, p_i^a (image *a*, Pts1) and p_i^b (image *b*, Pts 2) is an inlier only when the distance between p_i^b and the projection of p_i^a based on the transformation matrix falls within the specified threshold. The distance metric used in the RANSAC algorithm is as follows:

$$d = \sum_{i=1}^{Num} \min(D(p_i^b, \psi(p_i^a : H)), t)$$

The Least Median Squares algorithm assumes at least 50% of the point pairs can be mapped by a transformation matrix. The algorithm does not need to explicitly specify the distance threshold. Instead, it uses the median distance between all input point pairs. The distance metric used in the Least Median of Squares algorithm is as follows:

$$d = median(D(p_1^b, \psi(p_1^a : H)), D(p_2^b, \psi(p_2^a : H)), ..., D(p_{Num}^b, \psi(p_N^a : H)))$$

For both equations:

p_i^a is a point in image a (`Pts1`)

p_i^b is a point in image b (`Pts2`)

$\psi(p_i^a : H)$ is the projection of a point on image a based on transformation matrix H

$D(p_i^b, p_j^b)$ is the distance between two point pairs on image b

t is the threshold

Num is the number of points

The smaller the distance metric, the better the transformation matrix and therefore the more accurate the projection image.

Transformations

The Estimate Geometric Transformation block supports `Nonreflective similarity`, `affine`, and `projective` transformation types, which are described in this section.

Nonreflective similarity transformation supports translation, rotation, and isotropic scaling. It has four degrees of freedom and requires two pairs of points.
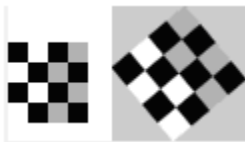
The transformation matrix is:
$$H = \begin{bmatrix} h_1 & -h_2 \\ h_2 & h_1 \\ h_3 & h_4 \end{bmatrix}$$

The projection of a point $\begin{bmatrix} x & y \end{bmatrix}$ by H is: $\begin{bmatrix} \hat{x} & \hat{y} \end{bmatrix} = \begin{bmatrix} x & y & 1 \end{bmatrix} H$

affine transformation supports nonisotropic scaling in addition to all transformations that the nonreflective similarity transformation supports. It has six degrees of freedom that can be determined from three pairs of noncollinear points.

The transformation matrix is: $H = \begin{bmatrix} h_1 & h_4 \\ h_2 & h_5 \\ h_3 & h_6 \end{bmatrix}$

The projection of a point $\begin{bmatrix} x & y \end{bmatrix}$ by H is: $\begin{bmatrix} \hat{x} & \hat{y} \end{bmatrix} = \begin{bmatrix} x & y & 1 \end{bmatrix} H$

Projective transformation supports tilting in addition to all transformations that the affine transformation supports.

The transformation matrix is : $h = \begin{bmatrix} h_1 & h_4 & h_7 \\ h_2 & h_5 & h_8 \\ h_3 & h_6 & h_9 \end{bmatrix}$

The projection of a point $\begin{bmatrix} x & y \end{bmatrix}$ by H is represented by homogeneous coordinates as:

$\begin{bmatrix} \hat{u} & \hat{v} & \hat{w} \end{bmatrix} = \begin{bmatrix} x & y & 1 \end{bmatrix} H$

Distance Measurement

For computational simplicity and efficiency, this block uses algebraic distance. The

algebraic distance for a pair of points, $\begin{bmatrix} x^a & y^a \end{bmatrix}^T$ on image a, and $\begin{bmatrix} x^b & y^b \end{bmatrix}$ on image b, according to transformation H, is defined as follows;

For projective transformation:

$$D(p_i^b, \psi(p_i^a : H)) = ((u^a - w^a x^b)^2 + (v^a - w^a y^b)^2)^{\frac{1}{2}}, \text{ where } \begin{bmatrix} \hat{u}^a & \hat{v}^a & \hat{w}^a \end{bmatrix} = \begin{bmatrix} x^a & y^a & 1 \end{bmatrix} H$$

For Nonreflective similarity or affine transformation:

$$D(p_i^b, \psi(p_i^a : H)) = ((x^a - x^b)^2 + (y^a - y^b)^2)^{\frac{1}{2}},$$

where $\begin{bmatrix} \hat{x}^a & \hat{y}^a \end{bmatrix} = \begin{bmatrix} x^a & y^a & 1 \end{bmatrix} H$

The block performs a comparison and repeats it K number of times between successive transformation matrices. If you select the **Find and exclude outliers** option, the RANSAC and Least Median Squares (LMS) algorithms become available. These algorithms calculate and compare a distance metric. The transformation matrix that produces the smaller distance metric becomes the new transformation matrix that the next comparison uses. A final transformation matrix is resolved when either:

- K number of random samplings is performed
- The RANSAC algorithm, when enough number of inlier point pairs can be mapped, (dynamically updating K)

The Estimate Geometric Transformation algorithm follows these steps:

1 A transformation matrix H is initialized to zeros
2 Set `count = 0` (Randomly sampling).
3 While `count < K`, where K is total number of random samplings to perform, perform the following;

   a   Increment the count; `count = count + 1`.

   b   Randomly select pair of points from images *a* and *b*, (2 pairs for Nonreflective similarity, 3 pairs for affine, or 4 pairs for projective).

   c   Calculate a transformation matrix H , from the selected points.

   d   If H has a distance metric less than that of H , then replace H with H .

      (Optional for RANSAC algorithm only)

      i   Update K dynamically.

      ii   Exit out of sampling loop if enough number of point pairs can be mapped by H .

4   Use all point pairs in images *a* and *b* that can be mapped by H to calculate a refined transformation matrix H

5   Iterative Refinement, (Optional for RANSAC and LMS algorithms)

   a   Denote all point pairs that can be mapped by H as inliers.

   b   Use inlier point pairs to calculate a transformation matrix H .

   c   If H has a distance metric less than that of H , then replace H with H , otherwise exit the loop.

Number of Random Samplings

The number of random samplings can be specified by the user for the RANSAC and Least Median Squares algorithms. You can use an additional option with the RANSAC algorithm, which calculates this number based on an accuracy requirement. The **Desired Confidence** level drives the accuracy.

The calculated number of random samplings, *K* used with the RANSAC algorithm, is as follows:

$$K = \frac{\log(1-p)}{\log(1-q^s)}$$

where

- *p* is the probability of independent point pairs belonging to the largest group that can be mapped by the same transformation. The probability is dynamically calculated

based on the number of inliers found versus the total number of points. As the probability increases, the number of samplings, K, decreases.

- q is the probability of finding the largest group that can be mapped by the same transformation.
- s is equal to the value 2, 3, or 4 for Nonreflective similarity, affine, and projective transformation, respectively.

Iterative Refinement of Transformation Matrix

The transformation matrix calculated from all inliers can be used to calculate a refined transformation matrix. The refined transformation matrix is then used to find a new set of inliers. This procedure can be repeated until the transformation matrix cannot be further improved. This iterative refinement is optional.

Parameters

Transformation Type

Specify transformation type, either `Nonreflective similarity`, `affine`, or `projective` transformation. If you select `projective` transformation, you can also specify a scalar algebraic distance threshold for determining inliers. If you select either `affine` or `projective` transformation, you can specify the distance threshold for determining inliers in pixels. See "Transformations" on page 1-269 for a more detailed discussion. The default value is `projective`.

Find and exclude outliers

When selected, the block finds and excludes outliers from the input points and uses only the inlier points to calculate the transformation matrix. When this option is not selected, all input points are used to calculate the transformation matrix.

Method

Select either the `RANdom SAmple Consensus (RANSAC)` or the `Least Median of Squares` algorithm to find outliers. See "RANSAC and Least Median Squares Algorithms" on page 1-268 for a more detailed discussion. This parameter appears when you select the **Find and exclude outliers** check box.

Algebraic distance threshold for determining inliers

Specify a scalar threshold value for determining inliers. The threshold controls the upper limit used to find the algebraic distance in the RANSAC algorithm. This parameter appears when you set the **Method** parameter to `Random Sample`

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Consensus (RANSAC) and the **Transformation type** parameter to `projective`. The default value is `1.5`.

Distance threshold for determining inliers (in pixels)

Specify the upper limit distance a point can differ from the projection location of its associating point. This parameter appears when you set the **Method** parameter to `Random Sample Consensus (RANSAC)` and you set the value of the **Transformation type** parameter to `Nonreflective similarity` or `affine`. The default value is `1.5`.

Determine number of random samplings using

Select `Specified value` to enter a positive integer value for number of random samplings, or select `Desired confidence` to set the number of random samplings as a percentage and a maximum number. This parameter appears when you select `Find and exclude outliers parameter`, and you set the value of the **Method** parameter to `Random Sample Consensus (RANSAC)`.

Number of random samplings

Specify the number of random samplings for the algorithm to perform. This parameter appears when you set the value of the **Determine number of random samplings using** parameter to `Specified value`.

Desired confidence (in %)

Specify a percent by entering a number between `0` and `100`. The `Desired confidence` value represents the probability of the algorithm to find the largest group of points that can be mapped by a transformation matrix. This parameter appears when you set the **Determine number of random samplings using** parameter to `Desired confidence`.

Maximum number of random samplings

Specify an integer number for the maximum number of random samplings. This parameter appears when you set the **Method** parameter to `Random Sample Consensus (RANSAC)` and you set the value of the **Determine number of random samplings using** parameter to `Desired confidence`.

Stop sampling earlier when a specified percentage of point pairs are determined to be inlier

Specify to stop random sampling when a percentage of input points have been found as inliers. This parameter appears when you set the **Method** parameter to `Random Sample Consensus (RANSAC)`.

Perform additional iterative refinement of the transformation matrix

Specify whether to perform refinement on the transformation matrix. This parameter appears when you select **Find and exclude outliers** check box.

Output Boolean signal indicating which point pairs are inliers

Select this option to output the inlier point pairs that were used to calculate the transformation matrix. This parameter appears when you select **Find and exclude outliers** check box. The block will not use this parameter with signed or double, data type points.

When Pts1 and Pts2 are built-in integers, set transformation matrix date type to

Specify transformation matrix data type as `Single` or `Double` when the input points are built-in integers. The block will not use this parameter with signed or double, data type points.

Examples

Calculate transformation matrix from largest group of point pairs

Examples of input data and application of the Estimate Geometric Transformation block appear in the following figures. Figures (a) and (b) show the point pairs. The points are denoted by stars or circles, and the numbers following them show how they are paired. Some point pairs can be mapped by the same transformation matrix. Other point pairs require a different transformation matrix. One matrix exists that maps the largest number of point pairs, the block calculates and returns this matrix. The block finds the point pairs in the largest group and uses them to calculate the transformation matrix. The point pairs connected by the magenta lines are the largest group.

The transformation matrix can then be used to stitch the images as shown in Figure (e).
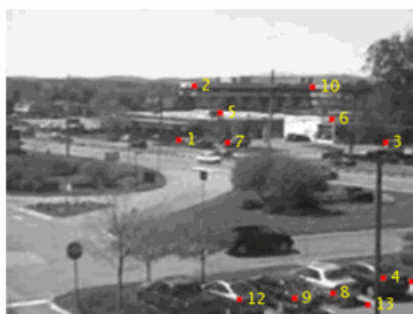
(a)

(b)
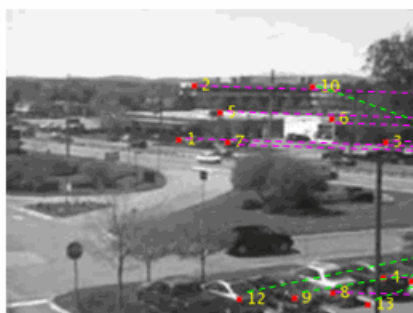
(c)
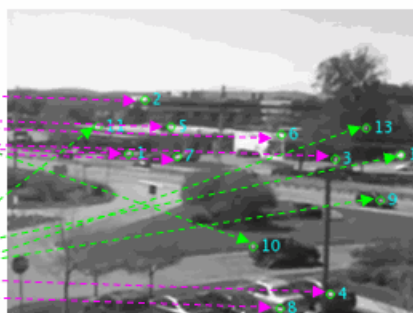
(d)

(e)

Video Mosaicking

To see an example of the Estimate Geometric Transformation block used in a model with other blocks, see the "Video Mosaicking" example.

Troubleshooting

The success of estimating the correct geometric transformation depends heavily on the quality of the input point pairs. If you chose the RANSAC or LMS algorithm, the block will randomly select point pairs to compute the transformation matrix and will use the transformation that best fits the input points. There is a chance that all of the randomly selected point pairs may contain outliers despite repeated samplings. In this case, the output transformation matrix, TForm, is invalid, indicated by a matrix of zeros.

To improve your results, try the following:
Increase the percentage of inliers in the input points.
Increase the number for random samplings.
For the RANSAC method, increase the desired confidence.
For the LMS method, make sure the input points have 50% or more inliers.
Use features appropriate for the image contents
Be aware that repeated patterns, for example, windows in office building, will cause false matches when you match the features. This increases the number of outliers.
Do not use this function if the images have significant parallax. You can use the estimateFundamentalMatrix function instead.
Choose the minimum transformation for your problem.
If a projective transformation produces the error message, "A portion of the input image was transformed to the location at infinity. Only transformation matrices that do not transform any part of the image to infinity are supported.", it is usually caused by a transformation matrix and an image that would result in an output distortion that does not fit physical reality. If the matrix was an output of the Estimate Geometric Transformation block, then most likely it could not find enough inliers.

References

R. Hartley and A. Ziserman, "Multiple View Geometry in Computer Vision," Second edition, Cambridge University Press, 2003

See Also

cp2tform	Image Processing Toolbox
vipmosaicking	Computer Vision System Toolbox

Introduced in R2008a

Find Local Maxima

Find local maxima in matrices
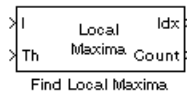
Library

Statistics

`visionstatistics`

Description

The Find Local Maxima block finds the local maxima within an input matrix. It does so by comparing the maximum value in the matrix to a user-specified threshold. The block considers a value to be a valid local maximum when the maximum value is greater than or equal to the specified threshold. The determination of the local maxima is based on the neighborhood, an area around and including the maximum value. After finding the local maxima, the block sets all the matrix values in the neighborhood, including the maximum value, to `0`. This step ensures that subsequent searches do not include this maximum. The size of the neighborhood must be appropriate for the data set. That is, the threshold must eliminate enough of the values around the maximum so that false peaks are not discovered. The process repeats until the block either finds all valid maximas or the number of local maximas equal the **Maximum number of local maxima** value. The block outputs one-based [x y] coordinates of the maxima. The data to all input ports must be the same data type.

If the input to this block is a Hough matrix output from the Hough Transform block, select the **Input is Hough matrix spanning full theta range** check box. If you select this check box, the block assumes that the Hough port input is antisymmetric about the rho axis and theta ranges from -pi/2 to pi/2 radians. If the block finds a local maxima near the boundary, and the neighborhood lies outside the Hough matrix, then the block detects only one local maximum. It ignores the corresponding antisymmetric maximum.

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Parameters

Maximum number of local maxima

Specify the maximum number of maxima you want the block to find.

Neighborhood size

Specify the size of the neighborhood around the maxima over which the block zeros out the values. Enter a two-element vector of positive odd integers, [*rc*]. Here, *r* represents the number of rows in the neighborhood, and *c* represents the number of columns.

Source of threshold value

Specify how to enter the threshold value. If you select `Input port`, the **Th** port appears on the block. If you select `Specify via dialog`, the **Threshold** parameter appears in the dialog box. Enter a scalar value that represents the value all maxima should meet or exceed.

Threshold

Enter a scalar value that represents the value all maxima should meet or exceed. This parameter is visible if, for the **Source of threshold value** parameter, you choose `Specify via dialog`.

Input is Hough matrix spanning full theta range

If you select this check box, the block assumes that the Hough port input is antisymmetric about the rho axis and theta ranges from -pi/2 to pi/2 radians.

Index output data type

Specify the data type of the **Idx** port output. Your choices are `double`, `single`, `uint8`, `uint16`, or `uint32`.

Output variable size signal

Specify output data type. When you uncheck the **Output variable size signal**, the **Count output data type** parameter appears in the dialog box.

Count output data types

Specify the data type of the Count port output. Your choices are `double`, `single`, `uint8`, `uint16`, or `uint32`. This parameter applies when you clear the **Output variable size signal** check box.

Examples

See "Detect Lines in Images" in the *Computer Vision System Toolbox User's Guide*.

Supported Data Types

The block outputs the one-based [x y] coordinates of the maxima at the **Idx** port and the number of valid local maxima found at the **Count** port.

Port	Input/Output	Supported Data Types	Complex Values Supported
I/Hough	Matrix in which you want to find the maxima.	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Th	Scalar value that represents the value the maxima should meet or exceed.	Same as I/Hough port	No
Idx	An *M*-by-2 matrix of one-based [x y] coordinates, where *M* represents the number of local maximas found.	• Double-precision floating point • Single-precision floating point • 8-, 16-, and 32-bit unsigned integer	No
Count	Scalar value that represents the number of maxima that meet or exceed the threshold value.	Same as Idx port	No

See Also

Hough Lines	Computer Vision System Toolbox

Corner Detection	Computer Vision System Toolbox
houghpeaks	Image Processing Toolbox
hough	Image Processing Toolbox

Introduced before R2006a

Frame Rate Display

Calculate average update rate of input signal
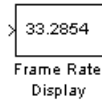
Library

Sinks

`visionsinks`

Description

The Frame Rate Display block calculates and displays the average update rate of the input signal. This rate is in relation to the wall clock time. For example, if the block displays 30, the model is updating the input signal 30 times every second. You can use this block to check the video frame rate of your simulation. During code generation, Simulink Coder does not generate code for this block.

Note This block supports intensity and color images on its port.

Port	Input	Supported Data Types	Complex Values Supported
Input	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No

Use the **Calculate and display rate every** parameter to control how often the block updates the display. When this parameter is greater than 1, the block displays the average update rate for the specified number of video frames. For example, if you enter 10, the block calculates the amount of time it takes for the model to pass 10 video frames to the block. It divides this time by 10 and displays this average video frame rate on the block.

Note If you do not connect the Frame Rate Display block to a signal line, the block displays the base (fastest) rate of the Simulink model.

Parameters

Calculate and display rate every

Use this parameter to control how often the block updates the display.

See Also

To Multimedia File	Computer Vision System Toolbox software
To Video Display	Computer Vision System Toolbox software
Video To Workspace	Computer Vision System Toolbox software
Video Viewer	Computer Vision System Toolbox software

Introduced before R2006a

From Multimedia File

Read video frames and audio samples from compressed multimedia file
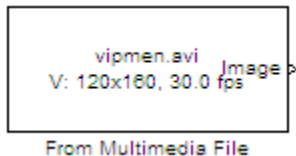
Library

Sources

`visionsources`

Description

The From Multimedia File block reads audio samples, video frames, or both from a multimedia file. The block imports data from the file into a Simulink model.

Note This block supports code generation for the host computer that has file I/O available. You cannot use this block with Simulink Desktop Real-Time™ software because that product does not support file I/O.

The generated code for this block relies on prebuilt library files. You can run this code outside the MATLAB environment, or redeploy it, but be sure to account for these extra library files when doing so. The `packNGo` function creates a single zip file containing all of the pieces required to run or rebuild this code. See `packNGo` for more information.

To run an executable file that was generated from a model containing this block, you may need to add precompiled shared library files to your system path. See "Simulink Coder", "Simulink Shared Library Dependencies", and "Accelerating Simulink Models" for details.

This block allows you to read WMA/WMV streams to disk or across a network connection. Similarly, the To Multimedia File block allows you to write WMA/WMV streams to disk or

across a network connection. If you want to play an MP3/MP4 file in Simulink, but you do not have the codecs, you can re-encode the file as WMA/WMV, which are supported by the Computer Vision System Toolbox.

Supported Platforms and File Types

The supported file formats available to you depend on the codecs installed on your system.

Platform	Supported File Name Extensions
All Platforms	AVI (`.avi`)
Windows®	**Image**: `.jpg`,`.bmp`
	Video: MPEG (`.mpeg`) MPEG-2 (`.mp2`) MPEG-1 `.mpg` MPEG-4, including H.264 encoded video (`.mp4`, `.m4v`) Motion JPEG 2000 (`.mj2`) Windows Media Video (`.wmv`,`.asf`, `.asx`, .asx) and any format supported by Microsoft DirectShow® 9.0 or higher.
	Audio: WAVE (`.wav`) Windows Media Audio File (`.wma`) Audio Interchange File Format (`.aif`, `.aiff`) Compressed Audio Interchange File Format(`.aifc`), MP3 (`.mp3`) Sun Audio (`.au`) Apple (`.snd`)
Macintosh	**Video**: `.avi` Motion JPEG 2000 (`.mj2`) MPEG-4, including H.264 encoded video (`.mp4`, `.m4v`) Apple QuickTime Movie (`.mov`) and any format supported by QuickTime as listed on http://support.apple.com/kb/HT3775.

Platform	Supported File Name Extensions
	Audio: Uncompressed `.avi`
Linux®	Motion JPEG 2000 (.mj2) Any format supported by your installed plug-ins for GStreamer 0.1 or higher, as listed on http://gstreamer.freedesktop.org/documentation/plugins.html, including Ogg Theora (.ogg).

Windows XP and Windows 7 x64 platform ships with a limited set of 64-bit video and audio codecs. If a compressed multimedia file fails to play, try saving the multimedia file to a supported file format listed in the table above.

If you use Windows, use Windows Media player Version 11 or later.

Note MJ2 files with bit depth higher than 8-bits is not supported by `vision.VideoFileReader`. Use `VideoReader` and `VideoWriter` for higher bit depths.

Reading audio from compressed MP4 files with video and audio is not supported by `vision.VideoFileReader`.

Ports

The output ports of the From Multimedia File block change according to the content of the multimedia file. If the file contains only video frames, the **Image**, intensity **I**, or **R**,**G**,**B** ports appear on the block. If the file contains only audio samples, the **Audio** port appears on the block. If the file contains both audio and video, you can select the data to emit. The following table describes available ports.

Port	Description
Image	M-by-N-by-P color video signal where P is the number of color planes.
I	M-by-N matrix of intensity values.
R, **G**, **B**	Matrix that represents one plane of the RGB video stream. Outputs from the R, G, or B ports must have same dimensions.
Audio	Vector of audio data.

Port	Description
Y, Cb, Cr	Matrix that represents one frame of the YCbCr video stream. The Y, Cb, Cr ports produce the following outputs: Y: $M \times N$ Cb: $M \times \dfrac{N}{2}$ Cr: $M \times \dfrac{N}{2}$

Sample Rates

The sample rate that the block uses depends on the audio and video sample rate. While the FMMF block operates at a single rate in Simulink, the underlying audio and video streams can produce different rates. In some cases, when the block outputs both audio and video, makes a small adjustment to the video rate.

Sample Time Calculations Used for Video and Audio Files

$$\text{Sample time} = \frac{ceil(AudioSampleRate \big/ FPS)}{AudioSampleRate}.$$

When audio sample time, $\dfrac{AudioSampleRate}{FPS}$ is noninteger, the equation cannot reduce to $\dfrac{1}{FPS}$.

In this case, to prevent synchronization problems, the block drops the corresponding video frame when the audio stream leads the video stream by more than $\dfrac{1}{FPS}$.

In summary, the block outputs one video frame at each Simulink time step. To calculate the number of audio samples to output at each time step, the block divides the audio sample rate by the video frame rate (fps). If the audio sample rate does not divide evenly by the number of video frames per second, the block rounds the number of audio samples

up to the nearest whole number. If necessary, the block periodically drops a video frame to maintain synchronization for large files.

Parameters

File name

Specify the name of the multimedia file from which to read. The block determines the type of file (audio and video, audio only, or video only) and provides the associated parameters.

If the location of the file does not appear on your MATLAB path, use the **Browse** button to specify the full path. Otherwise, if the location of this file appears on your MATLAB path, enter only the file name. On Windows platforms, this parameter supports URLs that point to MMS (Microsoft Media Server) streams.

Inherit sample time from file

Select the **Inherit sample time from file** check box if you want the block sample time to be the same as the multimedia file. If you clear this check box, enter the block sample time in the **Desired sample time** parameter field. The file that the From Multimedia File block references, determines the block default sample time. You can also set the sample time for this block manually. If you do not know the intended sample rate of the video, let the block inherit the sample rate from the multimedia file.

Desired sample time

Specify the block sample time. This parameter becomes available if you clear the **Inherit sample time from file** check box.

Number of times to play file

Enter a positive integer or `inf` to represent the number of times to play the file.

Output end-of-file indicator

Use this check box to determine whether the output is the last video frame or audio sample in the multimedia file. When you select this check box, a Boolean output port labeled EOF appears on the block. The output from the EOF port defaults to 1 when the last video frame or audio sample is output from the block. Otherwise, the output from the EOF port defaults to 0.

Multimedia outputs

Specify `Video and audio`, `Video only`, or `Audio only` output file type. This parameter becomes available only when a video signal has both audio and video.

Samples per audio channel

Specify number of samples per audio channel. This parameter becomes available for files containing audio.

Output color format

Specify whether you want the block to output `RGB`, `Intensity`, or `YCbCr 4:2:2` video frames. This parameter becomes available only for a signal that contains video. If you select `RGB`, use the **Image signal** parameter to specify how to output a color signal.

Image signal

Specify how to output a color video signal. If you select `One multidimensional signal`, the block outputs an *M*-by-*N*-by-*P* color video signal, where *P* is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port outputs one *M*-by-*N* plane of an RGB video stream. This parameter becomes available only if you set the **Image color space** parameter to RGB and the signal contains video.

Audio output sampling mode

Select **Sample based** or **Frame based** output. This parameter appears when you specify a file containing audio for the **File name** parameter.

Audio output data type

Set the data type of the audio samples output at the Audio port. This parameter becomes available only if the multimedia file contains audio. You can choose `double`, `single`, `int16`, or `uint8` types.

Video output data type

Set the data type of the video frames output at the **R**, **G**, **B**, or **Image** ports. This parameter becomes available only if the multimedia file contains video. You can choose `double`, `single`, `int8`, `uint8`, `int16`, `uint16`, `int32`, `uint32`, or `Inherit from file` types.

Supported Data Types

For source blocks to display video data properly, double- and single-precision floating-point pixel values must be between `0` and `1`. For other data types, the pixel values must be between the minimum and maximum values supported by their data type.

Port	Supported Data Types	Supports Complex Values?
Image	• Double-precision floating point • Single-precision floating point • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers	No
R, G, B	Same as the Image port	No
Audio	• Double-precision floating point • Single-precision floating point • 16-bit signed integers • 8-bit unsigned integers	No
Y, Cb,Cr	Same as the Image port	No

See Also

To Multimedia File	Computer Vision System Toolbox
"Specify Sample Time" (Simulink)	Simulink

Introduced before R2006a

Gamma Correction

Apply or remove gamma correction from images or video streams

Gamma Correction
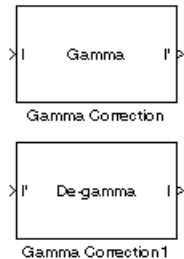
Gamma Correction1

Library

Conversions

`visionconversions`

Description

Use the Gamma Correction block to apply or remove gamma correction from an image or video stream. For input signals normalized between 0 and 1, the block performs gamma correction as defined by the following equations. For integers and fixed-point data types, these equations are generalized by applying scaling and offset values specific to the data type:

$$S_{LS} = \frac{1}{\dfrac{\gamma}{B_P^{(1/\gamma - 1)}} - \gamma B_P + B_P}$$

$$F_S = \frac{\gamma S_{LS}}{B_P^{(1/\gamma - 1)}}$$

$$C_O = F_S B_P^{1/\gamma} - S_{LS} B_P$$

$$I' = \begin{cases} S_{LS} I, & I \leq B_p \\ F_S I^{\frac{1}{\gamma}} - C_O, & I > B_p \end{cases}$$

S_{LS} is the slope of the straight line segment. B_P is the break point of the straight line segment, which corresponds to the **Break point** parameter. F_S is the slope matching factor, which matches the slope of the linear segment to the slope of the power function segment. C_O is the segment offset, which ensures that the linear segment and the power function segments connect. Some of these parameters are illustrated by the following diagram.
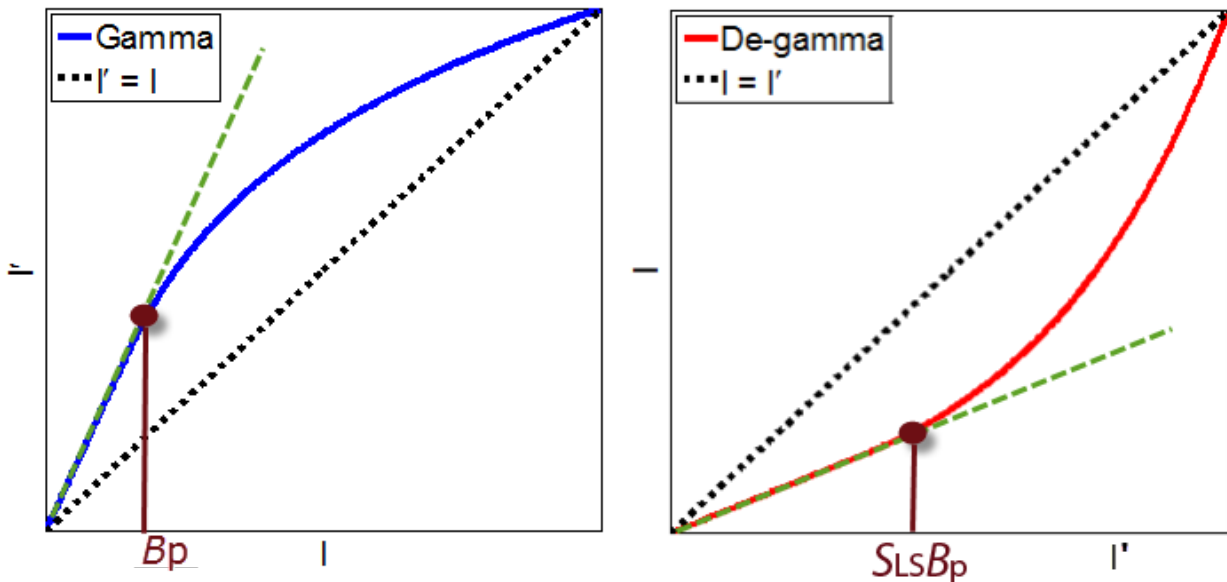
For normalized input signals, the block removes gamma correction, which linearizes the input video stream, as defined by the following equation:

$$I = \begin{cases} \dfrac{I'}{S_{LS}}, & I' \le S_{LS}B_p \\ \left(\dfrac{I'+C_O}{F_S}\right)^{\gamma}, & I' > S_{LS}B_p \end{cases}$$

Typical gamma values range from 1 to 3. Most monitor gamma values range from 1.8 to 2.2. Check with the manufacturer of your hardware to obtain the exact gamma value. Gamma function parameters for some common standards are shown in the following table:

Standard	Slope	Break Point	Gamma
CIE L*	9.033	0.008856	3
Recommendation ITU-R BT.709-3, Parameter Values for the HDTV Standards for Production and International Programme Exchange	4.5	0.018	$\dfrac{20}{9}$
sRGB	12.92	0.00304	2.4

Note This block supports intensity and color images on its ports.

The properties of the input and output ports are summarized in the following table:

Port	Input/Output	Supported Data Types	Complex Values Supported
I	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point (up to 16-bit word length) • 8- and 16-bit signed integer • 8- and 16-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
I'	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	Same as I port	No

Use the **Operation** parameter to specify the block's operation. If you want to perform gamma correction, select Gamma. If you want to linearize the input signal, select De-gamma.

If, for the **Operation** parameter, you select Gamma, use the **Gamma** parameter to enter the desired gamma value of the output video stream. This value must be greater than or equal to 1. If, for the **Operation** parameter, you select De-gamma, use the **Gamma** parameter to enter the gamma value of the input video stream.

Select the **Linear segment** check box if you want the gamma curve to have a linear portion near black. If you select this check box, the **Break point** parameter appears on the dialog box. Enter a scalar value that indicates the *I*-axis value of the end of the linear segment. The break point is shown in the first diagram of this block reference page.

Parameters

Operation

Specify the block's operation. Your choices are Gamma or De-gamma.

Gamma

If, for the **Operation** parameter, you select Gamma, enter the desired gamma value of the output video stream. This value must be greater than or equal to 1. If, for the **Operation** parameter, you select De-gamma, enter the gamma value of the input video stream.

Linear segment

Select this check box if you want the gamma curve to have a linear portion near the origin.

Break point

Enter a scalar value that indicates the *I*-axis value of the end of the linear segment. This parameter is visible if you select the **Linear segment** check box.

References

[1] Poynton, Charles. *Digital Video and HDTV Algorithms and Interfaces*. San Francisco, CA: Morgan Kaufman Publishers, 2003.

See Also

Color Space Conversion	Computer Vision System Toolbox software
imadjust	Image Processing Toolbox software

Introduced before R2006a

Gaussian Pyramid

Perform Gaussian pyramid decomposition

Library

Transforms

visiontransforms

Description

The Gaussian Pyramid block computes Gaussian pyramid reduction or expansion to resize an image. The image reduction process involves lowpass filtering and downsampling the image pixels. The image expansion process involves upsampling the image pixels and lowpass filtering. You can also use this block to build a Laplacian pyramid. For more information, see "Examples" on page 1-299.

Note This block supports intensity and color images on its ports.

Port	Output	Supported Data Types	Complex Values Supported
Input	In Reduce mode, the input can be an M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes. In Expand mode, the input can be a scalar, vector, or M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes.	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Output	In Reduce mode, the output can be a scalar, vector, or matrix that represents one level of a Gaussian pyramid. In Expand mode, the output can be a matrix that represents one level of a Gaussian pyramid.	Same as Input port	No

Use the **Operation** parameter to specify whether to reduce or expand the input image. If you select Reduce, the block applies a lowpass filter and then downsamples the input image. If you select Expand, the block upsamples and then applies a lowpass filter to the input image.

Use the **Pyramid level** parameter to specify the number of times the block upsamples or downsamples each dimension of the image by a factor of 2. For example, suppose you have a 4-by-4 input image. You set the **Operation** parameter to Reduce and the **Pyramid level** to 1. The block filters and downsamples the image and outputs a 2-by-2 pixel output image. If you have an M-by-N input image and you set the **Operation** parameter to Reduce, you can calculate the dimensions of the output image using the following equation:

$$\text{ceil}\left(\frac{M}{2}\right) - \text{by} - \text{ceil}\left(\frac{N}{2}\right)$$

You must repeat this calculation for each successive pyramid level. If you have an M-by-N input image and you set the **Operation** parameter to Expand, you can calculate the dimensions of the output image using the following equation:

$$\left[(M-1)2^l + 1\right] - \text{by} - \left[(N-1)2^l + 1\right]$$

In the previous equation, l is the scalar value from 1 to inf that you enter for the **Pyramid level** parameter.

Use the **Coefficient source** parameter to specify the coefficients of the lowpass filter. If you select Default separable filter [1/4-a/2 1/4 a 1/4 1/4-a/2], use the **a** parameter to define the coefficients in the vector of separable filter coefficients. If you select Specify via dialog, use the **Coefficient for separable filter** parameter to enter a vector of separable filter coefficients.

Examples

The following example model shows how to construct a Laplacian pyramid:

1   Open this model by typing

ex_laplacian

at the MATLAB command prompt.
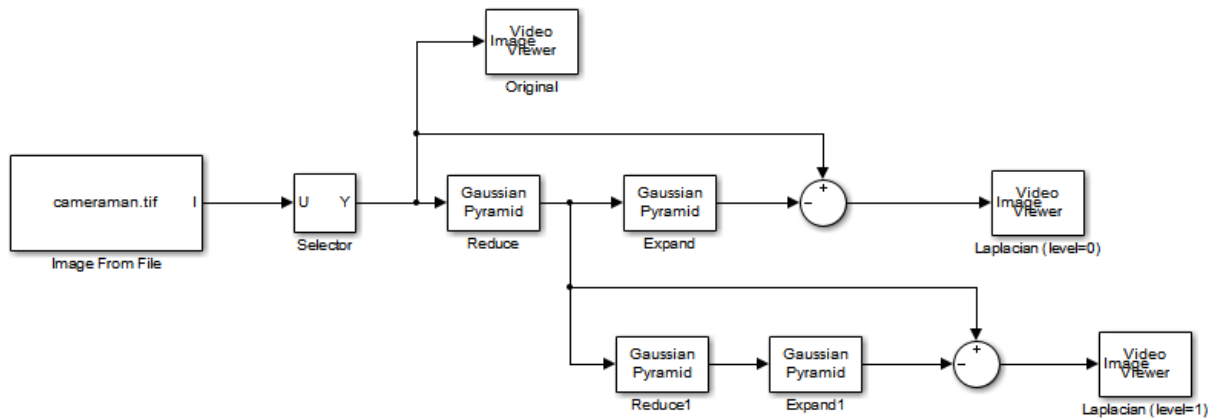
2 Run the model to see the following results.
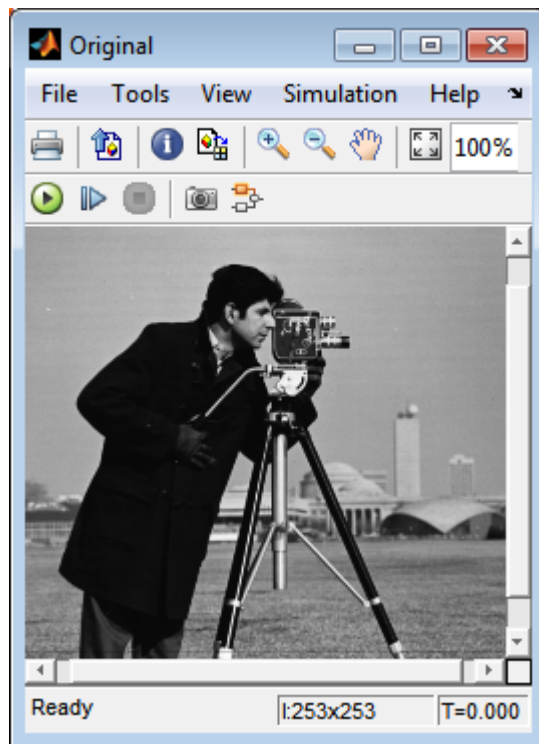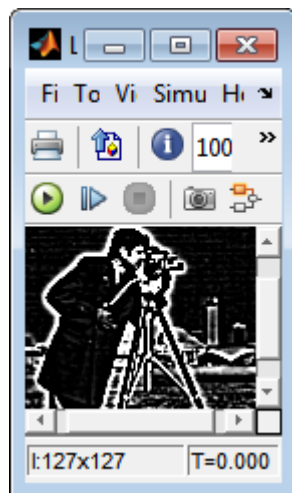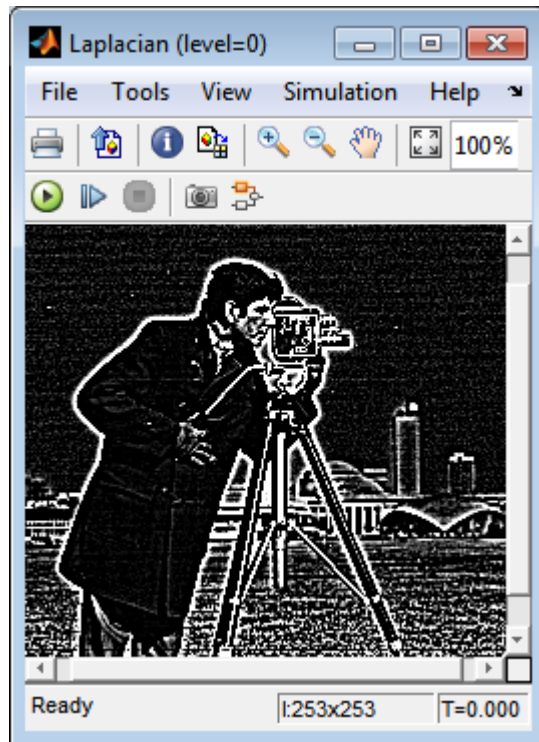
You can construct a Laplacian pyramid if the dimensions of the input image, R-by-C,

satisfy $R = M_R 2^N + 1$ and $C = M_c 2^N + 1$, where M_R, M_C, and N are integers. In this example, you have an input matrix that is 256-by-256. If you set M_R and M_C equal to 63 and N equal to 2, you find that the input image needs to be 253-by-253. So you use a Submatrix block to crop the dimensions of the input image to 253-by-253.

Fixed-Point Data Types

The following diagram shows the data types used in the Gaussian Pyramid block for fixed-point signals:
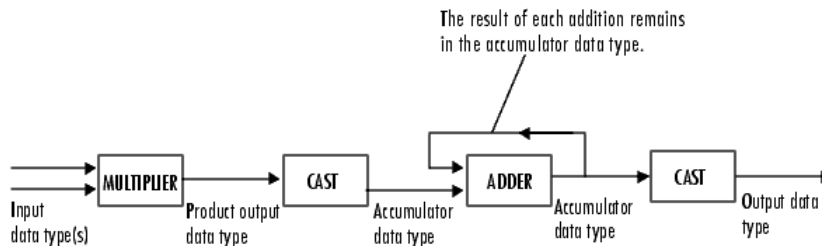
You can set the coefficients table, product output, accumulator, and output data types in the block mask.

Parameters

Operation

Specify whether you want to reduce or expand the input image.

Pyramid level

Specify the number of times the block upsamples or downsamples each dimension of the image by a factor of 2.

Coefficient source

Determine how to specify the coefficients of the lowpass filter. Your choices are `Default separable filter [1/4-a/2 1/4 a 1/4 1/4-a/2]` or `Specify via dialog`.

a

Enter a scalar value that defines the coefficients in the default separable filter `[1/4-a/2 1/4 a 1/4 1/4-a/2]`. This parameter is visible if, for the **Coefficient source** parameter, you select `Default separable filter [1/4-a/2 1/4 a 1/4 1/4-a/2]`.

Coefficients for separable filter

Enter a vector of separable filter coefficients. This parameter is visible if, for the **Coefficient source** parameter, you select `Specify via dialog`.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Coefficients

Choose how to specify the word length and the fraction length of the coefficients:

- When you select `Same word length as input`, the word length of the coefficients match that of the input to the block. In this mode, the fraction length of the coefficients is automatically set to the binary-point only scaling that provides you with the best precision possible given the value and word length of the coefficients.

- When you select `Specify word length`, you can enter the word length of the coefficients, in bits. The block automatically sets the fraction length to give you the best precision.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the coefficients, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the coefficients. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Product output

As shown in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate the product output word and fraction lengths.

- When you select `Same as input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Accumulator

As shown in the previous figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate the accumulator word and fraction lengths.

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

See Also

| Resize | Computer Vision System Toolbox software |

Introduced before R2006a

Histogram Equalization

Enhance contrast of images using histogram equalization

Library

Analysis & Enhancement

`visionanalysis`

Description

The Histogram Equalization block enhances the contrast of images by transforming the values in an intensity image so that the histogram of the output image approximately matches a specified histogram.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Hist	Vector of integer values that represents the desired intensity values in each bin	• Double-precision floating point • Single-precision floating point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Output	Matrix of intensity values	Same as I port	No

If the data type of input to the I port is floating point, the input to Hist port must be the same data type. The output signal has the same data type as the input signal.

Use the **Target histogram** parameter to designate the histogram you want the output image to have.

If you select `Uniform`, the block transforms the input image so that the histogram of the output image is approximately flat. Use the **Number of bins** parameter to enter the number of equally spaced bins you want the uniform histogram to have.

If you select `User-defined`, the **Histogram source** and **Histogram** parameters appear on the dialog box. Use the **Histogram source** parameter to select how to specify your histogram. If, for the **Histogram source** parameter, you select `Specify via dialog`, you can use the **Histogram** parameter to enter the desired histogram of the output image. The histogram should be a vector of integer values that represents the desired intensity values in each bin. The block transforms the input image so that the histogram of the output image is approximately the specified histogram.

If, for the **Histogram source** parameter, you select `Input port`, the Hist port appears on the block. Use this port to specify your desired histogram.

Note The vector input to the Hist port must be normalized such that the sum of the values in all the bins is equal to the number of pixels in the input image. The block does not error if the histogram is not normalized.

Examples

See "Adjust the Contrast of Intensity Images" and"Adjust the Contrast of Color Images" in the *Computer Vision System Toolbox User's Guide*.

Parameters

Target histogram

Designate the histogram you want the output image to have. If you select `Uniform`, the block transforms the input image so that the histogram of the output image is approximately flat. If you select `User-defined`, you can specify the histogram of your output image.

Number of bins

Enter the number of equally spaced bins you want the uniform histogram to have. This parameter is visible if, for the **Target histogram** parameter, you select `Uniform`.

Histogram source

Select how to specify your histogram. Your choices are `Specify via dialog` and `Input port`. This parameter is visible if, for the **Target histogram** parameter, you select `User-defined`.

Histogram

Enter the desired histogram of the output image. This parameter is visible if, for the **Target histogram** parameter, you select `User-defined`.

See Also

imadjust	Image Processing Toolbox
histeq	Image Processing Toolbox

Introduced before R2006a

Hough Lines

Find Cartesian coordinates of lines described by rho and theta pairs
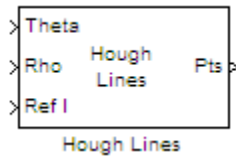
Hough Lines

Library

Transforms

`visiontransforms`

Description

The Hough Lines block finds the points of intersection between the reference image boundary lines and the line specified by a (rho, theta) pair. The block outputs one-based [x y] coordinates for the points of intersection. The boundary lines indicate the left and right vertical boundaries and the top and bottom horizontal boundaries of the reference image.

If the line specified by the (rho, theta) pair does not intersect two border lines in the reference image, the block outputs the values, [(0,0), (0,0)]. This output intersection value allows the next block in your model to ignore the points. Generally, the Hough Lines block precedes a block that draws a point or shape at the intersection.

The following figure shows the input and output coordinates for the Hough Lines block.

$$\begin{bmatrix} theta1 \\ theta2 \end{bmatrix} or [theta1 \quad theta2]$$

$$\begin{bmatrix} rho1 \\ rho2 \end{bmatrix} or [rho1 \quad rho2]$$

Reference image

$$\begin{bmatrix} x_{11} & y_{11} & x_{12} & y_{12} \\ x_{21} & y_{21} & x_{22} & y_{22} \end{bmatrix}$$

Theta
Rho | Hough Lines | Pts
Ref I

Hough Lines

Port Description

Port	Input/Output	Supported Data Types	Complex Values Supported
Theta	Vector of theta values that represent input lines	• Double-precision floating point • Single-precision floating point • Fixed point (signed, word length less than or equal to 32) • 8-, 16-, and 32-bit signed integer	No
Rho	Vector of rho values that represent input lines	Same as Theta port	No
Ref I	Matrix that represents a binary or intensity image or matrix that represents one plane of an RGB image	• Double-precision floating point • Single-precision floating point • Fixed-point (signed and unsigned) • Custom data types • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Pts	M-by-4 matrix of intersection values, where M is the number of input lines	• 32-bit signed integer	No

Parameters

Sine value computation method

If you select `Trigonometric function`, the block computes sine and cosine values to calculate the intersections of the lines during the simulation. If you select `Table lookup`, the block computes and stores the trigonometric values to calculate the intersections of the lines before the simulation starts. In this case, the block requires extra memory.

For floating-point inputs, set the **Sine value computation method** parameter to `Trigonometric function`. For fixed-point inputs, set the parameter to `Table lookup`.

Theta resolution (radians)

Use this parameter to specify the spacing of the theta-axis. This parameter appears in the dialog box only if, for the **Sine value computation method** parameter, you select `Table lookup`. parameter appears in the dialog box.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Sine table

Choose how to specify the word length of the values of the sine table. The fraction length of the sine table values always equals the word length minus one:

When you select `Specify word length`, you can enter the word length of the sine table.

The sine table values do not obey the **Rounding mode** and **Overflow mode** parameters; they saturate and round to `Nearest`.

Product output

Use this parameter to specify how to designate this product output word and fraction lengths:

When you select `Same as first input`, the characteristics match the characteristics of the first input to the block.

When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. All signals in the Computer Vision System Toolbox blocks have a bias of 0.

See "Multiplication Data Types" for illustrations depicting the use of the product output.

Accumulator

Use this parameter to specify how you would like to designate the accumulator word and fraction lengths.

When you select `Same as product output` the characteristics match the characteristics of the product output.

When you select `Binary point scaling`, you can enter the **Word length** and the **Fraction length** of the accumulator, in bits.

When you select `Slope and bias scaling`, you can enter the **Word length**, in bits, and the **Slope** of the **Accumulator**. All signals in the Computer Vision System Toolbox software have a bias of 0.

See "Multiplication Data Types" for illustrations depicting the use of the accumulator data type in this block.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Examples

The following figure shows Line 1 intersecting the boundaries of the reference image at $[(x_{11}, y_{11}) (x_{12}, y_{12})]$ and Line 2 intersecting the boundaries at $[(x_{21}, y_{21}) (x_{22}, y_{22})]$
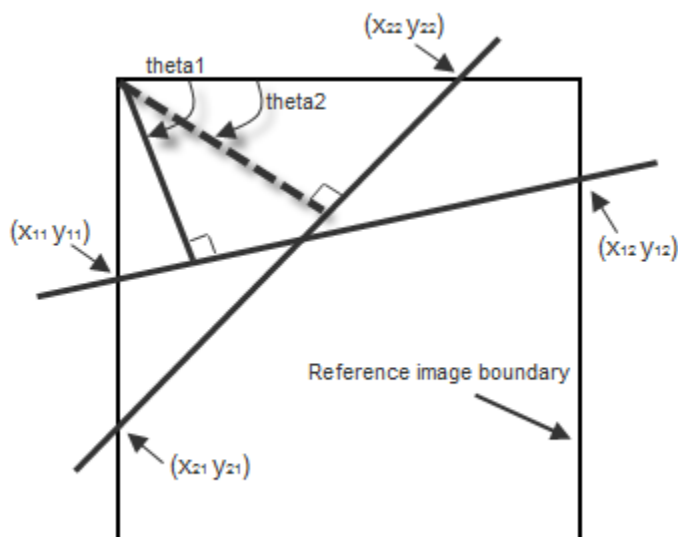
See "Detect Lines in Images" in the *Computer Vision System Toolbox User Guide*.

See Also

Find Local Maxima	Computer Vision System Toolbox
Hough Transform	Computer Vision System Toolbox

Introduced before R2006a

Hough Transform

Find lines in images
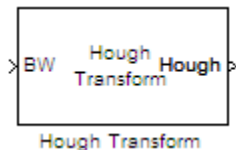
Hough Transform

Library

Transforms

visiontransforms

Description

Use the Hough Transform block to find straight lines in an image. The block outputs the Hough space matrix and, optionally, the *rho*-axis and *theta*-axis vectors. Peak values in the matrix represent potential straight lines in the input image. Generally, the Hough Transform block precedes the Hough Lines block which uses the output of this block to find straight lines in an image. You can instead use a custom algorithm to locate peaks in the Hough space matrix in order to identify potential straight lines.

Port	Input/Output	Supported Data Types	Supported Complex Values
BW	Matrix that represents a binary image	Boolean	No
Hough	Parameter space matrix	• Double-precision floating point • Single-precision floating point • Fixed point (unsigned, fraction length equal to 0) • 8-, 16-, 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Supported Complex Values
Theta	Vector of theta values	• Double-precision floating point • Single-precision floating point • Fixed point (signed) • 8-, 16-, 32-bit signed integer	No
Rho	Vector of rho values	Same as Theta port	No

Parameters

Theta resolution (radians)

Specify the spacing of the Hough transform bins along the *theta*-axis.

Rho resolution (pixels)

Specify the spacing of the Hough transform bins along the *rho*-axis.

Output theta and rho values

If you select this check box, the **Theta** and **Rho** ports appear on the block. The block outputs theta and rho-axis vector values at these ports.

Output data type

Specify the data type of your output signal.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Sine table

Choose how to specify the word length of the values of the sine table:

- When you select `Binary point scaling`, you can enter the word length of the sine table values, in bits.

- When you select `Slope and bias scaling`, you can enter the word length of the sine table values, in bits.

The sine table values do not obey the **Rounding mode** and **Overflow mode** parameters; they always saturate and round to `Nearest`.

Rho

Choose how to specify the word length and the fraction length of the rho values:

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the rho values, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the rho values. All signals in Computer Vision System Toolbox blocks have a bias of 0.

Product output

. Use this parameter to specify how to designate the product output word and fraction lengths:

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. All signals in Computer Vision System Toolbox blocks have a bias of 0.

See "Multiplication Data Types" for illustrations depicting the use of the product output.

Accumulator

Use this parameter to specify how to designate this accumulator word and fraction lengths:

- When you select `Same as product output`, these characteristics match the characteristics of the product output.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. All signals in Computer Vision System Toolbox blocks have a bias of 0.

  See "Multiplication Data Types" for illustrations depicting the use of the accumulator data type in this block.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Hough output

Choose how to specify the word length and fraction length of the Hough output of the block:

- When you select `Binary point scaling`, you can enter the word length of the Hough output, in bits. The fraction length always has a value of 0.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, of the Hough output. The slope always has a value of 0. All signals in Computer Vision System Toolbox blocks have a bias of 0.

Theta output

Choose how to specify the word length and fraction length of the theta output of the block:

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the theta output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the theta output. All signals in Computer Vision System Toolbox blocks have a bias of 0.

Algorithm

The Hough Transform block implements the Standard Hough Transform (SHT). The SHT uses the parametric representation of a line:

$$rho = x * \cos(theta) + y * \sin(theta)$$
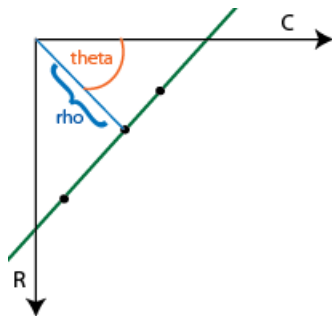
The upper-left corner pixel is assumed to be at x=0,y=0.

The variable *rho* indicates the perpendicular distance from the origin to the line.

The variable *theta* indicates the angle of inclination of the normal line from the x-axis. The range of *theta* is $-\dfrac{\pi}{2} \le \theta < +\dfrac{\pi}{2}$ with a step-size determined by the **Theta resolution (radians)** parameter. The SHT measures the angle of the line clockwise with respect to the positive x-axis.

The Hough Transform block creates an accumulator matrix. The (*rho, theta*) pair represent the location of a cell in the accumulator matrix. Every valid (logical true) pixel of the input binary image represented by (*R,C*) produces a rho value for all theta values. The block quantizes the rho values to the nearest number in the rho vector. The rho vector depends on the size of the input image and the user-specified rho resolution. The block increments a counter (initially set to zero) in those accumulator array cells represented by (*rho, theta*) pairs found for each pixel. This process validates the point (*R,C*) to be on the line defined by (*rho, theta*). The block repeats this process for each logical true pixel in the image. The **Hough** block outputs the resulting accumulator matrix.

Examples

See "Detect Lines in Images" in the *Computer Vision System Toolbox User Guide*.

See Also

Find Local Maxima	Computer Vision System Toolbox
Hough Lines	Computer Vision System Toolbox
hough	Image Processing Toolbox
houghlines	Image Processing Toolbox
houghpeaks	Image Processing Toolbox

Introduced before R2006a

Image Complement

Compute complement of pixel values in binary or intensity images

Image Complement

Library

Conversions

`visionconversions`

Description

The Image Complement block computes the complement of a binary or intensity image. For binary images, the block replaces pixel values equal to `0` with `1` and pixel values equal to `1` with `0`. For an intensity image, the block subtracts each pixel value from the maximum value that can be represented by the input data type and outputs the difference.

For example, suppose the input pixel values are given by $x(i)$ and the output pixel values are given by $y(i)$. If the data type of the input is double or single precision floating-point, the block outputs $y(i) = 1.0 - x(i)$. If the input is an 8-bit unsigned integer, the block outputs $y(i) = 255 - x(i)$.

Port	Input/Output	Supported Data Types	Complex Values Supported
Input	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Output	Complement of a binary or intensity	Same as Input port	No

The dimensions, data type, complexity, and frame status of the input and output signals are the same.

See Also

Autothreshold	Computer Vision System Toolbox software
Chroma Resampling	Computer Vision System Toolbox software
Color Space Conversion	Computer Vision System Toolbox software

Introduced before R2006a

Image Data Type Conversion

Convert and scale input image to specified output data type

```
Convert Image
to single

Image Data Type
Conversion
```

Library

Conversions

`visionconversions`

Description

The Image Data Type Conversion block changes the data type of the input to the user-specified data type and scales the values to the new data type's dynamic range. To convert between data types without scaling, use the Simulink Data Type Conversion block.

When converting between floating-point data types, the block casts the input into the output data type and clips values outside the range to 0 or 1. When converting to the Boolean data type, the block maps 0 values to 0 and all other values to one. When converting to or between all other data types, the block casts the input into the output data type and scales the data type values into the dynamic range of the output data type. For double- and single-precision floating-point data types, the dynamic range is between 0 and 1. For fixed-point data types, the dynamic range is between the minimum and maximum values that can be represented by the data type.

Note This block supports intensity and color images on its ports.

Port	Input/Output	Supported Data Types	Complex Values Supported
Input	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point (word length less than or equal to 16) • Boolean • 8-, 16-bit signed integer • 8-, 16-bit unsigned integer	No
Output	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	Same as Input port	No

The dimensions, complexity, and frame status of the input and output signals are the same.

Use the **Output data type** parameter to specify the data type of your output signal values.

Parameters

Output data type

Use this parameter to specify the data type of your output signal.

Signed

Select this check box if you want the output fixed-point data to be signed. This parameter is visible if, for the **Output data type** parameter, you choose `Fixed-point`.

Word length

Use this parameter to specify the word length of your fixed-point output. This parameter is visible if, for the **Output data type** parameter, you choose `Fixed-point`.

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Fraction length

    Use this parameter to specify the fraction length of your fixed-point output. This parameter is visible if, for the **Output data type** parameter, you choose `Fixed-point`.

See Also

Autothreshold	Computer Vision System Toolbox software

Introduced before R2006a

Image From File

Import image from image file

Image From File

Library

Sources

`visionsources`

Description

Use the Image From File block to import an image from a supported image file. For a list of supported file formats, see the `imread` function reference page in the MATLAB documentation. If the image is a M-by-N array, the block outputs a binary or intensity image, where M and N are the number of rows and columns in the image. If the image is a M-by-N-by-P array, the block outputs a color image, where M and N are the number of rows and columns in each color plane, P.

Port	Output	Supported Data Types	Complex Values Supported
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	Yes

Port	Output	Supported Data Types	Complex Values Supported
R, G, B	Scalar, vector, or matrix that represents one plane of the input RGB video stream. Outputs from the R, G, or B ports have the same dimensions.	Same as I port	Yes

For the Computer Vision System Toolbox blocks to display video data properly, double- and single-precision floating-point pixel values must be between 0 and 1. If the input pixel values have a different data type than the one you select using the **Output data type** parameter, the block scales the pixel values, adds an offset to the pixel values so that they are within the dynamic range of their new data type, or both.

Use the **File name** parameter to specify the name of the graphics file that contains the image to import into the Simulink modeling and simulation software. If the file is not on the MATLAB path, use the **Browse** button to locate the file. This parameter supports URL paths.

Use the **Sample time** parameter to set the sample period of the output signal.

Use the **Image signal** parameter to specify how the block outputs a color video signal. If you select `One multidimensional signal`, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.

Use the **Output port labels** parameter to label your output ports. Use the spacer character, |, as the delimiter. This parameter is visible if you set the **Image signal** parameter to `Separate color signals`.

On the **Data Types** pane, use the **Output data type** parameter to specify the data type of your output signal.

Parameters

File name

Specify the name of the graphics file that contains the image to import into the Simulink environment.

Sample time

Enter the sample period of the output signal.

Image signal

Specify how the block outputs a color video signal. If you select `One multidimensional signal`, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.

Output port labels

Enter the labels for your output ports using the spacer character, |, as the delimiter. This parameter is visible if you set the **Image signal** parameter to `Separate color signals`.

Output data type

Specify the data type of your output signal.

Signed

Select to output a signed fixed-point signal. Otherwise, the signal will be unsigned. This parameter is only visible if, from the **Output data type** list, you select `Fixed-point`.

Word length

Specify the word length, in bits, of the fixed-point output data type. This parameter is only visible if, from the **Output data type** list, you select `Fixed-point`.

Set fraction length in output to

Specify the scaling of the fixed-point output by either of the following two methods:

- Choose `Best precision` to have the output scaling automatically set such that the output signal has the best possible precision.

- Choose `User-defined` to specify the output scaling in the **Fraction length** parameter.

This parameter is only visible if, from the **Output data type** list, you select `Fixed-point` or when you select `User-defined`.

Fraction length

For fixed-point output data types, specify the number of fractional bits, or bits to the right of the binary point. This parameter is only visible when you select `Fixed-point` or `User-defined` for the **Output data type** parameter and `User-defined` for the **Set fraction length in output to** parameter.

User-defined data type

Specify any built-in or fixed-point data type. You can specify fixed-point data types using the `sfix`, `ufix`, `sint`, `uint`, `sfrac`, and `ufrac` functions from the Fixed-Point Designer™ library. This parameter is only visible when you select `User-defined` for the **Output data type** parameter.

See Also

From Multimedia File	Computer Vision System Toolbox software
Image From Workspace	Computer Vision System Toolbox software
To Video Display	Video and Image Processing Blockset software
Video From Workspace	Computer Vision System Toolbox software
Video Viewer	Computer Vision System Toolbox software
im2double	MATLAB software
im2uint8	Image Processing Toolbox software
imread	MATLAB

Introduced before R2006a

Image From Workspace

Import image from MATLAB workspace

checker_board(10) Image ▷

Image From Workspace

Library

Sources

```
visionsources
```

Description

Use the Image From Workspace block to import an image from the MATLAB workspace. If the image is a M-by-N workspace array, the block outputs a binary or intensity image, where M and N are the number of rows and columns in the image. If the image is a M-by-N-by-P workspace array, the block outputs a color image, where M and N are the number of rows and columns in each color plane, P.

Port	Output	Supported Data Types	Complex Values Supported
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No

Port	Output	Supported Data Types	Complex Values Supported
R, G, B	Scalar, vector, or matrix that represents one plane of the RGB video stream. Outputs from the R, G, or B ports have the same dimensions.	Same as I port	No

For the Computer Vision System Toolbox blocks to display video data properly, double- and single-precision floating-point pixel values must be between 0 and 1. If the input pixel values have a different data type than the one you select using the **Output data type** parameter, the block scales the pixel values, adds an offset to the pixel values so that they are within the dynamic range of their new data type, or both.

Use the **Value** parameter to specify the MATLAB workspace variable that contains the image you want to import into Simulink environment.

Use the **Sample time** parameter to set the sample period of the output signal.

Use the **Image signal** parameter to specify how the block outputs a color video signal. If you select One multidimensional signal, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select Separate color signals, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.

Use the **Output port labels** parameter to label your output ports. Use the spacer character, |, as the delimiter. This parameter is visible if you set the **Image signal** parameter to Separate color signals.

On the **Data Types** pane, use the **Output data type** parameter to specify the data type of your output signal.

Parameters

Value

Specify the MATLAB workspace variable that you want to import into Simulink environment.

Sample time

Enter the sample period of the output signal.

Image signal

Specify how the block outputs a color video signal. If you select `One multidimensional signal`, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.

Output port labels

Enter the labels for your output ports using the spacer character, |, as the delimiter. This parameter is visible if you set the **Image signal** parameter to `Separate color signals`.

Output data type

Specify the data type of your output signal.

Signed

Select to output a signed fixed-point signal. Otherwise, the signal is unsigned. This parameter is only visible if, from the **Output data type** list, you select `Fixed-point`.

Word length

Specify the word length, in bits, of the fixed-point output data type. This parameter is only visible if, from the **Output data type** list, you select `Fixed-point`.

Set fraction length in output to

Specify the scaling of the fixed-point output by either of the following two methods:

• Choose `Best precision` to have the output scaling automatically set such that the output signal has the best possible precision.

• Choose `User-defined` to specify the output scaling in the **Fraction length** parameter.

This parameter is only visible if, from the **Output data type** list, you select `Fixed-point` or when you select `User-defined`.

Fraction length

For fixed-point output data types, specify the number of fractional bits, or bits to the right of the binary point. This parameter is only visible when you select `Fixed-point` or `User-defined` for the **Output data type** parameter and `User-defined` for the **Set fraction length in output to** parameter.

User-defined data type

> Specify any built-in or fixed-point data type. You can specify fixed-point data types using the `sfix`, `ufix`, `sint`, `uint`, `sfrac`, and `ufrac` functions from the Fixed-Point Designer library. This parameter is only visible when you select `User-defined` for the **Output data type** parameter.

See Also

From Multimedia File	Computer Vision System Toolbox software
To Video Display	Computer Vision System Toolbox software
Video From Workspace	Computer Vision System Toolbox software
Video Viewer	Computer Vision System Toolbox software
`im2double`	Image Processing Toolbox software
`im2uint8`	Image Processing Toolbox software

Introduced before R2006a

Image Pad

Pad signal along its rows, columns, or both

```
I
   Image Pad
PVal

   Image Pad
```

Library

Utilities

`visionutilities`

Description

The Image Pad block expands the dimensions of a signal by padding its rows, columns, or both. To crop an image, you can use the Simulink Selector block, DSP System Toolbox™ Submatrix block, or the Image Processing Toolbox `imcrop` function.

Port	Input/Output	Supported Data Types	Complex Values Supported
Image / I	*M*-by-*N* matrix of intensity values or an *M*-by-*N*-by-*P* color video signal, where *P* is the number of color planes.	• Double-precision floating point. • Single-precision floating point. • Fixed point. • Boolean. • 8-, 16-, 32-bit signed integer. • 8-, 16-, 32-bit unsigned integer.	Yes
PVal	Scalar value that represents the constant pad value.	Same as I port.	Yes
Output	Padded scalar, vector, or matrix.	Same as I port.	Yes

Examples

Pad with a Constant Value

Suppose you want to pad the rows of your input signal with three initial values equal to 0 and your input signal is defined as follows:

$$\begin{bmatrix} a_{00} & a_{01} & a_{02} \\ a_{10} & a_{11} & a_{12} \\ a_{20} & a_{21} & a_{22} \end{bmatrix}$$

Set the Image Pad block parameters as follows:

- **Method** = Constant
- **Pad value source** = Specify via dialog
- **Pad value** = 0
- **Specify** = Output size
- **Add columns to** = Left
- **Output row mode** = User-specified
- **Number of output columns** = 6
- **Add rows to** = No padding

The Image Pad block outputs the following signal:

$$\begin{bmatrix} 0 & 0 & 0 & a_{00} & a_{01} & a_{02} \\ 0 & 0 & 0 & a_{10} & a_{11} & a_{12} \\ 0 & 0 & 0 & a_{20} & a_{21} & a_{22} \end{bmatrix}$$

Pad by Repeating Border Values

Suppose you want to pad your input signal with its border values, and your input signal is defined as follows:

$$\begin{bmatrix} a_{00} & a_{01} & a_{02} \\ a_{10} & a_{11} & a_{12} \\ a_{20} & a_{21} & a_{22} \end{bmatrix}$$

Set the Image Pad block parameters as follows:

- **Method** = `Replicate`
- **Specify** = `Pad size`
- **Add columns to** = `Both left and right`
- **Number of added columns** = 2
- **Add rows to** = `Both top and bottom`
- **Number of added rows** = [1 3]

The Image Pad block outputs the following signal:

$$\begin{bmatrix} a_{00} & a_{00} & a_{00} & a_{01} & a_{02} & a_{02} & a_{02} \\ a_{00} & a_{00} & a_{00} & a_{01} & a_{02} & a_{02} & a_{02} \\ a_{10} & a_{10} & a_{10} & a_{11} & a_{12} & a_{12} & a_{12} \\ a_{20} & a_{20} & a_{20} & a_{21} & a_{22} & a_{22} & a_{22} \\ a_{20} & a_{20} & a_{20} & a_{21} & a_{22} & a_{22} & a_{22} \\ a_{20} & a_{20} & a_{20} & a_{21} & a_{22} & a_{22} & a_{22} \\ a_{20} & a_{20} & a_{20} & a_{21} & a_{22} & a_{22} & a_{22} \end{bmatrix}$$ ⎯ Input matrix

The border values of the input signal are replicated on the top, bottom, left, and right of the input signal so that the output is a 7-by-7 matrix. The values in the corners of this

output matrix are determined by replicating the border values of the matrices on the top, bottom, left and right side of the original input signal.

Pad with Mirror Image

Suppose you want to pad your input signal using its mirror image, and your input signal is defined as follows:

$$\begin{bmatrix} a_{00} & a_{01} & a_{02} \\ a_{10} & a_{11} & a_{12} \\ a_{20} & a_{21} & a_{22} \end{bmatrix}$$

Set the Image Pad block parameters as follows:

- **Method** = Symmetric
- **Specify** = Pad size
- **Add columns to** = Both left and right
- **Number of added columns** = [5 6]
- **Add rows to** = Both top and bottom
- **Number of added rows** = 2

The Image Pad block outputs the following signal:

$$\begin{bmatrix} a_{11} & a_{12} & a_{12} & a_{11} & a_{10} & a_{10} & a_{11} & a_{12} & a_{12} & a_{11} & a_{10} & a_{10} & a_{11} & a_{12} \\ a_{01} & a_{02} & a_{02} & a_{01} & a_{00} & a_{00} & a_{01} & a_{02} & a_{02} & a_{01} & a_{00} & a_{00} & a_{01} & a_{02} \\ a_{01} & a_{02} & a_{02} & a_{01} & a_{00} & a_{00} & a_{01} & a_{02} & a_{02} & a_{01} & a_{00} & a_{00} & a_{01} & a_{02} \\ a_{11} & a_{12} & a_{12} & a_{11} & a_{01} & a_{10} & a_{11} & a_{12} & a_{12} & a_{11} & a_{10} & a_{10} & a_{11} & a_{12} \\ a_{21} & a_{22} & a_{22} & a_{21} & a_{20} & a_{20} & a_{21} & a_{22} & a_{22} & a_{21} & a_{20} & a_{20} & a_{21} & a_{22} \\ a_{21} & a_{22} & a_{22} & a_{21} & a_{20} & a_{20} & a_{21} & a_{22} & a_{22} & a_{21} & a_{20} & a_{20} & a_{21} & a_{22} \\ a_{11} & a_{12} & a_{12} & a_{11} & a_{01} & a_{01} & a_{11} & a_{12} & a_{12} & a_{11} & a_{10} & a_{10} & a_{11} & a_{12} \end{bmatrix}$$ Input matrix

The block flips the original input matrix and each matrix it creates about their top, bottom, left, and right sides to populate the 7-by-13 output signal. For example, in the preceding figure, you can see how the block flips the input matrix about its right side to create the matrix directly to its right.

Pad Using a Circular Repetition of Elements

Suppose you want to pad your input signal using a circular repetition of its values. Your input signal is defined as follows:

$$\begin{bmatrix} a_{00} & a_{01} & a_{02} \\ a_{10} & a_{11} & a_{12} \\ a_{20} & a_{21} & a_{22} \end{bmatrix}$$

Set the Image Pad block parameters as follows:

- **Method** = `Circular`
- **Specify** = `Output size`
- **Add columns to** = `Both left and right`
- **Number of output columns** = 9
- **Add rows to** = `Both top and bottom`
- **Number of output rows** = 9

The Image Pad block outputs the following signal:

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$$
\begin{bmatrix}
a_{00} & a_{01} & a_{02} & a_{00} & a_{01} & a_{02} & a_{00} & a_{01} & a_{02} \\
a_{10} & a_{11} & a_{12} & a_{10} & a_{11} & a_{12} & a_{10} & a_{11} & a_{12} \\
a_{20} & a_{21} & a_{22} & a_{20} & a_{21} & a_{22} & a_{20} & a_{21} & a_{22} \\
a_{00} & a_{01} & a_{02} & a_{00} & a_{01} & a_{02} & a_{00} & a_{01} & a_{02} \\
a_{10} & a_{11} & a_{12} & a_{10} & a_{11} & a_{12} & a_{10} & a_{11} & a_{12} \\
a_{20} & a_{21} & a_{22} & a_{20} & a_{21} & a_{22} & a_{20} & a_{21} & a_{22} \\
a_{00} & a_{01} & a_{02} & a_{00} & a_{01} & a_{02} & a_{00} & a_{01} & a_{02} \\
a_{10} & a_{11} & a_{12} & a_{10} & a_{11} & a_{12} & a_{10} & a_{11} & a_{12} \\
a_{20} & a_{21} & a_{22} & a_{20} & a_{21} & a_{22} & a_{20} & a_{21} & a_{22}
\end{bmatrix}
\quad \text{— Input matrix}
$$
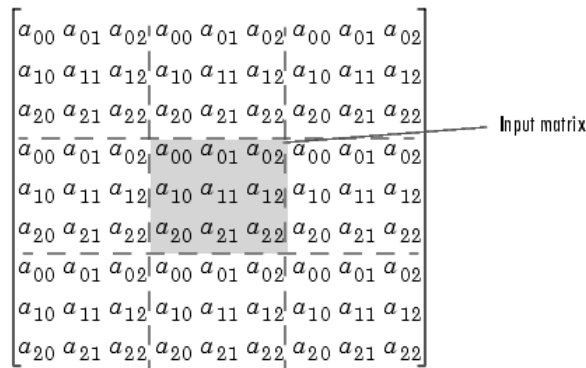
The block repeats the values of the input signal in a circular pattern to populate the 9-by-9 output matrix.

Parameters

Method

Specify how you want the block to pad your signal. The data type of the input signal is the data type of the output signal.

Use the **Method** parameter to specify how you pad the input signal.

- `Constant` — Pad with a constant value
- `Replicate` — Pad by repeating its border values
- `Symmetric` — Pad with its mirror image
- `Circular` — Pad using a circular repetition of its elements

If you set the **Method** parameter to `Constant`, the **Pad value source** parameter appears on the dialog box.

- `Input port` — The PVal port appears on the block. Use this port to specify the constant value with which to pad your signal
- `Specify via dialog` — The **Pad value** parameter appears in the dialog box. Enter the constant value with which to pad your signal.

Pad value source

If you select `Input port`, the PVal port appears on the block. Use this port to specify the constant value with which to pad your signal. If you select `Specify via dialog`, the **Pad value** parameter becomes available. This parameter is visible if, for the **Method** parameter, you select `Constant`.

Pad value

Enter the constant value with which to pad your signal. This parameter is visible if, for the **Pad value source** parameter, you select `Specify via dialog`. This parameter is tunable.

Specify

If you select `Pad size`, you can enter the size of the padding in the horizontal and vertical directions.

If you select `Output size`, you can enter the total number of output columns and rows. This setting enables you to pad the input signal. See the previous section for descriptions of the **Add columns to** and **Add rows to** parameters.

Add columns to

The **Add columns to** parameter controls the padding at the left, right or both sides of the input signal.

- `Left` — The block adds additional columns on the left side.
- `Right` — The block adds additional columns on the right side.
- `Both left and right` — The block adds additional columns to the left and right side.
- `No padding` — The block does not change the number of columns.

Use the **Add columns to** and **Number of added columns** parameters to specify the size of the padding in the horizontal direction. Enter a scalar value, and the block adds this number of columns to the left, right, or both sides of your input signal. If you set the **Add columns to** parameter to `Both left and right`, you can enter a two element vector. The left element controls the number of columns the block adds to the left side of the signal; the right element controls the number of columns the block adds to the right side of the signal.

Output row mode

Use the **Output row mode** parameter to describe how to pad the input signal.

- `User-specified` — Use the **Number of output rows** parameter to specify the total number of rows.

- `Next power of two` — The block pads the input signal along the rows until the length of the rows is equal to a power of two. When the length of the input signal's rows is equal to a power of two, the block does not pad the input signal's rows.

Number of added columns

This parameter controls how many columns are added to the right and/or left side of your input signal. Enter a scalar value, and the block adds this number of columns to the left, right, or both sides of your signal. If, for the **Add columns to** parameter you select `Both left and right`, enter a two-element vector. The left element controls the number of columns the block adds to the left side of the signal and the right element controls how many columns the block adds to the right side of the signal. This parameter is visible if, for the **Specify** parameter, you select `Pad size`.

Add rows to

The **Add rows to** parameter controls the padding at the top and bottom of the input signal.

- `Top` — The block adds additional rows to the top.
- `Bottom` — The block adds additional rows to the bottom.
- `Both top and bottom` — The block adds additional rows to the top and bottom.
- `No padding` — The block does not change the number of rows.

Use the **Add rows to** and **Number of added rows** parameters to specify the size of the padding in the vertical direction. Enter a scalar value, and the block adds this number of rows to the top, bottom, or both of your input signal. If you set the **Add rows to** parameter to `Both top and bottom`, you can enter a two element vector. The left element controls the number of rows the block adds to the top of the signal; the right element controls the number of rows the block adds to the bottom of the signal.

Output column mode

Describe how to pad the input signal. If you select `User-specified`, the Row size parameter appears on the block dialog box. If you select Next power of two, the block pads the input signal along the rows until the length of the rows is equal to a power of two. This parameter is visible if, for the Specify parameter, you select Output size.

Use the **Output column mode** parameter to describe how to pad the input signal.

- `User-specified` — Use the **Number of column rows** parameter to specify the total number of columns.

- `Next power of two` — The block pads the input signal along the columns until the length of the columns is equal to a power of two. When the length of the input signal's columns is equal to a power of two, the block does not pad the input signal's columns.

Number of added rows

This parameter controls how many rows are added to the top, bottom, or both of your input signal. Enter a scalar value and the block adds this number of columns to the top, bottom, or both of your signal. If, for the **Add rows to** parameter you select `Both top and bottom`, enter a two-element vector. The left element controls the number of rows the block adds to the top of the signal and the right element controls how many rows the block adds to the bottom of the signal. This parameter is visible if you set the **Specify** parameter to `Pad size`.

Action when truncation occurs

The following options are available for the **Action when truncation occurs** parameter:

- `None` — Select this option when you do not want to be notified that the input signal is truncated.
- `Warning` — Select this option when you want to receive a warning in the MATLAB Command Window when the input signal is truncated.
- `Error` — Select this option when you want an error dialog box displayed and the simulation terminated when the input signal is truncated.

See Also

Selector | Submatrix | `imcrop`

Introduced in R2007a

Insert Text

Draw text on image or video stream.

Library

Text & Graphics

`visiontextngfix`

Description

The Insert Text block draws formatted text or numbers on an image or video stream. The block uses the FreeType 2.3.5 library, an open-source font engine, to produce stylized text bitmaps. To learn more about the FreeType Project, visit `http://www.freetype.org/`. The Insert Text block does not support character sets other than ASCII.

The Insert Text block lets you draw one or more instances of text including:

- A single instance of text
- Multiple instances of the same text
- Multiple instances of text, with different text at each location

Port Description

Port	Description	Supported Data Types
Image	*M*-by-*N* matrix of intensity values or an *M*-by-*N*-by-*P* color video signal where *P* represents the number of color planes.	• Double-precision floating point • Single-precision floating point • Fixed point(signed, word length less than or equal to 32.) • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer
R, G, B	Matrix that represents one plane of the RGB video stream. Outputs from the R, G, or B ports have the same dimensions and data type.	Same as Input port
Select	One-based index value that indicates which text to display.	• Double-precision floating point. (This data type is only supported if the input to the I or R, G, and B ports is a floating-point data type.) • Single-precision floating point. (This data type is only supported if the input to the I or R, G, and B ports is a floating-point data type.) • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer

Port	Description	Supported Data Types
Variables	Vector or matrix whose values are used to replace ANSI C `printf`-style format specifications.	The data types supported by this port depend on the conversion specification you are using in the **Text** parameter. %d, %i, and %u: • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer %c and %s: • 8-bit unsigned integer %f: • Double-precision floating point • Single-precision floating point %o, %x, %X, %e, %E, %g, and %G: • Double-precision floating point • Single-precision floating point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer
Color	Intensity input — Scalar value used for all character vectors or a vector of intensity values whose length is equal to the number of character vectors. Color input — Three-element vector that specifies one color for all of the character vectors or an M-by-3 matrix of color values, where M represents the number of character vectors.	Same as Input port (The input to this port must be the same data type as the input to the Input port.)

Port	Description	Supported Data Types
Location	*M*-by-2 matrix of one-based [x y] coordinates, where *M* represents the number of text character vectors to insert. **Location** specifies the top-left corner of the text character vector bounding box.	• Double-precision floating point. (This data type is only supported if the input to the I or R, G, and B ports is a floating-point data type.) • Single-precision floating point. (This data type is only supported if the input to the I or R, G, and B ports is a floating-point data type.) • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer
Opacity	Scalar value that is used for all character vectors or vector of opacity values whose length is equal to the number of character vectors.	• Double-precision floating point. (This data type is only supported if the input to the Input or R, G, and B ports is a double-precision floating-point data type.) • Single-precision floating point. (This data type is only supported if the input to the I or R, G, and B ports is a single-precision floating-point data type.) • `ufix8_En7` (This data type is only supported if the input to the I or R, G, and B ports is a fixed-point data type.)

Row-Major Data Format

MATLAB and the Computer Vision System Toolbox blocks use column-major data organization. However, the Insert Text block gives you the option to process data that is stored in row-major format. When you select the **Input image is transposed (data order is row major)** check box, the block assumes that the input buffer contains contiguous data elements from the first row first, then data elements from the second row second, and so on through the last row. Use this functionality only when you meet all the following criteria:

• You are developing algorithms to run on an embedded target that uses the row-major format.

- You want to limit the additional processing required to take the transpose of signals at the interfaces of the row-major and column-major systems.

When you use the row-major functionality, you must consider the following issues:

- When you select this check box, the first two signal dimensions of the Insert Text block's input are swapped.
- All Computer Vision System Toolbox software blocks can be used to process data that is in the row-major format, but you need to know the image dimensions when you develop your algorithms.

  For example, if you use the 2-D FIR Filter block, you need to verify that your filter coefficients are transposed. If you are using the Rotate block, you need to use negative rotation angles, etc.
- Only three blocks have the **Input image is transposed (data order is row major)** check box. They are the Chroma Resampling, Deinterlacing, and Insert Text blocks. You need to select this check box to enable row-major functionality in these blocks. All other blocks must be properly configured to process data in row-major format.

Use the following two-step workflow to develop algorithms in row-major format to run on an embedded target.

Step 1:
Create block diagram

Algorithm blocks

Video source block

Transpose block

Transpose block

Video sink block

Embedded target source block

Step 2:
Replace source, transpose, and sink blocks with target source and sink blocks that produce data in row-major format

Embedded target sink block

Parameters

Text

Specify the text character vector to be drawn on the image or video stream. This parameter can be a single text character vector, such as `'Figure1'`, a cell array of character vectors, such as `{'Figure1','Figure2'}`, or an ANSI C `printf`-style format specifications, such as %s.. To create a **Select** port enter a cell array of character vectors. To create a **Variables** port, enter ANSI C printf-style format specifications, such as `%d`, `%f`, or `%s`.

When you enter a cell array of character vectors, the Insert Text block does not display all of the character vectors simultaneously. Instead, the **Select** port appears on the block to let you indicate which text character vectors to display. The input to this port must be a scalar value, where `1` indicates the first character vector. If the input is less than `1` or greater than one less than the number of character vectors in the cell array, no text will be drawn on the image or video frame.

When you enter ANSI C `printf`-style format specifications, such as `%d`, `%f`, or `%s`, the **Variables** port appears on the block. The block replaces the format specifications in the **Text** parameter with each element of the input vector . Use the `%s` option to specify a set of text character vectors for the block to display simultaneously at different locations. For example, using a Constant block, enter `[uint8('Text1') 0 uint8('Text2')]` for the **Constant value** parameter. The following table summarizes the supported conversion specifications.

Text Parameter Supported Conversion Specifications

Supported specifications	Support for multiple instances of the same specification	Support for mixed specifications
%d, %i, %u, %c, %f, %o, %x, %X, %e, %E, %g, and %G	Yes	No
%s	No	No

Color value source

Select where to specify the text color. Your choices are:

- `Specify via dialog` — the **Color value** parameter appears on the dialog box.

- `Input port` — the Color port appears on the block.

Color value

Specify the intensity or color of the text. This parameter is visible if, for the **Color source** parameter, you select `Specify via dialog`. Tunable.

The following table describes how to format the color of the text character vectors, which depend on the block input and the number of character vectors you want to insert. Color values for a floating-point data type input image must be between `0` and `1`. Color values for an 8-bit unsigned integer data type input image must between `0` and `255`.

Text Character Vector Color Values

Block Input	One Text Character Vector	Multiple Text Character Vectors
Intensity image	**Color value** parameter or the input to the **Color** port specified as a scalar intensity value	**Color value** parameter or the input to the **Color** port specified as a vector of intensity values whose length is equal to the number of character vectors.
Color image	**Color value** parameter or the input to the **Color** port specified as an RGB triplet that defines the color of the text	**Color value** parameter or the input to the **Color** port specified as an *M*-by-3 matrix of color values, where *M* represents the number of character vectors.

Location source

Indicate where you want to specify the text location. Your choices are:

- `Specify via dialog` — the **Location [x y]** parameter appears on the dialog box.
- `Input port` — the Location port appears on the block.

Location [x y]

Specify the text location. This parameter is visible if, for the **Location source** parameter, you select `Specify via dialog`. Tunable.

The following table describes how to format the location of the text character vectors depending on the number of character vectors you specify to insert. You can specify more than one location regardless of how many text character vectors you specify, but the only way to get a different text character vector at each location is to use the %s option for the **Text** parameter to specify a set of text character vectors. You can enter negative values or values that exceed the dimensions of the input image or video frame, but the text might not be visible.

Location Parameter Text Character Vector Insertion

Parameter	One Instance of One Text Character Vector	Multiple Instances of the Same Text Character Vector	Multiple Instances of Unique Text Character Vector
Location [x y] parameter setting or the input to the Location port	Two-element vector of the form [x y] that indicates the top-left corner of the text bounding box.	M-by-2 matrix, where M represents the number of locations at which to display the text . Each row contains the coordinates of the top-left corner of the text bounding box for the character vector, e.g., $[x_1\ y_1;\ x_2\ y_2]$	M-by-2 matrix, where M represents the number of text character vectors. Each row contains the coordinates of the top-left corner of the text bounding box for the character vector, e.g., $[x_1\ y_1;\ x_2\ y_2]$.

Opacity source

Indicate where you want to specify the text's opaqueness. Your choices are:

- `Specify via dialog` — the **Opacity** parameter appears on the dialog box.
- `Input port` — the Opacity port appears on the block.

Opacity

Specify the opacity of the text. This parameter is visible if, for the **Opacity source** parameter, you select `Specify via dialog`. Tunable.

The following table describes how to format the opacity of the text character vectors depending on the number of character vectors you want to insert.

Text String Opacity Values

Parameter	One Text String	Multiple Text Strings
Opacity parameter setting or the input to the Opacity port	Scalar value between 0 and 1, where 0 is translucent and 1 is opaque	Vector whose length is equal to the number of character vectors

Use the **Image signal** parameter to specify how to input and output a color video signal:

- One multidimensional signal — the block accepts an M-by-N-by-P color video signal, where P is the number of color planes, at one port.

- Separate color signals — additional ports appear on the block. Each port accepts one M-by-N plane of an RGB video stream.

Image signal

Specify how to input and output a color video signal. If you select One multidimensional signal, the block accepts an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select Separate color signals, additional ports appear on the block. Each port accepts one M-by-N plane of an RGB video stream.

Input image is transposed (data order is row major)

When you select this check box, the block assumes that the input buffer contains data elements from the first row first, then data elements from the second row second, and so on through the last row.

Font face

Specify the font of your text. The block populates this list with the fonts installed on your system. On Windows, the block searches the system registry for font files. On UNIX, the block searches the X Server's font path for font files.

Font size (points)

Specify the font size.

Anti-aliased

Select this check box if you want the block to smooth the edges of the text. This can be computationally expensive. If you want your model to run faster, clear this check box.

Examples

- "Annotate Video Files with Frame Numbers"

See Also

Draw Shapes	Computer Vision System Toolbox
Draw Markers	Computer Vision System Toolbox

Introduced in R2013a

Label

Label connected components in binary images

Library

Morphological Operations

`visionmorphops`

Description

The Label block labels the objects in a binary image, BW. The background is represented by pixels equal to 0 (black) and objects are represented by pixels equal to 1 (white). At the Label port, the block outputs a label matrix that is the same size as the input matrix. In the label matrix, pixels equal to 0 represent the background, pixels equal to 1 represent the first object, pixels equal to 2 represent the second object, and so on. At the Count port, the block outputs a scalar value that represents the number of labeled objects.

Port	Input/Output	Supported Data Types	Complex Values Supported
BW	Vector or matrix that represents a binary image	Boolean	No
Label	Label matrix	• 8-, 16-, and 32-bit unsigned integer	No
Count	Scalar that represents the number of labeled objects	Same as Label port	No

Use the **Connectivity** parameter to define which pixels are connected to each other. If you want a pixel to be connected to the other pixels located on the top, bottom, left, and

right, select 4. If you want a pixel to be connected to the other pixels on the top, bottom, left, right, and diagonally, select 8.

Consider the following 3-by-3 image. If, for the **Connectivity** parameter, you select 4, the block considers the white pixels marked by black circles to be connected.
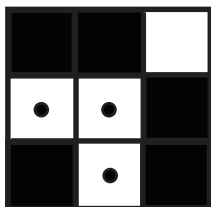
If, for the **Connectivity** parameter, you select 8, the block considers the white pixels marked by black circles to be connected.
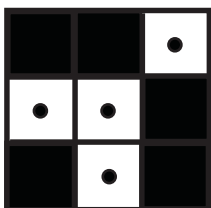
Use the **Output** parameter to determine the block's output. If you select `Label matrix and number of labels`, ports Label and Count appear on the block. The block outputs the label matrix at the Label port and the number of labeled objects at the Count port. If you select `Label matrix`, the Label port appears on the block. If you select `Number of labels`, the Count port appears on the block.

Use the **Output data type** parameter to set the data type of the outputs at the Label and Count ports. If you select `Automatic`, the block calculates the maximum number of objects that can fit inside the image based on the image size and the connectivity you specified. Based on this calculation, it determines the minimum output data type size that guarantees unique region labels and sets the output data type appropriately. If you select `uint32`, `uint16`, or `uint8`, the data type of the output is 32-, 16-, or 8-bit unsigned integers, respectively. If you select `uint16`, or `uint8`, the **If label exceeds data type size, mark remaining regions using** parameter appears in the dialog box. If the number of found objects exceeds the maximum number that can be represented by the

output data type, use this parameter to specify the block's behavior. If you select `Maximum value of the output data type`, the remaining regions are labeled with the maximum value of the output data type. If you select `Zero`, the remaining regions are labeled with zeroes.

Parameters

Connectivity

Specify which pixels are connected to each other. If you want a pixel to be connected to the pixels on the top, bottom, left, and right, select 4. If you want a pixel to be connected to the pixels on the top, bottom, left, right, and diagonally, select 8.

Output

Determine the block's output. If you select `Label matrix and number of labels`, the Label and Count ports appear on the block. The block outputs the label matrix at the Label port and the number of labeled objects at the Count port. If you select `Label matrix`, the Label port appears on the block. If you select `Number of labels`, the Count port appears on the block.

Output data type

Set the data type of the outputs at the Label and Count ports. If you select `Automatic`, the block determines the appropriate data type for the output. If you select `uint32`, `uint16`, or `uint8`, the data type of the output is 32-, 16-, or 8-bit unsigned integers, respectively.

If label exceeds data type size, mark remaining regions using

Use this parameter to specify the block's behavior if the number of found objects exceeds the maximum number that can be represented by the output data type. If you select `Maximum value of the output data type`, the remaining regions are labeled with the maximum value of the output data type. If you select `Zero`, the remaining regions are labeled with zeroes. This parameter is visible if, for the **Output data type** parameter, you choose `uint16` or `uint8`.

See Also

Bottom-hat	Computer Vision System Toolbox software
Closing	Computer Vision System Toolbox software

Dilation	Computer Vision System Toolbox software
Erosion	Computer Vision System Toolbox software
Opening	Computer Vision System Toolbox software
Top-hat	Computer Vision System Toolbox software
bwlabel	Image Processing Toolbox software
bwlabeln	Image Processing Toolbox software

Introduced before R2006a

Median Filter

Perform 2-D median filtering
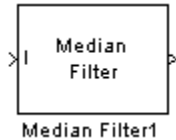
Median Filter1

Library

Filtering and Analysis & Enhancement

`visionanalysis`

`visionfilter`

Description

The Median Filter block replaces the central value of an *M-by-N* neighborhood with its median value. If the neighborhood has a center element, the block places the median value there, as illustrated in the following figure.
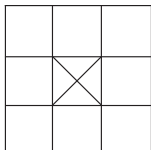
The block has a bias toward the upper-left corner when the neighborhood does not have an exact center. See the median value placement in the following figure.
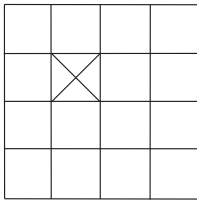
The block pads the edge of the input image, which sometimes causes the pixels within [M/2 N/2] of the edges to appear distorted. The median value is less sensitive than the mean to extreme values. As a result, the Median Filter block can remove salt-and-pepper noise from an image without significantly reducing the sharpness of the image.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Val	Scalar value that represents the constant pad value	Same as I port	No
Output	Matrix of intensity values	Same as I port	No

If the data type of the input signal is floating point, the output has the same data type. The data types of the signals input to the I and Val ports must be the same.

Fixed-Point Data Types

The information in this section is applicable only when the dimensions of the neighborhood are even.

For fixed-point inputs, you can specify accumulator and output data types as discussed in "Parameters" on page 1-358. Not all these fixed-point parameters apply to all types of fixed-point inputs. The following table shows the output and accumulator data type used for each fixed-point input.

Fixed-Point Input	Output Data Type	Accumulator Data Type
Even M	X	X
Odd M	X	
Odd M and complex	X	X
Even M and complex	X	X

When M is even, fixed-point signals use the accumulator and output data types. The accumulator data type store the result of the sum performed while calculating the average of the two central rows of the input matrix. The output data type stores the total result of the average.

Complex fixed-point inputs use the accumulator parameters. The calculation for the sum of the squares of the real and imaginary parts of the input occur, before sorting input elements. The accumulator data type stores the result of the sum of the squares.

Parameters

Neighborhood size

Specify the size of the neighborhood over which the block computes the median.

- Enter a scalar value that represents the number of rows and columns in a square matrix.
- Enter a vector that represents the number of rows and columns in a rectangular matrix.

Output size

This parameter controls the size of the output matrix.

- If you choose `Same as input port I`, the output has the same dimensions as the input to port I. The **Padding options** parameter appears in the dialog box. Use the **Padding options** parameter to specify how to pad the boundary of your input matrix.
- If you select `Valid`, the block only computes the median where the neighborhood fits entirely within the input image, with no need for padding. The dimensions of the output image are, `output rows = input rows - neighborhood rows + 1`, and

output columns = input columns - neighborhood columns + 1.

Padding options

Specify how to pad the boundary of your input matrix.

- Select `Constant` to pad your matrix with a constant value. The **Pad value source** parameter appears in the dialog box
- Select `Replicate` to pad your input matrix by repeating its border values.
- Select `Symmetric` to pad your input matrix with its mirror image.
- Select `Circular` to pad your input matrix using a circular repetition of its elements. This parameter appears if, for the **Output size** parameter, you select `Same as input port I`.

For more information on padding, see the Image Pad block reference page.

Pad value source

Use this parameter to specify how to define your constant boundary value.

- Select `Specify via dialog` to enter your value in the block parameters dialog box. The **Pad value** parameter appears in the dialog box.
- Select `Input port` to specify your constant value using the `Val` port. This parameter appears if, for the **Padding options** parameter, you select `Constant`.

Pad value

Enter the constant value with which to pad your matrix. This parameter appears if, for the **Pad value source** parameter, you select `Specify via dialog`. Tunable.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Note Only certain cases require the use of the accumulator and output parameters. Refer to "Fixed-Point Data Types" on page 1-357 for more information.

Accumulator

Use this parameter to specify the accumulator word and fraction lengths resulting from a complex-complex multiplication in the block:

- When you select `Same as input`, these characteristics match the related input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. This block requires power-of-two slope and a bias of 0.

Output

Choose how to specify the output word length and fraction length:

- When you select `Same as input`, these characteristics match the related input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. This block requires power-of-two slope and a bias of 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Gonzales, Rafael C. and Richard E. Woods. *Digital Image Processing. 2nd ed*. Englewood Cliffs, NJ: Prentice-Hall, 2002.

See Also

2-D Convolution	Computer Vision System Toolbox
2-D FIR Filter	Computer Vision System Toolbox
`medfilt2`	Image Processing Toolbox

Introduced before R2006a

Opening

Perform morphological opening on binary or intensity images

Library

Morphological Operations

`visionmorphops`

Description

The Opening block performs an erosion operation followed by a dilation operation using a predefined neighborhood or structuring element. This block uses flat structuring elements only.

Port	Input/Output	Supported Data Types	Complex Values Supported
	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Nhood	Matrix or vector of ones and zeros that represents the neighborhood values	Boolean	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Output	Scalar, vector, or matrix of intensity values that represents the opened image	Same as I port	No

The output signal has the same data type as the input to the I port.

Use the **Neighborhood or structuring element source** parameter to specify how to enter your neighborhood or structuring element values. If you select `Specify via dialog`, the **Neighborhood or structuring element** parameter appears in the dialog box. If you select `Input port`, the Nhood port appears on the block. Use this port to enter your neighborhood values as a matrix or vector of 1s and 0s. You can only specify a structuring element using the dialog box.

Use the **Neighborhood or structuring element** parameter to define the region the block moves throughout the image. Specify a neighborhood by entering a matrix or vector of 1s and 0s. Specify a structuring element with the `strel` function from the Image Processing Toolbox. If the structuring element is decomposable into smaller elements, the block executes at higher speeds due to the use of a more efficient algorithm.

Parameters

Neighborhood or structuring element source

Specify how to enter your neighborhood or structuring element values. Select `Specify via dialog` to enter the values in the dialog box. Select `Input port` to use the Nhood port to specify the neighborhood values. You can only specify a structuring element using the dialog box.

Neighborhood or structuring element

If you are specifying a neighborhood, this parameter must be a matrix or vector of 1s and 0s. If you are specifying a structuring element, use the `strel` function from the Image Processing Toolbox. This parameter is visible if, for the **Neighborhood or structuring element source** parameter, you select `Specify via dialog`.

References

[1] Soille, Pierre. *Morphological Image Analysis. 2nd ed*. New York: Springer, 2003.

See Also

Bottom-hat	Computer Vision System Toolbox software
Closing	Computer Vision System Toolbox software
Dilation	Computer Vision System Toolbox software
Erosion	Computer Vision System Toolbox software
Label	Computer Vision System Toolbox software
Top-hat	Computer Vision System Toolbox software
`imopen`	Image Processing Toolbox software
`strel`	Image Processing Toolbox software

Introduced before R2006a

Optical Flow

Estimate object velocities
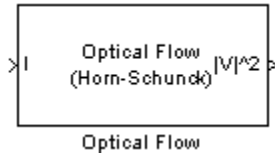
Optical Flow

Library

Analysis & Enhancement

`visionanalysis`

Description

The Optical Flow block estimates the direction and speed of object motion from one image to another or from one video frame to another using either the Horn-Schunck or the Lucas-Kanade method.

Port	Output	Supported Data Types	Complex Values Supported
I/I1	Scalar, vector, or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point (supported when the **Method** parameter is set to `Lucas-Kanade`)	No
I2	Scalar, vector, or matrix of intensity values	Same as I port	No
|V|^2	Matrix of velocity magnitudes	Same as I port	No

Port	Output	Supported Data Types	Complex Values Supported
V	Matrix of velocity components in complex form	Same as I port	Yes

To compute the optical flow between two images, you must solve the following optical flow constraint equation:

$$I_x u + I_y v + I_t = 0$$

.

- I_x, I_y, and I_t are the spatiotemporal image brightness derivatives.
- u is the horizontal optical flow.
- v is the vertical optical flow.

Horn-Schunck Method

By assuming that the optical flow is smooth over the entire image, the Horn-Schunck method computes an estimate of the velocity field, $[u \quad v]^T$, that minimizes this equation:

$$E = \iint (I_x u + I_y v + I_t)^2 \, dx dy + \alpha \iint \left\{ \left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial y} \right)^2 + \left(\frac{\partial v}{\partial x} \right)^2 + \left(\frac{\partial v}{\partial y} \right)^2 \right\} dx dy$$

.

In this equation, $\frac{\partial u}{\partial x}$ and $\frac{\partial u}{\partial y}$ are the spatial derivatives of the optical velocity component, u, and α scales the global smoothness term. The Horn-Schunck method minimizes the previous equation to obtain the velocity field, [u v], for each pixel in the image. This method is given by the following equations:

$$u_{x,y}^{k+1} = \bar{u}_{x,y}^{k} - \frac{I_x[I_x\bar{u}_{x,y}^{k} + I_y\bar{v}_{x,y}^{k} + I_t]}{\alpha^2 + I_x^2 + I_y^2}$$

$$v_{x,y}^{k+1} = \bar{v}_{x,y}^{k} - \frac{I_y[I_x\bar{u}_{x,y}^{k} + I_y\bar{v}_{x,y}^{k} + I_t]}{\alpha^2 + I_x^2 + I_y^2}$$

.

In these equations, $\begin{bmatrix} u_{x,y}^{k} & v_{x,y}^{k} \end{bmatrix}$ is the velocity estimate for the pixel at (x,y), and

$\begin{bmatrix} \bar{u}_{x,y}^{k} & \bar{v}_{x,y}^{k} \end{bmatrix}$ is the neighborhood average of $\begin{bmatrix} u_{x,y}^{k} & v_{x,y}^{k} \end{bmatrix}$. For $k = 0$, the initial velocity is 0.

To solve u and v using the Horn-Schunck method:

1

Compute I_x and I_y using the Sobel convolution kernel,

$\begin{bmatrix} -1 & -2 & -1; & 0 & 0 & 0; & 1 & 2 & 1 \end{bmatrix}$, and its transposed form, for each pixel in the first image.

2

Compute I_t between images 1 and 2 using the $\begin{bmatrix} -1 & 1 \end{bmatrix}$ kernel.

3 Assume the previous velocity to be 0, and compute the average velocity for each pixel

using $\begin{bmatrix} 0 & 1 & 0; & 1 & 0 & 1; & 0 & 1 & 0 \end{bmatrix}$ as a convolution kernel.

4 Iteratively solve for u and v.

Lucas-Kanade Method

To solve the optical flow constraint equation for u and v, the Lucas-Kanade method divides the original image into smaller sections and assumes a constant velocity in each section. Then, it performs a weighted least-square fit of the optical flow constraint

equation to a constant model for $\begin{bmatrix} u & v \end{bmatrix}^T$ in each section Ω. The method achieves this fit by minimizing the following equation:

$$\sum_{x \in \Omega} W^2 [I_x u + I_y v + I_t]^2$$

W is a window function that emphasizes the constraints at the center of each section. The solution to the minimization problem is

$$\begin{bmatrix} \sum W^2 I_x^2 & \sum W^2 I_x I_y \\ \sum W^2 I_y I_x & \sum W^2 I_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} = -\begin{bmatrix} \sum W^2 I_x I_t \\ \sum W^2 I_y I_t \end{bmatrix}$$

.

When you set the **Temporal gradient filter** to `Difference filter [-1 1]`, *u* and *v* are solved as follows:

1

Compute I_x and I_y using the kernel $\begin{bmatrix} -1 & 8 & 0 & -8 & 1 \end{bmatrix} / 12$ and its transposed form.

If you are working with fixed-point data types, the kernel values are signed fixed-point values with word length equal to 16 and fraction length equal to 15.

2

Compute I_t between images 1 and 2 using the $\begin{bmatrix} -1 & 1 \end{bmatrix}$ kernel.

3

Smooth the gradient components, I_x, I_y, and I_t, using a separable and isotropic 5-by-5 element kernel whose effective 1-D coefficients are $\begin{bmatrix} 1 & 4 & 6 & 4 & 1 \end{bmatrix} / 16$. If you are working with fixed-point data types, the kernel values are unsigned fixed-point values with word length equal to 8 and fraction length equal to 7.

4 Solve the 2-by-2 linear equations for each pixel using the following method:

•

If $A = \begin{bmatrix} a & b \\ b & c \end{bmatrix} = \begin{bmatrix} \sum W^2 I_x^2 & \sum W^2 I_x I_y \\ \sum W^2 I_y I_x & \sum W^2 I_y^2 \end{bmatrix}$

Then the eigenvalues of A are $\lambda_i = \dfrac{a+c}{2} \pm \dfrac{\sqrt{4b^2 + (a-c)^2}}{2}; i = 1,2$

In the fixed-point diagrams, $P = \dfrac{a+c}{2}, Q = \dfrac{\sqrt{4b^2 + (a-c)^2}}{2}$

- The eigenvalues are compared to the threshold, τ, that corresponds to the value you enter for the threshold for noise reduction. The results fall into one of the following cases:

Case 1: $\lambda_1 \geq \tau$ and $\lambda_2 \geq \tau$

A is nonsingular, the system of equations are solved using Cramer's rule.

Case 2: $\lambda_1 \geq \tau$ and $\lambda_2 < \tau$

A is singular (noninvertible), the gradient flow is normalized to calculate u and v.

Case 3: $\lambda_1 < \tau$ and $\lambda_2 < \tau$

The optical flow, u and v, is 0.

If you set the temporal gradient filter to `Derivative of Gaussian`, u and v are solved using the following steps. You can see the flow chart for this process at the end of this section:

1

Compute I_x and I_y using the following steps:

a Use a Gaussian filter to perform temporal filtering. Specify the temporal filter characteristics such as the standard deviation and number of filter coefficients using the **Number of frames to buffer for temporal smoothing** parameter.

b Use a Gaussian filter and the derivative of a Gaussian filter to smooth the image using spatial filtering. Specify the standard deviation and length of the image smoothing filter using the **Standard deviation for image smoothing filter** parameter.

2

Compute I_t between images 1 and 2 using the following steps:

a Use the derivative of a Gaussian filter to perform temporal filtering. Specify the temporal filter characteristics such as the standard deviation and number of

filter coefficients using the **Number of frames to buffer for temporal smoothing** parameter.

b Use the filter described in step 1b to perform spatial filtering on the output of the temporal filter.

3 Smooth the gradient components, I_x, I_y, and I_t, using a gradient smoothing filter. Use the **Standard deviation for gradient smoothing filter** parameter to specify the standard deviation and the number of filter coefficients for the gradient smoothing filter.

4 Solve the 2-by-2 linear equations for each pixel using the following method:

- If $A = \begin{bmatrix} a & b \\ b & c \end{bmatrix} = \begin{bmatrix} \sum W^2 I_x^2 & \sum W^2 I_x I_y \\ \sum W^2 I_y I_x & \sum W^2 I_y^2 \end{bmatrix}$

  Then the eigenvalues of A are $\lambda_i = \dfrac{a+c}{2} \pm \dfrac{\sqrt{4b^2 + (a-c)^2}}{2} ; i = 1, 2$

- When the block finds the eigenvalues, it compares them to the threshold, τ, that corresponds to the value you enter for the **Threshold for noise reduction** parameter. The results fall into one of the following cases:

  Case 1: $\lambda_1 \geq \tau$ and $\lambda_2 \geq \tau$

  A is nonsingular, so the block solves the system of equations using Cramer's rule.

  Case 2: $\lambda_1 \geq \tau$ and $\lambda_2 < \tau$

  A is singular (noninvertible), so the block normalizes the gradient flow to calculate u and v.

  Case 3: $\lambda_1 < \tau$ and $\lambda_2 < \tau$

  The optical flow, u and v, is 0.
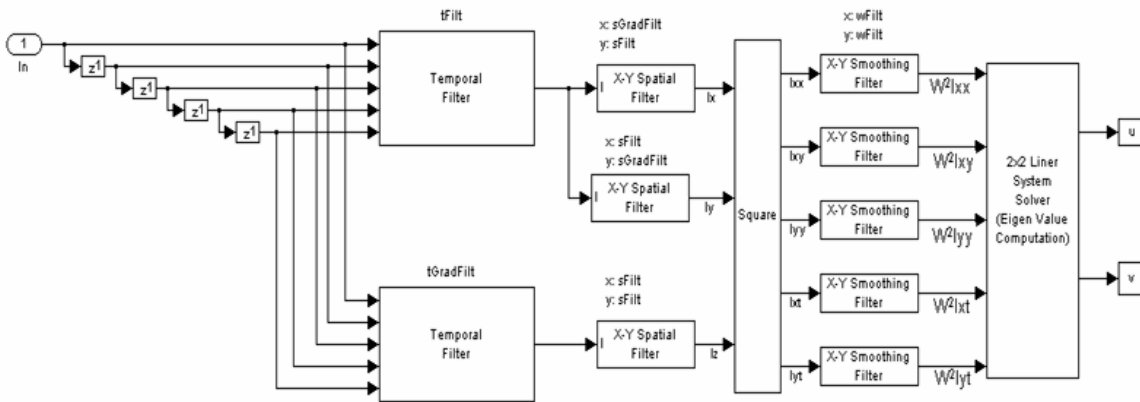
tFilt = Coefficients of Gaussian Filter
tGradFilt = Coefficients of the Derivative of a Gaussian Filter

sFilt = Coefficients of Gaussian Filter
sGradFilt = Coefficients of the Derivative of a Gaussian Filter

Fixed-Point Data Type Diagram

The following diagrams shows the data types used in the Optical Flow block for fixed-point signals. The block supports fixed-point data types only when the **Method** parameter is set to Lucas-Kanade.

Data type diagram for Optical Flow block's overall algorithm
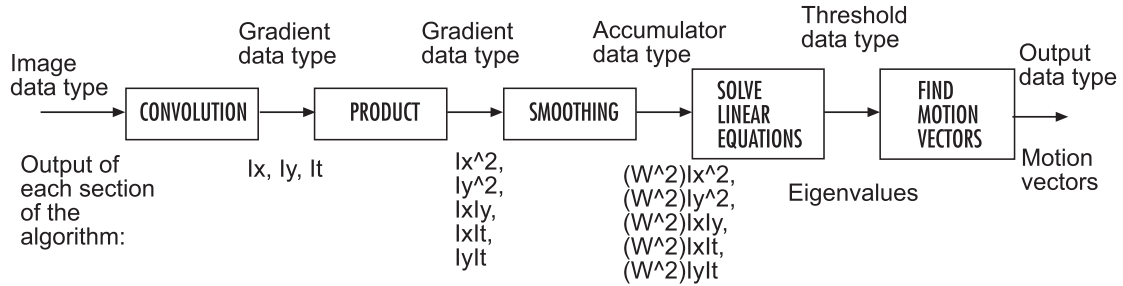
Data type diagram for convolution algorithm
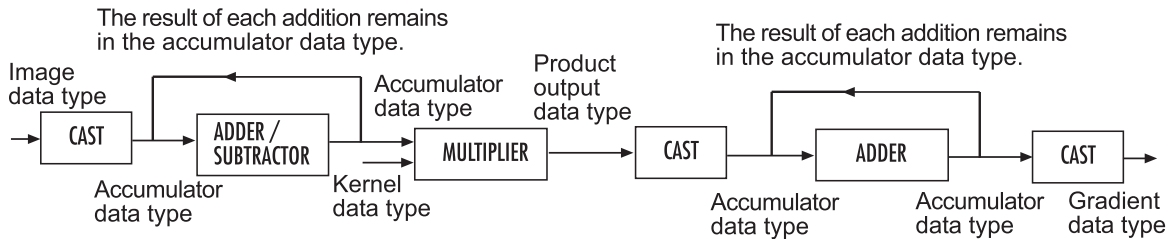
Data type diagram for smoothing algorithm
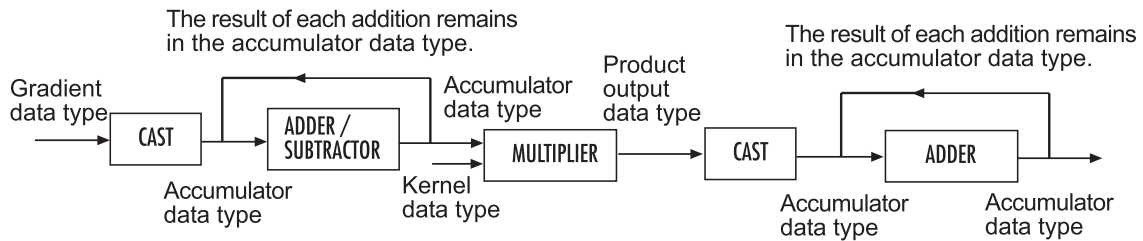
Data type diagram for product algorithm
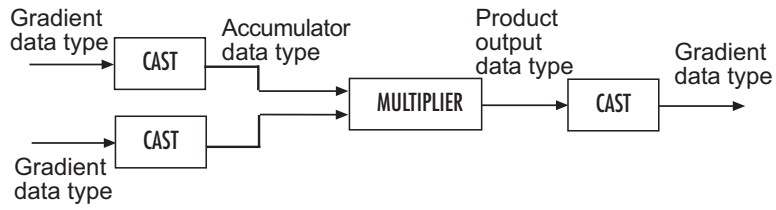
Solving linear equations to compute eigenvalues
(see Step 4 in the Lucas-Kanade Method section for the eigenvalue equations)

Data type diagram for P

The result of each addition remains
in the accumulator data type.

ADDER → RIGHT SHIFT

Accumulator
data type

Accumulator
data type

Accumulator
data type

Data type diagram for 4b^2

Accumulator
data type

Int32

MULTIPLIER → CAST → MULTIPLIER → CAST

Accumulator
data type

Product output
data type

Accumulator
data type

Product
output
data type

Accumulator
data type

Data type diagram for (a-c)^2

The result of each addition remains
in the accumulator data type.

Accumulator
data type

Product
output
data type

Accumulator
data type

ADDER → MULTIPLIER → CAST

Accumulator
data type

Accumulator
data type

Data type diagram for Q

The result of each addition remains
in the accumulator data type.

ADDER → SQUARE ROOT → RIGHT SHIFT

Accumulator
data type

Accumulator
data type

Accumulator
data type

Accumulator
data type

Data type diagram for eigenvalues

The result of each addition remains
in the accumulator data type.

Accumulator
data type

ADDER /
SUBTRACTOR → CAST

Accumulator
data type

Threshold
data type
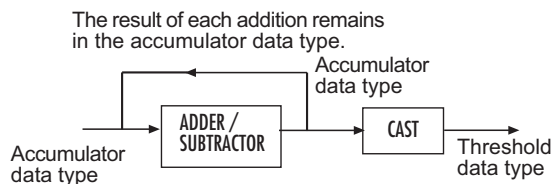
Data type diagram for finding the motion vectors algorithm
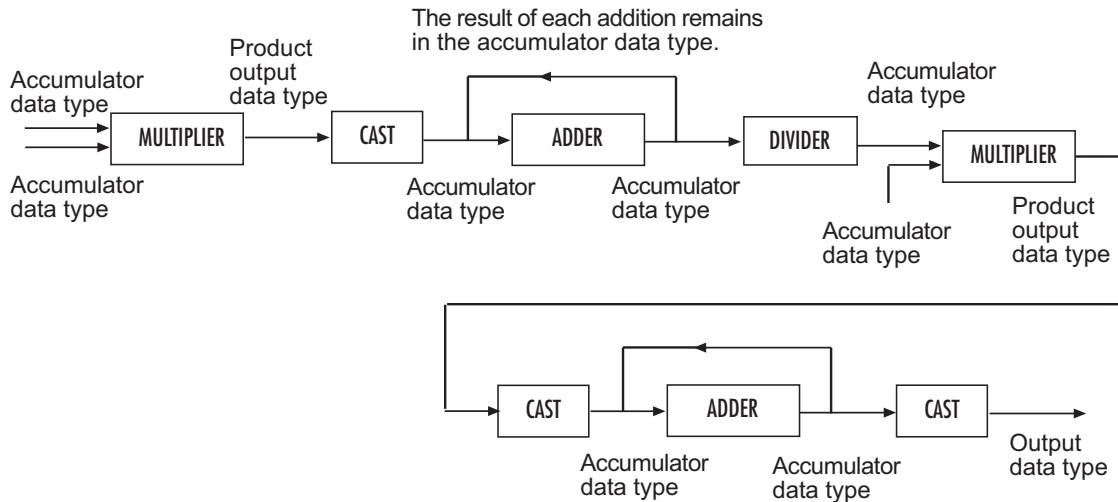
You can set the product output, accumulator, gradients, threshold, and output data types in the block mask.

Parameters

Method

Select the method the block uses to calculate the optical flow. Your choices are `Horn-Schunck` or `Lucas-Kanade`.

Compute optical flow between

Select `Two images` to compute the optical flow between two images. Select `Current frame and N-th frame back` to compute the optical flow between two video frames that are N frames apart.

This parameter is visible if you set the **Method** parameter to `Horn-Schunck` or you set the **Method** parameter to `Lucas-Kanade` and the **Temporal gradient filter** to `Difference filter [-1 1]`.

N

Enter a scalar value that represents the number of frames between the reference frame and the current frame. This parameter becomes available if you set the

Compute optical flow between parameter, you select `Current frame and N-th frame back`.

Smoothness factor

If the relative motion between the two images or video frames is large, enter a large positive scalar value. If the relative motion is small, enter a small positive scalar value. This parameter becomes available if you set the **Method** parameter to `Horn-Schunck`.

Stop iterative solution

Use this parameter to control when the block's iterative solution process stops. If you want it to stop when the velocity difference is below a certain threshold value, select `When velocity difference falls below threshold`. If you want it to stop after a certain number of iterations, choose `When maximum number of iterations is reached`. You can also select `Whichever comes first`. This parameter becomes available if you set the **Method** parameter to `Horn-Schunck`.

Maximum number of iterations

Enter a scalar value that represents the maximum number of iterations you want the block to perform. This parameter is only visible if, for the **Stop iterative solution** parameter, you select `When maximum number of iterations is reached` or `Whichever comes first`. This parameter becomes available if you set the **Method** parameter to `Horn-Schunck`.

Velocity difference threshold

Enter a scalar threshold value. This parameter is only visible if, for the **Stop iterative solution** parameter, you select `When velocity difference falls below threshold` or `Whichever comes first`. This parameter becomes available if you set the **Method** parameter to `Horn-Schunck`.

Velocity output

If you select `Magnitude-squared`, the block outputs the optical flow matrix where each element is of the form $u^2 + v^2$. If you select `Horizontal and vertical components in complex form`, the block outputs the optical flow matrix where each element is of the form $u + jv$.

Temporal gradient filter

Specify whether the block solves for *u* and *v* using a difference filter or a derivative of a Gaussian filter. This parameter becomes available if you set the **Method** parameter to `Lucas-Kanade`.

Number of frames to buffer for temporal smoothing

Use this parameter to specify the temporal filter characteristics such as the standard deviation and number of filter coefficients. This parameter becomes available if you set the **Temporal gradient filter** parameter to `Derivative of Gaussian`.

Standard deviation for image smoothing filter

Specify the standard deviation for the image smoothing filter. This parameter becomes available if you set the **Temporal gradient filter** parameter to `Derivative of Gaussian`.

Standard deviation for gradient smoothing filter

Specify the standard deviation for the gradient smoothing filter. This parameter becomes available if you set the **Temporal gradient filter** parameter to `Derivative of Gaussian`.

Discard normal flow estimates when constraint equation is ill-conditioned

Select this check box if you want the block to set the motion vector to zero when the optical flow constraint equation is ill-conditioned. This parameter becomes available if you set the **Temporal gradient filter** parameter to `Derivative of Gaussian`.

Output image corresponding to motion vectors (accounts for block delay)

Select this check box if you want the block to output the image that corresponds to the motion vector being output by the block. This parameter becomes available if you set the **Temporal gradient filter** parameter to `Derivative of Gaussian`.

Threshold for noise reduction

Enter a scalar value that determines the motion threshold between each image or video frame. The higher the number, the less small movements impact the optical flow calculation. This parameter becomes available if you set the **Method** parameter to `Lucas-Kanade`.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Product output

Use this parameter to specify how to designate the product output word and fraction lengths.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output in bits.

- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Accumulator

Use this parameter to specify how to designate this accumulator word and fraction lengths.

- When you select `Same as product output`, these characteristics match those of the product output.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator in bits.

- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Gradients

Choose how to specify the word length and fraction length of the gradients data type:

- When you select `Same as accumulator`, these characteristics match those of the accumulator.

- When you select `Same as product output`, these characteristics match those of the product output.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the quotient, in bits.

- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the quotient. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Threshold

Choose how to specify the word length and fraction length of the threshold data type:

- When you select `Same word length as first input`, the threshold word length matches that of the first input.

- When you select `Specify word length`, enter the word length of the threshold data type.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the threshold, in bits.

- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the threshold. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Output

Choose how to specify the word length and fraction length of the output data type:

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length in bits and the slope of the output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Barron, J.L., D.J. Fleet, S.S. Beauchemin, and T.A. Burkitt. *Performance of optical flow techniques*. CVPR, 1992.

See Also

Block Matching	Computer Vision System Toolbox software
Gaussian Pyramid	Computer Vision System Toolbox software

Introduced before R2006a

PSNR

Compute peak signal-to-noise ratio (PSNR) between images
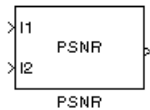
Library

Statistics

visionstatistics

Description

The PSNR block computes the peak signal-to-noise ratio, in decibels, between two images. This ratio is often used as a quality measurement between the original and a compressed image. The higher the PSNR, the better the quality of the compressed, or reconstructed image.

The *Mean Square Error (MSE)* and the *Peak Signal to Noise Ratio (PSNR)* are the two error metrics used to compare image compression quality. The MSE represents the cumulative squared error between the compressed and the original image, whereas PSNR represents a measure of the peak error. The lower the value of MSE, the lower the error.

To compute the PSNR, the block first calculates the mean-squared error using the following equation:

$$MSE = \frac{\sum_{M,N} [I_1(m,n) - I_2(m,n)]^2}{M * N}$$

In the previous equation, *M* and *N* are the number of rows and columns in the input images, respectively. Then the block computes the PSNR using the following equation:

$$PSNR = 10 \log_{10} \left(\frac{R^2}{MSE} \right)$$

In the previous equation, R is the maximum fluctuation in the input image data type. For example, if the input image has a double-precision floating-point data type, then R is 1. If it has an 8-bit unsigned integer data type, R is 255, etc.

Recommendation for Computing PSNR for Color Images

Different approaches exist for computing the PSNR of a color image. Because the human eye is most sensitive to luma information, compute the PSNR for color images by converting the image to a color space that separates the intensity (luma) channel, such as YCbCr. The Y (luma), in YCbCr represents a weighted average of R, G, and B. G is given the most weight, again because the human eye perceives it most easily. With this consideration, compute the PSNR only on the luma channel.

Ports

Port	Output	Supported Data Types	Complex Values Supported
I1	Scalar, vector, or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
I2	Scalar, vector, or matrix of intensity values	Same as I1 port	No
Output	Scalar value that represents the PSNR	• Double-precision floating point For fixed-point or integer input, the block output is double-precision floating point. Otherwise, the block input and output are the same data type.	No

Introduced before R2006a

Read Binary File

Read binary video data from files

Library

Sources

`visionsources`

Description

The Read Binary File block reads video data from a binary file and imports it into a Simulink model.

This block takes user specified parameters that describe the format of the video data. These parameters together with the raw binary file, which stores only raw pixel values, creates the video data signal for a Simulink model. The video data read by this block must be stored in row major format.

Note This block supports code generation only for platforms that have file I/O available. You cannot use this block to do code generation with Simulink Desktop Real-Time or Simulink Real-Time™.

Port	Output	Supported Data Types	Complex Values Supported
Output	Scalar, vector, or matrix of integer values	• 8-, 16- 32-bit signed integer • 8-, 16- 32-bit unsigned integer	No

Port	Output	Supported Data Types	Complex Values Supported
EOF	Scalar value	Boolean	No

Four Character Code Video Formats

Four Character Codes (FOURCC) identify video formats. For more information about these codes, see `http://www.fourcc.org`.

Use the **Four character code** parameter to identify the binary file format. Then, use the **Rows** and **Cols** parameters to define the size of the output matrix. These dimensions should match the matrix dimensions of the data inside the file.

Custom Video Formats

If your binary file contains data that is not in FOURCC format, you can configure the Read Binary File block to understand a custom format:

- Use the **Bit stream format** parameter to specify whether your data is planar or packed. If your data is packed, use the **Rows** and **Cols** parameters to define the size of the output matrix.

- Use the **Number of output components** parameter to specify the number of components in the binary file. This number corresponds to the number of block output ports.

- Use the **Component**, **Bits**, **Rows**, and **Cols** parameters to specify the component name, bit size, and size of the output matrices, respectively. The block uses the **Component** parameter to label the output ports.

- Use the **Component order in binary file** parameter to specify how the components are arranged within the file.

- Select the **Interlaced video** check box if the binary file contains interlaced video data.

- Select the **Input file has signed data** check box if the binary file contains signed integers.

- Use the **Byte order in binary file** to indicate whether your binary file has little endian or big endian byte ordering.

Parameters

File name

Specify the name of the binary file to read. If the location of this file is on your MATLAB path, enter the filename. If the location of this file is not on your MATLAB path, use the **Browse** button to specify the full path to the file as well as the filename.

Video format

Specify the format of the binary video data. Your choices are `Four character codes` or `Custom`. See "Four Character Code Video Formats" on page 1-385 or "Custom Video Formats" on page 1-385 for more details.

Four character code

From the drop-down list, select the binary file format.

Frame size: Rows, Cols

Define the size of the output matrix. These dimensions should match the matrix dimensions of the data inside the file.

Line ordering

Specify how the block fills the output matrix. If you select `Top line first`, the block first fills the first row of the output matrix with the contents of the binary file. It then fills the other rows in increasing order. If you select `Bottom line first`, the block first fills the last row of the output matrix. It then fills the other rows in decreasing order.

Number of times to play file

Specify the number of times to play the file. The number you enter must be a positive integer or `inf`, to play the file until you stop the simulation.

Output end-of-file indicator

Specifies the output is the last video frame in the binary file. When you select this check box, a Boolean output port labeled EOF appears on the block. The output from the EOF port is 1 when the last video frame in the binary file is output from the block. Otherwise, the output from the EOF port is 0.

Sample time

Specify the sample period of the output signal.

Bit stream format

Specify whether your data is planar or packed.

Frame size: Rows, Cols

Define the size of the output matrix. This parameter appears when you select a **Bit stream format** parameter of `Packed`.

Number of output components

Specify the number of components in the binary file.

Component, Bits, Rows, Cols

Specify the component name, bit size, and size of the output matrices, respectively.

Component order in binary file

Specify the order in which the components appear in the binary file.

Interlaced video

Select this check box if the binary file contains interlaced video data.

Input file has signed data

Select this check box if the binary file contains signed integers.

Byte order in binary file

Use this parameter to indicate whether your binary file has little endian or big endian byte ordering.

See Also

From Multimedia File	Computer Vision System Toolbox
Write Binary File	Computer Vision System Toolbox

Introduced before R2006a

Resize

Enlarge or shrink image sizes

Library

Geometric Transformations

`visiongeotforms`

Description

The Resize block enlarges or shrinks an image by resizing the image along one dimension (row or column). Then, it resizes the image along the other dimension (column or row).

This block supports intensity and color images on its ports. When you input a floating point data type signal, the block outputs the same data type.

Shrinking an image can introduce high frequency components into the image and aliasing might occur. If you select the **Perform antialiasing when resize factor is between 0 and 100** check box, the block performs low pass filtering on the input image before shrinking it.

Port Description

Port	Input/Output	Supported Data Types	Complex Values Supported
Image / Input	*M*-by-*N* matrix of intensity values or an *M*-by-*N*-by-*P* color video signal where *P* is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
ROI	Four-element vector [x y width height] that defines the ROI	• Double-precision floating point (only supported if the input to the Input port is floating point) • Single-precision floating point (only supported if the input to the Input port is floating point) • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
Output	Resized image	Same as Input port	No
Flag	Boolean value that indicates whether the ROI is within the image bounds	Boolean	No

ROI Processing

To resize a particular region of each image, select the **Enable ROI processing** check box. To enable this option, select the following parameter values.

- **Specify** = `Number of output rows and columns`
- **Interpolation method** = `Nearest neighbor`, `Bilinear`, or `Bicubic`
- Clear the **Perform antialiasing when resize factor is between 0 and 100** check box.

If you select the **Enable ROI processing** check box, the ROI port appears on the block. Use this port to define a region of interest (ROI) in the input matrix, that you want to

resize. The input to this port must be a four-element vector, [x y width height]. The first two elements define the upper-left corner of the ROI, and the second two elements define the width and height of the ROI.

If you select the **Enable ROI processing** check box, the **Output flag indicating if any part of ROI is outside image bounds** check box appears in the dialog box. If you select this check box, the Flag port appears on the block. The following tables describe the Flag port output.

Flag Port Output	Description
0	ROI is completely inside the input image.
1	ROI is completely or partially outside the input image.

Fixed-Point Data Types

The following diagram shows the data types used in the Resize block for fixed-point signals.
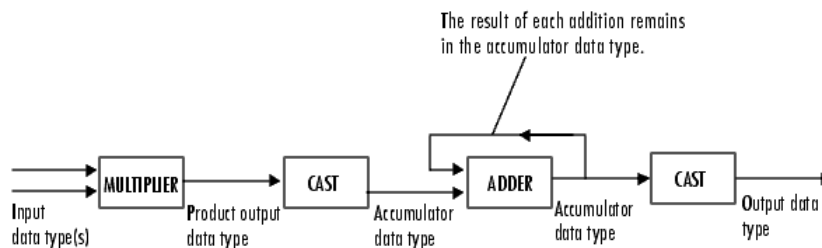
You can set the interpolation weights table, product output, accumulator, and output data types in the block mask.

Parameters

Specify

Specify which aspects of the image to resize. Your choices are `Output size as a percentage of input size`, `Number of output columns and preserve`

aspect ratio, `Number of output rows and preserve aspect ratio`, or `Number of output rows and columns`.

When you select `Output size as a percentage of input size`, the **Resize factor in %** parameter appears in the dialog box. Enter a scalar percentage value that is applied to both rows and columns.

When you select `Number of output columns and preserve aspect ratio`, the **Number of output columns** parameter appears in the dialog box. Enter a scalar value that represents the number of columns you want the output image to have. The block calculates the number of output rows so that the output image has the same aspect ratio as the input image.

When you select `Number of output rows and preserve aspect ratio`, the **Number of output rows** parameter appears in the dialog box. Enter a scalar value that represents the number of rows you want the output image to have. The block calculates the number of output columns so that the output image has the same aspect ratio as the input image.

When you select `Number of output rows and columns`, the **Number of output rows and columns** parameter appears in the dialog box. Enter a two-element vector, where the first element is the number of rows in the output image and the second element is the number of columns. In this case, the aspect ratio of the image can change.

Resize factor in %

Enter a scalar percentage value that is applied to both rows and columns or a two-element vector, where the first element is the percentage by which to resize the rows and the second element is the percentage by which to resize the columns. This parameter is visible if, for the **Specify** parameter, you select `Output size as a percentage of input size`.

You must enter a scalar value that is greater than zero. The table below describes the affect of the resize factor value:

Resize factor in %	Resizing of image
`0` < resize factor < `100`	The block shrinks the image.
resize factor = `100`	Image unchanged.

Resize factor in %	Resizing of image
resize factor > 100	The block enlarges the image.

The dimensions of the output matrix depend on the **Resize factor in %** parameter and are given by the following equations:

```
number_output_rows = round(number_input_rows*resize_factor/100);
```

```
number_output_cols = round(number_input_cols*resize_factor/100);
```

Number of output columns

Enter a scalar value that represents the number of columns you want the output image to have. This parameter is visible if, for the **Specify** parameter, you select `Number of output columns and preserve aspect ratio`.

Number of output rows

Enter a scalar value that represents the number of rows you want the output image to have. This parameter is visible if, for the **Specify** parameter, you select `Number of output rows and preserve aspect ratio`.

Number of output rows and columns

Enter a two-element vector, where the first element is the number of rows in the output image and the second element is the number of columns. This parameter is visible if, for the **Specify** parameter, you select `Number of output rows and columns`.

Interpolation method

Specify which interpolation method to resize the image.

When you select `Nearest neighbor`, the block uses one nearby pixel to interpolate the pixel value. This option though the most efficient, is the least accurate. When you select `Bilinear`, the block uses four nearby pixels to interpolate the pixel value. When you select `Bicubic` or `Lanczos2`, the block uses 16 nearby pixels to interpolate the pixel value. When you select `Lanczos3`, the block uses 36 surrounding pixels to interpolate the pixel value.

The Resize block performs optimally when you set this parameter to `Nearest neighbor` with one of the following conditions:

- You set the **Resize factor in %** parameter to a multiple of 100.

- Dividing 100 by the **Resize factor in %** parameter value results in an integer value.

Perform antialiasing when resize factor is between 0 and 100

If you select this check box, the block performs low-pass filtering on the input image before shrinking it to prevent aliasing.

Enable ROI processing

Select this check box to resize a particular region of each image. This parameter is available when the **Specify** parameter is set to `Number of output rows and columns`, the **Interpolation method** parameter is set to `Nearest neighbor`, `Bilinear`, or `Bicubic`, and the **Perform antialiasing when resize factor is between 0 and 100** check box is not selected.

Output flag indicating if any part of ROI is outside image bounds

If you select this check box, the Flag port appears on the block. The block outputs 1 at this port if the ROI is completely or partially outside the input image. Otherwise, it outputs 0.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Interpolation weights table

Choose how to specify the word length of the values of the interpolation weights table. The fraction length of the interpolation weights table values is always equal to the word length minus one:

- When you select `Same as input`, the word length of the interpolation weights table values match that of the input to the block.

- When you select `Binary point scaling`, you can enter the word length of the interpolation weights table values, in bits.

- When you select `Slope and bias scaling`, you can enter the word length of the interpolation weights table values, in bits.

Product output

As depicted in the preceding diagram, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths.

- When you select `Same as input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.
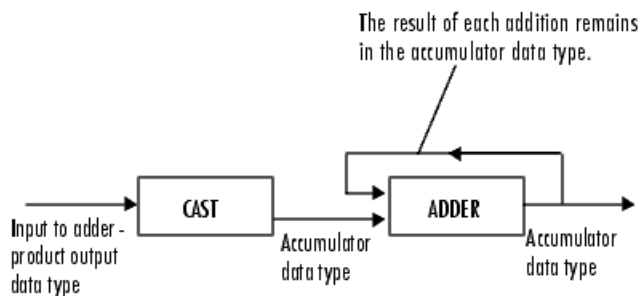
Accumulator

As depicted in the preceding diagram, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths.

- When you select `Same as product output`, these characteristics match those of the product output.

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as input`, these characteristics match those of the input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Ward, Joseph and David R. Cok. "Resampling Algorithms for Image Resizing and Rotation", *Proc. SPIE Digital Image Processing Applications*, vol. 1075, pp. 260-269, 1989.

[2] Wolberg, George. *Digital Image Warping*. Washington: IEEE Computer Society Press, 1990.

See Also

Rotate	Computer Vision System Toolbox software
Shear	Computer Vision System Toolbox software
Translate	Computer Vision System Toolbox software
`imresize`	Image Processing Toolbox software

Introduced before R2006a

Rotate

Rotate image by specified angle
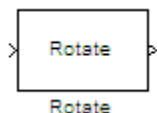
Library

Geometric Transformations

visiongeotforms

Description

Use the Rotate block to rotate an image by an angle specified in radians.

Note This block supports intensity and color images on its ports.

Port	Description
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes
Angle	Rotation angle
Output	Rotated matrix

The Rotate block uses the 3-pass shear rotation algorithm to compute its values, which is different than the algorithm used by the `imrotate` function in the Image Processing Toolbox.

Fixed-Point Data Types

The following diagram shows the data types used in the Rotate block for bilinear interpolation of fixed-point signals.
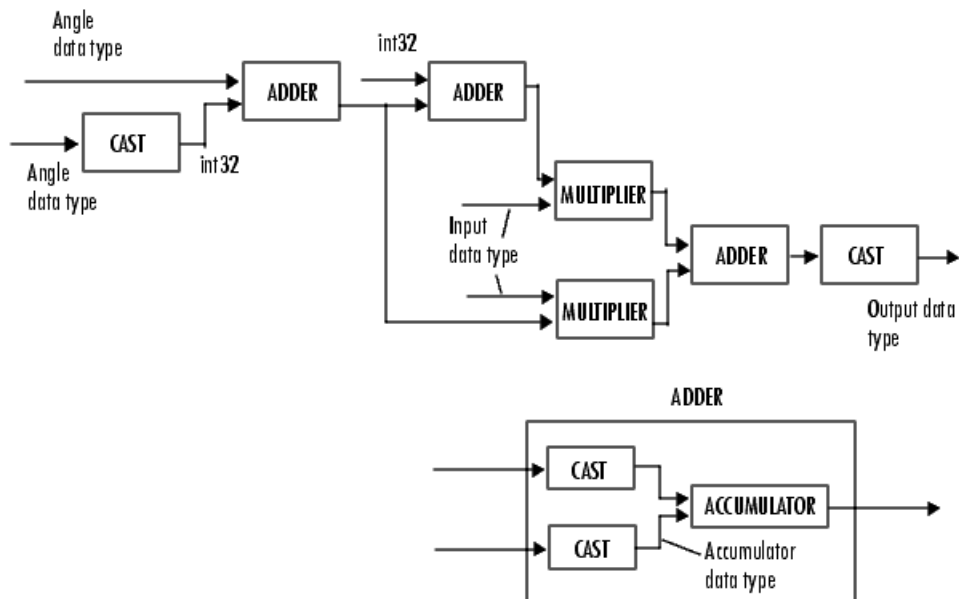
You can set the angle values, product output, accumulator, and output data types in the block mask.

The Rotate block requires additional data types. The Sine table value has the same word length as the angle data type and a fraction length that is equal to its word length minus one. The following diagram shows how these data types are used inside the block.
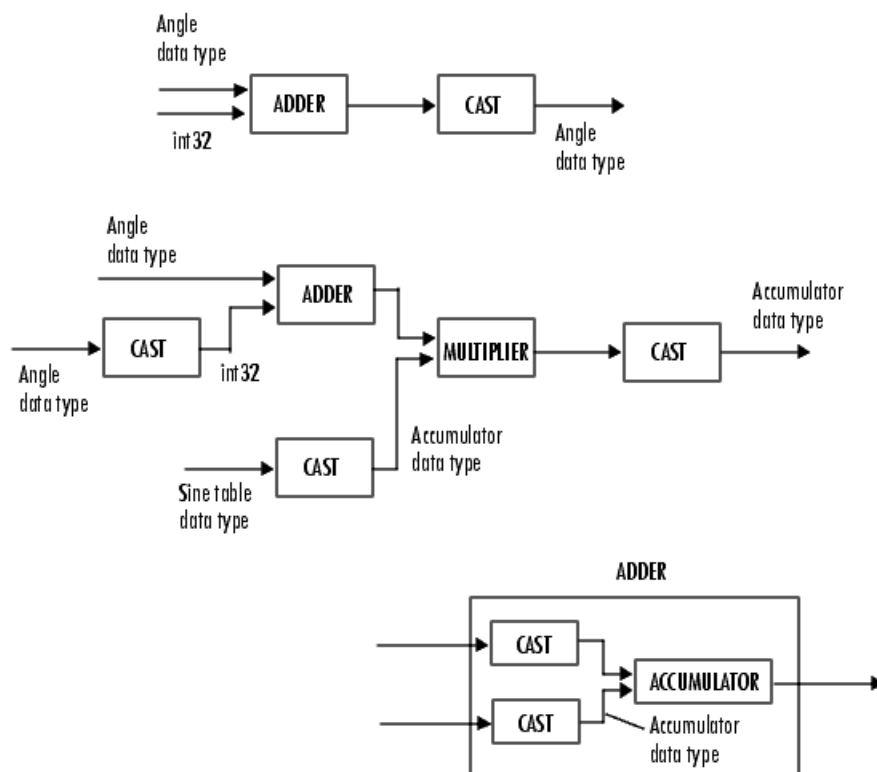
Note If overflow occurs, the rotated image might appear distorted.

Parameters

Output size

Specify the size of the rotated matrix. If you select `Expanded to fit rotated input image`, the block outputs a matrix that contains all the rotated image values. If you select `Same as input image`, the block outputs a matrix that contains the middle part of the rotated image. As a result, the edges of the rotated image might be cropped. Use the **Background fill value** parameter to specify the pixel values outside the image.

Rotation angle source

Specify how to enter your rotation angle. If you select `Specify via dialog`, the **Angle (radians)** parameter appears in the dialog box.

If you select `Input port`, the Angle port appears on the block. The block uses the input to this port at each time step as your rotation angle. The input to the Angle port must be the same data type as the input to the **I** port.

Angle (radians)

Enter a real, scalar value for your rotation angle. This parameter is visible if, for the **Rotation angle source** parameter, you select `Specify via dialog`.

When the rotation angle is a multiple of pi/2, the block uses a more efficient algorithm. If the angle value you enter for the **Angle (radians)** parameter is within 0.00001 radians of a multiple of pi/2, the block rounds the angle value to the multiple of pi/2 before performing the rotation.

Maximum angle (enter pi radians to accommodate all positive and negative angles)

Enter the maximum angle by which to rotate the input image. Enter a scalar value,

between 0 and π radians. The block determines which angle, $0 \leq angle \leq \max angle$, requires the largest output matrix and sets the dimensions of the output port accordingly.

This parameter is visible if you set the **Output size** parameter, to `Expanded to fit rotated input image`, and the **Rotation angle source** parameter to `Input port`.

Display rotated image in

Specify how the image is rotated. If you select `Center`, the image is rotated about its center point. If you select `Top-left corner`, the block rotates the image so that two corners of the rotated input image are always in contact with the top and left sides of the output image.

This parameter is visible if, for the **Output size** parameter, you select `Expanded to fit rotated input image`, and, for the **Rotation angle source** parameter, you select `Input port`.

Sine value computation method

Specify the value computation method. If you select `Trigonometric function`, the block computes sine and cosine values it needs to calculate the rotation of your image during the simulation. If you select `Table lookup`, the block computes and stores

the trigonometric values it needs to calculate the rotation of your image before the simulation starts. In this case, the block requires extra memory.

Background fill value

Specify a value for the pixels that are outside the image.

Interpolation method

Specify which interpolation method the block uses to rotate the image. If you select `Nearest neighbor`, the block uses the value of one nearby pixel for the new pixel value. If you select `Bilinear`, the new pixel value is the weighted average of the four nearest pixel values. If you select `Bicubic`, the new pixel value is the weighted average of the sixteen nearest pixel values.

The number of pixels the block considers affects the complexity of the computation. Therefore, the `Nearest-neighbor` interpolation is the most computationally efficient. However, because the accuracy of the method is proportional to the number of pixels considered, the `Bicubic` method is the most accurate. For more information, see "Nearest Neighbor, Bilinear, and Bicubic Interpolation Methods" in the *Computer Vision System Toolbox User's Guide*.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Angle values

Choose how to specify the word length and the fraction length of the angle values.

- When you select `Same word length as input`, the word length of the angle values match that of the input to the block. In this mode, the fraction length of the angle values is automatically set to the binary-point only scaling that provides you with the best precision possible given the value and word length of the angle values.

- When you select `Specify word length`, you can enter the word length of the angle values, in bits. The block automatically sets the fraction length to give you the best precision.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the angle values, in bits.

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- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the angle values. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

This parameter is only visible if, for the **Rotation angle source** parameter, you select `Specify via dialog`.

Product output

As depicted in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths.

- When you select `Same as first input`, these characteristics match those of the input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Accumulator

The result of each addition remains in the accumulator data type.

Input to adder - product output data type → CAST → Accumulator data type → ADDER → Accumulator data type

As depicted in the previous figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths.

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Supported Data Types

Port	Supported Data Types
Image	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer
Angle	Same as Image port
Output	Same as Image port

If the data type of the input signal is floating point, the output signal is the same data type as the input signal.

References

[1] Wolberg, George. *Digital Image Warping*. Washington: IEEE Computer Society Press, 1990.

See Also

Resize	Computer Vision System Toolbox software
Translate	Computer Vision System Toolbox software
Shear	Computer Vision System Toolbox software
`imrotate`	Image Processing Toolbox software

Introduced before R2006a

Shear

Shift rows or columns of image by linearly varying offset
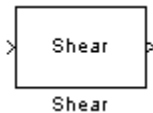
Shear

Library

Geometric Transformations

`visiongeotforms`

Description

The Shear block shifts the rows or columns of an image by a gradually increasing distance left or right or up or down.

Note This block supports intensity and color images on its ports.

Port	Input/Output	Supported Data Types	Complex Values Supported
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
S	Two-element vector that represents the number of pixels by which you want to shift your first and last rows or columns	Same as I port	No
Output	Shifted image	Same as I port	No

If the data type of the input to the I port is floating point, the input to the S port of this block must be the same data type. Also, the block output is the same data type.

Use the **Shear direction** parameter to specify whether you want to shift the rows or columns. If you select Horizontal, the first row has an offset equal to the first element of the **Row/column shear values [first last]** vector. The following rows have an offset that linearly increases up to the value you enter for the last element of the **Row/column shear values [first last]** vector. If you select Vertical, the first column has an offset equal to the first element of the **Row/column shear values [first last]** vector. The following columns have an offset that linearly increases up to the value you enter for the last element of the **Row/column shear values [first last]** vector.

Use the **Output size after shear** parameter to specify the size of the sheared image. If you select Full, the block outputs a matrix that contains the entire sheared image. If you select Same as input image, the block outputs a matrix that is the same size as the input image and contains the top-left portion of the sheared image. Use the **Background fill value** parameter to specify the pixel values outside the image.

Use the **Shear values source** parameter to specify how to enter your shear parameters. If you select Specify via dialog, the **Row/column shear values [first last]** parameter appears in the dialog box. Use this parameter to enter a two-element vector that represents the number of pixels by which you want to shift your first and last rows or columns. For example, if for the **Shear direction** parameter you select Horizontal and, for the **Row/column shear values [first last]** parameter, you enter [50 150], the block moves the top-left corner 50 pixels to the right and the bottom left corner of the input image 150 pixels to the right. If you want to move either corner to the left, enter negative values. If for the **Shear direction** parameter you select Vertical and, for the **Row/column shear values [first last]** parameter, you enter [-10 50], the block moves the top-left corner 10 pixels up and the top right corner 50 pixels down. If you want to move either corner down, enter positive values.

Use the **Interpolation method** parameter to specify which interpolation method the block uses to shear the image. If you select `Nearest neighbor`, the block uses the value of the nearest pixel for the new pixel value. If you select `Bilinear`, the new pixel value is the weighted average of the two nearest pixel values. If you select `Bicubic`, the new pixel value is the weighted average of the four nearest pixel values.

The number of pixels the block considers affects the complexity of the computation. Therefore, the nearest-neighbor interpolation is the most computationally efficient. However, because the accuracy of the method is proportional to the number of pixels considered, the bicubic method is the most accurate. For more information, see "Nearest Neighbor, Bilinear, and Bicubic Interpolation Methods" in the *Computer Vision System Toolbox User's Guide*.

If, for the **Shear values source** parameter, you select `Input port`, the S port appears on the block. At each time step, the input to the S port must be a two-element vector that represents the number of pixels by which to shift your first and last rows or columns.

If, for the **Output size after shear** parameter, you select `Full`, and for the **Shear values source** parameter, you select `Input port`, the **Maximum shear value** parameter appears in the dialog box. Use this parameter to enter a real, scalar value that represents the maximum number of pixels by which to shear your image. The block uses this parameter to determine the size of the output matrix. If any input to the S port is greater than the absolute value of the **Maximum shear value** parameter, the block saturates to the maximum value.

Fixed-Point Data Types

The following diagram shows the data types used in the Shear block for bilinear interpolation of fixed-point signals.
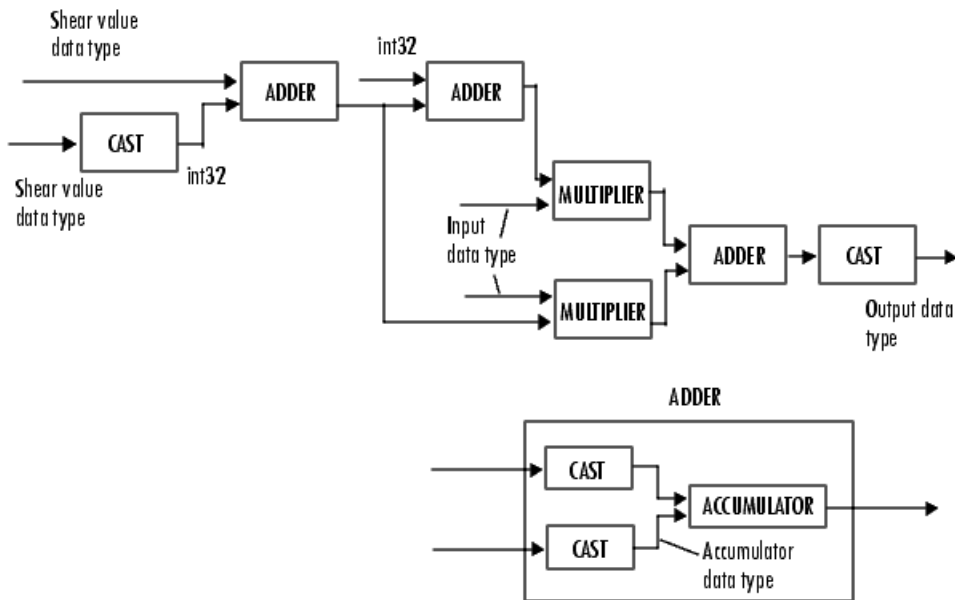
You can set the product output, accumulator, and output data types in the block mask.

Parameters

Shear direction

Specify whether you want to shift the rows or columns of the input image. Select `Horizontal` to linearly increase the offset of the rows. Select `Vertical` to steadily increase the offset of the columns.

Output size after shear

Specify the size of the sheared image. If you select `Full`, the block outputs a matrix that contains the sheared image values. If you select `Same as input image`, the block outputs a matrix that is the same size as the input image and contains a portion of the sheared image.

Shear values source

Specify how to enter your shear parameters. If you select `Specify via dialog`, the **Row/column shear values [first last]** parameter appears in the dialog box. If you

select `Input port`, port S appears on the block. The block uses the input to this port at each time step as your shear value.

Row/column shear values [first last]

Enter a two-element vector that represents the number of pixels by which to shift your first and last rows or columns. This parameter is visible if, for the **Shear values source** parameter, you select `Specify via dialog`.

Maximum shear value

Enter a real, scalar value that represents the maximum number of pixels by which to shear your image. This parameter is visible if, for the **Shear values source** parameter, you select `Input port`.

Background fill value

Specify a value for the pixels that are outside the image. This parameter is tunable.

Interpolation method

Specify which interpolation method the block uses to shear the image. If you select `Nearest neighbor`, the block uses the value of one nearby pixel for the new pixel value. If you select `Bilinear`, the new pixel value is the weighted average of the two nearest pixel values. If you select `Bicubic`, the new pixel value is the weighted average of the four nearest pixel values.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Shear values

Choose how to specify the word length and the fraction length of the shear values.

- When you select `Same word length as input`, the word length of the shear values match that of the input to the block. In this mode, the fraction length of the shear values is automatically set to the binary-point only scaling that provides you with the best precision possible given the value and word length of the shear values.

- When you select `Specify word length`, you can enter the word length of the shear values, in bits. The block automatically sets the fraction length to give you the best precision.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the shear values, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the shear values. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

This parameter is visible if, for the **Shear values source** parameter, you select `Specify via dialog`.

Product output

As depicted in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths.

- When you select `Same as first input`, these characteristics match those of the first input to the block at the I port.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Accumulator

As depicted in the previous figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths.

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as first input`, these characteristics match those of the first input to the block at the I port.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as first input`, these characteristics match those of the first input to the block at the I port.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Wolberg, George. *Digital Image Warping*. Washington: IEEE Computer Society Press, 1990.

See Also

Resize	Computer Vision System Toolbox software
Rotate	Computer Vision System Toolbox software
Translate	Computer Vision System Toolbox software

Introduced before R2006a

Template Matching

Locate a template in an image
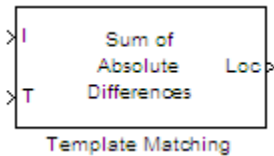
Template Matching

Library

Analysis & Enhancement

`visionanalysis`

Description

The Template Matching block finds the best match of a template within an input image. The block computes match metric values by shifting a template over a region of interest or the entire image, and then finds the best match location.

Port Description

Port	Supported Data Types
I (Input Image)	• Double-precision floating point • Single-precision floating point • Fixed point (signed, unsigned or both) • Boolean • 8-, 16-, and 32-bit signed integers • 8-, 16-, and 32-bit unsigned integers

Port	Supported Data Types
T (Template)	• Double-precision floating point • Single-precision floating point • Fixed point (signed, unsigned or both) • Boolean • 8-bit unsigned integers
ROI (Region of Interest, [x y width height])	• Double-precision floating point • Single-precision floating point • Fixed point (signed, unsigned or both) • Boolean • 8-bit unsigned integers
Metric (Match Metric Values)	• Double-precision floating point • Single-precision floating point • Fixed point (signed, unsigned or both) • Boolean • 32-bit unsigned integers
Loc (Best match location [x y])	• 32-bit unsigned integers
NMetric (Metric values in Neighborhood of best match)	• Double-precision floating point • Single-precision floating point • Fixed point (signed, unsigned or both) • Boolean • 8-bit unsigned integers
NValid (Neighborhood valid)	• Boolean
ROIValid (ROI valid)	• Boolean

Using the Template Matching Block

Choosing an Output Option

The block outputs either a matrix of match metric values or the zero-based location of the best template match. The block outputs the matrix to the **Metric** port or the location to the **Loc** port. Optionally, the block can output an *NxN* matrix of neighborhood match metric values to the **NMetric** port.

Input and Output Signal Sizes

The Template Matching block does not pad the input data. Therefore, it can only compute values for the match metrics between the input image and the template, where the template is positioned such that it falls entirely on the input image. A set of all such positions of the template is termed as the *valid* region of the input image. The size of the valid region is the difference between the sizes of the input and template images plus one.

$$size_{valid} = size_{input} - size_{template} + 1$$

The output at the **Metric** port for the **Match metric** mode is of the valid image size. The output at the **Loc** port for the **Best match index** mode is a two-element vector of indices relative to the top-left corner of the input image.

The neighborhood metric output at the **NMetric** port is of the size *NxN*, where *N* must be an odd number specified in the block mask.

Defining the Region of Interest (ROI)

To perform template matching on a subregion of the input image, select the **Enable ROI processing** check box. This check box adds the **ROI** input port to the Template Matching block. The ROI processing option is only available for the **Best match index** mode.

The ROI port requires a four-element vector that defines a rectangular area. The first two elements represent [x y] coordinates for the upper-left corner of the region. The second two elements represent the width and height of the ROI. The block outputs the best match location index relative to the top left corner of the input image.

Choosing a Match Metric

The block computes the match metric at each step of the iteration. Choose the match metric that best suits your application. The block calculates the global optimum for the
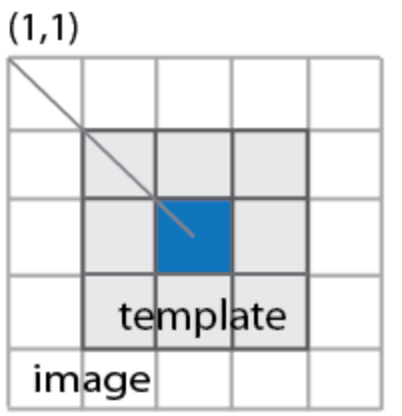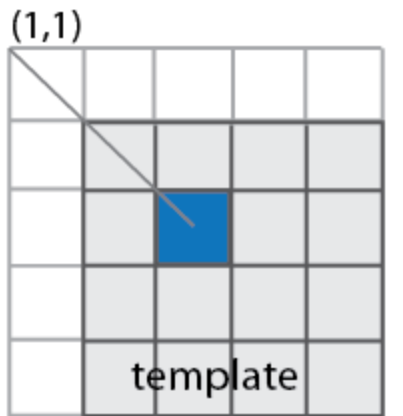
best metric value. It uses the valid subregion of the input image intersected by the ROI, if provided.

Returning the Matrix of Match Metric Values

The matrix of the match metrics always implements single-step exhaustive window iteration. Therefore, the block computes the metric values at every pixel.

Returning the Best Match Location

When in the ROI processing mode, the block treats the image around the ROI as an extension of the ROI subregion. Therefore, it computes the best match locations true to the actual boundaries of the ROI. The block outputs the best match coordinates, relative to the top-left corner of the image. The one-based [x y] coordinates of the location correspond to the center of the template. The following table shows how the block outputs the center coordinates for odd and even templates:

Odd number of pixels in template	Even number of pixels in template

Returning the Neighborhood Match Metric around the Best Match

When you select **Best match location** to return the matrix of metrics in a neighborhood around the best match, an exhaustive loop computes all the metric values for the N-by-N neighborhood. This output is particularly useful for performing template matching with subpixel accuracy.

Choosing a Search Method

When you select **Best match location** as the output option, you can choose to use either **Exhaustive** or **Three-step** search methods.

The **Exhaustive** search method is computationally intensive because it searches at every pixel location of the image. However, this method provides a more precise result.

The **Three-step** search method is a fast search that uses a neighborhood approach, which does not inspect every pixel. The search starts with a step size equal to or slightly greater than half of the maximum search range and then employs the following steps:

1   The block compares nine search points in each step. There is a central point and eight search points located on the search area boundary.

2   The block decrements the step size by one, after each step, ending the search with a step size of one pixel.

3   At each new step, the block moves the search center to the best matching point resulting from the previous step. The number one blue circles in the figure below represent a search with a starting step size of three. The number two green circles represent the next search, with step size of two, centered around the best match found from the previous search. Finally, the number three orange circles represent the final search, with step size of one, centered around the previous best match.
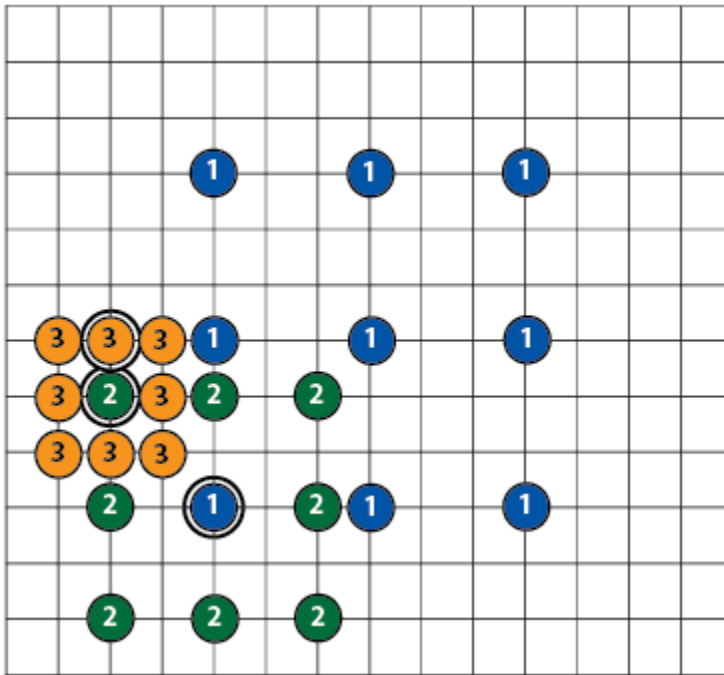
Three-Step Search

Using the ROIValid and NValid flags for Diagnostics

The **ROIValid** and **NValid** ports represent boolean flags, which track the valid Region of Interest (ROI) and neighborhood. You can use these flags to communicate with the downstream blocks and operations.

Valid Region of Interest

If you select the **Output flag indicating if ROI is valid** check box, the block adds the **ROIValid** port. If the ROI lies partially outside the valid image, the block only processes the intersection of the ROI and the valid image. The block sets the ROI flag output to this port as follows:

- True, set to 1 indicating the ROI lies completely inside the valid part of the input image.
- False, set to 0 indicating the ROI lies completely or partially outside of the valid part of the input image.

Valid Neighborhood

The neighborhood matrix of metric values is valid inside of the Region of Interest (ROI). You can use the Boolean flag at the **NValid** port to track the valid neighborhood region. The block sets the neighborhood **NValid** boolean flag output as follows:

- True, set to 1 indicating that the neighborhood containing the best match is completely inside the region of interest.

- False, set to 0 indicating that the neighborhood containing the best match is completely or partially outside of the region of interest.

Algorithm

The match metrics use a difference equation with general form:

$$d_p(x, y) = (\sum_{i=1}^{n} |x_i - y_i|^p)^{1/p}$$

l_n^p denotes the metric space (R^n, d_p) for R^n $n > 1$.

- **Sum of Absolute Differences (SAD)**
  This metric is also known as the *Taxicab* or *Manhattan Distance* metric. It sums the absolute values of the differences between pixels in the original image and the

  corresponding pixels in the template image. This metric is the l^1 norm of the difference image. The lowest SAD score estimates the best position of template within the search image. The general SAD distance metric becomes:

$$d_1(I_j, T) = \sum_{i=1}^{n} |I_{i,j} - T_i|$$

- **Sum of Squared Differences (SSD)**
  This metric is also known as the Euclidean Distance metric. It sums the square of the absolute differences between pixels in the original image and the corresponding pixels

  in the template image. This metric is the square of the l^2 norm of the difference image. The general SSD distance metric becomes:

$$d_2(I_j, T) = \sum_{i=1}^{n} \left| I_{i,j} - T_i \right|^2$$

- **Maximum Absolute Difference (MaxAD)**
  This metric is also known as the Uniform Distance metric. It sums the maximum of absolute values of the differences between pixels in the original image and the

  corresponding pixels in the template image. This distance metric provides the l^∞ norm of the difference image. The general MaxAD distance metric becomes:

$$d_\infty(I_j, T) = \lim_{x \to \infty} \sum_{i=1}^{n} \left| I_{i,j} - T_i \right|^p$$

which simplifies to:

$$d_\infty(I_j, T) = \max_{i}^{n} \left| I_{i,j} - T_i \right|^p$$

Parameters

Match metric

Select one of three types of match metrics:

- `Sum of absolute differences` (SAD)
- `Sum of squared differences` (SSD)
- `Maximum absolute difference` (MaxAD)

Output

Select one of two output types:

- **Match metric**
  Select this option to output the match metric matrix. This option adds the **Metric** output port to the block.

- **Best match location**
  Select this option to output the [x y] coordinates for the location of the best match. This option adds the **Loc** output port to the block. When you select **Best match location**, the **Search method**, **Output NxN matrix of metric values around best match**, and **Enable ROI processing** parameter options appear.

This option appears when you select **Best match location** for the **Output** parameter. Select one of two search methods.

- **Exhaustive**
- **Three-step**

This option appears when you select **Best match location** for the **Output** parameter. Select the check box to output a matrix of metric values centered around the best match. When you do so, the block adds the **NMetric** and **NValid** output ports.

This option appears when you select the **Output NxN matrix of metric values around best match** check box. Enter an integer number that determines the size of the N-by-N output matrix centered around the best match location index. N must be an odd number.

This option appears when you select **Best match location** for the **Output** parameter. Select the check box for the Template Matching block to perform region of interest processing. When you do so, the block adds the **ROI** input port, and the **Output flag indicating if ROI is valid** check box appears. The **ROI** input must have the format [x y width height], where [x y] are the coordinates of the upper-left corner of the ROI.

This option appears when you select the **Enable ROI processing** check box. Select the check box for the Template Matching block to indicate whether the ROI is within the valid region of the image boundary. When you do so, the block adds the **ROIValid** output port.

Data Type Parameters

Rounding mode

Select the "Rounding Modes" for fixed-point operations.

Overflow mode

Select the Overflow mode for fixed-point operations.

- **Wrap**
- **Saturate**

Product output

- Use this parameter to specify how to designate the product output word and fraction lengths. Refer to "Multiplication Data Types" for illustrations depicting the use of the product output data type in this block:

    - When you select **Same as input**, these characteristics match those of the input to the block.

    - When you select **Binary point scaling**, you can enter the word length and the fraction length of the product output, in bits.

    - When you select **Slope and bias scaling**, you can enter the word length, in bits, and the slope of the product output. This block requires power-of-two slope and a bias of zero.

Accumulator

Use this parameter to specify how you would like to designate the accumulator word and fraction lengths.

- When you select **Same as product output** the characteristics match the characteristics of the product output. See "Multiplication Data Types" for illustrations depicting the use of the accumulator data type in this block:

    When you select **Binary point scaling**, you can enter the **Word length** and the **Fraction length** of the accumulator, in bits.

    When you select **Binary point scaling**, you can enter the **Word length**, in bits, and the **Slope** of the **Accumulator**. All signals in the Computer Vision System Toolbox software have a bias of 0.

    The block casts inputs to the **Accumulator** to the accumulator data type. It adds each element of the input to the output of the adder, which remains in the accumulator data

type. Use this parameter to specify how to designate this accumulator word and fraction lengths.

Output

Choose how to specify the **Word length**, **Fraction length** and **Slope** of the Template Matching output:

- When you select **Same as first input**, these characteristics match the characteristics of the accumulator.

- When you select **Binary point scaling**, you can enter the **Word length** and **Fraction length** of the output, in bits.

- When you select **Slope and bias scaling**, you can enter the **Word length**, in bits, and the **Slope** of the output. All signals in the Computer Vision System Toolbox software have a bias of 0.

The **Output** parameter on the Data Types pane appears when you select **Metric matrix** or if you select **Best match location** and the **Output NxN matrix of metric values around best match** check box is selected.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

Reference

[1] Koga T., et. Al. Motion-compensated interframe coding for video conferencing. In National Telecommunications Conference. Nov. 1981, G5.3.1–5, New Orleans, LA.

[2] Zakai M., "General distance criteria" *IEEE Transaction on Information Theory*, pp. 94–95, January 1964.

[3] Yu, J., J. Amores, N. Sebe, Q. Tian, "A New Study on Distance Metrics as Similarity Measurement" IEEE International Conference on Multimedia and Expo, 2006 .

See Also

Block Matching	Image Processing Toolbox
Video Stabilization	Computer Vision System Toolbox

Introduced in R2009b

To Multimedia File

Write video frames and audio samples to multimedia file

To Multimedia File

Library

Sinks

`visionsinks`

Description

The To Multimedia File block writes video frames, audio samples, or both to a multimedia (`.avi, .wav, .mj2, .mp4, or .m4v`) file.

You can compress the video frames or audio samples by selecting a compression algorithm. You can connect as many of the input ports as you want. Therefore, you can control the type of video and/or audio the multimedia file receives.

Note This block supports code generation for platforms that have file I/O available. You cannot use this block with Simulink Desktop Real-Time software, because that product does not support file I/O.

This block performs best on platforms with Version 11 or later of Windows Media® Player software. This block supports only uncompressed RGB24 AVI files on Linux and Mac platforms.

The generated code for this block relies on prebuilt library files. You can run this code outside the MATLAB environment, or redeploy it, but be sure to account for these extra

library files when doing so. The packNGo function creates a single zip file containing all of the pieces required to run or rebuild this code. See `packNGo` for more information.

To run an executable file that was generated from a model containing this block, you may need to add precompiled shared library files to your system path. See "Simulink Coder", "Simulink Shared Library Dependencies", and "Accelerating Simulink Models" for details.

Ports

Port	Description
Image	M-by-N-by-3 matrix RGB, Intensity, or YCbCr 4:2:2 signal.
R, G, B	Matrix that represents one plane of the RGB video stream. Inputs to the R, G, or B port must have the same dimensions and data type.
Audio	Vector of audio data
Y, Cb, Cr	Matrix that represents one frame of the YCbCr video stream. The Y, Cb, and Cr ports use the following dimensions: Y: M x N Cb: M x $\dfrac{N}{2}$ Cr: M x $\dfrac{N}{2}$

Parameters

File name

Specify the name of the multimedia file. The block saves the file in your current folder. To specify a different file or location, click the **Save As...** button.

File type

Specify the file type of the multimedia file. You can select `avi` or `wav`.

Write

Specify whether the block writes video frames, audio samples, or both to the multimedia file. You can select `Video and audio`, `Video only`, or `Audio only`.

Video Quality

Quality of the video, specified as an integer scalar in the range [0 100]. This parameter applies only when you set **File Name** to MPEG4 and **Write** to Video only. By default, this parameter is set to 75.

Compression Factor (>1)

Specify the compression factor as an integer scalar greater than 1. This parameter is applicable only when the **File type** is set to MJ2000 and **Video compressor** is set to Lossy. By default, this parameter is set to 10.

Audio compressor

Select the type of compression algorithm to use to compress the audio data. This compression reduces the size of the multimedia file. Choose None (uncompressed) to save uncompressed audio data to the multimedia file.

Note The other items available in this parameter list are the audio compression algorithms installed on your system. For information about a specific audio compressor, see the documentation for that compressor.

Audio data type

Select the audio data type. You can use the **Audio data type** parameter only for uncompressed wave files.

Video compressor

Select the type of compression algorithm to use to compress the video data. This compression reduces the size of the multimedia file. Choose None (uncompressed) to save uncompressed video data to the multimedia file.

Note The other items available in this parameter list are the video compression algorithms installed on your system. For information about a specific video compressor, see the documentation for that compressor.

File color format

Select the color format of the data stored in the file. You can select either RGB or YCbCr 4:2:2.

Image signal

Specify how the block accepts a color video signal. If you select `One multidimensional signal`, the block accepts an *M*-by-*N*-by-*P* color video signal, where *P* is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port accepts one *M*-by-*N* plane of an RGB video stream.

Supported Data Types

For the block to display video data properly, double- and single-precision floating-point pixel values must be between `0` and `1`. Any other data type requires the pixel values between the minimum and maximum values supported by their data type.

Check the specific codecs you are using for supported audio rates.

Port	Supported Data Types	Supports Complex Values?
Image	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16- 32-bit signed integers • 8-, 16- 32-bit unsigned integers	No
R, G, B	Same as Image port	No
Audio	• Double-precision floating point • Single-precision floating point • 16-bit signed integers • 32-bit signed integers • 8-bit unsigned integers	No
Y, Cb, Cr	Same as Image port	No

See Also

From Multimedia File   Computer Vision System Toolbox

Introduced before R2006a

To Video Display

Display video data

To Video Display

Library

Sinks

`visionsinks`

Description

The To Video Display block displays video frames. This block is capable of displaying high definition video at high frame rates. It provides a lightweight, high performance, simple display, which accepts RGB and YCbCr formatted images. This block also generates code.

The generated code for this block relies on prebuilt .dll files. You can run this code outside the MATLAB environment, or redeploy it, but be sure to account for these extra .dll files when doing so. The `packNGo` function creates a single zip file containing all of the pieces required to run or rebuild this code. See `packNGo` for more information.

To run an executable file that was generated from a model containing this block, you may need to add precompiled shared library files to your system path. See "Simulink Coder", "Simulink Shared Library Dependencies", and "Accelerating Simulink Models" for details.

For the block to display video data properly, double- and single-precision floating-point pixel values must be from 0 to 1. For any other data type, the pixel values must be between the minimum and maximum values supported by their data type.

You can set the display for full screen, normal or, to maintain one-to-one size. When you save the model, the size and position of the display window is saved. Any changes while

working with the model should be saved again in order that these preferences are maintained when you run the model. The minimum display width of the window varies depending on your system's font size settings.

Rapid Accelerator

When you set your model to run in "Accelerator Mode" (Simulink), and do not select the **Open at Start of Simulation** option, the block will not be included during the run, and therefore the video display will not be visible.

Parameters

View Options

Window Size

> Select **Full-screen** mode to display your video stream in a full screen window. To exit or return to other applications from full-screen, select the display and use the **Esc** key.
> Select **Normal** mode to modify display size at simulation start time.
> Select **True Size (1:1)** mode to display a one-to-one pixel ratio of input image at simulation start time. The block displays the same information per pixel and does not change size from the input size. You can change the display size after the model starts.

Open at Start of Simulation

> Select `Open at Start of Simulation` from the **View** menu for the display window to appear while running the model. If not selected, you can double click the block to display the window.

Settings Options

Input Color Format

> Select the color format of the data stored in the input image.
> > Select **RGB** for the block to accept a matrix that represents one plane of the RGB video stream. Inputs to the **R**, **G**, or **B** ports must have the same dimension and data type.

Select **YCbCr 4:2:2** for the block to accept a matrix that represents one frame of the YCbCr video stream. The **Y** port accepts an M-by-N matrix. The **Cb** and **Cr**

ports accepts an M-by-$N/2$ matrix.

Image Signal

Specify how the block accepts a color video signal.

Select **One multidimensional signal**, for the block to accept an M-by-N-by-3 color video signal at one port.

Select **Separate color signals**, for additional ports to appear on the block. Each port accepts one M-by-N plane of an RGB video stream.

Supported Data Types

Port	Supported Data Types
Image	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16, and 32-bit signed integer • 8-, 16, and 32-bit unsigned integer
R, G, B	Same as Image port
YCbCr 4:2:2	Same as Image ports

See Also

Frame Rate Display	Computer Vision System Toolbox software
From Multimedia File	Computer Vision System Toolbox software
To Multimedia File	Computer Vision System Toolbox software
Video To Workspace	Computer Vision System Toolbox software
Video Viewer	Computer Vision System Toolbox software

Introduced before R2006a

Top-hat

Perform top-hat filtering on intensity or binary images

Library

Morphological Operations

`visionmorphops`

Description

The Top-hat block performs top-hat filtering on an intensity or binary image using a predefined neighborhood or structuring element. Top-hat filtering is the equivalent of subtracting the result of performing a morphological opening operation on the input image from the input image itself. This block uses flat structuring elements only.

Port	Input/Output	Supported Data Types	Complex Values Supported
I	Vector or matrix of intensity values	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer	No
Nhood	Matrix or vector of 1s and 0s that represents the neighborhood values	Boolean	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Output	Scalar, vector, or matrix that represents the filtered image	Same as I port	No

If your input image is a binary image, for the **Input image type** parameter, select `Binary`. If your input image is an intensity image, select `Intensity`.

Use the **Neighborhood or structuring element source** parameter to specify how to enter your neighborhood or structuring element values. If you select `Specify via dialog`, the **Neighborhood or structuring element** parameter appears in the dialog box. If you select `Input port`, the Nhood port appears on the block. Use this port to enter your neighborhood values as a matrix or vector of 1s and 0s. Choose your structuring element so that it matches the shapes you want to remove from your image. You can only specify a it using the dialog box.

Use the **Neighborhood or structuring element** parameter to define the region the block moves throughout the image. Specify a neighborhood by entering a matrix or vector of 1s and 0s. Specify a structuring element with the `strel` function from the Image Processing Toolbox. If the structuring element is decomposable into smaller elements, the block executes at higher speeds due to the use of a more efficient algorithm.

Parameters

Input image type

If your input image is a binary image, select `Binary`. If your input image is an intensity image, select `Intensity`.

Neighborhood or structuring element source

Specify how to enter your neighborhood or structuring element values. Select `Specify via dialog` to enter the values in the dialog box. Select `Input port` to use the Nhood port to specify the neighborhood values. You can only specify a structuring element using the dialog box.

Neighborhood or structuring element

If you are specifying a neighborhood, this parameter must be a matrix or vector of 1s and 0s. If you are specifying a structuring element, use the `strel` function from the Image Processing Toolbox. This parameter is visible if, for the **Neighborhood or structuring element source** parameter, you select `Specify via dialog`.

1-435

See Also

Bottom-hat	Computer Vision System Toolbox software
Closing	Computer Vision System Toolbox software
Dilation	Computer Vision System Toolbox software
Erosion	Computer Vision System Toolbox software
Label	Computer Vision System Toolbox software
Opening	Computer Vision System Toolbox software
`imtophat`	Image Processing Toolbox software
`strel`	Image Processing Toolbox software

Introduced before R2006a

Trace Boundary

Trace object boundaries in binary images
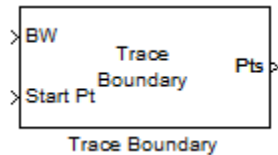
Library

Analysis & Enhancement

`visionanalysis`

Description

The Trace Boundary block traces object boundaries in binary images, where nonzero pixels represent objects and 0 pixels represent the background.

Port Descriptions

Port	Input/Output	Supported Data Types
BW	Vector or matrix that represents a binary image	Boolean
Start Pt	One-based [x y] coordinates of the boundary starting point.	• Double-precision floating point • Single-precision floating point • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer

Port	Input/Output	Supported Data Types
Pts	M-by-2 matrix of [x y] coordinates of the boundary points, where M represents the number of traced boundary pixels. M must be less than or equal to the value specified by the **Maximum number of boundary pixels** parameter. $$\begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \\ x_3 & y_3 \\ . & . \\ . & . \\ . & . \\ x_m & y_m \end{bmatrix}$$	Same as Start Pts port

Parameters

Connectivity

Specify which pixels are connected to each other. If you want a pixel to be connected to the pixels on the top, bottom, left, and right, select 4. If you want a pixel to be connected to the pixels on the top, bottom, left, right, and diagonally, select 8. For more information about this parameter, see the Label block reference page.

Initial search direction

Specify the first direction in which to look to find the next boundary pixel that is connected to the starting pixel.

If, for the **Connectivity** parameter, you select 4, the following figure illustrates the four possible initial search directions:

North

West

East

South
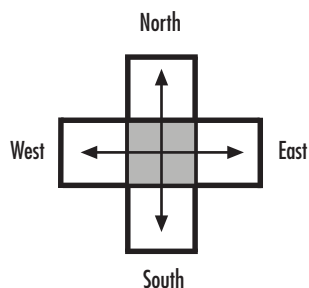
If, for the **Connectivity** parameter, you select 8, the following figure illustrates the eight possible initial search directions:

Northwest   North   Northeast

West

East

Southwest   South   Southeast
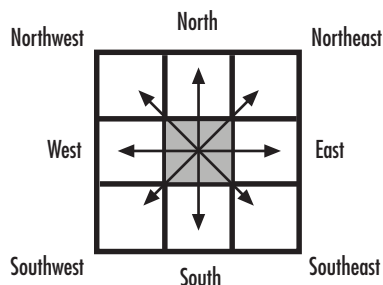
Trace direction

Specify the direction in which to trace the boundary. Your choices are Clockwise or Counterclockwise.

Maximum number of boundary pixels

Specify the maximum number of boundary pixels for each starting point. The block uses this value to preallocate the number of rows of the **Pts** port output matrix so that it can hold all the boundary pixel location values.

Use the **Maximum number of boundary pixels** parameter to specify the maximum number of boundary pixels for the starting point.

See Also

| Edge Detection | Computer Vision System Toolbox software |

Label	Computer Vision System Toolbox software
bwboundaries	Image Processing Toolbox software
bwtraceboundary	Image Processing Toolbox software

Introduced in R2011b

Translate

Translate image in 2-D plane using displacement vector

```
Translate
```
Translate
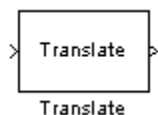
Library

Geometric Transformations

`visiongeotforms`

Description

Use the Translate block to move an image in a two-dimensional plane using a displacement vector, a two-element vector that represents the number of pixels by which you want to translate your image. The block outputs the image produced as the result of the translation.

Note This block supports intensity and color images on its ports.

Port	Input/Output	Supported Data Types	Complex Values Supported
Image / Input	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No

Port	Input/Output	Supported Data Types	Complex Values Supported
Offset	Vector of values that represent the number of pixels by which to translate the image	Same as I port	No
Output	Translated image	Same as I port	No

The input to the Offset port must be the same data type as the input to the Image port. The output is the same data type as the input to the Image port.

Use the **Output size after translation** parameter to specify the size of the translated image. If you select `Full`, the block outputs a matrix that contains the entire translated image. If you select `Same as input image`, the block outputs a matrix that is the same size as the input image and contains a portion of the translated image. Use the **Background fill value** parameter to specify the pixel values outside the image.

Use the **Offset source** parameter to specify how to enter your displacement vector. If you select `Specify via dialog`, the **Offset** parameter appears in the dialog box. Use it to enter your displacement vector, a two-element vector, `[r c]`, of real, integer values that represent the number of pixels by which you want to translate your image. The `r` value represents how many pixels up or down to shift your image. The `c` value represents how many pixels left or right to shift your image. The axis origin is the top-left corner of your image. For example, if you enter `[2.5 3.2]`, the block moves the image 2.5 pixels downward and 3.2 pixels to the right of its original location. When the displacement vector contains fractional values, the block uses interpolation to compute the output.

Use the **Interpolation method** parameter to specify which interpolation method the block uses to translate the image. If you translate your image in either the horizontal or vertical direction and you select `Nearest neighbor`, the block uses the value of the nearest pixel for the new pixel value. If you translate your image in either the horizontal or vertical direction and you select `Bilinear`, the new pixel value is the weighted average of the four nearest pixel values. If you translate your image in either the horizontal or vertical direction and you select `Bicubic`, the new pixel value is the weighted average of the sixteen nearest pixel values.

The number of pixels the block considers affects the complexity of the computation. Therefore, the nearest-neighbor interpolation is the most computationally efficient. However, because the accuracy of the method is roughly proportional to the number of pixels considered, the bicubic method is the most accurate. For more information, see

"Nearest Neighbor, Bilinear, and Bicubic Interpolation Methods" in the *Computer Vision System Toolbox User's Guide*.

If, for the **Output size after translation** parameter, you select `Full`, and for the **Offset source** parameter, you select `Input port`, the **Maximum offset** parameter appears in the dialog box. Use the **Maximum offset** parameter to enter a two-element vector of real, scalar values that represent the maximum number of pixels by which you want to translate your image. The block uses this parameter to determine the size of the output matrix. If the input to the Offset port is greater than the **Maximum offset** parameter values, the block saturates to the maximum values.

If, for the **Offset source** parameter, you select `Input port`, the Offset port appears on the block. At each time step, the input to the Offset port must be a vector of real, scalar values that represent the number of pixels by which to translate your image.

Fixed-Point Data Types

The following diagram shows the data types used in the Translate block for bilinear interpolation of fixed-point signals.
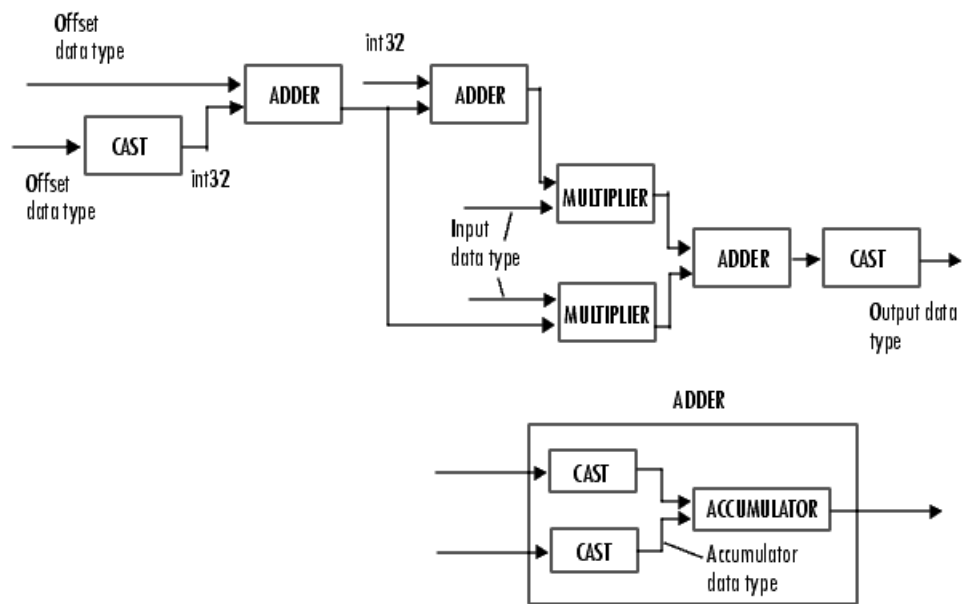
You can set the product output, accumulator, and output data types in the block mask as discussed in the next section.

Parameters

Output size after translation

If you select `Full`, the block outputs a matrix that contains the translated image values. If you select `Same as input image`, the block outputs a matrix that is the same size as the input image and contains a portion of the translated image.

Offset source

Specify how to enter your translation parameters. If you select `Specify via dialog`, the **Offset** parameter appears in the dialog box. If you select `Input port`, port O appears on the block. The block uses the input to this port at each time step as your translation values.

Offset source

Enter a vector of real, scalar values that represent the number of pixels by which to translate your image.

Background fill value

Specify a value for the pixels that are outside the image.

Interpolation method

Specify which interpolation method the block uses to translate the image. If you select `Nearest neighbor`, the block uses the value of one nearby pixel for the new pixel value. If you select `Bilinear`, the new pixel value is the weighted average of the four nearest pixel values. If you select `Bicubic`, the new pixel value is the weighted average of the sixteen nearest pixel values.

Maximum offset

Enter a vector of real, scalar values that represent the maximum number of pixels by which you want to translate your image. This parameter must have the same data type as the input to the Offset port. This parameter is visible if, for the **Output size after translation** parameter, you select `Full` and, for the **Offset source** parameter, you select `Input port`.

Rounding mode

Select the rounding mode for fixed-point operations.

Overflow mode

Select the overflow mode for fixed-point operations.

Offset values

Choose how to specify the word length and the fraction length of the offset values.

- When you select `Same word length as input`, the word length of the offset values match that of the input to the block. In this mode, the fraction length of the offset values is automatically set to the binary-point only scaling that provides you with the best precision possible given the value and word length of the offset values.

- When you select `Specify word length`, you can enter the word length of the offset values, in bits. The block automatically sets the fraction length to give you the best precision.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the offset values, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the offset values. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

This parameter is visible if, for the **Offset source** parameter, you select `Specify via dialog`.

Product output

As depicted in the previous figure, the output of the multiplier is placed into the product output data type and scaling. Use this parameter to specify how to designate this product output word and fraction lengths.

- When you select `Same as first input`, these characteristics match those of the first input to the block.

- When you select `Binary point scaling`, you can enter the word length and the fraction length of the product output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the product output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Accumulator

The result of each addition remains in the accumulator data type.

As depicted in the previous figure, inputs to the accumulator are cast to the accumulator data type. The output of the adder remains in the accumulator data type as each element of the input is added to it. Use this parameter to specify how to designate this accumulator word and fraction lengths.

- When you select `Same as product output`, these characteristics match those of the product output.
- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the accumulator, in bits.
- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the accumulator. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Output

Choose how to specify the word length and fraction length of the output of the block:

- When you select `Same as first input`, these characteristics match those of the first input to the block.
- When you select `Binary point scaling`, you can enter the word length and the fraction length of the output, in bits.

- When you select `Slope and bias scaling`, you can enter the word length, in bits, and the slope of the output. The bias of all signals in the Computer Vision System Toolbox blocks is 0.

Lock data type settings against change by the fixed-point tools

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on the block mask. For more information, see `fxptdlg`, a reference page on the Fixed-Point Tool in the Simulink documentation.

References

[1] Wolberg, George. *Digital Image Warping*. Washington: IEEE Computer Society Press, 1990.

See Also

Resize	Computer Vision System Toolbox software
Rotate	Computer Vision System Toolbox software
Shear	Computer Vision System Toolbox software

Introduced before R2006a

Video From Workspace

Import video signal from MATLAB workspace

Video From Workspace
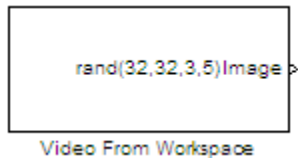
Library

Sources

`visionsources`

Description

The Video From Workspace block imports a video signal from the MATLAB workspace. If the video signal is a M-by-N-by-T workspace array, the block outputs an intensity video signal, where M and N are the number of rows and columns in a single video frame, and T is the number of frames in the video signal. If the video signal is a M-by-N-by-C-by-T workspace array, the block outputs a color video signal, where M and N are the number of rows and columns in a single video frame, C is the number of color channels, and T is the number of frames in the video stream. In addition to the video signals previously described, this block supports fi objects.

Note If you generate code from a model that contains this block, Simulink Coder takes a long time to compile the code because it puts all of the video data into the `.c` file. Before you generate code, you should convert your video data to a format supported by the From Multimedia File block or the Read Binary File block.

Port	Output	Supported Data Types	Complex Values Supported
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
R, G, B	Scalar, vector, or matrix that represents one plane of the RGB video stream. Outputs from the R, G, or B ports have the same dimensions.	Same as I port	No

For the Computer Vision System Toolbox blocks to display video data properly, double- and single-precision floating-point pixel values must be from 0 to 1. This block does not scale pixel values.

Use the **Signal** parameter to specify the MATLAB workspace variable from which to read. For example, to read an AVI file, use the following syntax:

```
mov = VideoReader('filename.avi')
```

If `filename.avi` has a colormap associated with it, the AVI file must satisfy the following conditions or the block produces an error:

• The colormap must be empty or have 256 values.

• The data must represent an intensity image.

• The data type of the image values must be `uint8`.

Use the **Sample time** parameter to set the sample period of the output signal.

When the block has output all of the available signal samples, it can start again at the beginning of the signal, repeat the final value, or generate 0s until the end of the simulation. The **Form output after final value by** parameter controls this behavior:

• When you specify `Setting To Zero`, the block generates zero-valued outputs for the duration of the simulation after generating the last frame of the signal.

- When you specify `Holding Final Value`, the block repeats the final frame for the duration of the simulation after generating the last frame of the signal.
- When you specify `Cyclic Repetition`, the block repeats the signal from the beginning after it reaches the last frame in the signal.

Use the **Image signal** parameter to specify how the block outputs a color video signal. If you select `One multidimensional signal`, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.

Use the **Output port labels** parameter to label your output ports. Use the spacer character, |, as the delimiter. This parameter is available when the **Image signal** parameter is set to `Separate color signals`.

Parameters

Signal

Specify the MATLAB workspace variable that contains the video signal, or use the `VideoReader` function to specify an AVI filename.

Sample time

Enter the sample period of the output.

Form output after final value by

Specify the output of the block after all of the specified signal samples have been generated. The block can output zeros for the duration of the simulation (`Setting to zero`), repeat the final value (`Holding Final Value`) or repeat the entire signal from the beginning (`Cyclic Repetition`).

Image signal

Specify how the block outputs a color video signal. If you select `One multidimensional signal`, the block outputs an M-by-N-by-P color video signal, where P is the number of color planes, at one port. If you select `Separate color signals`, additional ports appear on the block. Each port outputs one M-by-N plane of an RGB video stream.

Output port labels

Enter the labels for your output ports using the spacer character, |, as the delimiter. This parameter is available when the **Image signal** parameter is set to `Separate color signals`.

See Also

From Multimedia File	Computer Vision System Toolbox software
Image From Workspace	Computer Vision System Toolbox software
Read Binary File	Computer Vision System Toolbox software
To Video Display	Computer Vision System Toolbox software
Video Viewer	Computer Vision System Toolbox software

Introduced before R2006a

Video To Workspace

Export video signal to MATLAB workspace

Video To Workspace

Library

Sinks

`visionsinks`

Description

The Video To Workspace block exports a video signal to the MATLAB workspace. If the video signal is represented by intensity values, it appears in the workspace as a three-dimensional M-by-N-by-T array, where M and N are the number of rows and columns in a single video frame, and T is the number of frames in the video signal. If it is a color video signal, it appears in the workspace as a four-dimensional M-by-N-by-C-by-T array, where M and N are the number of rows and columns in a single video frame, C is the number of inputs to the block, and T is the number of frames in the video stream. During code generation, Simulink Coder does not generate code for this block.

Note This block supports intensity and color images on its ports.

Port	Input	Supported Data Types	Complex Values Supported
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes	• Double-precision floating point • Single-precision floating point • Fixed point • Boolean • 8-, 16-, 32-bit signed integer • 8-, 16-, 32-bit unsigned integer	No
R, G, B	Scalar, vector, or matrix that represents one plane of the RGB video stream. Outputs from the R, G, or B ports have the same dimensions.	Same as I port	No

Use the **Variable name** parameter to specify the MATLAB workspace variable to which to write the video signal.

Use the **Number of inputs** parameter to determine the number of inputs to the block. If the video signal is represented by intensity values, enter 1. If it is a color (R, G, B) video signal, enter 3.

Use the **Limit data points to last** parameter to determine the number of video frames, T, you want to export to the MATLAB workspace.

If you want to downsample your video signal, use the **Decimation** parameter to enter your decimation factor.

If your video signal is fixed point and you select the **Log fixed-point data as a fi object** check box, the block creates a fi object in the MATLAB workspace.

Use the **Input port labels** parameter to label your input ports. Use the spacer character, |, as the delimiter. This parameter is available if the **Number of inputs** parameter is greater than 1.

Parameters

Variable name

Specify the MATLAB workspace variable to which to write the video signal.

Number of inputs

Enter the number of inputs to the block. If the video signal is black and white, enter 1. If it is a color (R, G, B) video signal, enter 3.

Limit data points to last

Enter the number of video frames to export to the MATLAB workspace.

Decimation

Enter your decimation factor.

Log fixed-point data as a fi object

If your video signal is fixed point and you select this check box, the block creates a fi object in the MATLAB workspace. For more information of fi objects, see the Fixed-Point Designer documentation.

Input port labels

Enter the labels for your input ports using the spacer character, |, as the delimiter. This parameter is available if the **Number of inputs** parameter is greater than 1.

See Also

To Multimedia File	Computer Vision System Toolbox software
To Video Display	Computer Vision System Toolbox software
Video Viewer	Computer Vision System Toolbox software

Introduced before R2006a

Video Viewer

Display binary, intensity, or RGB images or video streams

Library

Sinks

visionsinks

Description

The Video Viewer block enables you to view a binary, intensity, or RGB image or a video stream. The block provides simulation controls for play, pause, and step while running the model. The block also provides pixel region analysis tools. During code generation, Simulink Coder software does not generate code for this block.

Note The To Video Display block supports code generation.

See the following table for descriptions of both input types.

Input	Description
Image	M-by-N matrix of intensity values or an M-by-N-by-P color video signal where P is the number of color planes.
R/G/B	Scalar, vector, or matrix that represents one plane of the RGB video stream. Inputs to the R, G, or B ports must have the same dimensions and data type.

Select **File > Image Signal** to set the input to either **Image** or **RGB**.

Dialogs
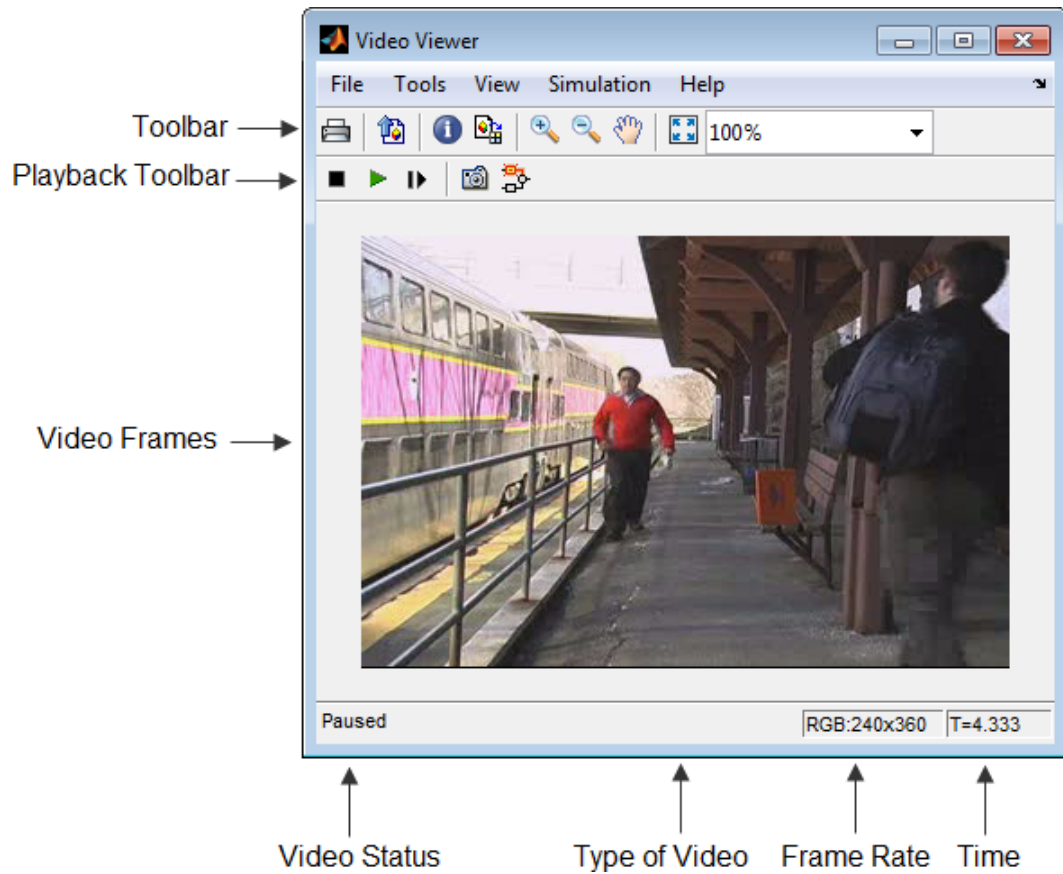
Toolbar

Toolbar

GUI	Menu Equivalent	Shortcut Keys and Accelerators	Description
🖨	**File > Print**	**Ctrl+P**	Print the current display window. Printing is only available when the display is not changing. You can enable printing by placing the display in snapshot mode, or by pausing or stopping model simulation, or simulating the model in step-forward mode. To print the current window to a figure rather than sending it to your printer, select **File > Print to figure**.
📷	**File > Export to Image Tool**	**Ctrl+E**	Send the current video frame to the Image Tool. For more information, see "Interact with Images Using Image Viewer App" (Image Processing Toolbox).
Note The Image Tool can only know that the frame is an intensity image if the colormap of the frame is grayscale (`gray(256)`). Otherwise, the Image Tool assumes the frame is an indexed image and disables the **Adjust Contrast** button.			
ⓘ	**Tools > Video Information**	**V**	View information about the video data source.
🔲	**Tools > Pixel Region**	N/A	Open the Pixel Region tool. For more information about this tool, see the Image Processing Toolbox documentation.
🔍	**Tools > Zoom In**	N/A	Zoom in on the video display.
🔍	**Tools > Zoom Out**	N/A	Zoom out of the video display.
✋	**Tools > Pan**	N/A	Move the image displayed in the GUI.

GUI	Menu Equivalent	Shortcut Keys and Accelerators	Description
⛶	**Tools > Maintain Fit to Window**	N/A	Scale video to fit GUI size automatically. Toggle the button on or off.
100%	N/A	N/A	Enlarge or shrink the video frame. This option becomes available if you do not select the **Maintain Fit to Window**.

Playback Toolbar

Playback Toolbar

GUI	Menu Equivalent	Shortcut Keys and Accelerators	Description
■	**Simulation > Stop**	**S**	Stop the video.
▶	**Simulation > Play**	**P**, Space bar	Play the video.
❚❚	**Simulation > Pause**	**P**, Space bar	Pause the video. This button appears only when the video is playing.
❚▶	**Simulation > Step Forward**	Right arrow, **Page Down**	Step forward one frame.
📷	**Simulation > Simulink Snapshot**	N/A	Click this button to freeze the display in the viewer window.
File-menu only	**Simulation > Drop Frames to Improve Performance**	**Ctrl+R**	Enable the viewer to drop video frames to improve performance.
⬚	**View > Highlight Simulink Signal**	**Ctrl+L**	In the model window, highlight the Simulink signal the viewer is displaying.

Setting Viewer Configuration

The Video Viewer Configuration preferences enables you to change the behavior and appearance of the graphic user interface (GUI) as well as the behavior of the playback shortcut keys.

- To open the Configuration dialog box, select **File > Configuration Set > Edit**.
- To save the configuration settings for future use, select **File > Configuration Set > Save as**.

Core Pane

The Core pane in the Viewer Configuration dialog box controls the GUI's general settings.
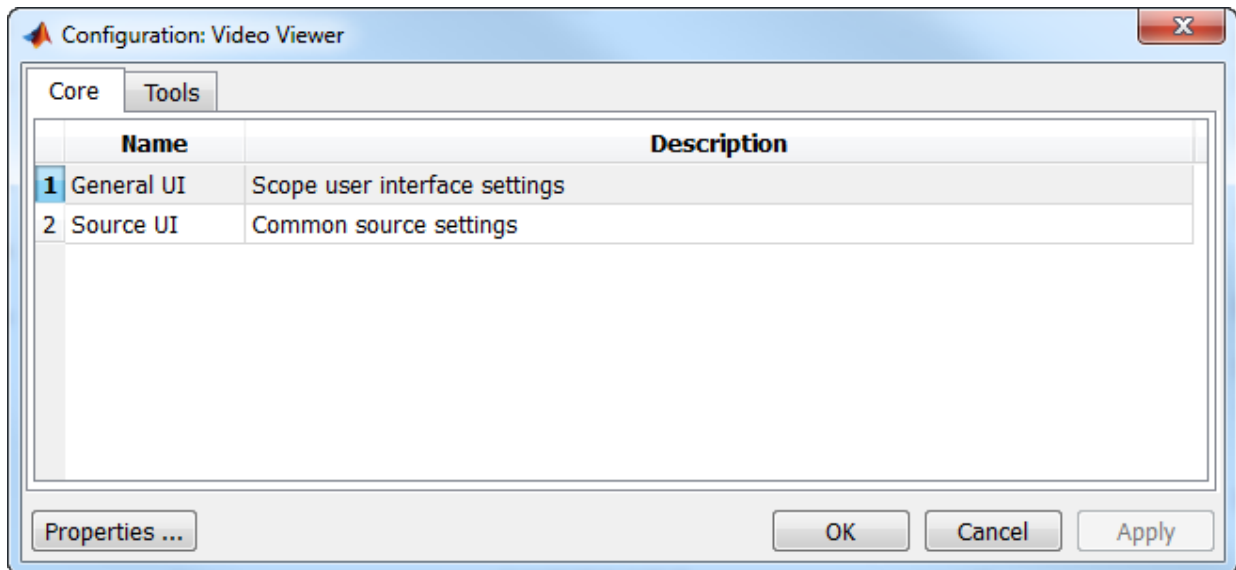
General UI
Click **General UI**, and click the **Options** button to open the General UI Options dialog box.
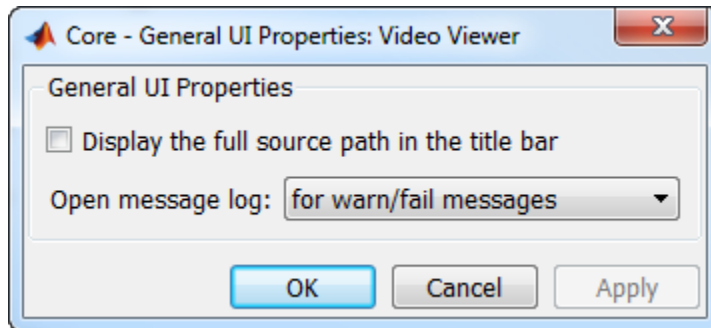
If you select the **Display the full source path in the title bar** check box, the GUI displays the model name and full Simulink path to the video data source in the title bar. Otherwise, it displays a shortened name.

Use the **Open message log:** parameter to control when the Message log window opens. You can use this window to debug issues with video playback. Your choices are `for any new messages`, `for warn/fail messages`, `only for fail messages`, or `manually`.

Tools Pane

The Tools pane in the Viewer Configuration dialog box contains the tools that appear on the Video Viewer GUI. Select the **Enabled** check box next to the tool name to specify which tools to include on the GUI.
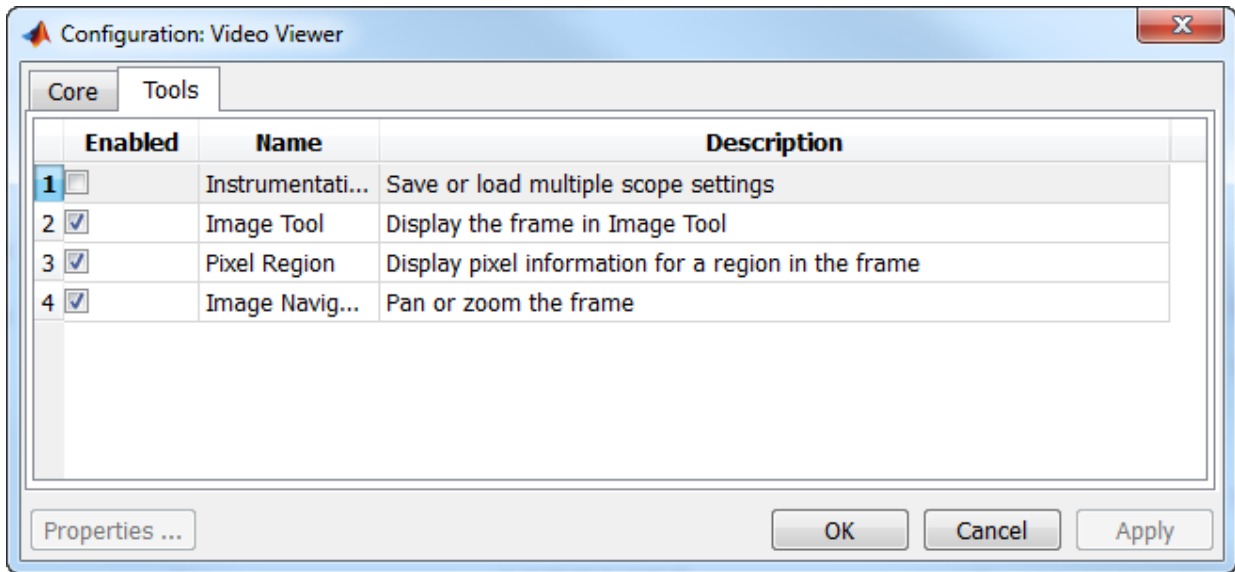
Image Tool

Click **Image Tool**, and then click the **Options** button to open the Image Tool Options dialog box.
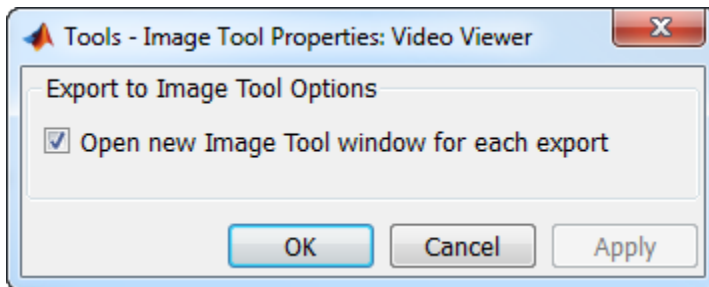
Select the **Open new Image Tool window for export** check box if you want to open a new Image Tool for each exported frame.

Pixel Region

Select the **Pixel Region** check box to display and enable the pixel region GUI button. For more information on working with pixel regions see Getting Information about the Pixels in an Image (Image Processing Toolbox).

Image Navigation Tools

Select the **Image Navigation Tools** check box to enable the pan-and-zoom GUI button.
Instrumentation Set
Select the **Instrumentation Set** check box to enable the option to load and save viewer settings. The option appears in the **File** menu.

Video Information

The Video Information dialog box lets you view basic information about the video. To open this dialog box, you can select **Tools > Video Information** , click the information button

 , or press the **V** key.
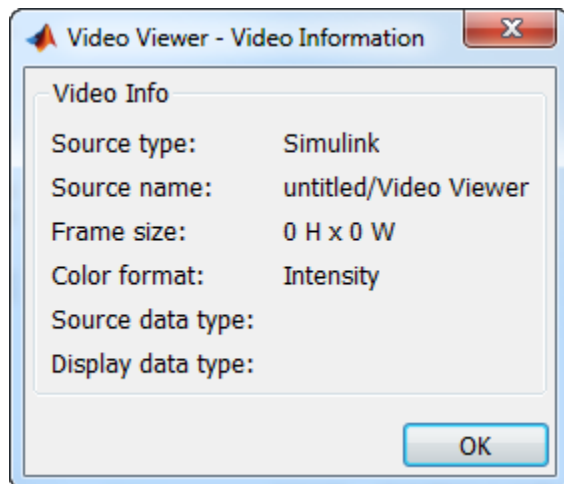
Colormap for Intensity Video

The Colormap dialog box lets you change the colormap of an intensity video. You cannot access the parameters on this dialog box when the GUI displays an RGB video signal. To open this dialog box for an intensity signal, select **Tools > Colormap** or press **C**.
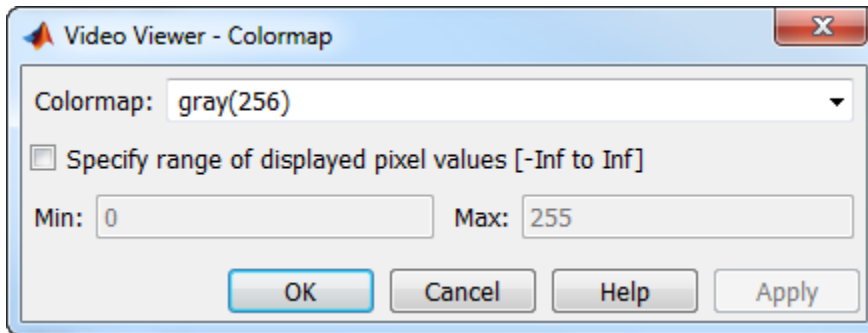
Use the **Colormap** parameter to specify the colormap to apply to the intensity video.

If you know that the pixel values do not use the entire data type range, you can select the **Specify range of displayed pixel values** check box and enter the range for your data. The dialog box automatically displays the range based on the data type of the pixel values.

Status Bar

A status bar appear along the bottom of the Video Viewer. It displays information pertaining to the video status (running, paused or ready), type of video (Intensity or RGB) and video time.

Message Log

The Message Log dialog provides a system level record of configurations and extensions used. You can filter what messages to display by **Type** and **Category**, view the records, and display record details.

The **Type** parameter allows you to select either `All`, `Info`, `Warn`, or `Fail` message logs. The **Category** parameter allows you to select either `Configuration` or `Extension` message summaries. The `Configuration` messages indicate when a new configuration file is loaded. The `Extension` messages indicate a component is registered. For example, you might see a `Simulink` message, which indicates the component is registered and available for configuration.

Saving the Settings of Multiple Video Viewer GUIs

The Video Viewer GUI enables you to save and load the settings of multiple GUI instances. Thus, you only need to configure the Video Viewer GUIs that are associated

with your model once. To save the GUI settings, select **File > Instrumentation Sets > Save Set**. To open the preconfigured GUIs, select **File > Instrumentation Sets > Load Set**.

Supported Data Types

Port	Supported Data Types
Image	• Double-precision floating point • Single-precision floating point • Boolean • 8-, 16-, and 32-bit signed integer • 8-, 16-, and 32-bit unsigned integer
R/G/B	Same as Image port

See Also

From Multimedia File	Computer Vision System Toolbox software
To Multimedia File	Computer Vision System Toolbox software
To Video Display	Computer Vision System Toolbox software
Video To Workspace	Computer Vision System Toolbox software
implay	Image Processing Toolbox

Introduced before R2006a

Warp

Apply projective or affine transformation to an image
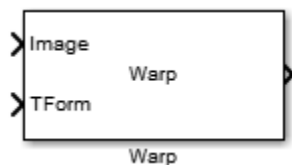
Library

Geometric Transformations

visiongeotforms

Description

The Warp block applies a projective on page 1-468 or affine on page 1-469 transformation to an image. You can transform the entire image or portions of the image using either a polygonal or rectangular region of interest (ROI).

Input Port Descriptions

Port	Input/Output	Description	Supported Data Types
Image	Input	*M*-by-*N* grayscale image or *M*-by-*N*-by-*3* truecolor image. • *M*— Number of rows in the image. • *N*— Number of columns in the image.	• Double-precision floating point • Single-precision floating point • 8- or 16-bit unsigned integers • 16-bit signed integers • logical

Port	Input/ Output	Description	Supported Data Types
TForm	Input	When you set **Transformation matrix source** to `Input port`, the **TForm** port accepts these inputs: • 3-by-2 matrix (affine transform). • 3-by-3 matrix (projective transform). When you set **Transformation matrix source** to `Custom`, specify the source in the **Transformation matrix** field.	• Double-precision floating point • Single-precision floating point
ROI	Input	When you enable the **ROI** input port, you can also enable an **Err_roi** output port to indicate if any part of an **ROI** is outside the input image. The **ROI** input port accepts an ROI rectangle, specified as a 4-element vector: [*x y width height*].	• Double-precision floating point • Single-precision floating point • 8-, 16-, or 32-bit signed integers • 8-, 16-, or 32-bit unsigned integers
Image	Output	Transformed image.	Same as input
Err_roi	Output	Indicates if any part of an ROI is outside the input image.	Boolean

Parameters

Transformation matrix source

Input matrix source, specified as either `Input port` or `Custom`. If you select `Custom`, you can enter the transformation matrix parameter in the field that appears with this selection.

Transformation matrix

Custom transformation matrix, specified as a 3-by-2 or 3-by-3 matrix. This parameters appears when you set **Transformation matrix source** to `Custom`.

Interpolation method

Interpolation method used to calculate output pixel values, specified as `Nearest neighbor`, `Bilinear`, or `Bicubic`. See "Nearest Neighbor, Bilinear, and Bicubic Interpolation Methods"for an overview of these methods.

Background fill value

Value of the pixels that are outside of the input image, specified as either a scalar value or a 3-element vector.

Output image position source

Source of the output image size, specified as either either `Same as input image` or `Custom`. If you select `Custom`, you can specify the bounding box in the field that appears with this selection.

Output image position vector [x y width height]

Position, width, and height of the output image, specified as a 4-element vector: [*x y width height*]. This parameter appears when you set **Output image position source** to `Custom`.

Enable ROI input port

Select this check box to enable the **ROI** input port. Use this port to specify the rectangular region you want to transform.

Enable output port indicating if any part of ROI is outside input image

Select this check box to enable the **Err_roi** output port.

References

[1] Wolberg, George . *Digital Image Warping*, 3rd edition. IEEE Computer Society Press, 1994.

[2] Hartley, Richard, and Andrew Zisserman. *Multiple View Geometry in Computer Vision*. 2nd edition. IEEE Computer Society Press, 2003.

See Also

`imwarp`, Estimate Geometric Transformation, Resize, RotateShearTranslate

Algorithms

The size of the transformation matrix dictates the transformation type.

Projective Transformation

In a projective transformation, the relationship between the input and the output points is defined by:

$$\begin{cases} \hat{x} = \dfrac{xh_1 + yh_2 + h_3}{xh_7 + yh_8 + h_9} \\ \hat{y} = \dfrac{xh_4 + yh_5 + h_6}{xh_7 + yh_8 + h_9} \end{cases}$$

where h_1, h_2,...,h_9 are transformation coefficients.

You must arrange the transformation coefficients as a 3-by-3 matrix as in:

$$H = \begin{bmatrix} h_1 & h_4 & h_7 \\ h_2 & h_5 & h_8 \\ h_3 & h_6 & h_9 \end{bmatrix}$$

.

Affine Transformation

In an affine transformation, The value of the pixel located at $[\hat{x}, \hat{y}]$ in the input image

determines the value of the pixel located at $[\hat{x}, \hat{y}]$ in the output image. The relationship between the input and output point locations is defined by:

$$\begin{cases} \hat{x} = xh_1 + yh_2 + h_3 \\ \hat{y} = xh_4 + yh_5 + h_6 \end{cases}$$

where h_1, h_2,...,h_6 are transformation coefficients.

You must arrange the transformation coefficients as a 3-by-2 matrix:

$$H = \begin{bmatrix} h_1 & h_4 \\ h_2 & h_5 \\ h_3 & h_6 \end{bmatrix}$$

See Also

Topics
"Video Mosaicking"

Introduced in R2015b

Write Binary File

Write binary video data to files

Library

Sinks

visionsinks

Description

The Write Binary File block takes video data from a Simulink model and exports it to a binary file.

This block produces a raw binary file with no header information. It has no encoded information providing the data type, frame rate or dimensionality. The video data for this block appears in row major format.

Note This block supports code generation only for platforms that have file I/O available. You cannot use this block to do code generation with Simulink Desktop Real-Time.

Port	Input	Supported Data Types	Complex Values Supported
Input	Matrix that represents the luma (Y') and chroma (Cb and Cr) components of a video stream	• 8-, 16- 32-bit signed integer • 8-, 16- 32-bit unsigned integer	No

Four Character Code Video Formats

Four Character Codes (FOURCC) identify video formats. For more information about these codes, see `http://www.fourcc.org`.

Use the **Four character code** parameter to identify the video format.

Custom Video Formats

You can use the Write Binary File block to create a binary file that contains video data in a custom format.

- Use the **Bit stream format** parameter to specify whether you want your data in planar or packed format.
- Use the **Number of input components** parameter to specify the number of components in the video stream. This number corresponds to the number of block input ports.
- Select the **Inherit size of components from input data type** check box if you want each component to have the same number of bits as the input data type. If you clear this check box, you must specify the number of bits for each component.
- Use the **Component** parameters to specify the component names.
- Use the **Component order in binary file** parameter to specify how to arrange the components in the binary file.
- Select the **Interlaced video** check box if the video stream represents interlaced video data.
- Select the **Write signed data to output file** check box if your input data is signed.
- Use the **Byte order in binary file** parameter to specify whether the byte ordering in the output binary file is little endian or big endian.

Parameters

File name

Specify the name of the binary file. To specify a different file or location, click the **Save As...** button.

Video format

Specify the format of the binary video data as either `Four character codes` or `Custom`. See "Four Character Code Video Formats" on page 1-471 or "Custom Video Formats" on page 1-471 for more details.

Four character code

From the list, select the binary file format.

Line ordering

Specify how the block fills the binary file. If you select `Top line first`, the block first fills the binary file with the first row of the video frame. It then fills the file with the other rows in increasing order. If you select `Bottom line first`, the block first fills the binary file with the last row of the video frame. It then fills the file with the other rows in decreasing order.

Bit stream format

Specify whether you want your data in planar or packed format.

Number of input components

Specify the number of components in the video stream. This number corresponds to the number of block input ports.

Inherit size of components from input data type

Select this check box if you want each component to have the same number of bits as the input data type. If you clear this check box, you must specify the number of bits for each component.

Component

Specify the component names.

Component order in binary file

Specify how to arrange the components in the binary file.

Interlaced video

Select this check box if the video stream represents interlaced video data.

Write signed data to output file

Select this check box if your input data is signed.

Byte order in binary file

Use this parameter to specify whether the byte ordering in the output binary file is little endian or big endian.

See Also

Read Binary File	Computer Vision System Toolbox
To Multimedia File	Computer Vision System Toolbox

Introduced before R2006a

Alphabetical List

pixelLabelImageDatastore

Datastore for semantic segmentation networks

Description

Use `pixelLabelImageDatastore` to create a datastore for training a semantic segmentation network using deep learning.

Creation

Syntax

```
pximds = pixelLabelImageDatastore(gTruth)
pximds = pixelLabelImageDatastore(imds,pxds)
pximds = pixelLabelImageDatastore( ___ ,Name,Value)
```

Description

`pximds = pixelLabelImageDatastore(gTruth)` returns a datastore for training a semantic segmentation network based on the input array of `groundTruth` objects. Use the output `pixelLabelImageDatastore` object with the Neural Network Toolbox™ function `trainNetwork` to train convolutional neural networks for semantic segmentation.

`pximds = pixelLabelImageDatastore(imds,pxds)` returns a datastore based on the input image datastore and the pixel label datastore objects. `imds` is an `ImageDatastore` object that represents the training input to the network. `pxds` is a `PixelLabelDatastore` object that represents the required network output.

`pximds = pixelLabelImageDatastore( ___ ,Name,Value)` additionally uses name-value pairs to set the `ColorPreprocessing`, `DataAugmentation`, `DispatchInBackground`, `OutputSize`, and `OutputSizeMode` properties. You can specify multiple name-value pairs. Enclose each property name in quotes.

For example, `pixelLabelImageDatastore(gTruth,'PatchesPerImage',40)` creates a denoising image datastore and randomly generates 40 noisy patches from each image in the image datastore, `imds`.

Input Arguments

gTruth — Ground truth data
groundTruth object

Ground truth data, specified as a `groundTruth` object. You can use the **Image Labeler** to create a `groundTruth` object for training a semantic segmentation network.

imds — Collection of images
ImageDatastore object

Collection of images, specified as an `ImageDatastore` object.

pxds — Collection of pixel labeled images
PixelLabelDatastore object

Collection of pixel labeled images, specified as a `PixelLabelDatastore` object. The object contains the pixel labeled images for each image contained in the `imds` input object.

Properties

Images — Image file names
character vector | cell array of character vectors

This property is read-only.

Image file names used as the source for ground truth images, specified as a character vector or a cell array of character vectors.

PixelLabelData — Pixel label file names
character | cell array of characters

This property is read-only.

Pixel label data file names used as the source for ground truth label images, specified as a character or a cell array of characters.

ClassNames — Class names
cell array of character vectors

This property is read-only.

Class names, specified as a cell array of character vectors.

ColorPreprocessing — Color channel preprocessing
'none' (default) | 'gray2rgb' | 'rgb2gray'

Color channel preprocessing, specified as 'none', 'gray2rgb', or 'rgb2gray'. Use this property when you need the image data created by the data source must be only color or grayscale, but the training set includes both. Suppose you need to train a network that expects color images but some of your training images are grayscale. Set ColorPreprocessing to 'gray2rgb' to replicate the color channels of the grayscale images in the input image set. Using the 'gray2rgb' option creates *M*-by-*N*-by-3 output images.

DataAugmentation — Preprocessing applied to input images
'none' (default) | imageDataAugmenter object

Preprocessing applied to input images, specified as an imageDataAugmenter object or 'none'. When DataAugmentation is 'none', no preprocessing is applied to input images. Training data can be augmented in real-time during training.

DispatchInBackground — Dispatch observations in background
false (default) | true

Dispatch observations in the background during training, prediction, and classification, specified as false or true. To use background dispatching, you must have Parallel Computing Toolbox™. If DispatchInBackground is true and you have Parallel Computing Toolbox, then pixelLabelImageDatastore asynchronously reads patches, adds noise, and queues patch pairs.

MiniBatchSize — Number of observations in each batch
positive integer

This property is read-only.

Number of observations that are returned in each batch. For training, prediction, or classification, the MiniBatchSize property is set to the mini batch size defined in trainingOptions.

NumObservations — Total number of observations in the datastore
positive integer

This property is read-only.

Total number of observations in the denoising image datastore. The number of observations is the length of one training epoch.

OutputSize — Size of output images
`[ ]` (default) | vector of two positive integers

Size of output images, specified as a vector of two positive integers. The first element specifies the number of rows in the output images, and the second element specifies the number of columns. When you specify `OutputSize`, image sizes are adjusted as necessary. By default, this property is empty, which means that the images are not adjusted.

OutputSizeMode — Method used to resize output images
`'resize'` (default) | `'centercrop'` | `'randcrop'`

Method used to resize output images, specified as one of the following. This property applies only when you set `OutputSize` to a value other than `[ ]`.

- `'resize'` — Scale the image to fit the output size. For more information, see `imresize`.
- `'centercrop'` — Take a crop from the center of the training image. The crop has the same size as the output size.
- `'randcrop'` — Take a random crop from the training image. The random crop has the same size as the output size.

Data Types: `char` | `string`

Object Functions

countEachLabel	Count occurrence of pixel label for data source images
hasdata	Determine if data is available to read
partitionByIndex	Partition pixelLabelImageDatastore according to indices
preview	Subset of data in datastore
read	Read data from pixelLabelImageDatastore
readall	Read all data in datastore

readByIndex	Read data specified by index from pixelLabelImageDatastore
reset	Reset datastore to initial state
shuffle	Shuffle data in pixelLabelImageDatastore

Examples

Train A Semantic Segmentation Network

Load the training data.

```
dataSetDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
imageDir = fullfile(dataSetDir,'trainingImages');
labelDir = fullfile(dataSetDir,'trainingLabels');
```

Create an image datastore for the images.

```
imds = imageDatastore(imageDir);
```

Create a `pixelLabelDatastore` for the ground truth pixel labels.

```
classNames = ["triangle","background"];
labelIDs   = [255 0];
pxds = pixelLabelDatastore(labelDir,classNames,labelIDs);
```

Visualize training images and ground truth pixel labels.

```
I = read(imds);
C = read(pxds);

I = imresize(I,5);
L = imresize(uint8(C),5);
imshowpair(I,L,'montage')
```

Create a semantic segmentation network. This network uses a simple semantic segmentation network based on a downsampling and upsampling design.

```
numFilters = 64;
filterSize = 3;
numClasses = 2;
layers = [
    imageInputLayer([32 32 1])
    convolution2dLayer(filterSize,numFilters,'Padding',1)
    reluLayer()
    maxPooling2dLayer(2,'Stride',2)
    convolution2dLayer(filterSize,numFilters,'Padding',1)
    reluLayer()
    transposedConv2dLayer(4,numFilters,'Stride',2,'Cropping',1);
    convolution2dLayer(1,numClasses);
    softmaxLayer()
    pixelClassificationLayer()
    ]

layers =
  10x1 Layer array with layers:

     1   ''    Image Input                 32x32x1 images with 'zerocenter' normalizat:
     2   ''    Convolution                 64 3x3 convolutions with stride [1   1] and [
     3   ''    ReLU                        ReLU
     4   ''    Max Pooling                 2x2 max pooling with stride [2   2] and padd:
```

```
    5   ''   Convolution                 64 3x3 convolutions with stride [1  1] and p
    6   ''   ReLU                        ReLU
    7   ''   Transposed Convolution      64 4x4 transposed convolutions with stride [
    8   ''   Convolution                 2 1x1 convolutions with stride [1  1] and pa
    9   ''   Softmax                     softmax
   10   ''   Pixel Classification Layer  Cross-entropy loss
```

Setup training options.

```
opts = trainingOptions('sgdm', ...
    'InitialLearnRate',1e-3, ...
    'MaxEpochs',100, ...
    'MiniBatchSize',64);
```

Create a pixel label image datastore that contains training data.

```
trainingData = pixelLabelImageDatastore(imds,pxds);
```

Train the network.

```
net = trainNetwork(trainingData,layers,opts);
```

```
Training on single GPU.
Initializing image normalization.
|===========================================================================================
| Epoch  |  Iteration  |  Time Elapsed  |  Mini-batch  |  Mini-batch  |  Base Learning
|        |             |   (hh:mm:ss)   |   Accuracy   |     Loss     |     Rate
|===========================================================================================
|      1 |           1 |    00:00:00    |    56.29%    |    0.6931    |       0.001
|     17 |          50 |    00:00:04    |    95.07%    |    0.5546    |       0.001
|     34 |         100 |    00:00:09    |    95.38%    |    0.4408    |       0.001
|     50 |         150 |    00:00:13    |    94.53%    |    0.3785    |       0.001
|     67 |         200 |    00:00:18    |    95.07%    |    0.3278    |       0.001
|     84 |         250 |    00:00:22    |    95.38%    |    0.2923    |       0.001
|    100 |         300 |    00:00:27    |    94.53%    |    0.2820    |       0.001
|===========================================================================================
```

Read and display a test image.

```
testImage = imread('triangleTest.jpg');
imshow(testImage)
```
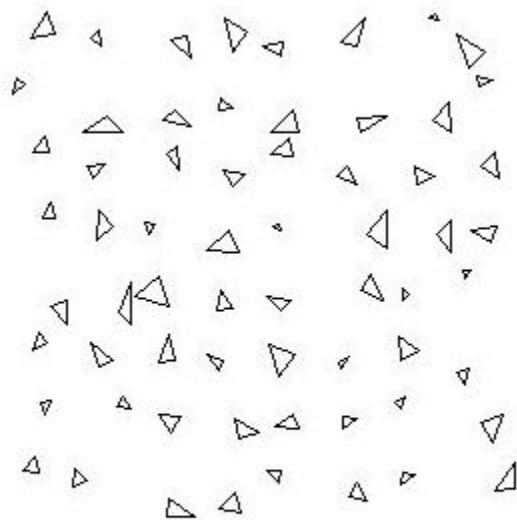
Segment the test image and display the results.

```
C = semanticseg(testImage,net);
B = labeloverlay(testImage,C);
imshow(B)
```
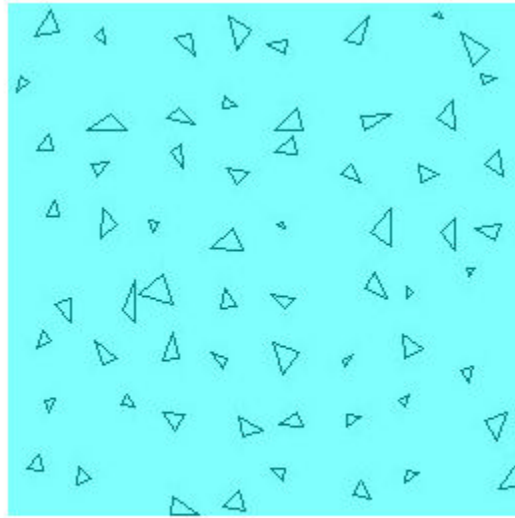
Improve the results

The network failed to segment the triangles and classified every pixel as "background". The training appeared to be going well with training accuracies greater than 90%. However, the network only learned to classify the background class. To understand why this happened, you can count the occurrence of each pixel label across the dataset.

```
tbl = countEachLabel(trainingData)
```

```
tbl=2×3 table
        Name         PixelCount      ImagePixelCount
    _____   _____      _____

    'triangle'           10326         2.048e+05
    'background'     1.9447e+05         2.048e+05
```

The majority of pixel labels are for the background. The poor results are due to the class imbalance. Class imbalance biases the learning process in favor of the dominant class.

That's why every pixel is classified as "background". To fix this, use class weighting to balance the classes. There are several methods for computing class weights. One common method is inverse frequency weighting where the class weights are the inverse of the class frequencies. This increases weight given to under-represented classes.

```
totalNumberOfPixels = sum(tbl.PixelCount);
frequency = tbl.PixelCount / totalNumberOfPixels;
classWeights = 1./frequency
```

classWeights = *2×1*

```
   19.8334
    1.0531
```

Class weights can be specified using the pixelClassificationLayer. Update the last layer to use a pixelClassificationLayer with inverse class weights.

```
layers(end) = pixelClassificationLayer('ClassNames',tbl.Name,'ClassWeights',classWeigh
```

Train network again.

```
net = trainNetwork(trainingData,layers,opts);
```

Training on single GPU.
Initializing image normalization.

Epoch	Iteration	Time Elapsed (hh:mm:ss)	Mini-batch Accuracy	Mini-batch Loss	Base Learning Rate
1	1	00:00:00	57.17%	0.6945	0.001
17	50	00:00:04	78.32%	0.6677	0.001
34	100	00:00:09	80.11%	0.4283	0.001
50	150	00:00:14	85.69%	0.3923	0.001
67	200	00:00:19	87.64%	0.3395	0.001
84	250	00:00:24	89.53%	0.3038	0.001
100	300	00:00:28	90.40%	0.2855	0.001

Try to segment the test image again.

```
C = semanticseg(testImage,net);
B = labeloverlay(testImage,C);
imshow(B)
```
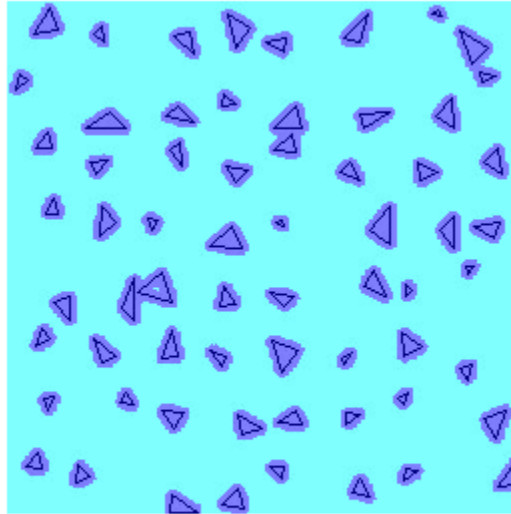
Using class weighting to balance the classes produced a better segmentation result. Additional steps to improve the results include increasing the number of epochs used for training, adding more training data, or modifying the network.

Augment Data While Training

Configure a pixel label image datastore to augment data while training.

Load training images and pixel labels.

```
dataSetDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
imageDir = fullfile(dataSetDir,'trainingImages');
labelDir = fullfile(dataSetDir,'trainingLabels');
```

Create an `imageDatastore` object to hold the training images.

```
imds = imageDatastore(imageDir);
```

Define the class names and their associated label IDs.

```
classNames = ["triangle","background"];
labelIDs   = [255 0];
```

Create a `pixelLabelDatastore` object to hold the ground truth pixel labels for the training images.

```
pxds = pixelLabelDatastore(labelDir, classNames, labelIDs);
```

Create an `imageDataAugmenter` object to randomly rotate and mirror image data.

```
augmenter = imageDataAugmenter('RandRotation',[-10 10],'RandXReflection',true)

augmenter =
  imageDataAugmenter with properties:

            FillValue: 0
      RandXReflection: 1
      RandYReflection: 0
         RandRotation: [-10 10]
           RandXScale: [1 1]
           RandYScale: [1 1]
           RandXShear: [0 0]
           RandYShear: [0 0]
     RandXTranslation: [0 0]
     RandYTranslation: [0 0]
```

Create a `pixelLabelImageDatastore` object to train the network with augmented data.

```
plimds = pixelLabelImageDatastore(imds,pxds,'DataAugmentation',augmenter)

plimds =
  pixelLabelImageDatastore with properties:

                  Images: {200x1 cell}
          PixelLabelData: {200x1 cell}
              ClassNames: {2x1 cell}
        DataAugmentation: [1x1 imageDataAugmenter]
      ColorPreprocessing: 'none'
              OutputSize: []
          OutputSizeMode: 'resize'
           MiniBatchSize: 1
```

```
        NumObservations: 200
    DispatchInBackground: 0
```

See Also

ImageDatastore | groundTruth | pixelLabelDatastore |
pixelLabelTrainingData | trainNetwork

Topics
"Semantic Segmentation Basics"
"Deep Learning Basics" (Neural Network Toolbox)
"Deep Learning in MATLAB" (Neural Network Toolbox)

Introduced in R2018a

partitionByIndex

Partition `pixelLabelImageDatastore` according to indices

Syntax

```
pximds2 = partitionByIndex(pximds,ind)
```

Description

`pximds2 = partitionByIndex(pximds,ind)` partitions a subset of observations in a pixel label image datastore, `pximds`, into a new datastore, `pximds2`. The desired observations are specified by indices, `ind`.

Input Arguments

pximds — Pixel label image datastore
pixelLabelImageDatastore

Pixel label image datastore, specified as a `pixelLabelImageDatastore` object.

ind — Indices
vector of positive integers

Indices of observations, specified as a vector of positive integers.

Output Arguments

pximds2 — Output datastore
pixelLabelImageDatastore object

Output datastore, returned as a `pixelLabelImageDatastore` object containing a subset of files from `pximds`.

See Also

pixelLabelImageDatastore | read | readByIndex | readall

Introduced in R2018a

read

Read data from `pixelLabelImageDatastore`

Syntax

```
data = read(pximds)
[data,info] = read(pximds)
```

Description

`data = read(pximds)` returns a batch of data from a pixel label image datastore, `pximds`. Subsequent calls to the `read` function continue reading from the endpoint of the previous call.

`[data,info] = read(pximds)` also returns information about the extracted data, including metadata, in `info`.

Input Arguments

pximds — Pixel label image datastore
`pixelLabelImageDatastore`

Pixel label image datastore, specified as a `pixelLabelImageDatastore` object. The datastore specifies a `MiniBatchSize` number of observations in each batch, and a `numObservations` total number of observations.

Output Arguments

data — Output data
table

Output data, returned as a table with `MiniBatchSize` number of rows.

For the last batch of data in the datastore `pximds`, if `numObservations` is not cleanly divisible by `MiniBatchSize`, then `read` returns a partial batch containing all the remaining observations in the datastore.

`info` — Information about read data
structure array

Information about read data, returned as a structure array. The structure array can contain the following fields.

Field Name	Description
Filename	`Filename` is a fully resolved path containing the path string, name of the file, and file extension.
FileSize	Total file size, in bytes. For MAT-files, `FileSize` is the total number of key-value pairs in the file.

See Also
matlab.io.datastore.read | pixelLabelImageDatastore | readByIndex | readall

Introduced in R2018a

readByIndex

Read data specified by index from `pixelLabelImageDatastore`

Syntax

```
data = readByIndex(pximds,ind)
[data,info] = readByIndex(pximds,ind)
```

Description

`data = readByIndex(pximds,ind)` returns a subset of observations from a pixel label image datastore, `pximds`. The desired observations are specified by indices, `ind`.

`[data,info] = readByIndex(pximds,ind)` also returns information about the observations, including metadata, in `info`.

Input Arguments

pximds — Pixel label image datastore
pixelLabelImageDatastore

Pixel label image datastore, specified as a `pixelLabelImageDatastore` object.

ind — Indices
vector of positive integers

Indices of observations, specified as a vector of positive integers.

Output Arguments

data — Observations from datastore
table

Observations from the datastore, returned as a table with `length(ind)` number of rows.

`info` — Information about read data
structure array

Information about read data, returned as a structure array. The structure array can contain the following fields.

Field Name	Description
Filename	`Filename` is a fully resolved path containing the path string, name of the file, and file extension.
FileSize	Total file size, in bytes. For MAT-files, `FileSize` is the total number of key-value pairs in the file.

See Also

partitionByIndex | pixelLabelImageDatastore | read | readall

Introduced in R2018a

shuffle

Shuffle data in `pixelLabelImageDatastore`

Syntax

```
pximds2 = shuffle(pximds)
```

Description

`pximds2 = shuffle(pximds)` returns a `pixelLabelImageDatastore` object containing a random ordering of the data from pixel label image datastore `pximds`.

Input Arguments

pximds — Pixel label image datastore
`pixelLabelImageDatastore`

Pixel label image datastore, specified as a `pixelLabelImageDatastore` object.

Output Arguments

pximds2 — Output datastore
`pixelLabelImageDatastore` object

Output datastore, returned as a `pixelLabelImageDatastore` object containing randomly ordered files from `pximds`.

See Also
`pixelLabelImageDatastore` | `read` | `readByIndex` | `readall`

Introduced in R2018a

crop2dLayer

Neural network layer in a neural network that can be used to crop an input feature map

Description

A crop layer contains information about how to crop a feature map.

A crop layer has two inputs:

- `'in'` — The feature map that will be cropped
- `'ref'` — A reference layer used to determine the size, [*height width*], of the cropped output

Once you create this layer, you can add it to a `layerGraph` to make serial connections between layers. To connect the crop layer to other layers, call `connectLayers` and specify the input names. The `connectLayers` function returns a connected `LayerGraph` object ready to train a network. Connecting layers requires Neural Network Toolbox.
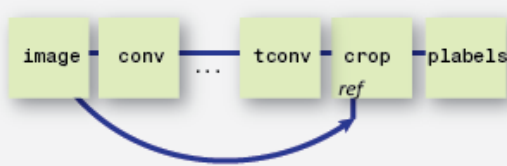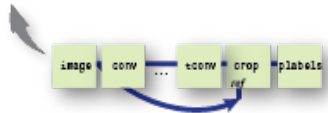
Creation

Syntax

```
layer = crop2dLayer('centercrop')
layer = crop2dLayer(Location)
layer = crop2dLayer( ___ ,'Name',Name)
```

Description

`layer = crop2dLayer('centercrop')` returns a layer that crops an input feature map, and sets the `Mode` property.

`layer = crop2dLayer(Location)` returns a layer that crops an input feature map using a rectangular window, and sets the `Location` property that indicates the position of the window.

`layer = crop2dLayer( ___ ,'Name',Name)` creates a layer for cropping and sets the optional `Name` property.

Properties

Name — Layer name
`''` (default) | character vector

Layer name, specified as a character vector. If `Name` is set to `''`, then the software automatically assigns a name at training time.

Data Types: `char`

Mode — Cropping mode
`'centercrop'` (default) | `'custom'`

Cropping mode, specified as `'centercrop'` or `'custom'`.

Mode	Description
`'centercrop'`	The location of the cropping window is the center of the input feature map.
`'custom'`	The location of the cropping window is based on the `Location` property. This value is automatically set when the `Location` property is specified as a 2-element row vector.

Data Types: `char`

Location — Cropping window location
`'auto'` (default) | 2-element row vector

Cropping window location, specified as `'auto'` or a 2-element row vector.

Location	Description
2-element row vector in the format [*x y*]	The upper-left corner of the cropping window is at the location [*x y*] of the input feature map. *x* indicates the location in the horizontal direction and *y* is the vertical direction.
`'auto'`	The cropping window is located at the center of the input feature map. This value is automatically set when the Mode property is specified as `'centercrop'`.

Examples

Create 2-D Drop Layer

Create a 2-D drop layer and connect both of the inputs using a layerGraph object.

Create the layers.

```
layers = [
    imageInputLayer([32 32 3],'Name','image')
    crop2dLayer('centercrop','Name','crop')
    ]

layers =
  2x1 Layer array with layers:

    1   'image'   Image Input   32x32x3 images with 'zerocenter' normalization
    2   'crop'    Crop 2D       center crop
```

Create a `layerGraph`. The first input of `crop2dLayer` is automatically connected to the first output of the image input layer.

```
lgraph = layerGraph(layers)

lgraph =
  LayerGraph with properties:

          Layers: [2x1 nnet.cnn.layer.Layer]
     Connections: [1x2 table]
```

Connect the second input to the image layer output.

```
lgraph = connectLayers(lgraph,'image','crop/ref')

lgraph =
  LayerGraph with properties:

        Layers: [2x1 nnet.cnn.layer.Layer]
    Connections: [2x2 table]
```

See Also

connectLayers | fcnLayers | layerGraph | pixelClassificationLayer | trainNetwork

Topics

"Semantic Segmentation Basics"
"Deep Learning Basics" (Neural Network Toolbox)

Introduced in R2017b

pixelClassificationLayer

Create pixel classification layer for semantic segmentation

Description

You can use the pixel classification layer to provide a categorical label for each image pixel processed by a convolutional neural network (CNN).

Creation

Syntax

```
layer = pixelClassificationLayer
layer = pixelClassificationLayer(Name,Value)
```

Description

`layer = pixelClassificationLayer` creates a pixel classification output layer for semantic image segmentation networks. The layer outputs the categorical label for each image pixel processed by a CNN. The layer automatically ignores undefined pixel labels during training.

`layer = pixelClassificationLayer(Name,Value)` returns a pixel classification output layer using Name,Value pair arguments to set the optional `ClassNames`, `ClassWeights`, and `Name` properties by using name-value pairs.

Properties

ClassNames — Class names
`'auto'` (default) | string vector | cell array of character vectors

Class names, specified as `'auto'`, a string vector, or a cell array of character vectors. When you set `ClassNames` to `'auto'`, the class names are automatically set during training.

`ClassWeights` — Class weights
`'none'` (default) | vector of real scalar

Class weights, specified as `'none'` or as a vector of real scalar. The elements of the vector correspond to the classes in `ClassNames`. If you specify `ClassWeights`, then you must specify `ClassNames`.

Use class weighting to balance classes when there are underrepresented classes in the training data.

`Name` — Layer name
`''` (default) | character vector

Layer name, specified as a character vector. If `Name` is set to `''`, then the software automatically assigns a name at training time.

Data Types: `char`

`OutputSize` — Output size
`'auto'` (default)

This property is read-only.

The output size of the layer. The value is `'auto'` prior to training, and is specified as a numeric value at training time.

`LossFunction` — Loss function
`'crossentropyex'` (default)

This property is read-only.

Loss function used for training, specified as `'crossentropyex'`.

Examples

Use Pixel Classification Layer to Create Semantic Segmentation Network

Predict the categorical label of every pixel in an input image.

```
layers = [
        imageInputLayer([32 32 3])
        convolution2dLayer(3,16,'Stride',2,'Padding',1)
        reluLayer
        transposedConv2dLayer(3,1,'Stride',2,'Cropping',1)
        softmaxLayer
        pixelClassificationLayer
    ]

layers =
  6x1 Layer array with layers:

     1   ''   Image Input               32x32x3 images with 'zerocenter' normalizat:
     2   ''   Convolution               16 3x3 convolutions with stride [2  2] and
     3   ''   ReLU                      ReLU
     4   ''   Transposed Convolution    1 3x3 transposed convolutions with stride [2
     5   ''   Softmax                   softmax
     6   ''   Pixel Classification Layer  Cross-entropy loss
```

Use Weighting to Balance Classes in Training Data

Balance classes using inverse class frequency weighting when some classes are underrepresented in the training data. First, count class frequencies over the training data using pixelLabelImageDatastore. Then, set the 'ClassWeights' in pixelClassificationLayer to the computed inverse class frequencies.

Set the location of image and pixel label data.

```
  dataDir = fullfile(toolboxdir('vision'),'visiondata');
  imDir = fullfile(dataDir,'building');
  pxDir = fullfile(dataDir,'buildingPixelLabels');
```

Create a pixel label image datastore using the ground truth images in imds and the pixel labeled images in pxds.

```
  imds = imageDatastore(imDir);
  classNames = ["sky" "grass" "building" "sidewalk"];
  pixelLabelID = [1 2 3 4];
```

```
pxds = pixelLabelDatastore(pxDir,classNames,pixelLabelID);
pximds = pixelLabelImageDatastore(imds,pxds);
```

Tabulate class distribution in dataset.

```
tbl = countEachLabel(pximds)
```

```
tbl=4×3 table
      Name        PixelCount     ImagePixelCount
    _____    _____     _____

    'sky'         3.1485e+05       1.536e+06
    'grass'       1.5979e+05       1.536e+06
    'building'    1.0312e+06       1.536e+06
    'sidewalk'         25313       9.216e+05
```

Calculate inverse frequency class weights.

```
totalNumberOfPixels = sum(tbl.PixelCount);
frequency = tbl.PixelCount / totalNumberOfPixels;
inverseFrequency = 1./frequency
```

```
inverseFrequency = 4×1

    4.8632
    9.5827
    1.4848
   60.4900
```

Set 'ClassWeights' to the inverse class frequencies.

```
layer = pixelClassificationLayer(...
    'ClassNames',tbl.Name,'ClassWeights',inverseFrequency)
```

```
layer =
  PixelClassificationLayer with properties:

          Name: ''
     ClassNames: {'sky'  'grass'  'building'  'sidewalk'}
   ClassWeights: [4x1 double]
     OutputSize: 'auto'

  Hyperparameters
```

```
LossFunction: 'crossentropyex'
```

See Also

fcnLayers | pixelLabelDatastore | pixelLabelImageDatastore | segnetLayers | semanticseg | trainNetwork

Topics
"Semantic Segmentation Basics"
"Deep Learning Basics" (Neural Network Toolbox)
"Deep Learning in MATLAB" (Neural Network Toolbox)
"Specify Layers of Convolutional Neural Network" (Neural Network Toolbox)

Introduced in R2017b

pixelLabelDatastore

Datastore for pixel label data

Description

You can use a `PixelLabelDatastore` object to read pixel label data for semantic segmentation.

To read pixel label data from a `PixelLabelDatastore`, use the `read` function. This function returns a categorical matrix that contains a categorical label assigned to every (i,j) pixel location.

Creation

Create a `PixelLabelDatastore` object using the `pixelLabelDatastore` function described here. Once the object is created, you can use functions that access and manage the data. You can use dot notation to modify the `ReadSize` and `ReadFcn` properties.

Syntax

```
pxds = pixelLabelDatastore(gTruth)
pxds = pixelLabelDatastore(location,classNames,pixelLabelIDs)
pxds = pixelLabelDatastore(location,Name,Value)
```

Description

`pxds = pixelLabelDatastore(gTruth)` creates a `PixelLabelDatastore` object from an array of `groundTruth` objects.

`pxds = pixelLabelDatastore(location,classNames,pixelLabelIDs)` creates a `PixelLabelDatastore` object from image files that store pixel label data, in the folder or files specified by `location`. The function creates the object using pixel IDs that map image pixel label values to class names.

`pxds = pixelLabelDatastore(location,Name,Value)` creates a `PixelLabelDatastore` object using `Name,Value` pair arguments to set the `ReadSize` property and the `IncludeSubfolders on page 2-0` value. You can specify multiple `Name,Value` pair arguments. Enclose each property name in quotes.

Input Arguments

gTruth — Ground truth
array of `groundTruth` objects

Ground truth, specified as an array of `groundTruth` objects. Each `groundTruth` object contains information about the data source, the list of label definitions, and all marked labels for a set of ground truth labels.

location — Folder or image file names
character vector | cell array of character vectors

Folder or image file names, specified as a character vector or cell array of character vectors. Images must contain `uint8` data.

location	Description
character vector	Name of a folder. Files within subfolders of the specified folder are not automatically included in the datastore. The datastore includes only images with supported file formats and ignores any other format. See a list of supported file formats by using the `imformats` function.
cell array of character vectors	File names of multiple images.

`pixelLabelDatastore` expands the file names and stores the full file paths in the `Files` property.

You can use the wildcard character (*) when specifying `location`. This character indicates that all matching files or all files in the matching folders are included in the datastore.

If the files are not in the current folder, then you must include the full or relative path.

If the files are not available locally, then the full path of the files or folders must be an internationalized resource identifier (IRI), such as `hdfs://hostname:portnumber/`

path_to_file. For information on using a `datastore` with Amazon S3™ and HDFS™, see "Read Remote Data" (MATLAB).

Example: `'file1.jpg'`

Example: `'../dir/data/file1.png'`

Example: `{'C:\dir\data\file1.tif','C:\dir\data\file2.tif'}`

Example: `'C:\dir\data\*.jpg'`

Data Types: `char` | `cell`

`classNames` — Class names
cell array of character vectors

Class names, specified as a cell array of character vectors. `pixelLabelDatastore` converts the names to a cell array and stores the names in the `ClassNames` property.

Example: `["sky" "grass" "building" "sidewalk"]`

`pixelLabelIDs` — IDs to relate pixel labels to class names
vector | *m*-by-3 matrix | cell array of column vectors | cell array of *m*-by-3 matrices

IDs to map pixel labels to `ClassNames`, specified as a vector, an *m*-by-3 matrix, a cell array of column vectors, or a cell array of *m*-by-3 matrices. Values must be integers in the range [0,255].

Format	Description
vector	The length of the vector must equal the number of class names. Values must be unique.
m-by-3 matrix	*m* corresponds to the number of class names. Each row contains a 3-element vector representing the RGB pixel value to associate with each class name. Vectors must be unique. Use this format for pixel label data stored as RGB images.
cell array of column vectors cell array of *m*-by-3 matrices	Use a cell array to map multiple pixel label IDs to one class name.

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'IncludeSubfolders',true`

IncludeSubfolders — Subfolder inclusion flag
`false` (default) | `true`

Subfolder inclusion flag, specified as the comma-separated pair consisting of `'IncludeSubfolders'` and `false` (0), or `true` (1). Specify `true` to include all files and subfolders within each folder or `false` to include only the files within each folder.

Properties

Files — Files included in datastore
character vector | cell array of character vectors

This property is read-only.

Files included in the datastore, specified as a character vector or cell array of character vectors. Each character vector is a full path to a file. When you create a `PixelLabelDatastore` object, use the `location` argument to set this property.

ClassNames — Class names
cell array of character vectors

This property is read-only.

Class names, specified as a cell array of character vectors.

ReadSize — Maximum number of image files
1 (default) | positive integer

Maximum number of image files to read in each call to the `read` function, specified as a positive integer.

AlternateFileSystemRoots — Alternate file system root paths
string vector | cell array

Alternate file system root paths, specified as the comma-separated pair consisting of `'AlternateFileSystemRoots'` and a string vector or a cell array. Use `'AlternateFileSystemRoots'` when you create a datastore on a local machine, but need to access and process the data on another machine (possibly of a different operating system). Also, when processing data using PCTParallel Computing Toolbox and MATLAB Distributed Computing Server™, and the data is stored on your local machines with a copy of the data available on different platform cloud or cluster machines, you must use `'AlternateFileSystemRoots'` to associate the root paths.

- To associate a set of root paths that are equivalent to one another, specify `'AlternateFileSystemRoots'` as a string vector. For example,

  `["Z:\datasets","/mynetwork/datasets"]`
- To associate multiple sets of root paths that are equivalent for the datastore, specify `'AlternateFileSystemRoots'` as a cell array containing multiple rows where each row represents a set of equivalent root paths. Specify each row in the cell array as either a string vector or a cell array of character vectors. For example:

  - Specify `'AlternateFileSystemRoots'` as a cell array of string vectors.

    `{["Z:\datasets", "/mynetwork/datasets"];...`
    `["Y:\datasets", "/mynetwork2/datasets","S:\datasets"]}`
  - Alternatively, specify `'AlternateFileSystemRoots'` as a cell array of cell array of character vectors.

    `{{'Z:\datasets','/mynetwork/datasets'};...`
    `{'Y:\datasets', '/mynetwork2/datasets','S:\datasets'}}`

The value of `'AlternateFileSystemRoots'` must satisfy these conditions:

- Contains one or more rows, where each row specifies a set of equivalent root paths.
- Each row specifies multiple root paths and each root path must contain at least two characters.
- Root paths are unique and are not subfolders of one another.
- Contains at least one root path entry that points to the location of the files.

For more information, see "Set Up Datastore for Processing on Different Machines or Clusters" (MATLAB).

Example: `["Z:\datasets","/mynetwork/datasets"]`

Data Types: `string` | `cell`

ReadFcn — Function that reads pixel labeled image data
@readDatastoreImage (default) | function handle

Function that reads pixel labeled image data, specified as a function handle. The custom read function must take an image file name as input, and then output the corresponding pixel labeled data as a categorical matrix. For example, if `customreader` is the specified function to read the image data, then it must have a signature similar to the following:

```
function C = customreader(filename)
...
end
```

If the read function has more than one output argument, then only the first one is used. The rest are ignored.

Example: @customreader

Object Functions

hasdata	Determine if data is available to read from datastore
countEachLabel	Count occurrence of pixel label for data source images
numpartitions	Number of partitions for pixel label datastore
partition	Partition a pixel label datastore
preview	Reads first image from pixel label datastore
read	Read next consecutive file from pixel label datastore
readall	Read all pixel label data
readimage	Read specified pixel label data file
reset	Reset pixel label datastore to initial state

Examples

Read and Display Pixel Label Data

Overlay pixel label data on an image.

Set the location of the image and pixel label data.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata');
imDir = fullfile(dataDir,'building');
pxDir = fullfile(dataDir,'buildingPixelLabels');
```

Create an image datastore and a pixel label datastore

```
imds = imageDatastore(imDir);
classNames = ["sky" "grass" "building" "sidewalk"];
pixelLabelID = [1 2 3 4];
pxds = pixelLabelDatastore(pxDir,classNames,pixelLabelID);
```

Read the image and pixel label data. `read(pxs)` returns a categorical matrix, `C`. The element $C(i,j)$ in the matrix is the categorical label assigned to the pixel at the location $l(i,j)$.

```
I = read(imds);
C = read(pxds);
```

Display the label categories in `C`.

```
categories(C)
```

```
ans = 4x1 cell array
    {'sky'     }
    {'grass'   }
    {'building'}
    {'sidewalk'}
```

Overlay and display the pixel label data onto the image.

```
B = labeloverlay(I,C);
figure
imshow(B)
```
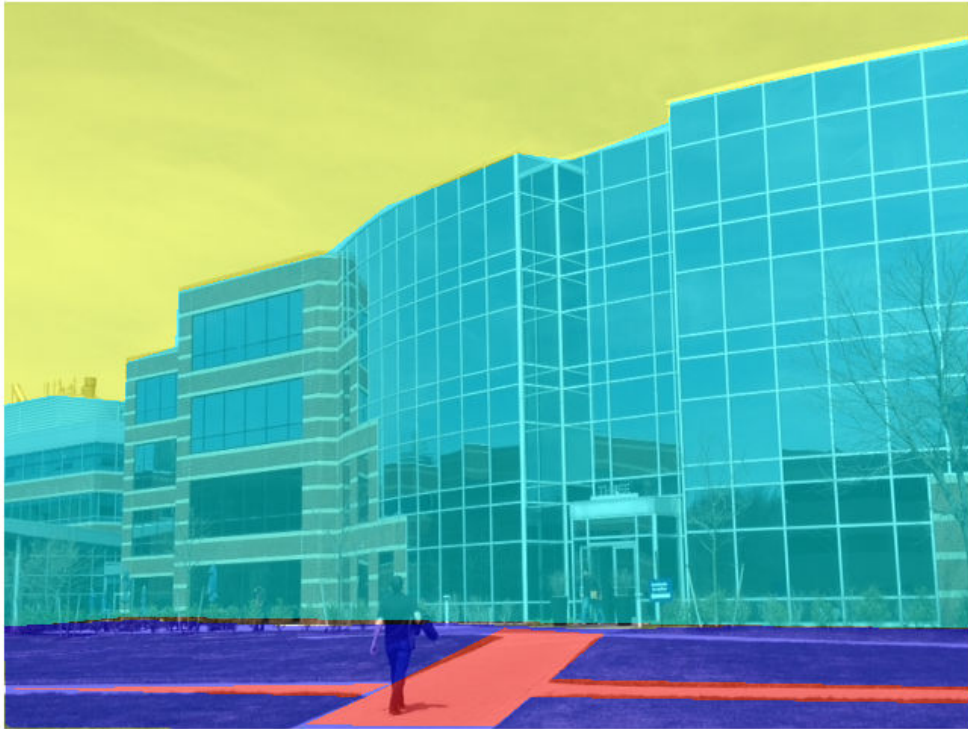
See Also

ImageDatastore | datastore | evaluateSemanticSegmentation | groundTruth | semanticSegmentationMetrics | semanticseg

Topics

"Semantic Segmentation Basics"
"Deep Learning Basics" (Neural Network Toolbox)

Introduced in R2017b

KAZEPoints

Object for storing KAZE interest points

Description

This object provides the ability to pass data between the `detectKAZEPoints` and extractFeatures functions. You can also use this object to manipulate and plot the data returned by these functions.Use the object to fill points interactively, where you might want to mix a non-KAZE interest oint detector with a KAZE descriptor.

Creation

Syntax

```
points = KAZEPoints(location)
points = KAZEPoints(I,Name,Value)
```

Description

`points = KAZEPoints(location)` constructs a `KAZEPoints` object from an *M*-by-2 array [*x y*] of location coordinates.

The scalar KAZEPoints object contains many points. Therefore `numel(KAZEPoints)` always returns 1. This value can be different than the result of `length(KAZEPoints)`, which returns the true number of points contained in the object.

`1points = KAZEPoints(I,Name,Value)` constructs a `KAZEPoints` object with additional properties specified by one or more Name,Value pair arguments

Properties

Scale — Scale
1.6 (default) | scalar | vector

Scale, specified as a scalar. The scale sets the size at which the interest points are detected.

`Metric` — Strength of response
0.0 (default) | numeric value | vector

Strength of response for the detected points, specified as a numeric value. The KAZE algorithm uses a determinant of an approximated Hessian.

`Orientation` — Orientation
0.0 (default) | radians

Orientation of the detected feature, specified as an angle in radians. The angle is measured from the *x*-axis with the origin set by the `location` input. The `extractFeatures` function sets this property. Do not set it manually.

Object Functions

isempty	Determine if KAZE points object is empty
length	Number of stored KAZE points
plot	Plot KAZE points
selectStrongest	Select KAZE points with strongest metrics
selectUniform	Select uniformly distributed subset of KAZE feature points

Examples

Detect KAZE Features

Detect KAZE features and display 10 strongest points.

Read an image.

```
I = imread('cameraman.tif');
```

Detect KAZE features in the image.

```
points = detectKAZEFeatures(I);
```

Select the 10 strongest points.

```
strongest = selectStrongest(points,10);
```

Display the selected points.

```
 imshow(I);
 hold on;
```

Display the location and scale. The size of the circles displayed relate to the scale.

```
plot(strongest);
hold on;
```
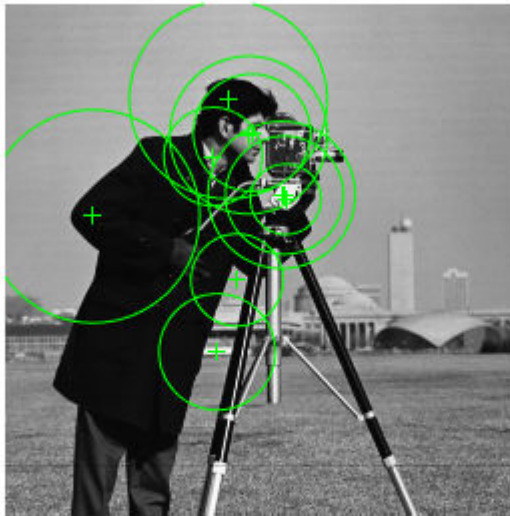

Display the [x y] coordinates for the strongest points in the MATLAB Command Window.

```
strongest.Location
```

ans = 10x2 single matrix

```
  138.5041   95.8063
  139.9253   95.8802
```

```
111.8975    48.2950
106.4036   174.1800
 44.3964   106.4899
122.0368    65.9064
116.2702   138.2877
123.6542    64.7193
104.2719    76.5821
140.6228    97.9271
```

Detect KAZE Features and Display Specific Points

Detect KAZE features and display set the specific KAZE points you want to plot.

Read an image.

```
I = imread('cameraman.tif');
```

Detect KAZE features in the image.

```
points = detectKAZEFeatures(I);
```

Select and display the last 5 points detected.

```
imshow(I);
hold on;
plot(points(end-4:end));
hold off;
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- To index locations with this object, use the syntax: `points.Location(idx,:)`, for `points` object. See visionRecovertformCodeGeneration_kernel.m, which is used in the "Introduction to Code Generation with Feature Matching and Registration" example.

See Also

MSERRegions | SURFPoints | cornerPoints | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectKAZEFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | matchFeatures

Introduced in R2017b

binaryFeatures class

Object for storing binary feature vectors

Description

This object provides the ability to pass data between the `extractFeatures` and `matchFeatures` functions. It can also be used to manipulate and plot the data returned by `extractFeatures`.

Construction

`features= binaryFeatures(featureVectors)` constructs a `binaryFeatures` object from the *M*-by-*N* input matrix, `featureVectors`. This matrix contains *M* feature vectors stored in *N* uint8 containers.

`features = binaryFeatures(featureVectors,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

featureVectors

Input feature vectors, specified as an *M*-by-*N* input matrix. This matrix contains *M* binary feature vectors stored in *N* uint8 containers.

Read-only Properties

Features

Feature vectors, stated as an *M*-by-*N* input matrix. This matrix consists of *M* feature vectors stored in *N* uint8 containers.

NumBits

Number of bits per feature, which is the number of uint8 feature vector containers times 8.

NumFeatures

Number of feature vectors contained in the `binaryFeatures` object.

Examples

Match Two Sets of Binary Feature Vectors

Input feature vectors.

```
features1 = binaryFeatures(uint8([1 8 7 2; 8 1 7 2]));
features2 = binaryFeatures(uint8([8 1 7 2; 1 8 7 2]));
```

Match the vectors using the Hamming distance.

```
[indexPairs matchMetric] = matchFeatures(features1, features2)
```

indexPairs = 2x2 uint32 matrix

```
    1   2
    2   1
```

matchMetric = 2x1 single column vector

```
     0
     0
```

See Also

extractFeatures | extractHOGFeatures | matchFeatures

Introduced in R2013a

cameraIntrinsics class

Object for storing intrinsic camera parameters

Syntax

```
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize)
intrinsics = cameraIntrinsics( ___ ,Name,Value)
```

Description

`intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize)` returns a camera intrinsics object that contains the focal length specified as [*fx,fy*], and the camera's principal point specified as [*cx, cy*]. See `cameraParameters` for more details.

`intrinsics = cameraIntrinsics( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

Input Arguments

`focalLength` — Camera focal length
two-element vector

Camera focal length, specified as a two-element vector, [*fx, fy*].

$$f_x = F \times sx$$

$$f_y = F \times sy$$

- *F* is the focal length in world units, typically millimeters
- [*sx, sy*] are the number of pixels per world unit in the x and y direction respectively

- *fx* and *fy* are in pixels

`principalPoint` — Optical center of camera
two-element vector

Optical center of camera, specified as a two-element vector, [*cx,cy*], in pixels.

`imageSize` — Image size produced by the camera
two-element vector

Image size produced by the camera, specified as a two-element vector, [*mrows,ncols*].

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example:

`RadialDistortion` — Radial lens distortion
[0,0] (default) | two-element vector | three-element vector

Radial lens distortion, specified as the comma-separated pair consisting of `RadialDistortion` and a two-element vector, [*k1,k2*], or a three-element vector, [*k1,k2,k3*]. *k1,k2*, and *k3* are radial distortion coefficients. Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion.

Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion.

negative radial distortion "pincushion"   no distortion   positive radial distortion "barrel"

The camera parameters object calculates the radial distorted location of a point. You can denote the distorted points as $(x_{distorted}, y_{distorted})$, as follows:

$x_{distorted} = x(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$

$y_{distorted} = y(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$

x, y = undistorted pixel locations
k_1, k_2, and k_3 = radial distortion coefficients of the lens
$r^2 = x^2 + y^2$
Typically, two coefficients are sufficient. For severe distortion, you can include k_3. The undistorted pixel locations appear in normalized image coordinates, with the origin at the optical center. The coordinates are expressed in world units.

TangentialDistortion — Tangential distortion coefficients
[0,0] (default) | two-element vector

Tangential distortion coefficients, specified as the comma-separated pair consisting of 'TangentialDistortion' and a 2-element vector, $[p_1, p_2]$. Tangential distortion occurs when the lens and the image plane are not parallel.

zero tangential distortion — lens and sensor are parallel — camera lens — vertical plane — camera sensor

tangential distortion — lens and sensor are not parallel — camera lens — vertical plane — camera sensor

The camera parameters object calculates the tangential distorted location of a point. You can denote the distorted points as ($x_{distorted}$, $y_{distorted}$), as follows:

$$x_{distorted} = x + [2 * p_1 * x * y + p_2 * (r^2 + 2 * x^2)]$$

$$y_{distorted} = y + [p_1 * (r^2 + 2*y^2) + 2 * p_2 * x * y]$$

x, y = undistorted pixel locations
p_1 and p_2 = tangential distortion coefficients of the lens
$r^2 = x^2 + y^2$
The undistorted pixel locations appear in normalized image coordinates, with the origin at the optical center. The coordinates are expressed in world units.

Skew — Camera axes skew
0 (default) | angle

Camera axes skew, specified as the comma-separated pair consisting of 'skew' and an angle. If the x and the y axes are exactly perpendicular, then the skew must be 0.

Properties

The properties are read-only.

FocalLength — Focal length
2-element vector

Focal length in *x* and *y*, stored as a 2-element vector [*fx*, *fy*] in pixels.
fx = F * *sx*
fy = F * *sy*
where, F is the focal length in world units, typically in millimeters, and [*sx*, *sy*] are the number of pixels per world unit in the *x* and *y* direction respectively. Thus, *fx* and *fy* are in pixels.

PrincipalPoint — Optical center of camera
two-element vector

Optical center of camera, stored as a two-element vector [*cx*,*cy*] in pixels. The vector contains the coordinates of the optical center of the camera.

ImageSize — Image size produced by the camera
two-element vector

Image size produced by the camera, stored as a two-element vector, [*mrows*,*ncols*].

RadialDistortion — Radial lens distortion
[0,0] (default) | two-element vector | three-element vector

Radial lens distortion, stored as the comma-separated pair consisting of RadialDistortion and a two-element vector, [*k1*,*k2*], or a three-element vector, [*k1*,*k2*,*k3*]. *k1*,*k2*, and *k3* are radial distortion coefficients. Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion.

Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion.

negative radial distortion   no distortion   positive radial distortion
"pincushion"   "barrel"

The camera parameters object calculates the radial distorted location of a point. You can denote the distorted points as ($x_{distorted}$, $y_{distorted}$), as follows:

$x_{distorted} = x(1 + k_1*r^2 + k_2*r^4 + k_3*r^6)$

$y_{distorted} = y(1 + k_1*r^2 + k_2*r^4 + k_3*r^6)$

x, y = undistorted pixel locations
k_1, k_2, and k_3 = radial distortion coefficients of the lens
$r^2 = x^2 + y^2$
Typically, two coefficients are sufficient. For severe distortion, you can include k_3. The undistorted pixel locations appear in normalized image coordinates, with the origin at the optical center. The coordinates are expressed in world units.

TangentialDistortion — Tangential distortion coefficients
[0,0] (default) | two-element vector

Tangential distortion coefficients, stored as the comma-separated pair consisting of 'TangentialDistortion' and a 2-element vector, [p_1,p_2]. Tangential distortion occurs when the lens and the image plane are not parallel.

The camera parameters object calculates the tangential distorted location of a point. You can denote the distorted points as $(x_{distorted}, y_{distorted})$, as follows:

$x_{distorted} = x + [2 * p_1 * x * y + p_2 * (r^2 + 2 * x^2)]$

$y_{distorted} = y + [p_1 * (r^2 + 2*y^2) + 2 * p_2 * x * y]$

x, y = undistorted pixel locations
p_1 and p_2 = tangential distortion coefficients of the lens
$r^2 = x^2 + y^2$
The undistorted pixel locations appear in normalized image coordinates, with the origin at the optical center. The coordinates are expressed in world units.

Skew — Camera axes skew
0 (default) | angle

Camera axes skew, stored as the comma-separated pair consisting of 'skew' and an angle. If the x and the y axes are exactly perpendicular, then the skew must be 0.

IntrinsicMatrix — Projection matrix
3-by-3 identity matrix (default) | 3-by-3 intrinsic matrix

Projection matrix, stored as the comma-separated pair consisting of 'IntrinsicMatrix' and a 3-by-3 matrix. For the matrix format, the object uses the following format:

$$\begin{bmatrix} f_x & 0 & 0 \\ s & f_y & 0 \\ c_x & c_y & 1 \end{bmatrix}$$

The coordinates $[c_x\ c_y]$ represent the optical center (the principal point), in pixels. When the x and y axis are exactly perpendicular, the skew parameter, s, equals 0.
$f_x = F*s_x$
$f_y = F*s_y$
F, is the focal length in world units, typically expressed in millimeters.
$[s_x, s_y]$ are the number of pixels per world unit in the x and y direction respectively.
f_x and f_y are expressed in pixels.

Output Arguments

intrinsics — Intrinsic camera parameters

Intrinsic camera parameters, returned as an object. The intrinsics object stores information about a camera's intrinsic calibration parameters, including lens distortion.

Examples

Create an Object Containing Fundamental Camera Parameters

Define camera parameters without lens distortion or skew.

Specify the focal length and principal point in pixels.

```
focalLength    = [800, 800];
principalPoint = [320, 240];
imageSize      = [480, 640];
```

Create a camera intrinsics object.

```
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize)


intrinsics =

  cameraIntrinsics with properties:

             FocalLength: [800 800]
          PrincipalPoint: [320 240]
               ImageSize: [480 640]
         RadialDistortion: [0 0]
     TangentialDistortion: [0 0]
                    Skew: 0
          IntrinsicMatrix: [3x3 double]
```

See Also
Camera Calibrator | **Stereo Camera Calibrator** | cameraParameters | undistortImage

Topics
"Single Camera Calibrator App"

Introduced in R2017a

pcplayer

Visualize streaming 3-D point cloud data

Description

Visualize 3-D point cloud data streams from devices such as Microsoft®Kinect®.

To improve performance, `pcplayer` automatically downsamples the rendered point cloud during interaction with the figure. The downsampling occurs only for rendering the point cloud and does not affect the saved points.

You can set the default center of rotation for the point cloud viewer to rotate around the axes center or around a point. Set the default behavior from the "Computer Vision System Toolbox Preferences".

Creation

Syntax

Use the `pcplayer` function to create a player for visualizing 3-D point cloud data.

```
player = pcplayer(xlimits,ylimits,zlimits)
player = pcplayer(xlimits,ylimits,zlimits,Name,Value)
```

Description

`player = pcplayer(xlimits,ylimits,zlimits)` returns a player with `xlimits,ylimits`, and `zlimits` set for the axes limits.

`player = pcplayer(xlimits,ylimits,zlimits,Name,Value)` returns a player with additional properties specified by one or more `Name,Value` pair arguments.

Input Arguments

xLimits — Range of *x*-axis coordinates
1-by-2 vector

Range of *x*-axis coordinates, specified as a 1-by-2 vector in the format [*min max*]. `pcplayer` does not display data outside these limits.

yLimits — Range of *y*-axis coordinates
1-by-2 vector

Range of *y*-axis coordinates, specified as a 1-by-2 vector in the format [*min max*]. `pcplayer` does not display data outside these limits.

zLimits — Range of *z*-axis coordinates
1-by-2 vector

Range of *z*-axis coordinates, specified as a 1-by-2 vector in the format [*min max*].`pcplayer` does not display data outside these limits.

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'VerticalAxisDir', 'Up'`.

MarkerSize — Diameter of marker
6 (default) | positive scalar

Diameter of marker, specified as the comma-separated pair consisting of `'MarkerSize'` and a positive scalar. The value specifies the approximate diameter of the point marker. MATLAB graphics defines the unit as points. A marker size larger than six can reduce the rendering performance.

VerticalAxis — Vertical axis
`'Z'` (default) | `'X'` | `'Y'`

Vertical axis, specified as the comma-separated pair consisting of `'VerticalAxis'` and a character vector specifying the vertical axis: `'X'`, `'Y'`, or `'Z'`.

VerticalAxisDir — Vertical axis direction
'Up' (default) | 'Down'

Vertical axis direction, specified as the comma-separated pair consisting of 'VerticalAxisDir' and a character vector specifying the direction of the vertical axis: 'Up' or 'Down'.

Properties

Axes — Player axes handle
axes graphics object

Player axes handle, specified as an axes graphics object.

Object Functions

hide	Hide player figure
isOpen	Visibility of point cloud player figure
show	Show player figure
view	Display point cloud

Examples

Terminate a Point Cloud Processing Loop

Create the player and add data.

```
player = pcplayer([0 1],[0 1],[0 1]);
```

Display continuous player figure. Use the isOpen method to check if player figure window is open.

```
while isOpen(player)
    ptCloud = pointCloud(rand(1000,3,'single'));
    view(player,ptCloud);
end
```

Terminate while-loop by closing pcplayer figure window.

Algorithms

`pcplayer` supports the `'opengl'` option for the `Renderer figure` property only.

See Also

pcdenoise | pcdownsample | pcfitplane | pcmerge | pcread | pcregistericp | pcshow | pcwrite | planeModel | plot3 | pointCloud | scatter3

Introduced in R2015b

hide

Hide player figure

Syntax

```
hide(player)
```

Description

`hide(player)` hides the `pcplayer` point cloud figure. To redisplay the player, use show on page 2-71(`player`).

Examples

Hide and Show 3-D Point Cloud Figure

Load point cloud.

```
ptCloud = pcread('teapot.ply');
```

Create the player and customize player axis labels.

```
player = pcplayer(ptCloud.XLimits,ptCloud.YLimits,ptCloud.ZLimits);
```

Hide figure.

```
hide(player)
```

Show figure.

```
show(player)
view(player,ptCloud);
```
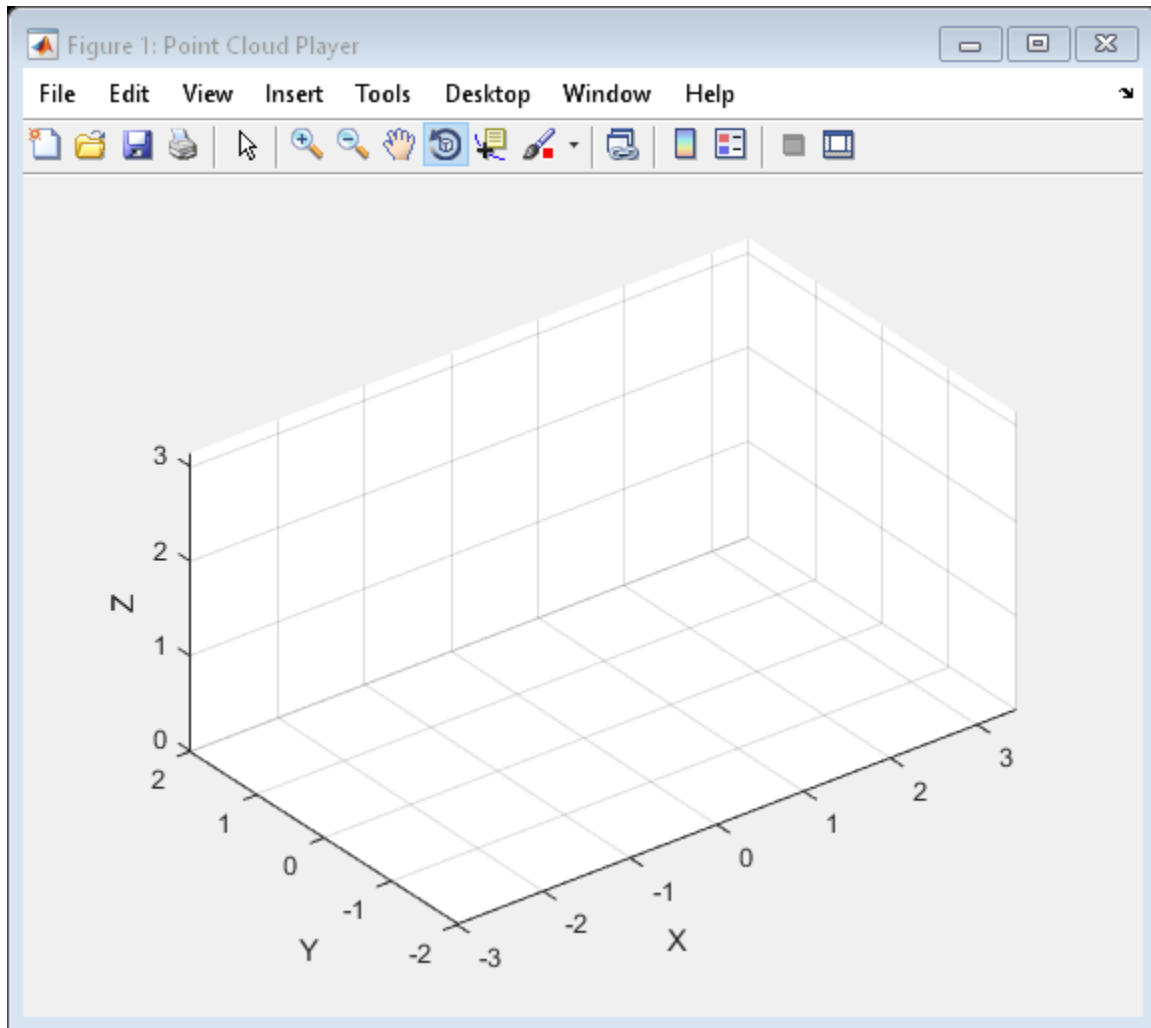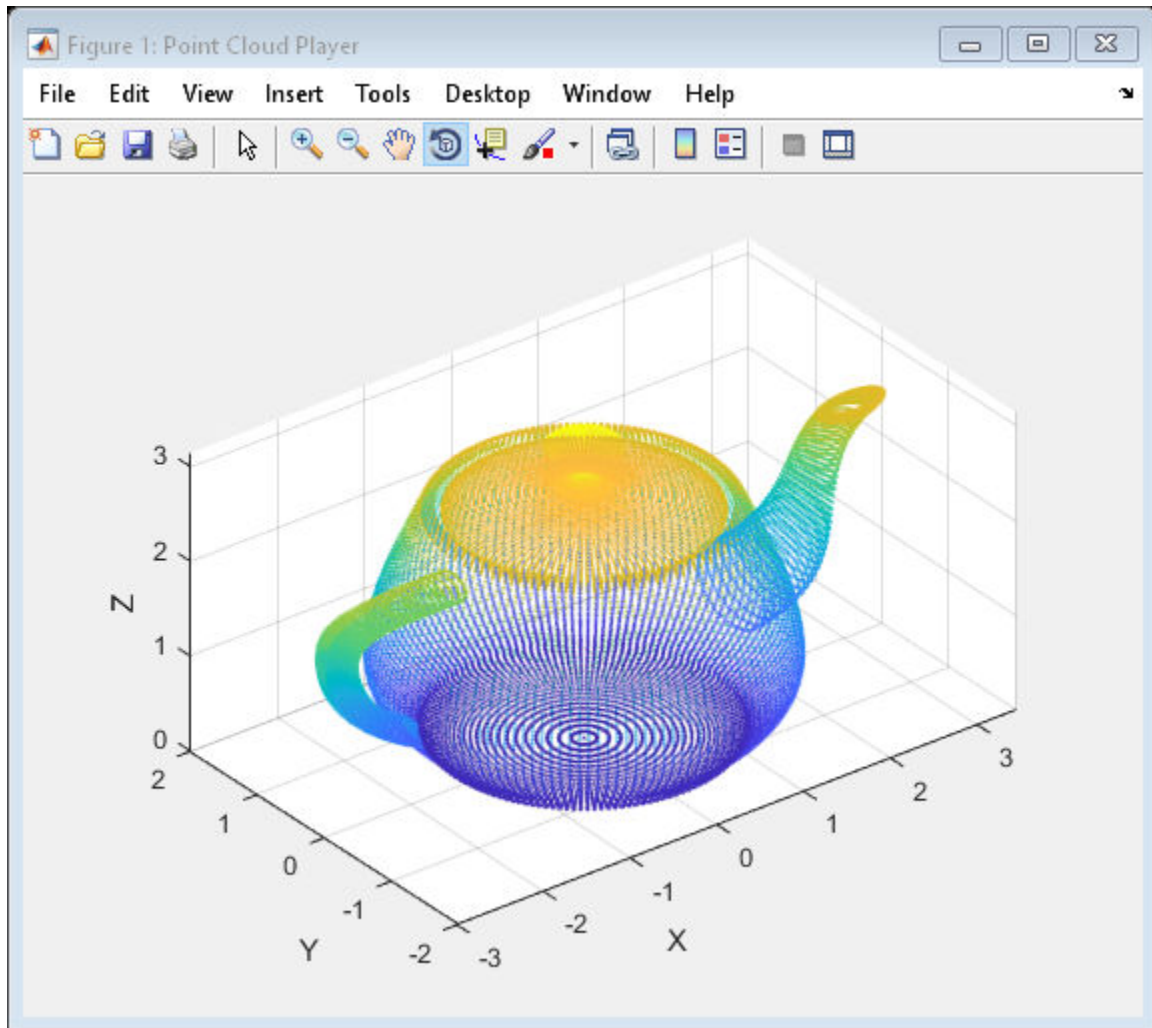
Input Arguments

player — Player
pcplayer object

Player for visualizing 3-D point cloud data streams, specified as a `pcplayer` object.

Introduced in R2015b

isOpen

Visibility of point cloud player figure

Syntax

```
isOpen(player)
```

Description

isOpen(player) returns `true` or `false` to indicate whether the point cloud player is visible.

Examples

Terminate a Point Cloud Processing Loop

Close the display of continuous point cloud player

Add data to the point cloud player.

```
player = pcplayer([0 1],[0 1],[0 1]);
```
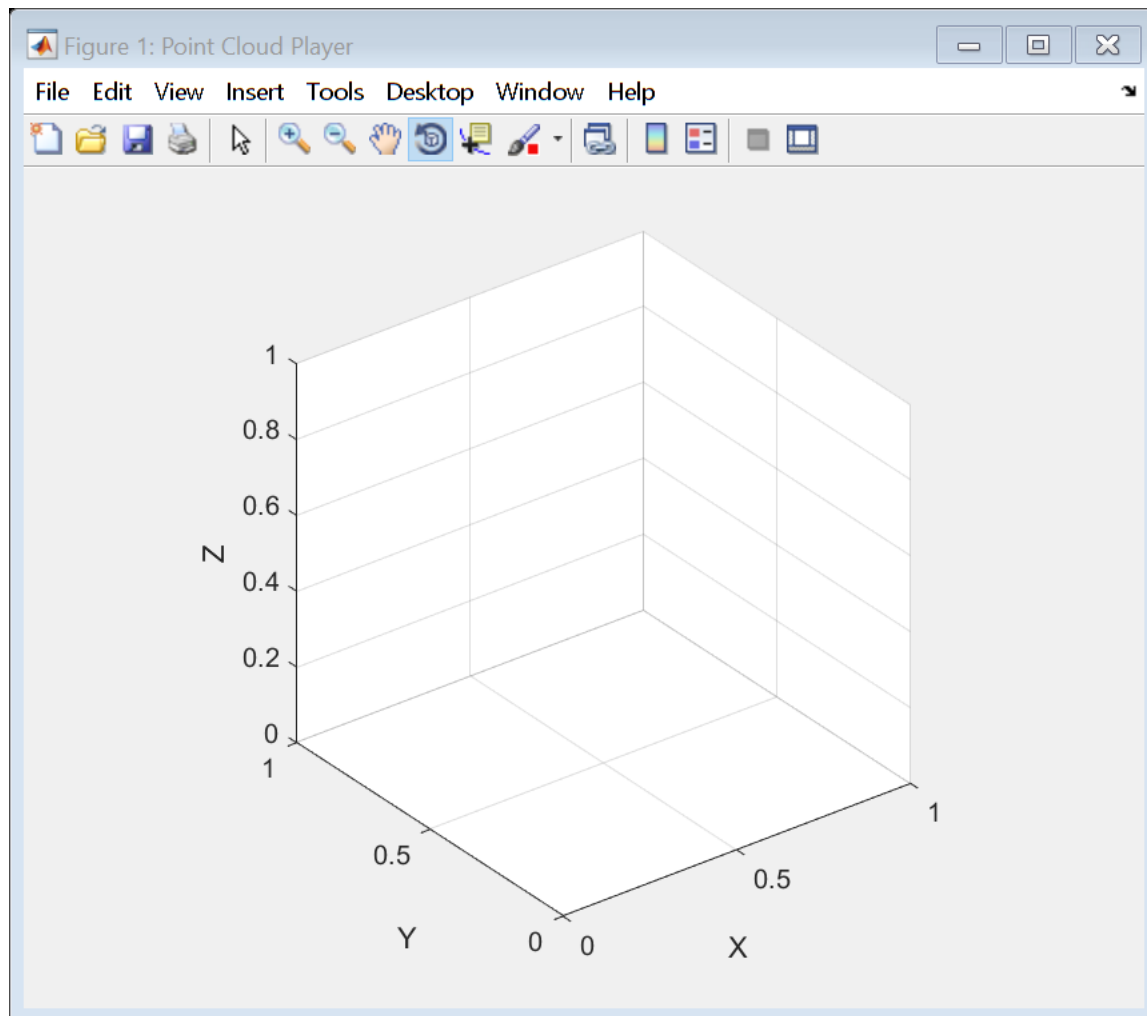
Display continuous player figure. Use the `isOpen` method to check if player figure window is open.

```
while isOpen(player)
    ptCloud = pointCloud(rand(1000,3,'single'));
    view(player, ptCloud);
end
```

Terminate the while-loop by closing `pcplayer` figure window.

Input Arguments

player — Player
`pcplayer` object

Player for visualizing 3-D point cloud data streams, specified as a `pcplayer` object

Introduced in R2015b

show

Show player figure

Syntax

```
show(player)
```

Description

show(player) makes the point cloud player figure visible again after closing or hiding it. You can use this method at the end of a while loop to show its display code.

Examples

Hide and Show 3-D Point Cloud Figure

Load point cloud.

```
ptCloud = pcread('teapot.ply');
```

Create the player and customize player axis labels.

```
player = pcplayer(ptCloud.XLimits,ptCloud.YLimits,ptCloud.ZLimits);
```

Hide figure.

```
hide(player)
```

Show figure.

```
show(player)
view(player,ptCloud);
```
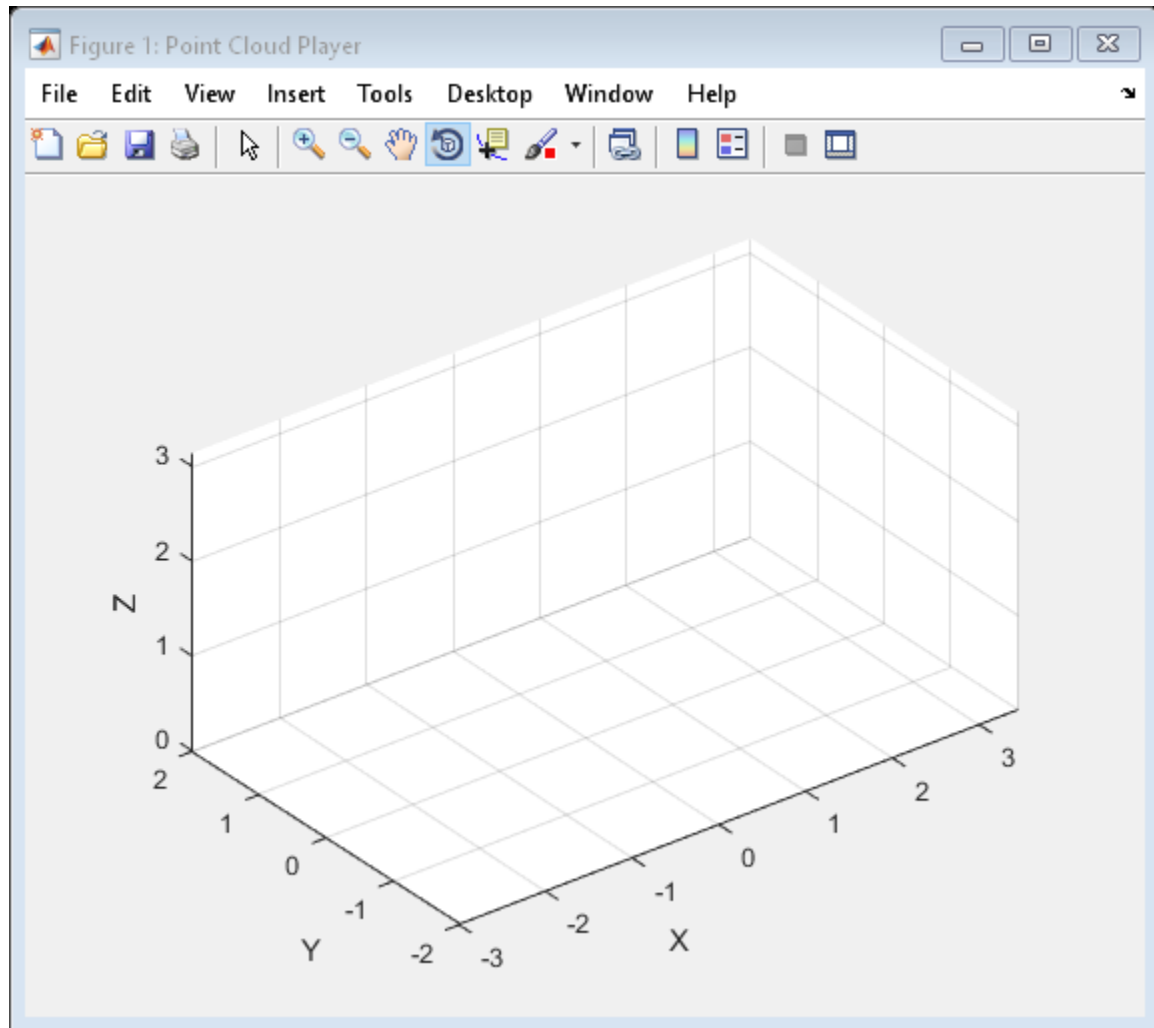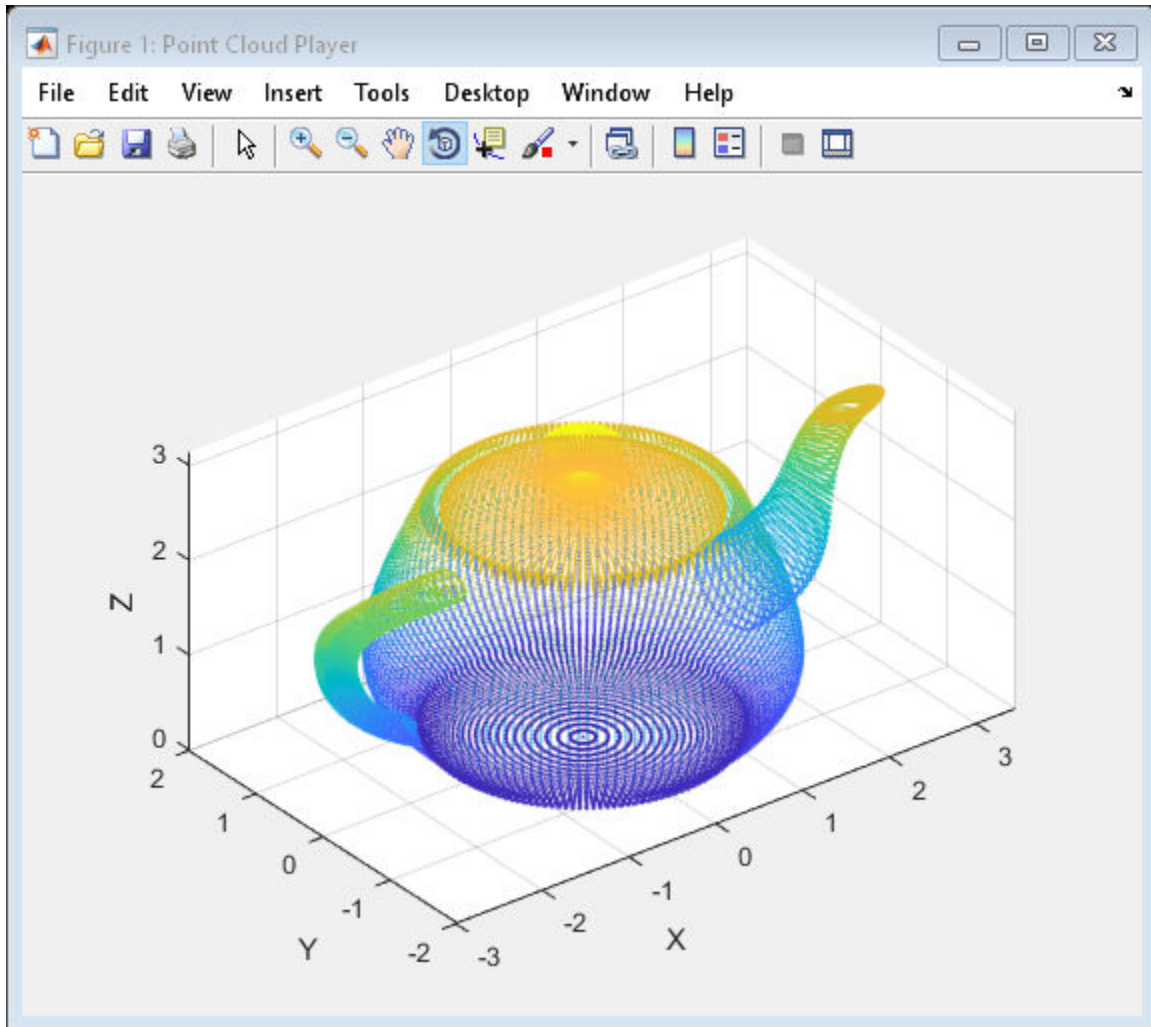
Input Arguments

player — Player
pcplayer object

Player for visualizing 3-D point cloud data streams, specified as a `pcplayer` object. Use this method to view the figure after you have removed it from display. For example, after you x-out of a figure and you want to view it again. This is particularly useful to use after a while loop that contains display code ends.

Introduced in R2015b

view

Display point cloud

Syntax

```
view(player,ptCloud)
view(player,xyzPoints)
view(player,xyzPoints,Color)
```

Description

view(player,ptCloud) displays a point cloud in the pcplayer figure window, player. The points, locations, and colors are stored in the ptCloud object.

view(player,xyzPoints) displays the points of a point cloud at the locations specified by the xyzPoints matrix. The color of each point is determined by the *z* value.

view(player,xyzPoints,Color) displays a point cloud with colors specified by Color.

Examples

View Rotating 3-D Point Cloud

Load point cloud.

```
ptCloud = pcread('teapot.ply');
```

Define a rotation matrix and 3-D transform.

```
x = pi/180;
R = [ cos(x) sin(x) 0 0
     -sin(x) cos(x) 0 0
      0       0   1 0
```

```
         0          0   0 1];

tform = affine3d(R);
```

Compute *x-_y_* limits that ensure that the rotated teapot is not clipped.

```
lower = min([ptCloud.XLimits ptCloud.YLimits]);
upper = max([ptCloud.XLimits ptCloud.YLimits]);

xlimits = [lower upper];
ylimits = [lower upper];
zlimits = ptCloud.ZLimits;
```

Create the player and customize player axis labels.

```
player = pcplayer(xlimits,ylimits,zlimits);

xlabel(player.Axes,'X (m)');
ylabel(player.Axes,'Y (m)');
zlabel(player.Axes,'Z (m)');
```
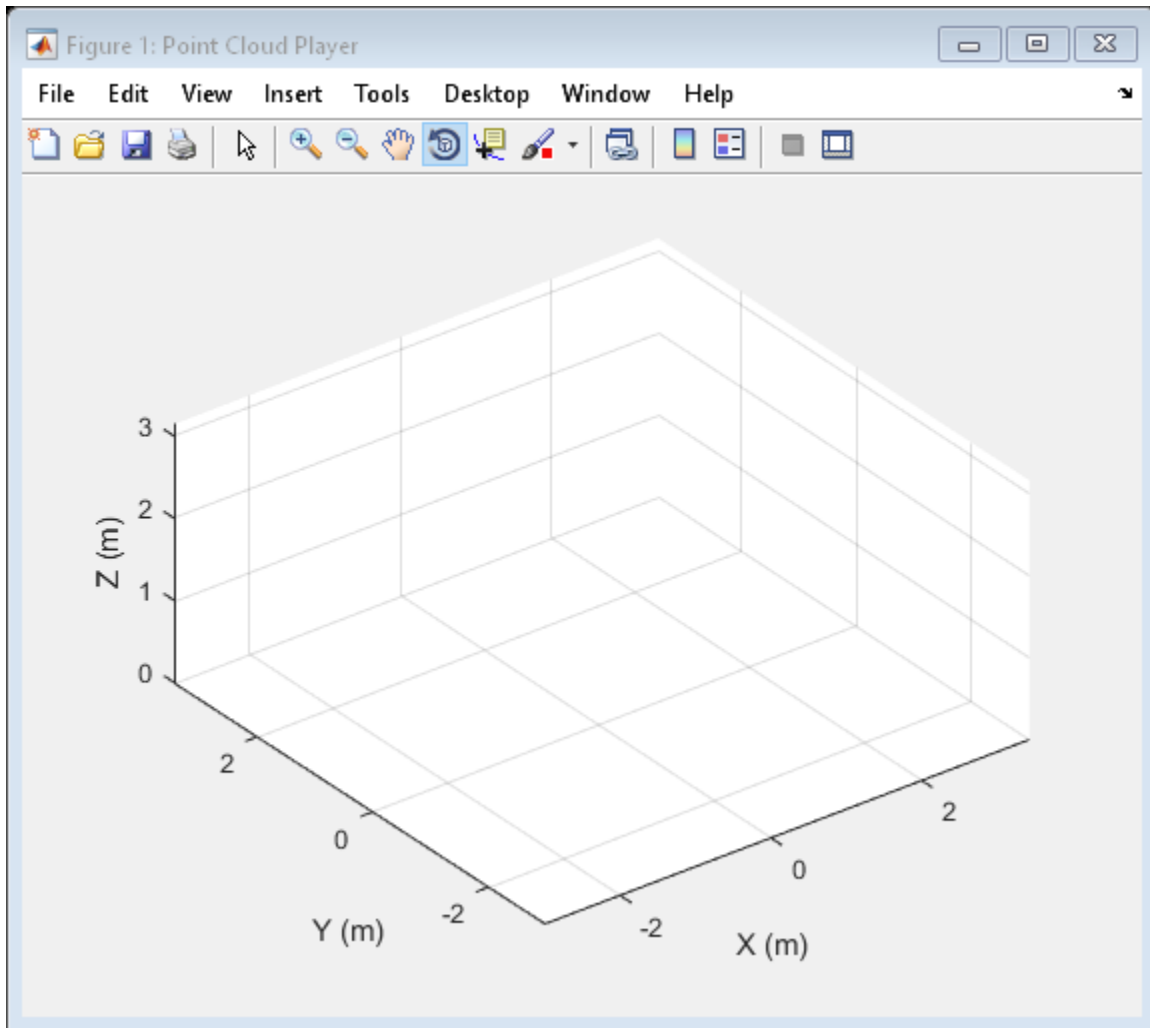
Rotate the teapot around the *z*-axis.

```
for i = 1:360
    ptCloud = pctransform(ptCloud,tform);
    view(player,ptCloud);
end
```

Input Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object. The object contains the locations, intensities, and RGB colors to render the point cloud.

Point Cloud Property	Color Rendering Result
`Location` only	Maps the z-value to a color value in the current color map.
`Location` and `Intensity`	Maps the intensity to a color value in the current color map.
`Location` and `Color`	Use provided color.
`Location`, `Intensity`, and `Color`	Use provided color.

player — Player
`pcplayer` object

Player for visualizing 3-D point cloud data streams, specified as a `pcplayer` object.

xyzPoints — Point cloud *x*, *y*, and *z* locations
M-by-3 numeric matrix | *M*-by-*N*-by-3 numeric matrix

Point cloud *x*, *y*, and *z* locations, specified as either an *M*-by-3 or an *M*-by-*N*-by-3 numeric matrix. The *M*-by-*N*-by-3 numeric matrix is commonly referred to as an organized point cloud. The `xyzPoints` numeric matrix contains *M* or *M*-by-*N* [*x*,*y*,*z*] points. The *z* values in the numeric matrix, which generally correspond to depth or elevation, determine the color of each point.

Color — Point cloud color
ColorSpec (Color Specification) color character vector | 1-by-3 RGB vector | *M*-by-1 vector | *M*-by-*N* matrix | *M*-by-3 matrix | *M*-by-*N*-by-3 matrix

Point cloud color of points, specified as a `ColorSpec (Color Specification)` color character vector, a 1-by-3 RGB vector, an *M*-by-1 vector, an *M*-by-*N*, *M*-by-3, or *M*-by-*N*-by-3 matrix. You can specify the same color for all points or a different color for each point. RGB values range between [0, 1] when you set `Color` to `single` or `double` and between [0, 255] when you set `Color` to `uint8`.

Points Input	Color Selection	Valid Values of Color	
xyzPoints	Same color for all points	ColorSpec (Color Specification) color character vector or a 1-by-3 RGB vector	
	Different color for each point	Vector or *M*-by-*N* matrix. The matrix must contain values that are linearly mapped to a color in the current colormap.	
		M-by-3 matrix or *M*-by-*N*-by-3 matrix containing RGB values for each point.	

Introduced in R2015b

pointTrack class

Object for storing matching points from multiple views

Syntax

```
track = pointTrack(viewIDs,points)
```

Description

`track = pointTrack(viewIDs,points)` returns an object that stores matching 2-D points from multiple views. You can also create this point track object using the `findTracks` method of the `viewSet` object.

Input Arguments

`viewIDs` — View IDs of camera poses
M-element vector

View IDs of camera poses, specified as an *M*-element vector of scalar integers.

`points` — 2-D points that match across multiple camera views
M-by-2 matrix

2-D points that match across multiple camera views, specified as an *M*-by-2 matrix of (x,y) point coordinates. You can use the `matchFeatures` function to find these points, and then save them using this object.

Output Arguments

`track` — Point track object
`pointTrack` object

Point track object, returned as a `pointTrack` object. You can use this object to store matching 2-D points from multiple views. You can also create this point track object using the `findTracks` method of the `viewSet` object.

Examples

Create a Point Track Object

Save (x , y) points and view IDs.

```
points = [10,20;11,21;12,22];
viewIDs = [1 2 3];
```

Create a `pointTrack` object to save points and IDs.

```
track = pointTrack(viewIDs,points);
```

•   "3-D Point Cloud Registration and Stitching"

See Also
`bundleAdjustment` | `matchFeatures` | `triangulateMultiview` | `viewSet` | `vision.PointTracker`

Topics
"3-D Point Cloud Registration and Stitching"
"Coordinate Systems"

Introduced in R2016a

vision.PointTracker System object

Package: vision

Track points in video using Kanade-Lucas-Tomasi (KLT) algorithm

Description

The point tracker object tracks a set of points using the Kanade-Lucas-Tomasi (KLT), feature-tracking algorithm. You can use the point tracker for video stabilization, camera motion estimation, and object tracking. It works particularly well for tracking objects that do not change shape and for those that exhibit visual texture. The point tracker is often used for short-term tracking as part of a larger tracking framework.

As the point tracker algorithm progresses over time, points can be lost due to lighting variation, out of plane rotation, or articulated motion. To track an object over a long period of time, you may need to reacquire points periodically.

To track a set of points:

1 Create the vision.PointTracker object and set its properties.
2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
pointTracker = vision.PointTracker
pointTracker = vision.PointTracker(Name,Value)
```

Description

`pointTracker = vision.PointTracker` returns a point tracker object that tracks a set of points in a video.

`pointTracker = vision.PointTracker(Name,Value)` creates a point tracker object, `pointTracker`, with additional options specified by one or more `Name,Value` pair arguments.

`Name` is a property name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: pointTracker = vision.PointTracker('NumPyramidLevels',3)

Initialize Tracking Process

To initialize the tracking process, you must use `initialize` to specify the initial locations of the points and the initial video frame.

`initialize(pointTracker,points,I)` initializes points to track and sets the initial video frame. The initial locations `POINTS`, must be an *M*-by-2 array of [x y] coordinates. The initial video frame, `I`, must be a 2-D grayscale or RGB image and must be the same size and data type as the video frames passed to the `step` method.

The `detectFASTFeatures`, `detectSURFFeatures`, `detectHarrisFeatures`, and `detectMinEigenFeatures` functions are few of the many ways to obtain the initial points for tracking.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

NumPyramidLevels — Number of pyramid levels
integer (default) | 3

Number of pyramid levels, specified as integer. The point tracker implementation of the KLT algorithm uses image pyramids. The tracker generates an image pyramid, where each level is reduced in resolution by a factor of two compared to the previous level. Selecting a pyramid level greater than 1, enables the algorithm to track the points at multiple levels of resolution, starting at the lowest level. Increasing the number of pyramid levels allows the algorithm to handle larger displacements of points between frames. However, computation cost also increases. Recommended values are between 1 and 4.

1. Optical flow computation at lowest resolution

2. Optical flow at next highest resolution

3. Final optical flow computation of original image

Distance the object moved between frames
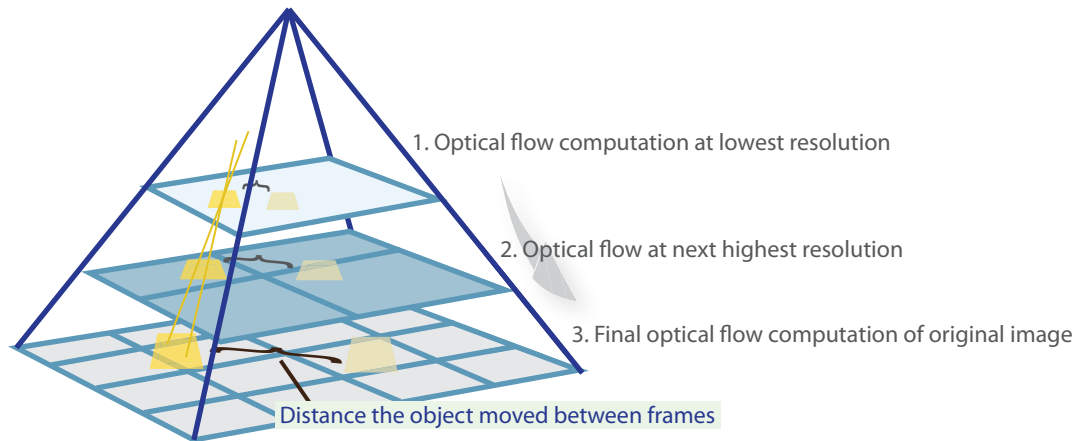
Each pyramid level is formed by down-sampling the previous level by a factor of two in width and height. The point tracker begins tracking each point in the lowest resolution level, and continues tracking until convergence. The object propagates the result of that level to the next level as the initial guess of the point locations. In this way, the tracking is refined with each level, up to the original image. Using the pyramid levels allows the point tracker to handle large pixel motions, which can comprise distances greater than the neighborhood size.

MaxBidirectionalError — Forward-backward error threshold
inf (default) | scalar

Forward-backward error threshold, specified as a scalar. If you set the value to less than inf, the tracker tracks each point from the previous to the current frame. It then tracks

the same points back to the previous frame. The object calculates the bidirectional error. This value is the distance in pixels from the original location of the points to the final location after the backward tracking. The corresponding points are considered invalid when the error is greater than the value set for this property. Recommended values are between 0 and 3 pixels.

Using the bidirectional error is an effective way to eliminate points that could not be reliably tracked. However, the bidirectional error requires additional computation. When you set the MaxBidirectionalError property to inf, the object does not compute the bidirectional error.
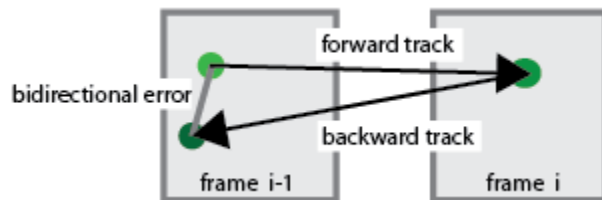
BlockSize — Size of neighborhood
[31 31] (default) | two-element vector

Size of neighborhood around each point being tracked, specified as a two-element vector, [*height*, *width*]. The *height* and *width* must be odd integers. This neighborhood defines the area for the spatial gradient matrix computation. The minimum value for BlockSize is [5 5]. Increasing the size of the neighborhood, increases the computation time.

MaxIterations — Maximum number of search iterations
30 (default) | integer

Maximum number of search iterations for each point, specified as an integer. The KLT algorithm performs an iterative search for the new location of each point until convergence. Typically, the algorithm converges within 10 iterations. This property sets the limit on the number of search iterations. Recommended values are between 10 and 50.

Usage

Syntax

```
[points,point_validity] = pointTracker(I)
[points,point_validity,scores] = pointTracker(I)
setPoints(pointTracker,points)
setPoints(pointTracker,points,point_validity)
```

Description

`[points,point_validity] = pointTracker(I)` tracks the points in the input frame, `I`.

`[points,point_validity,scores] = pointTracker(I)` additionally returns the confidence score for each point.

`setPoints(pointTracker,points)` sets the points for tracking. The method sets the *M*-by-2 `points` array of [*x y*] coordinates with the points to track. You can use this method if the points need to be redetected because too many of them have been lost during tracking.

`setPoints(pointTracker,points,point_validity)` additionally lets you mark points as either valid or invalid. The input logical vector `point_validity` of length *M*, contains the true or false value corresponding to the validity of the point to be tracked. The length *M* corresponds to the number of points. A false value indicates an invalid point that should not be tracked. For example, you can use this method with the `estimateGeometricTransform` function to determine the transformation between the point locations in the previous and current frames. You can mark the outliers as invalid.

Input Arguments

I — Video frame
grayscale | truecolor (RGB)

Video frame, specified as grayscale or truecolor (RGB).

Output Arguments

`points` — Tracked points
M-by-2 array

Tracked points, returned as an *M*-by-2 array of [x y] coordinates that correspond to the new locations of the points in the input frame, `I`.

`point_validity` — Reliability of track
M-by-1 logical array

Reliability of track for each point, returned as an an *M*-by-1 logical array. A point can be invalid for several reasons. The point can become invalid if it falls outside of the image. Also, it can become invalid if the spatial gradient matrix computed in its neighborhood is singular. If the bidirectional error is greater than the `MaxBidirectionalError` threshold, this condition can also make the point invalid.

`score` — Confidence score
M-by-1 array

Confidence score between `0` and `1`, returned as an *M*-by-1 array. The values correspond to the degree of similarity between the neighborhood around the previous location and new location of each point. These values are computed as a function of the sum of squared differences between the previous and new neighborhoods. The greatest tracking confidence corresponds to a perfect match score of `1`.

Object Functions

To use an object function, specify the System object™ as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to vision.PointTracker
initialize   Initialize video frame and points to track

Common to All System Objects
step   Run System object algorithm

release   Release resources and allow changes to System object property values and
          input characteristics
reset   Reset internal states of System object

Examples

Track a Face in Scene

Create System objects for reading and displaying video and for drawing a bounding box of
the object.

```
videoFileReader = vision.VideoFileReader('visionface.avi');
videoPlayer = vision.VideoPlayer('Position',[100,100,680,520]);
```

Read the first video frame, which contains the object, define the region.

```
objectFrame = videoFileReader();
objectRegion = [264,122,93,93];
```

As an alternative, you can use the following commands to select the object region using a
mouse. The object must occupy the majority of the region:

figure; imshow(objectFrame);

objectRegion=round(getPosition(imrect))

Show initial frame with a red bounding box.

```
objectImage = insertShape(objectFrame,'Rectangle',objectRegion,'Color','red');
figure;
imshow(objectImage);
title('Red box shows object region');
```

Red box shows object region

Detect interest points in the object region.

```
points = detectMinEigenFeatures(rgb2gray(objectFrame),'ROI',objectRegion);
```

Display the detected points.

```
pointImage = insertMarker(objectFrame,points.Location,'+','Color','white');
figure;
imshow(pointImage);
title('Detected interest points');
```

Detected interest points

Create a tracker object.

```
tracker = vision.PointTracker('MaxBidirectionalError',1);
```

Initialize the tracker.

```
initialize(tracker,points.Location,objectFrame);
```

Read, track, display points, and results in each video frame.

```
while ~isDone(videoFileReader)
     frame = videoFileReader();
     [points,validity] = tracker(frame);
     out = insertMarker(frame,points(validity, :),'+');
```

```
            videoPlayer(out);
    end
```


Release the video reader and player.

```
release(videoPlayer);
```

```
release(videoFileReader);
```

- "Face Detection and Tracking Using CAMShift"
- "Face Detection and Tracking Using the KLT Algorithm"

- "Face Detection and Tracking Using Live Video Acquisition"

References

[1] Lucas, Bruce D. and Takeo Kanade. "An Iterative Image Registration Technique with an Application to Stereo Vision,"*Proceedings of the 7th International Joint Conference on Artificial Intelligence*, April, 1981, pp. 674–679.

[2] Tomasi, Carlo and Takeo Kanade. *Detection and Tracking of Point Features*, Computer Science Department, Carnegie Mellon University, April, 1991.

[3] Shi, Jianbo and Carlo Tomasi. "Good Features to Track," *IEEE Conference on Computer Vision and Pattern Recognition*, 1994, pp. 593–600.

[4] Kalal, Zdenek, Krystian Mikolajczyk, and Jiri Matas. "Forward-Backward Error: Automatic Detection of Tracking Failures," *Proceedings of the 20th International Conference on Pattern Recognition*, 2010, pages 2756–2759, 2010.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
detectHarrisFeatures | detectMinEigenFeatures | detectSURFFeatures | estimateGeometricTransform | imrect | insertMarker | vision.HistogramBasedTracker

Topics
"Face Detection and Tracking Using CAMShift"
"Face Detection and Tracking Using the KLT Algorithm"
"Face Detection and Tracking Using Live Video Acquisition"

External Websites
Object Recognition and Tracking for Augmented Reality
Detect and Track Multiple Faces in a Live Video Stream

Introduced in R2012b

viewSet class

Object for managing data for structure-from-motion and visual odometry

Syntax

```
vSet = viewSet
```

Description

`vSet = viewSet` returns an empty `viewSet` object that stores views and connections between views. A view includes feature points and an absolute camera pose. A connection between two views includes point correspondences and the relative camera pose between them. Once you populate a `viewSet` object, you can use it to find point tracks across multiple views and retrieve the camera poses to be used by `triangulateMultiview` and `bundleAdjustment` functions.

Code Generation Support:
Supports Code Generation: No
Supports MATLAB Function block: No
"Code Generation Support, Usage Notes, and Limitations"

Properties

These properties are read-only.

NumViews — Number of views
integer

Number of views, stored as an integer.

Views — View attributes
four-column table

View attributes, stored as a four-column table. The table contains columns for `ViewID`, `Points`, `Orientation`, and `Location`. Use the `poses` method to obtain the IDs, orientation, and location for the points.

Connections — Pairwise connections between views
five-column table

Pairwise connections between views, stored as a five-column table. The columns are `ViewID1`, `ViewID2`, `Matches`, `RelativeOrientation`, and `RelativeLocation`. The number of entries in the table represent the number of connections. Each index in the `Matches` column represents a connection between the two views indicated by the view IDs.

Output Arguments

vSet — View set object
viewSet object

viewSet object used to store views and connections between the views.

Methods

addView	Add a new view to view set object
updateView	Modify an existing view in a view set object
deleteView	Delete an existing view from view set object
hasView	Check if view exists
addConnection	Add a connection between two views
updateConnection	Modify a connection between two views in a view set object
deleteConnection	Delete a connection between two views from view set object
hasConnection	Check if a connection exists between two views
findTracks	Find matched points across multiple views
poses	Returns camera poses associated to views

Examples

Find Point Tracks Across Sequence of Images

Load images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
images = imageSet(imageDir);
```

Compute features for the first image.

```
I = rgb2gray(read(images, 1));
pointsPrev = detectSURFFeatures(I);
[featuresPrev,pointsPrev] = extractFeatures(I,pointsPrev);
```

Create a `viewSet` object.

```
vSet = viewSet;
vSet = addView(vSet,1,'Points',pointsPrev);
```

Compute features and matches for the rest of the images.

```
for i = 2:images.Count
 I = rgb2gray(read(images,i));
```

```
points = detectSURFFeatures(I);
[features, points] = extractFeatures(I,points);
vSet = addView(vSet,i,'Points',points);
pairsIdx = matchFeatures(featuresPrev,features);
vSet = addConnection(vSet,i-1,i,'Matches',pairsIdx);
featuresPrev = features;
end
```

Find point tracks.

```
tracks = findTracks(vSet);
```

- "Structure From Motion From Multiple Views"
- "Structure From Motion From Two Views"
- "Code Generation for Depth Estimation From Stereo Video"

See Also
```
bundleAdjustment | detectBriskFeatures | detectFastFeatures |
detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures |
detectSURFFeatures | matchFeatures | pointTrack | table |
triangulateMultiview
```

Topics
"Structure From Motion From Multiple Views"
"Structure From Motion From Two Views"
"Code Generation for Depth Estimation From Stereo Video"
"Single Camera Calibrator App"
"Structure from Motion"

Introduced in R2016a

addView

Class: viewSet

Add a new view to view set object

Syntax

```
vSet = addView(vSet,viewId)
vSet = addView(vSet,viewId,Name,Value)
```

Description

`vSet = addView(vSet,viewId)` adds the view specified by `viewID` to the specified `viewSet` object.

`vSet = addView(vSet,viewId,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

vSet — View set object
viewSet object

`viewSet` object.

viewId — Camera pose view ID
integer

Camera pose view ID in the `viewSet` object, specified as an integer.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single

quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Location','[0,0,0]'`

`Points` — Image points
M-by-2 matrix | points object

Image points, specified as the comma-separated pair consisting of '`Points`' and an *M*-by-2 matrix of [*x*,*y*] coordinates or any points object.

`Orientation` — Orientation of the second camera relative to the first
3-by-3 matrix

Orientation of the second camera relative to the first, specified as the comma-separated pair consisting of '`Orientation`' and a 3-by-3 matrix.

`Location` — Location of the second camera relative to the first
three-element vector

Location of the second camera relative to the first, specified as the comma-separated pair consisting of '`Location`' and a three-element vector.

Output Arguments

`vSet` — View set object
`viewSet` object

`viewSet` object containing the added view specified by `viewId`.

Examples

Add View to View Set Object

Create an empty viewSet object.

`vSet = viewSet;`

Detect interest points in the image.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
I = imread(fullfile(imageDir,'image1.jpg'));
points = detectSURFFeatures(rgb2gray(I));
```

Add the points to the object.

```
vSet = addView(vSet,1,'Points',points,'Orientation',eye(3),'Location',[0,0,0]);
```

Introduced in R2016a

updateView

Class: viewSet

Modify an existing view in a view set object

Syntax

```
vSet = updateView(vSet,viewId)
vSet = updateView(vSet,viewId,Name,Value)
vSet = updateView(vSet,views)
```

Description

`vSet = updateView(vSet,viewId)` modifies the view specified by `viewId` in the specified `viewSet` object, `vSet`.

`vSet = updateView(vSet,viewId,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

`vSet = updateView(vSet,views)` modifies a view or a set of views specified by the `view` table.

Input Arguments

vSet — View set object
viewSet object

`viewSet` object.

viewId — Camera pose view ID
integer

Camera pose view ID in the `viewSet` object, specified as an integer.

views — Camera views
table

Camera views, specified as a table. The table must contain a column named `ViewID`, and one or more columns named `Points`, `Orientation`, or `Location`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `Location,'[0,0,0]'`

Points — Image points
M-by-2 matrix | points object

Image points, specified as the comma-separated pair consisting of `'Points'` and an *M*-by-2 matrix of [*x*,*y*] coordinates or any points object.

Orientation — Orientation of the second camera relative to the first camera
3-by-3 matrix

Orientation of the second camera relative to the first camera, specified as the comma-separated pair consisting of `'Orientation'` and a 3-by-3 matrix that represents the [*x*,*y*,*z*] orientation of the second camera.

Location — Location of the second camera relative to the first camera
three-element vector

Location of the second camera relative to the first camera, specified as the comma-separated pair consisting of `'Location'` and a three-element vector that represents the [*x*,*y*,*z*] location of the second camera in the first camera's coordinate system.

Output Arguments

vSet — View set object
viewSet object

`viewSet` object containing the modified view specified by `viewId`.

Examples

Update View in View Set Object

Create an empty `viewSet` object.

```
vSet = viewSet;
```

Detect interest points in the image.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
I = imread(fullfile(imageDir,'image1.jpg'));
points = detectSURFFeatures(rgb2gray(I));
```

Add the points to the object.

```
vSet = addView(vSet,1,'Points',points);
```

Update the view to specify the camera pose.

```
vSet = updateView(vSet, 1,'Orientation',eye(3),'Location',[0,0,0]);
```

Introduced in R2016a

deleteView

Class: viewSet

Delete an existing view from view set object

Syntax

```
vSet = deleteView(vSet,viewId)
```

Description

`vSet = deleteView(vSet,viewId)` deletes an existing view or a set of views from the specified `viewSet` object,`vSet`.

Input Arguments

vSet — View set object
viewSet object

A `viewSet` object.

viewId — View IDs
integer scalar | vector

View IDs, specified as an integer scalar for a single view, or as a vector of integers for a set of views.

Output Arguments

vSet — View set object
viewSet object

`viewSet` object.

Examples

Delete a View from View Set Object

Create an empty viewSet object.

```
vSet = viewSet;
```

Detect interest points in the image.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
I = imread(fullfile(imageDir,'image1.jpg'));
points = detectSURFFeatures(rgb2gray(I));
```

Add a view.

```
vSet = addView(vSet,1,'Points',points);
```

Delete the view.

```
vSet = deleteView(vSet,1);
```

Introduced in R2016a

hasView

Class: viewSet

Check if view exists

Syntax

```
tf = hasView(vSet,viewId)
```

Description

`tf = hasView(vSet,viewId)` returns `1` if the view specified by `viewID` exists and `0` if it does not exist.

Input Arguments

vSet — View set object
viewSet object

`viewSet` object.

viewId1 — View ID
integer

View ID in the `viewSet` object, specified as an integer.

Output Arguments

tf — Validity of view connection
logical

Validity of view connection, returned as a logical `1` or `0`.

Examples

Check If View Exists

Create an empty viewSet object.

```
vSet = viewSet;
```

Detect interest points in the image.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
I = imread(fullfile(imageDir,'image1.jpg'));
points = detectSURFFeatures(rgb2gray(I));
```

Add a new view.

```
vSet = addView(vSet, 1,'Points',points);
```

Confirm that the view with ID 1 exists.

```
tf = hasView(vSet,1);
```

Introduced in R2016a

addConnection

Class: viewSet

Add a connection between two views

Syntax

```
vSet = addConnection(vSet,viewId1,viewId2)
vSet = addConnection(vSet,viewId1,viewId2,Name,Value,)
```

Description

vSet = addConnection(vSet,viewId1,viewId2) adds a connection between two views in the specified viewSet object, vSet.

vSet = addConnection(vSet,viewId1,viewId2,Name,Value,) uses additional options specified by one or more Name,Value pair arguments.

Input Arguments

vSet — View set object
viewSet object

viewSet object.

viewId1 — View ID 1
integer

View ID 1 in the viewSet object, specified as an integer.

viewId2 — View ID 2
integer

View ID 2 in the viewSet object, specified as an integer.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Location','[0,0,0]'`

`Matches` — Indices of matched points between two views
M-by-2 matrix

Indices of matched points between two views, specified as the comma-separated pair consisting of '`Matches`' and an *M*-by-2 matrix.

`Orientation` — Orientation of the second camera relative to the first camera
3-by-3 matrix

Orientation of the second camera relative to the first camera, specified as the comma-separated pair consisting of '`Orientation`' and a 3-by-3 matrix that represents the [x,y,z] orientation of the second camera.

`Location` — Location of the second camera relative to the first camera
three-element vector

Location of the second camera relative to the first camera, specified as the comma-separated pair consisting of '`Location`' and a three-element vector that represents the [x,y,z] location of the second camera in the first camera's coordinate system.

Output Arguments

`vSet` — View set object
`viewSet` object

`viewSet` object.

Examples

Add Connection Between Two Views in View Set Object

Create an empty `viewSet` object.

```
vSet = viewSet;
```

Read a pair of images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
I1 = rgb2gray(imread(fullfile(imageDir,'image1.jpg')));
I2 = rgb2gray(imread(fullfile(imageDir,'image2.jpg')));
```

Detect interest points in the two images.

```
points1 = detectSURFFeatures(I1);
points2 = detectSURFFeatures(I2);
```

Add the points to the `viewSet` object.

```
vSet = addView(vSet,1,'Points',points1);
vSet = addView(vSet,2,'Points',points2);
```

Extract feature descriptors from both images.

```
features1 = extractFeatures(I1,points1);
features2 = extractFeatures(I2,points2);
```

Match features and store the matches.

```
indexPairs = matchFeatures(features1,features2);
```

Add the connection between the two views.

```
vSet = addConnection(vSet,1,2,'Matches',indexPairs);
```

Introduced in R2016a

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updateConnection

Class: viewSet

Modify a connection between two views in a view set object

Syntax

```
vSet = updateConnection(vSet,viewId1,viewId2)
vSet = updateConnection(vSet,viewId1,viewId2,Name,Value)
```

Description

`vSet = updateConnection(vSet,viewId1,viewId2)` modifies a connection between two views in the specified view set object, `vSet`.

`vSet = updateConnection(vSet,viewId1,viewId2,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

Input Arguments

vSet — View set object
viewSet object

`viewSet` object.

viewId1 — View ID 1
integer

View ID 1 in the `viewSet` object, specified as an integer.

viewId2 — View ID 2
integer

View ID 2 in the `viewSet` object, specified as an integer.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Location', '[0,0,0]'`

`Matches` — Indices of matched points between two views
M-by-2 matrix

Indices of matched points between two views, specified as the comma-separated pair consisting of '`Matches`' and an *M*-by-2 matrix.

`Orientation` — Orientation of the second camera relative to the first camera
3-by-3 matrix

Orientation of the second camera relative to the first camera, specified as the comma-separated pair consisting of '`Orientation`' and a 3-by-3 matrix that represents the [*x*,*y*,*z*] orientation of the second camera.

`Location` — Location of the second camera relative to the first camera
three-element vector

Location of the second camera relative to the first camera, specified as the comma-separated pair consisting of '`Location`' and a three-element vector that represents the [*x*,*y*,*z*] location of the second camera in the first camera's coordinate system.

Output Arguments

`vSet` — View set object
`viewSet` object

A `viewSet` object containing the modified connection.

Examples

Update Connection Between Two Views in View Set Object

Create an empty `viewSet` object.

```
vSet = viewSet;
```

Read a pair of images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
I1 = rgb2gray(imread(fullfile(imageDir,'image1.jpg')));
I2 = rgb2gray(imread(fullfile(imageDir,'image2.jpg')));
```

Detect interest points in the two images.

```
points1 = detectSURFFeatures(I1);
points2 = detectSURFFeatures(I2);
```

Add the points to the `viewSet` object.

```
vSet = addView(vSet, 1,'Points',points1);
vSet = addView(vSet, 2,'Points',points2);
```

Extract feature descriptors.

```
features1 = extractFeatures(I1,points1);
features2 = extractFeatures(I2,points2);
```

Match features and store the matches.

```
indexPairs = matchFeatures(features1, features2);
vSet = addConnection(vSet,1,2,'Matches',indexPairs);
```

Update the connection to store a relative pose between the views.

```
vSet = updateConnection(vSet,1,2,'Orientation', eye(3),'Location',[1 0 0]);
```

Introduced in R2016a

deleteConnection

Class: viewSet

Delete a connection between two views from view set object

Syntax

```
vSet = deleteConnection(vSet,viewId1,viewId2)
```

Description

`vSet = deleteConnection(vSet,viewId1,viewId2)` deletes a connection between two views in the specified `viewSet` object, `vSet`.

Input Arguments

vSet — View set object
`viewSet` object

`viewSet` object.

viewId1 — View ID 1
integer

View ID 1 in the `viewSet` object, specified as an integer.

viewId2 — View ID 2
integer

View ID 2 in the `viewSet` object, specified as an integer.

Output Arguments

vSet — View set object
viewSet object

viewSet object.

Examples

Delete a Connection Between Two Views In View Set Object

Create an empty viewSet object.

```
vSet = viewSet;
```

Read a pair of images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
I1 = rgb2gray(imread(fullfile(imageDir,'image1.jpg')));
I2 = rgb2gray(imread(fullfile(imageDir,'image2.jpg')));
```

Detect interest points in the two images.

```
points1 = detectSURFFeatures(I1);
points2 = detectSURFFeatures(I2);
```

Add the points to the viewSet object.

```
vSet = addView(vSet,1,'Points',points1);
vSet = addView(vSet,2,'Points',points2);
```

Extract feature descriptors.

```
features1 = extractFeatures(I1,points1);
features2 = extractFeatures(I2,points2);
```

Match features and store the matches.

```
indexPairs = matchFeatures(features1, features2);
vSet = addConnection(vSet,1,2,'Matches',indexPairs);
```

Delete the connection between the views.

```
vSet = deleteConnection(vSet,1,2);
```

Introduced in R2016a

hasConnection

Class: viewSet

Check if a connection exists between two views

Syntax

```
tf = hasConnection(vSet,viewId1,viewId2)
```

Description

`tf = hasConnection(vSet,viewId1,viewId2)` returns true if both views exist and have a connection.

Input Arguments

vSet — View set object
viewSet object

`viewSet` object.

viewId1 — View ID 1
integer

View ID 1 in the `viewSet` object, specified as an integer.

viewId2 — View ID 2
integer

View ID 2 in the `viewSet` object, specified as an integer.

Output Arguments

`tf` — Validity of view connection
logical

Validity of view connection, returned as a logical `1` or `0`.

Examples

Check Whether a Connection Exists Between Two Views

Create an empty `viewSet` object.

```
vSet = viewSet;
```

Add a pair of views.

```
vSet = addView(vSet,1);
vSet = addView(vSet,2);
```

Add a connection.

```
vSet = addConnection(vSet,1,2);
```

Confirm that the connection exists.

```
tf = hasConnection(vSet,1,2);
```

Introduced in R2016a

findTracks

Class: viewSet

Find matched points across multiple views

Syntax

```
tracks = findTracks(vSet)
tracks = findTracks(vSet,viewIds)
```

Description

`tracks = findTracks(vSet)` finds point tracks across multiple views.

`tracks = findTracks(vSet,viewIds)` finds point tracks across a subset of views.

Input Arguments

vSet — View set object
viewSet object

viewSet object.

viewIds — Subset of views
vector of integers

Subset of views in the `viewSet` object, specified as a vector of integers.

Output Arguments

tracks — Point track objects
array of `pointTrack` objects

Point track objects, returned as an array of `pointTrack` objects. Each track contains 2-D projections of the same 3-D world point.

Examples

Find Point Tracks Across Sequence of Images

Load images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata','structureFromMotion');
images = imageSet(imageDir);
```

Compute features for the first image.

```
I = rgb2gray(read(images, 1));
pointsPrev = detectSURFFeatures(I);
[featuresPrev,pointsPrev] = extractFeatures(I,pointsPrev);
```

Create a `viewSet` object.

```
vSet = viewSet;
vSet = addView(vSet,1,'Points',pointsPrev);
```

Compute features and matches for the rest of the images.

```
for i = 2:images.Count
 I = rgb2gray(read(images,i));
 points = detectSURFFeatures(I);
 [features, points] = extractFeatures(I,points);
 vSet = addView(vSet,i,'Points',points);
 pairsIdx = matchFeatures(featuresPrev,features);
 vSet = addConnection(vSet,i-1,i,'Matches',pairsIdx);
 featuresPrev = features;
end
```

Find point tracks.

```
tracks = findTracks(vSet);
```

Introduced in R2016a

poses

Class: viewSet

Returns camera poses associated to views

Syntax

```
cameraPoses = poses(vSet)
cameraPoses = poses(vSet,viewIds)
```

Description

`cameraPoses = poses(vSet)` returns the camera poses that correspond to the views contained in the input `viewSet`, object, `vSet`.

`cameraPoses = poses(vSet,viewIds)` returns the camera poses that correspond to a subset of views specified by the vector `viewIds`.

Input Arguments

vSet — View set object
viewSet object

`viewSet` object.

viewId — View IDs
integer scalar | vector

View IDs, specified as an integer scalar for a single view, or as a vector of integers for a set of views.

Output Arguments

cameraPoses — Camera pose information
three-column table

Camera pose information, returned as a three-column table. The table contains columns for `ViewId`, `Orientation`, and `Location`. The view IDs correspond to the IDs in the `viewSet` object. The orientations are specified as 3-by-3 rotation matrices and locations are specified as three-element vectors. You can pass the `cameraPoses` table to the `triangulateMultiview` and the `bundleAdjustment` functions.

Examples

Retrieve Camera Poses from View Set Object

Create an empty `viewSet` object.

```
vSet = viewSet;
```

Add views to the object.

```
vSet = addView(vSet,1,'Orientation',eye(3),'Location',[0,0,0]);
vSet = addView(vSet,2,'Orientation',eye(3),'Location',[1,0,0]);
```

Retrieve the absolute camera poses.

```
camPoses = poses(vSet);
```

See Also
bundleAdjustment | triangulateMultiview

Introduced in R2016a

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detect

Detect objects using ACF object detector

Syntax

```
bboxes = detect(detector,I)
[bboxes,scores] = detect(___ )
[___ ]= detect(___ ,roi)
[___ ] = detect(___ ,Name,Value)
```

Description

`bboxes = detect(detector,I)` detects objects within image `I` using the input aggregate channel features (ACF) object detector. The locations of objects detected are returned as a set of bounding boxes, `bboxes`.

`[bboxes,scores] = detect(___ )` also returns the detection scores for each bounding box using the previous input arguments.

`[___ ]= detect(___ ,roi)` detects objects within the rectangular search region specified by `roi`.

`[___ ] = detect(___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

Examples

Train a Stop Sign Detector Using an ACF Object Detector

Use the `trainACFObjectDetector` with training images to create an ACF object detector that can detect stop signs. Test the detector with a separate image.

Load the training data.

```
load('stopSignsAndCars.mat')
```

Select the ground truth for stop signs. These ground truth is the set of known locations of stop signs in the images.

```
stopSigns = stopSignsAndCars(:,1:2);
```

Add the full path to the image files.

```
stopSigns.imageFilename = fullfile(toolboxdir('vision'),...
    'visiondata',stopSigns.imageFilename);
```

Train the ACF detector. You can turn off the training progress output by specifying `'Verbose',false` as a `Name,Value` pair.

```
acfDetector = trainACFObjectDetector(stopSigns,'NegativeSamplesFactor',2);
```

```
ACF Object Detector Training
The training will take 4 stages. The model size is 34x31.
Sample positive examples(~100% Completed)
Compute approximation coefficients...Completed.
Compute aggregated channel features...Completed.
--------------------------------------------
Stage 1:
Sample negative examples(~100% Completed)
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 19 weak learners.
--------------------------------------------
Stage 2:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 20 weak learners.
--------------------------------------------
Stage 3:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 54 weak learners.
--------------------------------------------
Stage 4:
Sample negative examples(~100% Completed)
```

```
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 61 weak learners.
--------------------------------------------
ACF object detector training is completed. Elapsed time is 31.7646 seconds.
```

Test the ACF detector on a test image.

```
img = imread('stopSignTest.jpg');

[bboxes,scores] = detect(acfDetector,img);
```

Display the detection results and insert the bounding boxes for objects into the image.

```
for i = 1:length(scores)
   annotation = sprintf('Confidence = %.1f',scores(i));
   img = insertObjectAnnotation(img,'rectangle',bboxes(i,:),annotation);
end

figure
imshow(img)
```

Input Arguments

detector — ACF object detector
acfObjectDetector object

ACF object detector, specified as an acfObjectDetector object. To train the object detector, call trainACFObjectDetector.

I — Input image
grayscale image | truecolor image

Input image, specified as a real, nonsparse grayscale or truecolor image.

Data Types: uint8 | uint16 | int16 | double | single | logical

roi — Search region of interest
[*x y width height*]

Search region of interest, specified as an [*x y width height*] vector. The vector specifies the upper-left corner and size of a region in pixels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NumScaleLevels',4`

NumScaleLevels — Number of scale levels per octave
8 (default) | integer

Number of scale levels per octave, specified as the comma-separated pair consisting of `'NumScaleLevels'` and an integer. Each octave is a power-of-two downscaling of the image. Increase this number to detect people at finer scale increments. Recommended values are in the range [4,8].

WindowStride — Window stride for sliding window
4 (default) | integer

Window stride for sliding window, specified as the comma-separated pair consisting of `'WindowStride'`, and an integer. Set this value to the amount you want to move the window, in the *x* and *y* directions. The sliding window scans the images for object detection. The function uses the same stride for the *x* and *y* directions.

SelectStrongest — Select strongest bounding box
`true` (default) | `false`

Select strongest bounding box, specified as the comma-separated pair consisting of `'SelectStrongest'` and either `true` or `false`. The process, often referred to as nonmaximum suppression, eliminates overlapping bounding boxes based on their scores. Set this property to `true` to use the `selectStrongestBbox` function to select the strongest bounding box. Set this property to `false` to perform a custom selection operation and return all detected bounding boxes.

MinSize — Minimum region size
[*height width*] vector

Minimum region size in pixels, specified as the comma-separated pair consisting of 'MinSize' and a [*height width*] vector. By default, MinSize is the smallest object that the trained detector can detect.

MaxSize — Maximum region size
size(I) (default) | [*height width*] vector

Maximum region size, in pixels, that contains an object, specified as the comma-separated pair consisting of 'MaxSize' and a [*height width*] vector. You can reduce computation time by setting this value to the known region size for detecting a person. By default, the function determines the height and width of the image using the size of input image, I.

Threshold — Classification accuracy threshold
−1 (default) | numeric scalar

Classification accuracy threshold, specified as the comma-separated pair consisting of 'Threshold' and a numerical scalar. Typical values are in the range [–1,1]. During multiscale object detection, the threshold value controls the object or nonobject classification accuracy and speed. Increase this threshold to speed up the performance at the risk of missing true detections.

Output Arguments

bboxes — Location of objects detected within image
M-by-4 matrix

Location of objects detected within image, returned as an *M*-by-4 matrix defining *M* bounding boxes. Each row of bboxes contains a four-element vector, [*x*,*y*,*width*, *height*]. This vector specifies the upper-left corner and size of a bounding box in pixels.

scores — Detection scores
M-by-1 vector

Detection scores, returned as an *M*-by-1 vector of classification scores. Larger score values indicate higher confidence in the detection.

See Also

Image Labeler | acfObjectDetector | detectPeopleACF | trainACFObjectDetector | trainCascadeObjectDetector

Introduced in R2017a

acfObjectDetector

Detect objects using aggregate channel features

Description

Create a trained aggregate channel features (ACF) object detector. The ACF object detector recognizes specific objects in images, based on the training images and the object ground truth locations that are input to `trainACFObjectDetector`.

Creation

Use the `trainACFObjectDetector` function with training data to create an ACF object detector.

Syntax

```
detector = trainACFObjectDetector(trainingData)
detector = trainACFObjectDetector(trainingData,Name,Value)
```

Description

`detector = trainACFObjectDetector(trainingData)` returns a trained aggregate channel features (ACF) object detector.

`detector = trainACFObjectDetector(trainingData,Name,Value)` returns an ACF object detector with additional options specified by one or more Name,Value pair arguments.

Properties

ModelName — Name of the classification model
character vector

Name of the classification model, specified as a character vector. By default, the name is set to the heading of the second column of the `groundTruth` table specified in `trainACFObjectDetector`.

Example: 'stopSign'

ObjectTrainingSize — Size of training images
[*height width*] vector

This property is read-only.

Size of training images, specified as a [*height width*] vector.

Example: [100,100]

NumWeakLearners — Number of weak learners
scalar integer

This property is read-only.

Number of weak learners used in the detector, specified as a scalar integer. This property is set based on the `'MaxWeakLearners'` name-value pair in the `trainACFObjectDetector` function.

Object Functions

detect   Detect objects using ACF object detector

Examples

Train Stop Sign Detector Using ACF Object Detector

Load the training data.

```
load('stopSignsAndCars.mat')
```

Select the ground truth for stop signs.

```
stopSigns = stopSignsAndCars(:, 1:2);
```

Add the fullpath to image files.

```
stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);
```

Train the ACF detector.

```
acfDetector = trainACFObjectDetector(stopSigns,'NegativeSamplesFactor',2,'Verbose',fals
```

Test the ACF detector on a test image.

```
img = imread('stopSignTest.jpg');
```

```
[bboxes, scores] = detect(acfDetector, img);
```

Display the detection result.

```
for i = 1:length(scores)
    annotation = sprintf('Confidence = %.1f', scores(i));
    img = insertObjectAnnotation(img, 'rectangle', bboxes(i,:), annotation);
end

figure
imshow(img)
```
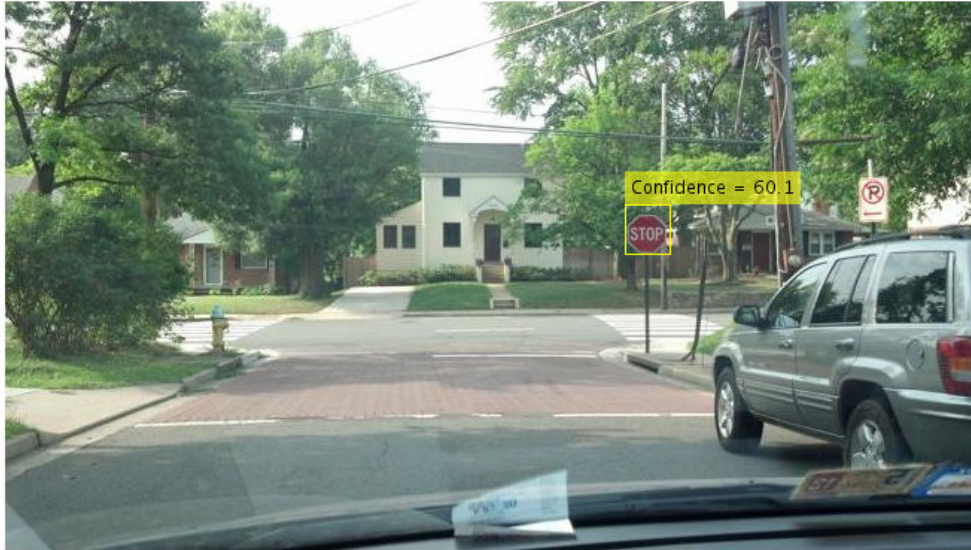
References

[1] Dollar, P., R. Appel, S. Belongie, and P. Perona. "Fast Feature Pyramids for Object Detection." *Pattern Analysis and Machine Intelligence, IEEE Transactions*. Vol. 36, Issue 8, 2014, pp. 1532–1545.

See Also

Image Labeler | detectPeopleACF | groundTruth | trainACFObjectDetector | trainCascadeObjectDetector

Introduced in R2017a

rcnnObjectDetector class

Detect objects using R-CNN deep learning detector

Syntax

`rcnnObjectDetector`

Description

`rcnnObjectDetector` contains a trained R-CNN (regions with convolutional neural networks) object detector returned by the `trainRCNNObjectDetector` function.

You must have a Statistics and Machine Learning Toolbox™ license to use this classifier.

Use of this function requires Neural Network Toolbox, Statistics and Machine Learning Toolbox, and a CUDA®-enabled NVIDIA® GPU with a compute capability of 3.0 or higher.

Properties

Network — Series network object
SeriesNetwork object

Series network object representing the convolutional neural network (CNN), specified as an `SeriesNetwork` object. The object is used within the R-CNN detector.

RegionProposalFcn — Region proposal method
function handle

Region proposal method, specified as a function handle.

ClassNames — Object class names
cell array

Object class names, specified as a cell array. The array contains the names of the object classes the R-CNN detector was trained to find.

Methods

detect   Detect objects using R-CNN deep learning detector
classifyRegions   Classifies objects within regions

Examples

Train R-CNN Stop Sign Detector

Load training data and network layers.

```
load('rcnnStopSigns.mat', 'stopSigns', 'layers')
```

Add the image directory to the MATLAB path.

```
imDir = fullfile(matlabroot, 'toolbox', 'vision', 'visiondata',...
  'stopSignImages');
addpath(imDir);
```

Set network training options to use mini-batch size of 32 to reduce GPU memory usage. Lower the InitialLearningRate to reduce the rate at which network parameters are changed. This is beneficial when fine-tuning a pre-trained network and prevents the network from changing too rapidly.

```
options = trainingOptions('sgdm', ...
  'MiniBatchSize', 32, ...
  'InitialLearnRate', 1e-6, ...
  'MaxEpochs', 10);
```

Train the R-CNN detector. Training can take a few minutes to complete.

```
rcnn = trainRCNNObjectDetector(stopSigns, layers, options, 'NegativeOverlapRange', [0 (

************************************************************************
Training an R-CNN Object Detector for the following object classes:
```

```
* stopSign

Step 1 of 3: Extracting region proposals from 27 training images...done.

Step 2 of 3: Training a neural network to classify objects in training data...
```

Epoch	Iteration	Time Elapsed (seconds)	Mini-batch Loss	Mini-batch Accuracy	Base Learr Rate
3	50	9.27	0.2895	96.88%	0.0000
5	100	14.77	0.2443	93.75%	0.0000
8	150	20.29	0.0013	100.00%	0.0000
10	200	25.94	0.1524	96.88%	0.0000

```
Network training complete.

Step 3 of 3: Training bounding box regression models for each object class...100.00%..

R-CNN training complete.
********************************************************************
```

Test the R-CNN detector on a test image.

```
img = imread('stopSignTest.jpg');

[bbox, score, label] = detect(rcnn, img, 'MiniBatchSize', 32);
```

Display strongest detection result.

```
[score, idx] = max(score);

bbox = bbox(idx, :);
annotation = sprintf('%s: (Confidence = %f)', label(idx), score);

detectedImg = insertObjectAnnotation(img, 'rectangle', bbox, annotation);

figure
imshow(detectedImg)
```

Remove the image directory from the path.

```
rmpath(imDir);
```

Resume Training an R-CNN Object Detector

Resume training an R-CNN object detector using additional data. To illustrate this procedure, half the ground truth data will be used to initially train the detector. Then, training is resumed using all the data.

Load training data and initialize training options.

```
load('rcnnStopSigns.mat', 'stopSigns', 'layers')

stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);

options = trainingOptions('sgdm', ...
```

```
    'MiniBatchSize', 32, ...
    'InitialLearnRate', 1e-6, ...
    'MaxEpochs', 10, ...
    'Verbose', false);
```

Train the R-CNN detector with a portion of the ground truth.

```
rcnn = trainRCNNObjectDetector(stopSigns(1:10,:), layers, options, 'NegativeOverlapRang
```

Get the trained network layers from the detector. When you pass in an array of network layers to `trainRCNNObjectDetector`, they are used as-is to continue training.

```
network = rcnn.Network;
layers = network.Layers;
```

Resume training using all the training data.

```
rcnnFinal = trainRCNNObjectDetector(stopSigns, layers, options);
```

Create a network for multiclass R-CNN object detection

Create an R-CNN object detector for two object classes: dogs and cats.

```
objectClasses = {'dogs','cats'};
```

The network must be able to classify both dogs, cats, and a "background" class in order to be trained using `trainRCNNObjectDetector`. In this example, a one is added to include the background.

```
numClassesPlusBackground = numel(objectClasses) + 1;
```

The final fully connected layer of a network defines the number of classes that the network can classify. Set the final fully connected layer to have an output size equal to the number of classes plus a background class.

```
layers = [ ...
    imageInputLayer([28 28 1])
    convolution2dLayer(5,20)
    fullyConnectedLayer(numClassesPlusBackground);
    softmaxLayer()
    classificationLayer()];
```

These network layers can now be used to train an R-CNN two-class object detector.

Use A Saved Network In R-CNN Object Detector

Create an R-CNN object detector and set it up to use a saved network checkpoint. A network checkpoint is saved every epoch during network training when the `trainingOptions` 'CheckpointPath' parameter is set. Network checkpoints are useful in case your training session terminates unexpectedly.

Load the stop sign training data.

```
load('rcnnStopSigns.mat','stopSigns','layers')
```

Add full path to image files.

```
stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);
```

Set the 'CheckpointPath' using the `trainingOptions` function.

```
checkpointLocation = tempdir;
options = trainingOptions('sgdm','Verbose',false, ...
    'CheckpointPath',checkpointLocation);
```

Train the R-CNN object detector with a few images.

```
rcnn = trainRCNNObjectDetector(stopSigns(1:3,:),layers,options);
```

Load a saved network checkpoint.

```
wildcardFilePath = fullfile(checkpointLocation,'convnet_checkpoint__*.mat');
contents = dir(wildcardFilePath);
```

Load one of the checkpoint networks.

```
filepath = fullfile(contents(1).folder,contents(1).name);
checkpoint = load(filepath);
```

```
checkpoint.net
```

```
ans =

  SeriesNetwork with properties:
```

```
    Layers: [15×1 nnet.cnn.layer.Layer]
```

Create a new R-CNN object detector and set it up to use the saved network.

```
rcnnCheckPoint = rcnnObjectDetector();
rcnnCheckPoint.RegionProposalFcn = @rcnnObjectDetector.proposeRegions;
```

Set the Network to the saved network checkpoint.

```
rcnnCheckPoint.Network = checkpoint.net


rcnnCheckPoint =

  rcnnObjectDetector with properties:

              Network: [1×1 SeriesNetwork]
           ClassNames: {'stopSign'   'Background'}
    RegionProposalFcn: @rcnnObjectDetector.proposeRegions
```

- "Image Category Classification Using Deep Learning"

See Also

Apps
Image Labeler

Functions
`SeriesNetwork | selectStrongestBboxMulticlass | trainFastRCNNObjectDetector | trainFasterRCNNObjectDetector | trainNetwork | trainRCNNObjectDetector | vision.CascadeObjectDetector`

Topics
"Image Category Classification Using Deep Learning"

Introduced in R2016b

detect

Class: rcnnObjectDetector

Detect objects using R-CNN deep learning detector

Syntax

```
bboxes = detect(rcnn,I)
[bboxes,scores] = detect(rcnn,I)
[ ___ ,labels] = detect(rcnn,I)
[ ___ ]= detect(rcnn,I,roi)
[ ___ ] = detect( ___ ,Name,Value)
[ ___ ] = detect( ___ ,'ExecutionEnvironment',resource)
```

Description

`bboxes = detect(rcnn,I)` detects objects within the image, `I`, using an R-CNN detector. The location of objects detected are returned in `bboxes`.

`[bboxes,scores] = detect(rcnn,I)` also returns the detection scores for each bounding box.

`[ ___ ,labels] = detect(rcnn,I)` also returns the labels assigned to the bounding boxes.

`[ ___ ]= detect(rcnn,I,roi)` detects objects within the rectangular search region specified by `roi`.

`[ ___ ] = detect( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

`[ ___ ] = detect( ___ ,'ExecutionEnvironment',resource)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

Input Arguments

rcnn — Trained R-CNN based object detector
rcnnObjectDetector object

Trained R-CNN based object detector, returned by the trainRCNNObjectDetector function. You can train an R-CNN detector to detect multiple object classes.

I — Input image
grayscale | true color

Input image, specified as a real, nonsparse grayscale or true color image.

Data Types: uint8 | uint16 | int16 | double | single | logical

roi — Search region of interest
four-element vector

Search region of interest, specified as a four-element vector, [*x*,*y*,*width*,*height*]. The vector specifies the upper-left corner and size of a region in pixels.

ExecutionEnvironment — Hardware resource
'auto' (default) | 'gpu' | 'cpu'

Hardware resource, specified as 'auto', 'gpu', or 'cpu'. Set the execution environment to the hardware resource to run the CNN, which is used with the R-CNN detector. Valid values for resource are:

resource	Action
'auto'	Use a GPU if it is available, otherwise use the CPU.
'gpu'	Use the GPU. To use a GPU, you must have Parallel Computing Toolbox, and a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher. If a suitable GPU is not available, an error message is issued.
'cpu'	Use the CPU.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single

quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

NumStrongestRegions — Maximum number of strongest region proposals
2000 (default) | integer

Maximum number of strongest region proposals to use for generating training samples, specified as the comma-separated pair consisting of `'NumStrongestRegions'` and an integer. Reduce this value to speed up processing time, although doing so decreases training accuracy. To use all region proposals, set this value to `inf`.

SelectStrongest — Eliminate overlapping bounding boxes
true (default) | `false`

Option to eliminate overlapping bounding boxes based on their scores, specified as the comma-separated pair consisting of `'SelectStrongest'` and a logical scalar. This process is often referred to as nonmaximum suppression. If you want to perform a custom selection operation, set this value to `false`. Setting it to `false`, returns all the detected bounding boxes.

When you set this property to `true`, the `selectStrongestBboxMulticlass` function is used to eliminate the overlapping boxes. For example:

```
selectStrongestBboxMulticlass(bbox,scores, ...
        'RatioType','Min', ...
        'OverlapThreshold',0.5);
```

MiniBatchSize — Size of smaller batches for R-CNN data processing
128 (default) | integer

Size of smaller batches for R-CNN data processing, specified as the comma-separated pair consisting of `'MiniBatchSize'` and an integer. Larger batch sizes lead to faster processing, but they take up more memory.

Output Arguments

bboxes — Location of objects detected within image
M-by-4 matrix

Location of objects detected within image, returned as an *M*-by-4 matrix defining *M* bounding boxes. Each row of `bboxes` contains a four-element vector, [*x*,*y*,*width*, *height*]. This vector specifies the upper-left corner and size of a bounding box in pixels.

scores — Detection scores
M-by-1 vector

Detection scores, returned as an *M*-by-1 vector of classification scores in the range [0,1]. Larger score values indicate higher confidence in the detection.

labels — Labels
M-by-1 array

Labels, returned as an *M*-by-1 categorical array of class names. Every region specified in `rois` is assigned a label. The labels used for object classes are defined during training using the `trainRCNNObjectDetector` function.

Examples

Train R-CNN Stop Sign Detector

Load training data and network layers.

```
load('rcnnStopSigns.mat', 'stopSigns', 'layers')
```

Add the image directory to the MATLAB path.

```
imDir = fullfile(matlabroot, 'toolbox', 'vision', 'visiondata',...
  'stopSignImages');
addpath(imDir);
```

Set network training options to use mini-batch size of 32 to reduce GPU memory usage. Lower the InitialLearningRate to reduce the rate at which network parameters are changed. This is beneficial when fine-tuning a pre-trained network and prevents the network from changing too rapidly.

```
options = trainingOptions('sgdm', ...
  'MiniBatchSize', 32, ...
  'InitialLearnRate', 1e-6, ...
  'MaxEpochs', 10);
```

Train the R-CNN detector. Training can take a few minutes to complete.

```
rcnn = trainRCNNObjectDetector(stopSigns, layers, options, 'NegativeOverlapRange', [0 (
```

```
*************************************************************************
Training an R-CNN Object Detector for the following object classes:

* stopSign

Step 1 of 3: Extracting region proposals from 27 training images...done.

Step 2 of 3: Training a neural network to classify objects in training data...
```

Epoch	Iteration	Time Elapsed (seconds)	Mini-batch Loss	Mini-batch Accuracy	Base Learn Rate
3	50	9.27	0.2895	96.88%	0.0000
5	100	14.77	0.2443	93.75%	0.0000
8	150	20.29	0.0013	100.00%	0.0000
10	200	25.94	0.1524	96.88%	0.0000

```
Network training complete.

Step 3 of 3: Training bounding box regression models for each object class...100.00%..

R-CNN training complete.
*************************************************************************
```

Test the R-CNN detector on a test image.

```
img = imread('stopSignTest.jpg');
```

```
[bbox, score, label] = detect(rcnn, img, 'MiniBatchSize', 32);
```

Display strongest detection result.

```
[score, idx] = max(score);
```

```
bbox = bbox(idx, :);
annotation = sprintf('%s: (Confidence = %f)', label(idx), score);
```

```
detectedImg = insertObjectAnnotation(img, 'rectangle', bbox, annotation);
```

```
figure
imshow(detectedImg)
```


Remove the image directory from the path.

```
rmpath(imDir);
```

Introduced in R2016b

classifyRegions

Class: rcnnObjectDetector

Classifies objects within regions

Syntax

```
[labels,scores] = classifyRegions(rcnn,I,rois)
[labels,scores,allScores] = classifyRegions( ___ )
[ ___ ] = classifyRegions( ___ Name,Value)
[ ___ ] = detect( ___ ,'ExecutionEnvironment',resource)
```

Description

`[labels,scores] = classifyRegions(rcnn,I,rois)` classifies objects within the regions specified by `rois` in the image, `I`, using the `rcnn` detector.

`[labels,scores,allScores] = classifyRegions( ___ )` optionally returns all the classification scores in an *M*-by-*N* matrix of *M* regions and *N* classes.

`[ ___ ] = classifyRegions( ___ Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

`[ ___ ] = detect( ___ ,'ExecutionEnvironment',resource)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

Input Arguments

`rcnn` — Trained R-CNN based object detector
`rcnnObjectDetector` object

Trained R-CNN based object detector, returned by the `trainRCNNObjectDetector` function. An R-CNN detector can be trained to detect multiple object classes.

I — Image
grayscale | true color

Image, specified as a real, nonsparse grayscale or true color image.

rois — Regions of interest
M-by-4 array

Regions of interest, specified by an *M*-by-4 array of rectangular regions. Each row contains a four-element vector, [*x*,*y*,*width*,*height*], that specifies the upper-left corner and size of a region in pixels.

ExecutionEnvironment — Hardware resource
`'auto'` (default) | `'gpu'` | `'cpu'`

Hardware resource, specified as `'auto'`, `'gpu'`, or `'cpu'`. Set the execution environment to the hardware resource to run the CNN, which is used with the R-CNN detector. Valid values for resource are:

resource	Action
`'auto'`	Use a GPU if it is available, otherwise use the CPU.
`'gpu'`	Use the GPU. To use a GPU, you must have Parallel Computing Toolbox, and a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher. If a suitable GPU is not available, an error message is issued.
`'cpu'`	Use the CPU.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

MiniBatchSize — Size of smaller batches for R-CNN data processing
128 (default) | integer

Size of smaller batches for R-CNN data processing, specified as the comma-separated pair consisting of `'MiniBatchSize'` and an integer. Larger batch sizes lead to faster processing, but takes up more memory.

Output Arguments

`labels` — Labels
M-by-1 array

Labels, returned as an *M*-by-1 categorical array of class names. Every region in `rois` is a assigned a label.

`scores` — Classification score
M-by-1 vector

Classification score, returned as an *M*-by-1 vector of classification scores in the range of [0,1]. Larger scores values indicate higher confidence in the classification.

`allScores` — All classification scores
M-by-*N* matrix

All classification scores, returned in an *M*-by-*N* matrix of *M* regions and *N* classes.

Examples

Train R-CNN Stop Sign Detector

Load training data and network layers.

```
load('rcnnStopSigns.mat', 'stopSigns', 'layers')
```

Add the image directory to the MATLAB path.

```
imDir = fullfile(matlabroot, 'toolbox', 'vision', 'visiondata',...
  'stopSignImages');
addpath(imDir);
```

Set network training options to use mini-batch size of 32 to reduce GPU memory usage. Lower the InitialLearningRate to reduce the rate at which network parameters are changed. This is beneficial when fine-tuning a pre-trained network and prevents the network from changing too rapidly.

```
options = trainingOptions('sgdm', ...
  'MiniBatchSize', 32, ...
```

```
        'InitialLearnRate', 1e-6, ...
        'MaxEpochs', 10);
```

Train the R-CNN detector. Training can take a few minutes to complete.

```
rcnn = trainRCNNObjectDetector(stopSigns, layers, options, 'NegativeOverlapRange', [0 0
```

```
**********************************************************************
Training an R-CNN Object Detector for the following object classes:

* stopSign

Step 1 of 3: Extracting region proposals from 27 training images...done.

Step 2 of 3: Training a neural network to classify objects in training data...
```

Epoch	Iteration	Time Elapsed (seconds)	Mini-batch Loss	Mini-batch Accuracy	Base Lear Rate
3	50	9.27	0.2895	96.88%	0.0000
5	100	14.77	0.2443	93.75%	0.0000
8	150	20.29	0.0013	100.00%	0.0000
10	200	25.94	0.1524	96.88%	0.0000

```
Network training complete.

Step 3 of 3: Training bounding box regression models for each object class...100.00%..

R-CNN training complete.
**********************************************************************
```

Test the R-CNN detector on a test image.

```
img = imread('stopSignTest.jpg');
```

```
[bbox, score, label] = detect(rcnn, img, 'MiniBatchSize', 32);
```

Display strongest detection result.

```
[score, idx] = max(score);
```

```
bbox = bbox(idx, :);
```

```
annotation = sprintf('%s: (Confidence = %f)', label(idx), score);

detectedImg = insertObjectAnnotation(img, 'rectangle', bbox, annotation);

figure
imshow(detectedImg)
```


Remove the image directory from the path.

```
rmpath(imDir);
```

Introduced in R2016b

bagOfFeatures class

Bag of visual words object

Syntax

```
bag = bagOfFeatures(imds)
bag = bagOfFeatures(imds,'CustomExtractor',extractorFcn)
bag = bagOfFeatures(imds,Name,Value)
```

Description

`bag = bagOfFeatures(imds)` returns a bag of features object. The `bag` output object is generated using samples from the `imds` input.

`bag = bagOfFeatures(imds,'CustomExtractor',extractorFcn)` returns a bag of features that uses a custom feature extractor function to extract features from the output bag to learn its visual vocabulary. `extractorFcn` is a function handle to a custom feature extraction function.

`bag = bagOfFeatures(imds,Name,Value)` returns a `bagOfFeatures` object with additional properties specified by one or more `Name,Value` pair arguments.

This object supports parallel computing using multiple MATLAB workers. Enable parallel computing from the "Computer Vision System Toolbox Preferences" dialog box. To open Computer Vision System Toolbox preferences, on the **Home** tab, in the **Environment** section, click **Preferences**. Then select **Computer Vision System Toolbox**.

Input Arguments

`imds` — Images
`ImageDatastore` object

Images, specified as an `ImageDatastore` object. The `bagOfFeatures` extracts an equal number of strongest features from the images contained in the `imds` object.

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number of strongest features = min(*number of features found in each set*) x
`StrongestFraction`

The object obtains the `StrongestFraction` value from the `'StrongestFeatures'`
property.

extractorFcn — Custom feature extractor function
function handle

Custom feature extractor function, specified the comma-separated pair consisting of
`'CustomExtractor'` and a function handle. This custom function extracts features from
the output `bagOfFeatures` object to learn the visual vocabulary of the object.

The function, `extractorFcn`, must be specified as a function handle for a file:

```
extractorFcn = @exampleBagOfFeaturesExtractor;
bag = bagOfFeatures(imds,'CustomExtractor',extractorFcn)
```

where `exampleBagOfFeaturesExtractor` is a MATLAB function. For example:

```
function [features,featureMetrics] = exampleBagOfFeaturesExtractor(img)
...
```

The function must be on the path or in the current working directory.

For more details on the custom extractor function and its input and output requirements,
see "Create a Custom Feature Extractor".

You can open an example function file, and use it as a template by typing the following
command at the MATLAB command-line:

```
edit('exampleBagOfFeaturesExtractor.m')
```

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the
argument name and `Value` is the corresponding value. `Name` must appear inside single
quotes (`'  '`). You can specify several name and value pair arguments in any order as
`Name1,Value1,...,NameN,ValueN`.

Example: `'VocabularySize',500` sets the size of the visual words to include in the bag
to `500`.

VocabularySize — Number of visual words
500 (default) | integer scalar

Number of visual words to include in the `bagOfFeatures` object, specified as the comma-separated pair consisting of `'VocabularySize'` and an integer scalar in the range [2, `inf`]. The `VocabularySize` value corresponds to *K* in the K-means clustering (Statistics and Machine Learning Toolbox) algorithm used to quantize features into the visual vocabulary.

StrongestFeatures — Fraction of strongest features
`0.8` (default) | `[0,1]`

Fraction of strongest features, specified as the comma-separated pair consisting of `'StrongestFeatures'` and a value in the range [0,1]. The value represents the fraction of strongest features to use from each label in the `imds` input.

Verbose — Enable progress display to screen
`true` (default) | false

Enable progress display to screen, specified as the comma-separated pair consisting of `'Verbose'` and the logical `true` or `false`.

PointSelection — Selection method for picking point locations
`'Grid'` (default) | `'Detector'`

Selection method for picking point locations for SURF feature extraction, specified as the comma-separated pair consisting of `'PointSelection'` and the character vector `'Grid'` or `'Detector'`. There are two stages for feature extraction. First, you select a method for picking the point locations, (SURF `'Detector'` or `'Grid'`), with the `PointSelection` property. The second stage extracts the features. The feature extraction uses a SURF extractor for both point selection methods.

When you set `PointSelection` to `'Detector'`, the feature points are selected using a speeded up robust feature (SURF) detector. Otherwise, the points are picked on a predefined grid with spacing defined by `'GridStep'`. This property applies only when you are not specifying a custom extractor with the `CustomExtractor` property.

GridStep — Grid step size
`[8 8]` (default) | 1-by-2 [*x y*] vector

Grid step size in pixels, specified as the comma-separated pair consisting of `'GridStep'` and an 1-by-2 [*x y*] vector. This property applies only when you set `PointSelection` to `'Grid'` and you are not specifying a custom extractor with the `CustomExtractor` property. The steps in the *x* and *y* directions define the spacing of a uniform grid. Intersections of the grid lines define locations for feature extraction.

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BlockWidth — Patch size to extract upright SURF descriptor
[32 64 96 128] (default) | 1-by-*N* vector

Patch size to extract upright SURF descriptor, specified as the comma-separated pair consisting of 'BlockWidth' and a 1-by-*N* vector of *N* block widths. This property applies only when you are not specifying a custom extractor with the CustomExtractor property. Each element of the vector corresponds to the size of a square block from which the function extracts upright SURF descriptors. Use multiple square sizes to extract multiscale features. All the square specified are used for each extraction points on the grid. This property only applies when you set PointSelection to 'Grid'. The block width corresponds to the scale of the feature. The minimum BlockWidth is 32 pixels.

Upright — Orientation of SURF feature vector
true (default) | logical scalar

Orientation of SURF feature vector, specified as the comma-separated pair consisting of 'Upright' and a logical scalar. This property applies only when you are not specifying a custom extractor with the CustomExtractor property. Set this property to true when you do not need to estimate the orientation of the SURF feature vectors. Set it to false when you need the image descriptors to capture rotation information.

Properties

CustomExtractor — Custom extraction function
function handle

Custom feature extractor function, specified as a handle to a function. The custom feature extractor function extracts features used to learn the visual vocabulary for

bagOfFeatures. You must specify `'CustomExtractor'` and the function handle, `extractorFcn`, to a custom feature extraction function.

The function, `extractorFcn`, must be specified as a function handle for a file:

```
extractorFcn = @exampleBagOfFeaturesExtractor;
bag = bagOfFeatures(imds,'CustomExtractor',extractorFcn)
```

where `exampleBagOfFeaturesExtractor` is a MATLAB function such as:

```
function [features,featureMetrics] = exampleBagOfFeaturesExtractor(img)
...
```

The function must be on the path or in the current working directory.

For more details on the custom extractor function and it's input and output requirements, see "Create a Custom Feature Extractor". You can open an example function file, and use it as a template by typing the following command at the MATLAB command-line:

```
edit('exampleBagOfFeaturesExtractor.m')
```

VocabularySize — Number of visual words
500 (default) | integer scalar

Number of visual words to include in the `bagOfFeatures` object, specified as the comma-separated pair consisting of `'VocabularySize'` and an integer scalar in the range [2, `inf`). The `VocabularySize` value corresponds to *K* in the "k-Means Clustering" (Statistics and Machine Learning Toolbox) algorithm used to quantize features into the visual vocabulary.

StrongestFeatures — Fraction of strongest features
0.8 (default) | [0,1]

Fraction of strongest features, specified as the comma-separated pair consisting of `'StrongestFeatures'` and a value in the range [0,1]. The value represents the strongest of strongest features to use from each labelcontained in `imds` input.

PointSelection — Point selection method
'Grid' (default) | 'Detector'

Selection method for picking point locations for SURF feature extraction, specified as the comma-separated pair consisting of `'PointSelection'` and the character vector `'Grid'` or `'Detector'`. There are two stages for feature extraction. First, you select a method

for picking the point locations, (SURF `'Detector'` or `'Grid'`), with the `PointSelection` property. The second stage extracts the features. The feature extraction uses a SURF extractor for both point selection methods.

When you set `PointSelection` to `'Detector'`, the feature points are selected using a speeded up robust feature (SURF) detector. Otherwise, the points are picked on a predefined grid with spacing defined by `'GridStep'`. This property applies only when you are not specifying a custom extractor with the `CustomExtractor` property.

`GridStep` — Grid step size
[8 8] (default) | 1-by-2 [*x y*] vector

Grid step size in pixels, specified as the comma-separated pair consisting of `'GridStep'` and an 1-by-2 [*x y*] vector. This property applies only when you set `PointSelection` to `'Grid'`. The steps in the *x* and *y* directions define the spacing of a uniform grid. Intersections of the grid lines define locations for feature extraction.

`BlockWidth` — Patch size to extract SURF descriptor
[32 64 96 128] (default) | 1-by-*N* vector

Patch size to extract SURF descriptor, specified as the comma-separated pair consisting of `'BlockWidth'` and a 1-by-*N* vector of *N* block widths. Each element of the vector corresponds to the size of a square block from which the function extracts SURF descriptors. Use multiple square sizes to extract multiscale features. All the square specified are used for each extraction points on the grid. This property only applies when you set `PointSelection` to `'Grid'`. The block width corresponds to the scale of the feature. The minimum `BlockWidth` is 32 pixels.

`Upright` — Orientation of SURF feature vector
`true` (default) | logical scalar

Orientation of SURF feature vector, specified as the comma-separated pair consisting of `'Upright'` and a logical scalar. This property applies only when you are not specifying a custom extractor with the `CustomExtractor` property. Set this property to `true` when you do not need to estimate the orientation of the SURF feature vectors. Set it to `false` when you need the image descriptors to capture rotation information.

Methods

encode   Create histogram of visual word occurrences

Examples

Create a Bag of Visual Words

Load two image sets.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imgSets = imageSet(setDir,'recursive');
```

Pick the first two images from each image set to create training sets.

```
trainingSets = partition(imgSets,2);
```

Create the bag of features. This process can take a few minutes.

```
bag = bagOfFeatures(trainingSets,'Verbose',false);
```

Compute histogram of visual word occurrences for one of the images. Store the histogram as feature vector.

```
img = read(imgSets(1),1);
featureVector = encode(bag,img);
```

Create a Bag of Features with a Custom Feature Extractor

Load an image set.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imds = imageDatastore(setDir,'IncludeSubfolders',true,'LabelSource',...
    'foldernames');
```

Specify a custom feature extractor.

```
extractor = @exampleBagOfFeaturesExtractor;
bag = bagOfFeatures(imds,'CustomExtractor',extractor)
```

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```
Creating Bag-Of-Features.
-------------------------
* Image category 1: books
* Image category 2: cups
* Extracting features using a custom feature extraction function: exampleBagOfFeaturesE

* Extracting features from 12 images...done. Extracted 230400 features.

* Keeping 80 percent of the strongest features from each category.

* Using K-Means clustering to create a 500 word visual vocabulary.
* Number of features       : 184320
* Number of clusters (K)    : 500

* Initializing cluster centers...100.00%.
* Clustering...completed 26/100 iterations (~0.56 seconds/iteration)...converged in 26

* Finished creating Bag-Of-Features

bag =
  bagOfFeatures with properties:

       CustomExtractor: @exampleBagOfFeaturesExtractor
        VocabularySize: 500
     StrongestFeatures: 0.8000
```

- "Image Category Classification Using Bag of Features"

References

Csurka, G., C. R. Dance, L. Fan, J. Willamowski, and C. Bray. *Visual Categorization with Bags of Keypoints*. Workshop on Statistical Learning in Computer Vision. 2004, ECCV 1 (1–22), 1–2.

See Also

imageCategoryClassifier | imageDatastore | trainImageCategoryClassifier

Topics
"Image Category Classification Using Bag of Features"

"Image Classification with Bag of Visual Words"
"Create a Custom Feature Extractor"

Introduced in R2014b

encode

Class: bagOfFeatures

Create histogram of visual word occurrences

Syntax

```
featureVector = encode(bag,I)
[featureVector,words] = encode(bag,I)

featureVector= encode(bag,imds)
[featureVector,words] = encode(bag,imds)

[ ___ ] = encode( ___ ,Name,Value)
```

Description

featureVector = encode(bag,I) returns a feature vector that represents a histogram of visual word occurrences contained in the input image, I. The input bag contains the bagOfFeatures object.

[featureVector,words] = encode(bag,I) optionally returns the visual words as a visualWords object. The visualWords object stores the visual words that occur in I and stores the locations of those words.

featureVector= encode(bag,imds) returns a feature vector that represents a histogram of visual word occurrences contained in imds. The input bag contains the bagOfFeatures object.

[featureVector,words] = encode(bag,imds) optionally returns an array of visualWords occurrences in imds. The visualWords object stores the visual words that occur in I and stores the locations of those words.

[___] = encode(___ ,Name,Value) returns a feature vector with optional input properties specified by one or more Name,Value pair arguments.

This method supports parallel computing using multiple MATLAB workers. Enable parallel computing from the "Computer Vision System Toolbox Preferences" dialog box. To open Computer Vision System Toolbox preferences, on the **Home** tab, in the **Environment** section, click **Preferences**. Then select **Computer Vision System Toolbox**.

Input Arguments

bag — Bag of features
bagOfFeatures object

Bag of features, specified as a bagOfFeatures object.

I — Input image
grayscale image | truecolor image

Input image, I, specified as a grayscale or truecolor image.

imds — Images
ImageDatastore object

Images, specified as an ImageDatastore object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Normalization — Type of normalization
'L2' (default) | 'none'

Type of normalization applied to the feature vector, specified as the comma-separated pair consisting of 'Normalization' and the character vector 'L2' or 'none'.

SparseOutput — Output sparsity
false (default) | true

Output sparsity, specified as the comma-separated pair consisting of 'SparseOutput' and as true or false. Set this property to true to return the visual word histograms in a sparse matrix. Setting this property to true reduces memory consumption for large visual vocabularies where the visual word histograms contain many zero elements.

Verbose — Enable progress display to screen
true (default) | false

Enable progress display to screen, specified as the comma-separated pair consisting of 'Verbose' and the logical true or false.

Output Arguments

featureVector — Histogram of visual word occurrences
1-by-bag.VocabularySize | *M*-by-bag.VocabularySize

Histogram of visual word occurrences, specified as *M*-by-bag.VocabularySize vector, where *M* is the total number of images in imds, numel(imds.Files).

words — Visual words object
visualWords object

Visual words object, returned as a visual words object or an array of visual words objects. The visualWords object stores the visual words that occur in the images and stores the locations of those words.

Examples

Encode an Image into a Feature Vector

Load a set of image.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imds = imageDatastore(setDir,'IncludeSubfolders',true,'LabelSource',...
    'foldernames');
```

Pick the first two images from each label.

```
trainingSet = splitEachLabel(imds,2);
```

Create bag of features.

```
bag = bagOfFeatures(trainingSet);
```

```
Creating Bag-Of-Features.
-------------------------
* Image category 1: books
* Image category 2: cups
* Selecting feature point locations using the Grid method.
* Extracting SURF features from the selected feature point locations.
** The GridStep is [8 8] and the BlockWidth is [32 64 96 128].

* Extracting features from 4 images...done. Extracted 76800 features.

* Keeping 80 percent of the strongest features from each category.

* Using K-Means clustering to create a 500 word visual vocabulary.
* Number of features        : 61440
* Number of clusters (K)     : 500

* Initializing cluster centers...100.00%.
* Clustering...completed 24/100 iterations (~0.39 seconds/iteration)...converged in 24

* Finished creating Bag-Of-Features
```

Encode one of the images into a feature vector.

```
img = readimage(trainingSet,1);
featureVector = encode(bag,img);
```

imageCategoryClassifier class

Predict image category

Syntax

```
imageCategoryClassifier
```

Description

`imageCategoryClassifier` is returned by the `trainImageCategoryClassifier` function. It contains a linear support vector machine (SVM) classifer trained to recognize an image category.

You must have a Statistics and Machine Learning Toolbox license to use this classifier.

This classifier supports parallel computing using multiple MATLAB workers. Enable parallel computing using the "Computer Vision System Toolbox Preferences" dialog. To open the Computer Vision System Toolbox preferences, on the **Home** tab, in the **Environment** section, click **Preferences**. Select **Computer Vision System Toolbox**.

Properties

Labels — Category labels
cell array

Category labels, specified as a cell array.

NumCategories — Number of trained categories
integer

Number of trained categories, stored as an integer value.

Methods

predict	Predict image category
evaluate	Evaluate image classifier on collection of image sets

Examples

Train, Evaluate, and Apply Image Category Classifier

Load two image categories.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imds = imageDatastore(setDir,'IncludeSubfolders',true,'LabelSource',...
    'foldernames');
```

Split the data set into a training and test data. Pick 30% of images from each set for the training data and the remainder 70% for the test data.

```
[trainingSet,testSet] = splitEachLabel(imds,0.3,'randomize');
```

Create bag of visual words.

```
bag = bagOfFeatures(trainingSet);
```

```
Creating Bag-Of-Features.
-----------------------
* Image category 1: books
* Image category 2: cups
* Selecting feature point locations using the Grid method.
* Extracting SURF features from the selected feature point locations.
** The GridStep is [8 8] and the BlockWidth is [32 64 96 128].

* Extracting features from 4 images...done. Extracted 76800 features.

* Keeping 80 percent of the strongest features from each category.

* Using K-Means clustering to create a 500 word visual vocabulary.
* Number of features        : 61440
* Number of clusters (K)     : 500
```

```
* Initializing cluster centers...100.00%.
* Clustering...completed 20/100 iterations (~0.24 seconds/iteration)...converged in 20
* Finished creating Bag-Of-Features
```

Train a classifier with the training sets.

```
categoryClassifier = trainImageCategoryClassifier(trainingSet,bag);
```

```
Training an image category classifier for 2 categories.
--------------------------------------------------------
* Category 1: books
* Category 2: cups

* Encoding features for 4 images...done.

* Finished training the category classifier. Use evaluate to test the classifier on a t
```

Evaluate the classifier using test images. Display the confusion matrix.

```
confMatrix = evaluate(categoryClassifier,testSet)
```

```
Evaluating image category classifier for 2 categories.
--------------------------------------------------------

* Category 1: books
* Category 2: cups

* Evaluating 8 images...done.

* Finished evaluating all the test sets.

* The confusion matrix for this test set is:


           PREDICTED
KNOWN    | books    cups
-------------------------
books    | 0.75     0.25
cups     | 0.25     0.75

* Average Accuracy is 0.75.

confMatrix = 2×2
```

```
0.7500    0.2500
0.2500    0.7500
```

Find the average accuracy of the classification.

```
mean(diag(confMatrix))
```

```
ans = 0.7500
```

Apply the newly trained classifier to categorize new images.

```
img = imread(fullfile(setDir,'cups','bigMug.jpg'));
[labelIdx, score] = predict(categoryClassifier,img);
```

Display the classification label.

```
categoryClassifier.Labels(labelIdx)
```

```
ans = 1x1 cell array
    {'cups'}
```

• "Image Category Classification Using Bag of Features"

References

Csurka, G., C. R. Dance, L. Fan, J. Willamowski, and C. Bray *Visual Categorization with Bag of Keypoints*, Workshop on Statistical Learning in Computer Vision, ECCV 1 (1-22), 1-2.

See Also

bagOfFeatures | fitcecoc | imageDatastore | trainImageCategoryClassifier

Topics

"Image Category Classification Using Bag of Features"
"Image Classification with Bag of Visual Words"

Introduced in R2014b

predict

Class: imageCategoryClassifier

Predict image category

Syntax

```
[labelIdx,score] = predict(categoryClassifier,I)
[labelIdx,score] = predict(categoryClassifier,imds)
[labelIdx,score] = predict( ___ ,Name,Value)
```

Description

`[labelIdx,score] = predict(categoryClassifier,I)` returns the predicted label index and score for the input image.

This supports parallel computing using multiple MATLAB workers. Enable parallel computing using the "Computer Vision System Toolbox Preferences" dialog. To open Computer Vision System Toolbox preferences, on the **Home** tab, in the **Environment** section, click **Preferences**. Select **Computer Vision System Toolbox**.

`[labelIdx,score] = predict(categoryClassifier,imds)` returns the predicted label index and score for the images specified in `imds`.

`[labelIdx,score] = predict( ___ ,Name,Value)` returns the predicted label index and score with optional input properties specified by one or more `Name,Value` pair arguments. You can use any of the input arguments from previous syntaxes.

Input Arguments

I — Input image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input image, specified as either an *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-D grayscale image.

categoryClassifier — Image category classifier
imageCategoryClassifier object

Image category classifier, specified as an imageCategoryClassifier object.

imds — Images
ImageDatastore object

Images, specified as an ImageDatastore object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'Verbose',true sets the value of 'Verbose' to the logical true.

Verbose — Enable progress display to screen
true (default) | false

Enable progress display to screen, specified as the comma-separated pair consisting of 'Verbose' and the logical true or false.

Output Arguments

labelIdx — Predicted label index
M-by-1 vector | scalar

Predicted label index, returned as either an *M*-by-1 vector for *M* images or a scalar value for a single image. The labelIdx output value corresponds to the index of an image set used to train the bag of features. The prediction index corresponds to the class with the lowest average binary loss of the ECOC SVM classifier.

score — Prediction score
1-by-*N* vector | *M*-by-*N* matrix

Prediction score, specified as a 1-by-*N* vector or an *M*-by-*N* matrix. *N* represents the number of classes. *M* represents the number of images in the imageSet input object,

imgSet. The score provides a negated average binary loss per class. Each class is a support vector machine (SVM) multiclass classifier that uses the error-correcting output codes (ECOC) approach.

Examples

Predict Category for Image

Load two image category sets.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imds = imageDatastore(setDir,'IncludeSubfolders',true,'LabelSource',...
    'foldernames');
```

Separate the two sets into training and test data. Pick 30% of images from each set for the training data and the remainder 70% for the test data.

```
[trainingSet,testSet] = splitEachLabel(imds,0.3,'randomize');
```

Create a bag of visual words.

```
bag = bagOfFeatures(trainingSet);
```

```
Creating Bag-Of-Features.
-----------------------
* Image category 1: books
* Image category 2: cups
* Selecting feature point locations using the Grid method.
* Extracting SURF features from the selected feature point locations.
** The GridStep is [8 8] and the BlockWidth is [32 64 96 128].

* Extracting features from 4 images...done. Extracted 76800 features.

* Keeping 80 percent of the strongest features from each category.

* Using K-Means clustering to create a 500 word visual vocabulary.
* Number of features       : 61440
* Number of clusters (K)     : 500

* Initializing cluster centers...100.00%.
* Clustering...completed 20/100 iterations (~0.29 seconds/iteration)...converged in 20
```

```
* Finished creating Bag-Of-Features
```

Train a classifier.

```
categoryClassifier = trainImageCategoryClassifier(trainingSet,bag);
```

```
Training an image category classifier for 2 categories.
--------------------------------------------------------
* Category 1: books
* Category 2: cups

* Encoding features for 4 images...done.

* Finished training the category classifier. Use evaluate to test the classifier on a t
```

Predict category label for one of the images in test set.

```
img = readimage(testSet,1);
[labelIdx, score] = predict(categoryClassifier,img);
categoryClassifier.Labels(labelIdx)
```

```
ans = 1x1 cell array
    {'books'}
```

evaluate

Class: imageCategoryClassifier

Evaluate image classifier on collection of image sets

Syntax

```
confMat = evaluate(classifier,imds)
[confMat,knownLabelIdx,predictedLabelIdx,score] = evaluate(
classifier,imds)
[ ___ ] = evaluate( ___ ,Name,Value)
```

Description

`confMat = evaluate(classifier,imds)` returns a normalized confusion matrix, `confMat`.

`[confMat,knownLabelIdx,predictedLabelIdx,score] = evaluate(classifier,imds)` additionally returns the corresponding label indexes and score.

`[ ___ ] = evaluate( ___ ,Name,Value)` uses additional input properties specified by one or more `Name,Value` pair arguments. You can use any of the arguments from previous syntaxes.

Input Arguments

imds — Images
ImageDatastore object

Images, specified as an `ImageDatastore` object.

classifier — Image category classifier
imageCategoryClassifier object

Image category classifier, specified as an `imageCategoryClassifier` object.

`imgSet` — Image set
`imageSet` object

Image set, specified as an `imageSet` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Verbose',true` sets the value of `'Verbose'` to the logical `true`.

`Verbose` — Enable progress display to screen
`true` (default) | false

Enable progress display to screen, specified as the comma-separated pair consisting of `'Verbose'` and the logical `true` or `false`.

Output Arguments

`confMat` — Confusion matrix
matrix

Confusion matrix, returned as a matrix. The row indices correspond to known labels and the columns correspond to the predicted labels.

`knownLabelIdx` — Label index for image set
M-by-1 vector | scalar

Label index for image set, returned as an *M*-by-1 vector for *M* images. The `knownLabelIdx` output value corresponds to the index of an image set used to train the bag of features.

`predictedLabelIdx` — Predicted label index
M-by-1 vector

Predicted label index, returned as an *M*-by-1 vector for *M* images. The `predictedLabelIdx` output value corresponds to the index of an image set used to train

the bag of features. The predicted index corresponds to the class with the largest value in the `score` output.

score — Prediction score
M-by-*N* matrix

Prediction score, specified as an *M*-by-*N* matrix. *N* represents the number of classes. *M* represents the number of images in the `imageSet` input object, `imgSet`. The score provides a negated average binary loss per class. Each class is a support vector machine (SVM) multiclass classifier that uses the error-correcting output codes (ECOC) approach.

Examples

Train, Evaluate, and Apply Image Category Classifier

Load two image categories.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imds = imageDatastore(setDir,'IncludeSubfolders',true,'LabelSource',...
    'foldernames');
```

Split the data set into a training and test data. Pick 30% of images from each set for the training data and the remainder 70% for the test data.

```
[trainingSet,testSet] = splitEachLabel(imds,0.3,'randomize');
```

Create bag of visual words.

```
bag = bagOfFeatures(trainingSet);
```

```
Creating Bag-Of-Features.
-------------------------
* Image category 1: books
* Image category 2: cups
* Selecting feature point locations using the Grid method.
* Extracting SURF features from the selected feature point locations.
** The GridStep is [8 8] and the BlockWidth is [32 64 96 128].

* Extracting features from 4 images...done. Extracted 76800 features.

* Keeping 80 percent of the strongest features from each category.
```

```
* Using K-Means clustering to create a 500 word visual vocabulary.
* Number of features          : 61440
* Number of clusters (K)      : 500

* Initializing cluster centers...100.00%.
* Clustering...completed 20/100 iterations (~0.24 seconds/iteration)...converged in 20

* Finished creating Bag-Of-Features
```

Train a classifier with the training sets.

```
categoryClassifier = trainImageCategoryClassifier(trainingSet,bag);
```

```
Training an image category classifier for 2 categories.
--------------------------------------------------------
* Category 1: books
* Category 2: cups

* Encoding features for 4 images...done.

* Finished training the category classifier. Use evaluate to test the classifier on a t
```

Evaluate the classifier using test images. Display the confusion matrix.

```
confMatrix = evaluate(categoryClassifier,testSet)
```

```
Evaluating image category classifier for 2 categories.
--------------------------------------------------------

* Category 1: books
* Category 2: cups

* Evaluating 8 images...done.

* Finished evaluating all the test sets.

* The confusion matrix for this test set is:


             PREDICTED
KNOWN    | books   cups
--------------------------
books    | 0.75    0.25
cups     | 0.25    0.75
```

```
* Average Accuracy is 0.75.
```

```
confMatrix = 2×2

    0.7500    0.2500
    0.2500    0.7500
```

Find the average accuracy of the classification.

```
mean(diag(confMatrix))
```

```
ans = 0.7500
```

Apply the newly trained classifier to categorize new images.

```
img = imread(fullfile(setDir,'cups','bigMug.jpg'));
[labelIdx, score] = predict(categoryClassifier,img);
```

Display the classification label.

```
categoryClassifier.Labels(labelIdx)
```

```
ans = 1x1 cell array
    {'cups'}
```

intrinsicsEstimationErrors class

Object for storing standard errors of estimated camera intrinsics and distortion coefficients

Syntax

intrinsicsEstimationErrors

Description

intrinsicsEstimationErrors contains the standard errors of estimated camera intrinsics and distortion coefficients. You can access the intrinsics and distortion standard errors using the object properties.

Properties

SkewError

Standard error of camera axes skew estimate

FocalLengthError

Standard error of focal length estimate

PrincipalPointError

Standard error of principal point estimate

RadialDistortionError

Standard error of radial distortion estimate

TangentialDistortionError

Standard error of tangential distortion estimate

See Also

Camera Calibrator | **Stereo Camera Calibrator** | cameraCalibrationErrors | extrinsicsEstimationErrors | intrinsicsEstimationErrors | stereoCalibrationErrors

Topics

"Single Camera Calibrator App"

Introduced in R2013b

extrinsicsEstimationErrors class

Object for storing standard errors of estimated camera extrinsics

Syntax

extrinsicsEstimationErrors

Description

extrinsicsEstimationErrors contains the standard errors of estimated camera extrinsics. You can access the extrinsics standard errors using the object properties.

Properties

RotationVectorsError

Standard error of camera rotations estimate

TranslationVectorsError

Standard error of camera translations estimate

See Also

Camera Calibrator | **Stereo Camera Calibrator** | cameraCalibrationErrors | intrinsicsEstimationErrors | stereoCalibrationErrors

Topics
"Single Camera Calibrator App"

Introduced in R2013b

BRISKPoints class

Object for storing BRISK interest points

Description

This object provides the ability to pass data between the `detectBRISKFeatures` and `extractFeatures` functions. You can also use it to manipulate and plot the data returned by these functions. You can use the object to fill the points interactively in situations where you might want to mix a non-BRISK interest point detector with a BRISK descriptor.

Tips

Although `BRISKPoints` can hold many points, it is a scalar object. Therefore, `NUMEL(BRISKPoints)` always returns 1. This value can differ from `LENGTH(BRISKPoints)`, which returns the true number of points held by the object.

Construction

`points = BRISKPoints(Location)` constructs a `BRISKPoints` object from an *M*-by-2 array of [x y] point coordinates, `Location`.

`points = BRISKPoints(Location,Name,Value)` constructs a `BRISKPoints` object with optional input properties specified by one or more `Name,Value` pair arguments. You can specify each additional property as a scalar or a vector whose length matches the number of coordinates in `Location`.

Input Arguments

Location

Point locations, specified as an *M*-by-2 array of [x y] point coordinates.

Properties

Count

Number of points held by the BRISK object, specified as a numeric value.

Default: 0

Location

Point locations, specified as an *M*-by-2 array of [x y] point coordinates.

Scale

Scale at which the feature is detected, specified as a value greater than or equal to 1.6.

Default: 12.0

Metric

Strength of detected feature, specified as a numeric value. The BRISK algorithm uses a determinant of an approximated Hessian.

Default: 0.0

Orientation

Orientation of the detected feature, specified as an angle, in radians. The angle is measured counterclockwise from the X-axis with the origin specified by the Location property. Do not set this property manually. Use the call to extractFeatures to fill in this value. The extractFeatures function modifies the default value of 0.0. Using BRISK interest points to extract a non-BRISK descriptor, (e.g. SURF, FREAK, MSER, etc.), can alter Orientation values. The Orientation is mainly useful for visualization purposes.

Default: 0.0

Methods

isempty	Returns true for empty object
length	Number of stored points
plot	Plot BRISK points
selectStrongest	Return points with strongest metrics
selectUniform	Return a uniformly distributed subset of feature points
size	Size of the BRISKPoints object

Examples

Detect BRISK Features in an Image

Read an image and detect the BRISK interest points.

```
I = imread('cameraman.tif');
points = detectBRISKFeatures(I);
```

Select and plot the 10 strongest interest points.

```
strongest = points.selectStrongest(10);
imshow(I); hold on;
plot(strongest);
```

Display the [x y] coordinates.

```
strongest.Location
```

ans = *10x2 single matrix*

```
   136.8434   114.7649
   143.7372   126.8453
   135.2803   123.5254
   134.8544   125.0714
   114.8065    47.3621
   105.1597   162.2291
   129.8372   108.4799
   114.6876   131.6573
   135.2267   127.3643
```

```
92.4255    63.2960
```

References

[1] Leutenegger, S., M. Chli, and R. Siegwart. *BRISK: Binary Robust Invariant Scalable Keypoints*, Proceedings of the IEEE International Conference on Computer Vision (ICCV) 2011.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- To index locations with this object, use the syntax: `points.Location(idx,:)`, for `points` object. See visionRecovertformCodeGeneration_kernel.m, which is used in the "Introduction to Code Generation with Feature Matching and Registration" example.

See Also
MSERRegions | SURFPoints | cornerPoints | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | matchFeatures

Introduced in R2014a

isempty

Class: BRISKPoints

Returns true for empty object

Syntax

```
isempty(BRISKPointsObj)
```

Description

`isempty(BRISKPointsObj)` returns a true value, if the `BRISKPointsObj` object is empty.

length

Class: BRISKPoints

Number of stored points

Syntax

```
length(BRISKPointsObj)
```

Description

length(BRISKPointsObj) returns the number of stored points in the BRISKPointsObj object.

plot

Class: BRISKPoints

Plot BRISK points

Syntax

```
briskPoints/plot
briskPoints/plot(AXES_HANDLE,...)
briskPoints/plot(AXES_HANDLE,Name,Value)
```

Description

`briskPoints/plot` plots BRISK points in the current axis.

`briskPoints/plot(AXES_HANDLE,...)` plot points using axes with the handle `AXES_HANDLE`.

`briskPoints/plot(AXES_HANDLE,Name,Value)` Additional control for the `plot` method requires specification of parameters and corresponding values. An additional option is specified by one or more `Name,Value` pair arguments.

Input Arguments

AXES_HANDLE

Handle for plot method to use for display. You can set the handle using `gca`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

showScale

Display proportional circle around feature. Set this value to `true` or `false`. When you set this value to `true`, the object draws a circle proportional to the scale of the detected feature, with the feature point located at its center. When you set this value to `false`, the object turns the display of the circle off.

The algorithm represents the scale of the feature with a circle of `6*Scale` radius. The BRISK algorithm uses this equivalent size of circular area to compute the orientation of the feature.

Default: `true`

showOrientation

Display a line corresponding to feature point orientation. Set this value to `true` or `false`. When you set this value to `true`, the object draws a line corresponding to the point's orientation. The object draws the line from the feature point location to the edge of the circle, indicating the scale.

Default: `false`

Examples

```
% Extract BRISK features
  I = imread('cameraman.tif');
  points = detectBRISKFeatures(I);

% Display
  imshow(I); hold on;
  plot(points);
```

selectStrongest

Class: BRISKPoints

Return points with strongest metrics

Syntax

```
strongestPoints = BRISKPoints.selectStrongest(N)
```

Description

`strongestPoints = BRISKPoints.selectStrongest(N)` returns N number of points with strongest metrics.

Examples

```
% Create object holding 50 points
  points = BRISKPoints(ones(50,2), 'Metric', 1:50);

% Keep 2 strongest features
  points = points.selectStrongest(2)
```

selectUniform

Class: BRISKPoints

Return a uniformly distributed subset of feature points

Syntax

```
pointsOut = selectUniform(pointsIn,N,imageSize)
```

Description

`pointsOut = selectUniform(pointsIn,N,imageSize)` returns N uniformly distributed points with the strongest metrics.

Input Arguments

pointsIn — BRISK points
BRISKPoints object

BRISK points, returned as a `BRISKPoints` object. This object contains information about BRISK features detected in a grayscale image. You can use the `detectBRISKFeatures` to obtain BRISK points.

N — Number of points
integer

Number of points, specified as an integer.

imageSize — Size of image
2-element vector | 3-element vector

Size of image, specified as a 2- or 3-element vector.

Examples

Select A Uniformly Distributed Subset of Features From an Image

Load an image.

```
im = imread('yellowstone_left.png');
```

Detect many corners by reducing the quality threshold.

```
points1 = detectBRISKFeatures(rgb2gray(im), 'MinQuality', 0.05);
```

Plot image with detected corners.

```
subplot(1,2,1);
imshow(im);
hold on
plot(points1);
hold off
title('Original points');
```

Original points

Select a uniformly distributed subset of points.

```
numPoints = 100;
points2 = selectUniform(points1,numPoints,size(im));
```

Plot images showing original and subset of points.

```
subplot(1, 2, 2);
imshow(im);
hold on
plot(points2);
hold off
title('Uniformly distributed points');
```

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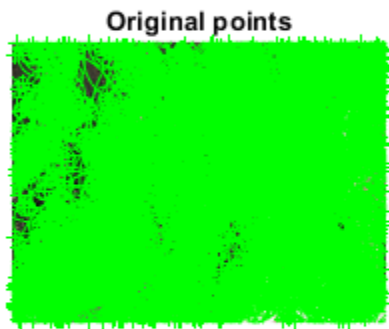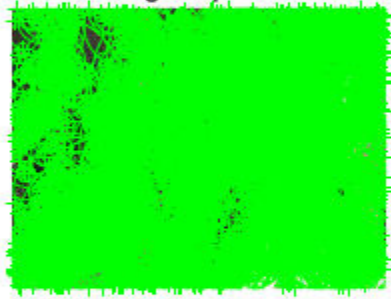
Original points   Uniformly distributed points

size

Class: BRISKPoints

Size of the BRISKPoints object

Syntax

```
size(BRISKPointsObj)
```

Description

`size(BRISKPointsObj)` returns the size of the `BRISKPointsObj` object.

- `sz = size(v)` returns the vector [`length(v)`, 1]
- `sz = size(v, 1)` returns the length of *v*
- `sz = size(v, N)`, for *N* >= 2, returns 1
- [*M*, *N*] = `size(v)` returns `length(v)` for *M* and 1 for *N*

imageSet class

Define collection of images

Syntax

```
imgSet = imageSet(imageLocation)
imgSetVector = imageSet(imgFolder,'recursive')
```

Construction

`imgSet = imageSet(imageLocation)` returns an object for storing an image data set or a collection of image data sets. You can use this object to manage your image data. The object contains image descriptions, locations of images, and the number of images in your collection.

`imgSetVector = imageSet(imgFolder,'recursive')` returns a vector of image sets found through a recursive search starting from `imgFolder`. The `imgSetVector` output is a 1-by-*NumFolders* vector, where *NumFolders* is the number of folders that contain at least one image.

Input Arguments

imageLocation — Image file location
character vector | cell array

Image file location, specified as a character vector or a cell array. The vector must specify the folder name that contains the images. The image files name extensions must be supported by `imread`. The cell array must contain image locations.

Example 2.1. Image file location

{'*imagePath1*','*imagePath2*', ..., '*imagePathX*'}, where each *imagePath* represents the path to an each image.

`imgFolder` — Start recursive image search folder
character vector

Start recursive image search folder, specified as a character vector. The function searches the folder structure recursively, starting from `imgFolder`.

Properties

`Description` — Information about the image set
character vector

Information about the image set, specified as a character vector. When you create an image set by recursively searching folders or by specifying a single folder location, the `Description` property is set to the folder name. When you specify individual image files, the `Description` property is not set. You can set the property manually.

Data Types: `char`

`Count` — Number of images in image set
integer

Number of images in image set.

Data Types: `double` | `single`

`ImageLocation` — Image locations
cell array of character vectors

Image locations, given as a cell array of character vectors.

Data Types: `cell`

Methods

partition	Divide image set into subsets
read	Read image at specified index
select	Select subset of images from image set

Common to All System Objects	
release	Allow System object property value changes

Examples

Create an Image Set From a Folder of Images

Read the folder of images.

```
imgFolder = fullfile(toolboxdir('vision'),'visiondata','stopSignImages');
imgSet = imageSet(imgFolder);
```

Display the first image in the image set collection.

```
imshow(read(imgSet,1));
```

Create an Array of Image Sets from Multiple Folders

Identify the path to the image sets.

```
imgFolder = fullfile(matlabroot, 'toolbox','vision',...
    'visiondata','imageSets');
```

Recursively scan the entire image set folder.

```
imgSets = imageSet(imgFolder,'recursive')

imgSets =
  1x2 imageSet array with properties:

    Description
    ImageLocation
    Count
```

Display the names of the scanned folders.

```
{imgSets.Description}
```

```
ans = 1x2 cell array
    {'books'}    {'cups'}
```

Display 2nd image from the 'cups' folder.

```
imshow(read(imgSets(2),2));
```

Create an Image Set by Specifying Individual Images

Specify individual images.

As an alternative to the method below, you can pick the files manually using imgetfile:
imgFiles = imgetfile('MultiSelect',true);

```
imgFiles = { fullfile(matlabroot,'toolbox','vision','visiondata','stopSignImages','imag
             fullfile(matlabroot,'toolbox','vision','visiondata','stopSignImages','imag
```

Create image set.

```
imgSet   = imageSet(imgFiles);
```

• "Image Category Classification Using Bag of Features"

See Also
```
bagOfFeatures | imageCategoryClassifier | imageSet | imgetfile |
trainImageCategoryClassifier
```

Topics
"Image Category Classification Using Bag of Features"

Introduced in R2014b

partition

Class: imageSet

Divide image set into subsets

Syntax

```
[set1,set2,...,setN] = partition(imgSet,groupSizes)
[set1,set2,...,setN] = partition(imgSet,groupPercentages)
[set1,set2,...,setN] = partition( ___ ,method)
```

Description

`[set1,set2,...,setN] = partition(imgSet,groupSizes)` partitions the input image set, `imgSet`, into the collection of subsets specified in `groupSizes`.

`[set1,set2,...,setN] = partition(imgSet,groupPercentages)` returns the partitioned image sets in terms of percentages.

`[set1,set2,...,setN] = partition( ___ ,method)` additionally specifies a method, `'sequential'` or `'randomized'`.

Input Arguments

`imgSet` — Image set
array of `imageSet` objects

Image set, specified as an array of `imageSet` objects.

`groupSizes` — Group size
scalar

Group size of images, specified as a scalar. The number of output arguments must be between 1 and `length(groupSizes) + 1`.

Example 2.2. Example

If you set `groupSizes` to [20 60], the method returns 20 images in `set1`, 60 images in `set2`, and the remainder of images in `set3`.

`groupPercentages` — Group size percentage
scalar

Group size of images by percentage.

Example 2.3. Example

If you set `groupPercentages` to [0.1 0.5], the method returns 10% of images in `set1`, 50% in `set2`, and the remainder in `set3`.

`method` — Image selection method
'sequential' (default) | 'randomized'

Image selection method, specified as either `method` or `'randomized'`. When you set `method` to `'randomized'` the images are randomly selected to form the new sets. When you set `method` to `'sequential'` the images are selected sequentially.

Examples

Partition Image Set

Create an image set.

```
imgFolder = fullfile(matlabroot,'toolbox','vision','visiondata','stopSignImages');
imgSet  = imageSet(imgFolder);
```

Divide the set into two groups: one with five images and the other with the remainder of the images from imgSet.

```
[setA1, setA2] = partition(imgSet,5);
```

Randomly partition the set into three groups: one with 20% of the images, the second group with 30%, and the third group with 50%.

```
[setB1, setB2, setB3] = partition(imgSet, [0.2, 0.3],'randomized');
```

read

Class: imageSet

Read image at specified index

Syntax

```
image = read(imgSet,idx)
```

Description

`image = read(imgSet,idx)` returns an image from the `imgSet` image set, located at the index `idx`.

Input Arguments

`imgSet` — Image set
array of `imageSet` objects

Image set, specified as an array of `imageSet` objects.

`idx` — Image location index
scalar

Image location index, specified as a scalar value.

Examples

Display Image from an Image Set

Create an image set.

```
imgFolder = fullfile(matlabroot,'toolbox','vision','visiondata','stopSignImages');
imgSet  = imageSet(imgFolder);
```

Display the fourth image from the set.

```
imshow(read(imgSet, 4));
```

select

Class: imageSet

Select subset of images from image set

Syntax

```
imgSetOut = select(imgSet,idx)
```

Description

imgSetOut = select(imgSet,idx) returns a new image set, imgSetOut, using the selection of images specified by the index idx.

Input Arguments

imgSet — Image set
array of imageSet objects

Image set, specified as an array of imageSet objects.

idx — Image location index
scalar | vector of linear indices | vector of logical indices

Image location index, specified as a scalar, vector of linear indices, or a vector of logical indices. The function uses the idx index to select the subset of images.

Examples

Select Images Specified by an Index

Read images from a folder.

```
imgFolder = fullfile(matlabroot,'toolbox','vision','visiondata','stopSignImages');
imgSet  = imageSet(imgFolder);
```

Select images 2 and 4 from the image set.

```
imgSetOut = select(imgSet, [2, 4]);
```

Select every other image from the image set.

```
imgSetOut2 = select(imgSet, 1:2:imgSet.Count);
```

invertedImageIndex class

Search index that maps visual words to images

Syntax

```
imageIndex = invertedImageIndex(bag)
imageIndex = invertedImageIndex(bag,'SaveFeatureLocations',tf)
imageIndex = invertedImageIndex( ___ ,Name,Value)
```

Construction

`imageIndex = invertedImageIndex(bag)` returns a search index object that you can use with the `retrieveImages` function to search for an image. The object stores the visual word-to-image mapping based on the input `bag`, a `bagOfFeatures` object.

`imageIndex = invertedImageIndex(bag,'SaveFeatureLocations',tf)` optionally specifies whether or not to save the feature location data in `imageIndex`.

`imageIndex = invertedImageIndex( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

Input Arguments

bag — Bag of visual words
`bagOfFeatures` object

Bag of visual words, specified as a `bagOfFeatures` object.

SaveFeatureLocations — Save feature locations
`true` (default) | `false`

Save feature locations, specified as a logical scalar. When you set this property to `true`, the image feature locations are saved in the `imageIndex` output object. Use location data

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to verify the spatial or geometric image search results. If you do not require feature locations, set this property to `false` to reduce memory consumption.

Properties

`ImageLocation` — Indexed image locations
cell array

Indexed image locations, stored as a cell array.

`ImageWords` — Visual words
1-by-*M* vector of `visualWords` objects

Visual words, stored as a 1-by-*M* vector of `visualWords` objects for each indexed image. The `visualWords` object contains the `WordIndex`, `Location`, `VocabularySize`, and `Count` properties for each indexed image.

`WordFrequency` — Word occurrence
M-by-1 vector

Word occurrence, specified as an *M*-by-1 vector. The vector contains the percentage of images in which each visual word occurs. These percentages are analogous to document frequency in text retrieval applications. The `WordFrequency` property contains the percentage of images in which each visual word occurs. It is often helpful to suppress the most common words to reduce the search set when looking for the most relevant images. Also helpful, is to suppress rare words as they probably come from outliers in the image set.

You can control how much the top and bottom end of the visual word distribution affects the search results by tuning the `WordFrequencyRange` property. A good way to set this value is to plot the sorted `WordFrequency` values.

`BagOfFeatures` — Bag of visual words
`bagOfFeatures` object

Bag of visual words, specified as the `bagOfFeatures` object used in the index.

`MatchThreshold` — Percentage of similar words required between query and potential image match
`0.01` (default) | numeric value in the range [0 1]

Percentage of similar words required between a query and a potential image match, specified as a numeric value in the range [0, 1]. To obtain more search results, lower this threshold.

WordFrequencyRange — Word frequency range
`[0.01 0.9]` (default) | two-element vector

Word frequency range, specified as a two-element vector of a lower and upper percentage, [*lower upper*]. Use the word frequency range to ignore common words (the upper percentage range) or rare words (the lower percentage range) within the image index. These words often occur as repeated patterns or outliers and can reduce search accuracy. You can control how much the top and bottom end of the visual word distribution affects the search results by tuning the `WordFrequencyRange` property. A good way to set this value is to plot the sorted `WordFrequency` values.

Methods

addImages	Add new images to image index
removeImages	Remove images from image index

Examples

Search ROI for Object

Define a set of images to search.

```
imageFiles = ...
  {'elephant.jpg', 'cameraman.tif', ...
   'peppers.png',  'saturn.png',...
   'pears.png',    'stapleRemover.jpg', ...
   'football.jpg', 'mandi.tif',...
   'kids.tif',     'liftingbody.png', ...
   'office_5.jpg', 'gantrycrane.png',...
   'moon.tif',     'circuit.tif', ...
   'tape.png',     'coins.png'};

imgSet = imageSet(imageFiles);
```

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Learn the visual vocabulary.

```
bag = bagOfFeatures(imgSet,'PointSelection','Detector',...
  'VocabularySize',1000);

Creating Bag-Of-Features.
-------------------------
* Image category 1: <undefined>
* Selecting feature point locations using the Detector method.
* Extracting SURF features from the selected feature point locations.
** detectSURFFeatures is used to detect key points for feature extraction.

* Extracting features from 16 images in image set 1...done. Extracted 3680 features.

* Keeping 80 percent of the strongest features from each category.

* Balancing the number of features across all image categories to improve clustering.
** Image category 1 has the least number of strongest features: 2944.
** Using the strongest 2944 features from each of the other image categories.

* Using K-Means clustering to create a 1000 word visual vocabulary.
* Number of features        : 2944
* Number of clusters (K)     : 1000

* Initializing cluster centers...100.00%.
* Clustering...completed 24/100 iterations (~0.11 seconds/iteration)...converged in 24

* Finished creating Bag-Of-Features
```

Create an image search index and add images.

```
imageIndex = invertedImageIndex(bag);
```

```
addImages(imageIndex, imgSet);

Encoding images using Bag-Of-Features.
--------------------------------------
* Image category 1: <undefined>
* Encoding 16 images from image set 1...done.

* Finished encoding images.
```

Specify a query image and an ROI to search for the target object, elephant.

```
queryImage = imread('clutteredDesk.jpg');
queryROI = [130 175 330 365];
```

```
figure
imshow(queryImage)
rectangle('Position',queryROI,'EdgeColor','yellow')
```
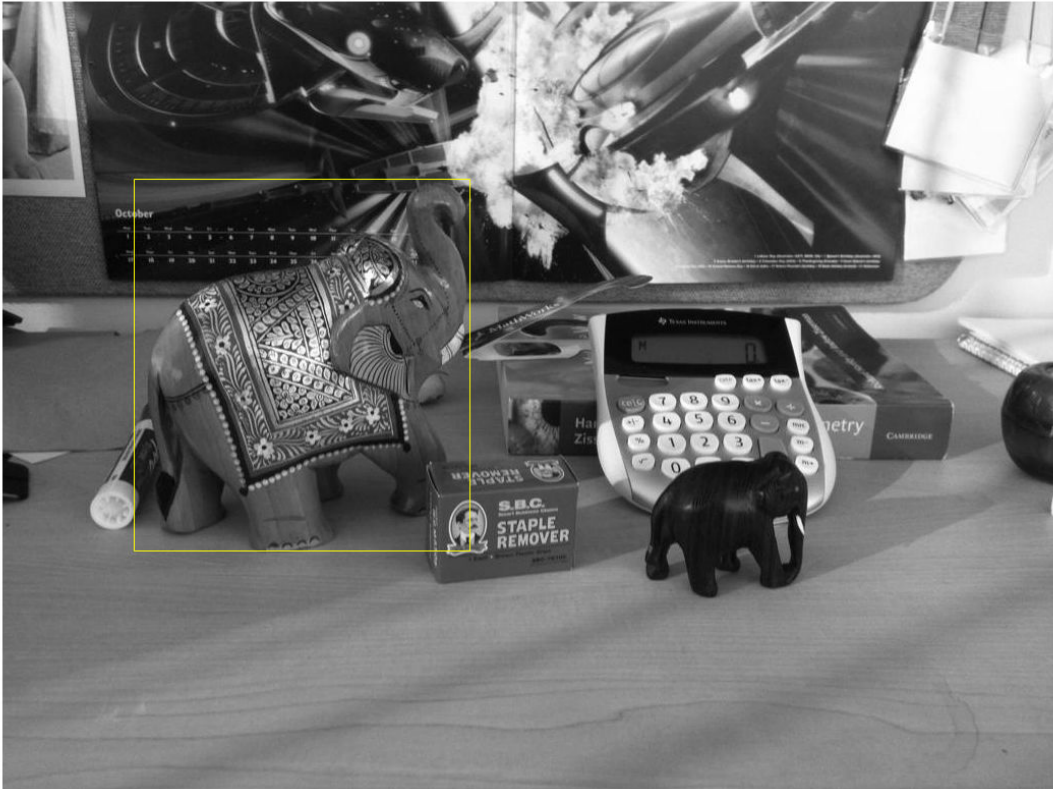

You can also use the `imrect` function to select an ROI interactively. For example, `queryROI = getPosition(imrect)`.

Find images that contain the object.

```
imageIDs = retrieveImages(queryImage,imageIndex,'ROI',queryROI)
```

```
imageIDs = 15×1

     1
    11
     2
     6
     8
    12
     3
    14
    13
    16
     ⋮


bestMatch = imageIDs(1);

figure
imshow(imageIndex.ImageLocation{bestMatch})
```

- "Image Retrieval Using Customized Bag of Features"

References

Sivic, J. and A. Zisserman. *Video Google: A text retrieval approach to object matching in videos*. ICCV (2003) pg 1470-1477.

Philbin, J., O. Chum, M. Isard, J. Sivic, and A. Zisserman. *Object retrieval with large vocabularies and fast spatial matching.* CVPR (2007).

See Also

bagOfFeatures | evaluateImageRetrieval | imageSet | indexImages | retrieveImages

Topics

"Image Retrieval Using Customized Bag of Features"
"Image Retrieval with Bag of Visual Words"

Introduced in R2015a

addImages

Class: invertedImageIndex

Add new images to image index

Syntax

```
addImages(imageIndex,imds)
addImages(imageIndex,imds,Name,Value)
```

Description

addImages(imageIndex,imds) adds the images in imds into the imageIndex object.

addImages(imageIndex,imds,Name,Value) uses additional options specified by one or more Name,Value pair arguments, using any of the preceding syntaxes.

This object supports parallel computing using multiple MATLAB workers. Enable parallel computing from the "Computer Vision System Toolbox Preferences" dialog box. To open Computer Vision System Toolbox preferences, on the **Home** tab, in the **Environment** section, click **Preferences**. Then select **Computer Vision System Toolbox**.

Input Arguments

imageIndex — Image search index
invertedImageIndex object

Image search index, specified as an invertedImageIndex object.

imds — Images
ImageDatastore object

Images, specified as an ImageDatastore object. imds contains new images to add to an existing index. Duplicate images are not ignored.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Verbose',true` sets the `'Verbose'` property set to `true`

Verbose — Display progress information
`true` (default) | `false`

Display progress information, specified as a logical scalar. Set `Verbose` to `true` to display progress information.

Examples

Add Image to Image Index

Define a set of images to search

```
imageFiles = ...
  {'elephant.jpg', 'cameraman.tif', ...
   'peppers.png',  'saturn.png',...
   'pears.png',    'stapleRemover.jpg', ...
   'football.jpg', 'mandi.tif',...
   'kids.tif',     'liftingbody.png', ...
   'office_5.jpg', 'gantrycrane.png',...
   'moon.tif',     'circuit.tif', ...
   'tape.png',     'coins.png'};

imds = imageDatastore(imageFiles);
```

Learn the visual vocabulary.

```
bag = bagOfFeatures(imds,'PointSelection','Detector',...
        'VocabularySize',1000,'Verbose',false);
```

Create an image search index.

```
imageIndex = invertedImageIndex(bag);
```

Add images.

```
addImages(imageIndex,imds);
```

```
Encoding images using Bag-Of-Features.
-------------------------------------

* Encoding 16 images...done.
```

removeImages

Class: invertedImageIndex

Remove images from image index

Syntax

removeImages(imageIndex,indices)

Description

removeImages(imageIndex,indices) removes the images from the imageIndex
object that correspond to the indices input.

Input Arguments

imageIndex — Image search index
invertedImageIndex object

Image search index, specified as an invertedImageIndex object.

indices — Image indices
vector

Image indices, specified as a row or column vector. The indices correspond to the images
within imageIndex.Location.

Examples

Remove Indexed Image

Create image set.

```
dataDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets','cups');
imds = imageDatastore(dataDir);
```

Index the image set.

```
imageIndex = indexImages(imds)
```

```
Creating an inverted image index using Bag-Of-Features.
--------------------------------------------------------

Creating Bag-Of-Features.
-------------------------

* Selecting feature point locations using the Detector method.
* Extracting SURF features from the selected feature point locations.
** detectSURFFeatures is used to detect key points for feature extraction.

* Extracting features from 6 images...done. Extracted 1708 features.

* Keeping 80 percent of the strongest features from each category.

* Balancing the number of features across all image categories to improve clustering.
** Image category 1 has the least number of strongest features: 1366.
** Using the strongest 1366 features from each of the other image categories.

* Using K-Means clustering to create a 20000 word visual vocabulary.
* Number of features       : 1366
* Number of clusters (K)    : 1366

* Initializing cluster centers...100.00%.
* Clustering...completed 1/100 iterations (~0.05 seconds/iteration)...converged in 1 it

* Finished creating Bag-Of-Features


Encoding images using Bag-Of-Features.
--------------------------------------

* Encoding 6 images...done.
Finished creating the image index.

imageIndex =
  invertedImageIndex with properties:

        ImageLocation: {6x1 cell}
```

```
        ImageWords: [6x1 vision.internal.visualWords]
     WordFrequency: [1x1366 double]
      BagOfFeatures: [1x1 bagOfFeatures]
    MatchThreshold: 0.0100
WordFrequencyRange: [0.0100 0.9000]
```

`imageIndex.ImageLocation`

```
ans = 6x1 cell array
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\bigMug.jpg'     }
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\blueCup.jpg'    }
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\handMade.jpg'   }
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\holdingCup.jpg'}
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\plaid.jpg'      }
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\plainWhite.jpg'}
```

Remove first and third image.

```
removeImages(imageIndex,[1 3]);
imageIndex.ImageLocation
```

```
ans = 4x1 cell array
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\blueCup.jpg'    }
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\holdingCup.jpg'}
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\plaid.jpg'      }
    {'B:\matlab\toolbox\vision\visiondata\imageSets\cups\plainWhite.jpg'}
```

cameraCalibrationErrors

Object for storing standard errors of estimated camera parameters

Description

`cameraCalibrationErrors` contains the standard errors of estimated camera parameters. The `estimateCameraParameters` function returns the `cameraCalibrationErrors` object. You can access the intrinsics and extrinsics standard errors using the object properties. You can display the standard errors using the object's `displayErrors` method.

Properties

`IntrinsicsErrors` — Stardard intrinsics error
intrinsicsEstimationErrors object

Standard error of the estimated intrinsics for a camera, specified as a `intrinsicsEstimationErrors` object.

`ExtrinsicsErrors` — Stardard extrinsics error
extrinsicsEstimationErrors object

Standard error of the estimate rotations and translations for a camera relative to the calibration pattern, specified as a `extrinsicsEstimationErrors` object.

Object Functions

displayErrors   Display standard errors of camera parameter estimates

Examples

Estimate and Display Camera Calibration Standard Errors

Create a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
 'calibration','mono'));
```

Detect the calibration pattern.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate the world coordinates of the corners of the squares. The units of the square are in millimeters.

```
squareSize = 29;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the camera.

```
I = readimage(images,1);
imageSize = [size(I,1),size(I,2)];
[params,~,errors] = estimateCameraParameters(imagePoints,worldPoints, ...
                            'ImageSize',imageSize);
```

Display the standard errors.

```
displayErrors(errors,params);

          Standard Errors of Estimated Camera Parameters
          -----------------------------------------------

Intrinsics
----------
Focal length (pixels):   [  714.1886 +/- 3.3219       710.3785 +/- 4.0579   ]
Principal point (pixels):[  563.6481 +/- 5.3967       355.7252 +/- 3.3036   ]
Radial distortion:       [   -0.3536 +/- 0.0091         0.1730 +/- 0.0488   ]

Extrinsics
----------
Rotation vectors:
                         [   -0.6096 +/- 0.0054        -0.1789 +/- 0.0073        -0.3835
                         [   -0.7283 +/- 0.0050        -0.0996 +/- 0.0072         0.1964
                         [   -0.6722 +/- 0.0051        -0.1444 +/- 0.0074        -0.1329
                         [   -0.5836 +/- 0.0056        -0.2901 +/- 0.0074        -0.5622
                         [   -0.3157 +/- 0.0065        -0.1441 +/- 0.0075        -0.1067
                         [   -0.7581 +/- 0.0052         0.1947 +/- 0.0072         0.4324
                         [   -0.7515 +/- 0.0051         0.0767 +/- 0.0072         0.2070
                         [   -0.6223 +/- 0.0053         0.0231 +/- 0.0073         0.3663
                         [    0.3443 +/- 0.0063        -0.2226 +/- 0.0073        -0.0437
```

```
Translation vectors (mm):
                        [ -146.0517 +/- 6.0391      -26.8685 +/- 3.7318       797.9026
                        [ -209.4358 +/- 6.9637      -59.4565 +/- 4.3578       921.8198
                        [ -129.3825 +/- 7.0907      -44.1030 +/- 4.3751       937.6831
                        [ -151.0049 +/- 6.6905      -27.3253 +/- 4.1339       884.2788
                        [ -174.9500 +/- 6.7056      -24.3499 +/- 4.1606       886.4961
                        [ -134.3097 +/- 7.8887     -103.4981 +/- 4.8925      1042.4553
                        [ -173.9846 +/- 7.6891      -73.1691 +/- 4.7812      1017.2385
                        [ -202.9448 +/- 7.4327      -87.9091 +/- 4.6482       983.6957
                        [ -319.8862 +/- 6.3213     -119.8898 +/- 4.0922       829.4581
```

- "Evaluating the Accuracy of Single Camera Calibration"

See Also

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Classes
cameraParameters | extrinsicsEstimationErrors |
intrinsicsEstimationErrors | stereoCalibrationErrors | stereoParameters

Functions
detectCheckerboardPoints | estimateCameraParameters |
generateCheckerboardPoints | showExtrinsics | showReprojectionErrors |
undistortImage | undistortPoints

Topics
"Evaluating the Accuracy of Single Camera Calibration"
"Single Camera Calibrator App"

Introduced in R2014b

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stereoCalibrationErrors class

Object for storing standard errors of estimated stereo parameters

Syntax

```
stereoCalibrationErrors
```

Description

`stereoCalibrationErrors` contains the standard errors of estimated stereo parameters. The `estimateCameraParameters` function returns the `stereoCalibrationErrors` object. You can access the standard errors for stereo calibration using the object's properties. You can display the standard errors using the object `displayErrors` method.

Properties

Camera1IntrinsicsErrors

Standard errors of camera 1 estimated intrinsics and distortion coefficients, specified as an `intrinsicsEstimationErrors` object.

Camera1ExtrinsicsErrors

Standard errors of camera 1 estimated extrinsics parameters, specified as an `extrinsicsEstimationErrors` object.

Camera2IntrinsicsErrors

Standard errors of camera 2 estimated intrinsics and distortion coefficients, specified as an `intrinsicsEstimationErrors` object.

RotationOfCamera2Error

Standard errors of rotated vector of camera 2 relative to camera 1, specified as a 3-element vector.

TranslationOfCamera2Error

Standard errors of translation of camera 2 relative to camera 1, specified as a 3-element vector.

Methods

displayErrors   Display standard errors of camera parameter estimation

Examples

Estimate and Display Stereo Calibration Standard Errors

Specify calibration images.

```
imageDir = fullfile(toolboxdir('vision'), 'visiondata', ...
  'calibration','stereo');
leftImages = imageDatastore(fullfile(imageDir,'left'));
rightImages = imageDatastore(fullfile(imageDir,'right'));
```

Detect the checkerboards.

```
[imagePoints, boardSize] = detectCheckerboardPoints(...
  leftImages.Files,rightImages.Files);
```

Specify world coordinates of checkerboard keypoints. Square size is in millimeters.

```
squareSize = 108;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the stereo camera system. Here both cameras have the same resolution.

```
I = readimage(leftImages,1);
imageSize = [size(I, 1), size(I, 2)];
```

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```
[params, ~, errors] = estimateCameraParameters(imagePoints,worldPoints, ...
                              'ImageSize',imageSize);
```

Display standard errors.

```
displayErrors(errors,params);
```

```
            Standard Errors of Estimated Stereo Camera Parameters
            ----------------------------------------------------

Camera 1 Intrinsics
-------------------
Focal length (pixels):   [ 1038.0286 +/- 0.6533    1037.9145 +/- 0.6389  ]
Principal point (pixels):[  656.0841 +/- 0.3408     485.5485 +/- 0.2639  ]
Radial distortion:       [   -0.3617 +/- 0.0008       0.1866 +/- 0.0026  ]

Camera 1 Extrinsics
-------------------
Rotation vectors:
                         [     0.1680 +/- 0.0007     -0.0271 +/- 0.0006       3.1125
                         [     0.1995 +/- 0.0006     -0.0523 +/- 0.0005      -3.0991
                         [     0.4187 +/- 0.0005     -0.1061 +/- 0.0004      -3.1113
                         [     0.5239 +/- 0.0005     -0.0604 +/- 0.0004      -3.0552
                         [     0.6807 +/- 0.0006     -0.0306 +/- 0.0005      -3.0331
                         [     0.3513 +/- 0.0007     -0.0993 +/- 0.0006      -3.0334
                         [     0.0212 +/- 0.0007     -0.1179 +/- 0.0007      -3.0833
                         [    -0.2765 +/- 0.0008     -0.0847 +/- 0.0007      -3.0943
                         [    -0.4407 +/- 0.0007     -0.1119 +/- 0.0006      -3.0652
                         [    -0.2537 +/- 0.0008     -0.1334 +/- 0.0007      -3.1039

Translation vectors (mm):
                         [   708.4192 +/- 0.4914    227.0500 +/- 0.4002    1492.8672
                         [   368.4408 +/- 0.5228    191.7200 +/- 0.4094    1589.9146
                         [   226.3710 +/- 0.5173    191.1429 +/- 0.4030    1578.4779
                         [    49.5377 +/- 0.5183    196.7495 +/- 0.4030    1580.5404
                         [  -172.4001 +/- 0.7003    150.9910 +/- 0.5406    2119.3253
                         [    10.7777 +/- 0.6784    176.8785 +/- 0.5276    2066.8343
                         [   295.4840 +/- 0.6616    167.8675 +/- 0.5158    2010.7713
                         [   614.2338 +/- 0.6457    166.2016 +/- 0.5153    1968.1798
                         [   767.0156 +/- 0.6106    165.5372 +/- 0.4991    1868.3334
                         [   953.8133 +/- 0.7336    -14.7981 +/- 0.6039    2255.6170

Camera 2 Intrinsics
-------------------
Focal length (pixels):   [ 1042.4817 +/- 0.6644    1042.2692 +/- 0.6534  ]
```

```
Principal point (pixels):[  640.5972 +/- 0.3305      479.0652 +/- 0.2633  ]
Radial distortion:       [   -0.3614 +/- 0.0007       0.1822 +/- 0.0022  ]

Position And Orientation of Camera 2 Relative to Camera 1
---------------------------------------------------------
Rotation of camera 2:         [   -0.0037 +/- 0.0002      0.0050 +/- 0.0004      -0
Translation of camera 2 (mm): [ -119.8720 +/- 0.0401     -0.4005 +/- 0.0414      -0
```

See Also

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Classes
cameraCalibrationErrors | cameraParameters | extrinsicsEstimationErrors
| intrinsicsEstimationErrors | stereoParameters

Functions
detectCheckerboardPoints | estimateCameraParameters |
generateCheckerboardPoints | showExtrinsics | showReprojectionErrors |
undistortImage | undistortPoints

Topics
"Single Camera Calibrator App"
"Stereo Camera Calibrator App"

Introduced in R2014b

displayErrors

Class: stereoCalibrationErrors

Display standard errors of camera parameter estimation

Syntax

```
displayErrors(estimationErrors,stereoParams)
```

Description

`displayErrors(estimationErrors,stereoParams)` displays stereo parameters and corresponding standard errors to the screen. The `estimationErrors` input must be a `stereoCalibrationErrors` object. The `stereoParams` input must be a `stereoParameters` object.

MSERRegions class

Object for storing MSER regions

Description

This object describes MSER regions and corresponding ellipses that have the same second moments as the regions. It passes data between the `detectMSERFeatures` and `extractFeatures` functions. The object can also be used to manipulate and plot the data returned by these functions.

Tips

Although `MSERRegions` may hold many regions, it is a scalar object. Therefore, `NUMEL(MSERRegions)` always returns 1. This value may differ from `LENGTH(MSERRegions)`, which returns the true number of regions held by the object.

Construction

`regions = MSERRegions(pixellist)` constructs an MSER regions object, `regions`, from an *M*-by-1 cell array of regions, `pixellist`. Each cell contains a *P*-by-2 array of [x y] coordinates for the detected MSER regions, where *P* varies based on the number of pixels in a region.

Input Arguments

`pixellist` — Cell array of point coordinates for detected MSER regions

Cell array of *M*-by-1 regions. Each region contains a *P*-by-2 array of [*x y*] coordinates of the detected MSER regions.

Properties

The following properties are read-only and are calculated once the input pixel list is specified.

Count

Number of stored regions

Default: `0`

Location

An *M*-by-2 array of [x y] centroid coordinates of ellipses that have the same second moments as the MSER regions.

Axes

A two-element vector, [majorAxis minorAxis]. This vector specifies the major and minor axis of the ellipse that have the same second moments as the MSER regions.

Orientation

A value in the range from -pi/2 to +pi/2 radians. This value represents the orientation of the ellipse as measured from the *X*-axis to the major axis of the ellipse. You can use this property for visualization purposes.

Methods

isempty	Returns true for empty object
length	Number of stored points
plot	Plot MSER regions
size	Size of the MSERRegions object

Examples

Detect MSER Features in an Image

Load an image.

```
I = imread('cameraman.tif');
```

Detect and store regions.

```
regions = detectMSERFeatures(I);
```

Display the centroids and axes of detected regions.

```
imshow(I); hold on;
plot(regions);
```

Display MSER Feature Regions from the MSERRegions Object

Detect and display the first 10 regions contained in the MSERRegions object.

Detect MSER features.

```
I = imread('cameraman.tif');
regions = detectMSERFeatures(I);
```

Display the first 10 regions in the MSERRegions object.

```
imshow(I); hold on;
plot(regions(1:10),'showPixelList', true);
```


Combine MSER Region Detector with SURF Descriptors

Extract and display SURF descriptors at locations identified by MSER detector.

Read image.

```
I = imread('cameraman.tif');
```

Detect MSER features.

```
regionsObj = detectMSERFeatures(I);
```

Extract and display SURF descriptors.

```
[features, validPtsObj] = extractFeatures(I, regionsObj);
imshow(I); hold on;
plot(validPtsObj,'showOrientation',true);
```


- "Find MSER Regions in an Image" on page 3-189
- "Detect SURF Interest Points in a Grayscale Image" on page 3-207
- "Automatically Detect and Recognize Text in Natural Images"

References

[1] Nister, D., and H. Stewenius, "Linear Time Maximally Stable Extremal Regions", *Lecture Notes in Computer Science*. 10th European Conference on Computer Vision, Marseille, France: 2008, no. 5303, pp. 183–196.

[2] Matas, J., O. Chum, M. Urba, and T. Pajdla. "Robust wide baseline stereo from maximally stable extremal regions. "*Proceedings of British Machine Vision Conference*, pages 384-396, 2002.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- For code generation, you must specify both the `pixellist` cell array and the `length` of each array, as the second input. The object outputs, `regions.PixelList` as an array. The region sizes are defined in `regions.Lengths`.

See Also
SURFPoints | detectMSERFeatures | detectSURFFeatures | edge | extractFeatures | matchFeatures

Topics
"Find MSER Regions in an Image" on page 3-189
"Detect SURF Interest Points in a Grayscale Image" on page 3-207
"Automatically Detect and Recognize Text in Natural Images"

Introduced in R2012a

isempty

Class: MSERRegions

Returns true for empty object

Syntax

```
isempty(MSERRegionsObj)
```

Description

isempty(MSERRegionsObj) returns a true value, if the MSERRegionsObj object is empty.

length

Class: MSERRegions

Number of stored points

Syntax

```
length(MSERRegionsObj)
```

Description

`length(MSERRegionsObj)` returns the number of stored points in the `MSERRegionsObj` object.

plot

Class: MSERRegions

Plot MSER regions

Syntax

```
MSERRegions.plot
MSERRegions.plot(AXES_HANDLE,...)
MSERRegions.plot(AXES_HANDLE,Name,Value)
```

Description

MSERRegions.plot plots MSER points in the current axis.

MSERRegions.plot(AXES_HANDLE,...) plots using axes with the handle AXES_HANDLE.

MSERRegions.plot(AXES_HANDLE,Name,Value) Additional control for the plot method requires specification of parameters and corresponding values. An additional option is specified by one or more Name,Value pair arguments.

Input Arguments

AXES_HANDLE

Handle for plot method to use for display. You can set the handle using gca.

Name-Value Pair Arguments

showEllipses

Display ellipses around feature. Set this value to true or false. When you set this value to true, the object draws an ellipse with the same 2nd order moments as the region.

When you set this value to `false`, only the ellipses centers are plotted.

Default: `true`

showOrientation

Display a line corresponding to the region's orientation. Set this value to `true` or `false`. When you set this value to `true`, the object draws a line corresponding to the region's orientation. The object draws the line from the ellipse's centroid to the edge of the ellipse, which indicates the region's major axis.

Default: `false`

showPixelList

Display the MSER regions. Set this value to `true` or `false`. When you set this value to `true`, the object plots the MSER regions using the JET colormap.

Examples

Plot MSER Regions

Extract MSER features and plot the regions.

Read image and extract MSER features.

```
I = imread('cameraman.tif');
regions = detectMSERFeatures(I);
imshow(I); hold on;
plot(regions);
```

Plot MSER Regions.

```
figure; imshow(I); hold on;
plot(regions,'showPixelList',true,'showEllipses',false);
hold off;
```

size

Class: MSERRegions

Size of the MSERRegions object

Syntax

`size(MSERRegionsObj)`

Description

`size(MSERRegionsObj)` returns the size of the `MSERRegionsObj` object.

cornerPoints class

Object for storing corner points

Description

This object stores information about feature points detected from a 2-D grayscale image.

Tips

Although `cornerPoints` may hold many points, it is a scalar object. Therefore, `NUMEL(cornerPoints)` always returns `1`. This value may differ from `LENGTH(cornerPoints)`, which returns the true number of points held by the object.

Construction

`points = cornerPoints(Location)` constructs a `cornerPoints` object from an *M*-by-2 array of [x y] point coordinates, `Location`.

`points = cornerPoints(Location,Name,Value)` constructs a `cornerPoints` object with optional input properties specified by one or more `Name,Value` pair arguments. Each additional property can be specified as a scalar or a vector whose length matches the number of coordinates in `Location`.

Input Arguments

Location

M-by-2 array of [x y] point coordinates.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single

quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Count

Number of points held by the object.

Default: `0`

Metric

Value describing strength of detected feature.

Default: `0.0`

Methods

isempty	Returns true for empty object
length	Number of stored points
plot	Plot corner points
selectStrongest	Return points with strongest metrics
selectUniform	Return a uniformly distributed subset of feature points
size	Size of the cornerPoints object
gather	Retrieve cornerPoints from the GPU

Examples

Plot Strongest Features from Detected Feature Points

Read image.

```
I = imread('cameraman.tif');
```

Detect feature points.

```
points = detectHarrisFeatures(I);
```

Display the 10 strongest points.

```
strongest = points.selectStrongest(10);
imshow(I); hold on;
plot(strongest);
```


Display the (x,y) coordinates.

```
strongest.Location
```

ans = *10x2 single matrix*

```
112.4516   208.4412
108.6510   228.1681
136.6969   114.7962
181.4160   205.9876
135.5823   123.4529
100.4951   174.3253
146.7581    94.7393
135.2899    92.6485
```

```
129.8439   110.0350
130.5716    91.0424
```

Create a Corner Points Object and Display Points

Create a checkerboard image.

```
I = checkerboard(50,2,2);
```

Load the locations.

```
location = [51    51    51   100   100   100   151   151   151;...
            50   100   150    50   101   150    50   100   150]';
```

Save points.

```
points = cornerPoints(location);
```

Display points on checkerboard.

```
imshow(I); hold on;
plot(points);
```
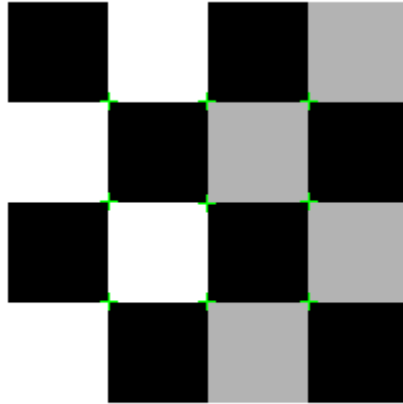
Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- To index locations with this object, use the syntax: `points.Location(idx,:)`, for `points` object. See visionRecovertformCodeGeneration_kernel.m, which is used in the "Introduction to Code Generation with Feature Matching and Registration" example.

See Also

BRISKPoints | MSERRegions | SURFPoints | binaryFeatures | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures |

detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures |
extractFeatures | extractHOGFeatures | matchFeatures

isempty

Class: cornerPoints

Returns true for empty object

Syntax

```
isempty(cornerPointsObj)
```

Description

`isempty(cornerPointsObj)` returns a true value, if the corner points object is empty.

length

Class: cornerPoints

Number of stored points

Syntax

`length(cornerPointsObj)`

Description

`length(cornerPointsObj)` returns the number of stored points in the corner points object.

plot

Class: cornerPoints

Plot corner points

Syntax

```
cornerPoints.plot
cornerPoints.plot(axesHandle, ___ )
```

Description

cornerPoints.plot plots corner points in the current axis.

cornerPoints.plot(axesHandle, ___) plots using axes with the handle
axesHandle instead of the current axes (gca).

Input Arguments

axesHandle

Handle for plot method to use for display. You can set the handle using gca.

Examples

Plot Corner Features

Read an image.

```
 I = imread('cameraman.tif');
```

Detect corner features.

```
featurePoints = detectHarrisFeatures(I);
```

Plot feature image with detected features.

```
imshow(I); hold on;
plot(featurePoints);
```

selectStrongest

Class: cornerPoints

Return points with strongest metrics

Syntax

```
cornerPoints = cornerPoints.selectStrongest(N)
```

Description

`cornerPoints = cornerPoints.selectStrongest(N)` returns `N` number of points with strongest metrics.

Examples

Select Strongest Features

Create object holding 50 points.

```
points = cornerPoints(ones(50,2), 'Metric', 1:50);
```

Keep 2 strongest features.

```
points = points.selectStrongest(2)

points =
  2x1 cornerPoints array with properties:

    Location: [2x2 single]
      Metric: [2x1 single]
       Count: 2
```

selectUniform

Class: cornerPoints

Return a uniformly distributed subset of feature points

Syntax

```
pointsOut = selectUniform(pointsIn,N,imageSize)
```

Description

`pointsOut = selectUniform(pointsIn,N,imageSize)` returns N uniformly distributed points with the strongest metrics.

Input Arguments

pointsIn — Corner points
cornerPoints object

SURF points, returned as a `cornerPoints` object. This object contains information about corner features detected in a grayscale image. You can use one of the detection functions to obtain the corner points.

N — Number of points
integer

Number of points, specified as an integer.

imageSize — Size of image
2-element vector | 3-element vector

Size of image, specified as a 2- or 3-element vector.

Examples

Select A Uniformly Distributed Subset of Features From an Image

Load an image.

```
im = imread('yellowstone_left.png');
```

Detect many corners by reducing the quality threshold.

```
points1 = detectHarrisFeatures(rgb2gray(im), 'MinQuality', 0.05);
```

Plot image with detected corners.

```
subplot(1,2,1);
imshow(im);
hold on
plot(points1);
hold off
title('Original points');
```

Original points

Select a uniformly distributed subset of points.

```
numPoints = 100;
points2 = selectUniform(points1,numPoints,size(im));
```

Plot images showing original and subset of points.

```
subplot(1, 2, 2);
imshow(im);
hold on
plot(points2);
hold off
title('Uniformly distributed points');
```
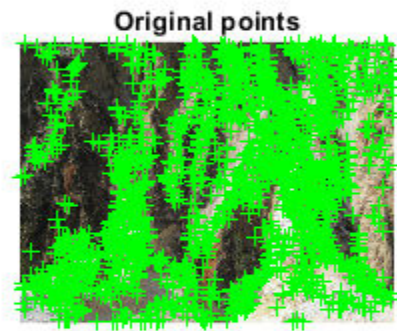
Original points
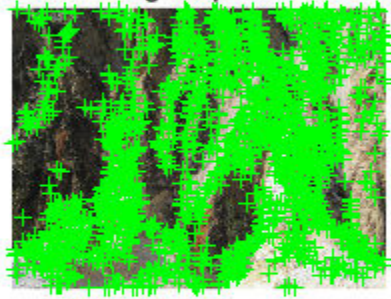
Uniformly distributed points
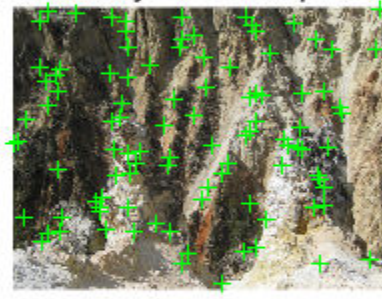
size

Class: cornerPoints

Size of the cornerPoints object

Syntax

`size(cornerPointsObj)`

Description

`size(cornerPointsObj)` returns the size of the corner points object.

gather

Class: cornerPoints

Retrieve cornerPoints from the GPU

Syntax

```
pointsCPU = gather(pointsGPU)
```

Description

`pointsCPU = gather(pointsGPU)` returns a `cornerPoints` object with data gathered from the GPU for the `Location` and `Metric` properties.

Examples

This example uses requires the Parallel Computing Toolbox.

Fine and plot corner points in an image.

```
I = gpuArray(imread('cameraman.tif'));
pointsGPU = detectHarrisFeatures(I);
imshow(I);
hold on;
plot(pointsGPU.selectStrongest(50));
```

Copy the corner points to the CPU for further processing.

```
pointsCPU = gather(pointsGPU);
```

SURFPoints class

Object for storing SURF interest points

Description

This object provides the ability to pass data between the `detectSURFFeatures` and `extractFeatures` functions. It can also be used to manipulate and plot the data returned by these functions. You can use the object to fill the points interactively. You can use this approach in situations where you might want to mix a non-SURF interest point detector with a SURF descriptor.

Tips

Although `SURFPoints` may hold many points, it is a scalar object. Therefore, `NUMEL(surfPoints)` always returns 1. This value may differ from `LENGTH(surfPoints)`, which returns the true number of points held by the object.

Construction

`points = SURFPoints(Location)` constructs a `SURFPoints` object from an *M*-by-2 array of [x y] point coordinates, `Location`.

`points = SURFPoints(Location,Name,Value)` constructs a `SURFPoints` object with optional input properties specified by one or more `Name,Value` pair arguments. Each additional property can be specified as a scalar or a vector whose length matches the number of coordinates in `Location`.

Input Arguments

`Location` — Point coordinates
M-by-2 array of [x y] point coordinates.

Point coordinates, specified as an *M*-by-2 array. The `Location` input contains *M* number of [x y] points.

Properties

`Count`

Number of points held by the object.

Default: `0`

`Location`

Array of [x y] point coordinates

`Scale`

Specifies scale at which the interest points were detected. This value must be greater than or equal to `1.6`.

Default: `1.6`

`Metric`

Value describing strength of detected feature. The SURF algorithm uses a determinant of an approximated Hessian.

Default: `0.0`

`SignOfLaplacian`

Sign of the Laplacian determined during the detection process. This value must be an integer, `-1`, `0`, or `1`. You can use this parameter to accelerate the feature matching process.

Blobs with identical metric values but different signs of Laplacian can differ by their intensity values. For example, a white blob on a blackground versus a black blob on a white background. You can use this parameter to quickly eliminate blobs that do not match.

For non-SURF detectors, this property is not relevant. For example, for corner features, you can simply use the default value of `0`.

Default: 0

`Orientation`

Orientation of the detected feature, specified as an angle, in radians. The angle is measured counter-clockwise from the X-axis with the origin specified by the `Location` property. Do not set this property manually. Rely instead, on the call to `extractFeatures` to fill in this value. The `extractFeatures` function modifies the default value of `0.0`.The `Orientation` is mainly useful for visualization purposes.

Default: `0.0`

Methods

isempty	Returns true for empty object
length	Number of stored points
plot	Plot SURF points
selectStrongest	Return points with strongest metrics
selectUniform	Return a uniformly distributed subset of feature points
size	Size of the SURFPoints object

Examples

Detect SURF Features

Read in image.

```
I = imread('cameraman.tif');
```

Detect SURF features.

```
points = detectSURFFeatures(I);
```

Display location and scale for the 10 strongest points.

```
strongest = points.selectStrongest(10);
imshow(I); hold on;
plot(strongest);
```


Display [x y] coordinates for the 10 strongest points on command line.

```
strongest.Location
```

ans = *10x2 single matrix*

```
139.7482    95.9542
107.4502   232.0347
116.6112   138.2446
105.5152   172.1816
113.6975    48.7220
104.4210    75.7348
111.3914   154.4597
106.2879   175.2709
```

```
131.1298    98.3900
124.2933    64.4942
```

Detect SURF Features and Display the Last 5 Points

Read in image.

```
I = imread('cameraman.tif');
```

Detect SURF feature.

```
points = detectSURFFeatures(I);
```

Display the last 5 points.

```
imshow(I); hold on;
plot(points(end-4:end));
```

- "Detect SURF Interest Points in a Grayscale Image" on page 3-207
- "Display MSER Feature Regions from the MSERRegions Object" on page 2-237
- "Find MSER Regions in an Image" on page 3-189
- "Detect MSER Features in an Image" on page 2-236

References

[1] Bay, H., A. Ess, T. Tuytelaars, and L. Van Gool. "SURF:Speeded Up Robust Features." *Computer Vision and Image Understanding (CVIU)*.Vol. 110, No. 3, pp. 346–359, 2008.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- To index locations with this object, use the syntax: `points.Location(idx,:)`, for `points` object. See visionRecovertformCodeGeneration_kernel.m, which is used in the "Introduction to Code Generation with Feature Matching and Registration" example.

See Also
BRISKPoints | MSERRegions | cornerPoints | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | matchFeatures

Topics
"Detect SURF Interest Points in a Grayscale Image" on page 3-207
"Display MSER Feature Regions from the MSERRegions Object" on page 2-237
"Find MSER Regions in an Image" on page 3-189
"Detect MSER Features in an Image" on page 2-236

Introduced in R2011b

isempty

Class: SURFPoints

Returns true for empty object

Syntax

```
isempty(SURFPointsObj)
```

Description

`isempty(SURFPointsObj)` returns a true value, if the `SURFPointsObj` object is empty.

length

Class: SURFPoints

Number of stored points

Syntax

```
length(SURFPointsObj)
```

Description

`length(SURFPointsObj)` returns the number of stored points in the `SURFPointsObj` object.

plot

Class: SURFPoints

Plot SURF points

Syntax

```
plot(axesHandle)
plot(axesHandle,Name,Value)
```

Description

`plot(axesHandle)` plots using axes with the handle `axesHandle`.

`plot(axesHandle,Name,Value)` additional control for the `plot` method specified by one or more `Name,Value` pair arguments.

Input Arguments

axesHandle

Handle for plot method to use for display. You can set the handle using `gca`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

ShowScale — Display proportional circle around feature
`true` (default) | `false`

Display proportional circle around feature, specified as a comma-separated pair consisting of `'ShowScale'` and the logical `true` or `false`. When you set this value to

`true`, the object draws a circle proportional to the scale of the detected feature. The circle contains the feature point located at its center. When you set this value to `false`, the object turns the display of the circle off.

The algorithm represents the scale of the feature with a circle of `6*Scale` radius. The SURF algorithm uses this equivalent size of circular area to compute the orientation of the feature.

`ShowOrientation` — Display a line corresponding to feature point orientation
`false` (default) | `true`

Display a line corresponding to feature point orientation, specified as a comma-separated pair consisting of '`ShowOrientation`' and the logical `true` or `false`. When you set this value to `true`, the object draws a line corresponding to the point's orientation. The object draws the line from the feature point location to the edge of the circle, indicating the scale.

Examples

Plot SURF features

Extract SURF features from an image.

```
I = imread('cameraman.tif');
points = detectSURFFeatures(I);
[features, valid_points] = extractFeatures(I,points);
```

Visualize 10 strongest SURF features, including their scales and orientation which were determined during the descriptor extraction process.

```
imshow(I);
hold on;
strongestPoints = valid_points.selectStrongest(10);
strongestPoints.plot('showOrientation',true);
```
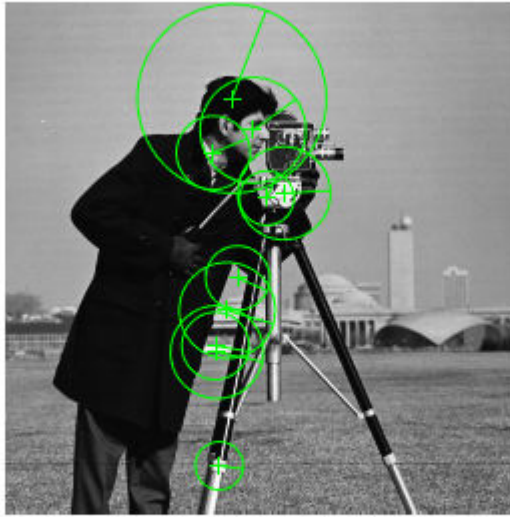
- "Image Retrieval Using Customized Bag of Features"
- "Object Detection in a Cluttered Scene Using Point Feature Matching"
- "Image Category Classification Using Bag of Features"

See Also

SURFPoints | detectSURFFeatures | extractFeatures

Topics

"Image Retrieval Using Customized Bag of Features"
"Object Detection in a Cluttered Scene Using Point Feature Matching"
"Image Category Classification Using Bag of Features"

selectStrongest

Class: SURFPoints

Return points with strongest metrics

Syntax

```
strongest = selectStrongest(points,N)
```

Description

`strongest = selectStrongest(points,N)` returns N number of points with strongest metrics.

Examples

Select Strongest Surf Features

Create object holding 50 points.

```
points = SURFPoints(ones(50,2),'Metric',1:50);
```

Keep the two strongest features.

```
points = selectStrongest(points,2)

points =
  2x1 SURFPoints array with properties:

             Scale: [2x1 single]
    SignOfLaplacian: [2x1 int8]
       Orientation: [2x1 single]
          Location: [2x2 single]
            Metric: [2x1 single]
             Count: 2
```

selectUniform

Class: SURFPoints

Return a uniformly distributed subset of feature points

Syntax

```
pointsOut = selectUniform(pointsIn,N,imageSize)
```

Description

`pointsOut = selectUniform(pointsIn,N,imageSize)` returns N uniformly distributed points with the strongest metrics.

Input Arguments

pointsIn — SURF points
surfPoints object

SURF points, returned as a `SURFPoints` object. This object contains information about SURF features detected in a grayscale image. You can use the `detectSURFFeatures` to obtain SURF points.

N — Number of points
integer

Number of points, specified as an integer.

imageSize — Size of image
2-element vector | 3-element vector

Size of image, specified as a 2- or 3-element vector.

Examples

Select A Uniformly Distributed Subset of Features From an Image

Load an image.

```
im = imread('yellowstone_left.png');
```

Detect and display SURF features.

```
points1 = detectSURFFeatures(rgb2gray(im));
subplot(1,2,1);
imshow(im);
hold on
plot(points1);
hold off
title('Original points');
```

Original points

Select a uniformly distributed subset of points.

```
numPoints = 100;
points2 = selectUniform(points1,numPoints,size(im));
```

Plot images showing original and subset of points.

```
subplot(1, 2, 2);
imshow(im);
hold on
plot(points2);
hold off
title('Uniformly distributed points');
```

Original points

Uniformly distributed points

size

Class: SURFPoints

Size of the SURFPoints object

Syntax

```
size(SURFPointsObj)
```

Description

`size(SURFPointsObj)` returns the size of the `SURFPointsObj` object.

vision.AlphaBlender System object

Package: vision

Combine images, overlay images, or highlight selected pixels

Description

The `AlphaBlender` System object combines two images, overlays one image over another, or highlights selected pixels.

To combine two images, overlay one image over another, or highlight selected pixels:

1   Create the vision.AlphaBlender object and set its properties.
2   Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
alphablend = vision.AlphaBlender
alphablend = vision.AlphaBlender(Name,Value)
```

Description

`alphablend = vision.AlphaBlender` creates an alpha blender System object, `alphablend`, to combines two images, overlays one image over another, or highlights selected pixels.

`alphablend = vision.AlphaBlender(Name,Value)` creates an alpha blender object, `alphablend`, with additional options specified by one or more `Name,Value` pair arguments.

Name is a property name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name-value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: alphablend = vision.AlphaBlender('Operation','Blend')

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the release function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

Operation — Operation
'Blend' | 'Binary mask' | 'Highlight selected pixels'

Operation, specified as 'Blend', 'Binary mask', or 'Highlight selected pixels'.

Operation	Description
'Blend'	Linearly combine the pixels of one image with the another image.
'Binary mask'	Overwrite the pixel values of one image with the pixel values of another image.
'Highlight selected pixels'	Uses the mask binary image input to determine which pixels are set to the maximum value supported by their data type.

OpacitySource — Source of opacity factor
Property (default) | 'Blend'

Source of opacity factor, specified as 'Property' or 'Input port'. This property applies when you set the Operation property to Blend.

Opacity — Pixel scale value
0.75 (default) | scalar | matrix

Pixel scale value, specified as a scalar or matrix. The object scales each pixel before combining the images. This property applies when you set the `OpacitySource` property to `Property`.

Tunable: Yes

MaskSource — Binary mask source
'Property' (default) | 'Input port'

Binary mask source, specified as `'Property'` or `'Input port'`. This property applies when you set the `Operation` property to `Binary mask`

Mask — Overwrite scalar
1 (default) | 0 | binary scalar | matrix of binary scalars

Overwrite scalar, specified as 0 or 1 for every pixel, or a matrix of 0s and 1s. This property applies when you set the `MaskSource` property to `Property`.

Tunable: Yes

LocationSource — Source for upper-left location
'Property' (default) | 'Input port'

Source of location of the upper-left corner of second input image

Source for the upper-left corner location of the second input image, specified as `Property` or `Input port`.

Location — Location
[1 1] | two-element vector

Location of the upper-left corner of the second input image relative to the location of the first input image, specified as a two-element vector in the format [x y]. This property applies when you set the `LocationSource` property to `Property`.

See "Coordinate Systems" for a discussion on pixel coordinates and spatial coordinates, which are the two main coordinate systems used in the Computer Vision System Toolbox.

Tunable: Yes

Fixed-Point Properties

RoundingMethod — Rounding method
'Floor' (default) | 'Convergent' | 'Floor' | ...

Rounding method, specified as 'Ceiling','Convergent', 'Floor', 'Nearest', 'Round', 'Simplest', 'Zero', or 'Floor'

OverflowAction — Overflow action
'Wrap' (default) | 'Saturate'

Overflow action for fixed-point operations, specified as 'Wrap' or 'Saturate'.

OpacityDataType — Opacity word and fraction lengths
'Same word length as input' (default) | 'Custom'

Opacity word and fraction lengths for fixed-point operations, specified as 'Same word length as input' or 'Custom'.

CustomOpacityDataType — Opacity word and fraction lengths
numerictype([],16) (default) | unscaled numerictype object

Opacity word and fraction lengths factor for fixed-point operations, specified as an unscaled numerictype object with a Signedness of Auto. This property applies when you set the OpacityDataType property to Custom

ProductDataType — Product word and fraction lengths
'Custom' (default) | 'Same as first input'

Product word and fraction lengths, specified as 'Custom' or 'Same as first input'.

CustomProductDataType — Product word and fraction lengths
numerictype([],32,10) (default) | scaled numerictype object

Product word and fraction lengths, specified as a scaled numerictype object with a 'Signedness' of 'Auto'. This property applies when you set the 'ProductDataType' property to 'Custom'

AccumulatorDataType — Accumulator word and fraction lengths
'Same as product' (default) | 'Custom'

Accumulator word and fraction lengths, specified as 'Same as product', 'Same as first input', or 'Custom'.

CustomAccumulatorDataType — Accumulator word and fraction lengths
numerictype([],32,10) (default) | scaled numerictype object

Accumulator word and fraction lengths, specified as a scaled numerictype object with a 'Signedness' of 'Auto'.

OutputDataType — Output word and fraction lengths
'Same as product' (default) | 'Custom'

Output word and fraction lengths, specified as 'Same as first input' or 'Custom'.

CustomOutputDataType — Output word and fraction lengths
numerictype([],32,10) (default) | scaled numerictype object

Output word and fraction lengths, specified as a scaled numerictype object with a 'Signedness' of 'Auto'.

Usage

Syntax

```
ab = alphablend(I1,I2)
ab = alphablend(I1,I2,opacity)
ab = alphablend(I1,I2,mask)
ab = alphablend(I1,mask)
ab = alphablend(I1,I2, ___ ,location)
```

Description

ab = alphablend(I1,I2) returns a alpha blender object that blends images I1 and I2.

ab = alphablend(I1,I2,opacity) uses the opacity input to combine pixel values of I1 and I2. To use the opacity input, you must set the Operation property to 'Blend' and the OpacitySource property to 'Input port'

ab = alphablend(I1,I2,mask) uses the mask input to overlay I1 over I2. To use the mask input with an overlay, you must set the Operation property to 'Binary mask' and the MaskSource property to 'Input port'.

`ab = alphablend(I1,mask)` uses the `mask` input to determine which pixels in `I1` are set to the maximum value supported by their data type. To use the `mask` input with an overlay, you must set the `Operation` property to `'Highlight selected pixels'` and the `MaskSource` property to `'Input port'`.

`ab = alphablend(I1,I2, ___ ,location)` additionally sets the upper-left corner `location` for `I2`. To use the `location` input, you must set the `LocationSource` property to `'Input port'`.

Input Arguments

`I1` — Input image
M-by-*N*-by-3 truecolor | *M*-by-*N* 2-D grayscale image

Input image, specified in truecolor or 2-D grayscale.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16`

`I2` — Input image
M-by-*N*-by-3 truecolor | *M*-by-*N* 2-D grayscale image

Input image, specified in truecolor or 2-D grayscale.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16`

`opacity` — Scale
scalar | matrix

Pixel scale value, specified as a scalar or matrix. The object scales each pixel before combining the images.

`mask` — Overwrite scalar
binary scalar | matrix of binary scalars

Overwrite scalar, specified as `0` or `1` for every pixel, or a matrix of `0`s and `1`s.

`location` — Location
two-element vector

Location of the upper-left corner of the second input image relative to the location of the first input image, specified as a two-element vector in the format [x y].

Tunable: Yes

Output Arguments

alphablend — Blended output image
M-by-*N*-by-3 truecolor | *M*-by-*N* 2-D grayscale image

Output blended image, returned as a combined image, overlayed image, or an image with selected pixels highlighted.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Common to All System Objects

step   Run System object algorithm
release   Release resources and allow changes to System object property values and input characteristics
reset   Reset internal states of System object

Examples

Blend Two Images

Display the two images.

```
I1 = im2single(imread('blobs.png'));
I2 = im2single(imread('circles.png'));
subplot(1,2,1);
imshow(I1);
subplot(1,2,2);
imshow(I2);
```
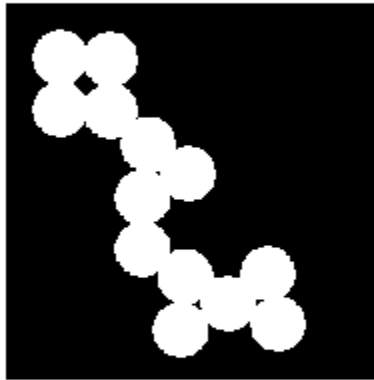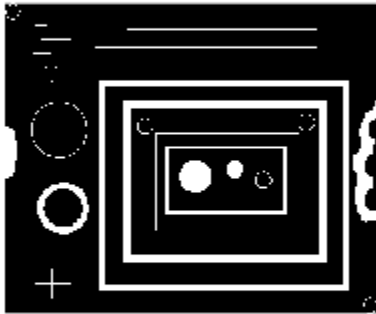
Blend the two images and display the result.

```
halphablend = vision.AlphaBlender;
J = step(halphablend,I1,I2);
figure;
imshow(J);
```
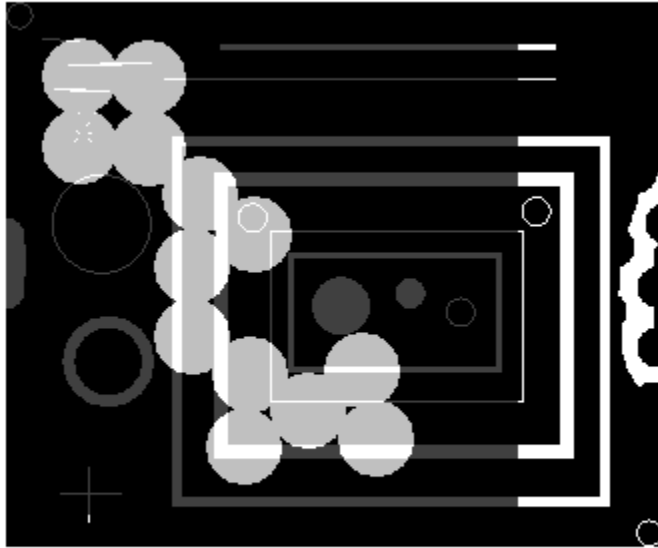
Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
`insertText`

Introduced in R2012a

vision.Autocorrelator System object

Package: vision

Compute 2-D autocorrelation of input matrix

Description

Note The `vision.Autocorrelator` System object will be removed in a future release. Use the `normxcorr2` function with equivalent functionality instead.

The `Autocorrelator` object computes 2-D autocorrelation of input matrix.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Autocorrelator` returns a System object, H, that performs two-dimensional auto-correlation of an input matrix.

`H = vision.Autocorrelator(`*`Name`*`,`*`Value`*`)` returns a 2-D autocorrelation System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

Fixed-Point Properties

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as `Same as product`, `Same as input`, or `Custom`. The default is `Same as product`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `AccumulatorDataType` property to `Custom`. The default is `numerictype([],32,30)`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Custom`. The default is `numerictype([],16,15)`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Custom`. The default is `numerictype([],32,30)`.

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as `Same as input` or `Custom`. The default is `Same as input`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`. The default is `Wrap`.

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as `Same as input`, `Custom`. The default is `Same as input`.

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

Methods

step	Compute cross-correlation of two input matrices

Common to All System Objects	
release	Allow System object property value changes

Examples

Compute The 2-D Autocorrelation of a Matrix

```
hac2d = vision.Autocorrelator;
```

Warning: The vision.Autocorrelator will be removed in a future release. Use the xcorr2

```
x = [1 2;2 1];
y = step(hac2d,x)
```

y = *3×3*

```
    1     4     4
    4    10     4
    4     4     1
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D Autocorrelation block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

*   See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

vision.Crosscorrelator

Introduced in R2012a

step

System object: vision.Autocorrelator
Package: vision

Compute cross-correlation of two input matrices

Syntax

```
Y = step(H,X)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`Y = step(H,X)` returns the 2-D autocorrelation, *Y*, of input matrix *X*.

Calling step on an unlocked System object will lock that object.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.BinaryFileReader System object

Package: vision

Read video data from binary files

Description

The `BinaryFileReader` object reads video data from binary files.

To read a binary file:

1   Create the vision.BinaryFileReader object and set its properties.
2   Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
bFileReader = vision.BinaryFileReader
bFileReader = vision.BinaryFileReader(Name,Value)
bFileReader = vision.BinaryFileReader(file,Name,Value)
```

Description

`bFileReader = vision.BinaryFileReader` returns a binary file reader object, `bFileReader`, that reads binary video data from the specified file in `I420` Four Character Code (FOURCC) video format.

`bFileReader = vision.BinaryFileReader(Name,Value)` creates a cascade object detector object, `bFileReader`, with additional options specified by one or more `Name,Value` pair arguments.

Name is a property name and Value is the corresponding value. Name must appear inside single quotes (''). You can specify several name-value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: bFileReader = vision.BinaryFileReader('Filename','vipmen.bin')

bFileReader = vision.BinaryFileReader(file,Name,Value) returns a binary file reader System object, bFileReader, with the Filename property set to file and other specified properties set to the specified values.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the release function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

Filename — File name
vipmen.bin (default) | character vector

File name, specified as a character vector. The full path for the file needs to be specified only if the file is not on theMATLAB path.

VideoFormat — Video file format
'Four character codes' (default) | 'Custom'

Video file format, specified as 'Four character codes' or 'Custom'.

FourCharacterCode — Four Character Code video format
binary file format

Four Character Code video format, specified as one of the available video formats. For more information on four character codes, see http://www.fourcc.org. This property applies when you set the VideoFormat property to 'Four character codes'.

BitstreamFormat — Format of data
'Planar' (default) | 'Packed'

Format of data, specified as `'Planar'` or `'Packed'`.This property applies when you set the `VideoFormat` property to `Custom`.

`OutputSize` — Size of output
M-by-*N* matrix

Size of output, specified as an *M*-by-*N* matrix. This property applies when you set the `BitstreamFormat` property to `'Packed'`.

`VideoComponentCount` — Number of video components in video stream
3 (default) | 1 | 2 | 4

Number of video components in video stream, specified as 1, 2, 3 or 4. This number corresponds to the number of video component outputs. This property applies when you set the `VideoFormat` property to `'Custom'`.

`VideoComponentBits` — Bit size of video components
[8 8 8] (default) | vector

Bit size of video components, specified as an integer vector of length *N*, where *N* is the value of the `VideoComponentCount` property. This property applies when you set the `VideoFormat` property to `'Custom'`.

`VideoComponentSizes` — Size of video components
[120 160; 60 80; 60 80] (default) | *N*-by-2 array

Size of video components, specified as an *N*-by-2 array, where *N* is the value of the `VideoComponentCount` property. Each row of the matrix corresponds to the size of that video component, with the first element denoting the number of rows and the second element denoting the number of columns. This property applies when you set the `VideoFormat` property to `'Custom'` and the `BitstreamFormat` property to `'Planar'`.

`VideoComponentOrder` — Order of video components
[1 2 3] (default) | 1-by-*N* vector

Order of video components, specified as a 1-by-*N* vector. This property must be set to a vector of length *N*, where *N* is set according to how you set the `BitstreamFormat` property. When you set the `BitStreamFormat` property to `'Planar'`, you must set *N* equal to the value of the `VideoComponentCount` property. Otherwise, you can set *N* equal to or greater than the value of the `VideoComponentCount` property. This property applies when you set the `VideoFormat` property to `'Custom'`.

InterlacedVideo — Interlaced video status
false (default) | true

Interlaced video status, specified as true or false. Set this property to true if the video stream represents interlaced video data. This property applies when you set the VideoFormat property to 'Custom'.

LineOrder — Fill binary file format
'Top line first' (default) | 'Bottom line first'

Fill binary file format, specified as 'Top line first', or 'Bottom line first'. If you set this property to 'Top line first', the first row of the video frame gets filled first. If you set this property to 'Bottom line first', the last row of the video frame gets filled first.

SignedData — Signed data
false (default) | true

Signed data, specified as true or false. Set this property to true for signed input data. This property applies when you set the VideoFormat property to 'Custom'

ByteOrder — Byte order
'Little endian' (default) | 'Big endian'

Byte order, specified as as 'Little endian' or 'Big endian'. This property applies when you set the VideoFormat property to 'Custom'.

PlayCount — Play count
1 (default) | positive integer

Play count for the number of times to play the file, specified as a positive integer.

Usage

Syntax

```
[Y,Cb,Cr] = bFileReader()
Y = bFileReader()
[Y,Cb,Cr,Alpha] = bFileReader()
```

```
[___,EOF] = bFileReader()
```

Description

`[Y,Cb,Cr] = bFileReader()` reads the luminance, `Y` and chrominance, `Cb` and `Cr` components of a video stream from the specified binary file when you set the `VideoFormat` property to `'Four character codes'`. Alternatively, it reads the values when you set the `VideoFormat` property to `'Custom'` and the `VideoComponentCount` property to 2.

`Y = bFileReader()` reads the video component `Y` from the binary file when you set the `VideoFormat` property to `'Custom'` and the `VideoComponentCount` property to 1.

`[Y,Cb,Cr,Alpha] = bFileReader()` additionally reads the `Alpha` when you set the `VideoFormat` property to `'Custom'` and the `VideoComponentCount` property to 4.

`[___,EOF] = bFileReader()` also returns the end-of-file indicator, `EOF`. `EOF` is set to `true` when the output contains the last video frame in the file.

Output Arguments

Y — Luminance value
M-by-*N* matrix

Luminance value, returned as an *M*-by-*N* matrix.

Cb — Chrominance value
M-by-*N* matrix

Chrominance value, returned as an *M*-by-*N* matrix.

Cr — Chrominance value
M-by-*N* matrix

Chrominance value, returned as an *M*-by-*N* matrix.

Alpha — Transparency
scalar

Transparency value, returned as a scalar in the range [0,1].

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to vision.BinaryFileReader

isDone End-of-file status (logical)

Common to All System Objects

step Run System object algorithm
release Release resources and allow changes to System object property values and input characteristics
reset Reset internal states of System object

Examples

Read Binary Video File and Play Back on Screen

Create a binary file reader and video player object.

```
hbfr = vision.BinaryFileReader();
hvp = vision.VideoPlayer;
```

Use the while loop to play the default video.

```
while ~isDone(hbfr)
y = hbfr();
hvp(y);
end
```
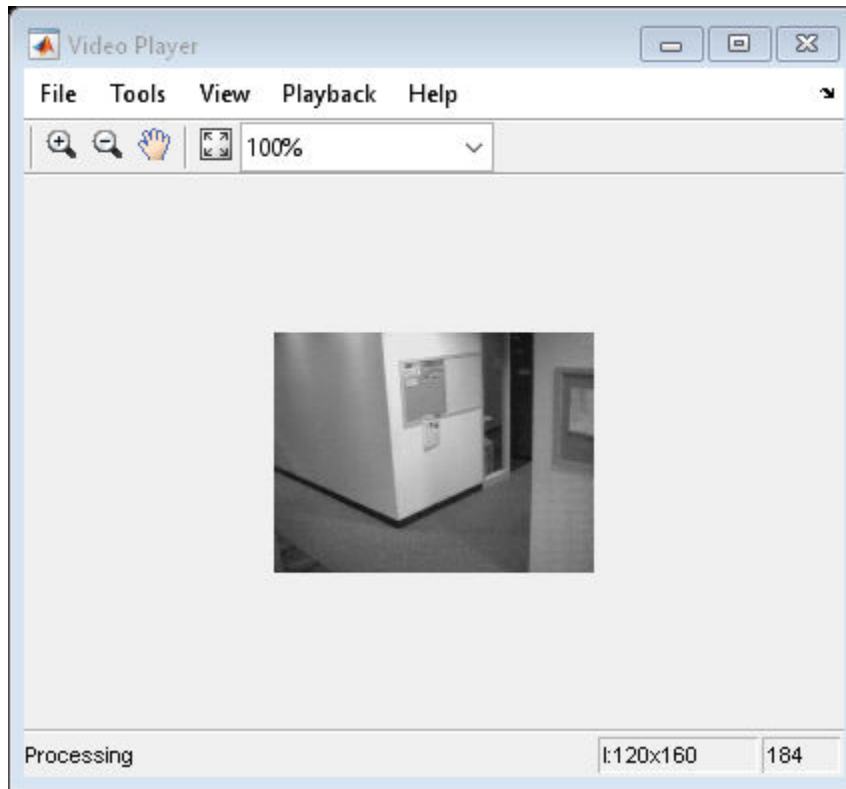
Close the input file and the video display.

```
release(hbfr);
release(hvp);
```
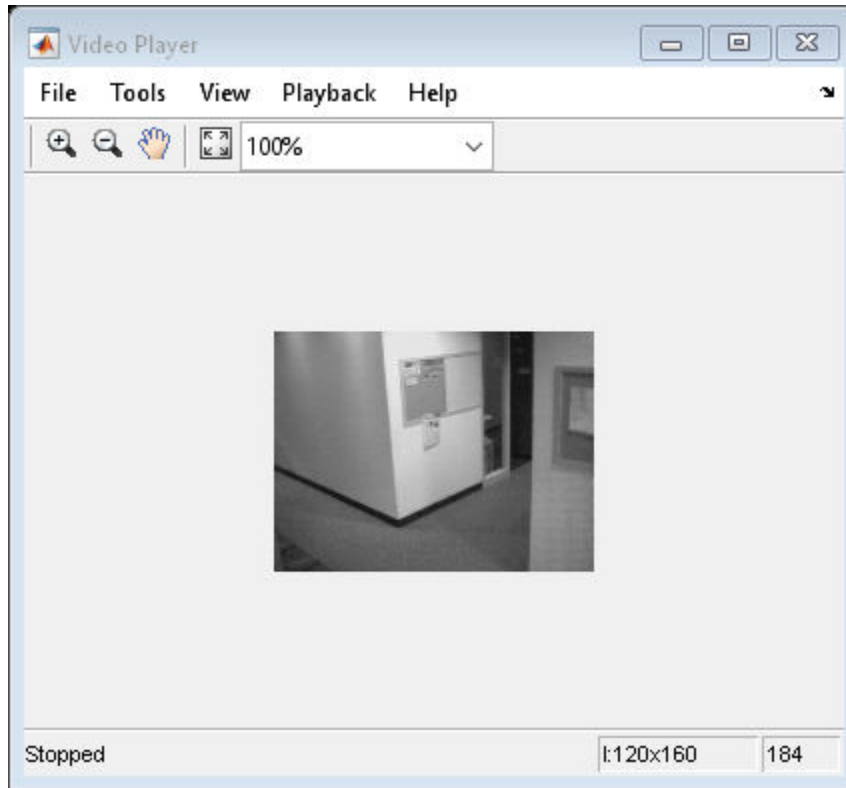
See Also

vision.BinaryFileWriter | vision.VideoFileReader

Introduced in R2012a

vision.BinaryFileWriter System object

Package: vision

Write binary video data to files

Description

The `BinaryFileWriter` object writes binary video data to files.

To write binary data to a file:

1 Create the vision.BinaryFileWriter object and set its properties.

2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
bFileWriter = vision.BinaryFileWriter
bFileWriter = vision.BinaryFileWriter(Name,Value)
```

Description

`bFileWriter = vision.BinaryFileWriter` returns a binary writer object that writes binary video data to an output file, `output.bin` in the `I420` Four Character Code format.

`bFileWriter = vision.BinaryFileWriter(Name,Value)` creates a cascade object detector object, `bFileWriter`, with additional options specified by one or more `Name,Value` pair arguments.

Name is a property name and Value is the corresponding value. Name must appear inside single quotes (''). You can specify several name-value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: bFileWriter = vision.BinaryFileWriter('Filename','output.bin')

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the release function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

Filename — File name
output.bin (default) | character vector

File name, specified as a character vector.

VideoFormat — Video file format
'Four character codes' (default) | 'Custom'

Video file format, specified as 'Four character codes' or 'Custom'.

FourCharacterCode — Four Character Code video format
binary file format

Four Character Code video format, specified as one of the available video formats. For more information on four character codes, see http://www.fourcc.org. This property applies when you set the VideoFormat property to 'Four character codes'.

BitstreamFormat — Format of data
'Planar' (default) | 'Packed'

Format of data, specified as 'Planar' or 'Packed'.This property applies when you set the VideoFormat property to Custom.

VideoComponentCount — Number of video components in video stream
3 (default) | 1 | 2 | 4

Number of video components in video stream, specified as 1, 2, 3 or 4. This number corresponds to the number of video component outputs. This property applies when you set the `VideoFormat` property to `'Custom'`.

`VideoComponentBitsSource` — Size of video components format
`'Auto'` (default) | `Property'`

Size of video components format, specified as `'Auto'` or `'Property'`. If this property is set to `'Auto'`, each component will have a `VideoComponentBits` property. This property applies when you set the `VideoFormat` property to `'Custom'`.

`VideoComponentBits` — Bit size of video components
[8 8 8] (default) | vector

Bit size of video components, specified as an integer vector of length N, where N is the value of the `VideoComponentCount` property. This property applies when you set the `VideoFormat` property to `'Custom'`.

`VideoComponentOrder` — Order of video components
[1 2 3] (default) | 1-by-N vector

Order of video components, specified as a 1-by-N vector. This property must be set to a vector of length N, where N is set according to how you set the `BitstreamFormat` property. When you set the `BitStreamFormat` property to `'Planar'`, you must set N equal to the value of the `VideoComponentCount` property. Otherwise, you can set N equal to or greater than the value of the `VideoComponentCount` property. This property applies when you set the `VideoFormat` property to `'Custom'`.

`InterlacedVideo` — Interlaced video status
false (default) | true

Interlaced video status, specified as `true` or `false`. Set this property to `true` if the video stream represents interlaced video data. This property applies when you set the `VideoFormat` property to `'Custom'`.

`LineOrder` — Fill binary file format
`'Top line first'` (default) | `'Bottom line first'`

Fill binary file format, specified as `'Top line first'`, or `'Bottom line first'`. If you set this property to `'Top line first'`, the first row of the video frame gets filled first. If you set this property to `'Bottom line first'`, the last row of the video frame gets filled first.

SignedData — Signed data
false (default) | true

Signed data, specified as true or false. Set this property to true for signed input data. This property applies when you set the VideoFormat property to 'Custom'

ByteOrder — Byte order
'Little endian' (default) | 'Big endian'

Byte order, specified as as 'Little endian' or 'Big endian'. This property applies when you set the VideoFormat property to 'Custom'.

Usage

Syntax

```
bFileWriter(Y,Cb,Cr)
bFileWriter(Y)
bFileWriter(Y,Cb)
bFileWriter(Y,Cb,Cr)
bFileWriter(Y,Cb,Cr,Alpha)
```

Description

bFileWriter(Y,Cb,Cr) writes one frame of video to the specified output file. Y , Cb, Cr represent the luma (Y) and chroma (Cb and Cr) components of a video stream. This option applies when you set the VideoFormat property to 'Four character codes'.

bFileWriter(Y) writes video component Y to the output file when the VideoFormat property is set to 'Custom' and the VideoComponentCount property is set to 1.

bFileWriter(Y,Cb) writes video components Y and Cb to the output file when the VideoFormat property is 'Custom' and the VideoComponentCount property is set to 2.

bFileWriter(Y,Cb,Cr) writes video components Y , Cb and Cr to the output file when the VideoFormat property is set to 'Custom' and the VideoComponentCount property is set to 3.

bFileWriter(Y,Cb,Cr,Alpha) writes video components Y , Cb, Cr and Alpha to the output file when the VideoFormat property is set to 'Custom', and the VideoComponentCount property is set to 4.

Input Arguments

Y — Luminance value
M-by-*N* matrix

Luminance value, returned as an *M*-by-*N* matrix.

Cb — Chrominance value
M-by-*N* matrix

Chrominance value, returned as an *M*-by-*N* matrix.

Cr — Chrominance value
M-by-*N* matrix

Chrominance value, returned as an *M*-by-*N* matrix.

Alpha — Transparency
scalar

Transparency value, returned as a scalar in the range [0,1].

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

```
release(obj)
```

Common to All System Objects

step   Run System object algorithm
release   Release resources and allow changes to System object property values and
          input characteristics
reset   Reset internal states of System object

Examples

Write Video Data to a Binary File

Set the output file name and create binary file reader and writer objects.

```
filename = fullfile(tempdir,'output.bin');
bFileReader = vision.BinaryFileReader;
bFileWriter = vision.BinaryFileWriter(filename);
```

Write to the file.

```
while ~isDone(bFileReader)
    [y,cb,cr] = bFileReader();
    bFileWriter(y,cb,cr);
end
```

Close the files.

```
release(bFileReader);
release(bFileWriter);
```

See Also

vision.BinaryFileReader | vision.VideoFileReader

Introduced in R2012a

vision.BlobAnalysis System object

Package: vision

Properties of connected regions

Description

The `BlobAnalysis` object computes statistics for connected regions in a binary image.

Use the `step` syntax below with input binary image, BW, blob analysis object, H, and any optional properties. The `step` method computes and returns statistics of the input binary image depending on the property values specified. The order of the returned values when there are multiple outputs are in the order they are described below:

[AREA,CENTROID,BBOX] = step(H,BW) returns the area, centroid and the bounding box of the blobs when the `AreaOutputPort`, `CentroidOutputPort` and `BoundingBoxOutputPort` properties are set to `true`. These are the only properties that are set to true by default. If you set any additional properties to `true`, the corresponding outputs follow the AREA,CENTROID, and BBOX outputs.

[___ ,MAJORAXIS] = step(H,BW) computes the major axis length MAJORAXIS of the blobs found in input binary image BW when the `MajorAxisLengthOutputPort` property is set to `true`.

[___ ,MINORAXIS] = step(H,BW) computes the minor axis length MINORAXIS of the blobs found in input binary image BW when the `MinorAxisLengthOutputPort` property is set to `true`.

[___ ,ORIENTATION] = step(H,BW) computes the ORIENTATION of the blobs found in input binary image BW when the `OrientationOutputPort` property is set to `true`.

[___ ,ECCENTRICITY] = step(H,BW) computes the ECCENTRICITY of the blobs found in input binary image BW when the `EccentricityOutputPort` property is set to `true`.

[___ ,EQDIASQ] = step(H,BW) computes the equivalent diameter squared EQDIASQ of the blobs found in input binary image BW when the `EquivalentDiameterSquaredOutputPort` property is set to `true`.

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[___ ,EXTENT] = step(H,BW) computes the EXTENT of the blobs found in input binary image BW when the ExtentOutputPort property is set to true.

[___ ,PERIMETER] = step(H,BW) computes the PERIMETER of the blobs found in input binary image BW when the PerimeterOutputPort property is set to true.

[___ ,LABEL] = step(H,BW) returns a label matrix LABEL of the blobs found in input binary image BW when the LabelMatrixOutputPort property is set to true.

Input/Output	Format	Supported Data Types
BW	Vector or matrix that represents a binary image	Boolean
AREA	Vector that represents the number of pixels in labeled regions	32-bit signed integer
CENTROID	M-by-2 matrix of centroid coordinates, where M represents the number of blobs	• Double-precision floating point • Single-precision floating point • Fixed point
BBOX	M-by-4 matrix of [x y width height] bounding box coordinates, where M represents the number of blobs and [x y] represents the upper left corner of the bounding box.	32-bit signed integer
MAJORAXIS	Vector that represents the lengths of major axes of ellipses	• Double-precision floating point • Single-precision floating point
MINORAXIS	Vector that represents the lengths of minor axes of ellipses	Same as MajorAxis port

Input/Output	Format	Supported Data Types
ORIENTATION	Vector that represents the angles between the major axes of the ellipses and the x-axis.	Same as MajorAxis port
ECCENTRICITY	Vector that represents the eccentricities of the ellipses	Same as MajorAxis port
EQDIASQ	Vector that represents the equivalent diameters squared	Same as Centroid port
EXTENT	Vector that represents the results of dividing the areas of the blobs by the area of their bounding boxes	Same as Centroid port
PERIMETER	Vector containing an estimate of the perimeter length, in pixels, for each blob	Same as Centroid port
LABEL	Label matrix	8-, 16-, or 32-bit unsigned integer

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.BlobAnalysis` returns a blob analysis System object, `H`, used to compute statistics for connected regions in a binary image.

`H = vision.BlobAnalysis(`*Name*`,`*Value*`)` returns a blob analysis object, `H`, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

AreaOutputPort

Return blob area

Setting this property to `true` outputs the area of the blobs. The default is `true`.

CentroidOutputPort

Return coordinates of blob centroids

Set this property to `true` to output the coordinates of the centroid of the blobs. The default is `true`.

BoundingBoxOutputPort

Return coordinates of bounding boxes

Set this property to `true` to output the coordinates of the bounding boxes. The default is `true`.

MajorAxisLengthOutputPort

Return vector whose values represent lengths of ellipses' major axes

Set this property to `true` to output a vector whose values represent the lengths of the major axes of the ellipses that have the same normalized second central moments as the labeled regions. This property applies when you set the `OutputDataType` property to `double` or `single`. The default is `false`.

MinorAxisLengthOutputPort

Return vector whose values represent lengths of ellipses' minor axes

Set this property to `true` to output a vector whose values represent the lengths of the minor axes of the ellipses that have the same normalized second central moments as the labeled regions. This property is available when the `OutputDataType` property is `double` or `single`. The default is `false`.

OrientationOutputPort

Return vector whose values represent angles between ellipses' major axes and x-axis

Set this property to true to output a vector whose values represent the angles between the major axes of the ellipses and the x-axis. This property applies when you set the `OutputDataType` property to `double` or `single`. The default is `false`.

EccentricityOutputPort

Return vector whose values represent ellipses' eccentricities

Set this property to `true` to output a vector whose values represent the eccentricities of the ellipses that have the same second moments as the region. This property applies when you set the `OutputDataType` property to `double` or `single`. The default is `false`.

EquivalentDiameterSquaredOutputPort

Return vector whose values represent equivalent diameters squared

Set this property to `true` to output a vector whose values represent the equivalent diameters squared. The default is `false`.

ExtentOutputPort

Return vector whose values represent results of dividing blob areas by bounding box areas

Set this property to `true` to output a vector whose values represent the results of dividing the areas of the blobs by the area of their bounding boxes. The default is `false`.

PerimeterOutputPort

Return vector whose values represent estimates of blob perimeter lengths

Set this property to `true` to output a vector whose values represent estimates of the perimeter lengths, in pixels, of each blob. The default is `false`.

OutputDataType

Output data type of statistics

Specify the data type of the output statistics as `double`, `single`, or `Fixed point`. Area and bounding box outputs are always an `int32` data type. `Major axis length`, `Minor axis length`, `Orientation` and `Eccentricity` do not apply when you set this property to `Fixed point`. The default is `double`.

Connectivity

Which pixels are connected to each other

Specify connectivity of pixels as 4 or 8. The default is 8.

LabelMatrixOutputPort

Return label matrix

Set this property to `true` to output the label matrix. The default is `false`.

MaximumCount

Maximum number of labeled regions in each input image

Specify the maximum number of blobs in the input image as a positive scalar integer. The maximum number of blobs the object outputs depends on both the value of this property, and on the size of the input image. The number of blobs the object outputs may be limited by the input image size. The default is 50.

MinimumBlobArea

Minimum blob area in pixels

Specify the minimum blob area in pixels. The default is 0. This property is tunable.

MaximumBlobArea

Maximum blob area in pixels

Specify the maximum blob area in pixels. The default is `intmax('uint32')`. This property is tunable.

ExcludeBorderBlobs

Exclude blobs that contain at least one image border pixel

Set this property to `true` if you do not want to label blobs that contain at least one pixel in the border of the image. The default is `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`. This property applies when you set the `OutputDataType` property to `Fixed point`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`. This property applies when you set the `OutputDataType` property to `Fixed point`.

ProductDataType

Product word and fraction lengths

This property is constant and is set to `Custom`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `EquivalentDiameterSquaredOutputPort` property to `true`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `EquivalentDiameterSquaredOutputPort` property to `true`. The default is `numerictype([],32,16)`.

AccumulatorDataType

Accumulator word and fraction lengths

This property is constant and is set to `Custom`. This property applies when you set the `OutputDataType` property to `Fixed point`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Fixed point`. The default is `numerictype([],32,0)`.

CentroidDataType

Centroid word and fraction lengths

Specify the centroid output's fixed-point data type as `Same as accumulator`, `Custom`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `CentroidOutputPort` property to `true`. The default is `Custom`.

CustomCentroidDataType

Centroid word and fraction lengths

Specify the centroid output's fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `CentroidDataType` property to `Custom` and when the `CentroidOutputPort` property to `true`. The default is `numerictype([],32,16)`.

EquivalentDiameterSquaredDataType

Equivalent diameter squared word and fraction lengths

Specify the equivalent diameters squared output's fixed-point data type as `Same as accumulator`, `Same as product`, `Custom`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `EquivalentDiameterSquaredOutputPort` property to `true`. The default is `Same as product`.

CustomEquivalentDiameterSquaredDataType

Equivalent diameter squared word and fraction lengths

Specify the equivalent diameters squared output's fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `EquivalentDiameterSquaredOutputPort` property to `Custom` and when the `EquivalentDiameterSquaredOutputPort` property to `true`. The default is `numerictype([],32,16)`.

ExtentDataType

Extent word and fraction lengths

Specify the extent output's fixed-point data type as `Same as accumulator` or `Custom`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `ExtentOutputPort` property to `true`.

CustomExtentDataType

Extent word and fraction lengths

Specify the extent output's fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Fixed point`, the `ExtentDataType` property to `Custom` and the `ExtentOutputPort` property to `true`. The default is `numerictype([],16,14)`.

PerimeterDataType

Perimeter word and fraction lengths

Specify the perimeter output's fixed-point data type as `Same as accumulator` or `Custom`. This property applies when you set the `OutputDataType` property to `Fixed point` and the `OutputDataType` property to `true`. The default is `Custom`.

CustomPerimeterDataType

Perimeter word and fraction lengths

Specify the perimeter output's fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Fixed point`, the `PerimeterDataType` property to `Custom` and the `PerimeterOutputPort` property to `true`. The default is `numerictype([],32,16)`.

Methods

step   Compute and returns statistics of input binary image

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Find the centroid of a blob.

```
hblob = vision.BlobAnalysis;
hblob.AreaOutputPort = false;
hblob.BoundingBoxOutputPort = false;
img = logical([0 0 0 0 0 0; ...
                0 1 1 1 1 0; ...
                0 1 1 1 1 0; ...
                0 1 1 1 1 0; ...
                0 0 0 0 0 0]);
centroid = step(hblob, img); % [x y] coordinates of the centroid
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the Blob Analysis block reference page. The object properties correspond to the block parameters, except:

- The **Warn if maximum number of blobs is exceeded** block parameter does not have a corresponding object property. The object does not issue a warning.

- The **Output blob statistics as a variable-size signal** block parameter does not have a corresponding object property.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

`graythresh` | `multithresh`

Introduced in R2012a

step

System object: vision.BlobAnalysis
Package: vision

Compute and returns statistics of input binary image

Syntax

```
AREA = step(H,BW)
[...,CENTROID] = step(H,BW)
[...,BBOX] = step(H,BW)
[...,MAJORAXIS] = step(H,BW)
[...,MINORAXIS] = step(H,BW)
[...,ORIENTATION] = step(H,BW)
[...,ECCENTRICITY] = step(H,BW)
[...,EQDIASQ] = step(H,BW)
[...,EXTENT] = step(H,BW)
[...,PERIMETER] = step(H,BW)
[...,LABEL] = step(H,BW)
[...,NUMBLOBS] = step(H,BW)
[AREA,CENTROID,BBOX] = step(H,BW)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`AREA = step(H,BW)` computes the `AREA` of the blobs found in input binary image `BW` when the `AreaOutputPort` property is set to `true`.

`[...,CENTROID] = step(H,BW)` computes the `CENTROID` of the blobs found in input binary image `BW` when the `CentroidOutputPort` property is set to `true`.

[...,BBOX] = step(H,BW) computes the bounding box BBOX of the blobs found in input binary image BW when the BoundingBoxOutputPort property is set to true.

[...,MAJORAXIS] = step(H,BW) computes the major axis length MAJORAXIS of the blobs found in input binary image BW when the MajorAxisLengthOutputPort property is set to true.

[...,MINORAXIS] = step(H,BW) computes the minor axis length MINORAXIS of the blobs found in input binary image BW when the MinorAxisLengthOutputPort property is set to true.

[...,ORIENTATION] = step(H,BW) computes the ORIENTATION of the blobs found in input binary image BW when the OrientationOutputPort property is set to true.

[...,ECCENTRICITY] = step(H,BW) computes the ECCENTRICITY of the blobs found in input binary image BW when the EccentricityOutputPort property is set to true.

[...,EQDIASQ] = step(H,BW) computes the equivalent diameter squared EQDIASQ of the blobs found in input binary image BW when the EquivalentDiameterSquaredOutputPort property is set to true.

[...,EXTENT] = step(H,BW) computes the EXTENT of the blobs found in input binary image BW when the ExtentOutputPort property is set to true.

[...,PERIMETER] = step(H,BW) computes the PERIMETER of the blobs found in input binary image BW when the PerimeterOutputPort property is set to true.

[...,LABEL] = step(H,BW) returns a label matrix LABEL of the blobs found in input binary image BW when the LabelMatrixOutputPort property is set to true.

[...,NUMBLOBS] = step(H,BW) returns the number of blobs found in the input binary image BW when the NumBlobsOutputPort property is set to true.

[AREA,CENTROID,BBOX] = step(H,BW) returns the area, centroid and the bounding box of the blobs, when the AreaOutputPort, CentroidOutputPort and BoundingBoxOutputPort properties are set to true. You can use this to calculate multiple statistics.

The step method computes and returns statistics of the input binary image depending on the property values specified. The different options can be used simultaneously. The order of the returned values when there are multiple outputs are in the order they are described.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.BlockMatcher System object

Package: vision

Estimate motion between images or video frames

Description

The `BlockMatcher` object estimates motion between images or video frames.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.BlockMatcher` returns a System object, H, that estimates motion between two images or two video frames. The object performs this estimation using a block matching method by moving a block of pixels over a search region.

`H = vision.BlockMatcher(Name,Value)` returns a block matcher System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Code Generation Support
Supports Code Generation: No
Supports MATLAB Function block: No
"System Objects in MATLAB Code Generation" (MATLAB Coder).
"Code Generation Support, Usage Notes, and Limitations".

Properties

ReferenceFrameSource

Reference frame source

Specify the source of the reference frame as one of `Input port` | `Property`. When you set the `ReferenceFrameSource` property to `Input port` a reference frame input must be specified to the `step` method of the block matcher object. The default is `Property`.

ReferenceFrameDelay

Number of frames between reference and current frames

Specify the number of frames between the reference frame and the current frame as a scalar integer value greater than or equal to zero. This property applies when you set the `ReferenceFrameSource` property to `Property`.

The default is `1`.

SearchMethod

Best match search method

Specify how to locate the block of pixels in frame $k+1$ that best matches the block of pixels in frame k. You can specify the search method as `Exhaustive` or `Three-step`. If you set this property to `Exhaustive`, the block matcher object selects the location of the block of pixels in frame $k+1$. The block matcher does so by moving the block over the search region one pixel at a time, which is computationally expensive.

If you set this property to `Three-step`, the block matcher object searches for the block of pixels in frame $k+1$ that best matches the block of pixels in frame k using a steadily decreasing step size. The object begins with a step size approximately equal to half the maximum search range. In each step, the object compares the central point of the search region to eight search points located on the boundaries of the region and moves the central point to the search point whose values is the closest to that of the central point. The object then reduces the step size by half, and begins the process again. This option is less computationally expensive, though sometimes it does not find the optimal solution.

The default is `Exhaustive`.

BlockSize

Block size

Specify the size of the block in pixels.

The default is `[17 17]`.

Overlap

Input image subdivision overlap

Specify the overlap (in pixels) of two subdivisions of the input image.

The default is `[0 0]`.

MaximumDisplacement

Maximum displacement search

Specify the maximum number of pixels that any center pixel in a block of pixels can move, from image to image or from frame to frame. The block matcher object uses this property to determine the size of the search region.

The default is `[7 7]`.

MatchCriteria

Match criteria between blocks

Specify how the System object measures the similarity of the block of pixels between two frames or images. Specify as one of `Mean square error (MSE)` | `Mean absolute difference (MAD)`. The default is `Mean square error (MSE)`.

OutputValue

Motion output form

Specify the desired form of motion output as one of `Magnitude-squared` | `Horizontal and vertical components in complex form`. The default is `Magnitude-squared`.

Fixed-Point Properties

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as one of `Same as input | Custom`. The default is `Custom`. This property applies when you set the `MatchCriteria` property to `Mean square error (MSE)`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `MatchCriteria` property to `Mean square error (MSE)` and the `ProductDataType` property to `Custom`.

The default is `numerictype([],32,0)`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as `Custom`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`.

The default is `numerictype([],32,0)`.

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as `Custom`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as an unscaled `numerictype` object with a `Signedness` of `Auto`. The `numerictype` object should be unsigned if the `OutputValue` property is `Magnitude-squared` and, signed if it is `Horizontal and vertical components in complex form`.

The default is `numerictype([],8)`.

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as one of `Wrap` | `Saturate`. The default is `Saturate`

Methods

step Compute motion of input image

Common to All System Objects	
release	Allow System object property value changes

Examples

Estimate Motion Using BlockMatcher

Read and convert RGB image to grayscale.

```
img1 = im2double(rgb2gray(imread('onion.png')));
```

Create a block matcher and alpha blender object.

```
hbm = vision.BlockMatcher('ReferenceFrameSource',...
        'Input port','BlockSize',[35 35]);
```

```
hbm.OutputValue = 'Horizontal and vertical components in complex form';
halphablend = vision.AlphaBlender;
```

Offset the first image by [5 5] pixels to create a second image.

```
img2 = imtranslate(img1,[5,5]);
```

Compute motion for the two images.

```
motion = hbm(img1,img2);
```

Blend the two images.

```
img12 = halphablend(img2,img1);
```

Use a quiver plot to show the direction of motion on the images.

```
[X,Y] = meshgrid(1:35:size(img1,2),1:35:size(img1,1));
imshow(img12)
hold on
quiver(X(:),Y(:),real(motion(:)),imag(motion(:)),0)
hold off
```
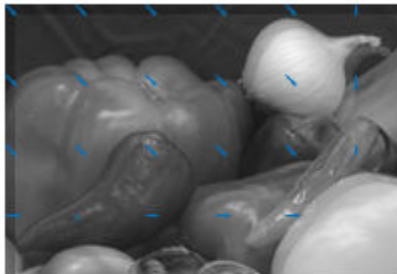
Algorithms

This object implements the algorithm, inputs, and outputs described on the Block Matching block reference page. The object properties correspond to the block parameters.

See Also

opticalFlow | opticalFlowFarneback | opticalFlowHS | opticalFlowLK | opticalFlowLKDoG

Introduced in R2012a

step

System object: vision.BlockMatcher
Package: vision

Compute motion of input image

Syntax

```
V = step(H,I)
C = step(H,I)
Y = step(H,I,IREF)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`V = step(H,I)` computes the motion of input image *I* from one video frame to another, and returns *V* as a matrix of velocity magnitudes.

`C = step(H,I)` computes the motion of input image *I* from one video frame to another, and returns *C* as a complex matrix of horizontal and vertical components, when you set the `OutputValue` property to `Horizontal and vertical components in complex form`.

`Y = step(H,I,IREF)` computes the motion between input image *I* and reference image *IREF* when you set the `ReferenceFrameSource` property to `Input port`.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions,

complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.CascadeObjectDetector System object

Package: vision

Detect objects using the Viola-Jones algorithm

Description

The cascade object detector uses the Viola-Jones algorithm to detect people's faces, noses, eyes, mouth, or upper body. You can also use the **Image Labeler** to train a custom classifier to use with this System object. For details on how the function works, see "Train a Cascade Object Detector".

To detect facial features or upper body in an image :

1   Create the vision.CascadeObjectDetector object and set its properties.
2   Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
detector = vision.CascadeObjectDetector
detector = vision.CascadeObjectDetector(model)
detector = vision.CascadeObjectDetector(XMLFILE)
detector = vision.CascadeObjectDetector(Name,Value)
```

Description

`detector = vision.CascadeObjectDetector` creates a detector to detect objects using the Viola-Jones algorithm.

detector = vision.CascadeObjectDetector(model) creates a detector configured to detect objects defined by the input character vector, model.

detector = vision.CascadeObjectDetector(XMLFILE) creates a detector and configures it to use the custom classification model specified with the XMLFILE input.

detector = vision.CascadeObjectDetector(Name,Value) creates a cascade object detector object, detector, with additional options specified by one or more Name,Value pair arguments.

Name is a property name and Value is the corresponding value. Name must appear inside single quotes (''). You can specify several name-value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: detector = vision.CascadeObjectDetector('ClassificationModel','UpperBody')

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the release function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

ClassificationModel — Trained cascade classification model
'FrontalFaceCART' (default) | character string

Trained cascade classification model, specified as a character vector. The ClassificationModel property controls the type of object to detect. By default, the detector is configured to detect faces.

You can set this character vector to an XML file containing a custom classification model, or to one of the valid model character vectors listed below. You can train a custom classification model using the trainCascadeObjectDetector function. The function can train the model using Haar-like features, histograms of oriented gradients (HOG), or local binary patterns (LBP). For details on how to use the function, see "Train a Cascade Object Detector".

Classification Model	Image Size Used to Train Model	Model Description
`'FrontalFaceCART'` (Default)	[20 20]	Detects faces that are upright and forward facing. This model is composed of weak classifiers, based on the classification and regression tree analysis (CART). These classifiers use Haar features to encode facial features. CART-based classifiers provide the ability to model higher-order dependencies between facial features. [1]
`'FrontalFaceLBP'`	[24 24]	Detects faces that are upright and forward facing. This model is composed of weak classifiers, based on a decision stump. These classifiers use local binary patterns (LBP) to encode facial features. LBP features can provide robustness against variation in illumination. [2]
`'UpperBody'`	[18 22]	Detects the upper-body region, which is defined as the head and shoulders area. This model uses Haar features to encode the details of the head and shoulder region. Because it uses more features around the head, this model is more robust against pose changes, e.g. head rotations/tilts. [3]
`'EyePairBig'` `'EyePairSmall'`	[11 45] [5 22]	Detects a pair of eyes. The `'EyePairSmall'` model is trained using a smaller image. This enables the model to detect smaller eyes than the `'EyePairBig'` model can detect.[4]
`'LeftEye'` `'RightEye'`	[12 18]	Detects the left and right eye separately. These models are composed of weak classifiers, based on a decision stump These classifiers use Haar features to encode details.[4]

Classification Model	Image Size Used to Train Model	Model Description
`'LeftEyeCART'` `'RightEyeCART'`	[20 20]	Detects the left and right eye separately. The weak classifiers that make up these models are CART-trees. Compared to decision stumps, CART-tree-based classifiers are better able to model higher-order dependencies. [5]
`'ProfileFace'`	[20 20]	Detects upright face profiles. This model is composed of weak classifiers, based on a decision stump. These classifiers use Haar features to encode face details.
`'Mouth'`	[15 25]	Detects the mouth. This model is composed of weak classifiers, based on a decision stump, which use Haar features to encode mouth details.[4]
`'Nose'`	[15 18]	This model is composed of weak classifiers, based on a decision stump, which use Haar features to encode nose details.[4]

MinSize — Size of smallest detectable object
[ ] (default) | two-element vector

Size of smallest detectable object, specified as a two-element vector [*height width*]. Set this property in pixels for the minimum size region containing an object. The value must be greater than or equal to the image size used to train the model. Use this property to reduce computation time when you know the minimum object size prior to processing the image. When you do not specify a value for this property, the detector sets it to the size of the image used to train the classification model.

For details explaining the relationship between setting the size of the detectable object and the `ScaleFactor` property, see "Algorithms" on page 2-345 section.

Tunable: Yes

MaxSize — Size of largest detectable object
[ ] (default) | two-element vector

Size of largest detectable object, specified as a two-element vector [*height width*]. Specify the size in pixels of the largest object to detect. Use this property to reduce computation

time when you know the maximum object size prior to processing the image. When you do not specify a value for this property, the detector sets it to `size(I)`.

For details explaining the relationship between setting the size of the detectable object and the `ScaleFactor` property, see the "Algorithms" on page 2-345 section.

ScaleFactor — Scaling for multiscale object detection
1.1 (default) | scalar

Scaling for multiscale object detection, specified as a value greater than `1.0001`. The scale factor incrementally scales the detection resolution between `MinSize` and `MaxSize`. You can set the scale factor to an ideal value using:
`size(I)/(size(I)-0.5)`

The detector scales the search region at increments between `MinSize` and `MaxSize` using the following relationship:

$search\ region$ = round(($Training\ Size$)*($\mathtt{ScaleFactor}^N$))

N is the current increment, an integer greater than zero, and $Training\ Size$ is the image size used to train the classification model.

Tunable: Yes

MergeThreshold — Detection threshold
4 (default) | integer

Detection threshold, specified as an integer. The threshold defines the criteria needed to declare a final detection in an area where there are multiple detections around an object. Groups of colocated detections that meet the threshold are merged to produce one bounding box around the target object. Increasing this threshold may help suppress false detections by requiring that the target object be detected multiple times during the multiscale detection phase. When you set this property to `0`, all detections are returned without performing thresholding or merging operation. This property is tunable.

UseROI — Use region of interest
false (default) | false

Use region of interest, specified as `false` or `false`. Set this property to `true` to detect objects within a rectangular region of interest within the input image.

Usage

Syntax

```
bbox = detector(I)
bbox = detector(I,roi)
```

Description

bbox = detector(I) returns an *M*-by-4 matrix, bbox, that defines *M* bounding boxes containing the detected objects. The detector performs multiscale object detection on the input image, I.

bbox = detector(I,roi) detects objects within the rectangular search region specified by roi. Set the 'UseROI' property to true to use this syntax.

Input Arguments

I — Input image
grayscale | truecolor (RGB)

Input image, specified as grayscale or truecolor (RGB).

model — Classification model
'FrontalFaceCART' (default) | character string

Classification model, specified as a character vector. The model input describes the type of object to detect. There are several valid model character vectors, such as 'FrontalFaceCART', 'UpperBody', and 'ProfileFace'. See the ClassificationModel property description for a full list of available models.

XMLFILE — Custom classification model
XML file

Custom classification model, specified as an XML file. lThe XMLFILE can be created using the trainCascadeObjectDetector function or OpenCV (Open Source Computer Vision) training functionality. You must specify a full or relative path to the XMLFILE, if it is not on the MATLAB path.

roi — Rectangular region of interest
four-element vector (default)

Rectangular region of interest within image I, specified as a four-element vector, [*x y width height*].

Output Arguments

bbox — Detections
M-by-4 matrix (default)

Detections, returned as an *M*-by-4 element matrix. Each row of the output matrix contains a four-element vector, [*x y width height*], that specifies in pixels, the upper-left corner and size of a bounding box.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

```
release(obj)
```

Common to All System Objects

step   Run System object algorithm
release   Release resources and allow changes to System object property values and
              input characteristics
reset   Reset internal states of System object

Examples

Detect Faces in an Image Using the Frontal Face Classification Model

Create a face detector object.

```
faceDetector = vision.CascadeObjectDetector;
```

Read the input image.

```
I = imread('visionteam.jpg');
```

Detect faces.

```
bboxes = faceDetector(I);
```

Annotate detected faces.

```
IFaces = insertObjectAnnotation(I,'rectangle',bboxes,'Face');
figure
imshow(IFaces)
title('Detected faces');
```


Detected faces
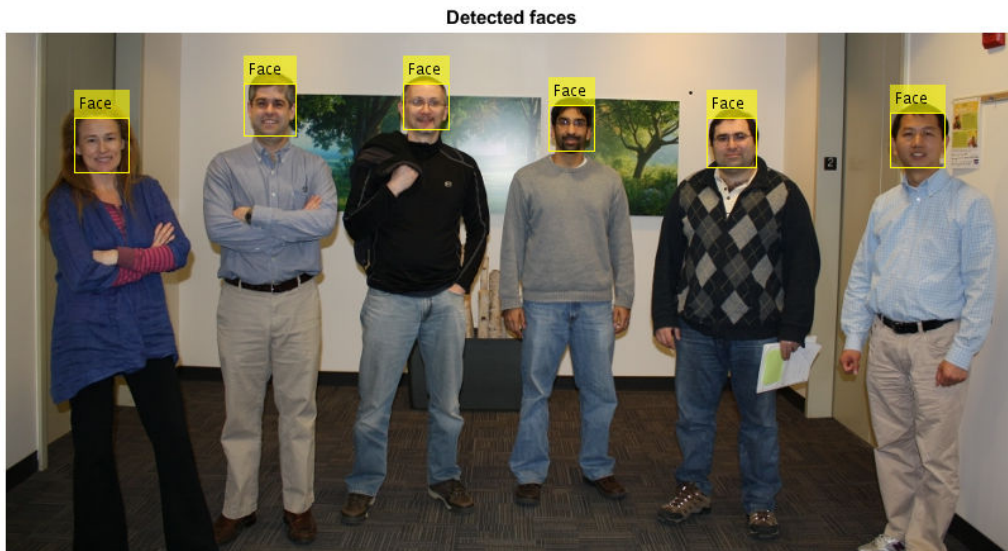
Detect Upper Body in Image Using Upper Body Classification Model

Create a body detector object and set properties.

```
bodyDetector = vision.CascadeObjectDetector('UpperBody');
bodyDetector.MinSize = [60 60];
bodyDetector.MergeThreshold = 10;
```

Read input image and detect upper body.

```
I2 = imread('visionteam.jpg');
bboxBody = bodyDetector(I2);
```

Annotate detected upper bodies.

```
IBody = insertObjectAnnotation(I2,'rectangle',bboxBody,'Upper Body');
figure
imshow(IBody)
title('Detected upper bodies');
```
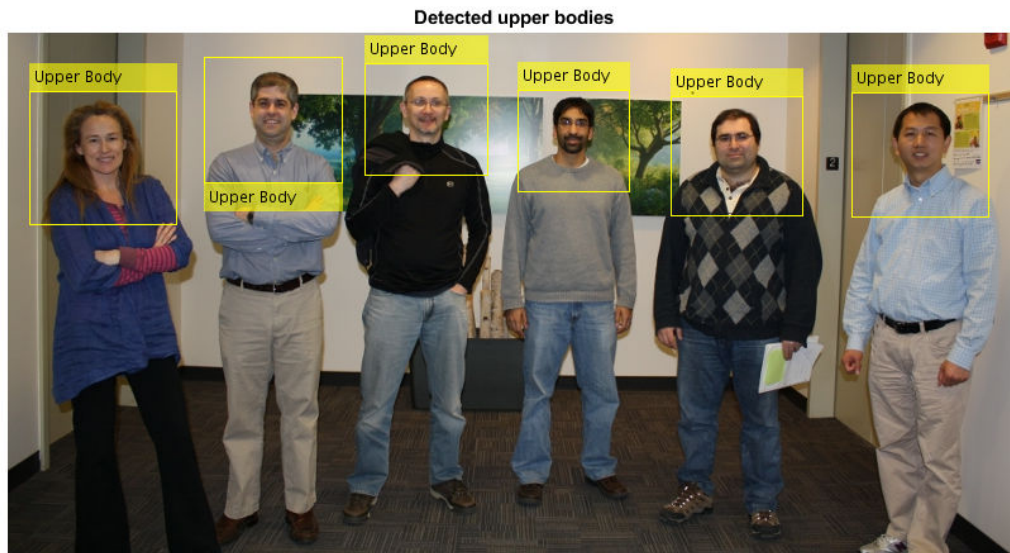

- "Face Detection and Tracking Using CAMShift"
- "Face Detection and Tracking Using the KLT Algorithm"
- "Face Detection and Tracking Using Live Video Acquisition"

Algorithms

Classification Model Training

Each model is trained to detect a specific type of object. The classification models are trained by extracting features from a set of known images. These extracted features are then fed into a learning algorithm to train the classification model. Computer Vision System Toolbox software uses the Viola-Jones cascade object detector. This detector uses HOG[7], LBP[8], and Haar-like [6] features and a cascade of classifiers trained using boosting.

The image size used to train the classifiers defines the smallest region containing the object. Training image sizes vary according to the application, type of target object, and available positive images. You must set the `MinSize` property to a value greater than or equal to the image size used to train the model.

Cascade of Classifiers

This object uses a cascade of classifiers to efficiently process image regions for the presence of a target object. Each stage in the cascade applies increasingly more complex binary classifiers, which allows the algorithm to rapidly reject regions that do not contain the target. If the desired object is not found at any stage in the cascade, the detector immediately rejects the region and processing is terminated. By terminating, the object avoids invoking computation-intensive classifiers further down the cascade.
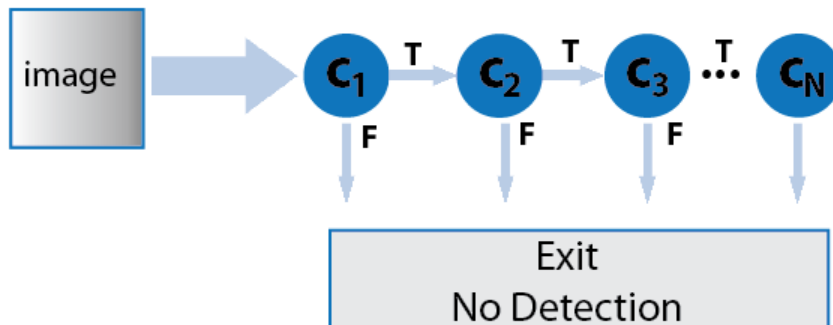
Multiscale Object Detection

The detector incrementally scales the input image to locate target objects. At each scale increment, a sliding window, whose size is the same as the training image size, scans the scaled image to locate objects. The `ScaleFactor` property determines the amount of scaling between successive increments.

The search region size is related to the `ScaleFactor` in the following way:

search region = round(($ObjectTrainingSize$)*($ScaleFactor^N$))

N is the current increment, an integer greater than zero, and *ObjectTrainingSize* is the image size used to train the classification model.
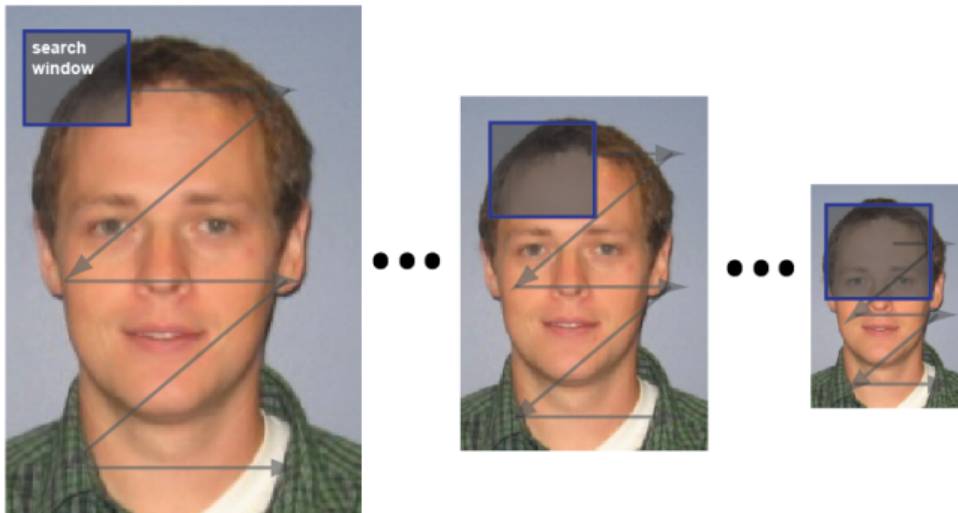
The search window traverses the image for each scaled increment.

Relationship Between MinSize, MaxSize, and ScaleFactor

Understanding the relationship between the size of the object to detect and the scale factor will help you set the properties accordingly. The `MinSize` and `MaxSize` properties limit the size range of the object to detect. Ideally, these properties are modified to reduce computation time when you know the approximate object size prior to processing the image. They are not designed to provide precise filtering of results, based on object size.

The behavior of these properties is affected by the ScaleFactor. The scale factor determines the quantization of the search window sizes.

search region = round((*Training Size*)*(ScaleFactor^N))

The actual range of returned object sizes may not be exactly what you select for the MinSize and MaxSize properties. For example,
For a ScaleFactor value of 1.1 with a 24x24 training size, for 5 increments, the search region calculation would be:

```
>> search region = round(24*1.1.^(1:5))
```

```
>> 26 29 32 35 39
```

If you were to set MaxSize to 34, due to the search region quantization, the actual maximum object size used by the algorithm would be 32.

Merge Detection Threshold

For each increment in scale, the search window traverses over the image producing multiple detections around the target object. The multiple detections are merged into one bounding box per target object. You can use the MergeThreshold property to control the number of detections required before combining or rejecting the detections. The size of the final bounding box is an average of the sizes of the bounding boxes for the individual detections and lies between MinSize and MaxSize.
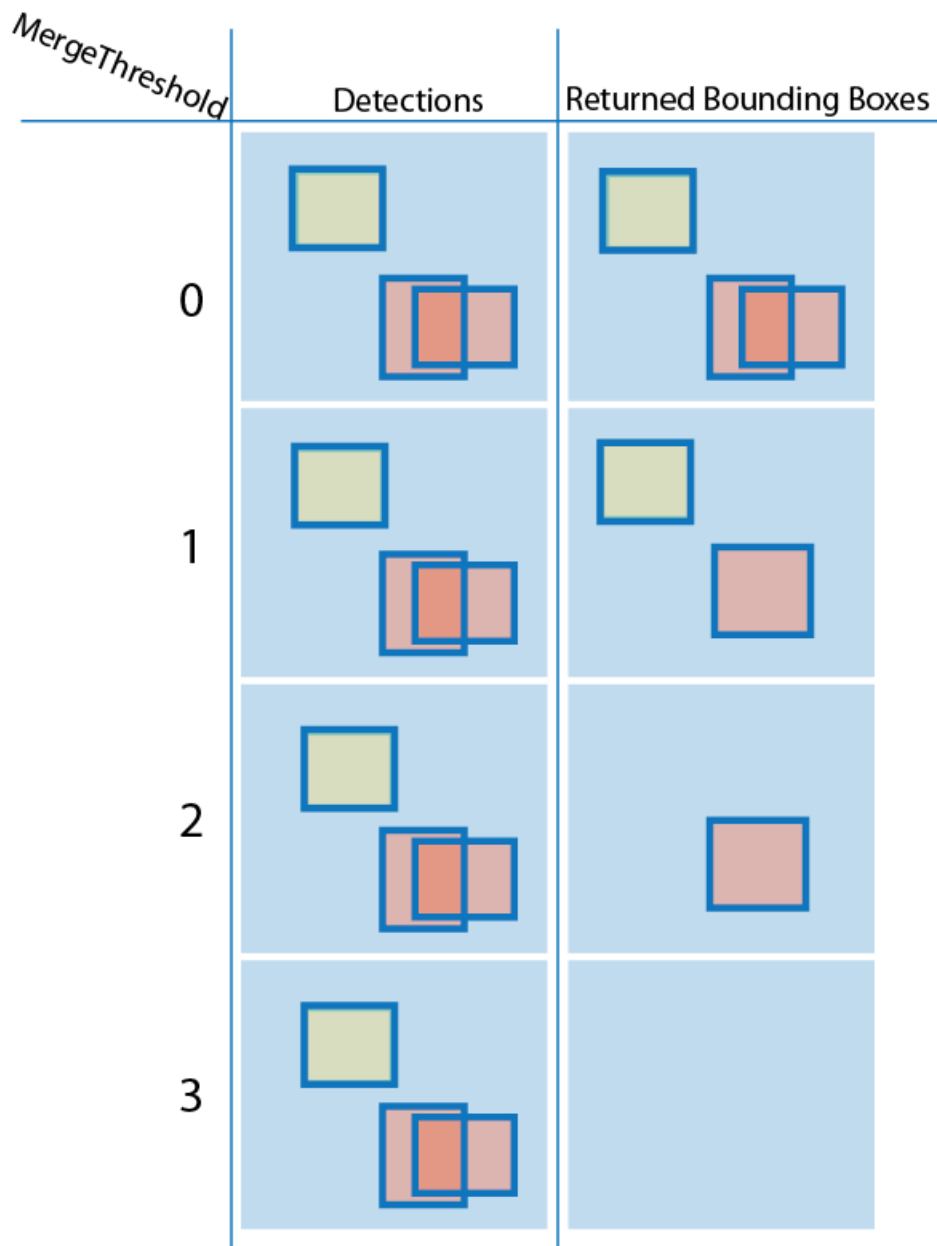
References

[1] Lienhart R., Kuranov A., and V. Pisarevsky "Empirical Analysis of Detection Cascades of Boosted Classifiers for Rapid Object Detection." *Proceedings of the 25th DAGM Symposium on Pattern Recognition.* Magdeburg, Germany, 2003.

[2] Ojala Timo, Pietikäinen Matti, and Mäenpää Topi, "Multiresolution Gray-Scale and Rotation Invariant Texture Classification with Local Binary Patterns" . In *IEEE Transactions on Pattern Analysis and Machine Intelligence, 2002*. Volume 24, Issue 7, pp. 971-987.

[3] Kruppa H., Castrillon-Santana M., and B. Schiele. "Fast and Robust Face Finding via Local Context" . *Proceedings of the Joint IEEE International Workshop on Visual Surveillance and Performance Evaluation of Tracking and Surveillance*, 2003, pp. 157–164.

[4] Castrillón Marco, Déniz Oscar, Guerra Cayetano, and Hernández Mario, " ENCARA2: Real-time detection of multiple faces at different resolutions in video streams" . In *Journal of Visual Communication and Image Representation*, 2007 (18) 2: pp. 130-140.

[5] Yu Shiqi " Eye Detection." Shiqi Yu's Homepage. http://yushiqi.cn/research/ eyedetection.

[6] Viola, Paul and Michael J. Jones, " Rapid Object Detection using a Boosted Cascade of Simple Features" , *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2001. Volume: 1, pp.511–518.

[7] Dalal, N., and B. Triggs, " Histograms of Oriented Gradients for Human Detection" . *IEEE Computer Society Conference on Computer Vision and Pattern Recognition*. Volume 1, (2005), pp. 886–893.

[8] Ojala, T., M. Pietikainen, and T. Maenpaa, " Multiresolution Gray-scale and Rotation Invariant Texture Classification With Local Binary Patterns" . *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Volume 24, No. 7 July 2002, pp. 971–987.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).
- XMLFILE must be a compile-time constant.

See Also
Image Labeler | insertShape | integralImage | trainCascadeObjectDetector | vision.PeopleDetector

Topics
"Face Detection and Tracking Using CAMShift"
"Face Detection and Tracking Using the KLT Algorithm"
"Face Detection and Tracking Using Live Video Acquisition"
"Define Ground Truth for Image Collections"
"Train a Cascade Object Detector"
"Multiple Object Tracking"

External Websites
Detect and Track Multiple Faces in a Live Video Stream

Introduced in R2012a

vision.Convolver System object

Package: vision

Compute 2-D discrete convolution of two input matrices

Description

Note The `vision.Convolver` System object will be removed in a future release. Use the `conv2` function with equivalent functionality instead.

The `Convolver` object computes 2-D discrete convolution of two input matrices.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Convolver` returns a System object, H, that performs two-dimensional convolution on two inputs.

`H = vision.Convolver(`*Name*,*Value*`)` returns a 2-D convolution System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

`OutputSize`

Specify dimensions of output

This property controls the size of the output scalar, vector, or matrix produced as a result of the convolution between the two inputs. You can set this property to one of `Full` | `Same as first input` | `Valid`. The default is `Full`. When you set this property to `Full`, the object outputs the full two-dimensional convolution with dimension, ($Ma+Mb$-1, $Na+Nb$-1). When you set this property to `Same as first input`, the object outputs the central part of the convolution with the same dimensions as the first input. When you set this property to `Valid`, the object outputs only those parts of the convolution that are computed without the zero-padded edges of any input. For this case, the object outputs dimension, ($Ma-Mb$+1, $Na-Nb$+1). (Ma, Na) is the size of the first input matrix and (Mb, Na) is the size of the second input matrix.

Normalize

Whether to normalize the output

Set to `true` to normalize the output. The default is `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as one of `Wrap` | `Saturate`. The default is `Wrap`.

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as one of `Same as first input` | `Custom`. The default is `Custom`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `ProductDataType` property to `Custom`. The default is `numerictype([],32,10)`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as one of `Same as product` | `Same as first input` | `Custom`. The default is `Same as product`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `AccumulatorDataType` property to `Custom`. The default is `numerictype([],32,10)`.

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as one of `Same as first input` | `Custom`. The default is `Custom`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Custom`. The default is `numerictype([],32,12)`.

Methods

step   Compute 2-D convolution of input matrices

Common to All System Objects	
release	Allow System object property value changes

Examples

Compute the 2D convolution of two matrices.

```
hconv2d = vision.Convolver;
x1 = [1 2;2 1];
x2 = [1 -1;-1 1];
y = step(hconv2d, x1, x2)
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D Convolution block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

vision.AutoCorrelator | vision.Crosscorrelator

Introduced in R2012a

step

System object: vision.Convolver
Package: vision

Compute 2-D convolution of input matrices

Syntax

```
Y = step(HCONV2D,X1,X2)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`Y = step(HCONV2D,X1,X2)` computes 2-D convolution of input matrices *X1* and *X2*.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.Crosscorrelator System object

Package: vision

2-D cross-correlation of two input matrices

Description

Note The `vision.Crosscorrelator` System object will be removed in a future release. Use the `normxcorr2` function with equivalent functionality instead.

The `Crosscorrelator` object computes 2-D cross-correlation of two input matrices.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Crosscorrelator` returns a System object, `H`, that performs two-dimensional cross-correlation between two inputs.

`H = vision.Crosscorrelator(`*Name*`,`*Value*`)` returns a 2-D cross correlation System object, `H`, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

`OutputSize`

Specify dimensions of output

This property controls the size of the output scalar, vector, or matrix produced as a result of the cross-correlation between the two inputs. This property can be set to one of `Full`, `Same as first input`, `Valid`. If this property is set to `Full`, the output is the full two-dimensional cross-correlation with dimensions ($Ma+Mb$-1, $Na+Nb$-1). if this property is set to `same as first input`, the output is the central part of the cross-correlation with the same dimensions as the first input. if this property is set to `valid`, the output is only those parts of the cross-correlation that are computed without the zero-padded edges of any input. this output has dimensions ($Ma-Mb$+1, $Na-Nb$+1). (Ma, Na) is the size of the first input matrix and (Mb, Nb) is the size of the second input matrix. The default is `Full`.

Normalize

Normalize output

Set this property to `true` to normalize the output. If you set this property to `true`, the object divides the output by $\sqrt{\sum\left(I_{1p}\bullet I_{1p}\right)\times\sum\left(I_2\bullet I_2\right)}$, where I_{1p} is the portion of the input matrix, I_1 that aligns with the input matrix, I_2. This property must be set to `false` for fixed-point inputs. The default is `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`. The default is `Wrap`.

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as `Same as first input`, `Custom`. The default is `Same as first input`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `ProductDataType` property to `Custom`. The default is `numerictype([],32,30)`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as `Same as product`, `Same as first input`, `Custom`.The default is `Same as product`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `AccumulatorDataType` property to `Custom`. The default is `numerictype([],32,30)`.

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as `Same as first input`, `Custom`. The default is `Same as first input`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Custom`. The default is `numerictype([],16,15)`.

Methods

step   Compute 2-D correlation of input matrices

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Compute the 2-D correlation of two matrices.

```
hcorr2d = vision.Crosscorrelator;
x1 = [1 2;2 1];
x2 = [1 -1;-1 1];
y = step(hcorr2d,x1,x2);
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D Correlation block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

vision.Autocorrelator

Introduced in R2012a

step

System object: vision.Crosscorrelator
Package: vision

Compute 2-D correlation of input matrices

Syntax

Y = step(H,X1,X2)

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Y = step(H,X1,X2) computes the 2-D correlation of input matrices *X1* and *X2*.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.DCT System object

Package: vision

Compute 2-D discrete cosine transform

Description

> **Note** The `vision.DCT` System object will be removed in a future release. Use the `dct2` function with equivalent functionality instead.

The `DCT` object computes a 2-D discrete cosine transform. The number of rows and columns of the input matrix must be a power of 2.

> **Note** Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.DCT` returns a discrete cosine transform System object, H, used to compute the two-dimensional discrete cosine transform (2-D DCT) of a real input signal.

`H = vision.DCT(`*Name*`,`*Value*`)` returns a discrete cosine transform System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

SineComputation

Specify how the System object computes sines and cosines as `Trigonometric function`, or `Table lookup`. This property must be set to `Table lookup` for fixed-point inputs.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`. This property applies when you set the `SineComputation` to `Table lookup`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Wrap`.

SineTableDataType

Sine table word-length designation

Specify the sine table fixed-point data type as `Same word length as input`, or `Custom`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Same word length as input`.

CustomSineTableDataType

Sine table word length

Specify the sine table fixed-point type as a signed, unscaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup` and you set the `SineTableDataType` property to `Custom`. The default is `numerictype(true,16)`.

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as `Full precision`, `Same as first input`, or `Custom`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Custom`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a signed, scaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup`, and the `ProductDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as `Full precision`, `Same as input`,`Same as product`, `Same as first input`, `Custom`. This property applies when you set the `SineComputation` property to `Table lookup`. The default is `Full precision`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a signed, scaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup`, and `AccumulatorDataType` property to `Custom`. The default is `numerictype(true, 32,30)`.

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as `Full precision`, `Same as first input`, or `Custom`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Custom`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a signed, scaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup`, and the `OutputDataType` property to `Custom`. The default is `numerictype(true,16,15)`.

Methods

step   Compute 2-D discrete cosine transform on input

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Use 2-D discrete cosine transform to analyze the energy content in an image. Set the DCT coefficients lower than a threshold of 0, and then reconstruct the image using the 2-D inverse discrete cosine transform object.

```
hdct2d = vision.DCT;
I = double(imread('cameraman.tif'));
J = step(hdct2d, I);
imshow(log(abs(J)),[]), colormap(jet(64)), colorbar

hidct2d = vision.IDCT;
J(abs(J) < 10) = 0;
It = step(hidct2d, J);
figure, imshow(I, [0 255]), title('Original image')
figure, imshow(It,[0 255]), title('Reconstructed image')
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D DCT block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
vision.IDCT

Introduced in R2012a

step

System object: vision.DCT
Package: vision

Compute 2-D discrete cosine transform on input

Syntax

Y = step(H,X)

Description

Note Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, y = step(obj,x) and y = obj(x) perform equivalent operations.

Y = step(H,X) returns the 2-D discrete cosine transform *Y* of input *X*.

Note H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

vision.Deinterlacer System object

Package: vision

Remove motion artifacts by deinterlacing input video signal

Description

The `Deinterlacer` object removes motion artifacts by deinterlacing input video signal.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Deinterlacer` returns a deinterlacing System object, H, that removes motion artifacts from images composed of weaved top and bottom fields of an interlaced signal.

`H = vision.Deinterlacer(Name,Value)` returns a deinterlacing System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

Method

Method used to deinterlace input video

Specify how the object deinterlaces the input video as one of `Line repetition` | `Linear interpolation` | `Vertical temporal median filtering`. The default is `Line repetition`.

TransposedInput

Indicate if input data is in row-major order

Set this property to `true` if the input buffer contains data elements from the first row first, then the second row second, and so on.

The default is `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`. This property applies when you set the `Method` property to `Linear Interpolation`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as one of `Wrap` | `Saturate`. The default is `Wrap`. This property applies when you set the `Method` property to `Linear Interpolation`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as one of `Same as input` | `Custom`. The default is `Custom`. This property applies when you set the `Method` property to `Linear Interpolation`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property is applicable when the `AccumulatorDataType` property is `Custom`. This property applies when you set the `Method` property to `Linear Interpolation`.

The default is numerictype([],12,3).

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as one of Same as input | Custom. This property applies when you set the Method property to Linear Interpolation. The default is Same as input.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled numerictype object with a Signedness of Auto. This property is applicable when the OutputDataType property is Custom. This property applies when you set the Method property to Linear Interpolation.

The default is numerictype([],8,0).

Methods

step	Deinterlace input video signal

Common to All System Objects	
release	Allow System object property value changes

Examples

Remove Motion Artifacts From Image

Create a deinterlacer object.

hdinterlacer = vision.Deinterlacer;

Read an image with motion artifacts.

I = imread('vipinterlace.png');

Apply the deinterlacer to the image.

```
clearimage = hdinterlacer(I);
```

Display the results.

```
imshow(I);
title('Original Image');
```

Original Image


```
figure, imshow(clearimage);
title('Image after deinterlacing');
```

Image after deinterlacing

Algorithms

This object implements the algorithm, inputs, and outputs described on the Deinterlacing block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

Introduced in R2012a

step

System object: vision.Deinterlacer
Package: vision

Deinterlace input video signal

Syntax

Y = step(H,X)

Description

Note Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, y = step(obj,x) and y = obj(x) perform equivalent operations.

Y = step(H,X) deinterlaces input *X* according to the algorithm set in the Method property.

Note H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

Remove Motion Artifacts From Image

Create a deinterlacer object.

```
hdinterlacer = vision.Deinterlacer;
```

Read an image with motion artifacts.

```
I = imread('vipinterlace.png');
```

Apply the deinterlacer to the image.

```
clearimage = hdinterlacer(I);
```

Display the results.

```
imshow(I);
title('Original Image');
```

Original Image

```
figure, imshow(clearimage);
title('Image after deinterlacing');
```

Image after deinterlacing

vision.DemosaicInterpolator System object

Package: vision

Bayer-pattern image conversion to true color

Description

Note The `vision.DemosaicInterpolator` System object will be removed in a future release. Use the `demosaic` function with equivalent functionality instead.

The `DemosaicInterpolator` object demosaics Bayer's format images. The object identifies the alignment as the sequence of R, G, and B pixels in the top-left four pixels of the image, in row-wise order.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.DemosaicInterpolator` returns a System object, H, that performs demosaic interpolation on an input image in Bayer format with the specified alignment.

`H = vision.DemosaicInterpolator(`*Name*`,`*Value*`)` returns a System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

Method

Interpolation algorithm

Specify the algorithm the object uses to calculate the missing color information as one of `Bilinear` | `Gradient-corrected linear`. The default is `Gradient-corrected linear`.

SensorAlignment

Alignment of the input image

Specify the sequence of R, G and B pixels that correspond to the 2-by-2 block of pixels in the top-left corner, of the image. It can be set to one of RGGB |GRBG | GBRG | BGGR. The default is RGGB. Specify the sequence in left-to-right, top-to-bottom order.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as one of `Wrap` | `Saturate`. The default is `Saturate`.

ProductDataType

Product output word and fraction lengths

Specify the product output fixed-point data type as one of `Same as input` | `Custom`. The default is `Custom`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `ProductDataType` property to `Custom`. The default is `numerictype([],32,10)`.

AccumulatorDataType

Data type of the accumulator

Specify the accumulator fixed-point data type as one of `Same as product | Same as input | Custom`. The default is `Same as product`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `AccumulatorDataType` property to `Custom`. The default is `numerictype([],32,10)`.

Methods

step   Perform demosaic operation on input

Common to All System Objects	
release	Allow System object property value changes

Examples

Demosaic a Bayer pattern encoded-image photographed by a camera with a sensor alignment of BGGR.

```
x = imread('mandi.tif');
hdemosaic = ...
    vision.DemosaicInterpolator('SensorAlignment', 'BGGR');
y = step(hdemosaic, x);

imshow(x,'InitialMagnification',20);
title('Original Image');
```

```
figure, imshow(y,'InitialMagnification',20);
title('RGB image after demosaic');
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the Demosaic block reference page. The object properties correspond to the block parameters, except: The **Output image signal** block parameter allows you to specify whether the block outputs the image as `One multidimensional signal` or `Separate color signals`. The object does not have a property that corresponds to the **Output image signal** block parameter. The object always outputs the image as an *M*-by-*N*-by-*P* color video signal.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
vision.GammaCorrector

Introduced in R2012a

step

System object: vision.DemosaicInterpolator
Package: vision

Perform demosaic operation on input

Syntax

Y = step(H,X)

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, y = step(obj,x) and y = obj(x) perform equivalent operations.

Y = step(H,X) performs the demosaic operation on the input *X*. The step method outputs an *M*-by-*N*-by-*P* color video signal, where *P* is the number of color planes.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.DeployableVideoPlayer System object

Package: vision

Display video

Description

The `DeployableVideoPlayer` object displays video frames. This player is capable of displaying high definition video at high frame rates. This video player object supports C code generation.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`depVideoPlayer = vision.DeployableVideoPlayer` returns a video player System object, `depVideoPlayer`, for displaying video frames. Each call to the `step` method, displays the next video frame. This object, unlike the `vision.VideoPlayer` object, can generate C code.

`depVideoPlayer = vision.DeployableVideoPlayer( ___ ,Name,Value)` configures the video player properties, specified as one or more `Name,Value` pair arguments. Unspecified properties have default values.

To display video:

1 Define and set up your deployable video player object using the constructor.
2 Call the `step` method with the deployable video player object, `depVideoPlayer`, and any optional properties. See the syntax below for using the `step` method.

`step(depVideoPlayer,I)` displays one grayscale or truecolor RGB video frame, `I`, in the video player.

`step(depVideoPlayer,Y,Cb,Cr)` displays one frame of YCbCr 4:2:2 video in the color components Y, Cb, and Cr when you set the `InputColorFormat` property to `YCbCr 4:2:2`. The number of columns in the Cb and Cr components must be half the number of columns in the Y component.

Properties

`Location` — Location of bottom left corner of video window
dependent on the screen resolution (default) | two-element vector

Location of bottom left corner of video window, specified as the comma-separated pair consisting of '`Location`' and a two-element vector. The first and second elements are specified in pixels and represent the horizontal and vertical coordinates respectively. The coordinates `[0 0]` represent the bottom left corner of the screen. The default location depends on the screen resolution, and will result in a window positioned in the center of the screen.

`Name` — Video window title bar caption
'`Deployable Video Player`'

Video window title bar caption, specified as the comma-separated pair consisting of '`Name`' and a character vector.

`Size` — Size of video display window
True size (1:1) (default) | Full-screen | Custom

Size of video display window, specified as the comma-separated pair consisting of '`Size`' and `Full-screen`, `True size (1:1)` or `Custom`. When this property is set to `Full-screen`, use the `Esc` key to exit out of full-screen mode.

`CustomSize` — Custom size for video player window
[300 410] (default) | two-element vector

Custom size for video player window, specified as the comma-separated pair consisting of '`CustomSize`' and a two-element vector. The first and second elements are specified in pixels and represent the horizontal and vertical components respectively. The video data will be resized to fit the window. This property applies when you set the `Size` property to `Custom`.

`InputColorFormat` — Color format of input signal
RGB (default) | `'YCbCr 4:2:2'`

Color format of input signal, specified as the comma-separated pair consisting of `'InputColorFormat'` and `'RGB'` or `'YCbCr 4:2:2'`. The number of columns in the Cb and Cr components must be half the number of columns in Y.

Methods

isOpen   Visible or hidden status for video player figure
step   Send multidimensional video to computer screen

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Play a Video From a File

Set up System objects to read and view a video file.

```
videoFReader  = vision.VideoFileReader('atrium.mp4');
depVideoPlayer = vision.DeployableVideoPlayer;
```

Continue to read frames of video until the last frame is read. Exit the loop if user closes the video player window.

```
cont = ~isDone(videoFReader);
  while cont
    frame = step(videoFReader);
    step(depVideoPlayer, frame);
    cont = ~isDone(videoFReader) && isOpen(depVideoPlayer);
  end
```

Release System objects.

```
release(videoFReader);
release(depVideoPlayer);
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generated code for this function uses a precompiled platform-specific shared library.
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
vision.VideoFileReader | vision.VideoFileWriter | vision.VideoPlayer

Introduced in R2012a

isOpen

System object: vision.DeployableVideoPlayer
Package: vision

Visible or hidden status for video player figure

Syntax

```
isOpen(h)
```

Description

isOpen(h) returns the visible or hidden status, as a logical, for the video player window. This method is not supported in code generation.

step

System object: vision.DeployableVideoPlayer
Package: vision

Send multidimensional video to computer screen

Syntax

```
step(depVideoPlayer,I)
step(depVideoPlayer,Y,Cb,Cr)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`step(depVideoPlayer,I)` displays one grayscale or truecolor RGB video frame, `I`, in the video player.

`step(depVideoPlayer,Y,Cb,Cr)` displays one frame of YCbCr 4:2:2 video in the color components Y, Cb, and Cr when you set the `InputColorFormat` property to `YCbCr 4:2:2`. The number of columns in the Cb and Cr components must be half the number of columns in the Y component.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.FFT System object

Package: vision

Two-dimensional discrete Fourier transform

Description

Note The `vision.FFT` System object will be removed in a future release. Use the `fft` function with equivalent functionality instead.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`fftObj = vision.FFT` returns a 2D FFT object, `fftObj`, that computes the fast Fourier transform of a two-dimensional input.

`fftObj = vision.FFT(`*Name*`,`*Value*`)` configures the System object properties, specified as one or more name-value pair arguments. Unspecified properties have default values.

To compute FFT:

1   Define and set up your FFT object using the constructor.
2   Call the `step` method with the input image, `I` and the FFT object, `fftObj`. See the syntax below for using the `step` method.

`J = step(fftObj,I)` computes the 2-D FFT, `J`, of an *M*-by-*N* input matrix `I`, where *M* and *N* specify the dimensions of the input. The dimensions *M* and *N* must be positive integer powers of two when any of the following are true:

The input is a fixed-point data type
You set the `BitReversedOutput` property to `true`.
You set the `FFTImplementation` property to `Radix-2`.

Properties

FFTImplementation

FFT implementation

Specify the implementation used for the FFT as one of `Auto` | `Radix-2` | `FFTW`. When you set this property to `Radix-2`, the FFT length must be a power of two.

Default: `Auto`

BitReversedOutput

Output in bit-reversed order relative to input

Designates the order of output channel elements relative to the order of input elements. Set this property to `true` to output the frequency indices in bit-reversed order.

Default: `false`

Normalize

Divide butterfly outputs by two

Set this property to `true` if the output of the FFT should be divided by the FFT length. This option is useful when you want the output of the FFT to stay in the same amplitude range as its input. This is particularly useful when working with fixed-point data types.

Default: `false` with no scaling

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`.

Default: Floor

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as Wrap or Saturate.

Default: Wrap

SineTableDataType

Sine table word and fraction lengths

Specify the sine table data type as Same word length as input, or Custom.

Default: Same word length as input

CustomSineTableDataType

Sine table word and fraction lengths

Specify the sine table fixed-point type as an unscaled numerictype object with a Signedness of Auto. This property applies only when you set the SineTableDataType property to Custom.

Default: numerictype([],16)

ProductDataType

Product word and fraction lengths

Specify the product data type as Full precision, Same as input, or Custom.

Default: Full precision

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled numerictype object with a Signedness of Auto. This property applies only when you set the ProductDataType property to Custom.

Default: numerictype([],32,30)

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator data type as Full precision, Same as input, Same as product, or Custom.

Default: Full precision

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled numerictype object with a Signedness of Auto. This property applies only when you set the AccumulatorDataType property to Custom.

Default: numerictype([],32,30)

OutputDataType

Output word and fraction lengths

Specify the output data type as Full precision, Same as input, or Custom.

Default: Full precision

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled numerictype object with a Signedness of Auto. This property applies when you set the OutputDataType property to Custom.

Default: numerictype([],16,15)

Methods

step   Compute 2D discrete Fourier transform of input

Common to All System Objects	
release	Allow System object property value changes

Examples

Use 2-D FFT to View Frequency Components of an Image

Create the FFT object

```
fftObj = vision.FFT;
```

Warning: The vision.FFT will be removed in a future release. Use the fft2 function with

Read in an image.

```
I = im2single(imread('pout.tif'));
```

Compute the FFT.

```
J = step(fftObj, I);
```

Shift zero-frequency components to the center of the spectrum.

```
J_shifted = fftshift(J);
```

Display original image and visualize its FFT magnitude response.

```
figure; imshow(I); title('Input image, I');
```

Input image, I


```
figure; imshow(log(max(abs(J_shifted), 1e-6)),[]), colormap(jet(64));
title('Magnitude of the FFT of I');
```

Magnitude of the FFT of I
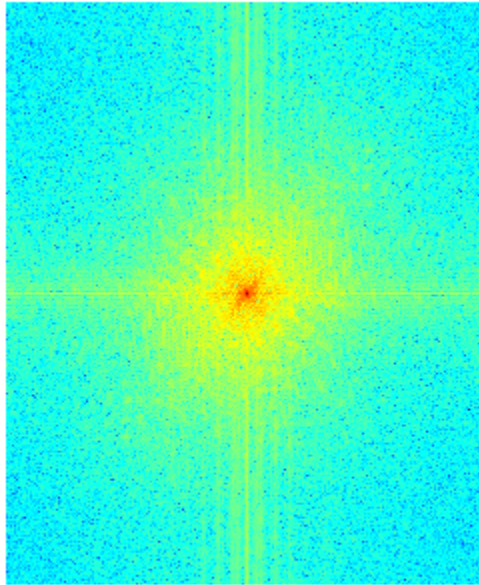
References

[1] FFTW (http://www.fftw.org)

[2] Frigo, M. and S. G. Johnson, "FFTW: An Adaptive Software Architecture for the FFT,"*Proceedings of the International Conference on Acoustics, Speech, and Signal Processing*, Vol. 3, 1998, pp. 1381-1384.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
fft2 | vision.DCT | vision.IDCT | vision.IFFT

Introduced in R2012a

step

System object: vision.FFT
Package: vision

Compute 2D discrete Fourier transform of input

Syntax

Y = step(H,X)

Description

Note Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, y = step(obj,x) and y = obj(x) perform equivalent operations.

Y = step(H,X) computes the 2D discrete Fourier transform (DFT), *Y*, of an *M*-by-*N* input matrix *X*, where the values of *M* and *N* are integer powers of two.

Note H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

vision.ForegroundDetector System object

Package: vision

Foreground detection using Gaussian mixture models

Description

The `ForegroundDetector` compares a color or grayscale video frame to a background model to determine whether individual pixels are part of the background or the foreground. It then computes a foreground mask. By using background subtraction, you can detect foreground objects in an image taken from a stationary camera.

To detect foreground in an image :

1   Create the vision.ForegroundDetector object and set its properties.
2   Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
detector = vision.ForegroundDetector
detector = vision.ForegroundDetector(Name,Value)
```

Description

`detector = vision.ForegroundDetector` computes and returns a foreground mask using the Gaussian mixture model (GMM).

`detector = vision.ForegroundDetector(Name,Value)` creates a foreground detector object, `detector`, with additional options specified by one or more `Name,Value` pair arguments.

Name is a property name and Value is the corresponding value. Name must appear inside single quotes (''). You can specify several name-value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: detector = vision.ForegroundDetector('LearningRate',0.005)

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the release function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

AdaptLearningRate — Adapt learning rate
'true' (default) | 'false'

Adapt learning rate, specified as 'true' or 'false'. This property enables the object to adapt the learning rate during the period specified by the NumTrainingFrames property. When you set this property to true, the object sets the LearningRate property to 1/ (current frame number). When you set this property to false, the LearningRate property must be set at each time step.

NumTrainingFrames — Number of initial video frames for training background model
150 (default) | integer

Number of initial video frames for training background model, specified as an integer. When you set the AdaptLearningRate to false, this property will not be available.

LearningRate — Learning rate for parameter updates
0.005 (default) | numeric scalar

Learning rate for parameter updates, specified as a numeric scalar. Specify the learning rate to adapt model parameters. This property controls how quickly the model adapts to changing conditions. Set this property appropriately to ensure algorithm stability.

The learning rate specified by this property can only be implemented when you set the AdaptLearningRate to true and after the training period specified by NumTrainingFrames is over.

Tunable: Yes

MinimumBackgroundRatio — Threshold to determine background model
0.7 (default) | numeric scalar

Threshold to determine background model, specified as a numeric scalar. Set this property to represent the minimum possibility for pixels to be considered background values. Multimodal backgrounds cannot be handled if this value is too small.

NumGaussians — Number of Gaussian modes in the mixture model
5 (default) | positive integer

Number of Gaussian modes in the mixture model, specified as a positive integer. Typically, you would set this value to 3, 4 or 5. Set the value to 3 or greater to be able to model multiple background modes.

InitialVariance — Initial mixture model variance
'Auto' (default) | numeric scalar

Initial mixture model variance, specified as a numeric scalar or the 'Auto' character vector.

Image Data Type	Initial Variance
double/single	(30/255)^2
uint8	30^2

This property applies to all color channels for color inputs.

Usage

Syntax

```
foregroundMask = detector(I)
foregroundMask = detector(I,learningRate)
```

Description

`foregroundMask = detector(I)` computes the foreground mask for input image `I`, and returns a logical mask. Values of `1` in the mask correspond to foreground pixels.

`foregroundMask = detector(I,learningRate)` computes the foreground mask using the `LearningRate`.

Input Arguments

`I` — Input image
grayscale | truecolor (RGB)

Input image, specified as grayscale or truecolor (RGB).

`learningRate` — Learning rate for parameter updates
`0.005` (default) | numeric scalar

Learning rate for parameter updates, specified as a numeric scalar. Specify the learning rate to adapt model parameters. This property controls how quickly the model adapts to changing conditions. Set this property appropriately to ensure algorithm stability.

The learning rate specified by this property can only be implemented when you set the `AdaptLearningRate` to `true` and after the training period specified by `NumTrainingFrames` is over.

Tunable: Yes

Output Arguments

`foregroundMask` — Foreground mask
binary mask

Foreground mask computed using a Gaussian mixture model, returned as a binary mask.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Common to All System Objects

step   Run System object algorithm

release   Release resources and allow changes to System object property values and input characteristics

reset   Reset internal states of System object

Examples

Detect Moving Cars In Video

Create a video source object to read file.

```
videoSource = vision.VideoFileReader('viptraffic.avi',...
    'ImageColorSpace','Intensity','VideoOutputDataType','uint8');
```

Create a detector object and set the number of training frames to 5 (because it is a short video.) Set initial standard deviation.

```
detector = vision.ForegroundDetector(...
        'NumTrainingFrames', 5, ...
        'InitialVariance', 30*30);
```

Perform blob analysis.

```
blob = vision.BlobAnalysis(...
        'CentroidOutputPort', false, 'AreaOutputPort', false, ...
        'BoundingBoxOutputPort', true, ...
        'MinimumBlobAreaSource', 'Property', 'MinimumBlobArea', 250);
```

Insert a border.

```
shapeInserter = vision.ShapeInserter('BorderColor','White');
```

Play results. Draw bounding boxes around cars.

```
videoPlayer = vision.VideoPlayer();
while ~isDone(videoSource)
    frame  = videoSource();
    fgMask = detector(frame);
```

```
bbox    = blob(fgMask);
out     = shapeInserter(frame,bbox);
videoPlayer(out);
end
```
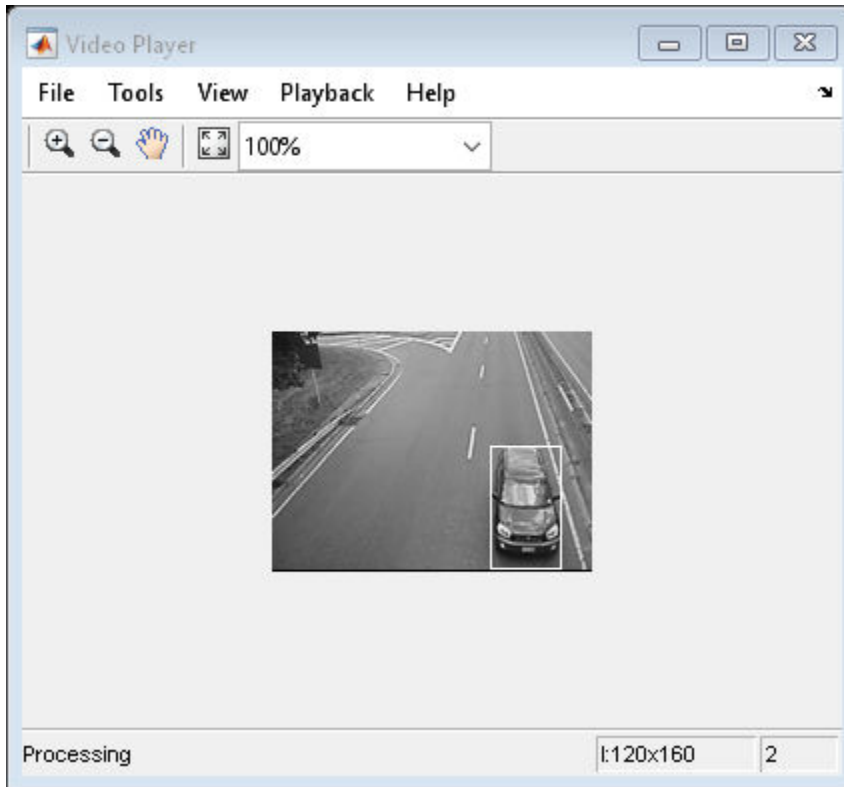

Release objects.

```
release(videoPlayer);
```
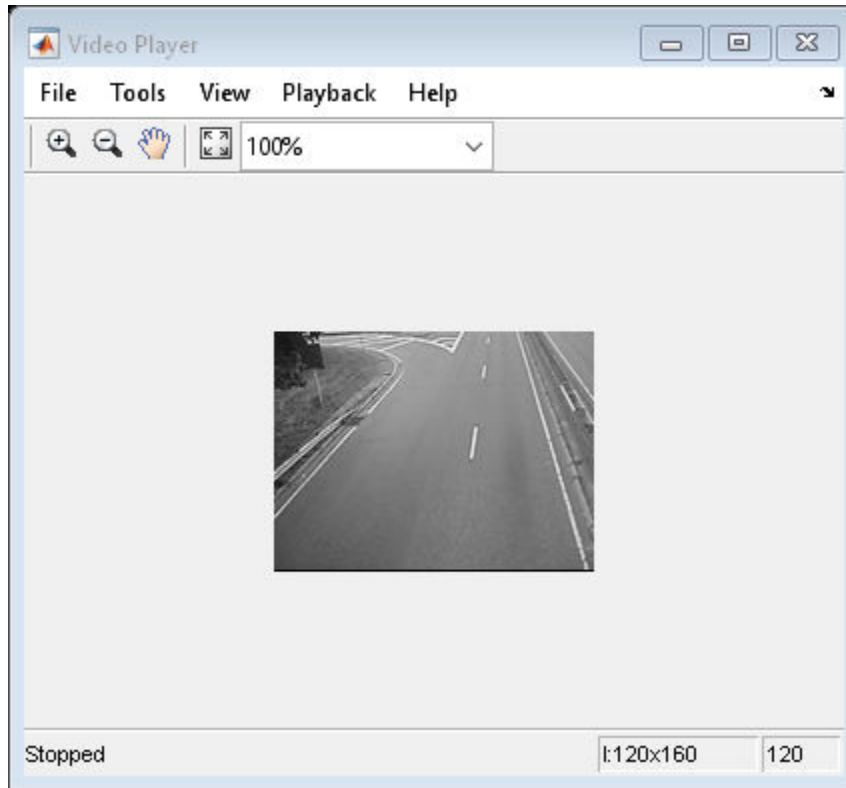
```
release(videoSource);
```

References

[1] Kaewtrakulpong, P. and R. Bowden. *An Improved Adaptive Background Mixture Model for Realtime Tracking with Shadow Detection*. In Proc. 2nd European Workshop on Advanced Video Based Surveillance Systems, AVBS01, VIDEO BASED SURVEILLANCE SYSTEMS: Computer Vision and Distributed Processing (September 2001)

[2] Stauffer, C. and W.E.L. Grimson. *Adaptive Background Mixture Models for Real-Time Tracking*, Computer Vision and Pattern Recognition, IEEE Computer Society Conference on, Vol. 2 (06 August 1999), pp. 2246-252 Vol. 2.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates platform-dependent library for MATLAB host target.
- Generates portable C code for non MATLAB host target.
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

Topics
"Multiple Object Tracking"

Introduced in R2011a

vision.GammaCorrector System object

Package: vision

Apply or remove gamma correction from images or video streams

Description

The `GammaCorrector` object applies gamma correction to input images or video streams.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.GammaCorrector` returns a System object, `HGAMMACORR`. This object applies or removes gamma correction from images or video streams.

`H = vision.GammaCorrector(`*Name,Value*`)` returns a gamma corrector object, `H`, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1, Value1,...,NameN,ValueN*).

`H = vision.GammaCorrector(GAMMA,`*Name,Value*`)` returns a gamma corrector object, `H`, with the Gamma property set to `GAMMA` and other specified properties set to the specified values.

Properties

`Correction`

Specify gamma correction or linearization

Specify the object's operation as one of `Gamma` | `De-gamma`. The default is `Gamma`.

Gamma

Gamma value of output or input

When you set the `Correction` property to `Gamma`, this property gives the desired gamma value of the output video stream. When you set the `Correction` property to `De-gamma`, this property indicates the gamma value of the input video stream. You must set this property to a numeric scalar value greater than or equal to `1`.

The default is `2.2`.

LinearSegment

Enable gamma curve to have linear portion near origin

Set this property to `true` to make the gamma curve have a linear portion near the origin.

The default is `true`.

BreakPoint

I-axis value of the end of gamma correction linear segment

Specify the I-axis value of the end of the gamma correction linear segment as a scalar numeric value between `0` and `1`. This property applies when you set the `LinearSegment` property to `true`.

The default is `0.018`.

Methods

step   Apply or remove gamma correction from input

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Improve image contrast.

```
hgamma = ...
  vision.GammaCorrector(2.0,'Correction','De-gamma');
x = imread('pears.png');
y = step(hgamma, x);

imshow(x); title('Original Image');
figure, imshow(y);
title('Enhanced Image after De-gamma Correction');
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the Gamma Correction block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• See "System Objects in MATLAB Code Generation" (MATLAB Coder).

Introduced in R2012a

step

System object: vision.GammaCorrector
Package: vision

Apply or remove gamma correction from input

Syntax

```
Y = step(H,X)
```

Description

> **Note** Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, y = step(obj,x) and y = obj(x) perform equivalent operations.

Y = step(H,X) applies or removes gamma correction from input *X* and returns the gamma corrected or linearized output *Y*.

> **Note** H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

vision.HistogramBasedTracker System object

Package: vision

Histogram-based object tracking

Description

The histogram-based tracker incorporates the continuously adaptive mean shift (CAMShift) algorithm for object tracking. It uses the histogram of pixel values to identify the tracked object.

To track an object:

1 Create the vision.HistogramBasedTracker object and set its properties.
2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
hbtracker = vision.HistogramBasedTracker
hbtracker = vision.HistogramBasedTracker(Name,Value)
```

Description

`hbtracker = vision.HistogramBasedTracker` returns a tracker that tracks an object by using the CAMShift algorithm. It uses the histogram of pixel values to identify the tracked object. To initialize the tracking process, you must use the `initializeObject` function to specify an exemplar image of the object.

`hbtracker = vision.HistogramBasedTracker(Name,Value)` creates a people detector object, `tracker`, with additional options specified by one or more `Name,Value` pair arguments.

`Name` is a property name and `Value` is the corresponding value. `Name` must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: hbtracker = vision.HistogramBasedTracker('ObjectHistogram',[])

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

`ObjectHistogram` — **Normalized pixel value histogram**
`[]` (default) | *N*-element vector.

Normalized pixel value histogram, specified as an *N*-element vector. This vector specifies the normalized histogram of the object's pixel values. Histogram values must be normalized to a value between `0` and `1`. You can use the `initializeObject` method to set the property.

Tunable: Yes

Usage

Syntax

```
bbox = hbtracker(I)
[bbox,orientation] = hbtracker(I)
[bbox,orientation,score] = hbtracker(I)
```

Description

`bbox = hbtracker(I)` returns a bounding box, of the tracked object. Before using the tracker, you must identify the object to track, and set the initial search window. Use the `initializeObject` function to do this.

`[bbox,orientation] = hbtracker(I)` additionally returns the angle between the *x*-axis and the major axis of the ellipse that has the same second-order moments as the object. The returned angle is between –pi/2 and pi/2.

`[bbox,orientation,score] = hbtracker(I)` additionally returns the confidence score for the returned bounding box that contains the tracked object.

Input Arguments

`I` — Video frame
grayscale | truecolor (RGB)

Video frame, specified as grayscale or truecolor (RGB).

Output Arguments

`bbox` — Bounding box
[*x y width height*]

Bounding box, returned as a four-element vector in the format, [*x y width height*].

`orientation` — Orientation
angle

Orientation, returned as an angle between –pi/2 and pi/2. The angle is measured from the *x*-axis and the major axis of the ellipse that has the same second-order moments as the object.

`score` — Score
scalar

Score, returned as a scalar in the range [0 1]. A value of 1 corresponds to the maximum confidence. 1.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to vision.HistogramBasedTracker

initializeObject   Set object to track
initializeSearchWindow   Set object to track

Common to All System Objects

step   Run System object algorithm
release   Release resources and allow changes to System object property values and
          input characteristics
reset   Reset internal states of System object

Examples

Track a Face

Track and display a face in each frame of an input video.

Create System objects for reading and displaying video and for drawing a bounding box of the object.

```
videoFileReader = vision.VideoFileReader('vipcolorsegmentation.avi');
videoPlayer = vision.VideoPlayer();
shapeInserter = vision.ShapeInserter('BorderColor','Custom', ...
    'CustomBorderColor',[1 0 0]);
```

Read the first video frame, which contains the object. Convert the image to HSV color space. Then define and display the object region.

```
objectFrame = videoFileReader();
objectHSV = rgb2hsv(objectFrame);
objectRegion = [40, 45, 25, 25];
objectImage = shapeInserter(objectFrame, objectRegion);
```

```
figure
imshow(objectImage)
title('Red box shows object region')
```


Red box shows object region

(Optionally, you can select the object region using your mouse. The object must occupy the majority of the region. Use the following command.)

```
% figure;
% imshow(objectFrame);
% objectRegion=round(getPosition(imrect))
```

Set the object, based on the hue channel of the first video frame.

```
tracker = vision.HistogramBasedTracker;
initializeObject(tracker, objectHSV(:,:,1) , objectRegion);
```

Track and display the object in each video frame. The while loop reads each image frame, converts the image to HSV color space, then tracks the object in the hue channel where it is distinct from the background. Finally, the example draws a box around the object and displays the results.

```
while ~isDone(videoFileReader)
  frame = videoFileReader();
  hsv = rgb2hsv(frame);
  bbox = tracker(hsv(:,:,1));

  out = shapeInserter(frame,bbox);
```

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```
    videoPlayer(out);
end
```


Release the video reader and player.

```
release(videoPlayer);
```

```
release(videoFileReader);
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

`imrect` | `rgb2hsv` | `size`

Introduced in R2012a

vision.IDCT System object

Package: vision

Compute 2-D inverse discrete cosine transform

Description

Note The `vision.IDCT` System object will be removed in a future release. Use the `idct2` function with equivalent functionality instead.

The `IDCT` object computes 2-D inverse discrete cosine transform of the input signal. The number of rows and columns of the input matrix must be a power of 2.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.IDCT` returns a System object, `H`, used to compute the two-dimensional inverse discrete cosine transform (2-D IDCT) of a real input signal.

`H = vision.IDCT(`*Name*`,`*Value*`)` returns a 2-D inverse discrete cosine transform System object, `H`, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN,ValueN*).

Properties

SineComputation

Specify how the System object computes sines and cosines as `Trigonometric function`, or `Table lookup`. This property must be set to `Table lookup` for fixed-point inputs.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.This property applies when you set the `SineComputation` to `Table lookup`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Wrap`.

SineTableDataType

Sine table word-length designation

Specify the sine table fixed-point data type as `Same word length as input`, or `Custom`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Same word length as input`.

CustomSineTableDataType

Sine table word length

Specify the sine table fixed-point type as a signed, unscaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup` and you set the `SineTableDataType` property to `Custom`. The default is `numerictype(true,16)`.

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as `Full precision`, `Same as first input`, or `Custom`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Custom`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a signed, scaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup`, and the `ProductDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as `Full precision`, `Same as input`,`Same as product`, `Same as first input`, `Custom`. This property applies when you set the `SineComputation` property to `Table lookup`. The default is `Full precision`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a signed, scaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup`, and `AccumulatorDataType` property to `Custom`. The default is `numerictype(true, 32,30)`.

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as `Full precision`, `Same as first input`, or `Custom`. This property applies when you set the `SineComputation` to `Table lookup`. The default is `Custom`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a signed, scaled `numerictype` object. This property applies when you set the `SineComputation` to `Table lookup`, and the `OutputDataType` property to `Custom`. The default is `numerictype(true,16,15)`.

Methods

step   Compute 2-D inverse discrete cosine transform of the input

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Use 2-D discrete cosine transform (DCT) to analyze the energy content in an image. Set the DCT coefficients lower than a threshold of 0. Reconstruct the image using 2-D inverse discrete cosine transform (IDCT).

```
hdct2d = vision.DCT;
I = double(imread('cameraman.tif'));
J = step(hdct2d, I);
imshow(log(abs(J)),[]), colormap(jet(64)), colorbar

hidct2d = vision.IDCT;
J(abs(J) < 10) = 0;
It = step(hidct2d, J);
figure, imshow(I, [0 255]), title('Original image')
figure, imshow(It,[0 255]), title('Reconstructed image')
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D IDCT block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

vision.DCT

Introduced in R2012a

step

System object: vision.IDCT
Package: vision

Compute 2-D inverse discrete cosine transform of the input

Syntax

Y = step(H,X)

Description

Note Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, y = step(obj,x) and y = obj(x) perform equivalent operations.

Y = step(H,X) computes the 2-D inverse discrete cosine transform, *Y*, of input *X*.

Note H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

vision.IFFT System object

Package: vision

Two–dimensional inverse discrete Fourier transform

Description

> **Note** The `vision.IFFT` System object will be removed in a future release. Use the `ifft` function with equivalent functionality instead.

The `vision.IFFT` object computes the inverse 2D discrete Fourier transform (IDFT) of a two-dimensional input matrix. The object uses one or more of the following fast Fourier transform (FFT) algorithms depending on the complexity of the input and whether the output is in linear or bit-reversed order:

- Double-signal algorithm
- Half-length algorithm
- Radix-2 decimation-in-time (DIT) algorithm
- Radix-2 decimation-in-frequency (DIF) algorithm
- An algorithm chosen by FFTW [1], [2]

> **Note** Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.IFFT` returns a 2D IFFT object, `H`, with the default property and value pair settings.

`H = vision.IFFT(`*`Name`*`,`*`Value`*`)` returns a 2D IFFT object, H, with each property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

FFTImplemenation

FFT implementation

Specify the implementation used for the FFT as one of `Auto` | `Radix-2` | `FFTW`. When you set this property to `Radix-2`, the FFT length must be a power of two.

BitReversedInput

Indicates whether input is in bit-reversed order

Set this property to `true` if the order of 2D FFT transformed input elements are in bit-reversed order. The default is `false`, which denotes linear ordering.

ConjugateSymmetricInput

Indicates whether input is conjugate symmetric

Set this property to `true` if the input is conjugate symmetric. The 2D DFT of a real valued signal is conjugate symmetric and setting this property to `true` optimizes the 2D IFFT computation method. Setting this property to `false` for conjugate symmetric inputs results in complex output values with nonzero imaginary parts. Setting this property to `true` for non conjugate symmetric inputs results in invalid outputs. This property must be `false` for fixed-point inputs. The default is `true`.

Normalize

Divide output by FFT length

Specify if the 2D IFFT output should be divided by the FFT length. The value of this property defaults to `true` and divides each element of the output by the product of the row and column dimensions of the input matrix.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as `Ceiling`, `Convergent`, `Floor`, `Nearest`, `Round`, `Simplest`, or `Zero`. This property applies when you set the `ConjugateSymmetricInput` property to `false`. The default is `Floor`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`. This property applies when you set the `ConjugateSymmetricInput` property to `false`. The default is `Wrap`.

SineTableDataType

Sine table word and fraction lengths

Specify the sine table data type as `Same word length as input`, `Custom`. This property applies when you set the `ConjugateSymmetricInput` property to `false`. The default is `Same word length as input`.

CustomSineTableDataType

Sine table word and fraction lengths

Specify the sine table fixed-point type as an unscaled `numerictype` object with a `Signedness` of `Auto`. This property applies only when the `ConjugateSymmetricInput` property to `false` and the `SineTableDataType` property is `Custom`. The default is `numerictype([],16)`.

ProductDataType

Product word and fraction lengths

Specify the product data type as `Full precision`, `Same as input`, or `Custom`. This property applies when you set the `ConjugateSymmetricInput` property to `false`. The default is `Full precision`.

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CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `ConjugateSymmetricInput` property to `false` and the `ProductDataType` property to `Custom`. The default is `numerictype([],32,30)`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator data type as `Full precision`, `Same as input`, `Same as product`, or `Custom`. This property applies when you set the `ConjugateSymmetricInput` property to `false`. The default is `Full precision`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `ConjugateSymmetricInput` property to `false` and the `AccumulatorDataType` property to `Custom`. The default is `numerictype([],32,30)`.

OutputDataType

Output word and fraction lengths

Specify the output data type as `Full precision`, `Same as input`, or `Custom`. This property applies when you set the `ConjugateSymmetricInput` property to `false`. The default is `Full precision`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `ConjugateSymmetricInput` property to `false` and the `OutputDataType` property is `Custom`. The default is `numerictype([],16,15)`.

Methods

step   Compute 2D inverse discrete Fourier transform

Common to All System Objects	
release	Allow System object property value changes

Examples

Use the 2D IFFT object to convert an intensity image.

```
 hfft2d = vision.FFT;
 hifft2d = vision.IFFT;

% Read in the image
        xorig = single(imread('cameraman.tif'));

% Convert the image from the spatial
% to frequency domain and back
        Y = step(hfft2d, xorig);
       xtran = step(hifft2d, Y);

% Display the newly generated intensity image
        imshow(abs(xtran), []);
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D IFFT block reference page. The object properties correspond to the Simulink block parameters.

References

[1] FFTW (http://www.fftw.org)

[2] Frigo, M. and S. G. Johnson, "FFTW: An Adaptive Software Architecture for the FFT,"*Proceedings of the International Conference on Acoustics, Speech, and Signal Processing*, Vol. 3, 1998, pp. 1381-1384.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
vision.DCT | vision.FFT | vision.IDCT

Introduced in R2012a

step

System object: vision.IFFT
Package: vision

Compute 2D inverse discrete Fourier transform

Syntax

Y = step(H,X)

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`Y = step(H,X)` computes the 2D inverse discrete Fourier transform (IDFT), *Y*, of an *M*-by-*N* input matrix *X*, where the values of *M* and *N* are integer powers of two.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

integralKernel class

Define filter for use with integral images

Description

This object describes box filters for use with integral images.

Construction

`intKernel = integralKernel(bbox,weights)` defines an upright box filter using an *M*-by-4 matrix of bounding boxes and their corresponding weights.

`intKernel = integralKernel(bbox,weights,orientation)` the specified orientation.

Input Arguments

bbox — Bounding boxes
4-element vector | *M*-by-4 matrix

Bounding boxes, specified as either a 4-element [*x*,*y*,*width*, *height*] vector or an *M*-by-4 matrix of individual bounding boxes. The bounding box defines the filter. The (*x*,*y*) coordinates represent the top-most corner of the kernel. The (*width*, *height*) elements represent the width and height accordingly. Specifying the bounding boxes as an *M*-by-4 matrix is particularly useful for constructing Haar-like features composed of multiple rectangles.

Sums are computed over regions defined by `bbox`. The bounding boxes can overlap. See "Define an 11-by-11 Average Filter" on page 2-433 for an example of how to specify a box filter.

weights — Weights
M-length vector

Weights, specified as an *M*-length vector of weights corresponding to the bounding boxes.

For example, a conventional filter with the coefficients:

```
h    = [1   1   1   1;
         1   1   1   1;
        -1  -1  -1  -1;
        -1  -1  -1  -1]
```

and two regions:
region 1: x=1, y=1, width = 4, height = 2
region 2: x=1, y=3, width = 4, height = 2
can be specified as

```
boxH = integralKernel([1 1 4 2; 1 3 4 2], [1, -1])
```

orientation — Filter orientation
`'upright'` | `'rotated'`

Filter orientation, specified as the character vector `'upright'` or `'rotated'`. When you set the orientation to `'rotated'`, the (x,y) components refer to the location of the top-left corner of the bounding box. The (*width*,*height*) components refer to a 45-degree line from the top-left corner of the bounding box.

Properties

These properties are read-only.

BoundingBoxes — Bounding boxes
4-element vector | *M*-by-4 matrix

Bounding boxes, stored as either a 4-element [x,y,*width*, *height*] vector or an *M*-by-4 matrix of individual bounding boxes.

Weights — Weights
vector

Weights, stored as a vector containing a weight for each bounding box. The weights are used to define the coefficients of the filter.

Coefficients — Filter coefficients
numeric

Filter coefficients, stored as a numeric value.

Center — Filter center
[*x*,*y*] coordinates

Filter center, stored as [*x*,*y*] coordinates. The filter center represents the center of the bounding rectangle. It is calculated by halving the dimensions of the rectangle. For even dimensional rectangles, the center is placed at subpixel locations. Hence, it is rounded up to the next integer.

For example, for this filter, the center is at [3,3].
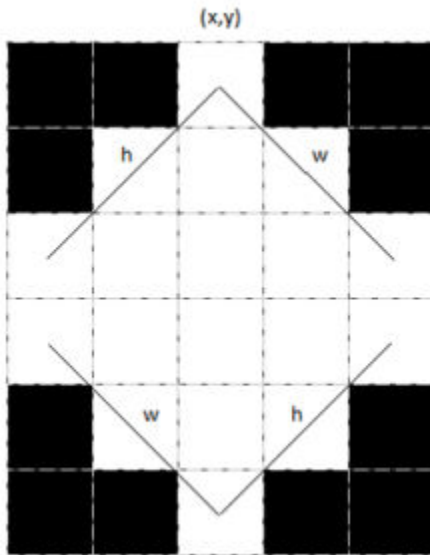
These coordinates are in the kernel space, where the top-left corner is (1,1). To place the center in a different location, provide the appropriate bounding box specification. For this filter, the best workflow would be to construct the upright kernel and then call the `rot45` method to provide the rotated version.

Size — Filter size
2-element vector

Filter size, stored as a 2-element vector. The size of the kernel is computed to be the dimensions of the rectangle that bounds the kernel. For a single bounding box vector

[*x*,*y*,*width*, *height*], the kernel is bounded within a rectangle of dimensions [(*width* +*height*) (*width*+*height*)-1].

For cascaded rectangles, the lowest corner of the bottom-most rectangle defines the size. For example, a filter with a bounding box specification of [3 1 3 3], with weights set to 1, produces a 6-by-5 filter with this kernel:
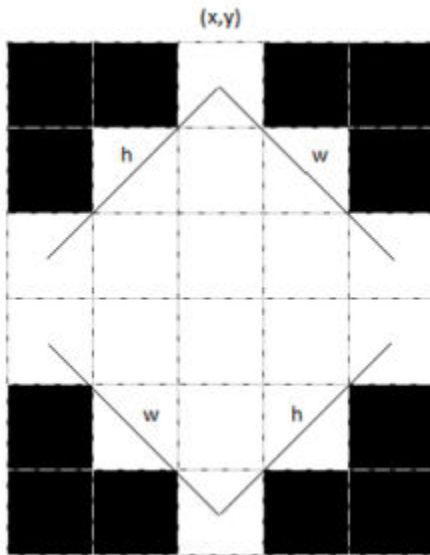
Orientation — Filter orientation
'upright' (default) | 'rotated'

Filter orientation, stored as the character vector 'upright' or 'rotated'.

Methods

transpose	Transpose filter
rot45	Rotates upright kernel clockwise by 45 degrees

Examples

Define an 11-by-11 Average Filter

```
avgH = integralKernel([1 1 11 11], 1/11^2);
```

Define a Filter to Approximate a Gaussian Second Order Partial Derivative in Y Direction

```
ydH = integralKernel([1,1,5,9;1,4,5,3], [1, -3]);
```

You can also define this filter as integralKernel([1,1,5,3;1,4,5,3;1,7,5,3], [1, -2, 1]);|. This filter definition is less efficient because it requires three bounding boxes.

Visualize the filter.

```
ydH.Coefficients
```

ans = *9×5*

```
     1     1     1     1     1
     1     1     1     1     1
     1     1     1     1     1
    -2    -2    -2    -2    -2
    -2    -2    -2    -2    -2
    -2    -2    -2    -2    -2
     1     1     1     1     1
     1     1     1     1     1
     1     1     1     1     1
```

Create a Haar-like Wavelet to Detect 45-Degree Edges

Create the filter.

```
K = integralKernel([3,1,3,3;6 4 3 3], [1 -1], 'rotated');
```

Visualize the filter and mark the center.

```
    imshow(K.Coefficients, [], 'InitialMagnification', 'fit');
    hold on;
```

```
plot(K.Center(2),K.Center(1), 'r*');
impixelregion;
```
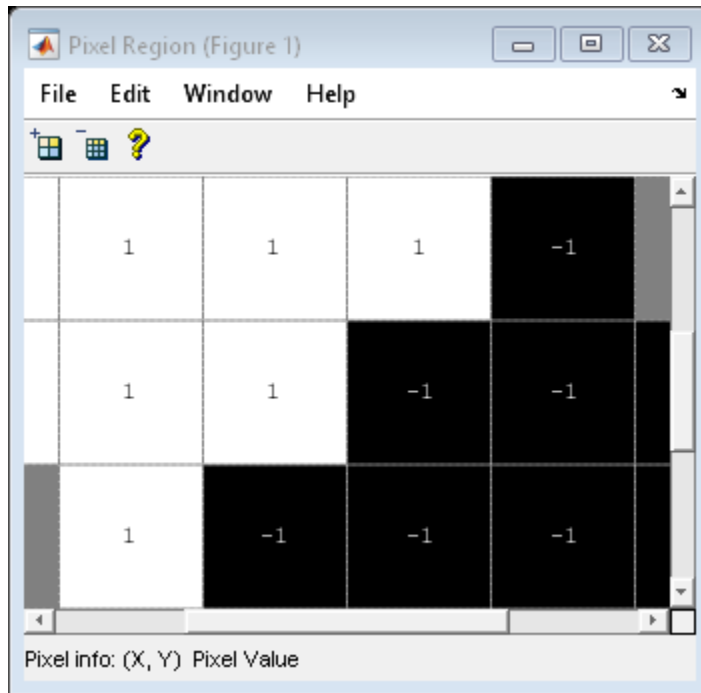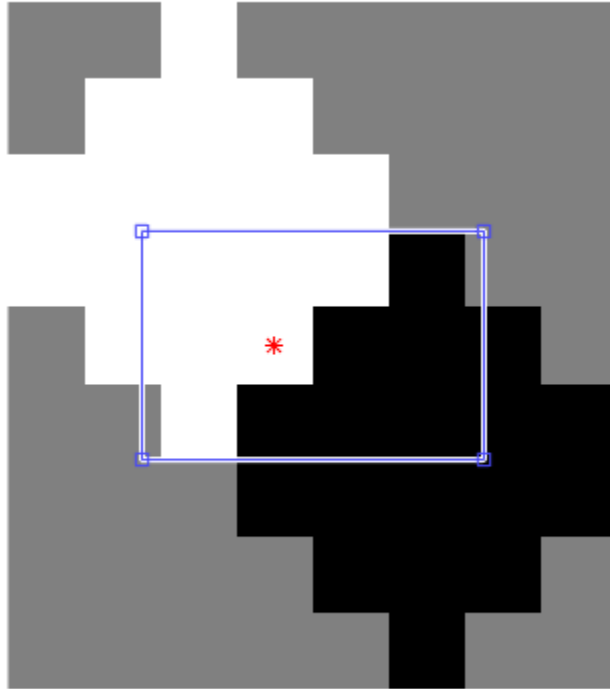
Blur an Image Using an Average Filter

Read and display the input image.

```
I = imread('pout.tif');
imshow(I);
```

Compute the integral image.

```
intImage = integralImage(I);
```

Apply a 7-by-7 average filter.

```
avgH = integralKernel([1 1 7 7], 1/49);
J = integralFilter(intImage, avgH);
```

Cast the result back to the same class as the input image.

```
J = uint8(J);
figure
imshow(J);
```

- "Compute an Integral Image" on page 3-411
- "Find Vertical and Horizontal Edges in Image"

More About

Computing an Integral Image and Using it for Filtering with Box Filters

The `integralImage` function together with the `integralKernel` object and `integralFilter` function complete the workflow for box filtering based on integral images. You can use this workflow for filtering with box filters.

- Use the `integralImage` function to compute the integral images
- Use the `integralFilter` function for filtering

- Use the `integralKernel` object to define box filters

The `integralKernel` object allows you to transpose the filter. You can use this to aim a directional filter. For example, you can turn a horizontal edge detector into vertical edge detector.

References

Viola, Paul, and Michael J. Jones. "Rapid Object Detection using a Boosted Cascade of Simple Features". *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*. Vol. 1, 2001, pp. 511–518.

See Also
SURFPoints | detectMSERFeatures | detectSURFFeatures | integralFilter | integralImage

Topics
"Compute an Integral Image" on page 3-411
"Find Vertical and Horizontal Edges in Image"

Introduced in R2012a

transpose

Class: integralKernel

Transpose filter

Syntax

```
transposedKernel = transpose(intKernel)
```

Description

`transposedKernel = transpose(intKernel)` transposes the integral kernel. You can use this operation to change the direction of an oriented filter.

Example

Construct Haar-like Wavelet Filters

Horizontal filter

```
horiH = integralKernel([1 1 4 3; 1 4 4 3], [-1, 1]);
```

Using the dot and apostrophe create a vertical filter.

```
vertH = horiH.';
```

Using the transpose method.

```
verticalH = transpose(horiH);
```

rot45

Rotates upright kernel clockwise by 45 degrees

Syntax

```
rotKernel = rot45(intKernel)
```

Description

`rotKernel = rot45(intKernel)` rotates upright kernel clockwise by 45 degrees.

Example

Construct and Rotate a Haar-like Wavelet Filter

Create a horizontal filter.

```
H = integralKernel([1 1 4 3; 1 4 4 3], [-1, 1]);
```

Rotate the filter 45 degrees.

```
rotH = rot45(H);
```

vision.KalmanFilter class

Package: vision

Kalman filter for object tracking

Description

The Kalman filter object is designed for tracking. You can use it to predict a physical object's future location, to reduce noise in the detected location, or to help associate multiple physical objects with their corresponding tracks. A Kalman filter object can be configured for each physical object for multiple object tracking. To use the Kalman filter, the object must be moving at constant velocity or constant acceleration.

The Kalman filter algorithm involves two steps, prediction and correction (also known as the update step). The first step uses previous states to predict the current state. The second step uses the current measurement, such as object location, to correct the state. The Kalman filter implements a discrete time, linear State-Space System.

Note To make configuring a Kalman filter easier, you can use the `configureKalmanFilter` object to configure a Kalman filter. It sets up the filter for tracking a physical object in a Cartesian coordinate system, moving with constant velocity or constant acceleration. The statistics are the same along all dimensions. If you need to configure a Kalman filter with different assumptions, do not use the function, use this object directly.

Construction

`obj = vision.KalmanFilter` returns a Kalman filter object for a discrete time, constant velocity system. In this "State-Space System" on page 2-444, the state transition model, *A*, and the measurement model, *H*, are set as follows:

Variable	Value
A	[1 1 0 0; 0 1 0 0; 0 0 1 1; 0 0 0 1]

Variable	Value
H	[1 0 0 0; 0 0 1 0]

`obj = vision.KalmanFilter(StateTransitionModel,MeasurementModel)` configures the state transition model, *A*, and the measurement model, *H*.

`obj = vision.KalmanFilter(StateTransitionModel,MeasurementModel, ControlModel)` additionally configures the control model, *B*.

`obj = vision.KalmanFilter(StateTransitionModel,MeasurementModel, ControlModel,Name,Value)` configures the Kalman filter object properties, specified as one or more `Name,Value` pair arguments. Unspecified properties have default values.

To Track Objects:

Use the `predict` and `correct` methods based on detection results.

- When the tracked object is detected, use the `predict` and `correct` methods with the Kalman filter object and the detection measurement. Call the methods in the following order:

  ```
  [...] = predict(obj);
  [...] = correct(obj,measurement);
  ```

- When the tracked object is not detected, call the `predict` method, but not the `correct` method. When the tracked object is missing or occluded, no measurement is available. Set the methods up with the following logic:

  ```
  [...] = predict(obj);
  If measurement exists
      [...] = correct(obj,measurement);
  end
  ```

- If the tracked object becomes available after missing for the past *t*-1 contiguous time steps, you can call the `predict` method *t* times. This syntax is particularly useful to process asynchronous video.. For example,

  ```
  for i = 1:k
    [...] = predict(obj);
  end
  [...] = correct(obj,measurement)
  ```

Use the `distance` method to find the best matches. The computed distance values describe how a set of measurements matches the Kalman filter. You can thus select a

measurement that best fits the filter. This strategy can be used for matching object detections against object tracks in a multiobject tracking problem. This distance computation takes into account the covariance of the predicted state and the process noise. The `distance` method can only be called after the `predict` method.

Distance Equation

$$d(z) = (z - Hx)^T \sum{}^{-1}(z - Hx) + \ln|\Sigma|$$

Where $\Sigma = HPH^T + R$ and $|\Sigma|$ is the determinant of Σ. You can then find the best matches by examining the returned distance values.[2]

`d = distance(obj, z_matrix)` computes a distance between the location of a detected object and the predicted location by the Kalman filter object. Each row of the *N*-column `z_matrix` input matrix contains a measurement vector. The `distance` method returns a row vector where each distance element corresponds to the measurement input.

State-Space System

This object implements a discrete time, linear state-space system, described by the following equations.

State equation:	$x(k) = Ax(k-1) + Bu(k-1) + w(k-1)$
Measurement equation:	$z(k) = Hx(k) + v(k)$

Variable Definition

Variable	Description	Dimension
k	Time.	Scalar
x	State. Gaussian vector with covariance P. $[\, x \sim N(\bar{x}, P)\,]$	*M*-element vector
P	State estimation error covariance.	*M*-by-*M* matrix

Variable	Description	Dimension
A	State transition model.	M-by-M matrix
B	Control model.	M-by-L matrix
u	Control input.	L-element vector
w	Process noise; Gaussian vector with zero mean and covariance Q. $[\,w \sim N(0, Q)\,]$	M-element vector
Q	Process noise covariance.	M-by-M matrix
z	Measurement. For example, location of detected object.	N-element vector
H	Measurement model.	N-by-M matrix
v	Measurement noise; Gaussian vector with zero mean and covariance R. $[\,v \sim N(0, R)\,]$	N-element vector
R	Measurement noise covariance.	N-by-N matrix

Properties

StateTransitionModel

Model describing state transition between time steps (*A*)

Specify the transition of state between times as an *M*-by-*M* matrix. After the object is constructed, this property cannot be changed. This property relates to the *A* variable in the "State-Space System" on page 2-444.

Default: `[1 1 0 0; 0 1 0 0; 0 0 1 1; 0 0 0 1]`

MeasurementModel

Model describing state to measurement transformation (*H*)

Specify the transition from state to measurement as an *N*-by-*M* matrix. After the object is constructed, this property cannot be changed. This property relates to the *H* variable in the "State-Space System" on page 2-444.

Default: `[1 0 0 0; 0 0 1 0]`

`ControlModel`

Model describing control input to state transformation (*B*)

Specify the transition from control input to state as an *M*-by-*L* matrix. After the object is constructed, this property cannot be changed. This property relates to the *B* variable in the "State-Space System" on page 2-444.

Default: []

`State`

State (*x*)

Specify the state as a scalar or an *M*-element vector. If you specify it as a scalar it will be extended to an *M*-element vector. This property relates to the *x* variable in the "State-Space System" on page 2-444.

Default: [0]

`StateCovariance`

State estimation error covariance (*P*)

Specify the covariance of the state estimation error as a scalar or an *M*-by-*M* matrix. If you specify it as a scalar it will be extended to an *M*-by-*M* diagonal matrix. This property relates to the *P* variable in the "State-Space System" on page 2-444.

Default: [1]

`ProcessNoise`

Process noise covariance (*Q*)

Specify the covariance of process noise as a scalar or an *M*-by-*M* matrix. If you specify it as a scalar it will be extended to an *M*-by-*M* diagonal matrix. This property relates to the *Q* variable in the "State-Space System" on page 2-444.

Default: [1]

`MeasurementNoise`

Measurement noise covariance (*R*)

Specify the covariance of measurement noise as a scalar or an *N*-by-*N* matrix. If you specify it as a scalar it will be extended to an *N*-by-*N* diagonal matrix. This property relates to the *R* variable in the "State-Space System" on page 2-444.

Default: [1]

Methods

distance   Confidence value of measurement

correct   Correction of measurement, state, and state estimation error covariance

predict   Prediction of measurement

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Track Location of An Object

Track the location of a physical object moving in one direction.

Generate synthetic data which mimics the 1-D location of a physical object moving at a constant speed.

```
detectedLocations = num2cell(2*randn(1,40) + (1:40));
```

Simulate missing detections by setting some elements to empty.

```
detectedLocations{1} = [];
  for idx = 16: 25
      detectedLocations{idx} = [];
  end
```

Create a figure to show the location of detections and the results of using the Kalman filter for tracking.

```
figure;
hold on;
```

```
ylabel('Location');
ylim([0,50]);
xlabel('Time');
xlim([0,length(detectedLocations)]);
```
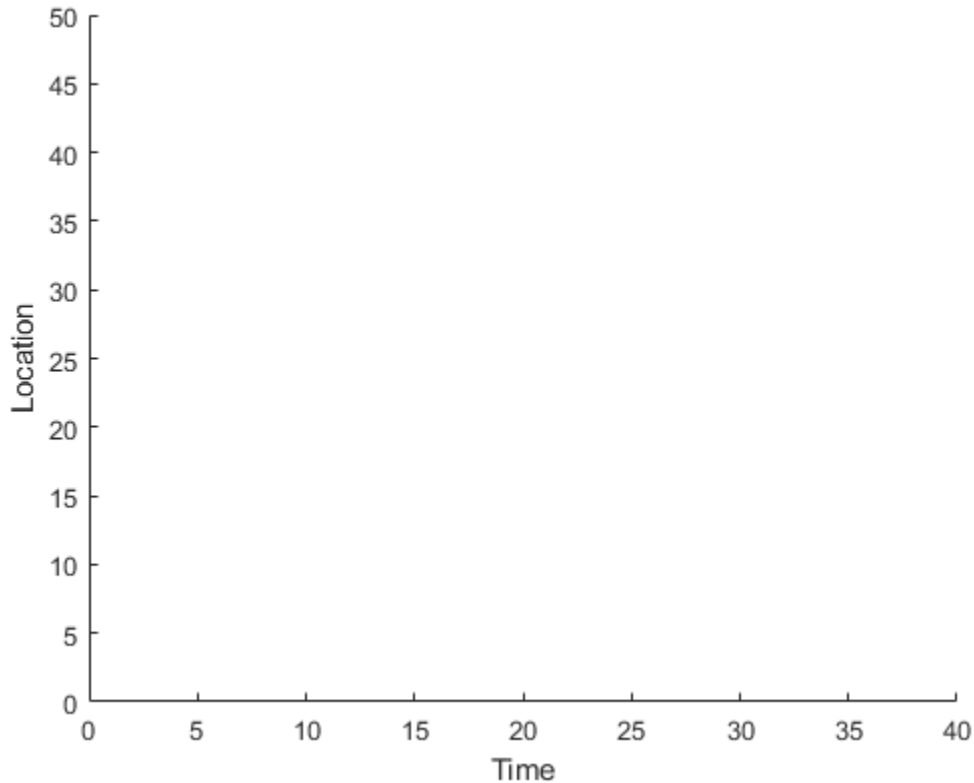

Create a 1-D, constant speed Kalman filter when the physical object is first detected. Predict the location of the object based on previous states. If the object is detected at the current time step, use its location to correct the states.

```
kalman = [];
for idx = 1: length(detectedLocations)
    location = detectedLocations{idx};
    if isempty(kalman)
        if ~isempty(location)
```

```
      stateModel = [1 1;0 1];
      measurementModel = [1 0];
      kalman = vision.KalmanFilter(stateModel,measurementModel,'ProcessNoise',1e-4,'Me
     kalman.State = [location, 0];
    end
  else
    trackedLocation = predict(kalman);
    if ~isempty(location)
      plot(idx, location,'k+');
     d = distance(kalman,location);
      title(sprintf('Distance:%f', d));
      trackedLocation = correct(kalman,location);
    else
      title('Missing detection');
    end
    pause(0.2);
    plot(idx,trackedLocation,'ro');
  end
 end
legend('Detected locations','Predicted/corrected locations');
```
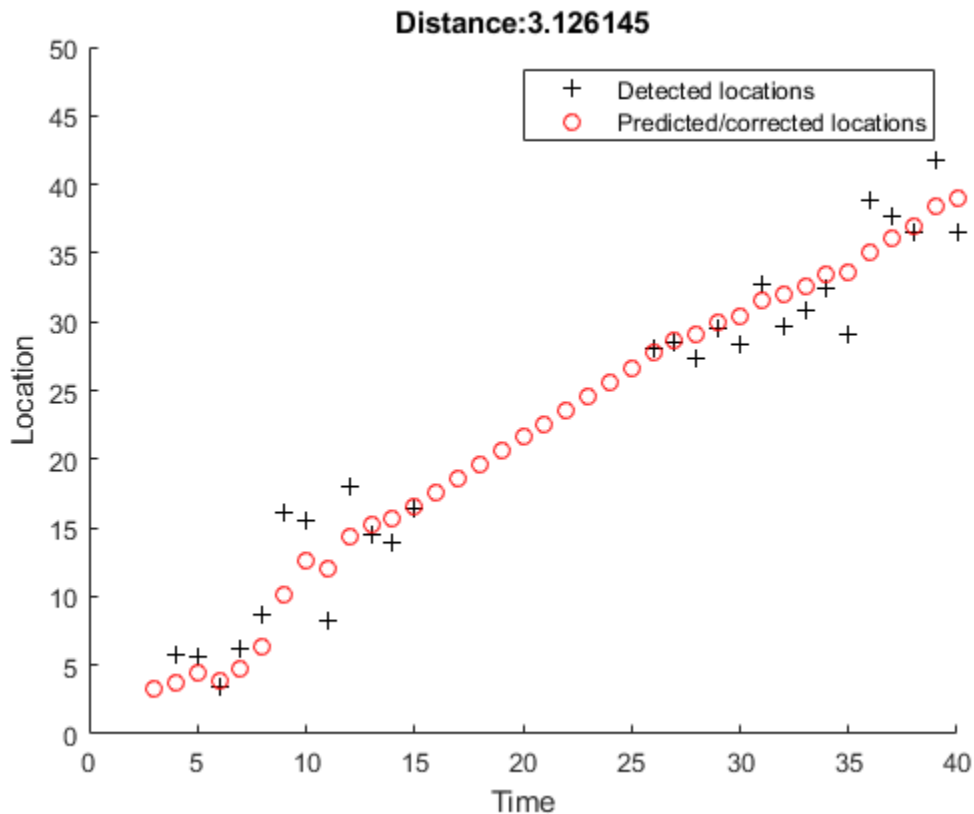
Copyright 2015 The MathWorks, Inc.

Remove Noise From a Signal

Use Kalman filter to remove noise from a random signal corrupted by a zero-mean Gaussian noise.

Synthesize a random signal that has value of 1 and is corrupted by a zero-mean Gaussian noise with standard deviation of 0.1.

```
x = 1;
len = 100;
z = x + 0.1 * randn(1,len);
```

Remove noise from the signal by using a Kalman filter. The state is expected to be constant, and the measurement is the same as state.

```
stateTransitionModel = 1;
measurementModel = 1;
obj = vision.KalmanFilter(stateTransitionModel,measurementModel,'StateCovariance',1,'Pr

z_corr = zeros(1,len);
for idx = 1: len
 predict(obj);
 z_corr(idx) = correct(obj,z(idx));
end
```

Plot results.

```
figure, plot(x * ones(1,len),'g-');
hold on;
plot(1:len,z,'b+',1:len,z_corr,'r-');
legend('Original signal','Noisy signal','Filtered signal');
```
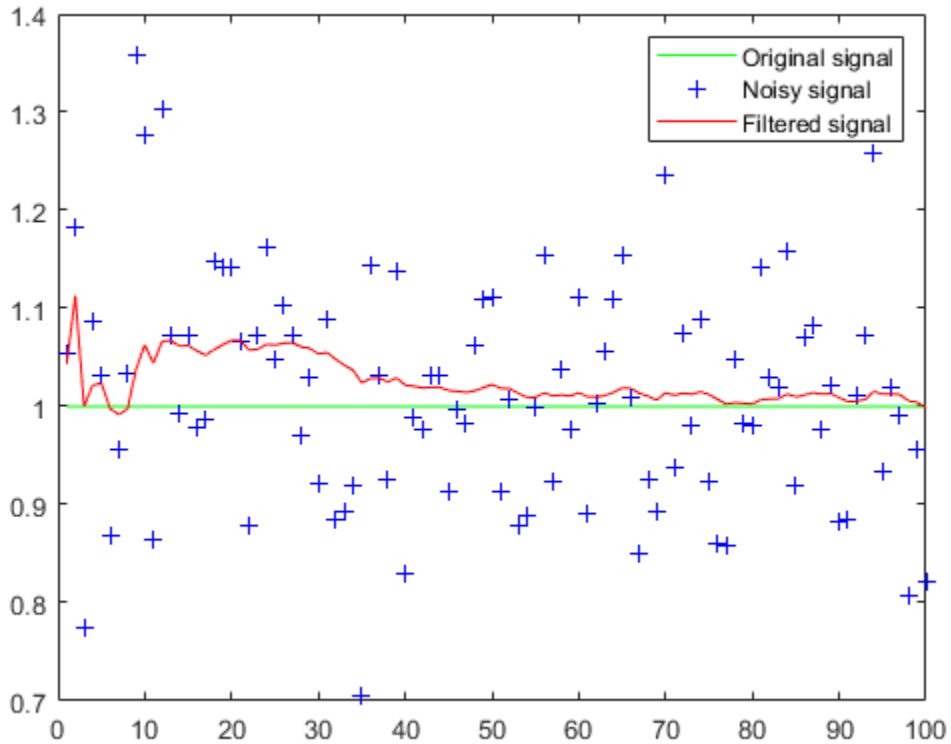
Referencess

[1] Welch, Greg, and Gary Bishop, *An Introduction to the Kalman Filter*, TR 95–041. University of North Carolina at Chapel Hill, Department of Computer Science.

[2] Blackman, S. *Multiple-Target Tracking with Radar Applications.* Artech House, Inc., pp. 93, 1986.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
assignDetectionsToTracks | configureKalmanFilter

Introduced in R2012b

distance

Class: vision.KalmanFilter
Package: vision

Confidence value of measurement

Syntax

```
d = distance(obj, z_matrix)
```

Description

`d = distance(obj, z_matrix)` computes a distance between the location of a detected object and the predicted location by the Kalman filter object. Each row of the *N*-column `z_matrix` input matrix contains a measurement vector. The distance method returns a row vector where each distance element corresponds to the measurement input.

This distance computation takes into account the covariance of the predicted state and the process noise. The `distance` method can only be called after the `predict` method.

correct

Class: vision.KalmanFilter
Package: vision

Correction of measurement, state, and state estimation error covariance

Syntax

```
[z_corr,x_corr,P_corr] = correct(obj,z)
```

Description

`[z_corr,x_corr,P_corr] = correct(obj,z)` returns the correction of measurement, state, and state estimation error covariance. The correction is based on the current measurement z, an N-element vector. The object overwrites the internal state and covariance of the Kalman filter with corrected values.

predict

Class: vision.KalmanFilter
Package: vision

Prediction of measurement

Syntax

```
[z_pred,x_pred,P_pred] = predict(obj)
[z_pred,x_pred,P_pred] = predict(obj,u)
```

Description

`[z_pred,x_pred,P_pred] = predict(obj)` returns the prediction of measurement, state, and state estimation error covariance at the next time step (e.g., the next video frame). The object overwrites the internal state and covariance of the Kalman filter with the prediction results.

`[z_pred,x_pred,P_pred] = predict(obj,u)` additionally lets you specify the control input, *u*, an *L*-element vector. This syntax applies when you set the control model, *B*.

vision.LocalMaximaFinder System object

Package: vision

Find local maxima in matrices

Description

The `LocalMaximaFinder` object finds local maxima in matrices.

After constructing the object and optionally setting properties, use the `step` method to find the coordinates of the local maxima in the input image. Use the `step` syntax below with input matrix, `I`, `LocalMaximaFinder` object, `H`, and any optional properties. `IDX = step(H,I)` returns [x y] coordinates of the local maxima in an *M*-by-2 matrix, `IDX`. *M* represents the number of local maximas found. The maximum value of *M* may not exceed the value set in the `MaximumNumLocalMaxima` property.
`[...] = step(H,I,THRESH)` finds the local maxima in input image `I`, using the threshold value THRESH, when you set the `ThresholdSource` property to `Input port`.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.LocalMaximaFinder` returns a local maxima finder System object, `H`, that finds local maxima in input matrices.

`H = vision.LocalMaximaFinder(`*Name*`,`*Value*`)` returns a local maxima finder object, `H`, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

`H = vision.LocalMaximaFinder(MAXNUM,NEIGHBORSIZE,`*Name*`,`*Value*`)` returns a local maxima finder object, `H`, with the `MaximumNumLocalMaxima` property set to

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MAXNUM, `NeighborhoodSize` property set to `NEIGHBORSIZE`, and other specified properties set to the specified values.

Properties

`MaximumNumLocalMaxima`

Maximum number of maxima to find

Specify the maximum number of maxima to find as a positive scalar integer value. The default is 2.

`NeighborhoodSize`

Neighborhood size for zero-ing out values

Specify the size of the neighborhood around the maxima, over which the System object zeros out values, as a 2-element vector of positive odd integers. The default is `[5 7]`.

`ThresholdSource`

Source of threshold

Specify how to enter the threshold value as `Property`, or `Input port`. The default is `Property`.

`Threshold`

Value that all maxima should match or exceed

Specify the threshold value as a scalar of MATLAB built-in numeric data type. This property applies when you set the `ThresholdSource` property to `Property`. The default is 10. This property is tunable.

`HoughMatrixInput`

Indicator of Hough Transform matrix input

Set this property to `true` if the input is antisymmetric about the rho axis and the theta

value ranges from $-\frac{\pi}{2}$ to $\frac{\pi}{2}$ radians, which correspond to a Hough matrix.

When you set this property to `true`, the object assumes a Hough matrix input . The block applies additional processing, specific to Hough transform on the right and left boundaries of the input matrix.

The default is `false`.

IndexDataType

Data type of index values

Specify the data type of index values as `double`, `single` , `uint8`, `uint16`, or `uint32`. The default is `uint32`.

Methods

step   Find local maxima in input image

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Find a local maxima in an input.

```
I = [0 0 0 0 0 0 0 0 0 0 0 0 0; ...
     0 0 0 1 1 2 3 2 1 1 0 0; ...
     0 0 0 1 2 3 4 3 2 1 0 0; ...
     0 0 0 1 3 5 7 5 3 1 0 0; ... % local max at x=7, y=4
     0 0 0 1 2 3 4 3 2 1 0 0; ...
     0 0 0 1 1 2 3 2 1 1 0 0; ...
     0 0 0 0 0 0 0 0 0 0 0 0];

hLocalMax = vision.LocalMaximaFinder;
hLocalMax.MaximumNumLocalMaxima = 1;
hLocalMax.NeighborhoodSize = [3 3];
hLocalMax.Threshold = 1;

location = step(hLocalMax, I)
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the Find Local Maxima block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
hough | vision.Maximum

Introduced in R2012a

step

System object: vision.LocalMaximaFinder
Package: vision

Find local maxima in input image

Syntax

```
IDX = step(H,I)
[...] = step(H,I,THRESH)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

IDX = `step(H,I)` returns [x y] coordinates of the local maxima in an *M*-by-2 matrix, IDX, where *M* represents the number of local maximas found. The maximum value of *M* may not exceed the value set in the `MaximumNumLocalMaxima` property.

`[...] = step(H,I,THRESH)` finds the local maxima in input image I, using the threshold value THRESH, when you set the `ThresholdSource` property to `Input port`.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.Maximum System object

Package: vision

Find maximum values in input or sequence of inputs

Description

The `Maximum` object finds maximum values in an input or sequence of inputs.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Maximum` returns an object, H, that computes the value and index of the maximum elements in an input or a sequence of inputs.

`H = vision.Maximum(`*Name*`,`*Value*`)` returns a maximum-finding object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

ValueOutputPort

Output maximum value

Set this property to `true` to output the maximum value of the input. This property applies when you set the `RunningMaximum` property to `false`.

Default:`true`.

RunningMaximum

Calculate over single input or multiple inputs

When you set this property to `true`, the object computes the maximum value over a sequence of inputs. When you set this property to `false`, the object computes the maximum value over the current input.

Default: `false`.

IndexOutputPort

Output the index of the maximum value

Set this property to `true` to output the index of the maximum value of the input. This property applies only when you set the `RunningMaximum` property to `false`.

Default:`true`.

ResetInputPort

Additional input to enable resetting of running maximum

Set this property to `true` to enable resetting of the running maximum. When you set this property to `true`, a reset input must be specified to the `step` method to reset the running maximum. This property applies only when you set the `RunningMaximum` property to `true`.

Default: `false`.

ResetCondition

Condition that triggers resetting of running maximum

Specify the event that resets the running maximum as `Rising edge`, `Falling edge`, `Either edge`, or `Non-zero`. This property applies only when you set the `ResetInputPort` property to `true`.

Default: `Non-zero`.

IndexBase

Numbering base for index of maximum value

Specify the numbering used when computing the index of the maximum value as starting from either `One` or `Zero`. This property applies only when you set the `IndexOutputPort` property to true.

Default: `One`.

Dimension

Dimension to operate along

Specify how the maximum calculation is performed over the data as `All`, `Row`, `Column`, or `Custom`. This property applies only when you set the `RunningMaximum` property to `false`.

Default: `Column`.

CustomDimension

Numerical dimension to calculate over

Specify the integer dimension of the input signal over which the object finds the maximum. The value of this property cannot exceed the number of dimensions in the input signal. This property only applies when you set the `Dimension` property to `Custom`.

Default: `1`.

ROIProcessing

Enable region-of-interest processing

Set this property to `true` to enable calculation of the maximum value within a particular region of an image. This property applies when you set the `Dimension` property to `All` and the `RunningMaximum` property to `false`.

Default:`false`.

ROIForm

Type of region of interest

Specify the type of region of interest as `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`. This property applies only when you set the `ROIProcessing` property to `true`.

Default: `Rectangles`.

ROIPortion

Calculate over entire ROI or just perimeter

Specify whether to calculate the maximum over the `Entire ROI` or the `ROI perimeter`. This property applies only when you set the `ROIForm` property to `Rectangles`.

Default: `Entire ROI`.

ROIStatistics

Calculate statistics for each ROI or one for all ROIs

Specify whether to calculate `Individual statistics for each ROI` or a `Single statistic for all ROIs`. This property applies only when you set the `ROIForm` property to `Rectangles`, `Lines`, or `Label matrix`.

ValidityOutputPort

Output flag indicating if any part of ROI is outside input image

Set this property to `true` to return the validity of the specified ROI as completely or partially inside of the image. This applies when you set the `ROIForm` property to `Lines` or `Rectangles`.

Set this property to `true` to return the validity of the specified label numbers. This applies when you set the `ROIForm` property to `Label matrix`.

Default: `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` || `Convergent` | `Nearest` | `Round` | `Simplest` | `Zero`.

Default: `Floor`.

OverflowAction

Action to take when integer input is out-of-range

Specify the overflow action as `Wrap` or `Saturate`.

Default: `Wrap`.

ProductDataType

Data type of product

Specify the product fixed-point data type as `Same as input` or `Custom`.

Default: `Same as input`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object. This property applies only when you set the `AccumulatorDataType` property to `Custom`.

Default: `numerictype(true,32,30)`.

AccumulatorDataType

Data type of accumulator

Specify the accumulator fixed-point data type as `Same as product`, `Same as input`, or `Custom`.

Default:`Same as product`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object. This property applies only when you set the `AccumulatorDataType` property to `Custom`.

Default: `numerictype(true,32,30)`.

Methods

reset	Reset computation of running maximum
step	Compute maximum value

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Determine the maximum value and its index in a grayscale image.

```
img = im2single(rgb2gray(imread('peppers.png')));
hmax = vision.Maximum;
[m, ind] = step(hmax, img);
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D Maximum block reference page.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
vision.Mean | vision.Minimum

Introduced in R2012a

reset

System object: vision.Maximum
Package: vision

Reset computation of running maximum

Syntax

```
reset(H)
```

Description

reset(H) resets the computation of the running maximum for the Maximum object H.

step

System object: vision.Maximum
Package: vision

Compute maximum value

Syntax

```
[VAL,IND] = step(H,X)
VAL = step(H,X)
IND = step(H,X)
VAL = step(H,X,R)
[...] = step(H,I,ROI)
[...] = step(H,I,LABEL,LABELNUMBERS)
[...,FLAG] = step(H,I,ROI)
[...,FLAG] = step(H,I,LABEL,LABELNUMBERS)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`[VAL,IND] = step(H,X)` returns the maximum value, VAL, and the index or position of the maximum value, IND, along a dimension of X specified by the value of the `Dimension` property.

`VAL = step(H,X)` returns the maximum value, VAL, of the input X. When the `RunningMaximum` property is `true`, VAL corresponds to the maximum value over a sequence of inputs.

IND = step(H,X) returns the zero- or one-based index IND of the maximum value. To enable this type of processing, set the IndexOutputPort property to true and the ValueOutputPort and RunningMaximum properties to false.

VAL = step(H,X,R) computes the maximum value, VAL, over a sequence of inputs, and resets the state of H based on the value of reset signal, R, and the ResetCondition property. To enable this type of processing, set the RunningMaximum property to true and the ResetInputPort property to true.

[...] = step(H,I,ROI) computes the maximum of an input image, I, within the given region of interest, ROI. To enable this type of processing, set the ROIProcessing property to true and the ROIForm property to Lines, Rectangles or Binary mask.

[...] = step(H,I,LABEL,LABELNUMBERS) computes the maximum of an input image, I, for a region whose labels are specified in the vector LABELNUMBERS. To enable this type of processing, set the ROIProcessing property to true and the ROIForm property to Label matrix.

[...,FLAG] = step(H,I,ROI) also returns FLAG, indicating whether the given region of interest is within the image bounds. To enable this type of processing, set the ROIProcessing and ValidityOutputPort properties to true and the ROIForm property to Lines, Rectangles or Binary mask.

[...,FLAG] = step(H,I,LABEL,LABELNUMBERS) also returns FLAG, indicating whether the input label numbers are valid. To enable this type of processing, set the ROIProcessing and ValidityOutputPort properties to true and the ROIForm property to Label matrix.

Note H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

vision.Mean System object

Package: vision

Find mean value of input or sequence of inputs

Description

The `Mean` object finds the mean of an input or sequence of inputs.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Mean` returns an object, H, that computes the mean of an input or a sequence of inputs.

`H = vision.Mean(`*`Name`*`,`*`Value`*`)` returns a mean-finding object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

RunningMean

Calculate over single input or multiple inputs

When you set this property to `true`, the object calculates the mean over a sequence of inputs. When you set this property to `false`, the object computes the mean over the current input. The default is `false`.

ResetInputPort

Additional input to enable resetting of running mean

Set this property to `true` to enable resetting of the running mean. When you set this property to `true`, a reset input must be specified to the `step` method to reset the running mean. This property applies only when you set the `RunningMean` property to `true`. The default is `false`.

ResetCondition

Condition that triggers resetting of running mean

Specify the event that resets the running mean as `Rising edge`, `Falling edge`, `Either edge`, or `Non-zero`. This property applies only when you set the `ResetInputPort` property to `true`. The default is `Non-zero`.

Dimension

Dimension to operate along

Specify how the mean calculation is performed over the data as `All`, `Row`, `Column`, or `Custom`. This property applies only when you set the `RunningMean` property to `false`. The default is `All`.

CustomDimension

Numerical dimension to calculate over

Specify the integer dimension, indexed from one, of the input signal over which the object calculates the mean. The value of this property cannot exceed the number of dimensions in the input signal. This property only applies when you set the `Dimension` property to `Custom`. The default is `1`.

ROIProcessing

Enable region-of-interest processing

Set this property to `true` to enable calculation of the mean within a particular region of an image. This property applies when you set the `Dimension` property to `All` and the `RunningMean` property to `false`. The default is `false`.

ROIForm

Type of region of interest

Specify the type of region of interest as `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`. This property applies only when you set the `ROIProcessing` property to `true`. The default is `Rectangles`.

ROIPortion

Calculate over entire ROI or just perimeter

Specify whether to calculate the mean over the `Entire ROI` or the `ROI perimeter`. This property applies only when you set the `ROIForm` property to `Rectangles`. The default is `Entire ROI`.

ROIStatistics

Calculate statistics for each ROI or one for all ROIs

Specify whether to calculate `Individual statistics for each ROI` or a `Single statistic for all ROIs`. This property applies only when you set the `ROIForm` property to `Rectangles`, `Lines`, or `Label matrix`. The default is `Individual statistics for each ROI`.

ValidityOutputPort

Output flag indicating if any part of ROI is outside input image

Set this property to `true` to return the validity of the specified ROI as completely or partially inside of the image. This applies when you set the `ROIForm` property to `Lines` or `Rectangles`.

Set this property to `true` to return the validity of the specified label numbers. This applies when you set the `ROIForm` property to `Label matrix`.

The default is `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

OverflowAction

Action to take when integer input is out-of-range

Specify the overflow action as `Wrap` or `Saturate`. The default is `Wrap`.

AccumulatorDataType

Data type of accumulator

Specify the accumulator fixed-point data type as `Same as input`, or `Custom`. The default is `Same as input`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object. This property applies only when you set the `AccumulatorDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

OutputDataType

Data type of output

Specify the output fixed-point data type as `Same as accumulator`, `Same as input`, or `Custom`. The default is `Same as accumulator`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object. This property applies only when you set the `OutputDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

Methods

reset   Reset computation of running mean

step   Compute mean of input

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Determine the mean of a grayscale image.

```
img = im2single(rgb2gray(imread('peppers.png')));
hmean = vision.Mean;
m = step(hmean,img);
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D Mean block reference page.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
vision.Maximum | vision.Minimum

Introduced in R2012a

reset

System object: vision.Mean
Package: vision

Reset computation of running mean

Syntax

```
reset(H)
```

Description

`reset(H)` resets the computation of the running mean for the `Mean` object `H`.

step

System object: vision.Mean
Package: vision

Compute mean of input

Syntax

```
Y = step(H,X)
Y = step(H,X,R)
Y = step(H,X,ROI)
Y = step(H,X,LABEL,LABELNUMBERS)
[Y,FLAG] = step(H,X,ROI)
[Y,FLAG] = step(H,X,LABEL,LABELNUMBERS)
```

Description

Note Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, y = step(obj,x) and y = obj(x) perform equivalent operations.

Y = step(H,X) computes the mean of input image elements *X*. When you set the RunningMean property to true, the output *Y* corresponds to the mean of the input elements over successive calls to the step method.

Y = step(H,X,R) computes the mean value of the input image elements *X* over successive calls to the step method, and optionally resets the computation of the running mean based on the value of reset signal, *R* and the value of the ResetCondition property. To enable this type of processing, set the RunningMean property to true and the ResetInputPort property to true.

Y = step(H,X,ROI) computes the mean of input image elements *X* within the given region of interest specified by the input *ROI*. To enable this type of processing, set the

ROIProcessing property to `true` and the `ROIForm` property to `Lines`, `Rectangles` or `Binary mask`.

`Y = step(H,X,LABEL,LABELNUMBERS)` computes the mean of the input image elements, *X*, for the region whose labels are specified in the vector *LABELNUMBERS*. The regions are defined and labeled in the matrix *LABEL*. To enable this type of processing, set the `ROIProcessing` property to `true` and the `ROIForm` property to `Label matrix`.

`[Y,FLAG] = step(H,X,ROI)` also returns the output *FLAG*, indicating whether the given region of interest *ROI*, is within the image bounds. To enable this type of processing, set the `ROIProcessing` and `ValidityOutputPort` properties to `true` and the `ROIForm` property to `Lines`, `Rectangles` or `Binary mask`.

`[Y,FLAG] = step(H,X,LABEL,LABELNUMBERS)` also returns the output *FLAG* which indicates whether the input label numbers are valid. To enable this type of processing, set the `ROIProcessing` and `ValidityOutputPort` properties to `true` and the `ROIForm` property to `Label matrix`.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

---

vision.Median System object

Package: vision

Find median values in an input

Description

The `Median` object finds median values in an input.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Median` returns a System object, H, that computes the median of the input or a sequence of inputs.

`H = vision.Median(`*Name*`,`*Value*`)` returns a median System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

SortMethod

Sort method

Specify the sort method used for calculating the median as `Quick sort` or `Insertion sort`.

Dimension

Dimension with which to operate along

Specify how the calculation is performed over the data as `All`, `Row`, `Column`, or `Custom`. The default is `All`

CustomDimension

Numerical dimension over which to calculate

Specify the integer dimension of the input signal over which the object calculates the mean. The value of this property cannot exceed the number of dimensions in the input signal. This property only applies when you set the `Dimension` property to `Custom`. The default is `1`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

OverflowAction

Action to take when integer input is out-of-range

Specify the overflow action as `Wrap` or `Saturate`. The default is `Wrap`.

ProductDataType

Product output word and fraction lengths

Specify the product output fixed-point data type as `Same as input` or `Custom`. The default is `Same as input`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object. This property applies when you set the `ProductDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

AccumulatorDataType

Data type of accumulator

Specify the accumulator fixed-point data type as `Same as input`, or `Custom`. The default is `Same as input`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object. This property applies only when you set the `AccumulatorDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

OutputDataType

Data type of output

Specify the output fixed-point data type as `Same as accumulator`, `Same as input`, or `Custom`. The default is `Same as accumulator`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object. This property applies only when you set the `OutputDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

Methods

step   Compute median of input

Common to All System Objects	
release	Allow System object property value changes

Examples

Determine the median in a grayscale image.

```
img = im2single(rgb2gray(imread('peppers.png')));
hmdn = vision.Median;
med = step(hmdn,img);
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D Median block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• See "System Objects in MATLAB Code Generation" (MATLAB Coder).

Introduced in R2012a

step

System object: vision.Median
Package: vision

Compute median of input

Syntax

```
Y = step(H,X)
```

Description

> **Note** Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`Y = step(H,X)` computes median of input *X*.

> **Note** H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.Minimum System object

Package: vision

Find minimum values in input or sequence of inputs

Description

The `Minimum` object finds minimum values in an input or sequence of inputs.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Minimum` returns an object, H, that computes the value and index of the minimum elements in an input or a sequence of inputs.

`H = vision.Minimum(Name,Value)` returns a minimum-finding object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

ValueOutputPort

Output minimum value

Set this property to `true` to output the minimum value of the input. This property applies when you set the `RunningMinimum` property to `false`.

Default: `true`

RunningMinimum

Calculate over single input or multiple inputs

When you set this property to `true`, the object computes the minimum value over a sequence of inputs. When you set this property to `false`, the object computes the minimum value over the current input.

Default: `false`

IndexOutputPort

Output the index of the minimum value

Set this property to `true` to output the index of the minimum value of the input. This property applies only when you set the `RunningMinimum` property to `false`.

Default: `true`

ResetInputPort

Additional input to enable resetting of running minimum

Set this property to `true` to enable resetting of the running minimum. When you set this property to `true`, a reset input must be specified to the `step` method to reset the running minimum. This property applies only when you set the `RunningMinimum` property to `true`.

Default: `false`

ResetCondition

Condition that triggers resetting of running minimum

Specify the event that resets the running minimum as `Rising edge`, `Falling edge`, `Either edge`, or `Non-zero`. This property applies only when you set the `ResetInputPort` property to `true`.

Default: `Non-zero`

Dimension

Dimension to operate along

Specify how the minimum calculation is performed over the data as `All`, `Row`, `Column`, or `Custom`. This property applies only when you set the `RunningMinimum` property to `false`.

Default:`Column`.

CustomDimension

Numerical dimension to calculate over

Specify the integer dimension of the input signal over which the object finds the minimum. The value of this property cannot exceed the number of dimensions in the input signal. This property only applies when you set the `Dimension` property to `Custom`.

Default:`1`.

ROIProcessing

Enable region-of-interest processing

Set this property to `true` to enable calculation of the minimum value within a particular region of an image. This property applies when you set the `Dimension` property to `All` and the `RunningMinimum` property to `false`.

Default: `false`.

ROIForm

Type of region of interest

Specify the type of region of interest as `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`. This property applies only when you set the `ROIProcessing` property to `true`.

Default: `Rectangles`.

ROIPortion

Calculate over entire ROI or just perimeter

Specify whether to calculate the minimum over the `Entire ROI` or the `ROI perimeter`. This property applies only when you set the `ROIForm` property to `Rectangles`.

Default: `Entire ROI`.

ROIStatistics

Calculate statistics for each ROI or one for all ROIs

Specify whether to calculate `Individual statistics for each ROI` or a `Single statistic for all ROIs`. This property applies only when you set the `ROIForm` property to `Rectangles`, `Lines`, or `Label matrix`.

ValidityOutputPort

Output flag indicating if any part of ROI is outside input image

Set this property to `true` to return the validity of the specified ROI as completely or partially inside of the image. This applies when you set the `ROIForm` property to `Lines` or `Rectangles`.

Set this property to `true` to return the validity of the specified label numbers. This applies when you set the `ROIForm` property to `Label matrix`.

Default: `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`.

Default: `Floor`.

OverflowAction

Action to take when integer input is out-of-range

Specify the overflow action as `Wrap` or `Saturate`.

Default: `Wrap`.

ProductDataType

Data type of product

Specify the product fixed-point data type as `Same as input` or `Custom`.

Default:`Same as input`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object. This property applies only when you set the `AccumulatorDataType` property to `Custom`.

Default:`numerictype(true,32,30)`.

AccumulatorDataType

Data type of accumulator

Specify the accumulator fixed-point data type as `Same as product`, `Same as input`, or `Custom`.

Default: `Same as product`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object. This property applies only when you set the `AccumulatorDataType` property to `Custom`.

Default:`numerictype(true,32,30)`.

Methods

reset	Reset computation of running minimum
step	Compute minimum value

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Determine the minimum value and its index in a grayscale image.

```
img = im2single(rgb2gray(imread('peppers.png')));
hmax = vision.Minimum;
[m, ind] = step(hmax, img);
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the 2-D Minimum block reference page.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

vision.Maximum | vision.Mean

Introduced in R2012a

reset

System object: vision.Minimum
Package: vision

Reset computation of running minimum

Syntax

```
reset(H)
```

Description

reset(H) resets computation of the running minimum for the Minimum object H.

step

System object: vision.Minimum
Package: vision

Compute minimum value

Syntax

```
[VAL,IND] = step(H,X)
VAL = step(H,X)
IND = step(H,X)
VAL = step(H,X,R)
[...] = step(H,I,ROI)
[...] = step(H,I,LABEL,LABELNUMBERS)
[...,FLAG] = step(H,I,ROI)
[...,FLAG] = step(H,I,LABEL,LABELNUMBERS)
```

Description

Note Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`[VAL,IND] = step(H,X)` returns the minimum value, VAL, and the index or position of the minimum value, IND, along a dimension of X specified by the value of the `Dimension` property.

`VAL = step(H,X)` returns the minimum value, VAL, of the input X. When the `RunningMinimum` property is `true`, VAL corresponds to the minimum value over a sequence of inputs.

IND = step(H,X) returns the zero- or one-based index IND of the minimum value. To enable this type of processing, set the IndexOutputPort property to true and the ValueOutputPort and RunningMinimum properties to false.

VAL = step(H,X,R) computes the minimum value, VAL, over a sequence of inputs, and resets the state of H based on the value of reset signal, R, and the ResetCondition property. To enable this type of processing, set the RunningMinimum property to true and the ResetInputPort property to true.

[...] = step(H,I,ROI) computes the minimum of an input image, I, within the given region of interest, ROI. To enable this type of processing, set the ROIProcessing property to true and the ROIForm property to Lines, Rectangles or Binary mask.

[...] = step(H,I,LABEL,LABELNUMBERS) computes the minimum of an input image, I, for a region whose labels are specified in the vector LABELNUMBERS. To enable this type of processing, set the ROIProcessing property to true and the ROIForm property to Label matrix.

[...,FLAG] = step(H,I,ROI) also returns FLAG, indicating whether the given region of interest is within the image bounds. To enable this type of processing, set the ROIProcessing and ValidityOutputPort properties to true and the ROIForm property to Lines, Rectangles or Binary mask.

[...,FLAG] = step(H,I,LABEL,LABELNUMBERS) also returns FLAG, indicating whether the input label numbers are valid. To enable this type of processing, set the ROIProcessing and ValidityOutputPort properties to true and the ROIForm property to Label matrix.

Note H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

---

vision.VideoFileReader System object

Package: vision

Read video frames and audio samples from video file

Description

The `VideoFileReader` object reads video frames, images, and audio samples from a video file. The object can also read image files.

Supported Platforms and File Types

The supported file formats available to you depend on the codecs installed on your system.

Platform	Supported File Name Extensions
All Platforms	AVI (`.avi`)
Windows	**Image**: `.jpg`,`.bmp`
	Video: MPEG (.mpeg) MPEG-2 (.mp2) MPEG-1 `.mpg` MPEG-4, including H.264 encoded video (.mp4, .m4v) Motion JPEG 2000 (.mj2) Windows Media Video (`.wmv`,`.asf`, `.asx`, .asx) and any format supported by Microsoft DirectShow® 9.0 or higher.

Platform	Supported File Name Extensions
	Audio: WAVE (`.wav`) Windows Media Audio File (`.wma`) Audio Interchange File Format (`.aif`, `.aiff`) Compressed Audio Interchange File Format(`.aifc`), MP3 (`.mp3`) Sun Audio (`.au`) Apple (`.snd`)
Macintosh	**Video**: `.avi` Motion JPEG 2000 (`.mj2`) MPEG-4, including H.264 encoded video (.mp4, .m4v) Apple QuickTime Movie (.mov) and any format supported by QuickTime as listed on http://support.apple.com/kb/HT3775.
	Audio: Uncompressed `.avi`
Linux	Motion JPEG 2000 (`.mj2`) Any format supported by your installed plug-ins for GStreamer 0.1 or higher, as listed on http://gstreamer.freedesktop.org/documentation/plugins.html, including Ogg Theora (.ogg).

Windows XP and Windows 7 x64 platform ships with a limited set of 64-bit video and audio codecs. If a compressed multimedia file fails to play, try saving the multimedia file to a supported file format listed in the table above.

If you use Windows, use Windows Media player Version 11 or later.

Note MJ2 files with bit depth higher than 8-bits is not supported by `vision.VideoFileReader`. Use `VideoReader` and `VideoWriter` for higher bit depths.

Reading audio from compressed MP4 files with video and audio is not supported by `vision.VideoFileReader`.

To read a file:

1 Create the vision.VideoFileReader object and set its properties.

2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
videoFReader = vision.VideoFileReader(Filename)
videoFReader = vision.VideoFileReader(Name,Value)
```

Description

`videoFReader = vision.VideoFileReader(Filename)` returns a video file reader System object, `videoFReader`, that sequentially reads video frames or audio samples from an input file, `Filename`.

`videoFReader = vision.VideoFileReader(Name,Value)` creates an video file reader object, `videoFReader`, with additional options specified by one or more `Name,Value` pair arguments.

`Name` is a property name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `videoFReader = vision.VideoFileReader(Filename,'PlayCount',1)`

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

`Filename` — File name
`vipmen.avi` (default) | character vector

File name, specified as a character vector. The full path for the file needs to be specified only if the file is not on the MATLAB path.

`PlayCount` — Number of times to play file
`1` (default) | positive integer | `inf`

Number of times to play file, specified as a positive integer.

`AudioOutputPort` — Output audio data
`false` (default) | `true`

Output audio data, specified as `true` or `false`. Use this property to control the audio output only when the input file contains audio and video streams.

`ImageColorSpace` — Image format
`RGB` (default) | `YCbCr 4:2:2` | intensity video

Image format, specified as `RGB`, `YCbCr 4:2:2`, or intensity video frames when the input file contains video.

`VideoOutputDataType` — Output video data type
`single` (default)

Output video data type, specified as one of the data types listed and `inherit`. This property applies when the input file contains video.

Data Types: `double` | `int8` | `int16` | `int32` | `uint8` | `uint16`

`AudioOutputDataType` — Output audio samples data type
`int16` (default)

Output audio samples data type, specified as one of the data types listed and `inherit`. This property applies when the input file contains audio.

Data Types: `double` | `single` | `int16` | `uint8`

Usage

Syntax

```
videoFrame = videoFReader(Filename)
[Y,Cb,Cr] = videoFReader(Filename)
[I,audio] = videoFReader(Filename)
[Y,Cb,Cr,audio] = videoFReader(Filename)
[ ___ ,EOF] = videoFReader(Filename)
```

Description

`videoFrame = videoFReader(Filename)` returns next video frame.

`[Y,Cb,Cr] = videoFReader(Filename)` returns the next frame of `YCbCr 4:2:2` format video in the color components Y, Cb, and Cr. This syntax requires that you set the `'ImageColorSpace'` property to `'YCbCr 4:2:2'`

`[I,audio] = videoFReader(Filename)` returns the next video frame, `I`, and one frame of audio samples, `AUDIO`. This syntax requires that you set the `AudioOutputPort` property to `true`.

`[Y,Cb,Cr,audio] = videoFReader(Filename)` returns the next frame of `YCbCr 4:2:2` video in the color components Y, Cb, and Cr, and one frame of audio samples in `audio`. This syntax requires that you set the `'AudioOutputPort'` property to `true`, and the `'ImageColorSpace'` property to `'YCbCr 4:2:2'` .

`[ ___ ,EOF] = videoFReader(Filename)` returns the end-of-file indicator, `EOF`. The object sets `EOF` to `true` each time the output contains the last audio sample and/or video frame.

Input Arguments

Filename — File name
`vipmen.avi` (default) | character vector

File name, specified as a character vector. The full path for the file needs to be specified only if the file is not on the MATLAB path. The file types are:

Platforms	File Formats
All Platforms	AVI, including uncompressed, indexed, grayscale, and Motion JPEG-encoded video (`.avi`) Motion JPEG 2000 (`.mj2`)
All Windows	MPEG-1 (`.mpg`) Windows Media Video (`.wmv`, `.asf`, `.asx`) Any format supported by Microsoft DirectShow®
Windows 7 or later	MPEG-4, including H.264 encoded video (`.mp4`, `.m4v`) Apple QuickTime Movie (`.mov`) Any format supported by Microsoft Media Foundation
Macintosh	Most formats supported by QuickTime Player, including: MPEG-1 (`.mpg`) MPEG-4, including H.264 encoded video (`.mp4`, `.m4v`) Apple QuickTime Movie (`.mov`) 3GPP 3GPP2 AVCHD DV **Note:** For OS X Yosemite (Version 10.10) and later, MPEG-4/H.264 files written using `VideoWriter`, play correctly, but display an inexact frame rate.
Linux	Any format supported by your installed plug-ins for GStreamer 1.0 or higher, as listed on http://gstreamer.freedesktop.org/documentation/plugins.html, including Ogg Theora (`.ogg`).

Output Arguments

videoFrame — Video frame
truecolor | 2-D grayscale image

Video frame, returned as a truecolor or 2-D grayscale image.

Y,Cb,Cr — YCbCr color format
'YCbCr 4:2:2'

YCbCr color format, returned in the YCbCr 4:2:2 format.

audio — One frame of audio samples

One frame of audio samples, returned in one of the following formats.

Platform Support	File Format
All platforms	WAVE (.wav)
	OGG (.ogg)
	FLAC (.flac)
	AU (.au)
	AIFF (.aiff, .aif)
	AIFC (.aifc)
Windows 7 (or later), Macintosh, and Linux	MP3 (.mp3)
	MPEG-4 AAC (.m4a, .mp4)

EOF — End-of-file
true | false

End-of-file indicator, returned as true or false.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

```
release(obj)
```

Specific to vision.VideoFileReader

info   Information about specified video file
isDone   End-of-file status (logical)

Common to All System Objects

step   Run System object algorithm
release   Release resources and allow changes to System object property values and
          input characteristics
reset   Reset internal states of System object

Examples

Read and Play a Video File

Load the video using a video reader object.

```
videoFReader = vision.VideoFileReader('ecolicells.avi');
```

Create a video player object to play the video file.

```
videoPlayer = vision.VideoPlayer;
```

Use a while loop to read and play the video frames. Pause for 0.1 seconds after displaying each frame.

```
while ~isDone(videoFReader)
  videoFrame = videoFReader();
  videoPlayer(videoFrame);
  pause(0.1)
end
```

Release the objects.

```
release(videoPlayer);
```

```
release(videoFReader);
```

Tips

- Video Reading Performance on Windows Systems:To achieve better video reader performance on Windows for MP4 and MOV files, MATLAB uses the system's graphics hardware for decoding. However, in some cases using the graphics card for decoding can result in poorer performance depending on the specific graphics hardware on the system. If you notice slower video reader performance on your system, turn off the hardware acceleration by typing:

  ```
  matlab.video.read.UseHardwareAcceleration('off')
  ```

  Hardware acceleration can be reenabled by typing:

```
matlab.video.read.UseHardwareAcceleration('on')
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generated code for this function uses a precompiled platform-specific shared library.
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
VideoReader | VideoWriter | implay | vision.VideoFileWriter | vision.VideoPlayer

Introduced in R2012a

vision.VideoFileWriter System object

Package: vision

Write video frames and audio samples to video file

Description

The `VideoFileWriter` object writes video frames and audio samples to a video file. The video and audio can be compressed. The available compression types depend on the encoders installed on the platform.

Note This block supports code generation for platforms that have file I/O available. You cannot use this block with Simulink Desktop Real-Time software, because that product does not support file I/O.

This object performs best on platforms with Version 11 or later of Windows Media Player software. This object supports only uncompressed RGB24 AVI files on Linux and Mac platforms.

The generated code for this object relies on prebuilt library files. You can run this code outside the MATLAB environment, or redeploy it, but be sure to account for these extra library files when doing so. The packNGo function creates a single zip file containing all of the pieces required to run or rebuild this code. See `packNGo` for more information.

To run an executable file that was generated from an object, you may need to add precompiled shared library files to your system path. See "MATLAB Coder" and "Simulink Shared Library Dependencies" for details.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`videoFWriter = vision.VideoFileWriter` returns a video file writer System object, `videoFWriter`. It writes video frames to an uncompressed `'output.avi'` video file. Every call to the `step` method writes a video frame.

`videoFWriter = vision.VideoFileWriter(FILENAME)` returns a video file writer object, `videoFWriter` that writes video to a file, FILENAME. The file type can be `.avi`, `.mj2`, `.mp4`, and `.m4v` specified by the `FileFormat` property.

`videoFWriter = vision.VideoFileWriter(...,'Name',Value)` configures the video file writer properties, specified as one or more name-value pair arguments. Unspecified properties have default values.

To write to a file:

1 Define and set up your video file writer object using the constructor.
2 Call the `step` method with the optional output filename, FILENAME, the video file writer object, `videoFWriter`, and any optional properties. See the syntax below for using the `step` method.

`step(videoFWriter,I)` writes one frame of video, `I`, to the output file. The input video can be an *M*-by-*N*-by-3 truecolor RGB video frame, or an *M*-by-*N* grayscale video frame.

`step(videoFWriter,Y,Cb,Cr)` writes one frame of YCbCr 4:2:2 video. The width of Cb and Cr color components must be half of the width of Y. You must set the value of the `FileColorSpace` property to `'YCbCr 4:2:2'`.

`step(videoFWriter,I,AUDIO)` writes one frame of the input video, `I`, and one frame of audio samples, AUDIO, to the output file. This applies when you set the `AudioInputPort` property to `true`.

`step(videoFWriter,Y,Cb,Cr,AUDIO)` writes one frame of YCbCr 4:2:2 video, and one frame of audio samples, AUDIO, to the output file. This applies when you set the `AudioInputPort` to `true` and the `FileColorSpace` property to `'YCbCr 4:2:2'`. The width of Cb and Cr color components must be half of the width of Y.

Properties

`Filename`

Video output file name

Specify the name of the video file as a character vector. The file extension you give for `Filename` must match the `FileFormat`. The supported file extensions are, `'.avi'`, `'.mj2'`, `'.mp4'`, and `'.m4v'`.

Default: `output.avi`

`FileFormat`

Output file format

Specify the format of the file that is created. Supported formats and abbreviations:

File Format	Description	File Extension	Supported Platform
AVI	Audio-Video Interleave file	`.avi`	All platforms
MJ2000	Motion JPEG 2000 file	`.mj2`	All platforms
MPEG4	MPEG-4/H.264 Video	`.mp4` , `.m4v`	Windows and Mac

Default: `AVI`

`AudioInputPort`

Write audio data

Use this property to control whether the object writes audio samples to the video file. Set this value to `true` to write audio data. To write audio and video to a file, you must use the `.avi` format .

Default: `false`

`FrameRate`

Video frame rate

Specify the frame rate of the video data in frames per second as a positive numeric scalar.

For videos which also contain audio data, the rate of the audio data will be determined as the rate of the video multiplied by the number of audio samples passed in each invocation of the `step` method. For example, if you use a frame rate of `30`, and pass 1470 audio samples to the `step` method, the object sets the audio sample to `44100`, ($1470 \times 30 = 44100$).

Default: `30`

AudioCompressor

Audio compression encoder

Specify the type of compression algorithm to implement for audio data. This compression reduces the size of the video file. Choose `None (uncompressed)` to save uncompressed audio data to the video file. The other options reflect the available audio compression algorithms installed on your system. This property applies only when writing `AVI` files on Windows platforms.

VideoCompressor

Video compression encoder

Specify the type of compression algorithm to use to compress the video data. This compression reduces the size of the video file. Choose `None (uncompressed)` to save uncompressed video data to the video file. The `VideoCompressor` property can also be set to one of the compressors available on your system. To obtain a list of available video compressors, you can use tab completion. Follow these steps:

1 Instantiate the object:
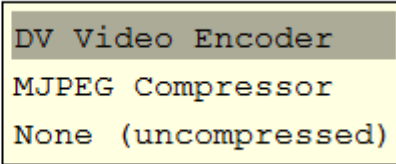
```
y = vision.VideoFileWriter
```

2 To launch the tab completion functionality, type the following up to the open quote.

```
y.VideoCompressor='
```

A list of compressors available on your system will appear after you press the `Tab` key. For example:

```
>>
>>
>>
>>
>>
>> y.VideoCompressor='
```

DV Video Encoder
MJPEG Compressor
None (uncompressed)

This property applies only when writing AVI files on Windows platforms.

AudioDataType

Uncompressed audio data type

Specify the compressed output audio data type. This property only applies when you write uncompressed WAV files.

FileColorSpace

Color space for output file

Specify the color space of AVI files as RGB or YCbCr 4:2:2. This property applies when you set the FileFormat property to AVI and only on Windows platforms.

Default: RGB

Quality

Control size of output video file

Specify the output video quality as an integer in the range [0,100]. Increase this value for greater video quality. However, doing so increases the file size. Decrease the value to lower video quality with a smaller file size.

The Quality property only applies when you are writing MPEG4 video files (on Windows or Mac) or when you are writing MJPEG-AVI video only files on a Mac or Linux.

CompressionFactor

Target ratio between number of bytes in input image and compressed image

Specify the compression factor as an integer greater than 1 to indicate the target ratio between the number of bytes in the input image and the compressed image. The data is compressed as much as possible, up to the specified target. This property applies only when writing Lossy MJ2000 files.

Methods

Common to All System Objects	
release	Allow System object property value changes

Examples

Write a Video to an AVI File

Set up the reader and writer objects.

```
videoFReader = vision.VideoFileReader('viplanedeparture.mp4');
videoFWriter = vision.VideoFileWriter('myFile.avi','FrameRate',...
    videoFReader.info.VideoFrameRate);
```

Write the first 50 frames from original file into a newly created AVI file.

```
for i=1:50
    videoFrame = step(videoFReader);
    step(videoFWriter,videoFrame);
end
```

Close the input and output files.

```
release(videoFReader);
release(videoFWriter);
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.
Usage notes and limitations:

- Generated code for this function uses a precompiled platform-specific shared library.
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
VideoReader | VideoWriter | vision.VideoFileReader | vision.VideoPlayer

Introduced in R2012a

step

System object: vision.VideoFileWriter
Package: vision

Write input video data to file

Syntax

```
step(videoFWriter,I)
step(videoFWriter,Y,Cb,Cr)
step(videoFWriter,I,AUDIO)
step(videoFWriter,Y,Cb,Cr,AUDIO)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`step(videoFWriter,I)` writes one frame of the input video, `I`, to the output file. The input video can be an *M*-by-*N*-by-3 truecolor RGB video frame, or an *M*-by-*N* grayscale video frame where *M*-by-*N* represents the size of the image.

`step(videoFWriter,Y,Cb,Cr)` writes one frame of YCbCr 4:2:2 video. The width of Cb and Cr color components must be half of the width of Y. You must set the value of the `FileColorSpace` property to `'YCbCr 4:2:2'`.

`step(videoFWriter,I,AUDIO)` writes one frame of the input video, `I`, and one frame of audio samples, `AUDIO`, to the output file. This applies when you set the `AudioInputPort` property to `true`.

`step(videoFWriter,Y,Cb,Cr,AUDIO)` writes one frame of YCbCr 4:2:2 video, and one frame of audio samples, `AUDIO`, to the output file. This applies when you set the

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`AudioInputPort` to `true` and the `FileColorSpace` property to `'YCbCr 4:2:2'`. The width of Cb and Cr color components must be half of the width of Y.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

---

ocrText class

Object for storing OCR results

Description

ocrText contains recognized text and metadata collected during optical character recognition (OCR). The ocr function returns the ocrText object. You can access the information contained in the object with the ocrText properties. You can also locate text that matches a specific pattern with the object's locateText method.

Properties

Text — Text recognized by OCR
array of characters

Text recognized by OCR, specified as an array of characters. The text includes white space and new line characters.

CharacterBoundingBoxes — Bounding box locations
M-by-4 matrix

Bounding box locations, stored as an *M*-by-4 matrix. Each row of the matrix contains a four-element vector, [*x y width height*]. The [*x y*] elements correspond to the upper-left corner of the bounding box. The [*width height*] elements correspond to the size of the rectangular region in pixels. The bounding boxes enclose text found in an image using the ocr function. Bounding boxes width and height that correspond to new line characters are set to zero. Character modifiers found in languages, such as Hindi, Tamil, and Bangalese, are also contained in a zero width and height bounding box.

CharacterConfidences — Character recognition confidence
array

Character recognition confidence, specified as an array. The confidence values are in the range [0, 1]. A confidence value, set by the ocr function, should be interpreted as a probability. The ocr function sets confidence values for spaces between words and sets

new line characters to `NaN`. Spaces and new line characters are not explicitly recognized during OCR. You can use the confidence values to identify the location of misclassified text within the image by eliminating characters with low confidence.

`Words` — Recognized words
cell array

Recognized words, specified as a cell array.

`WordBoundingBoxes` — Bounding box location and size
M-by-4 matrix

Bounding box location and size, stored as an *M*-by-4 matrix. Each row of the matrix contains a four-element vector, [*x y width height*], that specifies the upper left corner and size of a rectangular region in pixels.

`WordConfidences` — Recognition confidence
array

Recognition confidence, specified as an array. The confidence values are in the range [0, 1]. A confidence value, set by the `ocr` function, should be interpreted as a probability. The `ocr` function sets confidence values for spaces between words and sets new line characters to `NaN`. Spaces and new line characters are not explicitly recognized during OCR. You can use the confidence values to identify the location of misclassified text within the image by eliminating words with low confidence.

Methods

locateText	Locate text pattern

Examples

Find and Highlight Text in an Image

```
businessCard = imread('businessCard.png');
ocrResults = ocr(businessCard);
bboxes = locateText(ocrResults, 'MathWorks', 'IgnoreCase', true);
```

```
Iocr = insertShape(businessCard, 'FilledRectangle', bboxes);
figure; imshow(Iocr);
```


Find Text Using Regular Expressions

```
businessCard = imread('businessCard.png');
ocrResults   = ocr(businessCard);
bboxes = locateText(ocrResults, 'www.*com','UseRegexp', true);
img    = insertShape(businessCard, 'FilledRectangle', bboxes);
figure; imshow(img);
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

See Also
insertShape | ocr | regexp | strfind

Introduced in R2014a

locateText

Class: ocrText

Locate text pattern

Syntax

```
bboxes = locateText(ocrText,pattern)
bboxes = locateText(ocrText,pattern,Name, Value)
```

Description

`bboxes = locateText(ocrText,pattern)` returns the location and size of bounding boxes stored in the `ocrText` object. The `locateText` method returns only the locations of bounding boxes which correspond to text within an image that exactly match the input `pattern`.

`bboxes = locateText(ocrText,pattern,Name, Value)` uses additional options specified by one or more `Name,Value` arguments.

Input Arguments

`ocrText` — Object containing OCR results
`ocrText` object

Recognized text and metrics, returned as an `ocrText` object. The object contains the recognized text, the location of the recognized text within the input image, and the metrics indicating the confidence of the results. The confidence values range between `0` and `100` and represent a percent probability. When you specify an *M*-by-4 `roi`, the function returns `ocrText` as an *M*-by-1 array of `ocrText` objects. Confidence values range between 0 and 1. Interpret the confidence values as probabilities.

`pattern` — OCR character vector pattern
single character vector | cell array of character vectors

OCR character vector pattern, specified as a single character vector or a cell array of character vectors. The method returns onlythe locations of bounding boxes which correspond to text within an image that exactly match the input `pattern`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

UseRegexp — Regular expression
`false` (default) | logical scalar

Regular expression, specified as a logical scalar. When you set this property to `true`, the method treats the pattern as a regular expression. For more information about regular expressions, see `regexp`.

IgnoreCase — Case sensitivity
`false` (default) | logical scalar

Case sensitivity, specified as a logical scalar. When you set this property to `true`, the method performs case-insensitive text location.

Output Arguments

bbox — Text bounding boxes
method | *M*-by-4 matrix

Text bounding boxes, specified as an *M*-by-4 matrix. Each row of the matrix contains a four-element vector, [*x y width height*]. The [*x y*] elements correspond to the upper-left corner of the bounding box. The [*width height*] elements correspond to the size of the rectangular region in pixels. The bounding boxes enclose text found in an image using the `ocr` function. The `ocr` function stores OCR results in the `ocrText` object.
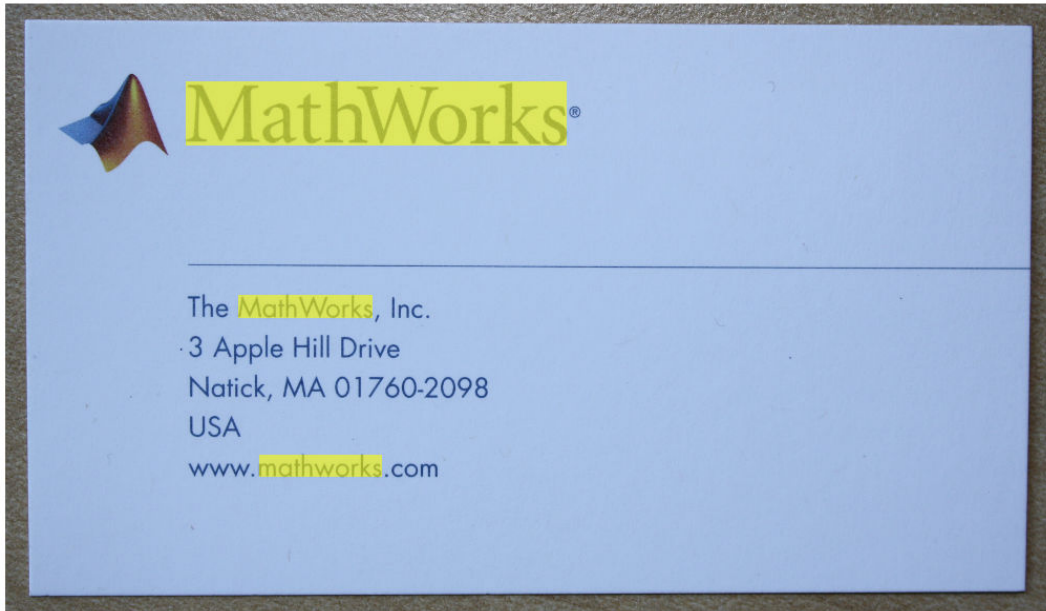
Examples

Find and Highlight Text in an Image

```
businessCard = imread('businessCard.png');
ocrResults = ocr(businessCard);
bboxes = locateText(ocrResults, 'MathWorks', 'IgnoreCase', true);
Iocr = insertShape(businessCard, 'FilledRectangle', bboxes);
figure; imshow(Iocr);
```


Find Text Using Regular Expressions

```
businessCard = imread('businessCard.png');
ocrResults   = ocr(businessCard);
bboxes = locateText(ocrResults, 'www.*com','UseRegexp', true);
img    = insertShape(businessCard, 'FilledRectangle', bboxes);
figure; imshow(img);
```
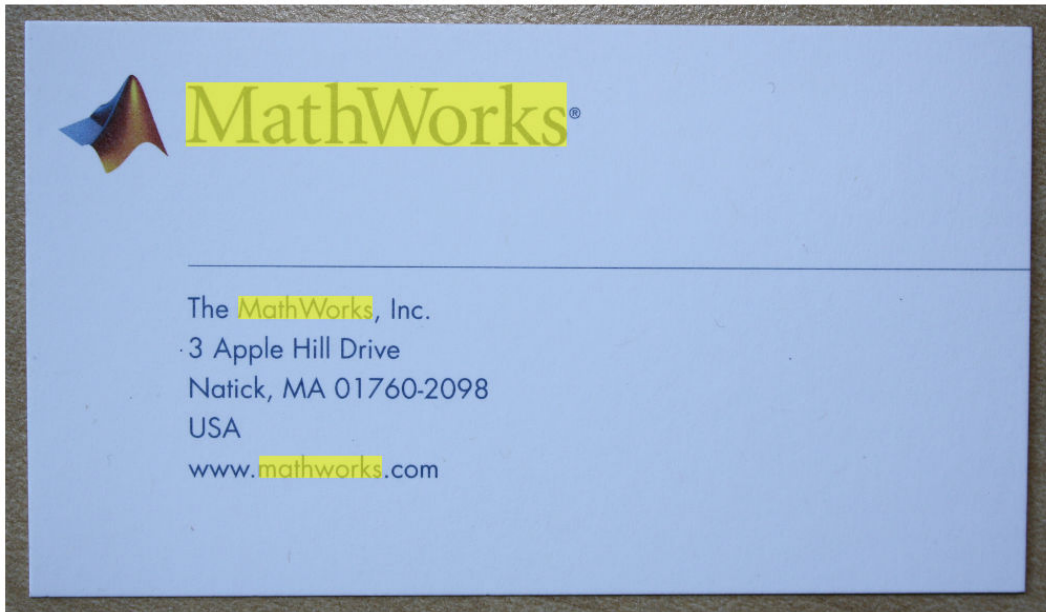
pointCloud class

Object for storing a 3-D point cloud

Syntax

```
ptCloud = pointCloud(xyzPoints)
ptCloud = pointCloud(xyzPoints,Name,Value)
```

Description

`ptCloud = pointCloud(xyzPoints)` returns a point cloud object with coordinates specified by `xyzPoints`.

`ptCloud = pointCloud(xyzPoints,Name,Value)` returns a point cloud object, with additional properties specified by one or more `Name,Value` pair arguments.

Tips

The `pointCloud` object is a `handle` object. If you want to create a separate copy of a point cloud, you can use the MATLAB `copy` method.
`ptCloudB = copy(ptCloudA)`

If you want to preserve a single copy of a point cloud, which can be modified by point cloud functions, use the same point cloud variable name for the input and output.
`ptCloud = pcFunction(ptCloud)`

Input Arguments

xyzPoints — Point cloud *x*, *y*, and *z* locations
M-by-3 matrix | *M*-by-*N*-by-3 matrix

Point cloud *x*, *y*, and *z* locations, specified as either an *M*-by-3 or an *M*-by-*N*-by-3 matrix. The *M*-by-*N*-by-3 matrix is commonly referred to as an organized point cloud. The `xyzPoints` matrix contains *M* or *M*-by-*N* [*x,y,z*] points. The *z* values in the matrix, which

generally correspond to depth or elevation, determine the color of each point. The `xyzPoints` input must be numeric.

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Color',[0 0 255]`

`Color` — Point cloud color
[ ] (default) | *M*-by-3 matrix | *M*-by-*N*-by-3 matrix

Point cloud color of points, specified as the comma-separated pair of `'Color'` and an *M*-by-3, or *M*-by-*N*-by-3 matrix. RGB values range between [0, 255]. Single or double inputs are rescaled to [0, 255].

Coordinates	Valid Values of Color	
M-by-3 matrix	*M*-by-3 matrix	
M-by-*N*-by-3 matrix	*M*-by-*N*-by-3 matrix containing RGB values for each point.	

`Normal` — Normal vector
[ ] (default) | *M*-by-3 matrix | *M*-by-*N*-by-3 matrix

Normal vector at each point, specified as the comma-separated pair consisting of `'Normal'` and a matrix. The normal matrix contains the coordinates for each point and their normal vectors.

Coordinates	Normal Matrix
M-by-3 matrix	*M*-by-3 matrix, where each row contains a corresponding normal vector.
M-by-*N*-by-3 matrix	*M*-by-*N*-by-3 matrix containing a 1-by-1-by-3 normal vector for each point.

`Intensity` — Grayscale intensities
[ ] (default) | *M*-by-1 vector | *M*-by-*N* matrix

Grayscale intensities at each point, specified as the comma-separated pair consisting of 'Intensity' and a *M*-by-1 vector or *M*-by-*N* matrix.

Coordinates	Intensity Value
M-by-3 matrix	*M*-by-1 vector, where each element contains a scalar value for each point.
M-by-*N*-by-3 matrix	*M*-by-*N* matrix containing a scalar value for each point.

Properties

Location — Point coordinates
M-by-3 matrix | *M*-by-*N*-by-3 matrix

Point coordinates, stored as an *M*-by-3 or *M*-by-*N*-by-3 matrix. Each entry specifies the *x*, *y*, *z* coordinates of a point. This property is read-only.

Color — RGB color of point
M-by-3 matrix | *M*-by-*N*-by-3 matrix

RGB color of point, specified as an *M*-by-3 or *M*-by-*N*-by-3 matrix. Each entry specifies the RGB color of a point.

Data Types: uint8

Normal — Normal vector
M-by-3 matrix | *M*-by-*N*-by-3 matrix

Normal vector, specified as an *M*-by-3 matrix or *M*-by-*N*-by-3 matrix. Each entry specifies the *x*, *y*, *z* component of a normal vector of a point. The data type must be the same as the Location data type.

Intensity — Grayscale intensities
[ ] (default) | *M*-by-1 vector | *M*-by-*N* matrix

Grayscale intensities at each point, specified as the comma-separated pair consisting of 'Intensity' and a *M*-by-1 vector or *M*-by-*N* matrix.

Count — Number of points
positive integer

Number of points, stored as a positive integer. This property is read-only.

XLimits — Range of *x*-axis coordinates
1-by-2 vector

Range of coordinates along *x*-axis, stored as a 1-by-2 vector. This property is read-only.

YLimits — Range of *y*-axis coordinates
1-by-2 vector

Range of coordinates along *y*-axis, stored as a 1-by-2 vector. This property is read-only.

ZLimits — Range of *z*-axis coordinates
1-by-2 vector

Range of coordinates along *z*-axis, stored as a 1-by-2 vector. This property is read-only.

Methods

findNearestNeighbors	Find nearest neighbors of a point
findNeighborsInRadius	Find neighbors within a radius
findPointsInROI	Find points within ROI
removeInvalidPoints	Remove invalid points
select	Select points by index

Examples

Find Shortest Distance Between Two Point Clouds

Create two point clouds.

```
ptCloud1 = pointCloud(rand(100,3,'single'));
ptCloud2 = pointCloud(1+rand(100,3,'single'));

minDist = inf;
```

Find the nearest neighbor in `ptCloud2` for each point in `ptCloud1`.

```
for i = 1 : ptCloud1.Count
    point = ptCloud1.Location(i,:);
    [~,dist] = findNearestNeighbors(ptCloud2,point,1);
    if dist < minDist
        minDist = dist;
    end
end
```

• "3-D Point Cloud Registration and Stitching"

See Also

affine3d | pcdenoise | pcdownsample | pcmerge | pcplayer | pcread | pcregistericp | pcregisterndt | pcshow | pctransform | pcwrite

Topics

"3-D Point Cloud Registration and Stitching"
"Coordinate Systems"

Introduced in R2015a

findNearestNeighbors

Class: pointCloud

Find nearest neighbors of a point

Syntax

```
[indices,dists] = findNearestNeighbors(ptCloud,point,K)
[indices,dists] = findNearestNeighbors(ptCloud,point,K,Name, Value)
```

Description

`[indices,dists] = findNearestNeighbors(ptCloud,point,K)` returns the K nearest neighbors of a query point within the input point cloud. The `point` input is an [*X*,*Y*,*Z*] vector.

`[indices,dists] = findNearestNeighbors(ptCloud,point,K,Name, Value)` uses additional options specified by one or more `Name,Value` arguments.

Input Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object.

point — Query point
[*X*,*Y*,*Z*] vector.

Query point, specified as an [*X*,*Y*,*Z*] vector.

K — Number of nearest neighbors
positive integer

Number of nearest neighbors, specified as a positive integer.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Sort — Sort indices
`false` (default) | `true`

Sort indices, specified as a logical scalar. When you set `Sort` to `true`, the returned indices are sorted in the ascending order based on the distance from a query point. To turn sorting off, set `Sort` to `false`.

MaxLeafChecks — Number of leaf nodes
`inf` (default) | integer

Number of leaf nodes, specified as an integer. Set `MaxLeafChecks` to the number of leaf nodes to search in the Kdtree. When you set this value to `inf`, the entire tree is searched. When the entire tree is searched, it produces exact search results. Increasing the number of leaf nodes to check increases accuracy, but reduces efficiency.

Output Arguments

`indices` — Indices of stored points
column vector

Indices of stored points, returned as a column vector. The `indices` output contains K linear indices to the stored points in the point cloud.

`dists` — Distances to query point
column vector

Distances to query point, returned as a column vector. The `dists` contains K Euclidean distances to the query point.

Examples

Find K-Nearest Neighbors in a Point Cloud

Create a point cloud object with randomly generated points.

```
ptCloud = pointCloud(1000*rand(100,3,'single'));
```

Define a query point and the number of neighbors.

```
point = [50,50,50];
K = 10;
```

Get the indices and the distances of 10 nearest points.

```
[indices,dists] = findNearestNeighbors(ptCloud,point,K);
```

References

Muja, M. and David G. Lowe. "Fast Approximate Nearest Neighbors with Automatic Algorithm Configuration". *In VISAPP International Conference on Computer Vision Theory and Applications*. 2009. pp. 331–340.

See Also
pointCloud

Introduced in R2015a

findNeighborsInRadius

Class: pointCloud

Find neighbors within a radius

Syntax

```
[indices,dists] = findNeighborsInRadius(ptCloud,point,radius)
[indices,dists] = findNeighborsInRadius(ptCloud,point,radius,Name,
Value)
```

Description

`[indices,dists] = findNeighborsInRadius(ptCloud,point,radius)` returns the neighbors within a radius of a query point.

`[indices,dists] = findNeighborsInRadius(ptCloud,point,radius,Name, Value)` uses additional options specified by one or more `Name,Value` arguments.

Input Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object.

point — Query point
[*X,Y,Z*] vector.

Query point, specified as an [*X,Y,Z*] vector.

radius — Radius
scalar

Radius, specified as a scalar. The function finds the neighbors within the `radius` of a query point.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Sort — Sort indices
`false` (default) | `true`

Sort indices, specified as a logical scalar. When you set `Sort` to `true`, the returned indices are sorted in the ascending order based on the distance from a query point. To turn sorting off, set `Sort` to `false`.

MaxLeafChecks — Number of leaf nodes
`inf` (default) | integer

Number of leaf nodes, specified as an integer. Set `MaxLeafChecks` to the number of leaf nodes to search in the Kdtree. When you set this value to `inf`, the entire tree is searched. When the entire tree is searched, it produces exact search results. Increasing the number of leaf nodes to check increases accuracy, but reduces efficiency.

Output Arguments

indices — Indices of stored points
column vector

Indices of stored points, returned as a column vector. The `indices` output contains K linear indices to the stored points in the point cloud.

dists — Distances to query point
column vector

Distances to query point, returned as a column vector. The `dists` contains K Euclidean distances to the query point.

Examples

Find Neighbors Within A Given Radius Using Kdtree

Create a point cloud object with randomly generated points.

```
ptCloud = pointCloud(100*rand(1000,3,'single'));
```

Define a query point and set the radius.

```
point = [50,50,50];
radius =  5;
```

Get all of the points within the radius.

```
[indices, dists] = findNeighborsInRadius(ptCloud,point,radius)
```

```
indices =

  0x1 empty uint32 column vector


dists =

  0x1 empty single column vector
```

References

Muja, M. and David G. Lowe. "Fast Approximate Nearest Neighbors with Automatic Algorithm Configuration". *In VISAPP International Conference on Computer Vision Theory and Applications*. 2009. pp. 331–340.

Introduced in R2015a

findPointsInROI

Class: pointCloud

Find points within ROI

Syntax

```
indices = findPointsInROI(ptCloud,roi)
```

Description

`indices = findPointsInROI(ptCloud,roi)` returns the points within a region of interest.

Input Arguments

`ptCloud` — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object.

`roi` — Region of interest
3-by-2 matrix

Region of interest, specified as a 3-by-2 matrix. The format defining the region of interest cuboid matrix is [*xmin*, *xmax*; *ymin*, *ymax*; *zmin*, *zmax*].

Output Arguments

`indices` — Linear indices to stored points
column vector

Linear indices to stored points, returned as a column vector. The indices vector contains the stored points in the `ptCloud` object.

Examples

Find Points Within Cuboid

Create a point cloud object with randomly generated points.

```
ptCloudA = pointCloud(100*rand(1000,3,'single'));
```

Define a cuboid.

```
roi = [0,50;0,inf;0,inf];
```

Find all the points within the cuboid.

```
indices = findPointsInROI(ptCloudA, roi);
ptCloudB = select(ptCloudA,indices);
```

Display points within the ROI.

```
pcshow(ptCloudA.Location,'r');
hold on;
pcshow(ptCloudB.Location,'g');
hold off;
```
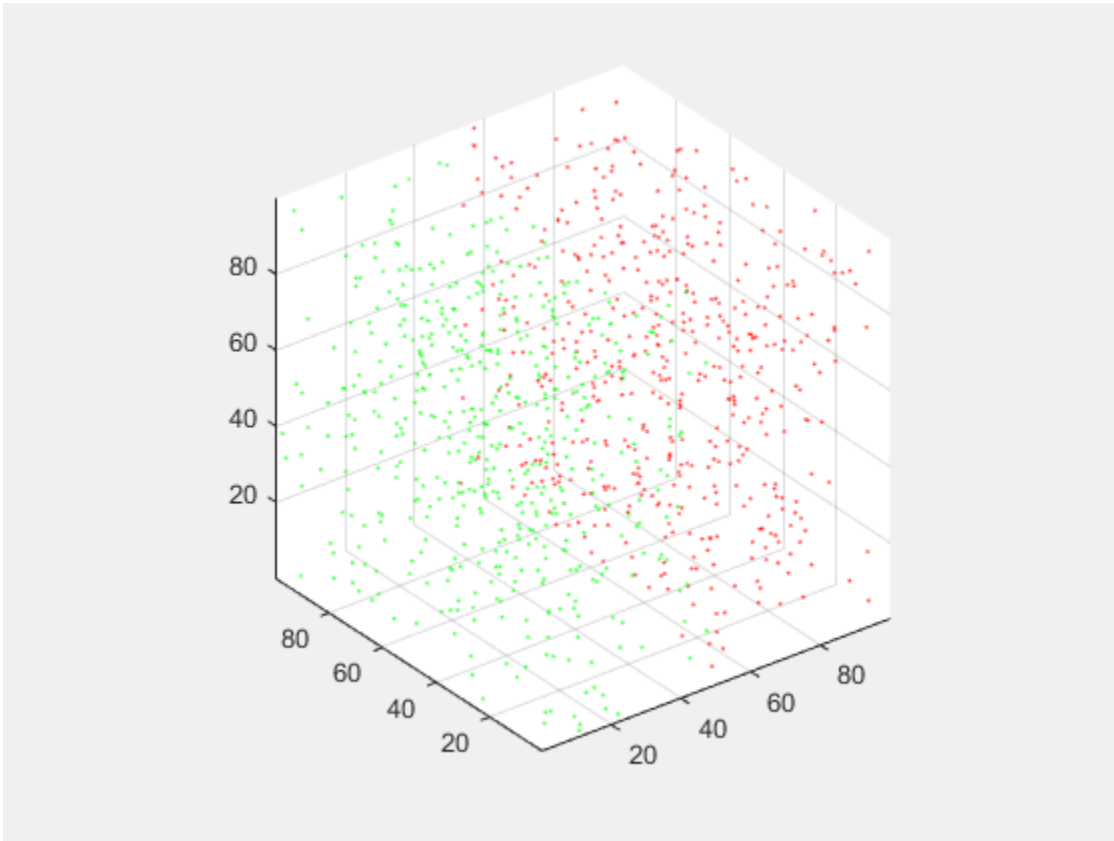
References

Muja, M. and David G. Lowe. "Fast Approximate Nearest Neighbors with Automatic Algorithm Configuration". *In VISAPP International Conference on Computer Vision Theory and Applications*. 2009. pp. 331–340.

Introduced in R2015a

removeInvalidPoints

Class: pointCloud

Remove invalid points

Syntax

```
[ptCloudOut,indices]= removeInvalidPoints(ptCloud)
```

Description

[ptCloudOut,indices]= removeInvalidPoints(ptCloud) removes points with Inf or NaN coordinates from point cloud and provides indices of valid points.

Input Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, specified as a pointCloud object.

Output Arguments

ptCloudOut — Point cloud with points removed
pointCloud object

Point cloud, returned as a pointCloud object with Inf or NaN coordinates removed.

Note After calling this function, an organized point cloud (*M*-by-*N*-by-3) becomes an unorganized (*X*-by-3) point cloud.

`indices` — Indices of valid points
vector

Indices of valid points in the point cloud, specified as a vector.

Examples

Remove Infinite-valued Points From a Point Cloud

Create a point cloud object.

```
ptCloud = pointCloud(nan(100,3))

ptCloud =
  pointCloud with properties:

     Location: [100x3 double]
        Color: []
       Normal: []
    Intensity: []
        Count: 100
       XLimits: [0x2 double]
       YLimits: [0x2 double]
       ZLimits: [0x2 double]
```

```
% Remove invalid points.
ptCloud = removeInvalidPoints(ptCloud)

ptCloud =
  pointCloud with properties:

     Location: [0x3 double]
        Color: []
       Normal: []
    Intensity: []
        Count: 0
       XLimits: [0x2 double]
       YLimits: [0x2 double]
       ZLimits: [0x2 double]
```

Introduced in R2015a

select

Class: pointCloud

Select points by index

Syntax

```
ptCloudOut = select(ptCloud,indices)
ptCloudOut = select(ptCloud,row,column)
ptCloudOut = select( ___ ,'OutputSize',outputSize)
```

Description

ptCloudOut = select(ptCloud,indices) returns a `pointCloud` object containing the points selected using linear indices.

ptCloudOut = select(ptCloud,row,column) returns a `pointCloud` object containing the points selected using row and column subscripts.

ptCloudOut = select(___ ,'OutputSize',outputSize) returns a `pointCloud` object including the number of points specified by `outputSize`.

Input Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object.

indices — Indices of stored points
vector

Indices of stored points, specified as a vector.

row — row subscript
vector

Row subscript, specified as a vector. This syntax applies only to organized point cloud in the format (M-by-N-by-3).

column — column subscript
vector

Column subscript, specified as a vector. This syntax applies only to organized point cloud in the format (M-by-N-by-3).

outputSize — Size of output point cloud
`'selected'` (default) | `'full'`

Size of the output point cloud, `ptCloudOut`, specified as `'selected'` or `'full'`.

- If the size is `'selected'`, then `ptCloudOut` only contains the selected points from the input point cloud, `ptCloud`.
- If the size is `'full'`, then `ptCloudOut` is the same size as `ptCloud`. Unselected points are filled with `NaN`. The color of unselected points is [0 0 0].

Output Arguments

ptCloudOut — Selected point cloud
`pointCloud` object

Point cloud, returned as a `pointCloud` object.

Examples

Downsample Point Cloud With Fixed Step

Read and display a point cloud file.

```
ptCloud = pcread('teapot.ply');
figure
pcshow(ptCloud);
```
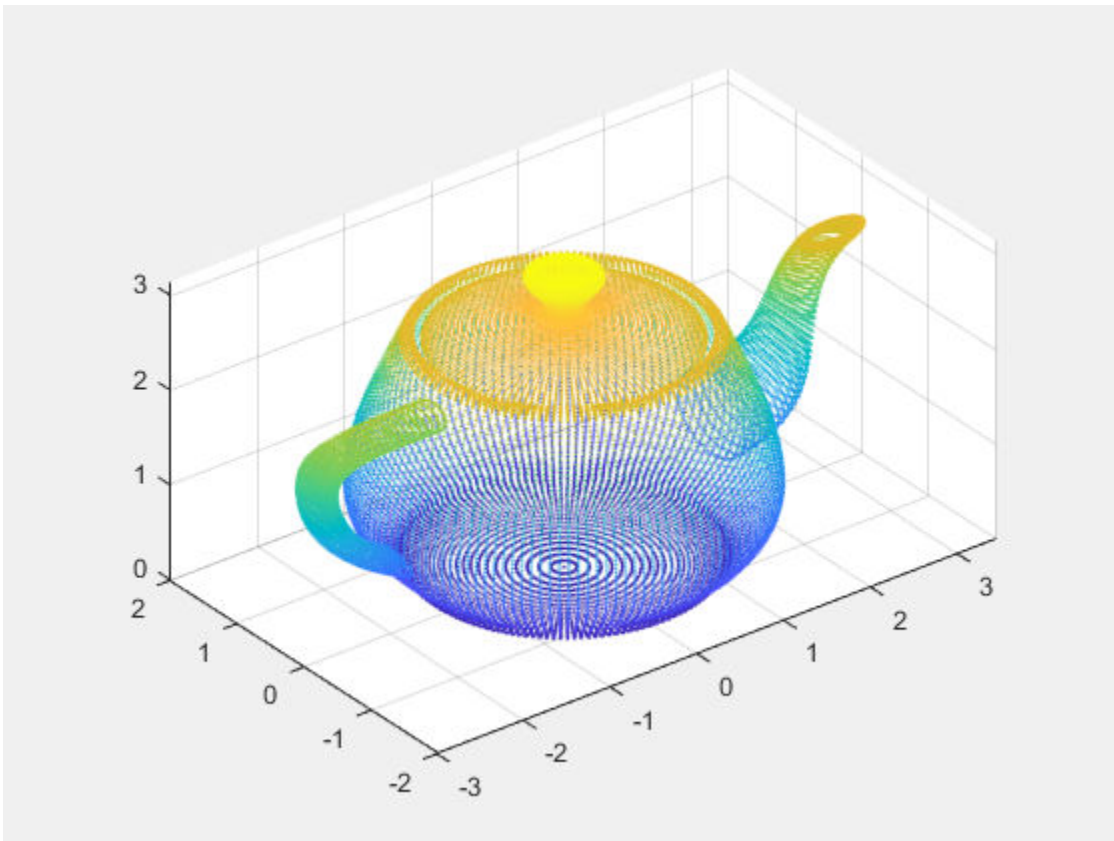
Downsample a point cloud with fixed step size

```
stepSize = 10;
indices = 1:stepSize:ptCloud.Count;
```

Select indexed point cloud.

```
ptCloudOut = select(ptCloud,indices);
```

Display the selected point cloud.

```
figure
pcshow(ptCloudOut);
```

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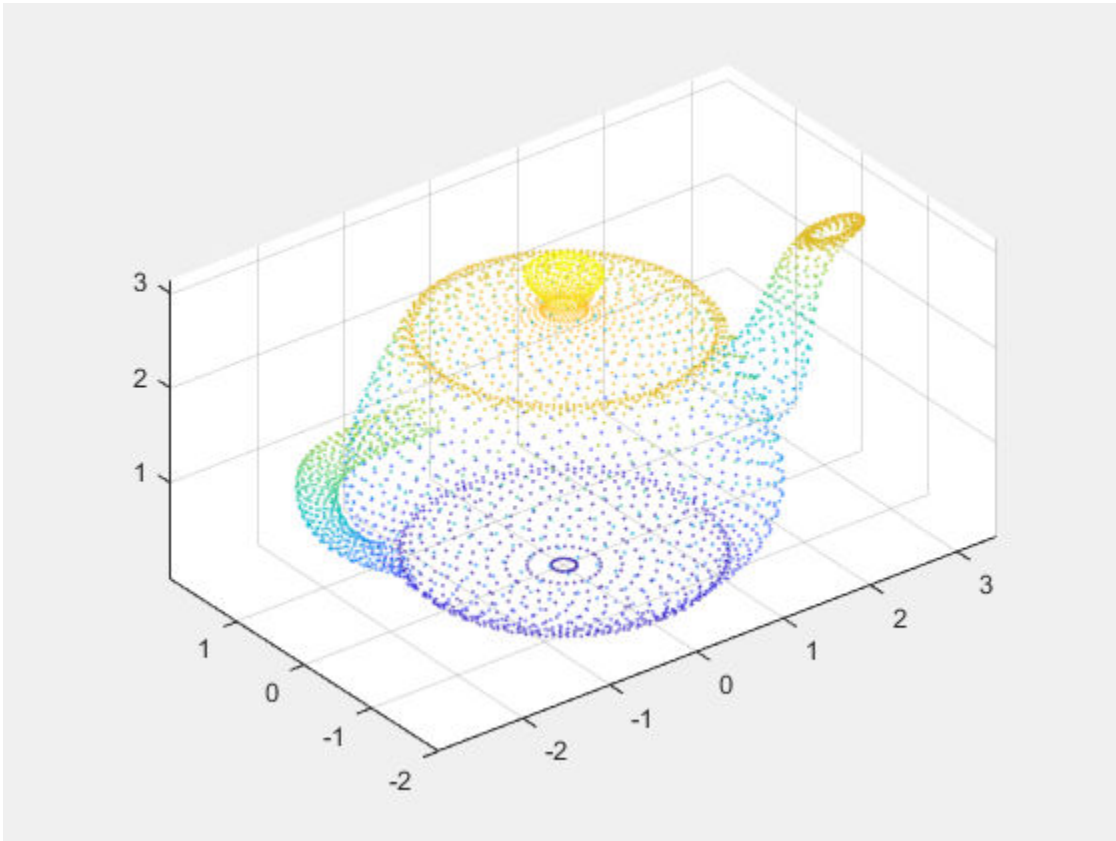
Introduced in R2015a

cylinderModel class

Object for storing a parametric cylinder model

Syntax

```
model = cylinderModel(params)
```

Description

Object for storing a parametric cylinder model.

Construction

`model = cylinderModel(params)` constructs a parametric cylinder model from the 1-by-7 `params` input vector that describes a cylinder.

Input Arguments

`params` — cylinder parameters
1-by-7 scalar vector

Cylinder parameters, specified as a 1-by-7 scalar vector containing seven parameters [$x1,y1,z1,x2,y2,z2,r$] that desribe a cylinder.

- [$x1,y1,z1$] and [$x2,y2,z2$] are the centers of each end-cap surface of the cylinder.
- r is the radius of the cylinder.

Properties

These properties are read-only.

`Parameters` — Cylinder model parameters
1-by-7 scalar vector

Cylinder model parameters, stored as a 1-by-7 scalar vector that describes a cylinder [*x1*,*y1*,*z1*,*x2*,*y2*,*z2*,*r*] that describe a cylinder.

- [*x1*,*y1*,*z1*] and [*x2*,*y2*,*z2*] are the centers of each end-cap surface of the cylinder.
- *r* is the radius of the cylinder.

`Center` — Center of cylinder
1-by-3 vector

Center of cylinder, stored as a 1-by-3 vector.

`Height` — Height of cylinder
scalar

Height of cylinder, stored as a scalar.

`Radius` — Radius of cylinder
scalar

Radius of cylinder, stored as a scalar.

Methods

plot	Plot cylinder in a figure window

Examples

Detect Cylinder in Point Cloud

Load the point cloud.

```
load('object3d.mat');
```

Display point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Detect a Cylinder in a Point Cloud')
```


Set the maximum point-to-cylinder distance (5 mm) for the cylinder fitting.

```
maxDistance = 0.005;
```

Set the region of interest to constrain the search.

```
roi = [0.4,0.6;-inf,0.2;0.1,inf];
sampleIndices = findPointsInROI(ptCloud,roi);
```

Set the orientation constraint.

```
referenceVector = [0,0,1];
```

Detect the cylinder in the point cloud and extract it.

```
model = pcfitcylinder(ptCloud,maxDistance,referenceVector,...
        'SampleIndices',sampleIndices);
```

Plot the cylinder.

```
hold on
plot(model)
```


Detect a Cylinder in a Point Cloud

•   "3-D Point Cloud Registration and Stitching"

See Also

affine3d | pcdenoise | pcdownsample | pcfitcylinder | pcfitplane |
pcfitsphere | pcmerge | pcplayer | pcread | pcregistericp | pcshow |
pctransform | pcwrite | planeModel | pointCloud | sphereModel

Topics

"3-D Point Cloud Registration and Stitching"

Introduced in R2015b

plot

Class: cylinderModel

Plot cylinder in a figure window

Syntax

```
plot(model)
plot(model,'Parent',ax)
```

Description

`H = plot(model)` plots a cylinder within the axis limits of the current figure. `H` is the handle to `surf`, a 3-D shaded surface plot.

`H = plot(model,'Parent',ax)` additionally specifies an output axes.

Input Arguments

model — Parametric cylinder model
cylinder model

Parametric cylinder model returned by `cylinderModel`.

'ax' — Output axes
`gca` (default) | axes

Output axes, specified as the current axes for displaying the cylinder.

Examples

Detect Cylinder in Point Cloud

Load the point cloud.

```
load('object3d.mat');
```

Display point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Detect a Cylinder in a Point Cloud')
```

Set the maximum point-to-cylinder distance (5 mm) for the cylinder fitting.

```
maxDistance = 0.005;
```

Set the region of interest to constrain the search.

```
roi = [0.4,0.6;-inf,0.2;0.1,inf];
sampleIndices = findPointsInROI(ptCloud,roi);
```

Set the orientation constraint.

```
referenceVector = [0,0,1];
```

Detect the cylinder in the point cloud and extract it.

```
model = pcfitcylinder(ptCloud,maxDistance,referenceVector,...
        'SampleIndices',sampleIndices);
```

Plot the cylinder.

```
hold on
plot(model)
```

Detect a Cylinder in a Point Cloud

See Also

cylinderModel | pcfitcylinder

Introduced in R2015b

planeModel

Object for storing a parametric plane model

Description

Construct and store a parametric plane model based on parameters that describe a plane.

Creation

Syntax

Use the `planeModel` object to construct a parameteric plane model.

```
model = planeModel(Parameters)
```

Description

`model = planeModel(Parameters)` constructs a parametric plane model from the 1-by-4 `params` input vector that describes a plane.

Input Arguments

`Parameters` — Plane parameters
1-by-4 scalar vector

Plane parameters, specified as a 1-by-4 vector. This input specifies the `Parameters` property. The four parameters [*a*,*b*,*c*,*d*] describe the equation for a plane:

$$ax + by + cz + d = 0$$

Properties

These properties are read-only.

`Parameters` — **Plane model parameters**
1-by-4 vector

Plane model parameters, stored as a 1-by-4 vector. These parameters are specified by the `params` input argument.

`Normal` — **Normal vector of the plane**
1-by-3 vector

Normal vector of the plane, stored as a 1-by-3 vector. The [*a*,*b*,*c*] vector specifies the unnormalized normal vector of the plane.

Object Functions

planeModel.plot   Plot plane in a figure window
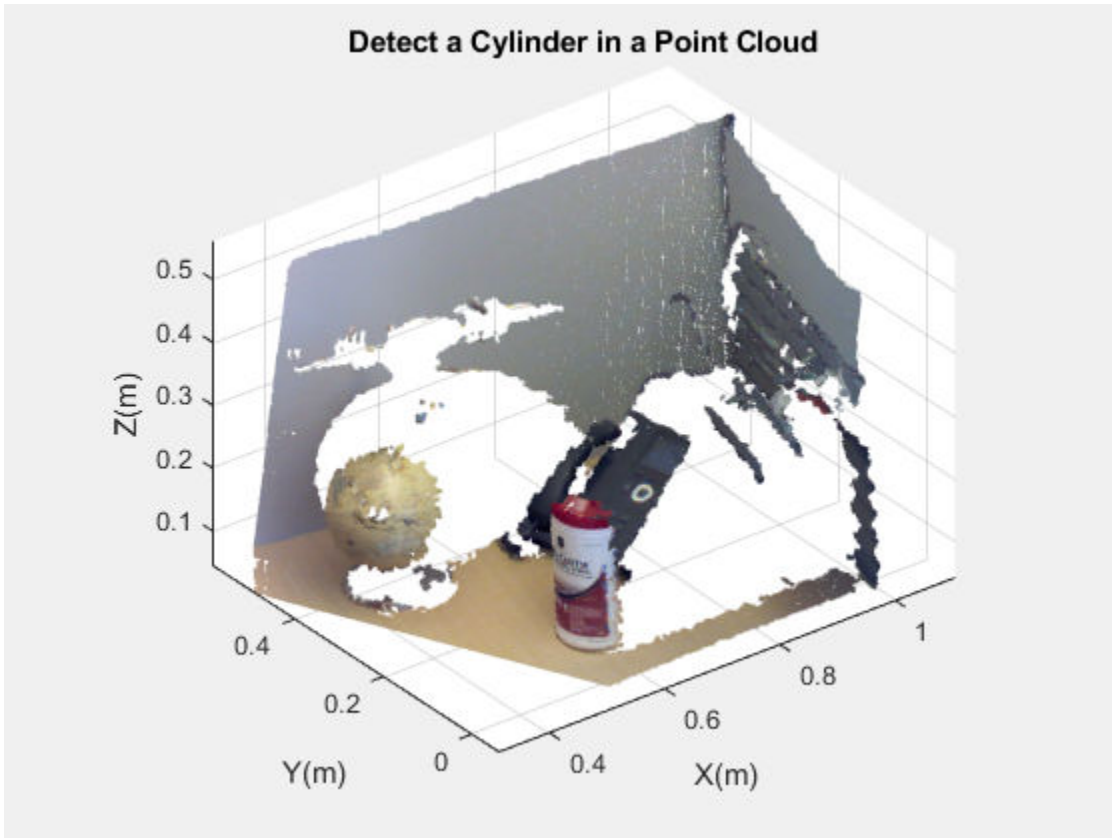
Examples

Detect Multiple Planes from Point Cloud

Load the point cloud.

```
load('object3d.mat')
```

Display and label the point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Original Point Cloud')
```

Set the maximum point-to-plane distance (2cm) for plane fitting.

```
maxDistance = 0.02;
```

Set the normal vector of the plane.

```
referenceVector = [0,0,1];
```

Set the maximum angular distance to 5 degrees.

```
maxAngularDistance = 5;
```

Detect the first plane, the table, and extract it from the point cloud.

```
[model1,inlierIndices,outlierIndices] = pcfitplane(ptCloud,...
            maxDistance,referenceVector,maxAngularDistance);
```

```
plane1 = select(ptCloud,inlierIndices);
remainPtCloud = select(ptCloud,outlierIndices);
```

Set the region of interest to constrain the search for the second plane, left wall.

```
roi = [-inf,inf;0.4,inf;-inf,inf];
sampleIndices = findPointsInROI(remainPtCloud,roi);
```

Detect the left wall and extract it from the remaining point cloud.

```
[model2,inlierIndices,outlierIndices] = pcfitplane(remainPtCloud,...
            maxDistance,'SampleIndices',sampleIndices);
plane2 = select(remainPtCloud,inlierIndices);
remainPtCloud = select(remainPtCloud,outlierIndices);
```

Plot the two planes and the remaining points.

```
figure
pcshow(plane1)
title('First Plane')
```

First Plane

```
figure
pcshow(plane2)
title('Second Plane')
```

Second Plane

```
figure
pcshow(remainPtCloud)
title('Remaining Point Cloud')
```

Remaining Point Cloud

- "3-D Point Cloud Registration and Stitching"

See Also

affine3d | cylinderModel | pcdenoise | pcdownsample | pcfitcylinder | pcfitplane | pcfitsphere | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pctransform | pcwrite | pointCloud | sphereModel

Topics

"3-D Point Cloud Registration and Stitching"

Introduced in R2015b

planeModel.plot

Plot plane in a figure window

Syntax

```
plot(model)
plot(model,Name,Value)
```

Description

`H = plot(model)` plots a plane within the axis limits of the current figure. `H` is the handle to the `patch`.

`H = plot(model,Name,Value)` includes additional options specified by one or more `Name,Value` pair arguments.

Examples

Detect Plane in Point Cloud

Load point cloud.

```
load('object3d.mat');
```

Display the point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Detect a plane in a point cloud')
```
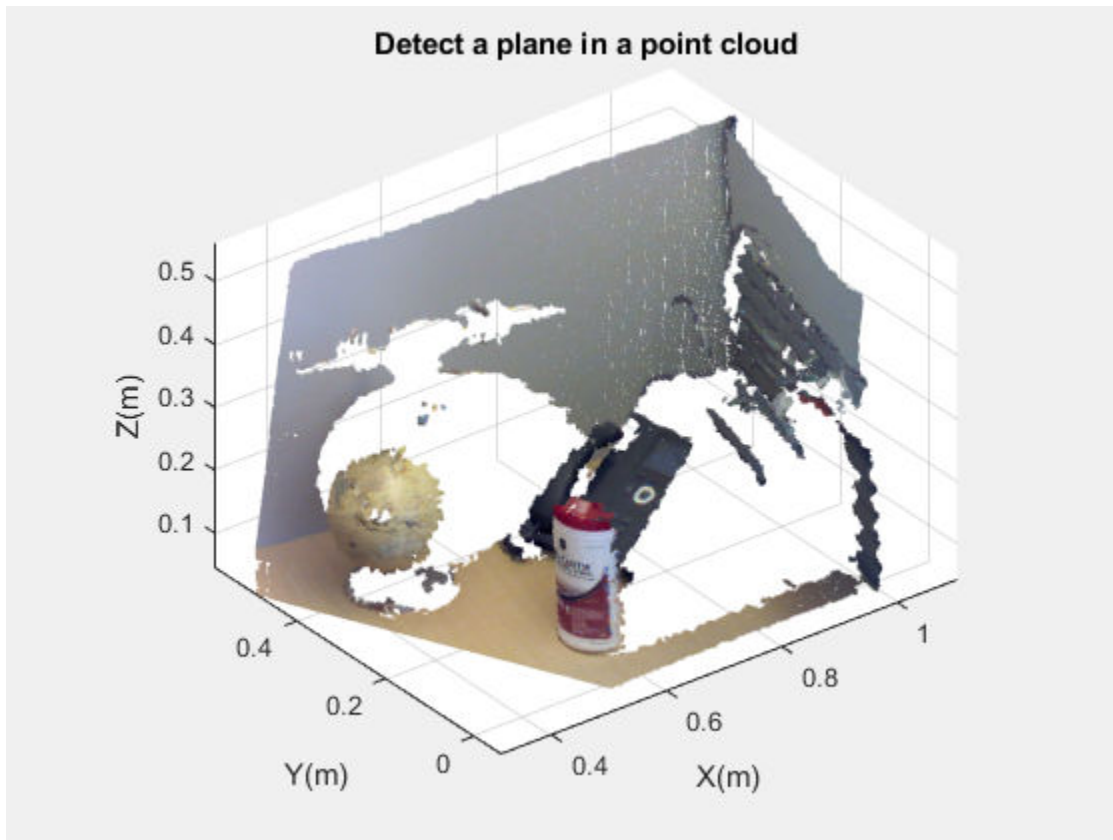
Detect a plane in a point cloud

Set the maximum point-to-plane distance (2cm) for plane fitting.

```
maxDistance = 0.02;
```

Set the normal vector of a plane.

```
referenceVector = [0, 0, 1];
```

Set the maximum angular distance (5 degrees).

```
maxAngularDistance = 5;
```

Detect the table in the point cloud and extract it.

```
model = pcfitplane(ptCloud,maxDistance,referenceVector,maxAngularDistance);
```

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Plot the plane.

```
hold on
plot(model)
```


Detect a plane in a point cloud
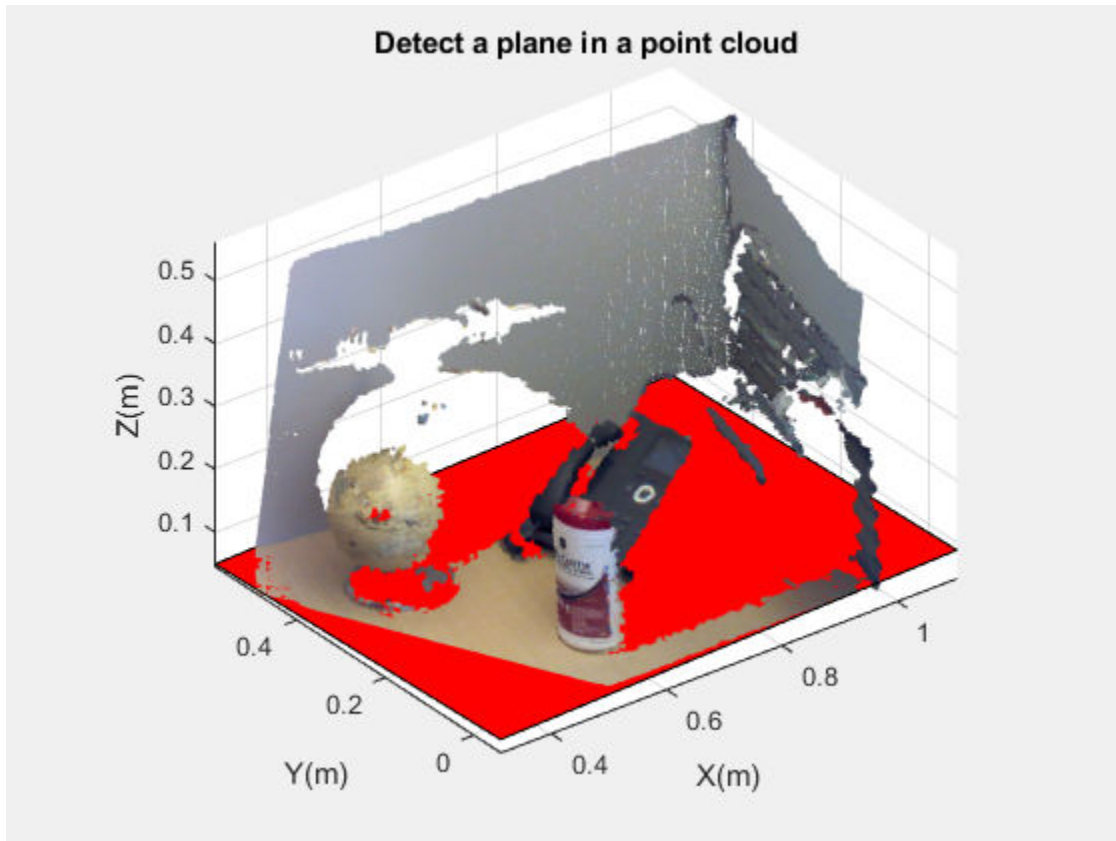
Input Arguments

`model` — Parametric plane model
plane model

Parametric plane model returned by `planeModel`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'VerticalAxisDir', 'Up'`.

Color — 'red'
`gca` (default) | axes

Output axes, specified as the comma-separated pair of `'Parent'` and the current axes for displaying the visualization.

Color — Color of the plane
`'red'` | color character vector | `[R G B]` vector

Color of the plane, specified as the comma-separated pair of `'Color'` and either a color character vector or an `[R G B]` vector. The `[R G B]` values mut be in the range of `[0 1]`. Supported color character vectors are listed in `ColorSpec` specifications.

Introduced in R2015b

sphereModel class

Object for storing a parametric sphere model

Syntax

```
model = sphereModel(params)
```

Description

Object for storing a parametric sphere model

Construction

`model = sphereModel(params)` constructs a parametric sphere model from the 1-by-4 `params` input vector that describes a sphere.

Input Arguments

params — Sphere parameters
1-by-4 scalar vector

Sphere parameters, specified as a 1-by-4 scalar vector. This input specifies the `Parameters` property. The four parameters $[a,b,c,d]$ satisfy the equation for a sphere:

$$(x-a)^2 + (y-b)^2 + (z-c)^2 = d^2$$

Properties

These properties are read-only.

`Parameters` — Sphere model parameters
1-by-4 vector

Sphere model parameters, stored as a 1-by-4 vector. These parameters are specified by the `params` input argument. The four parameters [*a*,*b*,*c*,*d*] satisfy the equation for a sphere:

$$(x-a)^2 + (y-b)^2 + (z-c)^2 = d^2$$

`Center` — Center of the sphere
1-by-3 vector

Center of the sphere, stored as a 1-by-3 vector [*xc*,*yc*,*zc*] that specifies the center coordinates of the sphere.

`Radius` — Radius of sphere
scalar

Radius of sphere, stored as a scalar value.

Methods

plot   Plot sphere in a figure window

Examples

Detect Sphere in Point Cloud

Load point cloud.

```
load('object3d.mat');
```

Display point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
```

```
zlabel('Z(m)')
title('Detect a sphere in a point cloud')
```


Set the maximum point-to-sphere distance (1cm), for sphere fitting.

```
maxDistance = 0.01;
```

Set the region of interest to constrain the search.

```
roi = [-inf, 0.5; 0.2, 0.4; 0.1, inf];
sampleIndices = findPointsInROI(ptCloud, roi);
```

Detect the globe in the point cloud and extract it.

```
model = pcfitsphere(ptCloud, maxDistance, 'SampleIndices', sampleIndices);
```

Plot the sphere.

```
hold on
plot(model)
```


Detect a sphere in a point cloud

• "3-D Point Cloud Registration and Stitching"

See Also

affine3d | cylinderModel | pcdenoise | pcdownsample | pcfitcylinder |
pcfitplane | pcfitsphere | pcmerge | pcplayer | pcread | pcregistericp |
pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics
"3-D Point Cloud Registration and Stitching"

Introduced in R2015b

plot

Class: sphereModel

Plot sphere in a figure window

Syntax

```
plot(model)
plot(model,'Parent',ax)
```

Description

H = `plot(model)` plots a sphere in the current figure. H is the handle to `surf`, a 3-D shaded surface plot.

H = `plot(model,'Parent',ax)` additionally allows you to specify an output axes.

Input Arguments

model — Parametric sphere model
sphere model

Parametric sphere model returned by `sphereModel`.

'Parent' — Output axes
`gca` (default) | axes

Output axes, specified as the comma-separated pair of `'Parent'` and the current axes for displaying the visualization.

Examples

Detect Sphere in Point Cloud

Load point cloud.

```
load('object3d.mat');
```

Display point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Detect a sphere in a point cloud')
```

Set the maximum point-to-sphere distance (1cm), for sphere fitting.

```
maxDistance = 0.01;
```

Set the region of interest to constrain the search.

```
roi = [-inf, 0.5; 0.2, 0.4; 0.1, inf];
sampleIndices = findPointsInROI(ptCloud, roi);
```

Detect the globe in the point cloud and extract it.

```
model = pcfitsphere(ptCloud, maxDistance, 'SampleIndices', sampleIndices);
```

Plot the sphere.

```
hold on
plot(model)
```

Detect a sphere in a point cloud
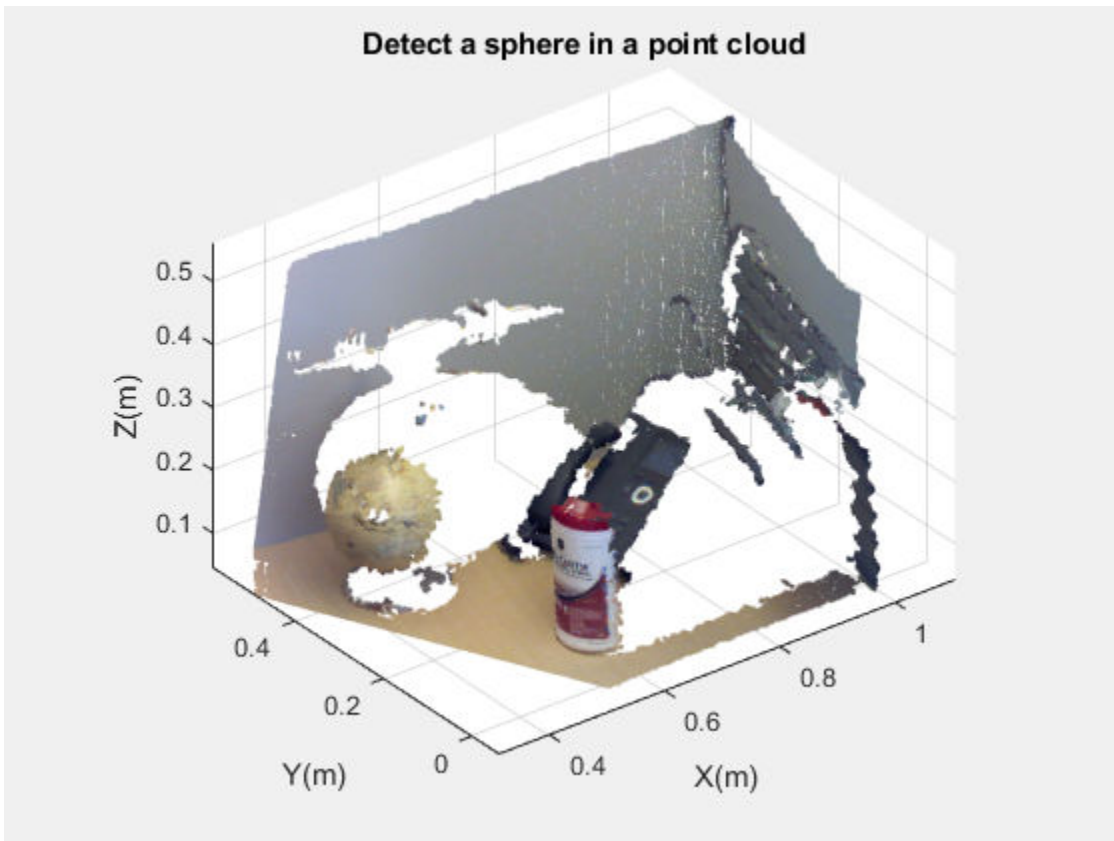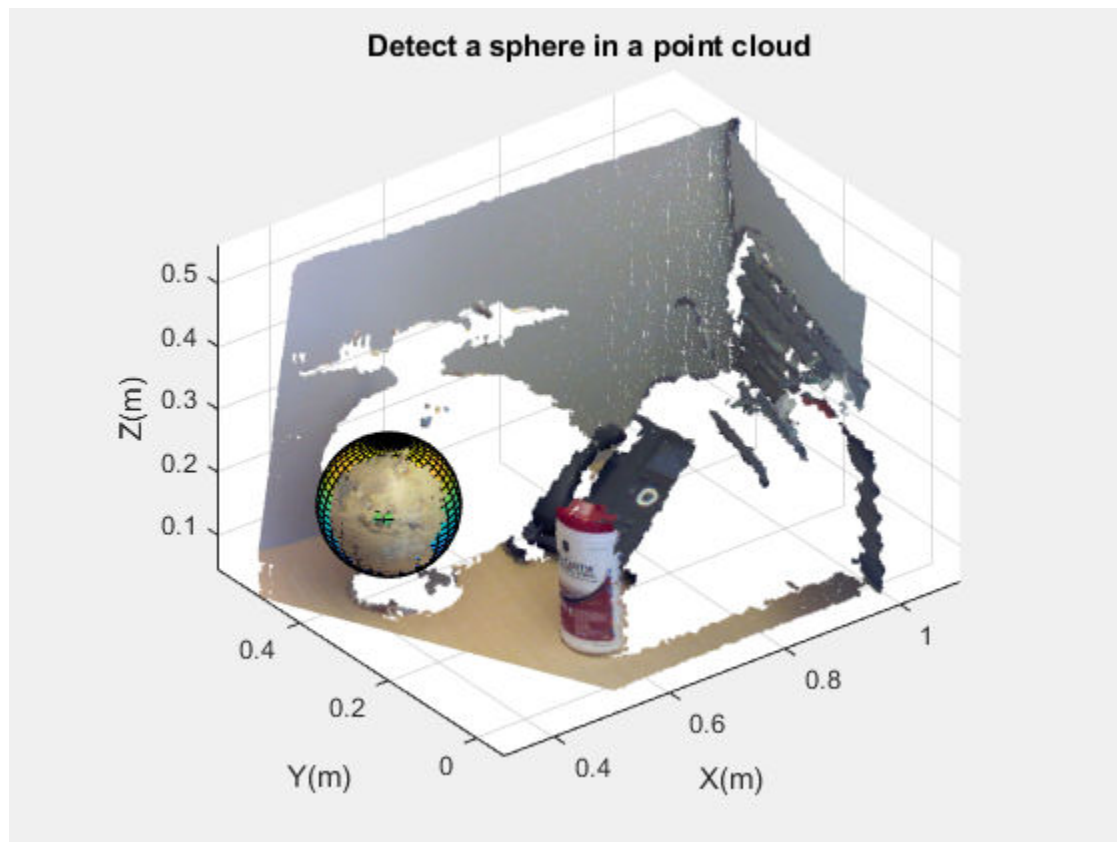
See Also

`pcfitsphere` | `sphereModel`

Introduced in R2015b

opticalFlow class

Object for storing optical flow matrices

Description

> **Note** The `vision.opticalFlow` System object will be removed in a future release. Use `opticalFlowHS`, `opticalFlowLKDoG`, `opticalFlowLK`, or `opticalFlowFarneback` with equivalent functionality instead.

The `OpticalFlow` object stores the direction and speed of a moving object from one image or video frame to another.

Construction

`flow = opticalFlow(Vx,Vy)` constructs an optical flow object from two equal-sized matrices, `Vx` and `Vy`, which are the *x* and *y* components of velocity.

`flow = opticalFlow( ___ ,Name,Value)` includes additional options specified by one or more `Name,Value` pair arguments.

Code Generation Support
Supports Code Generation: Yes
Supports MATLAB Function block: Yes
"Code Generation Support, Usage Notes, and Limitations".

Input Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Vx',randn(100,100)`

Vx — *X* component of velocity
M-by-*N* matrix

X component of velocity, specified as the comma-separated pair consisting of `'Vx'` and an *M*-by-*N* matrix.

Vy — *Y* component of velocity
M-by-*N* matrix

Y component of velocity, specified as the comma-separated pair consisting of `'Vy'` and an *M*-by-*N* matrix.

Orientation — Phase angles of optical flow
M-by-*N* matrix

Phase angles of optical flow in radians, specified as the comma-separated pair consisting of `'Orientation'` and an *M*-by-*N* matrix of size `Vx` or `Vy`.

Magnitude — Magnitude of optical flow
M-by-*N* matrix

Magnitude of optical flow, specified as the comma-separated pair consisting of `'Magnitude'` and an *M*-by-*N* matrix.

Methods

plot   Plot optical flow

Examples

Construct Optical Flow Object and Plot Its Velocity

Construct an optical flow object.

```
opflow = opticalFlow(randn(100,100),randn(100,100));
```

Plot the velocity of the object as a quiver plot.

```
plot(opflow,'DecimationFactor',[10 10],'ScaleFactor',10);
```
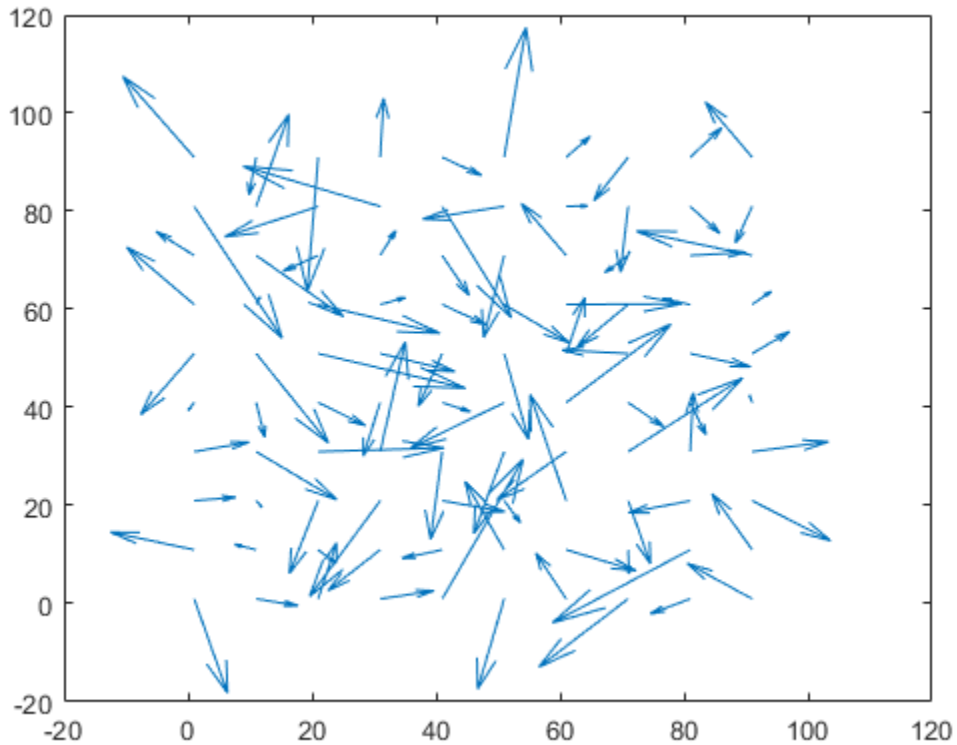

See Also
opticalFlowFarneback | opticalFlowHS | opticalFlowLK | opticalFlowLKDoG |
quiver

Introduced in R2015a

plot

Class: opticalFlow

Plot optical flow

Syntax

```
plot(flow)
plot(flow,Name,Value)
```

Description

`plot(flow)` plots the optical flow vectors.

`plot(flow,Name,Value)` includes additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

`flow` — **Object for storing optical flow matrices**
`opticalFlow` object

Object for storing optical flow velocity matrices, specified as an `opticalFlow` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

`'DecimationFactor'` — **Decimation factor of velocity vectors**
`[1 1]` | 2-element vector

Decimation factor of velocity vectors, specified as the comma-separated pair consisting of `DecimationFactor` and a 2-element vector. The 2-element vector, [*XDecimFactor YDecimFactor*], specifies the decimation factor of velocity vectors along the *x* and *y* directions. *XDecimFactor* and *YDecimFactor* are positive scalar integers. Increase the value of this property to get a less cluttered quiver plot.

`'ScaleFactor'` — Scaling factor for velocity vector display
1 | positive integer-valued scalar

Scaling factor for velocity vector display, specified as the comma-separated pair consisting of `'ScaleFactor'` and a positive integer-valued scalar. Increase this value to display longer vectors.

`'Parent'` — Display axes
`gca` handle

Display axes, specified as the comma-separated pair consisting of `'Parent'` and the handle to an axes.

Examples

Construct Optical Flow Object and Plot Its Velocity

Construct an optical flow object.

```
opflow = opticalFlow(randn(100,100),randn(100,100));
```

Plot the velocity of the object as a quiver plot.

```
plot(opflow,'DecimationFactor',[10 10],'ScaleFactor',10);
```
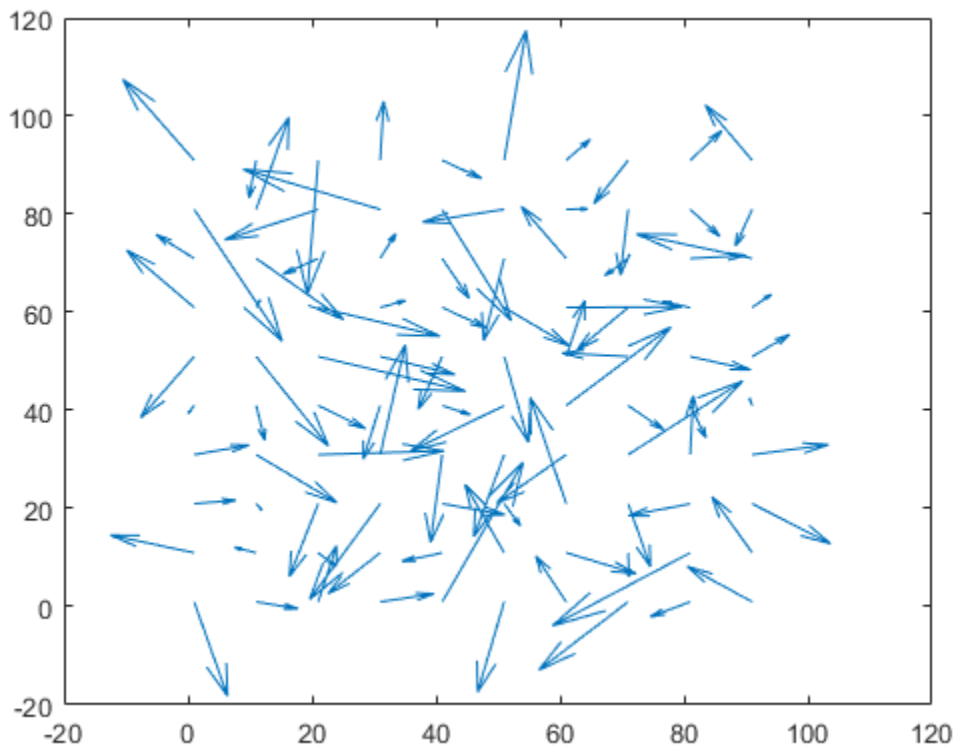
See Also

opticalFlow | quiver

Introduced in R2015a

opticalFlowHS class

Estimate optical flow using Horn-Schunck method

Description

Estimate the direction and speed of a moving object from one image or video frame to another using the Horn-Schunck method.

Construction

`opticFlow = opticalFlowHS` returns an optical flow object that is used to estimate the direction and speed of an object's motion. `opticalFlowHS` uses the Horn-Schunck algorithm.

`opticFlow = opticalFlowHS(Name,Value)` includes additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MaxIteration',10`

Smoothness — Expected smoothness
1 (default) | positive scalar

Expected smoothness of optical flow, specified as the comma-separated pair consisting of `'Smoothness'` and a positive scalar. Increase this value when there is increased motion between consecutive frames. A typical value for `'Smoothness'` is around 1.

MaxIteration — Maximum number of iterations
10 (default) | positive integer-valued scalar

Maximum number of iterations to perform in the optical flow iterative solution, specified as the comma-separated pair consisting of `'MaxIteration'` and a positive integer-valued scalar. Increase this value to estimate objects with low velocity.

Computation stops when the number of iterations equals `MaxIteration` or when the algorithm reaches the value set by `VelocityDifference`. To use only `MaxIteration` to stop computation, set `VelocityDifference` to `0`.

VelocityDifference — Minimum absolute velocity difference
`0` (default) | positive scalar

Minimum absolute velocity difference at which to stop iterative computation, specified as the comma-separated pair consisting of `'VelocityDifference'` and a positive scalar. This value depends on the input data type. Decrease this value to estimate the optical flow of objects that have low velocity.

Computation stops when the number of iterations equals `MaxIteration` or when the algorithm reaches the value set by `VelocityDifference`. To only use `MaxIteration` to stop computation, set `VelocityDifference` to `0`. To use only `VelocityDifference`, set `MaxIteration` to Inf

Methods

reset	Reset the internal state of the object
estimateFlow	Estimate optical flow

Examples

Compute Optical Flow Using Horn-Schunck Method

Read in a video file.

```
vidReader = VideoReader('viptraffic.avi');
```

Create optical flow object.

```
opticFlow = opticalFlowHS;
```

Estimate the optical flow of objects in the video.

```matlab
while hasFrame(vidReader)
    frameRGB = readFrame(vidReader);
    frameGray = rgb2gray(frameRGB);

    flow = estimateFlow(opticFlow,frameGray);

    imshow(frameRGB)
    hold on
    plot(flow,'DecimationFactor',[5 5],'ScaleFactor',25)
    hold off
end
```


Algorithms

To compute the optical flow between two images, you must solve the following optical flow constraint equation:

$$I_x u + I_y v + I_t = 0$$

.

- I_x, I_y, and I_t are the spatiotemporal image brightness derivatives.

- *u* is the horizontal optical flow.
- *v* is the vertical optical flow.

Horn-Schunck Method

By assuming that the optical flow is smooth over the entire image, the Horn-Schunck method computes an estimate of the velocity field, $[u \quad v]^T$, that minimizes this equation:

$$E = \iint (I_x u + I_y v + I_t)^2 \, dxdy + \alpha \iint \left\{ \left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial y} \right)^2 + \left(\frac{\partial v}{\partial x} \right)^2 + \left(\frac{\partial v}{\partial y} \right)^2 \right\} dxdy$$

.

In this equation, $\frac{\partial u}{\partial x}$ and $\frac{\partial u}{\partial y}$ are the spatial derivatives of the optical velocity component, *u*, and α scales the global smoothness term. The Horn-Schunck method minimizes the previous equation to obtain the velocity field, [u v], for each pixel in the image. This method is given by the following equations:

$$u_{x,y}^{k+1} = \bar{u}_{x,y}^k - \frac{I_x [I_x \bar{u}_{x,y}^k + I_y \bar{v}_{x,y}^k + I_t]}{\alpha^2 + I_x^2 + I_y^2}$$

$$v_{x,y}^{k+1} = \bar{v}_{x,y}^k - \frac{I_y [I_x \bar{u}_{x,y}^k + I_y \bar{v}_{x,y}^k + I_t]}{\alpha^2 + I_x^2 + I_y^2}$$

.

In these equations, $\left[u_{x,y}^k \quad v_{x,y}^k \right]$ is the velocity estimate for the pixel at (*x*,*y*), and $\left[\bar{u}_{x,y}^k \quad \bar{v}_{x,y}^k \right]$ is the neighborhood average of $\left[u_{x,y}^k \quad v_{x,y}^k \right]$. For *k = 0*, the initial velocity is 0.

To solve *u* and *v* using the Horn-Schunck method:

1

Compute I_x and I_y using the Sobel convolution kernel,

$\begin{bmatrix} -1 & -2 & -1; & 0 & 0 & 0; & 1 & 2 & 1 \end{bmatrix}$, and its transposed form, for each pixel in the first image.

2

Compute I_t between images 1 and 2 using the $\begin{bmatrix} -1 & 1 \end{bmatrix}$ kernel.

3 Assume the previous velocity to be 0, and compute the average velocity for each pixel

using $\begin{bmatrix} 0 & 1 & 0; & 1 & 0 & 1; & 0 & 1 & 0 \end{bmatrix}$ as a convolution kernel.

4 Iteratively solve for *u* and *v*.

References

[1] Barron, J. L., D. J. Fleet, S. S. Beauchemin, and T. A. Burkitt. "Performance of optical flow techniques". *CVPR*, 1992.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

See Also

opticalFlow | opticalFlowFarneback | opticalFlowLK | opticalFlowLKDoG | quiver

Introduced in R2015a

reset

Class: opticalFlowHS

Reset the internal state of the object

Syntax

```
reset(opticFlow)
```

Description

`reset(opticFlow)` resets the internal state of the optical flow object. Doing this sets the previous frame to black.

Introduced in R2015a

estimateFlow

Class: opticalFlowHS

Estimate optical flow

Syntax

```
flow = estimateFlow(opticFlow,I)
```

Description

`flow = estimateFlow(opticFlow,I)` estimates the optical flow of the input image, `I`, with respect to the previous image. The function sets the previous image for the first run to a black image. After the first run, each new image, `I`, becomes the current image, and the image from the last run becomes the previous one. You can also use flow estimation to predict a future position of a moving object for image reconstruction.

Input Arguments

`opticFlow` — Object for storing optical flow velocity matrices
`opticalFlow` object

Object for storing optical flow velocity matrices, specified as an `opticalFlow` object.

`I` — Input image
grayscale image

Input image, specified as a grayscale image. To process the first frame, the function sets the previous frame to black.

Output Arguments

`flow` — Object for storing optical flow velocity matrices
`opticalFlow` object

Object for storing optical flow velocity matrices, returned as an `opticalFlow` object.

Examples

Compute Optical Flow Using Horn-Schunck Method

Read in a video file.

```
vidReader = VideoReader('viptraffic.avi');
```

Create optical flow object.

```
opticFlow = opticalFlowHS;
```

Estimate the optical flow of objects in the video.

```
while hasFrame(vidReader)
    frameRGB = readFrame(vidReader);
    frameGray = rgb2gray(frameRGB);

    flow = estimateFlow(opticFlow,frameGray);

    imshow(frameRGB)
    hold on
    plot(flow,'DecimationFactor',[5 5],'ScaleFactor',25)
    hold off
end
```

Introduced in R2015a

opticalFlowLK class

Estimate optical flow using Lucas-Kanade method

Description

Estimate the direction and speed of a moving object from one image or video frame to another using the Lucas-Kanade method.

Construction

`opticFlow = opticalFlowLK` returns an optical flow object used to estimate the direction and speed of an object's motion. `opticalFlowLK` uses the Lucas-Kanade algorithm and a difference filter, `[-1 1]`, for temporal smoothing.

`opticFlow = opticalFlowLK(Name,Value)` includes additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NoiseThreshold',0.0039`

NoiseThreshold — Threshold for noise reduction
`0.0039` (default) | positive scalar

Threshold for noise reduction, specified as the comma-separated pair consisting of `'NoiseThreshold'` and a positive scalar. The more you increase this number, the less an object's movement affects the optical flow calculation.

Methods

estimateFlow	Estimate optical flow
reset	Reset the internal state of the object

Examples

Compute Optical Flow Using Lucas-Kanade Algorithm

Read in a video file.

```
vidReader = VideoReader('viptraffic.avi');
```

Create optical flow object.

```
opticFlow = opticalFlowLK('NoiseThreshold',0.009);
```

Estimate and display the optical flow of objects in the video.

```
while hasFrame(vidReader)
    frameRGB = readFrame(vidReader);
    frameGray = rgb2gray(frameRGB);

    flow = estimateFlow(opticFlow,frameGray);

    imshow(frameRGB)
    hold on
    plot(flow,'DecimationFactor',[5 5],'ScaleFactor',10)
    hold off
end
```

Algorithms

To compute the optical flow between two images, you must solve the following optical flow constraint equation:

$$I_x u + I_y v + I_t = 0$$

.

-
    I_x, I_y, and I_t are the spatiotemporal image brightness derivatives.
- u is the horizontal optical flow.
- v is the vertical optical flow.

Lucas-Kanade Method

To solve the optical flow constraint equation for u and v, the Lucas-Kanade method divides the original image into smaller sections and assumes a constant velocity in each section. Then, it performs a weighted least-square fit of the optical flow constraint equation to a constant model for $[u \quad v]^T$ in each section Ω. The method achieves this fit by minimizing the following equation:

$$\sum_{x \in \Omega} W^2 [I_x u + I_y v + I_t]^2$$

W is a window function that emphasizes the constraints at the center of each section. The solution to the minimization problem is

$$\begin{bmatrix} \sum W^2 I_x^2 & \sum W^2 I_x I_y \\ \sum W^2 I_y I_x & \sum W^2 I_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} = - \begin{bmatrix} \sum W^2 I_x I_t \\ \sum W^2 I_y I_t \end{bmatrix}$$

.

The Lucas-Kanade method computes I_t using a difference filter, [-1 1].

u and *v* are solved as follows:

1

Compute I_x and I_y using the kernel $\begin{bmatrix} -1 & 8 & 0 & -8 & 1 \end{bmatrix} / 12$ and its transposed form.

2

Compute I_t between images 1 and 2 using the $\begin{bmatrix} -1 & 1 \end{bmatrix}$ kernel.

3

Smooth the gradient components, I_x, I_y, and I_t, using a separable and isotropic 5-by-5 element kernel whose effective 1-D coefficients are $\begin{bmatrix} 1 & 4 & 6 & 4 & 1 \end{bmatrix} / 16$.

4 Solve the 2-by-2 linear equations for each pixel using the following method:

-

  If $A = \begin{bmatrix} a & b \\ b & c \end{bmatrix} = \begin{bmatrix} \sum W^2 I_x^2 & \sum W^2 I_x I_y \\ \sum W^2 I_y I_x & \sum W^2 I_y^2 \end{bmatrix}$

  Then the eigenvalues of A are $\lambda_i = \dfrac{a+c}{2} \pm \dfrac{\sqrt{4b^2 + (a-c)^2}}{2} ; i = 1, 2$

- The eigenvalues are compared to the threshold, τ, that corresponds to the value you enter for the threshold for noise reduction. The results fall into one of the following cases:

  Case 1: $\lambda_1 \geq \tau$ and $\lambda_2 \geq \tau$

A is nonsingular, the system of equations are solved using Cramer's rule.

Case 2: $\lambda_1 \geq \tau$ and $\lambda_2 < \tau$

A is singular (noninvertible), the gradient flow is normalized to calculate u and v.

Case 3: $\lambda_1 < \tau$ and $\lambda_2 < \tau$

The optical flow, u and v, is 0.

References

[1] Barron, J. L., D. J. Fleet, S. S. Beauchemin, and T. A. Burkitt. "Performance of optical flow techniques". *CVPR*, 1992.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

See Also
opticalFlow | opticalFlowFarneback | opticalFlowHS | opticalFlowLKDoG | quiver

Introduced in R2015a

estimateFlow

Class: opticalFlowHS

Estimate optical flow

Syntax

```
flow = estimateFlow(opticFlow,I)
```

Description

`flow = estimateFlow(opticFlow,I)` estimates the optical flow of the input image, `I`, with respect to the previous image. The function sets the previous image for the first run to a black image. After the first run, each new image, `I`, becomes the current image, and the image from the last run becomes the previous one. You can also use flow estimation to predict a future position of a moving object for image reconstruction.

Input Arguments

`opticFlow` — Object for storing optical flow velocity matrices
`opticalFlow` object

Object for storing optical flow velocity matrices, specified as an `opticalFlow` object.

`I` — Input image
grayscale image

Input image, specified as a grayscale image. To process the first frame, the function sets the previous frame to black.

Output Arguments

`flow` — Object for storing optical flow velocity matrices
`opticalFlow` object

Object for storing optical flow velocity matrices, returned as an `opticalFlow` object.

Examples

Compute Optical Flow Using Lucas-Kanade Algorithm

Read in a video file.

```
vidReader = VideoReader('viptraffic.avi');
```

Create optical flow object.

```
opticFlow = opticalFlowLK('NoiseThreshold',0.009);
```

Estimate and display the optical flow of objects in the video.

```
while hasFrame(vidReader)
    frameRGB = readFrame(vidReader);
    frameGray = rgb2gray(frameRGB);

    flow = estimateFlow(opticFlow,frameGray);

    imshow(frameRGB)
    hold on
    plot(flow,'DecimationFactor',[5 5],'ScaleFactor',10)
    hold off
end
```

Introduced in R2015a

reset

Class: opticalFlowLK

Reset the internal state of the object

Syntax

```
reset(opticFlow)
```

Description

`reset(opticFlow)` resets the internal state of the optical flow object. Doing this sets the previous frame to black.

Introduced in R2015a

opticalFlowLKDoG class

Estimate optical flow using Lucas-Kanade derivative of Gaussian method

Description

Estimate the direction and speed of a moving object from one image or video frame to another using the Lucas-Kanade derivative of Gaussian (DoG) method.

Construction

`opticFlow = opticalFlowLKDoG` returns an optical flow object that is used to estimate the direction and speed of an object's motion. `opticalFlowLKDoG` uses the Lucas-Kanade method and a derivative of Gaussian (DoG) filter for temporal smoothing.

`opticFlow = opticalFlowLKDoG(Name,Value)` includes additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NumFrames',3`

NumFrames — Number of buffered frames
3 (default) | positive integer-valued scalar

Number of buffered frames for temporal smoothing, specified as the comma-separated pair consisting of `'NumFrames'` and a positive integer-valued scalar. The more you increase this number, the less an object's abrupt movement affects the optical flow calculation. The amount of delay in flow estimation depends on the value of `NumFrames`.

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The output flow corresponds to the image at $t_{flow} = (t_{current} - (NumFrames - 1)/2)$, where $t_{current}$ is the time of the current image.

`ImageFilterSigma` — Standard deviation for image smoothing filter
1.5 | positive scalar

Standard deviation for image smoothing filter, specified as the comma-separated pair consisting of `'ImageFilterSigma'` and a positive scalar.

`GradientFilterSigma` — Standard deviation for gradient smoothing filter
1 | positive scalar

Standard deviation for gradient smoothing filter, specified as the comma-separated pair consisting of `'GradientFilterSigma'` and a positive scalar.

`NoiseThreshold` — Threshold for noise reduction
0.0039 (default) | positive scalar

Threshold for noise reduction, specified as the comma-separated pair consisting of `'NoiseThreshold'` and a positive scalar. As you increase this number, the less an object's movement impacts the optical flow calculation.

Methods

estimateFlow	Estimate optical flow
reset	Reset the internal state of the object

Examples

Compute Optical Flow Using Lucas-Kanade derivative of Gaussian

Read in a video file.

```
vidReader = VideoReader('viptraffic.avi');
```

Create optical flow object.

```
opticFlow = opticalFlowLKDoG('NumFrames',3);
```

Estimate the optical flow of the objects and display the flow vectors.

```
while hasFrame(vidReader)
   frameRGB = readFrame(vidReader);
   frameGray = rgb2gray(frameRGB);

   flow = estimateFlow(opticFlow,frameGray);

   imshow(frameRGB);
   hold on;
   plot(flow,'DecimationFactor',[5 5],'ScaleFactor',25);
   hold off;
end
```


Algorithms

To compute the optical flow between two images, you must solve the following optical flow constraint equation:

$$I_x u + I_y v + I_t = 0$$

.

- I_x, I_y, and I_t are the spatiotemporal image brightness derivatives.
- u is the horizontal optical flow.
- v is the vertical optical flow.

Lucas-Kanade Derivative of Gaussian Method

To solve the optical flow constraint equation for u and v, the Lucas-Kanade method divides the original image into smaller sections and assumes a constant velocity in each section. Then, it performs a weighted least-square fit of the optical flow constraint equation to a constant model for $[u \quad v]^T$ in each section Ω. The method achieves this fit by minimizing the following equation:

$$\sum_{x \in \Omega} W^2 [I_x u + I_y v + I_t]^2$$

W is a window function that emphasizes the constraints at the center of each section. The solution to the minimization problem is

$$\begin{bmatrix} \sum W^2 I_x^2 & \sum W^2 I_x I_y \\ \sum W^2 I_y I_x & \sum W^2 I_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} = - \begin{bmatrix} \sum W^2 I_x I_t \\ \sum W^2 I_y I_t \end{bmatrix}$$

.

The Lucas-Kanade method computes I_t using a derivative of Gaussian filter.

To solve the optical flow constraint equation for u and v:

1. Compute I_x and I_y using the following steps:

   a. Use a Gaussian filter to perform temporal filtering. Specify the temporal filter characteristics such as the standard deviation and number of filter coefficients using the `NumFrames` property.

   b. Use a Gaussian filter and the derivative of a Gaussian filter to smooth the image using spatial filtering. Specify the standard deviation and length of the image smoothing filter using the `ImageFilterSigma` property.

2

Compute I_t between images 1 and 2 using the following steps:

a Use the derivative of a Gaussian filter to perform temporal filtering. Specify the temporal filter characteristics such as the standard deviation and number of filter coefficients using the `NumFrames` property.

b Use the filter described in step 1b to perform spatial filtering on the output of the temporal filter.

3

Smooth the gradient components, I_x, I_y, and I_t, using a gradient smoothing filter. Use the `GradientFilterSigma` property to specify the standard deviation and the number of filter coefficients for the gradient smoothing filter.

4 Solve the 2-by-2 linear equations for each pixel using the following method:

- If $A = \begin{bmatrix} a & b \\ b & c \end{bmatrix} = \begin{bmatrix} \sum W^2 I_x^2 & \sum W^2 I_x I_y \\ \sum W^2 I_y I_x & \sum W^2 I_y^2 \end{bmatrix}$

  Then the eigenvalues of A are $\lambda_i = \dfrac{a+c}{2} \pm \dfrac{\sqrt{4b^2 + (a-c)^2}}{2}; i = 1,2$

- When the algorithm finds the eigenvalues, it compares them to the threshold, τ, that corresponds to the value you enter for the `NoiseThreshold` property. The results fall into one of the following cases:

  Case 1: $\lambda_1 \geq \tau$ and $\lambda_2 \geq \tau$

  A is nonsingular, so the algorithm solves the system of equations using Cramer's rule.

  Case 2: $\lambda_1 \geq \tau$ and $\lambda_2 < \tau$

  A is singular (noninvertible), so the algorithm normalizes the gradient flow to calculate *u* and *v*.

  Case 3: $\lambda_1 < \tau$ and $\lambda_2 < \tau$

  The optical flow, *u* and *v*, is 0.

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References

[1] Barron, J.L., D.J. Fleet, S.S. Beauchemin, and T.A. Burkitt. *Performance of optical flow techniques*. CVPR, 1992.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

See Also
opticalFlow | opticalFlowFarneback | opticalFlowHS | opticalFlowLK | quiver

Introduced in R2015a

estimateFlow

Class: opticalFlowLKDoG

Estimate optical flow

Syntax

```
flow = estimateFlow(opticFlow,I)
```

Description

`flow = estimateFlow(opticFlow,I)` estimates optical flow using the current image, `I`, and the previous images. The function sets the previous images for the first run to a black image. After the first run, each new image, `I`, becomes the current image, and the image from the last run becomes the previous one. You can also use flow estimation to predict a future position of a moving object for image reconstruction.

The amount of delay in flow estimation depends on the value of `NumFrames`. The output flow corresponds to the image at $t_{flow} = (t_{current} - (NumFrames - 1) / 2)$, where $t_{current}$ is the time of the current image.

Input Arguments

`opticFlow` — Object for storing optical flow velocity matrices
opticalFlow object

Object for storing optical flow velocity matrices, specified as an `opticalFlow` object.

`I` — Input image
grayscale image

Input image, specified as a grayscale image. To process the first frame, the function sets the previous frame to black.

Output Arguments

`flow` — Object for storing optical flow velocity matrices
`opticalFlow` object

Object for storing optical flow velocity matrices, returned as an `opticalFlow` object.

Examples

Compute Optical Flow Using Lucas-Kanade derivative of Gaussian

Read in a video file.

```
vidReader = VideoReader('viptraffic.avi');
```

Create optical flow object.

```
opticFlow = opticalFlowLKDoG('NumFrames',3);
```

Estimate the optical flow of the objects and display the flow vectors.

```
while hasFrame(vidReader)
  frameRGB = readFrame(vidReader);
  frameGray = rgb2gray(frameRGB);

  flow = estimateFlow(opticFlow,frameGray);

  imshow(frameRGB);
  hold on;
  plot(flow,'DecimationFactor',[5 5],'ScaleFactor',25);
  hold off;
end
```

Introduced in R2015a

reset

Class: opticalFlowLKDoG

Reset the internal state of the object

Syntax

```
reset(opticFlow)
```

Description

`reset(opticFlow)` resets the internal state of the optical flow object. Doing this sets the previous frame to black.

Introduced in R2015a

opticalFlowFarneback class

Estimate optical flow using Farneback method

Description

Estimate the direction and speed of a moving object from one image or video frame to another using the Farneback method.

Construction

opticFlow = opticalFlowFarneback returns an optical flow object that you can use to estimate the direction and speed of an object's motion. estimateFlow method of this class uses the Farneback algorithm to estimate the optical flow.

opticFlow = opticalFlowFarneback(Name,Value) includes additional options specified by one or more Name,Value pair arguments.

Input Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'NumPyramidLevels',3

NumPyramidLevels — Number of pyramid layers
3 (default) | positive scalar

Number of pyramid layers, specified as the comma-separated pair consisting of 'NumPyramidLevels' and a positive scalar. The value includes the initial image as one of the layers. When you set this value to 1, opticalFlowFarneback uses the original image only. It does not add any pyramid layers.

The `opticalFlowFarneback` algorithm generates an image pyramid, where each level has a lower resolution compared to the previous level. When you select a pyramid level greater than 1, the algorithm can track the points at multiple levels of resolution, starting at the lowest level. Increasing the number of pyramid levels enables the algorithm to handle larger displacements of points between frames. However, the number of computations also increases. Recommended values are between 1 and 4. The diagram shows an image pyramid with 3 levels.

1. Optical flow computation at lowest resolution

2. Optical flow at next highest resolution

3. Final optical flow computation of original image

Distance the object moved between frames
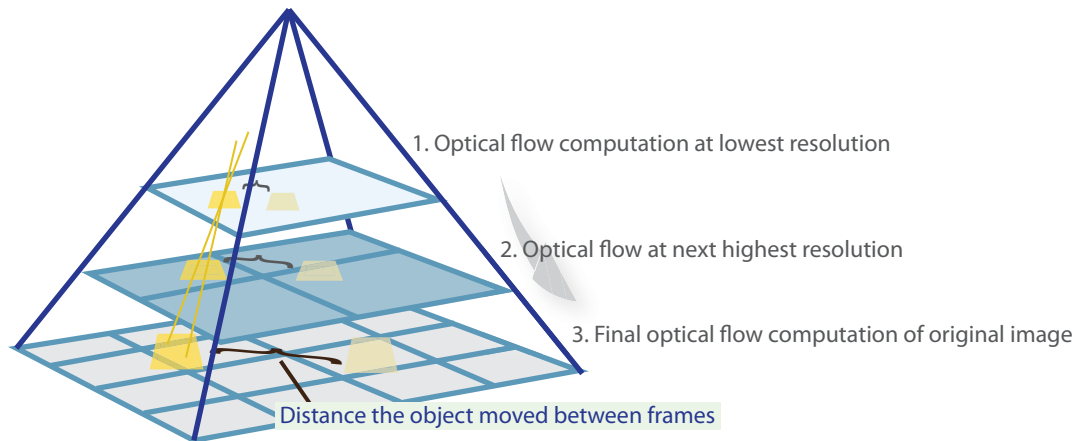
The algorithm forms each pyramid level by downsampling the previous level. The tracking begins in the lowest resolution level, and continues tracking until convergence. The optical flow algorithm propagates the result of that level to the next level as the initial guess of the point locations. In this way, the algorithm refines the tracking with each level, ending with the original image. Using the pyramid levels enables the optical flow algorithm to handle large pixel motions, which can be distances greater than the neighborhood size.

PyramidScale — Image scale
0.5 (default) | positive scalar in the range (0,1)

Image scale, specified as the comma-separated pair consisting of 'PyramidScale' and a positive scalar in the range (0,1). The pyramid scale is applied to each image at every pyramid level. A value of 0.5 creates a classical pyramid, where each level reduces in resolution by a factor of two compared to the previous level.

NumIterations — Number of search iterations per pyramid level
3 (default) | positive integer

Number of search iterations per pyramid level, specified as the comma-separated pair consisting of 'NumIterations' and a positive integer. The Farneback algorithm performs an iterative search for the new location of each point until convergence.

NeighborhoodSize — Size of the pixel neighborhood
5 (default) | positive integer

Size of the pixel neighborhood, specified as the comma-separated pair consisting of 'NeighborhoodSize' and a positive integer. Increase the neighborhood size to increase blurred motion. The blur motion yields a more robust estimation of optical flow. A typical value for NeighborhoodSize is 5 or 7.

FilterSize — Averaging filter size
15 (default) | positive integer in the range [2, Inf)

Averaging filter size, specified as the comma-separated pair consisting of 'FilterSize' and a positive integer in the range [2, Inf). After the algorithm computes the displacement (flow), the averaging over neighborhoods is done using a Gaussian filter of size (FilterSize * FilterSize). Additionally, the pixels close to the borders are given a reduced weight because the algorithm assumes that the polynomial expansion coefficients are less reliable there. Increasing the filter size increases the robustness of the algorithm to image noise. The larger the filter size, the greater the algorithm handles image noise and fast motion detection, making it more robust.

Methods

estimateFlow	Estimate optical flow
reset	Reset the internal state of the object

Examples

Optical Flow Estimation Using the Farneback Algorithm

Load a video.

```
vidReader = VideoReader('visiontraffic.avi','CurrentTime',11);
```

Set up an optical flow object to do the estimate.

```
opticFlow = opticalFlowFarneback;
```

Read in video frames and estimate optical flow of each frame. Display the video frames with flow vectors.

```
while hasFrame(vidReader)
    frameRGB = readFrame(vidReader);
    frameGray = rgb2gray(frameRGB);

    flow = estimateFlow(opticFlow,frameGray);

    imshow(frameRGB)
    hold on
    plot(flow,'DecimationFactor',[5 5],'ScaleFactor',2)
    hold off
end
```

References

[1] Farneback, G. "Two-Frame Motion Estimation Based on Polynomial Expansion." *Proceedings of the 13th Scandinavian Conference on Image Analysis*. Gothenburg, Sweden, 2003.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".

See Also

opticalFlow | opticalFlowHS | opticalFlowLK | opticalFlowLKDoG | quiver

Introduced in R2015b

estimateFlow

Class: opticalFlowFarneback

Estimate optical flow

Syntax

```
flow = estimateFlow(opticFlow,I)
```

Description

`flow = estimateFlow(opticFlow,I)` estimates the optical flow of the input image, `I`, with respect to the previous image. The function sets the previous image for the first run to a black image. After the first run, each new image, `I`, becomes the current image, and the image from the last run becomes the previous one. You can also use flow estimation to predict a future position of a moving object for image reconstruction.

Input Arguments

`opticFlow` — Object for storing optical flow velocity matrices
`opticalFlow` object

Object for storing optical flow velocity matrices, specified as an `opticalFlow` object.

`I` — Input image
grayscale image

Input image, specified as a grayscale image. To process the first frame, the function sets the previous frame to black.

Output Arguments

`flow` — Object for storing optical flow velocity matrices
`opticalFlow` object

Object for storing optical flow velocity matrices, returned as an `opticalFlow` object.

Examples

Optical Flow Estimation Using the Farneback Algorithm

Load a video.

```
vidReader = VideoReader('visiontraffic.avi','CurrentTime',11);
```

Set up an optical flow object to do the estimate.

```
opticFlow = opticalFlowFarneback;
```

Read in video frames and estimate optical flow of each frame. Display the video frames with flow vectors.

```
while hasFrame(vidReader)
    frameRGB = readFrame(vidReader);
    frameGray = rgb2gray(frameRGB);

    flow = estimateFlow(opticFlow,frameGray);

    imshow(frameRGB)
    hold on
    plot(flow,'DecimationFactor',[5 5],'ScaleFactor',2)
    hold off
end
```

Introduced in R2015b

reset

Class: opticalFlowFarneback

Reset the internal state of the object

Syntax

```
reset(opticFlow)
```

Description

reset(opticFlow) resets the internal state of the optical flow object. Doing this sets the previous frame to black.

Introduced in R2015b

vision.PeopleDetector System object

Package: vision

Detect upright people using HOG features

Description

The people detector object detects people in an input image using the Histogram of Oriented Gradient (HOG) features and a trained Support Vector Machine (SVM) classifier. The object detects unoccluded people in an upright position.

To detect people in an image:

1 Create the vision.PeopleDetector object and set its properties.
2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
peopleDetector = vision.PeopleDetector
peopleDetector = vision.PeopleDetector(model)
peopleDetector = vision.PeopleDetector(Name,Value)
```

Description

`peopleDetector = vision.PeopleDetector` returns a people detector object, `peopleDetector`, that tracks a set of points in a video.

`peopleDetector = vision.PeopleDetector(model)` creates a people detector object and sets the `ClassificationModel` property to `model`.

`peopleDetector = vision.PeopleDetector(Name,Value)` creates a people detector object, `peopleDetector`, with additional options specified by one or more `Name,Value` pair arguments.

`Name` is a property name and `Value` is the corresponding value. `Name` must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: peopleDetector = vision.PeopleDetector(`'ClassificationModel','UprightPeople_128x64'`)

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

ClassificationModel — Name of classification model
`'UprightPeople_128x64'` (default) | `'UprightPeople_96x48'`

Name of classification model, specified as `'UprightPeople_128x64'` or `'UprightPeople_96x48'`. The pixel dimensions indicate the image size used for training.

The images used to train the models include background pixels around the person. Therefore, the actual size of a detected person is smaller than the training image size.

ClassificationThreshold — People classification threshold
1 (default) | nonnegative scalar value

People classification threshold, specified as a nonnegative scalar value. Use this threshold to control the classification of individual image subregions during multiscale detection. The threshold controls whether a subregion gets classified as a person. You can increase this value when there are many false detections. The higher the threshold value, the more stringent the requirements are for the classification. Vary the threshold over a range of values to find the optimum value for your data set. Typical values range from `0` to `4`.

Tunable: Yes

`MinSize` — Smallest region containing a person
`[ ]` (default) | two-element vector

Smallest region containing a person, specified in pixels as a two-element vector, [*height width*]. Set this property to the minimum size region containing a person. You can reduce computation time when you set this property. To do so, set this property to a value larger than the image size used to train the classification model. When you do not specify this property, the detector sets it to the image size used to train the classification model.

Tunable: Yes

`MaxSize` — Largest region containing a person
`[ ]` (default) | two-element vector

Largest region that contains a person, specified in pixels as a two-element vector, [*height width*]. Set this property to the largest region containing a person. You can reduce computation time when you set this property. To do so, set this property to a value smaller than the size of the input image. When you do not specify this property, the detector sets it to the input image size. This property is tunable.

`ScaleFactor` — Multiscale object detection scaling
`1.05` (default) | numeric value greater than `1.0001`

Multiscale object detection scaling, specified as a value greater than `1.0001`. The scale factor incrementally scales the detection resolution between `MinSize` and `MaxSize`. You can set the scale factor to an ideal value using:
`size(I)/(size(I)-0.5)`
The object calculates the detection resolution at each increment.

round(*TrainingSize**(`ScaleFactor`^{N}))

In this case, the *TrainingSize* is `[128 64]` for the `'UprightPeople_128x64'` model and `[96 48]` for the `'UprightPeople_96x48'` model. *N* is the increment. Decreasing the scale factor can increase the detection accuracy. However, doing so increases the computation time. This property is tunable.

`WindowStride` — Detection window stride
`[8 8]` (default) | scalar | two-element vector

Detection window stride in pixels, specified as a scalar or a two-element vector, [*x y*]. The detector uses the window stride to slide the detection window across the image. When

you specify this value as a vector, the first and second elements are the stride size in the *x* and *y* directions. When you specify this value as a scalar, the stride is the same for both *x* and *y*. Decreasing the window stride can increase the detection accuracy. However, doing so increases computation time. Increasing the window stride beyond `[8 8]` can lead to a greater number of missed detections. This property is tunable.

MergeDetections — Merge detection control
true | false

Merge detection control, specified as `true` or `false`. This property controls whether similar detections are merged. Set this property to `true` to merge bounding boxes using a mean-shift based algorithm. Set this property to `false` to output the unmerged bounding boxes.

For more flexibility and control of merging parameters, you can use the `selectStrongestBbox` function in place of the `MergeDetections` algorithm. To do this, set the `MergeDetections` property to `false`. See the "Tracking Pedestrians from a Moving Car" example, which shows the use of the people detector and the `selectStrongestBbox` function.

UseROI — Use region of interest
false (default) | true

Use region of interest, specified as `true` or `false`. Set this property to `true` to detect objects within a rectangular region of interest within the input image.

Usage

Syntax

```
bboxes = peopleDetector(I)
[bboxes, scores] = peopleDetector(I)
[ ___ ] = peopleDetector(I,roi)
```

Description

bboxes = `peopleDetector(I)` performs multiscale object detection on the input image, I and returns an *M*-by-4 matrix defining *M* bounding boxes. *M* represents the

number of detected people. Each row of the output matrix, BBOXES, contains a four-element vector, [x y width height]. This vector specifies, in pixels, the upper-left corner and size, of a bounding box. When no people are detected, the step method returns an empty vector. The input image, I, must be a grayscale or truecolor (RGB) image.

[bboxes, scores] = peopleDetector(I) additionally returns a confidence value for the detections.

[___] = peopleDetector(I,roi)detects people within the rectangular search region, roi.

Input Arguments

I — Input image
grayscale | truecolor (RGB)

Input image, specified as grayscale or truecolor (RGB).

roi — Rectangular region of interest
four-element vector (default)

Rectangular region of interest within image I, specified as a four-element vector, [*x y width height*].

model — Classification model
'UprightPeople_128x64' (default) | 'UprightPeople_96x48'

Classification model, specified as 'UprightPeople_128x64' or 'UprightPeople_96x48'.

Output Arguments

peopleDetector — People detector
object (default)

People detector object, returned as an object. The detector detects people in an input image using the Histogram of Oriented Gradient (HOG) features and a trained SVM classifier. The object detects unoccluded people in an upright position.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

```
release(obj)
```

Common to All System Objects

step   Run System object algorithm
release   Release resources and allow changes to System object property values and
            input characteristics
reset   Reset internal states of System object

Examples

Detect People

Create a people detector and load the input image.

```
peopleDetector = vision.PeopleDetector;
I = imread('visionteam1.jpg');
```

Detect people using the people detector object.

```
[bboxes,scores] = peopleDetector(I);
```

Annotate detected people.

```
I = insertObjectAnnotation(I,'rectangle',bboxes,scores);
figure, imshow(I)
title('Detected people and detection scores');
```

Detected people and detection scores

- "Tracking Pedestrians from a Moving Car"

References

[1] Dalal, N. and B. Triggs. "Histograms of Oriented Gradients for Human Detection,"*Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, June 2005, pp. 886-893.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
detectPeopleACF | extractHOGFeatures | insertObjectAnnotation | vision.CascadeObjectDetector

Topics
"Tracking Pedestrians from a Moving Car"
"Multiple Object Tracking"

Introduced in R2012b

vision.Pyramid System object

Package: vision

Perform Gaussian pyramid decomposition

Description

Note The `vision.Pyramid` System object will be removed in a future release. Use the `impyramid` function with equivalent functionality instead.

The `Pyramid` object computes Gaussian pyramid reduction or expansion. The image reduction step involves lowpass filtering and downsampling the image pixels. The image expansion step involves upsampling the image pixels and lowpass filtering.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`gaussPyramid = vision.Pyramid` returns a System object, `gaussPyramid`, that computes a Gaussian pyramid reduction or expansion of an image.

`gaussPyramid = vision.Pyramid(`*Name*`,`*Value*`)` configures the System object properties, specified as one or more name-value pair arguments. Unspecified properties have default values.

To compute a Gaussian pyramid:

1 Define and set up your pyramid object using the constructor.
2 Call the `step` method with the input image, `I` and the pyramid object, `gaussPyramid`. See the syntax below for using the `step` method.

`J = step(gaussPyramid,I)` computes `J`, the Gaussian pyramid decomposition of input `I`.

Properties

Operation

Reduce or expand the input image

Specify whether to reduce or expand the input image as `Reduce` or `Expand`. If this property is set to `Reduce`, the object applies a lowpass filter and then downsamples the input image. If this property is set to `Expand`, the object upsamples and then applies a lowpass filter to the input image.

Default: `Reduce`

PyramidLevel

Level of decomposition

Specify the number of times the object upsamples or downsamples each dimension of the image by a factor of 2.

Default: `1`

SeparableFilter

How to specify the coefficients of low pass filter

Indicate how to specify the coefficients of the lowpass filter as `Default` or `Custom`.

Default: `Default`

CoefficientA

Coefficient 'a' of default separable filter

Specify the coefficients in the default separable filter `1/4-a/2 1/4 a 1/4 1/4-a/2` as a scalar value. This property applies when you set the `SeparableFilter` property to `Default`.

Default: `0.375`

CustomSeparableFilter

Separable filter coefficients

Specify separable filter coefficients as a vector. This property applies when you set the `SeparableFilter` property to `Custom`.

Default: `[0.0625 0.25 0.375 0.25 0.0625]`

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`.

Default: `Floor`

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`.

Default: `Wrap`

SeparableFilterDataType

CustomSeparableFilter word and fraction lengths

Specify the coefficients fixed-point data type as `Same word length as input`, `Custom`.

Default: `Custom`

CustomSeparableFilterDataType

CustomSeparableFilter word and fraction lengths

Specify the coefficients fixed-point type as a signed `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `SeparableFilterDataType` property to `Custom`.

Default: numerictype([],16,14)

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as Same as input, or Custom.

Default: Custom

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled numerictype object with a Signedness of Auto. This property applies when you set the ProductDataType property to Custom.

Default: numerictype([],32,10)

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as Same as product, Same as input, or Custom.

Default: Same as product

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a signed, scaled numerictype object with a Signedness of Auto. This property applies when you set the AccumulatorDataType property to Custom.

Default: numerictype([],32,0)

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as Same as input , or Custom.

Default: `Custom`

`CustomOutputDataType`

Output word and fraction lengths

Specify the output fixed-point type as a signed, scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Custom`.

Default: `numerictype([],32,10)`

Methods

step   Compute Gaussian pyramid decomposition of input

Common to All System Objects	
release	Allow System object property value changes

Examples

Compute Four-level Multiresolution Pyramid of Image

Read image into the workspace.

```
I = imread('cameraman.tif');
```

Perform a series of reductions. The first call reduces the original image. The other calls to impyramid use the previously reduced image.

```
I1 = impyramid(I, 'reduce');
I2 = impyramid(I1, 'reduce');
I3 = impyramid(I2, 'reduce');
```

View the original image and the reduced versions.

```
figure, imshow(I)
```

```
figure, imshow(I1)
```



```
figure, imshow(I2)
```

```
figure, imshow(I3)
```


Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also
`impyramid` | `imresize`

Introduced in R2012a

step

System object: vision.Pyramid
Package: vision

Compute Gaussian pyramid decomposition of input

Syntax

```
J = step(gaussPyramid,I)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`J = step(gaussPyramid,I)` computes J, the Gaussian pyramid decomposition of input I.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

semanticSegmentationMetrics

Semantic segmentation quality metrics

Description

A `semanticSegmentationMetrics` object encapsulates semantic segmentation quality metrics for a set of images.

Creation

Create a `semanticSegmentationMetrics` object using the `evaluateSemanticSegmentation` function.

Properties

`ConfusionMatrix` — Confusion matrix
square table

This property is read-only.

Confusion matrix, specified as a square table. Each table element (i,j) is the count of pixels known to belong to class i but predicted to belong to class j.

`NormalizedConfusionMatrix` — Normalized confusion matrix
table

This property is read-only.

Normalized confusion matrix, specified as a square table. Each table element (i,j) is the count of pixels known to belong to class i but predicted to belong to class j, divided by the total number of pixels predicted in class j. Elements are in the range [0, 1].

`DataSetMetrics` — Data set metrics
table

This property is read-only.

Semantic segmentation metrics aggregated over the data set, specified as a table. `DataSetMetrics` contains up to five metrics, depending on the value of the `'Metrics'` name-value pair used with `evaluateSemanticSegmentation`:

- `GlobalAccuracy` — Ratio of correctly classified pixels to total pixels, regardless of class.
- `MeanAccuracy` — Ratio of correctly classified pixels in each class to total pixels, averaged over all classes. The value is equal to the mean of `ClassMetrics.Accuracy`.
- `MeanIoU` — Average intersection over union (IoU) of all classes. The value is equal to the mean of `ClassMetrics.IoU`.
- `WeightedIoU` — Average IoU of all classes, weighted by the number of pixels in the class.
- `MeanBFScore` — Average boundary F1 (BF) score of all images. The value is equal to the mean of `ImageMetrics.BFScore`.

`ClassMetrics` — Class metrics
table

This property is read-only.

Semantic segmentation metrics for each class, specified as a table. `ClassMetrics` contains up to three metrics for each class, depending on the value of the `'Metrics'` name-value pair used with `evaluateSemanticSegmentation`:

- `Accuracy` — Ratio of correctly classified pixels in each class to the total number of pixels belonging to that class according to the ground truth. Accuracy can be expressed as:
  Accuracy = TP / (TP + FN)
  TP is the number of true positives and FN is the number of false negatives.
- `IoU` — Ratio of correctly classified pixels to the total number of pixels that are assigned that class by the ground truth and the predictor. IoU can be expressed as:
  IoU = TP / (TP + FP + FN)
  The image describes the true positives (TP), false positives (FP), and false negatives (FN).
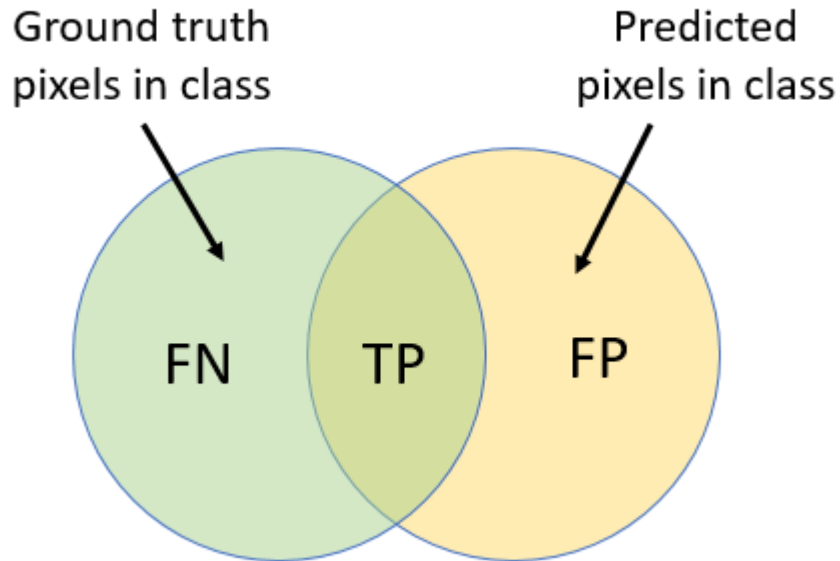
- `MeanBFScore` — Boundary F1 score for each class, averaged over all images.

`ImageMetrics` — Image metrics
table

This property is read-only.

Semantic segmentation metrics for each image in the data set, specified as a table. `ImageMetrics` contains up to five metrics, depending on the value of the `'Metrics'` name-value pair used with `evaluateSemanticSegmentation`:

- `GlobalAccuracy` — Ratio of correctly classified pixels to total pixels, regardless of class
- `MeanAccuracy` — Ratio of correctly classified pixels to total pixels, averaged over all classes in the image
- `MeanIoU` — Average IoU of all classes in the image
- `WeightedIoU` — Average IoU of all classes in the image, weighted by the number of pixels in each class

• `MeanBFScore` — Average BF score of each class in the image

Each image metric returns a vector, with one element for each image in the data set. The order of the rows matches the order of the images defined by the input `PixelLabelDatastore` objects representing the data set.

Examples

Evaluate Results of Semantic Segmentation

The `triangleImages` data set has 100 test images with ground truth labels. Define the location of the data set.

```
dataSetDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
```

Define the location of the test images.

```
testImagesDir = fullfile(dataSetDir,'testImages');
```

Define the location of the ground truth labels.

```
testLabelsDir = fullfile(dataSetDir,'testLabels');
```

Create an imageDatastore holding the test images.

```
imds = imageDatastore(testImagesDir);
```

Define the class names and their associated label IDs.

```
classNames = ["triangle","background"];
labelIDs   = [255 0];
```

Create a pixelLabelDatastore holding the ground truth pixel labels for the test images.

```
pxdsTruth = pixelLabelDatastore(testLabelsDir,classNames,labelIDs);
```

Load a semantic segmentation network that has been trained on the training images of `noisyShapes`.

```
net = load('triangleSegmentationNetwork');
net = net.net;
```

Run the network on the test images. Predicted labels are written to disk in a temporary directory and returned as a pixelLabelDatastore.

```
pxdsResults = semanticseg(imds,net,"WriteLocation",tempdir);

Running semantic segmentation network
------------------------------------
* Processing 100 images.
* Progress: 100.00%
```

Evaluate the prediction results against the ground truth.

```
metrics = evaluateSemanticSegmentation(pxdsResults,pxdsTruth);

Evaluating semantic segmentation results
-------------------------------[==================================================]
Elapsed time: 00:00:02
Estimated time remaining: 00:00:00
* Finalizing... Done.
* Data set metrics:
```

GlobalAccuracy	MeanAccuracy	MeanIoU	WeightedIoU	MeanBFScore
0.90624	0.95085	0.61588	0.87529	0.40652

Display the classification accuracy, the intersection over union, and the boundary F-1 score for each class.

```
metrics.ClassMetrics
```

ans=*2×3 table*

	Accuracy	IoU	MeanBFScore
triangle	1	0.33005	0.028664
background	0.9017	0.9017	0.78438

See Also

bfscore | evaluateSemanticSegmentation | jaccard | plotconfusion

Topics

"Semantic Segmentation Basics"

"Deep Learning Basics" (Neural Network Toolbox)

Introduced in R2017b

vision.StandardDeviation System object

Package: vision

Find standard deviation of input or sequence of inputs

Description

The `StandardDeviation` object finds standard deviation of input or sequence of inputs.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.StandardDeviation` returns a System object, H, that computes the standard deviation of the entire input.

`H = vision.StandardDeviation(`*Name*`,`*Value*`)` returns a standard deviation System object, H, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

RunningStandardDeviation

Enable calculation over successive calls to step method

Set this property to `true` to enable the calculation of standard deviation over successive calls to the `step` method. The default is `false`.

ResetInputPort

Reset in running standard deviation mode

Set this property to `true` to enable resetting the running standard deviation. When the property is set to `true`, a reset input must be specified to the `step` method to reset the running standard deviation. This property applies when you set the `RunningStandardDeviation` property to `true`. The default is `false`.

ResetCondition

Reset condition for running standard deviation mode

Specify the event to reset the running standard deviation to `Rising edge`, `Falling edge`, `Either edge`, or `Non-zero`. This property applies when you set the `ResetInputPort` property to `true`. The default is `Non-zero`.

Dimension

Numerical dimension to operate along

Specify how the standard deviation calculation is performed over the data as `All`, `Row`, `Column`, or `Custom`. The default is `All`.

CustomDimension

Numerical dimension to operate along

Specify the dimension (one-based value) of the input signal, over which the standard deviation is computed. The value of this property cannot exceed the number of dimensions in the input signal. This property applies when you set the `Dimension` property to `Custom`. The default is `1`.

ROIProcessing

Enable region of interest processing

Set this property to `true` to enable calculating the standard deviation within a particular region of each image. This property applies when you set the `Dimension` property to `All` and the `RunningStandardDeviation` property to `false`. The default is `false`.

ROIForm

Type of region of interest

Specify the type of region of interest to `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`. This property applies when you set the `ROIProcessing` property to `true`. The default is `Rectangles`.

ROIPortion

Calculate over entire ROI or just perimeter

Specify the region over which to calculate the standard deviation to `Entire ROI`, or `ROI perimeter`. This property applies when you set the `ROIForm` property to `Rectangles`. The default is `Entire ROI`.

ROIStatistics

Statistics for each ROI, or one for all ROIs

Specify what statistics to calculate as `Individual statistics for each ROI`, or `Single statistic for all ROIs`. This property does not apply when you set the `ROIForm` property to `Binary mask`. The default is `Individual statistics for each ROI`

ValidityOutputPort

Output flag indicating if any part of ROI is outside input image

Set this property to `true` to return the validity of the specified ROI as completely or partially inside of the image. This applies when you set the `ROIForm` property to `Lines` or `Rectangles`.

Set this property to `true` to return the validity of the specified label numbers. This applies when you set the `ROIForm` property to `Label matrix`.

The default is `false`.

Methods

reset	Reset running standard deviation state
step	Compute standard deviation of input

Common to All System Objects	
release	Allow System object property value changes

Examples

Determine the standard deviation in a grayscale image.

```
img = im2single(rgb2gray(imread('peppers.png')));
hstd2d = vision.StandardDeviation;
std = step(hstd2d,img);
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the Standard Deviation block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• See "System Objects in MATLAB Code Generation" (MATLAB Coder).

Introduced in R2012a

reset

System object: vision.StandardDeviation
Package: vision

Reset running standard deviation state

Syntax

```
reset(H)
```

Description

reset(H) resets the internal states of System object *H*, used for computing running standard deviation when the RunningStandardDeviation property is true.

stereoParameters

Object for storing stereo camera system parameters

Description

The `stereoParameters` object stores the intrinsic and extrinsic parameters of two cameras and their geometric relationship.

Creation

You can create a `stereoParameters` object using the `stereoParameters` function described here. You can also create a `stereoParameters` object by using the `estimateCameraParameters` with an *M*-by-2-by-*numImages*-by-2 array of input image points, where *M* is the number of keypoint coordinates in each pattern.

Syntax

```
stereoParams = stereoParameters(cameraParameters1,cameraParameters2,
rotationOfCamera2,translationOfCamera2)
stereoParams = stereoParameters(paramStruct)
```

Description

`stereoParams = stereoParameters(cameraParameters1,cameraParameters2, rotationOfCamera2,translationOfCamera2)` creates a `stereoParameters` object that contains the parameters of a stereo camera system, and sets the CameraParameters1 on page 2-0   , CameraParameters2 on page 2-0   , RotationOfCamera2 on page 2-0   , and TranslationOfCamera2 on page 2-0   properties.

`stereoParams = stereoParameters(paramStruct)` creates an identical `stereoParameters` object from an existing `stereoParameters` object with parameters stored in `paramStruct`.

Input Arguments

paramStruct — Stereo parameters
struct

Stereo parameters, specified as a stereo parameters struct. To get a `paramStruct` from an existing `stereoParameters` object, use the `toStruct` function.

Properties

Intrinsic and extrinsic parameters of the two cameras

CameraParameters1 — Parameters of camera 1
cameraParameters object

Parameters of camera 1 , specified as a `cameraParameters` object. The object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

CameraParameters2 — Parameters of camera 2
cameraParameters object

Parameters of camera 2 , specified as a `cameraParameters` object. The object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

Geometric relationship between the two cameras

RotationOfCamera2 — Rotation of camera 2
3-by-3 matrix

Rotation of camera 2 relative to camera 1, specified as a 3-by-3 matrix.

TranslationOfCamera2 — Translation of camera 2
3-element vector

Translation of camera 2 relative to camera 1, specified as a 3-element vector.

FundamentalMatrix — Fundamental matrix
3-by-3 matrix

Fundamental matrix, stored as a 3-by-3 matrix. The fundamental matrix relates the two stereo cameras, such that the following equation must be true:

$$[P_2 \quad 1] * FundamentalMatrix * [P_1 \quad 1]' = 0$$

P_1, the point in image 1 in pixels, corresponds to the point, P_2, in image 2.

EssentialMatrix — Essential matrix
3-by-3 matrix

Essential matrix, stored as a 3-by-3 matrix. The essential matrix relates the two stereo cameras, such that the following equation must be true:

$$[P_2 \quad 1] * EssentialMatrix * [P_1 \quad 1]' = 0$$

P_1, the point in image 1, corresponds to P_2, the point in image 2. Both points are expressed in normalized image coordinates, where the origin is at the camera's optical center. The x and y pixel coordinates are normalized by the focal length f_x and f_y.

Accuracy of estimated parameters

MeanReprojectionError — Average Euclidean distance
number of pixels

Average Euclidean distance between reprojected points and detected points over all image pairs, specified in pixels.

Settings for camera parameter estimation

NumPatterns — Number of calibrated patterns
integer

Number of calibration patterns that estimate the extrinsics of the two cameras, stored as an integer.

WorldPoints — World coordinates
M-by-2 array

World coordinates of key points in the calibration pattern, specified as an M-by-2 array. M represents the number of key points in the pattern.

WorldUnits — World points units
'mm' (default) | character vector

World points units, specified as a character vector. The character vector describes the units of measure.

Object Functions

toStruct   Convert a stereo parameters object into a struct

Examples

Stereo Camera Calibration

Specify calibration images.

```
leftImages = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','stereo','left'));
rightImages = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','stereo','right'));
```

Detect the checkerboards.

```
[imagePoints,boardSize] = ...
  detectCheckerboardPoints(leftImages.Files,rightImages.Files);
```

Specify the world coordinates of the checkerboard keypoints. Square size is in millimeters.

```
squareSize = 108;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the stereo camera system. Both cameras have the same resolution.

```
I = readimage(leftImages,1);
imageSize = [size(I,1),size(I,2)];
params = estimateCameraParameters(imagePoints,worldPoints, ...
                                  'ImageSize',imageSize);
```

Visualize the calibration accuracy.

```
  showReprojectionErrors(params);
```

Visualize camera extrinsics.

```
figure;
showExtrinsics(params);
```

Extrinsic Parameters Visualization

References

[1] Zhang, Z. "A Flexible New Technique for Camera Calibration". *IEEE Transactions on Pattern Analysis and Machine Intelligence*.Vol. 22, No. 11, 2000, pp. 1330–1334.

[2] Heikkila, J, and O. Silven. "A Four-step Camera Calibration Procedure with Implicit Image Correction." *IEEE International Conference on Computer Vision and Pattern Recognition*. 1997.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

- Use the `toStruct` method to pass a `stereoParameters` object into generated code. See the "Code Generation for Depth Estimation From Stereo Video" example.

See Also

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Classes
`cameraParameters` | `extrinsicsEstimationErrors` | `intrinsicsEstimationErrors` | `stereoCalibrationErrors`

Functions
`detectCheckerboardPoints` | `estimateCameraParameters` | `estimateFundamentalMatrix` | `generateCheckerboardPoints` | `reconstructScene` | `rectifyStereoImages` | `showExtrinsics` | `showReprojectionErrors` | `undistortImage` | `undistortPoints`

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Code Generation for Depth Estimation From Stereo Video"
"Single Camera Calibrator App"
"Stereo Camera Calibrator App"

Introduced in R2014a

toStruct

Convert a stereo parameters object into a struct

Syntax

paramStruct = toStruct(stereoParams)

Description

paramStruct = toStruct(stereoParams) returns a struct containing the stereo parameters in the stereoParams input object. You can use the struct to create an identical stereoParameters object. Use the struct for C code generation. You can call toStruct, and then pass the resulting structure into the generated code, which recreates the stereoParameters object.

Input Arguments

stereoParams — Stereo parameters
stereoParameters object

Stereo parameters, specified as a stereoParameters object. The object contains the parameters of the stereo camera system.

Output Arguments

paramStruct — Stereo parameters
struct

Stereo parameters, returned as a stereo parameters struct.

See Also

Topics
"Code Generation for Depth Estimation From Stereo Video"

Introduced in R2015a

step

System object: vision.StandardDeviation
Package: vision

Compute standard deviation of input

Syntax

```
Y = step(H,X)
Y = step(H,X,R)
Y = step(H,X,ROI)
Y = step(H,X,LABEL,LABELNUMBERS)
[Y, FLAG] = step(H,X,ROI)
[Y, FLAG] = step(H,X,LABEL,LABELNUMBERS)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`Y = step(H,X)` computes the standard deviation of input elements *X*. When you set the `RunningStandardDeviation` property to `true`, the output *Y* corresponds to the standard deviation of the input elements over successive calls to the `step` method.

`Y = step(H,X,R)` computes the standard deviation of the input elements over successive calls to the `step` method, and optionally resets its state based on the value of reset signal *R*, the `ResetInputPort` property and the `ResetCondition` property. This option applies when you set the `RunningStandardDeviation` property to `true` and the `ResetInputPort` property to `true`.

Y = step(H,X,ROI) uses additional input *ROI* as the region of interest when you set the ROIProcessing property to true and the ROIForm property to Lines, Rectangles or Binary mask.

Y = step(H,X,LABEL,LABELNUMBERS) computes the standard deviation of input image *X* for region labels contained in vector *LABELNUMBERS*, with matrix *LABEL* marking pixels of different regions. This option applies when you set the ROIProcessing property to true and the ROIForm property to Label matrix.

[Y, FLAG] = step(H,X,ROI) also returns output *FLAG*, which indicates whether the given region of interest is within the image bounds. This applies when you set the ValidityOutputPort property to true.

[Y, FLAG] = step(H,X,LABEL,LABELNUMBERS) also returns the output *FLAG* which indicates whether the input label numbers are valid when you set the ValidityOutputPort property to true.

Note H specifies the System object on which to run this step method.

The object performs an initialization the first time the step method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the release method to unlock the object.

---

vision.TemplateMatcher System object

Package: vision

Locate template in image

Description

The template matcher object locates a template in an image. Use the step syntax below with input image I, template T, template matcher object, H, and any optional properties.

LOC = step(H,I,T) computes the [x y] location coordinates, LOC, of the best template match between the image matrix, I, and the template matrix, T. The step method outputs the coordinates relative to the top left corner of the image. The LOC [x y] coordinates correspond to the center of the template. The object centers the location slightly different for templates with an odd or even number of pixels, (see the table below for details). The object computes the location by shifting the template in single-pixel increments throughout the interior of the image.

METRIC = step(H,I,T) computes the match metric values for input image, I, with T as the template. This applies when you set the OutputValue property to Metric matrix.

LOC = step(H,I,T,ROI) computes the location of the best template match, LOC, in the specified region of interest, ROI. This applies when you set the OutputValue property to Best match location and the ROIInputPort property to true. The input ROI must be a four element vector, [x y width height], where the first two elements represent the [x y] coordinates of the upper-left corner of the rectangular ROI.

[LOC,ROIVALID] = step(H,I,T,ROI) computes the location of the best template match, LOC, in the specified region of interest, ROI. The step method also returns a logical flag ROIVALID indicating if the specified ROI is outside the bounds of the input image I. This applies when you set the OutputValue property to Best match location, and both the ROIInputPort and ROIValidityOutputPort properties to true.

[LOC,NVALS,NVALID] = step(H,I,T) returns the location of the best template match LOC, the metric values around the best match NVALS, and a logical flag NVALID. A false value for NVALID indicates that the neighborhood around the best match extended

outside the borders of the metric value matrix NVALS. This applies when you set the OutputValue property to `Best match location` and the BestMatchNeighborhoodOutputPort property to `true`.

`[LOC,NVALS,NVALID,ROIVALID] = step(H,I,T,ROI)` returns the location of the best template match LOC, the metric values around the best match NVALS, and two logical flags, NVALID and ROIVALID. A `false` value for NVALID indicates that the neighborhood around the best match extended outside the borders of the metric value matrix NVALS. A `false` value for ROIVALID indicates that the specified ROI is outside the bounds of the input image I. This applies when you set the OutputValue property to `Best match location`, and the BestMatchNeighborhoodOutputPort, ROIInputPort, and ROIValidityOutputPort properties to `true`.

Typical use of the template matcher involves finding a small region within a larger image. The region is specified by the template image which can be as large as the input image, but which is typically smaller than the input image.

The object outputs the best match coordinates, relative to the top-left corner of the image. The [x y] coordinates of the location correspond to the center of the template. When you use a template with an odd number of pixels, the object uses the center of the template. When you use a template with an even number of pixels, the object uses the centered upper-left pixel for the location. The following table shows how the object outputs the location (LOC), of odd and even templates:

Odd number of pixels in template	Even number of pixels in template
(1,1) template image	(1,1) template image

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.TemplateMatcher` returns a template matcher System object, H. This object performs template matching by shifting a template in single-pixel increments throughout the interior of an image.

`H = vision.TemplateMatcher(`*Name*`,`*Value*`)` returns a template matcher object, H, with each specified property set to the specified value.

Properties

`Metric`

Metric used for template matching

Specify the metric to use for template matching as one of `Sum of absolute differences` | `Sum of squared differences` | `Maximum absolute difference`. The default is `Sum of absolute differences`.

OutputValue

Type of output

Specify the output you want the object to return as one of `Metric matrix` | `Best match location`. The default is `Best match location`.

SearchMethod

Specify search criteria to find minimum difference between two inputs

Specify how the object searches for the minimum difference between the two input matrices as `Exhaustive` or `Three-step`. If you set this property to `Exhaustive`, the object searches for the minimum difference pixel by pixel. If you set this property to `Three-step`, the object searches for the minimum difference using a steadily decreasing step size. The `Three-step` method is computationally less expensive than the `Exhaustive` method, but sometimes does not find the optimal solution. This property applies when you set the `OutputValue` property to `Best match location`.

The default is `Exhaustive`.

BestMatchNeighborhoodOutputPort

Enable metric values output

Set this property to `true` to return two outputs, *NMETRIC* and *NVALID*. The output *NMETRIC* denotes an *N*-by-*N* matrix of metric values around the best match, where *N* is the value of the `NeighborhoodSize` property. The output NVALID is a logical indicating whether the object went beyond the metric matrix to construct output *NMETRIC*. This property applies when you set the `OutputValue` property to `Best match location`.

The default is `false`.

NeighborhoodSize

Size of the metric values

Specify the size, *N*, of the *N*-by-*N* matrix of metric values as an odd number. For example, if the matrix size is 3-by-3 set this property to 3. This property applies when you set the

OutputValue property to `Best match location` and the
`BestMatchNeighborhoodOutputPort` property to `true`.

The default is 3.

ROIInputPort

Enable ROI specification through input

Set this property to `true` to define the Region of Interest (ROI) over which to perform the template matching. If you set this property to `true`, the ROI is specified using an input to the `step` method. Otherwise the entire input image is used.

The default is `false`.

ROIValidityOutputPort

Enable output of a flag indicating if any part of ROI is outside input image

When you set this property to `true`, the object returns an ROI flag. The flag, when set to `false`, indicates a part of the ROI is outside of the input image. This property applies when you set the `ROIInputPort` property to `true`.

The default is`false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` , `Convergent`, `Floor`, `Nearest`, `Round`, `Simplest`, or `Zero`.

The default is `Floor`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as one of `Wrap` or `Saturate`.

The default is `Wrap`.

ProductDataType

Product word and fraction lengths

Specify the product fixed-point data type as `Same as first input` or `Custom`. This property applies when you set the `Metric` property to `Sum of squared differences`.

The default is `Custom`.

CustomProductDataType

Product word and fraction lengths

Specify the product fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `Metric` property to `Sum of squared differences`, and the `ProductDataType` property to `Custom`.

The default is `numerictype([],32,30)`.

AccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point data type as one of `Same as first input` or `Custom`.

The default is `Custom`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `AccumulatorDataType` property to `Custom`.

The default is `numerictype([],32,0)`.

OutputDataType

Output word and fraction lengths

Specify the output fixed-point data type as one of `Same as first input` or `Custom`. The default is `Same as first input`.This property applies when you set the

OutputValue property to `Metric matrix`. This property applies when you set the OutputValue property to `Best match location`, and the BestMatchNeighborhoodOutputPort property to `true`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object with a `Signedness` of `Auto`. This property applies when you set the `OutputDataType` property to `Custom`.

The default is `numerictype([],32,0)`.

Methods

step   Finds the best template match within image

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Video Stabilization

This example shows how to remove the effect of camera motion from a video stream.

Introduction

In this example we first define the target to track. In this case, it is the back of a car and the license plate. We also establish a dynamic search region, whose position is determined by the last known target location. We then search for the target only within this search region, which reduces the number of computations required to find the target. In each subsequent video frame, we determine how much the target has moved relative to the previous frame. We use this information to remove unwanted translational camera motions and generate a stabilized video.

Initialization

Create a System object™ to read video from a multimedia file. We set the output to be of intensity only video.

```
% Input video file which needs to be stabilized.
filename = 'shaky_car.avi';

hVideoSource = vision.VideoFileReader(filename, ...
                                    'ImageColorSpace', 'Intensity',...
                                    'VideoOutputDataType', 'double');
```

Create a template matcher System object to compute the location of the best match of the target in the video frame. We use this location to find translation between successive video frames.

```
hTM = vision.TemplateMatcher('ROIInputPort', true, ...
                            'BestMatchNeighborhoodOutputPort', true);
```

Create a System object to display the original video and the stabilized video.

```
hVideoOut = vision.VideoPlayer('Name', 'Video Stabilization');
hVideoOut.Position(1) = round(0.4*hVideoOut.Position(1));
hVideoOut.Position(2) = round(1.5*(hVideoOut.Position(2)));
hVideoOut.Position(3:4) = [650 350];
```

Here we initialize some variables used in the processing loop.

```
pos.template_orig = [109 100]; % [x y] upper left corner
pos.template_size = [22 18];   % [width height]
pos.search_border = [15 10];   % max horizontal and vertical displacement
pos.template_center = floor((pos.template_size-1)/2);
pos.template_center_pos = (pos.template_orig + pos.template_center - 1);
fileInfo = info(hVideoSource);
W = fileInfo.VideoSize(1); % Width in pixels
H = fileInfo.VideoSize(2); % Height in pixels
BorderCols = [1:pos.search_border(1)+4 W-pos.search_border(1)+4:W];
BorderRows = [1:pos.search_border(2)+4 H-pos.search_border(2)+4:H];
sz = fileInfo.VideoSize;
TargetRowIndices = ...
  pos.template_orig(2)-1:pos.template_orig(2)+pos.template_size(2)-2;
TargetColIndices = ...
  pos.template_orig(1)-1:pos.template_orig(1)+pos.template_size(1)-2;
SearchRegion = pos.template_orig - pos.search_border - 1;
Offset = [0 0];
```

```
Target = zeros(18,22);
firstTime = true;
```

Stream Processing Loop

This is the main processing loop which uses the objects we instantiated above to stabilize the input video.

```
while ~isDone(hVideoSource)
    input = step(hVideoSource);

    % Find location of Target in the input video frame
    if firstTime
      Idx = int32(pos.template_center_pos);
      MotionVector = [0 0];
      firstTime = false;
    else
      IdxPrev = Idx;

      ROI = [SearchRegion, pos.template_size+2*pos.search_border];
      Idx = step(hTM, input, Target, ROI);

      MotionVector = double(Idx-IdxPrev);
    end

    [Offset, SearchRegion] = updatesearch(sz, MotionVector, ...
        SearchRegion, Offset, pos);

    % Translate video frame to offset the camera motion
    Stabilized = imtranslate(input, Offset, 'linear');

    Target = Stabilized(TargetRowIndices, TargetColIndices);

    % Add black border for display
    Stabilized(:, BorderCols) = 0;
    Stabilized(BorderRows, :) = 0;

    TargetRect = [pos.template_orig-Offset, pos.template_size];
    SearchRegionRect = [SearchRegion, pos.template_size + 2*pos.search_border];

    % Draw rectangles on input to show target and search region
    input = insertShape(input, 'Rectangle', [TargetRect; SearchRegionRect],...
                        'Color', 'white');
    % Display the offset (displacement) values on the input image
    txt = sprintf('(%+05.1f,%+05.1f)', Offset);
```

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```
input = insertText(input(:,:,1),[191 215],txt,'FontSize',16, ...
                    'TextColor', 'white', 'BoxOpacity', 0);
% Display video
step(hVideoOut, [input(:,:,1) Stabilized]);
end
```


Release

Here you call the release method on the objects to close any open files and devices.

```
release(hVideoSource);
```

Conclusion

Using the Computer Vision System Toolbox™ functionality from MATLAB® command line it is easy to implement complex systems like video stabilization.

Appendix

The following helper function is used in this example.

- updatesearch.m

Algorithms

This object implements the algorithm, inputs, and outputs described on the Template Matching block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

insertMarker | opticalFlowFarneback | opticalFlowHS | opticalFlowLK | opticalFlowLKDoG

Introduced in R2012a

step

System object: vision.TemplateMatcher
Package: vision

Finds the best template match within image

Syntax

```
LOC = step(H,I,T)
METRIC = step(H,I,T)
LOC = step(H,I,T,ROI)
[LOC,ROIVALID] = step(H,I,T,ROI)
[LOC,NVALS,NVALID] = step(H,I,T)
[LOC,NVALS,NVALID,ROIVALID] = step(H,I,T,ROI)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`LOC = step(H,I,T)` computes the [x y] location coordinates, `LOC`, of the best template match between the image matrix, `I`, and the template matrix, `T`. The `step` method outputs the coordinates relative to the top left corner of the image. The object computes the location by shifting the template in single-pixel increments throughout the interior of the image.

`METRIC = step(H,I,T)` computes the match metric values for input image, `I`, with `T` as the template. This applies when you set the `OutputValue` property to `Metric matrix`.

`LOC = step(H,I,T,ROI)` computes the location of the best template match, `LOC`, in the specified region of interest, `ROI`. This applies when you set the `OutputValue` property to `Best match location` and the `ROIInputPort` property to `true`. The input `ROI` must

be a four element vector, [x y width height], where the first two elements represent the [x y] coordinates of the upper-left corner of the rectangular ROI.

`[LOC,ROIVALID] = step(H,I,T,ROI)` computes the location of the best template match, `LOC`, in the specified region of interest, `ROI`. The step method also returns a logical flag `ROIVALID` indicating if the specified `ROI` is outside the bounds of the input image `I`. This applies when you set the `OutputValue` property to `Best match location`, and both the `ROIInputPort` and `ROIValidityOutputPort` properties to `true`.

`[LOC,NVALS,NVALID] = step(H,I,T)` returns the location of the best template match `LOC`, the metric values around the best match `NVALS`, and a logical flag `NVALID`. A `false` value for `NVALID` indicates that the neighborhood around the best match extended outside the borders of the metric value matrix `NVALS`. This applies when you set the `OutputValue` property to `Best match location` and the `BestMatchNeighborhoodOutputPort` property to `true`.

`[LOC,NVALS,NVALID,ROIVALID] = step(H,I,T,ROI)` returns the location of the best template match `LOC`, the metric values around the best match `NVALS`, and two logical flags, `NVALID` and `ROIVALID`. A `false` value for `NVALID` indicates that the neighborhood around the best match extended outside the borders of the metric value matrix `NVALS`. A `false` value for `ROIVALID` indicates that the specified `ROI` is outside the bounds of the input image `I`. This applies when you set the `OutputValue` property to `Best match location`, and the `BestMatchNeighborhoodOutputPort`, `ROIInputPort`, and `ROIValidityOutputPort` properties to `true`.

Typical use of the template matcher involves finding a small region within a larger image. The region is specified by the template image which can be as large as the input image, but which is typically smaller than the input image.

The object outputs the best match coordinates, relative to the top-left corner of the image. The [x y] coordinates of the location correspond to the center of the template. When you use a template with an odd number of pixels, the object uses the center of the template. When you use a template with an even number of pixels, the object uses the centered upper-left pixel for the location. The following table shows how the object outputs the location (`LOC`), of odd and even templates:

Odd number of pixels in template	Even number of pixels in template

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.Variance System object

Package: vision

Find variance values in an input or sequence of inputs

Description

The `Variance` object finds variance values in an input or sequence of inputs.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.Variance` returns a System object, `H`, that computes the variance of an input or a sequence of inputs.

`H = vision.Variance(`*Name*,*Value*`)` returns a variance System object, `H`, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

RunningVariance

Enable calculation over successive calls to step method

Set this property to `true` to enable the calculation of the variance over successive calls to the `step` method. The default is `false`.

ResetInputPort

Enable resetting via an input in running variance mode

Set this property to `true` to enable resetting the running variance. When the property is set to `true`, a reset input must be specified to the `step` method to reset the running variance. This property applies when you set the `RunningVariance` property to `true`. The default is `false`.

ResetCondition

Reset condition for running variance mode

Specify the event to reset the running variance as `Rising edge`, `Falling edge`, `Either edge`, or `Non-zero`. This property applies when you set the `ResetInputPort` property to `true`. The default is `Non-zero`.

CustomDimension

Numerical dimension to operate along

Specify the dimension (one-based value) of the input signal, over which the variance is computed. The value of this property cannot exceed the number of dimensions in the input signal. This property applies when you set the `Dimension` property to `Custom`. The default is `1`.

Dimension

Numerical dimension to operate along

Specify how the variance calculation is performed over the data as `All`, `Row`, `Column`, or `Custom`. This property applies only when you set the `RunningVariance` property to `false`. The default is `All`.

ROIForm

Type of region of interest

Specify the type of region of interest as `Rectangles`, `Lines`, `Label matrix`, or `Binary mask`. This property applies when you set the `ROIProcessing` property to `true`. Full ROI processing support requires a Computer Vision System Toolbox license. If you only have the DSP System Toolbox license, the `ROIForm` property value options are limited to `Rectangles`. The default is `Rectangles`.

ROIPortion

Calculate over entire ROI or just perimeter

Specify the region over which to calculate the variance as `Entire ROI`, or `ROI perimeter`. This property applies when you set the `ROIForm` property to `Rectangles`. The default is `Entire ROI`.

ROIProcessing

Enable region of interest processing

Set this property to `true` to enable calculating the variance within a particular region of each image. This property applies when you set the `Dimension` property to `All` and the `RunningVariance` property to `false`. Full ROI processing support requires a Computer Vision System Toolbox license. If you only have the DSP System Toolbox license, the `ROIForm` property value options are limited to `Rectangles`. The default is `false`.

ROIStatistics

Statistics for each ROI, or one for all ROIs

Specify what statistics to calculate as `Individual statistics for each ROI`, or `Single statistic for all ROIs`. This property does not apply when you set the `ROIForm` property to `Binary mask`. The default is `Individual statistics for each ROI`.

ValidityOutputPort

Output flag indicating if any part of ROI is outside input image

Set this property to `true` to return the validity of the specified ROI as completely or partially inside of the image. This applies when you set the `ROIForm` property to `Lines` or `Rectangles`.

Set this property to `true` to return the validity of the specified label numbers. This applies when you set the `ROIForm` property to `Label matrix`.

The default is `false`.

Fixed-Point Properties

RoundingMethod

Rounding method for fixed-point operations

Specify the rounding method as one of `Ceiling` | `Convergent` | `Floor` | `Nearest` | `Round` | `Simplest` | `Zero`. The default is `Floor`.

OverflowAction

Overflow action for fixed-point operations

Specify the overflow action as `Wrap` or `Saturate`. The default is `Wrap`.

InputSquaredProductDataType

Input squared product and fraction lengths

Specify the input-squared product fixed-point data type as `Same as input` or Custom. The default is `Same as input`.

CustomInputSquaredProductDataType

Input squared product word and fraction lengths

Specify the input-squared product fixed-point type as a scaled `numerictype` object. This property applies when you set the `InputSquaredProductDataType` property to `Custom`. The default is `numerictype(true,32,15)`.

InputSumSquaredProductDataType

Input-sum-squared product and fraction lengths

Specify the input-sum-squared product fixed-point data type as `Same as input-squared product` or `Custom`. The default is `Same as input-squared product`.

CustomInputSumSquaredProductDataType

Input sum-squared product and fraction lengths

Specify the input-sum-squared product fixed-point type as a scaled `numerictype` object. This property applies when you set the `InputSumSquaredProductDataType` property to `Custom`. The default is `numerictype(true,32,23)`.

AccumulatorDataType

Data type of the accumulator

Specify the accumulator fixed-point data type as `Same as input`, or `Custom`. The default is `Same as input`.

CustomAccumulatorDataType

Accumulator word and fraction lengths

Specify the accumulator fixed-point type as a scaled `numerictype` object. This property applies when you set the `AccumulatorDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

OutputDataType

Data type of output

Specify the output fixed-point data type as `Same as accumulator`, `Same as input`, or `Custom`. The default is `Same as accumulator`.

CustomOutputDataType

Output word and fraction lengths

Specify the output fixed-point type as a scaled `numerictype` object.

This property applies when you set the `OutputDataType` property to `Custom`. The default is `numerictype(true,32,30)`.

Methods

reset	Reset the internal states of the variance object
step	Compute variance of input

Common to All System Objects	
release	Allow System object property value changes

Examples

Determine the variance in a grayscale image.

```
img = im2single(rgb2gray(imread('peppers.png')));
hvar2d = vision.Variance;
var2d = step(hvar2d,img);
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

Introduced in R2012a

reset

System object: vision.Variance
Package: vision

Reset the internal states of the variance object

Syntax

reset(H)

Description

reset(H) resets the internal states of System object H to their initial values.

step

System object: vision.Variance
Package: vision

Compute variance of input

Syntax

```
Y = step(H,X)
Y = step(H,X,R)
Y = step(H,X,ROI)
Y = step(H,X,LABEL,LABELNUMBERS)
[Y,FLAG] = step(H,X,ROI)
[Y,FLAG] = step(H,X,LABEL,LABELNUMBERS)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`Y = step(H,X)` computes the variance of input *X*. When you set the `RunningVariance` property to `true`, the output *Y* corresponds to the standard deviation of the input elements over successive calls to the `step` method.

`Y = step(H,X,R)` computes the variance of the input elements *X* over successive calls to the `step` method, and optionally resets its state based on the value of the reset signal *R*, the `ResetInputPort` property and the `ResetCondition` property. This option applies when you set the `RunningVariance` property to `true` and the `ResetInputPort` to `true`.

`Y = step(H,X,ROI)` computes the variance of input image *X* within the given region of interest *ROI* when you set the `ROIProcessing` property to `true` and the `ROIForm` property to `Lines`, `Rectangles` or `Binary mask`.

`Y = step(H,X,LABEL,LABELNUMBERS)` computes the variance of input image *X* for region labels contained in vector *LABELNUMBERS*, with matrix *LABEL* marking pixels of different regions. This option applies when you set the `ROIProcessing` property to `true` and the `ROIForm` property to `Label matrix`.

`[Y,FLAG] = step(H,X,ROI)` also returns the output *FLAG*, which indicates whether the given region of interest is within the image bounds. This applies when you set both the `ROIProcessing` and the `ValidityOutputPort` properties to `true` and the `ROIForm` property to `Lines`, `Rectangles` or `Binary mask`.

`[Y,FLAG] = step(H,X,LABEL,LABELNUMBERS)` also returns the *FLAG*, which indicates whether the input label numbers are valid. This applies when you set both the `ROIProcessing` and `ValidityOutputPort` properties to `true` and the `ROIForm` property to `Label matrix`.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.VideoPlayer System object

Package: vision

Play video or display image

Description

The `VideoPlayer` object can play a video or display image sequences.

Note If you own the MATLAB Coder product, you can generate C or C++ code from MATLAB code in which an instance of this system object is created. When you do so, the scope system object is automatically declared as an extrinsic variable. In this manner, you are able to see the scope display in the same way that you would see a figure using the `plot` function, without directly generating code from it. For the full list of system objects supporting code generation, see "Code Generation Support, Usage Notes, and Limitations".

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`videoPlayer = vision.VideoPlayer` returns a video player object, `videoPlayer`, for displaying video frames. Each call to the `step` method displays the next video frame.

`videoPlayer = vision.VideoPlayer(`*`Name`*`,`*`Value`*`)` configures the video player properties, specified as one or more name-value pair arguments. Unspecified properties have default values.

To display video frames:

1 Define and set up your video player object using the constructor.

2 Call the `step` method with the video player object, `VideoPlayer`, and any optional properties. See the syntax below for using the `step` method.

`step(videoPlayer,I)` displays one grayscale or truecolor RGB video frame, `I`, in the video player.

Properties

Name

Caption display on video player window

Specify the caption to display on the video player window as a character vector.

Default: `Video`

Position

Size and position of the video player window in pixels

Specify the size and position of the video player window in pixels as a four-element vector of the form: `[left bottom width height]`. This property is tunable.

Default: Dependent on the screen resolution. Window positioned in the center of the screen with size of 410 pixels in width by 300 pixels in height.

Methods

isOpen	Visible or hidden status for video player figure
reset	Reset displayed frame number to zero
step	Play video or image sequence
show	Turn figure visibility on
hide	Turn figure visibility off

Common to All System Objects	
release	Allow System object property value changes

Examples

Play a Video File

Read video from a file and set up player object.

```
videoFReader = vision.VideoFileReader('viplanedeparture.mp4');
videoPlayer = vision.VideoPlayer;
```

Play video. Every call to the step method reads another frame.

```
while ~isDone(videoFReader)
   frame = step(videoFReader);
   step(videoPlayer,frame);
end
```
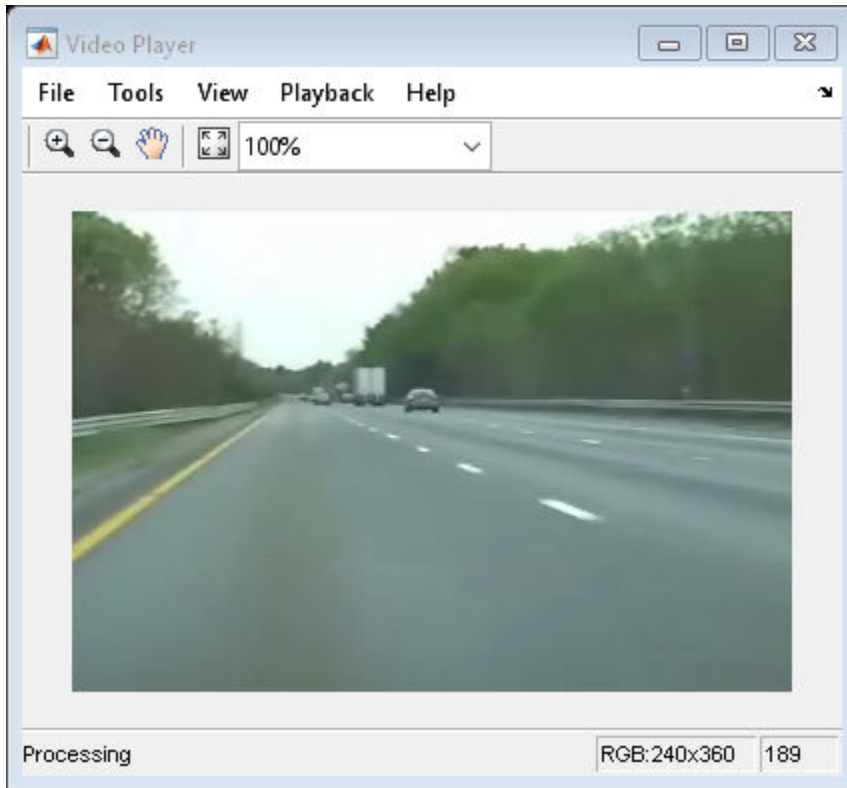
Close the file reader and video player.

```
release(videoFReader);
release(videoPlayer);
```
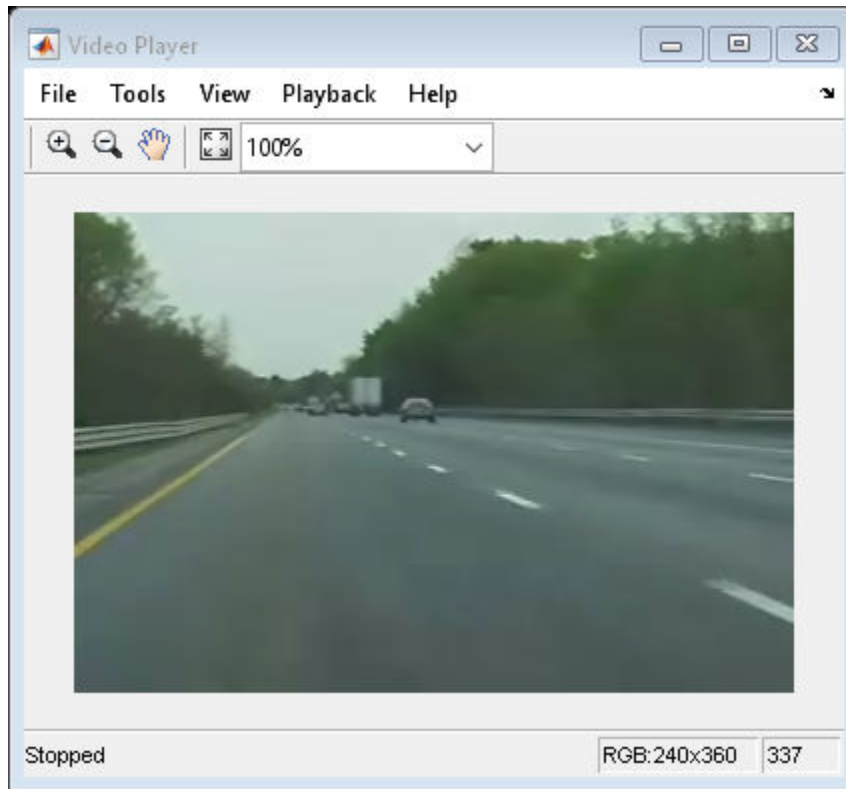
- "Face Detection and Tracking Using CAMShift"
- "Face Detection and Tracking Using the KLT Algorithm"
- "Face Detection and Tracking Using Live Video Acquisition"
- "Video Display in a Custom User Interface"

See Also

`implay` | `imshow` | `vision.DeployableVideoPlayer` | `vision.VideoFileReader` | `vision.VideoFileWriter`

Topics
"Face Detection and Tracking Using CAMShift"

"Face Detection and Tracking Using the KLT Algorithm"
"Face Detection and Tracking Using Live Video Acquisition"
"Video Display in a Custom User Interface"

Introduced in R2012a

isOpen

System object: vision.VideoPlayer
Package: vision

Visible or hidden status for video player figure

Syntax

```
isOpen(h)
```

Description

isOpen(h) returns the visible or hidden status, as a logical, for the video player window. This method is not supported in code generation.

reset

System object: vision.VideoPlayer
Package: vision

Reset displayed frame number to zero

Syntax

```
reset(H)
```

Description

reset(H) resets the displayed frame number of the video player to zero.

step

System object: vision.VideoPlayer
Package: vision

Play video or image sequence

Syntax

```
step(videoPlayer,I)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`step(videoPlayer,I)` displays one grayscale or truecolor RGB video frame,`I`, in the video player.

show

System object: vision.VideoPlayer
Package: vision

Turn figure visibility on

Syntax

show(H)

Description

show(H) turns video player figure visibility on.

hide

System object: vision.VideoPlayer
Package: vision

Turn figure visibility off

Syntax

```
hide(H)
```

Description

`hide(H)` turns video player figure visibility off.

fastRCNNObjectDetector class

Detect objects using Fast R-CNN deep learning detector

Description

The `fastRCNNObjectDetector` object contains a Fast R-CNN (regions with convolution neural networks) object detector returned by the `trainFastRCNNObjectDetector` function. Use of the `fastRCNNObjectDetector` object requires Neural Network Toolbox.

When using the `detect` or `classifyRegions` method, use of a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

Properties

ModelName — Name of the trained object detector
character vector

Name of the trained object detector, specified as a character vector. By default, the `trainFastRCNNObjectDetector` function sets the name. You can modify the name after training.

Network — Trained Fast R-CNN object detection network
`vision.cnn.FastRCNN` object

Trained Fast R-CNN object detection network, specified as a `vision.cnn.FastRCNN` object. The object stores the layers that define the convolutional neural network used within the R-CNN detector. This network classifies region proposals produced by RegionProposalFcn.

RegionProposalFcn — Region proposal method
function handle

Region proposal method, specified as a function handle.

`ClassNames` — Object class names
cell array

Names of the object classes that the Fast R-CNN detector was trained to find, specified as a cell array.

`MinObjectSize` — Minimum object size supported
[*height width*] vector

Minimum object size supported by the Fast R-CNN network, specified as a [*height width*] vector. The minimum size depends on the network architecture.

Methods

detect	Detect objects using Fast R-CNN object detector
classifyRegions	Classify objects within regions using Fast R-CNN object detector

See Also

Apps
Image Labeler

Functions
SeriesNetwork | selectStrongestBboxMulticlass | trainACFObjectDetector | trainFastRCNNObjectDetector | trainFasterRCNNObjectDetector | trainNetwork

Introduced in R2017a

detect

Class: fastRCNNObjectDetector

Detect objects using Fast R-CNN object detector

Syntax

```
bboxes = detect(detector,I)
[bboxes,scores] = detect(detector,I)
[ ___ ,labels] = detect(detector,I)
[ ___ ] = detect( ___ ,roi)
[ ___ ] = detect( ___ ,Name,Value)
```

Description

bboxes = detect(detector,I) detects objects within image I by using a Fast R-CNN (regions with convolutional neural networks) object detector. The locations of objects detected are returned in bboxes.

[bboxes,scores] = detect(detector,I) also returns the detection scores for each bounding box.

[___ ,labels] = detect(detector,I) also returns a categorical array of labels assigned to the bounding boxes, using the previous input arguments. The labels used for object classes are defined during training using the trainFastRCNNObjectDetector function.

[___] = detect(___ ,roi) detects objects within the rectangular search region specified by roi.

[___] = detect(___ ,Name,Value) uses additional options specified by one or more Name,Value pair arguments. Unspecified properties have default values.

Input Arguments

`detector` — Fast R-CNN object detector
`fastRCNNObjectDetector` object

Fast R-CNN object detector, specified as a `fastRCNNObjectDetector` object. To train the object detector, call `trainFastRCNNObjectDetector`.

`I` — Input image
grayscale image | truecolor image

Input image, specified as a real, nonsparse, grayscale or truecolor image.

The detector is sensitive to the range of the input image. Therefore, ensure that the input image range is similar to the range of the images used to train the detector. For example, if the detector was trained on `uint8` images, rescale the input image to the range [0, 255] by using `im2uint8` or `rescale`.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`

`roi` — Search region of interest
four-element vector

Search region of interest, specified as a four-element vector, [*x y width height*]. The vector specifies the upper-left corner and size of a region in pixels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NumStrongestRegions',1000`

`Threshold` — Detection threshold
`0.5` (default) | scalar

Detection threshold, specified as a numeric scalar in the range [0,1]. Detections with scores less than the threshold value are removed. Increase this value to reduce false positives.

NumStrongestRegions — Maximum number of strongest region proposals
2000 (default) | integer

Maximum number of strongest region proposals, specified as an integer. Reduce this value to speed up processing time at the cost of detection accuracy. To use all region proposals, specify this value as `Inf`.

SelectStrongest — Select strongest bounding box
`true` (default) | `false`

Select strongest bounding box, specified as `true` or `false`. The process, often referred to as nonmaximum suppression, eliminates overlapping bounding boxes based on their scores. Set this property to `true` to use the `selectStrongestBboxMulticlass` function to select the strongest bounding box. To return all detected bounding boxes or to perform a custom selection operation, set this property to `false`.

When you set this property to `true`, the `selectStrongestBboxMulticlass` function is used to eliminate the overlapping boxes. For example:

```
 selectStrongestBboxMulticlass(bbox,scores, ...
           'RatioType','Min', ...
           'OverlapThreshold',0.5);
```

MinSize — Minimum size of region containing an object
[*height width*] vector

Minimum size in pixels of a region containing an object, specified as a [*height width*] vector. When the minimum size is known, set this parameter to reduce computation time. By default, `'MinSize'` is the smallest object that the trained network can detect.

MaxSize — Maximum size of region containing an object
[*height width*] vector

Maximum size in pixels of a region containing an object, specified as a [*height width*] vector. When the maximum size is known, set this parameter to reduce computation time. The height and width of `I` determine the default `'MaxSize'` value.

ExecutionEnvironment — Hardware resource
`'auto'` (default) | `'gpu'` | `'cpu'`

Hardware resource, specified as `'auto'`, `'gpu'`, or `'cpu'`. Set the execution environment to the hardware resource you want to run the R-CNN detector on. The table shows the valid hardware resource values.

Resource	Action
`'auto'`	Use a GPU if it is available. Otherwise, use the CPU.
`'gpu'`	Use the GPU. To use a GPU, you must have Parallel Computing Toolbox, and a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher. If a suitable GPU is not available, the method returns an error message.
`'cpu'`	Use the CPU.

Output Arguments

bboxes — Location of objects detected within image
M-by-4 matrix

Location of objects detected within image, returned as an *M*-by-4 matrix defining *M* bounding boxes. Each row of bboxes contains a four-element vector, [*x y widthheight*]. This vector specifies the upper-left corner and size of a bounding box in pixels.

scores — Detection scores
M-by-1 vector

Detection scores, returned as an *M*-by-1 vector of classification scores in the range of [0,1]. Larger score values indicate higher confidence in the detection.

labels — Labels for bounding boxes
M-by-1 categorical array

Labels for bounding boxes, returned as an *M*-by-1 categorical array of object class names. These class names are defined when training the object detector using trainFastRCNNObjectDetector

See Also

Functions
peopleDetectorACF | selectStrongestBbox | trainFastRCNNObjectDetector

Apps
Image Labeler

Introduced in R2017a

fasterRCNNObjectDetector class

Detect objects using Faster R-CNN deep learning detector

Description

The `fasterRCNNObjectDetector` object contains a Faster R-CNN (regions with convolution neural networks) object detector returned by the `trainFasterRCNNObjectDetector` function. Use of the `fasterRCNNObjectDetector` object requires the Neural Network Toolbox.

When using the `detect` method, use of a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

Properties

ModelName — Name of the trained object detector
character vector

Name of the trained object detector, specified as a character vector. By default, the `trainFasterRCNNObjectDetector` function sets the name. You can modify the name after training.

Network — Trained Faster R-CNN object detection network
`vision.cnn.FastRCNN` object

Trained Faster R-CNN object detection network, specified as a `vision.cnn.FastRCNN` object. The object stores the layers that define the convolutional neural network used within the R-CNN detector. This network classifies region proposals produced by `RegionProposalFcn`.

RegionProposalNetwork — Trained region proposal network
`vision.cnn.RegionProposalNetwork` object

Trained region proposal network (RPN), specified as a `vision.cnn.RegionProposalNetwork` object. This object represents the RPN used in

the R-CNN detector. The RPN shares weights with the network stored in `Network` property.

ClassNames — Object class names
cell array

Names of the object classes that the Faster R-CNN detected was trained to find, specified as a cell array.

MinBoxSizes — Minimum anchor box sizes
m-by-2 matrix

Minimum anchor box sizes used to build the anchor box pyramid of the region proposal network (RPN), specified as a matrix. Each row defines the [*height width*] of an anchor box.

BoxPyramidScale — Anchor box pyramid scale
scalar

Anchor box pyramid scale factor used to successively upscale anchor box sizes, specified as a scalar.

NumBoxPyramidLevels — Number of anchor box pyramid levels
scalar

Number of levels in each anchor box pyramid, specified as a scalar.

MinObjectSize — Minimum object size supported
[*height width*] vector

Minimum object size supported by the Faster R-CNN network, specified as a [*height width*] vector. The minimum size depends on the network architecture.

Methods

detect   Detect objects using Faster R-CNN object detector

See Also

Apps
Image Labeler

Functions
SeriesNetwork | selectStrongestBboxMulticlass | trainACFObjectDetector |
trainFastRCNNObjectDetector | trainFasterRCNNObjectDetector |
trainNetwork

Introduced in R2017a

detect

Class: fasterRCNNObjectDetector

Detect objects using Faster R-CNN object detector

Syntax

```
bboxes = detect(detector,I)
[bboxes,scores] = detect(detector,I)
[ ___ ,labels] = detect(detector,I)
[ ___ ] = detect( ___ ,roi)
[ ___ ] = detect( ___ ,Name,Value)
```

Description

bboxes = detect(detector,I) detects objects within image I using a Faster R-CNN (regions with convolutional neural networks) detector. The locations of objects detected are returned in bboxes.

[bboxes,scores] = detect(detector,I) also returns the detection scores for each bounding box.

[___ ,labels] = detect(detector,I) also returns a categorical array of labels assigned to the bounding boxes, using the previous input arguments. The labels used for object classes are defined during training using the trainFasterRCNNObjectDetector function.

[___] = detect(___ ,roi) detects objects within the rectangular search region specified by roi.

[___] = detect(___ ,Name,Value) uses additional options specified by one or more Name,Value pair arguments. Unspecified properties have default values.

Input Arguments

`detector` — Faster R-CNN object detector
`fasterRCNNObjectDetector` object

Faster R-CNN object detector, specified as an `fasterRCNNObjectDetector` object. To train the object detector, call `trainFasterRCNNObjectDetector`.

`I` — Input image
grayscale image | truecolor image

Input image, specified as a real, nonsparse, grayscale or truecolor image.

The detector is sensitive to the range of the input image. Therefore, ensure that the input image range is similar to the range of the images used to train the detector. For example, if the detector was trained on `uint8` images, rescale the input image to the range [0, 255] by using `im2uint8` or `rescale`.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`

`roi` — Search region of interest
four-element vector

Search region of interest, specified as a four-element vector, [*x y width height*]. The vector specifies the upper-left corner and size of a region in pixels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NumStongestRegions',1000`

`Threshold` — Detection threshold
`0.5` (default) | scalar

Detection threshold, specified as a numeric scalar in the range [0,1]. Detections with scores less than the threshold value are removed. Increase this value to reduce false positives.

NumStrongestRegions — Maximum number of strongest region proposals
2000 (default) | integer

Maximum number of strongest region proposals, specified as an integer. Reduce this value to speed up processing time at the cost of detection accuracy. To use all region proposals, specify this value as Inf.

SelectStrongest — Select strongest bounding box
true (default) | false

Select strongest bounding box, specified as true or false. The process, often referred to as nonmaximum suppression, eliminates overlapping bounding boxes based on their scores. Set this property to true to use the selectStrongestBboxMulticlass function to select the strongest bounding box. To return all detected bounding boxes or to perform a custom selection operation, set this property to false.

MinSize — Minimum size of region containing an object
[*height width*] vector

Minimum size in pixels of a region containing an object, specified as a [*height width*] vector. When the minimum size is known, set this parameter to reduce computation time. By default, 'MinSize' is the smallest object that the trained network can detect.

MaxSize — Maximum size of region containing an object
[*height width*] vector

Maximum size in pixels of a region containing an object, specified as a [*height width*] vector. When the maximum size is known, set this parameter to reduce computation time. The height and width of I determine the default 'MaxSize' value.

ExecutionEnvironment — Hardware resource
'auto' (default) | 'gpu' | 'cpu'

Hardware resource, specified as 'auto', 'gpu', or 'cpu'. Set the execution environment to the hardware resource you want to run the R-CNN detector on. The table shows the valid hardware resource values.

Resource	Action
'auto'	Use a GPU if it is available. Otherwise, use the CPU.

Resource	Action
`'gpu'`	Use the GPU. To use a GPU, you must have Parallel Computing Toolbox, and a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher. If a suitable GPU is not available, the method returns an error message.
`'cpu'`	Use the CPU.

Output Arguments

bboxes — Location of objects detected within image
M-by-4 matrix

Location of objects detected within image, returned as an *M*-by-4 matrix defining *M* bounding boxes. Each row of bboxes contains a four-element vector, [*x y widthheight*]. This vector specifies the upper-left corner and size of a bounding box in pixels.

scores — Detection scores
M-by-1 vector

Detection scores, returned as an *M*-by-1 vector of classification scores in the range of [0,1]. Larger score values indicate higher confidence in the detection.

labels — Labels for bounding boxes
M-by-1 categorical array

Labels for bounding boxes, returned as an *M*-by-1 categorical array of object class names. These class names are defined when training the object detector using trainFastRCNNObjectDetector

See Also

Functions
peopleDetectorACF | selectStrongestBbox | trainFasterRCNNObjectDetector

Apps
Image Labeler

Introduced in R2017a

classifyRegions

Class: fastRCNNObjectDetector

Classify objects within regions using Fast R-CNN object detector

Syntax

```
[labels,scores] = classifyRegions(detector,I,rois)
[labels,scores,allScores] = classifyRegions(detector,I,rois)
[ ___ ] = classifyRegions( ___ Name,Value)
```

Description

`[labels,scores] = classifyRegions(detector,I,rois)` classifies objects within the regions specified by `rois` in image `I`, using the Fast R-CNN (regions with convolutional neural networks) detector. Classification scores and corresponding labels are returned for each region.

`[labels,scores,allScores] = classifyRegions(detector,I,rois)` optionally returns all the classification scores in an *M*-by-*N* matrix of *M* regions and *N* classes.

`[ ___ ] = classifyRegions( ___ Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments using the previous input arguments. Unspecified properties have default values.

Input Arguments

detector — Fast R-CNN object detector
fastRCNNObjectDetector object

Fast R-CNN object detector, specified as a `fastRCNNObjectDetector` object. To train the object detector, call `trainFastRCNNObjectDetector`.

I — Input image
grayscale image | truecolor image

Input image, specified as a real, nonsparse grayscale or truecolor image.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`

`rois` — Regions of interest
M-by-4 array

Regions of interest, specified by an *M*-by-4 array of rectangular regions. Each row contains a four-element vector, [*x y width height*], that specifies the upper-left corner and size of a region in pixels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

`ExecutionEnvironment` — Hardware resource
`'auto'` (default) | `'gpu'` | `'cpu'`

Hardware resource, specified as the comma-separated pair consisting of `'ExecutionEnvironment'` and `'auto'`, `'gpu'`, or `'cpu'`. Set the execution environment to the hardware resource you want to run the R-CNN detector on. The table shows the valid hardware resource values.

Resource	Action
`'auto'`	Use a GPU if it is available. Otherwise, use the CPU.
`'gpu'`	Use the GPU. To use a GPU, you must have Parallel Computing Toolbox, and a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher. If a suitable GPU is not available, the method returns an error message.
`'cpu'`	Use the CPU.

Output Arguments

`labels` — Labels
M-by-1 categorical array

Labels, returned as an *M*-by-1 categorical array of class names. Every region in `rois` is assigned a label.

`scores` — Classification score
M-by-1 vector

Classification score, returned as an *M*-by-1 vector of classification scores in the range of [0,1]. Larger scores values indicate higher confidence in the classification.

`allScores` — All classification scores
M-by-*N* matrix

All classification scores, returned in an *M*-by-*N* matrix of *M* regions and *N* classes.

See Also

Functions
peopleDetectorACF | selectStrongestBbox | trainFastRCNNObjectDetector

Apps
Image Labeler

Introduced in R2017a

step

System object: vision.ChromaResampler
Package: vision

Resample input chrominance components

Syntax

```
[Cb1,Cr1] = step(H,Cb,Cr)
```

Description

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

`[Cb1,Cr1] = step(H,Cb,Cr)` resamples the input chrominance components `Cb` and `Cr` and returns `Cb1` and `Cr1` as the resampled outputs.

Note H specifies the System object on which to run this `step` method.

The object performs an initialization the first time the `step` method is executed. This initialization locks *nontunable properties* and input specifications, such as dimensions, complexity, and data type of the input data. If you change a nontunable property or an input specification, the System object issues an error. To change nontunable properties or inputs, you must first call the `release` method to unlock the object.

vision.ChromaResampler System object

Package: vision

Downsample or upsample chrominance components of images

Description

The `ChromaResampler` object downsamples or upsample chrominance components of images.

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Construction

`H = vision.ChromaResampler` returns a chroma resampling System object, `H`, that downsamples or upsamples chroma components of a YCbCr signal to reduce the bandwidth and storage requirements.

`H = vision.ChromaResampler(`*Name*`,`*Value*`)` returns a chroma resampling System object, `H`, with each specified property set to the specified value. You can specify additional name-value pair arguments in any order as (*Name1*, *Value1*,...,*NameN*,*ValueN*).

Properties

Resampling

Resampling format

To downsample the chrominance components of images, set this property to one of the following:

```
[4:4:4 to 4:2:2]
[4:4:4 to 4:2:0 (MPEG1)]
[4:4:4 to 4:2:0 (MPEG2)]
[4:4:4 to 4:1:1]
[4:2:2 to 4:2:0 (MPEG1)]
[4:2:2 to 4:2:0 (MPEG2)]
```

To upsample the chrominance components of images, set this property to one of the following:

```
[4:2:2 to 4:4:4]
[4:2:0 (MPEG1) to 4:4:4]
[4:2:0 (MPEG2) to 4:4:4]
[4:1:1 to 4:4:4]
[4:2:0 (MPEG1) to 4:2:2]
[4:2:0 (MPEG2) to 4:2:2]
```

The default is `[4:4:4 to 4:2:2]`

InterpolationFilter

Method used to approximate missing values

Specify the interpolation method used to approximate the missing chrominance values as one of `Pixel replication` | `Linear`. The default is `Linear`. When you set this property to `Linear`, the object uses linear interpolation to calculate the missing values. When you set this property to `Pixel replication`, the object replicates the chrominance values of the neighboring pixels to create the upsampled image. This property applies when you upsample the chrominance values.

AntialiasingFilterSource

Lowpass filter used to prevent aliasing

Specify the lowpass filter used to prevent aliasing as one of `Auto` | `Property` | `None`. The default is `Auto`. When you set this property to `Auto`, the object uses a built-in lowpass filter. When you set this property to `Property`, the coefficients of the filters are specified by the `HorizontalFilterCoefficients` and `VerticalFilterCoefficients` properties. When you set this property to `None`, the object does not filter the input signal. This property applies when you downsample the chrominance values.

HorizontalFilterCoefficients

Horizontal filter coefficients

Specify the filter coefficients to apply to the input signal. This property applies when you set the `Resampling` property to one of `[4:4:4 to 4:2:2]`|`[4:4:4 to 4:2:0 (MPEG1)]`|`[4:4:4 to 4:2:0 (MPEG2)]`|`[4:4:4 to 4:1:1]` and the `AntialiasingFilterSource` property to `Property`. The default is `[0.2 0.6 0.2]`.

VerticalFilterCoefficients

Vertical filter coefficients

Specify the filter coefficients to apply to the input signal. This property applies when you set the `Resampling` property to one of `[4:4:4 to 4:2:0 (MPEG1)]`|`[4:4:4 to 4:2:0 (MPEG2)]`|`[4:2:2 to 4:2:0 (MPEG1)]`|`[4:2:2 to 4:2:0 (MPEG2)]` and the `AntialiasingFilterSource` property to `Property`. The default is `[0.5 0.5]`.

TransposedInput

Input is row-major format

Set this property to `true` when the input contains data elements from the first row first, then data elements from the second row second, and so on through the last row. Otherwise, the object assumes that the input data is stored in column-major format. The default is `false`.

Methods

step   Resample input chrominance components

Common to All System Objects	
`release`	Allow System object property value changes

Examples

Resample the chrominance components of an image.

```
H = vision.ChromaResampler;
hcsc = vision.ColorSpaceConverter;
x = imread('peppers.png');
x1 = step(hcsc, x);
[Cb, Cr] = step(H, x1(:,:,2), x1(:,:,3));
```

Algorithms

This object implements the algorithm, inputs, and outputs described on the Chroma Resampling block reference page. The object properties correspond to the block parameters.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

applycform | makecform | rgb2gray | rgb2ycbcr

Introduced in R2012a

groundTruthDataSource

Object for storing ground truth data sources

Description

The `groundTruthDataSource` object defines the source of ground truth data. Use this object to specify a data source for the `groundTruth` object. The source can be a video, an image collection supported by the **Image Labeler**, an image sequence supported by the **Ground Truth Labeler**, or a custom reader.

Creation

Syntax

```
gtSource = groundTruthDataSource(imageFiles)
gtSource = groundTruthDataSource(videoName)
gtSource = groundTruthDataSource(imageSeqFolder)
gtSource = groundTruthDataSource(imageSeqFolder,timeStamps)
gtSource = groundTruthDataSource(sourceName,readerFcn,timeStamps)
```

Description

gtSource = groundTruthDataSource(imageFiles) returns a ground truth data source object for a collection of images specified by imageFiles.

gtSource = groundTruthDataSource(videoName) returns a ground truth data source object for a video file specified by videoName.

gtSource = groundTruthDataSource(imageSeqFolder) returns a ground truth data source object for an image sequence located in the folder specified by imageSeqFolder.

gtSource = groundTruthDataSource(imageSeqFolder,timeStamps) returns a ground truth data source object for an image sequence with a corresponding timestamp

for each image contained in the specified folder. `timeStamps` sets the TimeStamps property.

`gtSource = groundTruthDataSource(sourceName,readerFcn,timeStamps)` returns a ground truth data source object by using the custom reader function handle, `readerFcn`. `sourceName` sets the Source property and `timeStamps` set the `TimeStamps` property. The custom reader function loads an image from `sourceName` that corresponds to the current timestamp specified in the duration vector `timeStamps`.

Input Arguments

imageFiles — Image file names
cell array of strings | cell array of character vectors

Image file names, specified as a cell array of strings or character vectors.

videoName — Name of video file
string scalar or character vector

Name of video file, specified as a string scalar or character vector.

imageSeqFolder — Image sequence folder
scalar string | character vector

Image sequence folder, specified as a scalar string or a character vector. The image files name extensions must be supported by `imformats`. The images are loaded in the order returned by the `dir` command.

readerFcn — Custom reader function
function handle

Custom reader function, specified as a function handle. The custom reader function must load an image from a source at a specified timestamp by using this syntax::

`outputImage = readerFcn(sourceName,currentTimeStamp)`

readerFcn: Name of your custom reader function
sourceName: Name of data source
currentTimeStamp: Current timestamp, as specified by the input vector `timeStamp`

The `outputImage` from the custom function must be a grayscale or true color image in any format supported by `imshow`. See "Use Custom Data Source Reader for Ground Truth Labeling" (Automated Driving System Toolbox) for more information.

Properties

`TimeStamps` — Duration vector of timestamps
duration vector

Duration vector of timestamps. For a video file `TimeStamps` is automatically populated with the timestamps that are present for the video frames. For an image collection, the `TimeStamps` property remains empty.

`Source` — Source of ground truth data
character vector | cell array of character vectors

This property is read-only.

Source of ground truth data, specified as a character vector or cell array of character vectors. The source name can refer to a video file name, image sequence file names, or custom data source names.

Examples

Create a Ground Truth Data Source From a Video File

Use the `groundTruthDataSource` object to create a data source.

Read a video file and create a data source.

```
videoName = 'vipunmarkedroad.avi';
dataSource = groundTruthDataSource(videoName)

dataSource =
  groundTruthDataSource with properties:

        Source: ...tlab\toolbox\vision\visiondata\vipunmarkedroad.avi
     TimeStamps: [84x1 duration]
```

Create a VideoReader to read the video frames.

```
reader = VideoReader(videoName);
```

Read the 5th frame in the video and display

```
timeStamp = seconds(dataSource.TimeStamps(5));
reader.CurrentTime = timeStamp;
I = readFrame(reader);

figure
imshow(I)
```


Create Data Source From Image Sequence

Create a ground truth data source from a an image sequence stored in a specified folder.

Specify the folder containing a sequence of images.

```
imageDir = fullfile(matlabroot,'toolbox','vision',...
        'visiondata','building');
```

Create a data source for the images that are in the `imageDir` folder.

```
dataSource = groundTruthDataSource(imageDir)
```

```
dataSource = 
  groundTruthDataSource with properties:

                    Source: {
                              'B:\matlab\toolbox\vision\visiondata\building\building1.J
                              'B:\matlab\toolbox\vision\visiondata\building\building2.J
                              'B:\matlab\toolbox\vision\visiondata\building\building3.J
                               ... and 2 more
                            }
                 TimeStamps: [5x1 duration]
```

Read the 5th frame in the sequence.

```
I = imread(dataSource.Source{5});
figure
imshow(I)
```

Create Data Source Using Custom Reader

Create a ground truth data source using a custom reader.

Specify image directory containing sequence of road images.

```
imageDir = fullfile(matlabroot,'toolbox','vision',...
        'visiondata','building');
```

Use an image data store as a custom data source.

```
imgDataStore = imageDatastore(imageDir);
```

Write a reader function to read images from the data source. The first input argument, `sourceName,` of the custom reader function, `readerFcn`, is not used. The 2nd input, `currentTimeStamp,` is converted from a duration scalar to a 1-based index suitable for the data source.

```
readerFcn = @(~,idx)readimage(imgDataStore,seconds(idx));
```

Create a data source for the images in the `imageDir` folder using `readerFcn`.

```
dataSource = groundTruthDataSource(imageDir,readerFcn,1:5)
```

```
dataSource =
  groundTruthDataSource with properties:

       Source: B:\matlab\toolbox\vision\visiondata\building
    TimeStamps: [5x1 duration]
```

Read the 5th frame in the sequence.

```
I = readerFcn(imageDir, seconds(5));
figure
imshow(I)
```

See Also

Apps
Ground Truth Labeler | Image Labeler

Functions
duration | groundTruth | imageDatastore | labelType |
objectDetectorTrainingData

Topics
"Define Ground Truth for Image Collections"
"Train an Object Detector from Ground Truth Data"
"Create Automation Algorithm for Image Labeling"
"Use Custom Data Source Reader for Ground Truth Labeling" (Automated Driving System Toolbox)
"Define Ground Truth Data for Video or Image Sequences" (Automated Driving System Toolbox)

Introduced in R2017a

groundTruth

Object for storing ground truth labels

Description

The `groundTruth` object contains information about the data source, the list of label definitions, and all marked labels for a set of ground truth labels. You can export or import a `groundTruth` object from the **Ground Truth Labeler** and **Image Labeler** apps. You can create training data for an object detector from arrays of `groundTruth` objects by using the `objectDetectorTrainingData` function.

Creation

Syntax

`gTruth = groundTruth(dataSource,labelDefs,labelData)`

Description

`gTruth = groundTruth(dataSource,labelDefs,labelData)` returns an object containing ground truth labels that can be imported into the **Ground Truth Labeler** and **Image Labeler** apps. The `dataSource`, `labelDefinitions`, and `labelData` inputs set the properties. Label definitions describe the labels, sublabels, and attributes. Label data contains the identifying information, position, and timestamps for the labels.

Properties

DataSource — Source of ground truth data
`groundTruthDataSource` object

Source of ground truth data, specified as a `groundTruthDataSource` object. The object contains information that describes the video, image sequence, or custom data source from which ground truth data was labeled.

To access images from the original data source, you can use `VideoReader`, `imageDatastore`, or a custom reader function. See "Use Custom Data Source Reader for Ground Truth Labeling" (Automated Driving System Toolbox).

LabelDefinitions — Label definitions
`table`

This property is read-only.

Label definitions, specified as a table with up to five columns. The possible columns are *Name*, *Type*, *PixelLabelID*, *Description*, and *Hierarchy*.

The table includes the *PixelLabelID* column when you use pixel labels and includes the *Hierarchy* column when you create sublabels and/or attributes. The table always contains the *Name*, *Type*, and *Description* columns. Descriptions for labels are optional, so that column can be empty.

Label Definition	Description
Name	Character vector specifying the name of the label category.
Type	`labelType` enumeration that specifies the label category type.
PixelLabelID	A scalar, column vector, or an *M*-by-3 matrix of integer-valued label IDs. PixelLabelID specifies the pixel label values used to represent a label category. This value is required when you set *Type* to `labelType.PixelLabel`. Pixel label ID values must be between 0 and 255.
Description	Character vector that describes the label category. The description label definition is optional.
Hierarchy	A struct containing sublabel and attribute data. The app populates the hierarchy column when you create a sublabel or attribute. This label definition only applies to the **Ground Truth Labeler**. See "Define ROI Label Definitions" (Automated Driving System Toolbox)

For example, this definition table contains six label categories, cars, sky, vegetation, road, Signs, and laneMarkers.

```
>> gTruthhighway.LabelDefinitions

ans =

  6×5 table

        Name           Type      PixelLabelID      Description        Hierarchy
      _____     _____    _____   _____   _____

      'cars'         Rectangle        []         'all types'          [1×1 struct]
      'sky'          PixelLabel       [1]         ''                   []
      'vegetation'   PixelLabel       [2]         'Trees along highway' []
      'road'         PixelLabel       [3]         ''                   []
      'Signs'        Rectangle        []          ''                   []
      'laneMarkers'  Line             []          ''                   [1×1 struct]
```

Note Attributes and sublabels are only available in the **Ground Truth Labeler**. In the example above, two of the labels contain attributes, therefore a Hierarchy column was created for all labels.

The following code below represents a table with two label categories:

```
defs = table({'Cars';'Lanes'}, ...
    [labelType.Rectangle;labelType.Line], ...
    'VariableNames',{'Name','Type'})
```

LabelData — Label data for each ROI and scene label
table | timetable

This property is read-only.

Label data for each ROI and scene label, specified as a `table` for image collections or a `timetable` for videos or image sequence. Each column of the table or timetable holds labels for a single label category. `LabelData` describes the elements of the table. The label categories are specified as `labelType` enumerations.

Label Category	Label Values
labelType.Rectangle	Labels in each row are stored as M-by-4 matrices of [x,y,$width$,$height$] bounding box locations.

Label Category	Label Values
`labelType.Line`	Labels in each row are stored as *M*-by-1 cell arrays. Each element of the cell array holds [*x*,*y*] locations for the points used to mark the polyline.
`labelType.PixelLabel`	Label data for all label categories is represented by a single label matrix. The matrix must be stored on disk as a `uint8` image. The image file name must be specified as a character vector in the `LabelData` table. The label matrix must contain 1 or 3 channels. For a 3-channel matrix, the RGB pixel values represent label IDs.
`labelType.Scene`	Labels in each row are stored as logical values representing the presence or absence of the scene label for the image.
`labelType.Custom`	Labels in each row are stored in the way they are provided in the table. These labels are not imported into the labeling app.

Supported GroundTruth Objects

	Ground Truth Labeler App	Image Labeler App
Data source	Video file, image sequence folder, custom reader	Image files
Label definitions	`Rectangle`, `Line`, `PixelLabel`, or `Scene` label types	`Rectangle`, `PixelLabel` or `Scene` label types
Label data	Timetable of `Rectangle`, `Line`, `PixelLabel`, or `Scene` label types	Table (no timetable) for `Rectangle`, `PixelLabel`, or `Scene` label types

Labels, sublabels, and attributes per frame are stored in structs

At time interval: 0.05 sec, there are:
5 Vehicles, 2 LaneMarkers, and 2 Signs labels marked in the scene

Position, attribute data, and sublabel structs for the 5 vehicles labeled at interval 0.05 sec

Position of a door belonging to white sedan vehicle

To add ground truth data that is not an ROI (`Rectangle`, `Line`, `PixelLabel`) or `Scene` label category to a `groundTruth` object, provide a label definition with a `labelType` that is `Custom`. The custom data is not visible when you load it into the labeling app.

Object Functions

selectLabels   Select ground truth data for a set of labels

Examples

Create Ground Truth for Stop Signs and Cars

Create a data source from a collection of images.

```
data = load('stopSignsAndCars.mat');
imageFilenames = data.stopSignsAndCars.imageFilename(1:2)

imageFilenames = 2x1 cell array
    {'stopSignImages/image001.jpg'}
    {'stopSignImages/image002.jpg'}


imageFilenames = fullfile(toolboxdir('vision'),'visiondata',imageFilenames);
dataSource = groundTruthDataSource(imageFilenames);
```

Define labels used to specify the ground truth.

```
names = {'stopSign';'carRear'};
types = [
    labelType('Rectangle')
    labelType('Rectangle')
    ];

labelDefs = table(names,types,'VariableNames',{'Name','Type'})

labelDefs=2×2 table
      Name          Type
    _____    _____

    'stopSign'    Rectangle
    'carRear'     Rectangle
```

Initialize label data for rectangle ROIs.

```
numRows = numel(imageFilenames);
stopSignTruth = {[856   318    39    41]; [445   523    52    54]};
carRearTruth = {[398   378   315   210]; [332   633   691   287]};
```

Construct a table of label data.

```
labelData = table(stopSignTruth,carRearTruth,'VariableNames',names)

labelData=2×2 table
      stopSign         carRear
    _____    _____

    [1x4 double]    [1x4 double]
    [1x4 double]    [1x4 double]
```

Create a ground truth object.

```
gTruth = groundTruth(dataSource,labelDefs,labelData)

gTruth =
  groundTruth with properties:

          DataSource: [1x1 groundTruthDataSource]
    LabelDefinitions: [2x2 table]
           LabelData: [2x2 table]
```

Create Ground Truth Data of Road Lanes

Create a `groundTruth` object to store data representing marked road lanes.

Create a data source from video.

```
dataSource = groundTruthDataSource({'stopSignTest.jpg'});
```

Define labels used to specify ground truth.

```
names = {'Lane'};
types = [labelType('Line')];
labelDefs = table(names,types,'VariableNames',{'Name','Type'})

labelDefs=1×2 table
     Name       Type
     _____     ____

    'Lane'      Line
```

Assign two lane markers in the first frame.

```
laneMarkerTruth{1} = {[257 254;311 180] [327 183;338 205;374 250]};
```

Construct a table of label data.

```
labelData = table(laneMarkerTruth,'VariableNames',names)

labelData=1×1 table
         Lane
    _____
```

```
     {1x2 cell}
```

Create a groundTruth object.

```
gTruth = groundTruth(dataSource,labelDefs,labelData)

gTruth =
  groundTruth with properties:

          DataSource: [1x1 groundTruthDataSource]
    LabelDefinitions: [1x2 table]
           LabelData: [1x1 table]
```

Create Ground Truth Data For Pixel Labels

Create a groundTruth object to store data representing parts of a scene.

Create a data source.

```
dataSource = groundTruthDataSource({'visionteam.jpg'});
```

Define pixel labels to represent a person and the background of an image.

```
names = {'Person';'Background'};
types = [labelType('PixelLabel');labelType('PixelLabel')];
```

Define pixel label IDs for the two types of labels. Assign label ID 1 to correspond to Person and ID 2 to the Background.

```
pixelLabelID = {1;2};
```

Create a label definitions table.

```
labelDefs = table(names,types, pixelLabelID, ...
                  'VariableNames',{'Name','Type','PixelLabelID'})

labelDefs=2×3 table
        Name             Type        PixelLabelID
    _____    _____    _____

    'Person'         PixelLabel         [1]
    'Background'     PixelLabel         [2]
```

Specify the location of the pixel label data for the image.

```
dataFile = {'pixelLabeledVisionTeam.jpg'}

dataFile = 1x1 cell array
    {'pixelLabeledVisionTeam.jpg'}
```

Construct a table of label data for the pixel label data.

```
labelData = table(dataFile,'VariableNames',{'PixelLabelData'})

labelData=1×1 table
            PixelLabelData
    _____

    'pixelLabeledVisionTeam.jpg'
```

Create a `groundTruth` object.

```
gTruth = groundTruth(dataSource,labelDefs,labelData)

gTruth =
  groundTruth with properties:

          DataSource: [1x1 groundTruthDataSource]
    LabelDefinitions: [2x3 table]
           LabelData: [1x1 table]
```

Create Ground Truth for Car and Lane Markers

Create a data source from a video.

```
videoName = 'caltech_cordova1.avi';
dataSource = groundTruthDataSource(videoName);
```

Define labels used to specify the ground truth.

```
names = {'Cars';'LaneMarkers'};
types = [labelType('Rectangle');labelType('Line')];
labelDefs = table(names,types,'VariableNames',{'Name','Type'});
```

Create labels for cars and lane markers.

```
numRows = numel(dataSource.TimeStamps);
carsTruth = cell(numRows,1);
laneMarkerTruth = cell(numRows,1);
```

Add two car labels and two lane markers to the first frame.

```
carsTruth{1} = [182 186 31 22;404 191 53 34];
laneMarkerTruth{1} = {[257 254;311 180] [327 183;338 205;374 250]};
```

Create a table of label data.

```
labelData = table(carsTruth,laneMarkerTruth,'VariableNames',names);
```

Create a `groundTruth` object. To import this object into the Ground Truth Labeler app, click **Import Labels**.

```
gTruth = groundTruth(dataSource,labelDefs,labelData);
```

Tips

`groundTruth` objects for video-based data sources rely on the video reading capabilities of your operating system. A `groundTruth` object created using a video data source remains consistent only for the same platform that was used to create it. To create a platform-specific `groundTruth` object, convert the video into a sequence of images.

See Also

Apps
Ground Truth Labeler

Functions
`groundTruthDataSource` | `labelType` | `objectDetectorTrainingData`

Topics

"Define Ground Truth Data for Video or Image Sequences" (Automated Driving System Toolbox)

"Use Custom Data Source Reader for Ground Truth Labeling" (Automated Driving System Toolbox)

Introduced in R2017a

selectLabels

Select ground truth data for a set of labels

Syntax

```
gtLabel = selectLabels(gTruth,labelNames)
gtLabel = selectLabels(gTruth,types)
```

Description

gtLabel = selectLabels(gTruth,labelNames) returns a new groundTruth object containing only the labels specified by labelNames.

gtLabel = selectLabels(gTruth,types) returns a new groundTruth object containing only the labels type specified by types.

Examples

Create Ground Truth for Stop Signs and Cars

Create a data source from a collection of images.

```
data = load('stopSignsAndCars.mat');
imageFilenames = data.stopSignsAndCars.imageFilename(1:2)

imageFilenames = 2x1 cell array
    {'stopSignImages/image001.jpg'}
    {'stopSignImages/image002.jpg'}


imageFilenames = fullfile(toolboxdir('vision'),'visiondata',imageFilenames);
dataSource = groundTruthDataSource(imageFilenames);
```

Define labels used to specify the ground truth.

```
names = {'stopSign';'carRear'};
types = [
    labelType('Rectangle')
    labelType('Rectangle')
    ];

labelDefs = table(names,types,'VariableNames',{'Name','Type'})

labelDefs=2×2 table
      Name          Type
    _____    _____

    'stopSign'    Rectangle
    'carRear'     Rectangle
```

Initialize label data for rectangle ROIs.

```
numRows = numel(imageFilenames);
stopSignTruth = {[856    318     39     41]; [445    523     52     54]};
carRearTruth = {[398    378    315    210]; [332    633    691    287]};
```

Construct a table of label data.

```
labelData = table(stopSignTruth,carRearTruth,'VariableNames',names)

labelData=2×2 table
     stopSign          carRear
    _____    _____

    [1x4 double]    [1x4 double]
    [1x4 double]    [1x4 double]
```

Create a ground truth object.

```
gTruth = groundTruth(dataSource,labelDefs,labelData)

gTruth =
  groundTruth with properties:

          DataSource: [1x1 groundTruthDataSource]
    LabelDefinitions: [2x2 table]
           LabelData: [2x2 table]
```

Input Arguments

gTruth — Ground truth labels
groundTruth object

Ground truth labels, specified as a groundTruth object

labelNames — Label names
cell array of character vectors

Label names, specified as a cell array of character vectors.

types — Label type
labelType enumeration

Label type, specified as a labelType enumeration.

Output Arguments

gtLabel — Ground truth object with only specified labels
groundTruth object

Ground truth object with only specified labels, returned as a groundTruth object.

Introduced in R2017a

vision.labeler.AutomationAlgorithm

Interface for algorithm automation in ground truth labeling

Description

`AutomationAlgorithm` specifies the interface for defining custom automation algorithms to run in the labeling apps, such as the **Image Labeler** and the **Ground Truth Labeler**. Classes that inherit from the `AutomationAlgorithm` interface can be used with the automation workflow of the labeling apps to generate ground truth labels. Use of the **Ground Truth Labeler** requires Automated Driving System Toolbox™.

Properties

The `AutomationAlgorithm` class predefines this set of properties.

`SelectedLabelDefinitions` — Selected label definitions
struct array

Selected label definitions, specified as a struct array containing one or two elements. The fields correspond to selected label definitions in the labeling app. Selected label definitions are highlighted in yellow on the left panels titled **ROI Label Definition** and **Scene Label Definition** in the labeling app.

Field	Description
Type	Enumeration of class `labelType` with possible values of `Rectangle`, `Line`, `PixelLabel`, or `Scene`. Invalid label definitions are grayed out. The **Ground Truth Labeler** supports `Rectangle`, `Line`, and `Scene` labels. The **Image Labeler** supports `Rectangle`, `PixelLabel`, and `Scene` labels.
Name	Character vector that contains the name of the label definition

Field	Description
PixelLabelID	Positive integer that holds the ID for each selected pixel label **Note** This field is valid only for labels of type `PixelLabel`.

Example: Define `SelectedLabelDefinitions` structure array for `Rectangle` and `Scene` labels:

```
selectedLabelDefs(1).Name = 'Car';
selectedLabelDefs(1).Type = labelType.Rectangle;
selectedLabelDefs(2).Name = 'Sunny';
selectedLabelDefs(2).Type = labelType.Scene;
```

Example: Define `SelectedLabelDefinitions` structure for `PixelLabel` label:

```
selectedLabelDefs.Name = 'Road';
selectedLabelDefs.Type = labelType.PixelLabel;
selectedLabelDefs.PixelLabelID = 2;
```

ValidLabelDefinitions — All valid label definitions
struct array

All valid label definitions that satisfy the `checkLabelDefinition` method, specified as a struct array containing these fields.

Field	Description
Type	Enumeration of class `labelType` with possible values of `Rectangle`, `Line`, `PixelLabel`, or `Scene`. Invalid label definitions are grayed out.
Name	character vector that contains the name of the label definition
PixelLabelID	Positive integer that holds the ID for each valid pixel label **Note** This field is valid only for labels of type `PixelLabel`.

GroundTruth — Ground truth of marked labels
groundTruth object

Ground truth of marked labels, specified as a `groundTruth` object. The object holds all the labels marked in the labeling app prior to automation.

Clients of `AutomationAlgorithm` class are required to define the following properties. These properties setup the name, description, and user instructions for your automated algorithm.

Name — Automation algorithm name
character vector

Automation algorithm name, specified as a character vector.

Description — Automation algorithm description
character vector

Algorithm description, specified as a character vector.

UserDirections — Algorithm directions displayed in app
cell array

Algorithm directions displayed in app, specified as a cell array. `UserDirections` are specified as a `cellstr`, with each string representing a separate direction. Use the `checkSetup` method to verify that the directions have been adhered to.

Methods

Clients of an `AutomationAlgorithm` implement these user-defined functions to define execution of the algorithm.

checkLabelDefinition	Validate label definition
checkSetup	Set up validation (optional)
initialize	Initialize state for algorithm execution (optional)
run	Run label automation on every frame in interval
terminate	Terminate automated algorithm (optional)

Clients of an `AutomationAlgorithm` can also implement the user-defined `settingsDialog` function to display algorithm settings, or a constructor with no input arguments.

For more information on creating your own automation algorithm, see:

- Create Automation Algorithm for the **Image Labeler**
- Create Automation Algorithm (Automated Driving System Toolbox) for the **Ground Truth Labeler**

See Also

Apps
Ground Truth Labeler | **Image Labeler**

Functions
groundTruth | groundTruthDataSource | imageDatastore | labelType | objectDetectorTrainingData | vision.labeler.mixin.Temporal

Topics
"Create Automation Algorithm for Image Labeling"
"Automate Ground Truth Labeling of Lane Boundaries" (Automated Driving System Toolbox)

Introduced in R2017a

checkLabelDefinition

Validate label definition

The labeler app calls the `checkLabelDefinition` method for each *ROI Label* and *Scene Label* definition. The method restricts an automation algorithm to use only relevant labels. For example, a label definition of type `Rectangle` must not be used to mark a lane boundary.

Clients of `AutomationAlgorithm` must implement this method.

Syntax

```
isValid = checkLabelDefinition(algObj,labelDef)
```

Description

`isValid = checkLabelDefinition(algObj,labelDef)` returns `true` for valid label definitions and `false` for invalid definitions for the automation algorithm provided by `algObj`. `labelDef` is a struct containing label definitions. Definitions that return `false` are disabled during automation.

Examples

These examples show two ways of defining the `checkLabelDefinition` method for a client of an automation algorithm.

Restrict Automation to Rectangular ROI Labels

This `checkLabelDefinition` method designates `Rectangle` labels as valid, and all other labels as invalid.

```
function checkLabelDefinition(algObj,labelDef)

    if labelDef.Type == labelType.Rectangle
```

```
        isValid = true;
    else
        isValid = false;
    end
end
```

Restrict Automation to Any ROI

This `checkLabelDefinition` method designates ROI labels (`Rectangle` and `Line`) as valid, and all other labels as invalid.

```
function checkLabelDefinition(algObj,labelDef)

    if isROI(labelDef.Type)
        isValid = true;
    else
        isValid = false;
    end
end
```

Input Arguments

algObj — Automation algorithm
vision.labeler.AutomationAlgorithm object

Automation algorithm, specified as a `vision.labeler.AutomationAlgorithm` object.

labelDef — Label definition
struct

Label definition, specified as a struct containing *Type* and *Name* fields.

Field	Description
Type	Enumeration of class `labelType` with possible values of `Rectangle`, `Line`, `PixelLabel`, and `Scene`.
Name	Character vector containing the name of the specified label.

Example: Create a `labelDef` structure for a `Rectangle` label:

```
labelDef(1).Type = labelType.Rectangle;
labelDef(1).Name = 'Car';
```

Output Arguments

isValid — Flag to validate label definition
true | false

Flag to validate label definition, returned as `true` or `false`.

Tips

- To access the selected label definitions (highlighted in yellow on the left panels titled **ROI Label Definition** and **Scene Label Definition** in the labeling app), use the `SelectedLabelDefinitions` property.

See Also

labelType | vision.labeler.AutomationAlgorithm

Introduced in R2017a

checkSetup

Set up validation (optional)

The `checkSetup` method checks the validity of the setup when you click **Run** in the labeling app. If `checkSetup` returns `true`, then the setup is valid and the app proceeds to execute the `initialize`, `run`, and `terminate` methods.

Clients of `AutomationAlgorithm` can optionally implement this method.

Syntax

```
isReady = checkSetup(algObj)
isReady = checkSetup(algObj,labelsToAutomate)
```

Description

`isReady = checkSetup(algObj)` returns `true` if you completed set up correctly and the automation algorithm `algObj` can begin execution. Otherwise, `checkSetup` returns `false`.

`isReady = checkSetup(algObj,labelsToAutomate)` additionally provides a table, `labelsToAutomate`, that contains labels selected for the automation algorithm to use for labeling. This syntax is available only for time-dependent (temporal) automation algorithms (requires Automated Driving System Toolbox). For more information, see "Temporal Automation Algorithms" (Automated Driving System Toolbox).

Examples

Check Setup for ROI Labels

This example shows how to define a `checkSetup` method for a client of a temporal automation algorithm. This method determines that an automation algorithm is ready to run if at least one ROI label exists. Note that this method uses a `labelsToAutomate` argument, which requires Automated Driving System Toolbox.

```
function isReady = checkSetup(algObj,labelsToAutomate)

    notEmpty = ~isempty(labelsToAutomate);

    hasROILabels = any(labelsToAutomate.Type == labelType.Rectangle);

    if notEmpty && hasROILabels
        isReady = true;
    else
        isReady = false;
    end

end
```

Input Arguments

algObj — Automation algorithm
vision.labeler.AutomationAlgorithm object

Automation algorithm, specified as a `vision.labeler.AutomationAlgorithm` object.

labelsToAutomate — Selected labels
table

Selected labels (ROI and Scene) that are marked before executing the algorithm, specified as a `table` with the following variables.

Variable Name	Description
Type	Enumeration of class `labelType` with possible values of `Rectangle`, `Line` and `Scene`.
Name	Character vector containing the name of the specified label.
Time	Scalar `double` specifying the time, in seconds, when the label was marked.

Variable Name	Description	
Position	**Label Type**	**Description**
	Rectangle	Position of bounding box locations, specified as a 1-by-4 vector in the format [*x*,*y*,*w*,*h*].
	Line	Points along a polyline, specified as an *N*-by-2 vector in the format [*x1*,*y1*;*x2*,*y2*; . . . *xN*,*yN*] for *N* points.
	Scene	[]

Example of a `labelsToAutomate` table:

```
    Type            Name           Time          Position
  _____    _____    _____    _____

  Rectangle     'Car'            0.033333      [1x4 double]
  Line          'LaneMarker'     0.066667      [5x2 double]
  Scene         'Sunny'               0.1      [         0]
```

Output Arguments

isReady — Set up validation
`true` | `false`

Set up validation, returned as `true` or `false`.

See Also

`labelType` | `vision.labeler.AutomationAlgorithm`

Introduced in R2017a

initialize

Initialize state for algorithm execution (optional)

The `initialize` method initializes the state of the automation algorithm before the automation algorithm runs.

Clients of `AutomationAlgorithm` can optionally implement this method.

Syntax

```
initialize(algObj,I)
initialize(algObj,I,labelsToAutomate)
```

Description

`initialize(algObj,I)` initializes state of the `algObj` automation algorithm. `I` is a numeric matrix containing the frame that corresponds to the start of the interval.

Clients of `AutomationAlgorithm` must implement this user-defined method.

`initialize(algObj,I,labelsToAutomate)` additionally provides a table, `labelsToAutomate`, that contains labels selected for the automation algorithm to use for labeling. This syntax is available only for time-dependent (temporal) automation algorithms (requires Automated Driving System Toolbox). For more information, see "Temporal Automation Algorithms" (Automated Driving System Toolbox).

Input Arguments

algObj — Automation algorithm
vision.labeler.AutomationAlgorithm object

Automation algorithm, specified as a `vision.labeler.AutomationAlgorithm` object.

I — Image frame corresponding to start of time interval
numeric matrix

Image frame corresponding to start of time interval, specified as a numeric matrix.

`labelsToAutomate` — Selected labels
table

Selected labels (ROI and Scene) that are marked before executing the algorithm, specified as a `table` with the following variables.

Variable Name	Description		
Type	Enumeration of class `labelType` with possible values of `Rectangle`, `Line` and `Scene`.		
Name	Character vector containing the name of the specified label.		
Time	Scalar `double` specifying the time, in seconds, when the label was marked.		
Position	**Label Type**	**Description**	
	`Rectangle`	Position of bounding box locations, specified as a 1-by-4 vector in the format [*x*,*y*,*w*,*h*].	
	`Line`	Points along a polyline, specified as an *N*-by-2 vector in the format [*x1*,*y1*;*x2*,*y2*; . . . *xN*,*yN*] for *N* points.	
	`Scene`	[]	

Example of a `labelsToAutomate` table:

```
    Type            Name            Time          Position
  _____      _____      _____      _____

  Rectangle      'Car'             0.033333      [1x4 double]
  Line           'LaneMarker'      0.066667      [5x2 double]
  Scene          'Sunny'                0.1      [         0]
```

See Also

checkSetup | labelType | run | terminate |
vision.labeler.AutomationAlgorithm

Introduced in R2017a

run

Run label automation on every frame in interval

run computes the labels for a single image frame by executing the automation algorithm.

Clients of `AutomationAlgorithm` must implement this method.

Syntax

autoLabels = run(algObj,I)

Description

autoLabels = run(algObj,I) processes a single image, I, using the algObj automation algorithm, and returns the automated labels in autoLabels.

Input Arguments

algObj — Automation algorithm
vision.labeler.AutomationAlgorithm object

Automation algorithm, specified as a `vision.labeler.AutomationAlgorithm` object.

I — Image frame
numeric matrix

Image frame, specified as a numeric matrix.

Output Arguments

autoLabels — Labels from automation
table | struct array | categorical matrix

Labels from automation, returned as one of the following.

- For algorithms without pixel labels, `autoLabels` is returned as a table (or struct array) containing these variable (or field) names.

Variable Name	Description
Type	Enumeration of class `labelType` with possible values of `Rectangle`, `Line` and `Scene`.
Name	Character vector containing the name of the specified label.
Position	1-by-4 vector in the format [*x,y,w,h*] that specifies the position of bounding box locations for the `Rectangle labelType`. *N*-by-2 vector in the format [*x1,y1;x2,y2; . . . xN,yN*] that specifies N points along a polyline for the `Line labelType`. [] for `Scene labelType`.

Example of an `autoLabels` table:

```
      Name              Type            Position
  _____       _____       _____

  'Car'              Rectangle       [1×4 double]
  'LaneMarker'       Line            [3×2 double]
  'Sunny'            Scene           [          1]
```

For information on defining a table, see "Create autoLabels Table or Structure" on page 2-750.

- For algorithms with pixel labels, `autoLabels` is returned as a `categorical` label matrix, where each category represents a pixel label.

Extended Information

Create `autoLabels` Table or Structure

When you implement the `run` method for an automation algorithm without pixel labels, you must populate a table or structure with the labels from automation, according to `autoLabels`. This code demonstrates how to populate a structure array with three elements.

```
% Rectangle labeled 'Car' positioned with top-left at (20,20)
% with width and height equal to 50.
```

```matlab
autoLabels(1).Name = 'Car';
autoLabels(1).Type = labelType('Rectangle');
autoLabels(1).Position = [20 20 50 50];

% Line labeled 'LaneMarker' with 3 points.
autoLabels(2).Name = 'LaneMarker';
autoLabels(2).Type = labelType('Line');
autoLabels(2).Position = [100 100; 100 110; 110 120];

% Scene labeled 'Sunny'
autoLabels(3).Name = 'Sunny';
autoLabels(3).Type = labelType('Scene');
autoLabels(3).Position = true;
```

See Also

checkSetup | initialize | labelType | terminate |
vision.labeler.AutomationAlgorithm

Introduced in R2017a

settingsDialog

Display algorithm settings (optional)

The `settingsDialog` method runs when the user clicks Settings in the labeling app. Use this method to provide a dialog figure with controls for user settings required for the algorithm. Use a modal dialog, created using functions like `dialog`, `inputdlg` or `listdlg`.

Clients of `AutomationAlgorithm` can optionally implement this method.

Syntax

settingsDialog(algObj)

Description

`settingsDialog(algObj)` displays automated algorithm settings in a dialog.

Input Arguments

algObj — Automation algorithm
vision.labeler.AutomationAlgorithm object

Automation algorithm, specified as a `vision.labeler.AutomationAlgorithm` object.

Introduced in R2017a

terminate

Terminate automated algorithm (optional)

The `terminate` method cleans up the state of the automation algorithm after `run` processes the last frame in the specified interval or when the user stops the automation algorithm.

Clients of `AutomationAlgorithm` can optionally implement this method.

Syntax

`terminate(algObj)`

Description

`terminate(algObj)` cleans up the state of the automation algorithm.

Input Arguments

algObj — Automation algorithm
vision.labeler.AutomationAlgorithm object

Automation algorithm, specified as a `vision.labeler.AutomationAlgorithm` object.

See Also
checkSetup | initialize | run | vision.labeler.AutomationAlgorithm

Introduced in R2017a

labelType

Enumeration of supported label types

Description

`labelType` creates an enumeration to specify the type of label to view in the **Image Labeler** and **Ground Truth Labeler** apps.

Creation

Syntax

`labelType`

Description

`labelType` creates an enumeration to specify a type of label.

Enumerations

These properties represent enumerations.

`Rectangle` — Rectangular region of interest
enumeration

Rectangular region of interest (ROI) label, specified as a label enumeration.

`Line` — Polyline region of interest label
enumeration

Polyline region of interest label, specified as a label enumeration.

Scene — Scene label
enumeration

Scene label, specified as a label enumeration. Scene labels can be marked on a frame or on an interval of frames.

`Custom` — Custom label type
enumeration

Custom label type, specified as a label enumeration. Labeler apps do not display labels with type `Custom`.

`PixelLabel` — Label marked as pixel labeled region
enumeration

Label marked as pixel labeled region of interest, specified as a label enumeration. The pixel labeled ROI provides labels for every pixel within the ROI and can be used to label a group of neighboring pixels that share the same label category.

Object Functions

isCustom   Determine if label types are Custom labels
isROI   Determine if label types are ROI labels
isScene   Determine if label types are Scene labels

Examples

Define Label Types and Create Label Definitions Table

Create a label definitions table to use for a ground truth data object.

Define label names.

```
Name = {'Car';'LeftLaneMarker';'RightLaneMarker';'Sunny'};
```

Define label types.

```
Type = labelType({'Rectangle';'Line';'Line';'Scene'});
```

Create label definitions.

```
labelDefs = table(Name,Type)

labelDefs=4×2 table
         Name             Type

    _____    _____

    'Car'               Rectangle
    'LeftLaneMarker'    Line
    'RightLaneMarker'   Line
    'Sunny'             Scene
```

List the ROI label names.

```
roiLabelIndices = isROI(labelDefs.Type);
roiLabelNames = labelDefs.Name(roiLabelIndices)

roiLabelNames = 3x1 cell array
    {'Car'             }
    {'LeftLaneMarker' }
    {'RightLaneMarker'}
```

List the Scene label names.

```
sceneLabelIndices = isScene(labelDefs.Type);
sceneLabelNames = labelDefs.Name(sceneLabelIndices)

sceneLabelNames = 1x1 cell array
    {'Sunny'}
```

See Also

Apps
Ground Truth Labeler | Image Labeler

Functions
`groundTruth | groundTruthDataSource`

Topics
"Define Ground Truth for Image Collections"

"Train an Object Detector from Ground Truth Data"
"Create Automation Algorithm for Image Labeling"
"Define Ground Truth Data for Video or Image Sequences" (Automated Driving System Toolbox)

Introduced in R2017a

isCustom

Determine if label types are `Custom` labels

Syntax

```
tf = isCustom(labelTypes)
```

Description

`tf = isCustom(labelTypes)` returns a logical array that indicates which elements in `labelTypes` are `Custom` label types. `isCustom` returns logical `1` (true) for `Custom` labels and otherwise returns logical `0` (false).

Input Arguments

`labelTypes` — Type of labels
enumeration

Types of labels, specified a `labelType` enumeration. `labelType` can contain `Rectangle`, `Line`, `Scene`, `PixelLabel`, or `Custom` labels.

Introduced in R2017a

isROI

Determine if label types are ROI labels

Syntax

```
tf = isROI(labelTypes)
```

Description

`tf = isROI(labelTypes)` returns a logical array that indicates which elements in `labelTypes` are ROI label types. `isROI` returns logical `1` (true) for `ROI` labels and otherwise returns logical `0` (false). Valid `ROI` label types are `Rectangle` and `Line`.

Input Arguments

`labelTypes` — Type of labels
enumeration

Types of labels, specified a `labelType` enumeration. `labelType` can contain `Rectangle`, `Line`, `Scene`, `PixelLabel`, or `Custom` labels.

Introduced in R2017a

isScene

Determine if label types are `Scene` labels

Syntax

```
tf = isScene(labelTypes)
```

Description

`tf = isScene(labelTypes)` returns a logical array that indicates which elements in `labelTypes` are `Scene` label types. `isScene` returns logical `1` (true) for `Scene` labels and otherwise returns logical `0` (false).

Input Arguments

`labelTypes` — Type of labels
enumeration

Types of labels, specified a `labelType` enumeration. `labelType` can contain `Rectangle`, `Line`, `Scene`, `PixelLabel`, or `Custom` labels.

Introduced in R2017a

cameraParameters

Object for storing camera parameters

Description

The `cameraParameters` object stores the intrinsic, extrinsic, and lens distortion parameters of a camera.

Creation

You can create a `cameraParameters` object using the `cameraParameters` function described here. You can also create a `cameraParameters` object by using the `estimateCameraParameters` with an *M*-by-2-by-*numImages* array of input image points, where *M* is the number of keypoint coordinates in each pattern.

Syntax

```
cameraParams = cameraParameters
cameraParams = cameraParameters(Name,Value)
cameraParams = cameraParameters(paramStruct)
```

Description

`cameraParams = cameraParameters` creates a `cameraParameters` object that contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

`cameraParams = cameraParameters(Name,Value)` sets properties on page 2-762 of the `cameraParameters` object by using one or more `Name,Value` pair arguments. Unspecified properties use default values.

`cameraParams = cameraParameters(paramStruct)` creates an identical `cameraParameters` object from an existing `cameraParameters` object with parameters stored in `paramStruct`.

Input Arguments

paramStruct — Camera parameters
struct

Stereo parameters, specified as a stereo parameters struct. To get a `paramStruct` from an existing `cameraParameters` object, use the `toStruct` function.

Properties

Intrinsic camera parameters:

IntrinsicMatrix — Projection matrix
3-by-3 identity matrix

Projection matrix, specified as a 3-by-3 identity matrix. The object uses the following format for the matrix format:

$$\begin{bmatrix} f_x & 0 & 0 \\ s & f_y & 0 \\ c_x & c_y & 1 \end{bmatrix}$$

The coordinates $[c_x \ c_y]$ represent the optical center (the principal point), in pixels. When the x and y axis are exactly perpendicular, the skew parameter, s, equals 0.
$f_x = F*s_x$
$f_y = F*s_y$
F, is the focal length in world units, typically expressed in millimeters.
$[s_x, s_y]$ are the number of pixels per world unit in the x and y direction respectively.
fx and fy are expressed in pixels.

PrincipalPoint — Optical center
2-element vector

Optical center, specified as a 2-element vector $[cx, cy]$ in pixels. The vector contains the coordinates of the optical center of the camera.

FocalLength — Focal length
2-element vector

Focal length in *x* and *y*, specified as a 2-element vector [*fx*, *fy*].

fx = F * *sx*

fy = F * *sy*

where, F is the focal length in world units, typically in millimeters, and [*sx*, *sy*] are the number of pixels per world unit in the *x* and *y* direction respectively. Thus, *fx* and *fy* are in pixels.

Skew — Camera axes skew
0 (default) | scalar

Camera axes skew, specified as a scalar. If the *x* and the *y* axes are exactly perpendicular, then set the skew to 0.

Camera lens distortion:

RadialDistortion — Radial distortion coefficients
[0 0 0] (default) | 2-element vector | 3-element vector

Radial distortion coefficients, specified as either a 2- or 3-element vector. When you specify a 2-element vector, the object sets the third element to 0. Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion. The camera parameters object calculates the radial distorted location of a point. You can denote the distorted points as ($x_{\text{distorted}}$, $y_{\text{distorted}}$), as follows:

$$x_{\text{distorted}} = x(1 + k_1*r^2 + k_2*r^4 + k_3*r^6)$$

$$y_{\text{distorted}} = y(1 + k_1*r^2 + k_2*r^4 + k_3*r^6)$$

x, y = undistorted pixel locations

k_1, k_2, and k_3 = radial distortion coefficients of the lens

$r^2 = x^2 + y^2$

Typically, two coefficients are sufficient. For severe distortion, you can include k_3. The undistorted pixel locations appear in normalized image coordinates, with the origin at the optical center. The coordinates are expressed in world units.

TangentialDistortion — Tangential distortion coefficients
[0 0]' (default) | 2-element vector

Tangential distortion coefficients, specified as a 2-element vector. Tangential distortion occurs when the lens and the image plane are not parallel. The camera parameters object

calculates the tangential distorted location of a point. You can denote the distorted points as ($x_{\text{distorted}}$, $y_{\text{distorted}}$), as follows:

$x_{\text{distorted}} = x + [2 * p_1 * y + p_2 * (r^2 + 2 * x^2)]$

$y_{\text{distorted}} = y + [p_1 * (r^2 + 2*y^2) + 2 * p_2 * x]$

x, y = undistorted pixel locations
p_1 and p_2 = tangential distortion coefficients of the lens
$r^2 = x^2 + y^2$
The undistorted pixel locations appear in normalized image coordinates, with the origin at the optical center. The coordinates are expressed in world units.

Extrinsic camera parameters:

`RotationMatrices` — 3-D rotation matrix
3-by-3-by-*P* matrix (read-only)

3-D rotation matrix, specified as a 3-by-3-by-*P*, with *P* number of pattern images. Each 3-by-3 matrix represents the same 3-D rotation as the corresponding vector.

The following equation provides the transformation that relates a world coordinate in the checkerboard's frame [*X Y Z*] and the corresponding image point [*x y*]:

$$s\begin{bmatrix} x & y & 1 \end{bmatrix} = \begin{bmatrix} X & Y & Z & 1 \end{bmatrix} \begin{bmatrix} R \\ t \end{bmatrix} K$$

R is the 3-D rotation matrix.
t is the translation vector.
K is the `IntrinsicMatrix`.
s is a scalar.
This equation does not take distortion into consideration. Distortion is removed by the `undistortImage` function.

`RotationVectors` — 3-D rotation vectors
[ ] (default) | *M*-by-3 matrix (read-only)

3-D rotation vectors , specified as a *M*-by-3 matrix containing *M* rotation vectors. Each vector describes the 3-D rotation of the camera's image plane relative to the corresponding calibration pattern. The vector specifies the 3-D axis about which the camera is rotated, where the magnitude is the rotation angle in radians. The corresponding 3-D rotation matrices are given by the `RotationMatrices` property

TranslationVectors — Camera translations
M-by-3 matrix | [ ]

Camera translations, specified as an *M*-by-3 matrix. This matrix contains translation vectors for *M* images. The vectors contain the calibration pattern that estimates the calibration parameters. Each row of the matrix contains a vector that describes the translation of the camera relative to the corresponding pattern, expressed in world units.

The following equation provides the transformation that relates a world coordinate in the checkerboard's frame [*X Y Z*] and the corresponding image point [*x y*]:

$$s\begin{bmatrix} x & y & 1 \end{bmatrix} = \begin{bmatrix} X & Y & Z & 1 \end{bmatrix}\begin{bmatrix} R \\ t \end{bmatrix}K$$

R is the 3-D rotation matrix.
t is the translation vector.
K is the `IntrinsicMatrix`.
s is a scalar.
This equation does not take distortion into consideration. Distortion is removed by the `undistortImage` function.

You must set the `RotationVectors` and `TranslationVectors` properties in the constructor to ensure that the number of rotation vectors equals the number of translation vectors. Setting only one property but not the other results in an error.

Estimated camera parameter accuracy:

MeanReprojectionError — Average Euclidean distance
numeric value (read-only)

Average Euclidean distance between reprojected and detected points, specified as a numeric value in pixels.

ReprojectionErrors — Estimated camera parameters accuracy
M-by-2-by-*P* array

Estimated camera parameters accuracy, specified as an *M*-by-2-by-*P* array of [*x y*] coordinates. The [*x y*] coordinates represent the translation in *x* and *y* between the reprojected pattern key points and the detected pattern key points. The values of this property represent the accuracy of the estimated camera parameters. *P* is the number of pattern images that estimates camera parameters. *M* is the number of keypoints in each image.

ReprojectedPoints — World points reprojected onto calibration images
M-by-2-by-*P* array

World points reprojected onto calibration images, specified as an *M*-by-2-by-*P* array of [*x y*] coordinates. *P* is the number of pattern images and *M* is the number of keypoints in each image.

Settings for camera parameter estimation:

NumPatterns — Number of calibrated patterns
integer

Number of calibration patterns that estimates camera extrinsics, specified as an integer. The number of calibration patterns equals the number of translation and rotation vectors.

WorldPoints — World coordinates
M-by-2 array | [ ]

World coordinates of key points on calibration pattern, specified as an *M*-by-2 array. *M* represents the number of key points in the pattern.

WorldUnits — World points units
'mm' (default) | character vector

World points units, specified as a character vector. The character vector describes the units of measure.

EstimateSkew — Estimate skew flag
false (default) | logical scalar

Estimate skew flag, specified as a logical scalar. When you set the logical to true, the object estimates the image axes skew. When you set the logical to false, the image axes are exactly perpendicular.

NumRadialDistortionCoefficients — Number of radial distortion coefficients
2 (default) | 3

Number of radial distortion coefficients, specified as the number '2' or '3'.

EstimateTangentialDistortion — Estimate tangential distortion flag
false (default) | logical scalar

Estimate tangential distortion flag, specified as the logical scalar `true` or `false`. When you set the logical to `true`, the object estimates the tangential distortion. When you set the logical to `false`, the tangential distortion is negligible.

Object Functions

pointsToWorld	Determine world coordinates of image points
toStruct	Convert a camera parameters object into a struct
worldToImage	Project world points into image

Examples

Remove Distortion from an Image Using the Camera Parameters Object

Use the camera calibration functions to remove distortion from an image. This example creates a vision.CameraParameters object manually, but in practice, you would use the estimateCameraParameters or the cameraCalibrator app to derive the object.

Create a vision.CameraParameters object manually.

```
IntrinsicMatrix = [715.2699 0 0; 0 711.5281 0; 565.6995 355.3466 1];
radialDistortion = [-0.3361 0.0921];
cameraParams = cameraParameters('IntrinsicMatrix',IntrinsicMatrix,'RadialDistortion',ra
```

Remove distortion from the images.

```
I = imread(fullfile(matlabroot,'toolbox','vision','visiondata','calibration','mono','in
J = undistortImage(I,cameraParams);
```

Display the original and the undistorted images.

```
figure; imshowpair(imresize(I, 0.5),imresize(J, 0.5),'montage');
title('Original Image (left) vs. Corrected Image (right)');
```
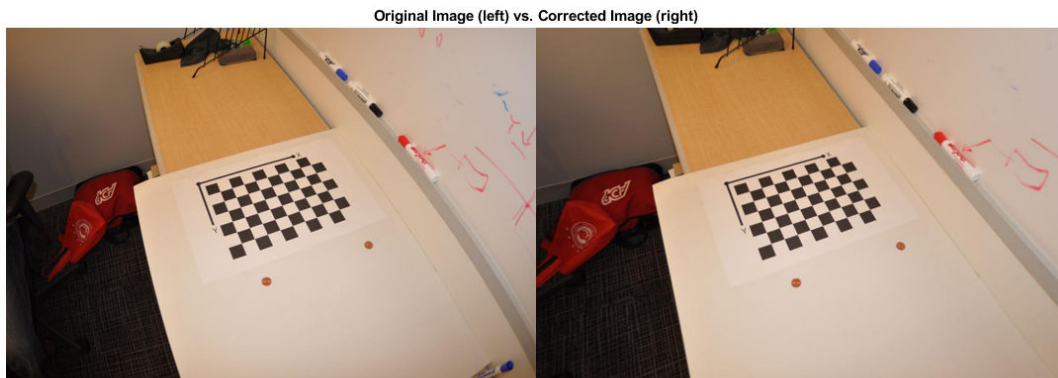
Original Image (left) vs. Corrected Image (right)

- "Measuring Planar Objects with a Calibrated Camera"
- "Code Generation for Depth Estimation From Stereo Video"

References

[1] Zhang, Z. "A flexible new technique for camera calibration". *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 22, No. 11, pp. 1330–1334, 2000.

[2] Heikkila, J, and O. Silven. "A Four-step Camera Calibration Procedure with Implicit Image Correction", *IEEE International Conference on Computer Vision and Pattern Recognition*, 1997.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.
- Use the `toStruct` method to pass a `cameraParameters` object into generated code. See the "Code Generation for Depth Estimation From Stereo Video" example.

See Also

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Classes
cameraCalibrationErrors | extrinsicsEstimationErrors |
intrinsicsEstimationErrors | stereoParameters

Functions
detectCheckerboardPoints | estimateCameraParameters |
generateCheckerboardPoints | showExtrinsics | showReprojectionErrors |
undistortImage

Topics
"Measuring Planar Objects with a Calibrated Camera"
"Code Generation for Depth Estimation From Stereo Video"
"Single Camera Calibrator App"

Introduced in R2014a

fisheyeCalibrationErrors

Object for storing standard errors of estimated fisheye camera parameters

Description

`fisheyeCalibrationErrors` contains the standard errors of estimated camera parameters. You can access the standard errors of the intrinsics and extrinsics by using the object properties. To display the standard errors, use the `displayErrors` function.

Creation

The `estimateFisheyeParameters` function returns the `fisheyeCalibrationErrors` object.

Properties

IntrinsicsErrors — Standard errors of estimated intrinsics
`fisheyeIntrinsicsEstimationErrors` object

Standard errors of the estimated intrinsics for a fisheye camera, specified as a `fisheyeIntrinsicsEstimationErrors` object.

ExtrinsicsErrors — Standard errors of estimated rotations and translations
`extrinsicsEstimationErrors` object

Standard errors of the estimated rotations and translations for a fisheye camera relative to the calibration pattern, specified as a `extrinsicsEstimationErrors` object.

Object Functions

displayErrors   Display standard errors of camera parameter estimates

Examples

Display Fisheye Camera Calibration Errors

Gather a set of checkerboard calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata',...
 'calibration','gopro'));
```

Detect the calibration pattern from the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate world coordinates for the corners of the checkerboard squares.

```
squareSize = 29; % millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the fisheye parameters using image and world points. Use the first image to get the image size. Also, store the errors from the calibration.

```
I = readimage(images,1);
imageSize = [size(I,1) size(I,2)];
[params,~,errors] = estimateFisheyeParameters(imagePoints, ...
                                worldPoints,imageSize);
```

Display the standard errors of the estimated camera parameters.

```
displayErrors(errors,params);

          Standard Errors of Estimated Camera Parameters
          -----------------------------------------------

Intrinsics
----------
Mapping coefficients:    [  875.0782 +/- 0.9451       -0.0003 +/- -0.0000      -0.0000
Distortion center (pixels):[ 1005.8165 +/- 0.6871      743.0346 +/- 0.5578   ]
Stretch matrix parameters:[    1.0000 +/- 0.0000        0.0000 +/- 0.0000        0.0000

Extrinsics
----------
Rotation vectors:
                          [    -0.0699 +/- 0.0010       -0.0267 +/- 0.0009       0.0258
```

```
                              [    0.3628 +/- 0.0010      0.2950 +/- 0.0009      -0.1967
                              [   -0.2159 +/- 0.0009      0.3442 +/- 0.0009      -0.1941
                              [    0.0282 +/- 0.0009     -0.3784 +/- 0.0009       0.0829
                              [    0.0146 +/- 0.0008      0.4575 +/- 0.0009      -0.1215
                              [    0.6775 +/- 0.0008      0.1089 +/- 0.0008      -0.0386
                              [   -0.4936 +/- 0.0008      0.0063 +/- 0.0008       0.0486
                              [    0.3823 +/- 0.0008      0.2797 +/- 0.0008       0.1509
                              [    0.5171 +/- 0.0008     -0.3295 +/- 0.0008       0.0541
                              [   -0.1896 +/- 0.0008     -0.3543 +/- 0.0009       0.2637
                              [   -0.2911 +/- 0.0008      0.3680 +/- 0.0008      -0.1329

Translation vectors (mm):
                              [ -132.9182 +/- 0.1609    -82.6066 +/- 0.1356     195.1106
                              [ -178.9931 +/- 0.1905    -15.7750 +/- 0.1712     241.7126
                              [ -183.7957 +/- 0.2168    -56.7378 +/- 0.1884     269.9739
                              [  -17.6295 +/- 0.1315    -70.2875 +/- 0.1041     157.0826
                              [ -161.9824 +/- 0.1808    -46.9681 +/- 0.1569     228.4060
                              [ -122.4240 +/- 0.1309    -16.0260 +/- 0.1153     162.6247
                              [ -112.4268 +/- 0.1745   -125.5877 +/- 0.1428     212.8055
                              [ -148.7137 +/- 0.1387    -72.5409 +/- 0.1260     173.7615
                              [  -49.5392 +/- 0.0919    -24.8329 +/- 0.0745     104.3541
                              [   -3.4045 +/- 0.1274    -93.4074 +/- 0.1010     155.8247
                              [ -160.7344 +/- 0.1855    -51.9152 +/- 0.1600     234.4075
```

See Also

estimateFisheyeParameters | extrinsicsEstimationErrors |
fisheyeIntrinsicsEstimationErrors | fisheyeParameters

Introduced in R2017b

fisheyeIntrinsics

Object for storing intrinsic fisheye camera parameters

Description

The `fisheyeIntrinsics` object stores the camera intrinsics for a fisheye camera. See `fisheyeParameters` for details on other fisheye parameters.

Creation

Syntax

```
intrinsics = fisheyeIntrinsics(mappingCoeffs,imageSize,
distortionCenter)
intrinsics = fisheyeIntrinsics( ___ ,stretchMatrix)
```

Description

`intrinsics = fisheyeIntrinsics(mappingCoeffs,imageSize, distortionCenter)` returns a `fisheyeIntrinsics` object with the specified `[a0 a2 a3 a4]` polynomial coefficients, image size, and center of distortion. These input arguments are assigned directly to the corresponding properties of the object. See `fisheyeParameters` for more details.

`intrinsics = fisheyeIntrinsics( ___ ,stretchMatrix)` additionally specifies a 2-by-2 transformation matrix that describes the alignment between the sensor plane and the image plane. The default value is an identity matrix.

Properties

MappingCoeffecients — Polynomial coefficients for projection function
`[a0 a2 a3 a4]` vector

Polynomial coefficients for the projection function described by Scaramuzza's Taylor model, specified as an `[a0 a2 a3 a4]` vector.

`DistortionCenter` — Center of distortion in pixels
`[cx cy]` vector

Center of distortion in pixels, specified as a `[cx cy]` vector.

`Stretchmatrix` — Transformation from sensor plane to pixel in camera image plane
2-by-2 transformation matrix

Transformation from the sensor plane to a pixel in the camera image plane, specified as a 2-by-2 transformation matrix. This misalignment is caused by the lens not being parallel to the sensor and by the digitization process.

`ImageSize` — Image size
`[mrows ncols]` vector

Image size, specified as an `[mrows ncols]` vector.

Object Functions

pointsToWorld   Determine world coordinates of image points
worldToImage   Project world points into image

Examples

Create Fisheye Intrinsics

Specify the mapping coefficients, image size, and distortion center parameters of a `fisheyeIntrinsics` object. Ignore optical axis misalignment.

```
mappingCoeffs = [880 -3e-4 0 0];      % mapping polynomial coefficients
imageSize = [1500 2000];              % in [mrows ncols]
distortionCenter = [1000 750];        % in pixels

intrinsics = fisheyeIntrinsics(mappingCoeffs,imageSize,distortionCenter);
```

References

[1] Scaramuzza, D., A. Martinelli, and R. Siegwart. "A Toolbox for Easy Calibrating Omindirectional Cameras." *Proceedings to IEEE International Conference on Intelligent Robots and Systems (IROS 2006)*. Beijing, China, October 7–15, 2006.

[2] Urban, S., J. Leitloff, and S. Hinz. "Improved Wide-Angle, Fisheye and Omnidirecitonal Camera Calibration." *ISPRS Journal of Photogrammetry and Remove Sensing*. Vol. 108, 2015, pp.72–79.

See Also

estimateFisheyeParameters | fisheyeParameters

Introduced in R2017b

fisheyeIntrinsicsEstimationErrors

Object for storing standard errors of estimated fisheye camera intrinsics

Description

`fisheyeIntrinsicsEstimationErrors` contains the standard errors of estimated fisheye camera intrinsics.

Creation

The `estimateFisheyeParameters` function returns the `fisheyeCalibrationErrors` object, which contains `fisheyeIntrinsicsEstimationErrors` and `extrinsicsEstimationErrors` as properties.

Properties

`MappingCoefficentsError` — Standard error of mapping coefficient estimates
4-element vector

Standard error of mapping coefficient estimates, specified as a 4-element vector.

`DistortionCenterError` — Standard error of distortion center estimates
2-element vector

Standard error of distortion center estimates, specified as a two-element vector.

`StretchMatrixError` — Standard error of stretch matrix estimate
3-element vector

Standard error of stretch matrix estimate, specified as a 3-element vector.

See Also
`cameraCalibrationErrors` | `stereoCalibrationErrors`

Introduced in R2017b

fisheyeParameters

Object for storing fisheye camera parameters

Description

The `fisheyeParameters` object is used to store fisheye camera parameters. Use `estimateFisheyeParameters` to estimate parameters using calibration images.

Creation

Syntax

```
fisheyeParams = fisheyeParameters(intrinsics)
fisheyeParams = fisheyeParameters(intrinsics,Name,Value)
```

Description

`fisheyeParams = fisheyeParameters(intrinsics)` returns an object that contains intrinsic and extrinsic parameters of a fisheye camera. `intrinsics` must be a `fisheyeIntrinsics` object. This syntax sets the `Intrinsics` property of the object.

`fisheyeParams = fisheyeParameters(intrinsics,Name,Value)` configures the `fisheyeParams` object properties using one or more `Name,Value` pair arguments. Enclose the property name in single quotes. Unspecified properties have their default values. For example, `'WorldUnits','m'` sets the world units to `'m'`.

Properties

Intrinsic Camera Parameters

Intrinsics — Fisheye intrinsic camera parameters
fisheyeIntrinsics object

Fisheye intrinsic camera parameters, specified as a `fisheyeIntrinsics` object.

Extrinsic Camera Parameters

`RotationVectors` — Camera rotations

[ ] (default) | *M*-by-3 matrix

Camera rotations, specified as an *M*-by-3 matrix. The matrix contains rotation vectors for *M* images, where each image contains the calibration pattern that estimates the calibration parameters. Each row of the matrix contains a vector that describes the 3-D rotation of the camera relative to the corresponding pattern.

Each vector specifies the 3-D axis about which the camera is rotated. The magnitude of the vector represents the angle of rotation in radians. You can convert any rotation vector to a 3-by-3 rotation matrix using the Rodrigues formula.

To ensure that the number of rotation vectors equals the number of translation vectors, you must set the `RotationVectors` and `TranslationVectors` properties together when creating the object. Setting only one property results in an error.

`TranslationVectors` — Camera translations

[ ] (default) | *M*-by-3 matrix

Camera translations, specified as an *M*-by-3 matrix. This matrix contains translation vectors for *M* images. The vectors contain the calibration pattern that estimates the calibration parameters. Each row of the matrix contains a vector that describes the translation of the camera relative to the corresponding pattern, expressed in world units.

To ensure that the number of rotation vectors equals the number of translation vectors, you must set the `RotationVectors` and `TranslationVectors` properties together when creating the object. Setting only one property results in an error.

Accuracy of Estimated Camera Parameters

`ReprojectionErrors` — Reprojection errors

[ ] (default) | *M*-by-2-by-*P* array

Reprojection errors, specified as an *M*-by-2-by-*P* array of [*x*,*y*] pairs. The [*x*,*y*] pairs represent the translation in *x* and *y* between the reprojected pattern keypoints and the detected pattern keypoints.

Settings Used to Estimate Camera Parameters

NumPatterns — Number of calibrated patterns
integer

Number of calibration patterns used to estimate camera extrinsics, specified as an integer. The number of calibration patterns must equal the number of translation and rotation vectors.

WorldPoints — World coordinates
[] (default) | *M*-by-2 matrix

World coordinates of key points on the calibration pattern, specified as an *M*-by-2 matrix. *M* represents the number of key points in the pattern.

WorldUnits — World point units
'mm' (default) | character vector

World point units, specified as the comma-separated pair consisting of `'WorldUnits'` and a character vector representing units. This argument is used simply to store the unit type and does not affect any calculations. Any character vector is valid.

EstimateAlignment — Estimate axes alignment
false (default) | true

Estimate axes alignment, specified as `false` or `true`. Set to `true` if the optical axis of the fisheye lens is not perpendicular to the image plane.

Examples

Create Fisheye Parameters Object Manually

Create a fisheye parameters object by specifying the properties manually. Alternatively, you can create this object using the `estimateFisheyeParameters` function.

Specify fisheye intrinsics.

```
mappingCoefficients = rand(1,4);
distortionCenter = [320 240];
imageSize = [480 640];
intrinsics = fisheyeIntrinsics(mappingCoefficients,imageSize,distortionCenter);
```

Create a `fisheyeParameters` object using the specified intrinsics.

```
params = fisheyeParameters(intrinsics);
```

References

[1] Scaramuzza, D., A. Martinelli, and R. Siegwart. "A Toolbox for Easy Calibrating Omindirectional Cameras." *Proceedings to IEEE International Conference on Intelligent Robots and Systems (IROS 2006)*. Beijing, China, October 7–15, 2006.

[2] Urban, S., J. Leitloff, and S. Hinz. "Improved Wide-Angle, Fisheye and Omnidirecitonal Camera Calibration." *ISPRS Journal of Photogrammetry and Remove Sensing*. Vol. 108, 2015, pp.72–79.

See Also

estimateFisheyeParameters | fisheyeIntrinsics | showExtrinsics | showReprojectionErrors | undistortFisheyeImage

Topics

"Fisheye Calibration Basics"

Introduced in R2017b

Functions Alphabetical

initializeObject

System object: vision.HistogramBasedTracker
Package: vision

Set object to track

Syntax

```
initializeObject(H,I,R)
```

Description

Use the `initializeObject` method to set the object to track, and to set the initial search window. Use this method before calling the `step` method.

`initializeObject(H,I,R)` sets the object to track by extracting it from the [x y width height] region R located in the 2-D input image, `I`. The input image, `I`, can be any 2-D feature map that distinguishes the object from the background. For example, the image can be a hue channel of the HSV color space. Typically, `I` will be the first frame in which the object appears. The region, R, is also used for the initial search window, in the next call to the `step` method. For best results, the object must occupy the majority of the region, R.

`initializeObject(H,I,R,N)` additionally, lets you specify N, the number of histogram bins. By default, N is set to 16. Increasing N enhances the ability of the tracker to discriminate the object. However, this approach also narrows the range of changes to the object's visual characteristics that the tracker can accommodate. Consequently, this narrow range increases the likelihood of losing track.

initializeObject

Set object to track

Syntax

```
initializeObject(hbtracker,I,R)
initializeObject(hbtracker,I,R,N)
```

Description

`initializeObject(hbtracker,I,R)` sets the object to track by extracting it from the [x y width height] region R located in the 2-D input image, `I`. The input image, `I`, can be any 2-D feature map that distinguishes the object from the background. For example, the image can be a hue channel of the HSV color space. Typically, `I` will be the first frame in which the object appears. The region, `R`, is also used for the initial search window, in the next call to the `step` method. For best results, the object must occupy the majority of the region, `R`.

`initializeObject(hbtracker,I,R,N)` additionally, lets you specify `N`, the number of histogram bins.

Examples

Track a Face

Track and display a face in each frame of an input video.

Create System objects for reading and displaying video and for drawing a bounding box of the object.

```
videoFileReader = vision.VideoFileReader('vipcolorsegmentation.avi');
videoPlayer = vision.VideoPlayer();
shapeInserter = vision.ShapeInserter('BorderColor','Custom', ...
    'CustomBorderColor',[1 0 0]);
```

Read the first video frame, which contains the object. Convert the image to HSV color space. Then define and display the object region.

```
objectFrame = videoFileReader();
objectHSV = rgb2hsv(objectFrame);
objectRegion = [40, 45, 25, 25];
objectImage = shapeInserter(objectFrame, objectRegion);

figure
imshow(objectImage)
title('Red box shows object region')
```


Red box shows object region

(Optionally, you can select the object region using your mouse. The object must occupy the majority of the region. Use the following command.)

```
% figure;
% imshow(objectFrame);
% objectRegion=round(getPosition(imrect))
```

Set the object, based on the hue channel of the first video frame.

```
tracker = vision.HistogramBasedTracker;
initializeObject(tracker, objectHSV(:,:,1) , objectRegion);
```

Track and display the object in each video frame. The while loop reads each image frame, converts the image to HSV color space, then tracks the object in the hue channel where it is distinct from the background. Finally, the example draws a box around the object and displays the results.
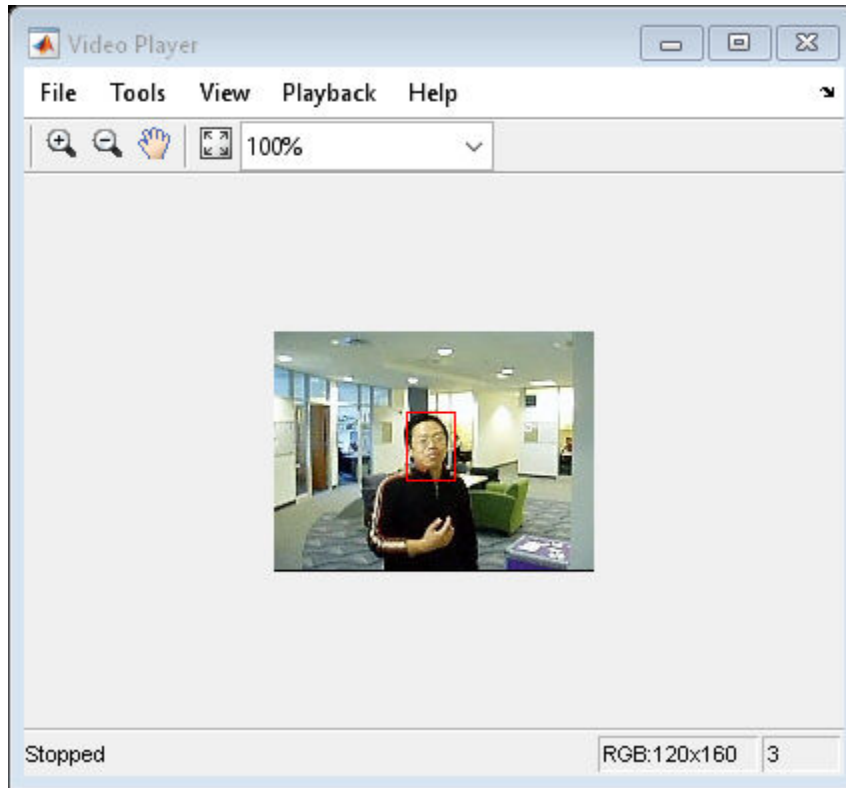
```
while ~isDone(videoFileReader)
  frame = videoFileReader();
  hsv = rgb2hsv(frame);
  bbox = tracker(hsv(:,:,1));

  out = shapeInserter(frame,bbox);
  videoPlayer(out);
end
```


Release the video reader and player.

```
release(videoPlayer);
```

```
release(videoFileReader);
```

Input Arguments

hbtracker — Histogram based tracker
vision.HistogramBasedTracker object

Histogram based tracker, specified as a vision.HistogramBasedTracker object.

I — Video frame
grayscale | truecolor (RGB)

Video frame, specified as grayscale or truecolor (RGB).

R — Initial search window
[*x y width height*]

Initial search window, specified in the format [*x y width height*].

N — Number of histogram bins
16 (default) | integer

Number of histogram bins, specified as an integer. Increasing the number of bins enhances the ability of the tracker to discriminate the object. However, this approach also narrows the range of changes to the object's visual characteristics that the tracker can accommodate. Consequently, this narrow range increases the likelihood of losing track.

Introduced in R2012a

initialize

Initialize video frame and points to track

Syntax

```
initialize(pointTracker,points,I)
```

Description

`initialize(pointTracker,points,I)` initializes points to track and sets the initial video frame. The function sets the *M*-by-2 `points` array of [x y] coordinates with the points to track, and sets the initial video frame, `I`.

If you want to use the point tracker as a persistent variable, you must call `initialize` only during creation. If you call `initialize` in a loop, the previous state is lost and therefore, the tracker cannot maintain tracking.

Examples

Track a Face in Scene

Create System objects for reading and displaying video and for drawing a bounding box of the object.

```
videoFileReader = vision.VideoFileReader('visionface.avi');
videoPlayer = vision.VideoPlayer('Position',[100,100,680,520]);
```

Read the first video frame, which contains the object, define the region.

```
objectFrame = videoFileReader();
objectRegion = [264,122,93,93];
```

As an alternative, you can use the following commands to select the object region using a mouse. The object must occupy the majority of the region:
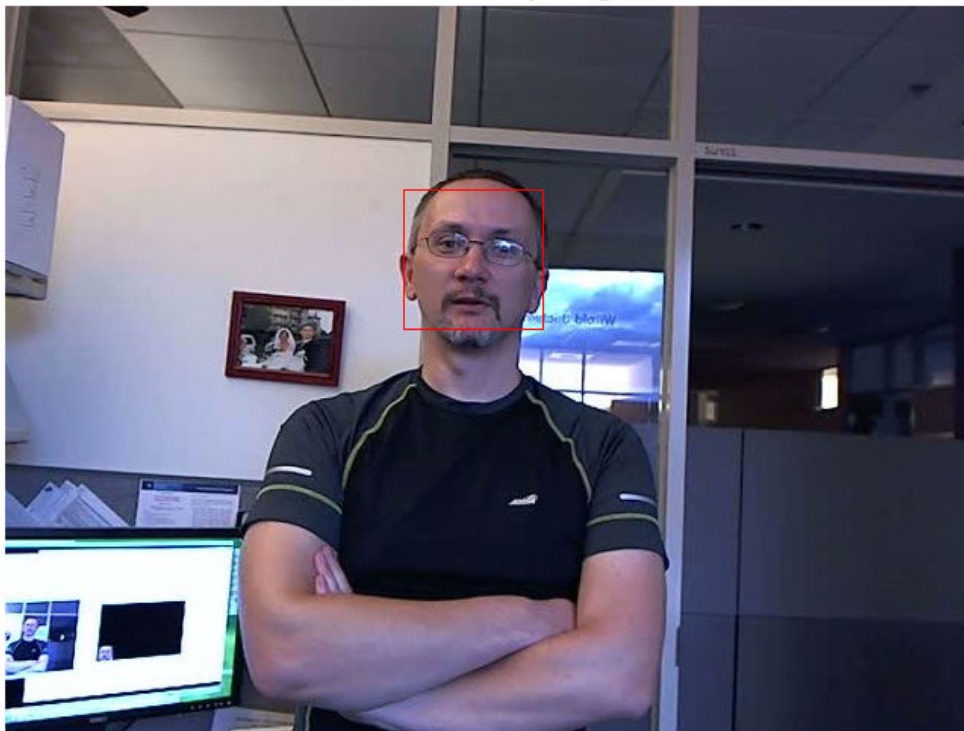
figure; imshow(objectFrame);

objectRegion=round(getPosition(imrect))

Show initial frame with a red bounding box.

```
objectImage = insertShape(objectFrame,'Rectangle',objectRegion,'Color','red');
figure;
imshow(objectImage);
title('Red box shows object region');
```


Red box shows object region

Detect interest points in the object region.

```
points = detectMinEigenFeatures(rgb2gray(objectFrame),'ROI',objectRegion);
```

Display the detected points.

```
pointImage = insertMarker(objectFrame,points.Location,'+','Color','white');
figure;
imshow(pointImage);
title('Detected interest points');
```


Detected interest points

Create a tracker object.

```
tracker = vision.PointTracker('MaxBidirectionalError',1);
```
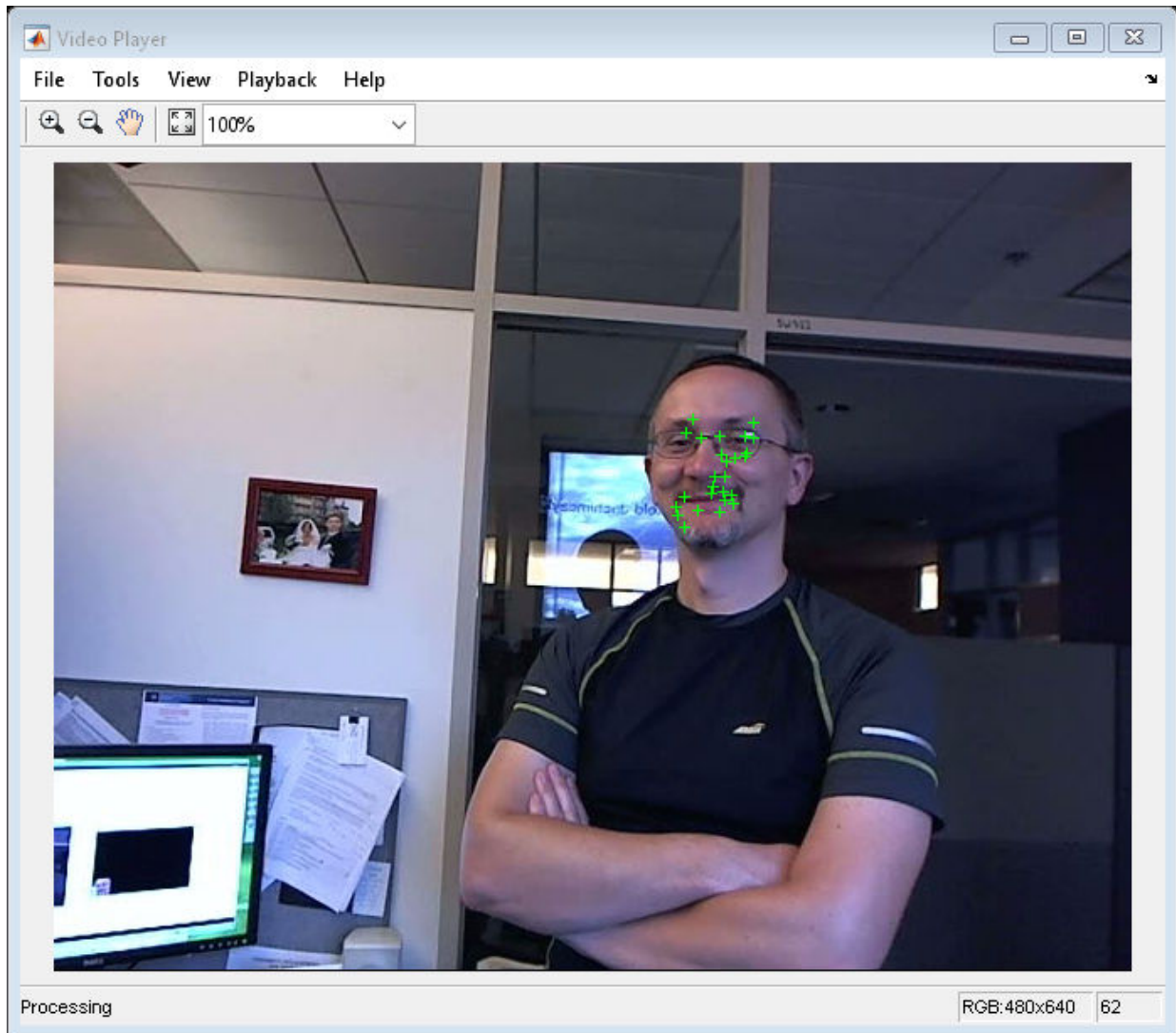
Initialize the tracker.

```
initialize(tracker,points.Location,objectFrame);
```
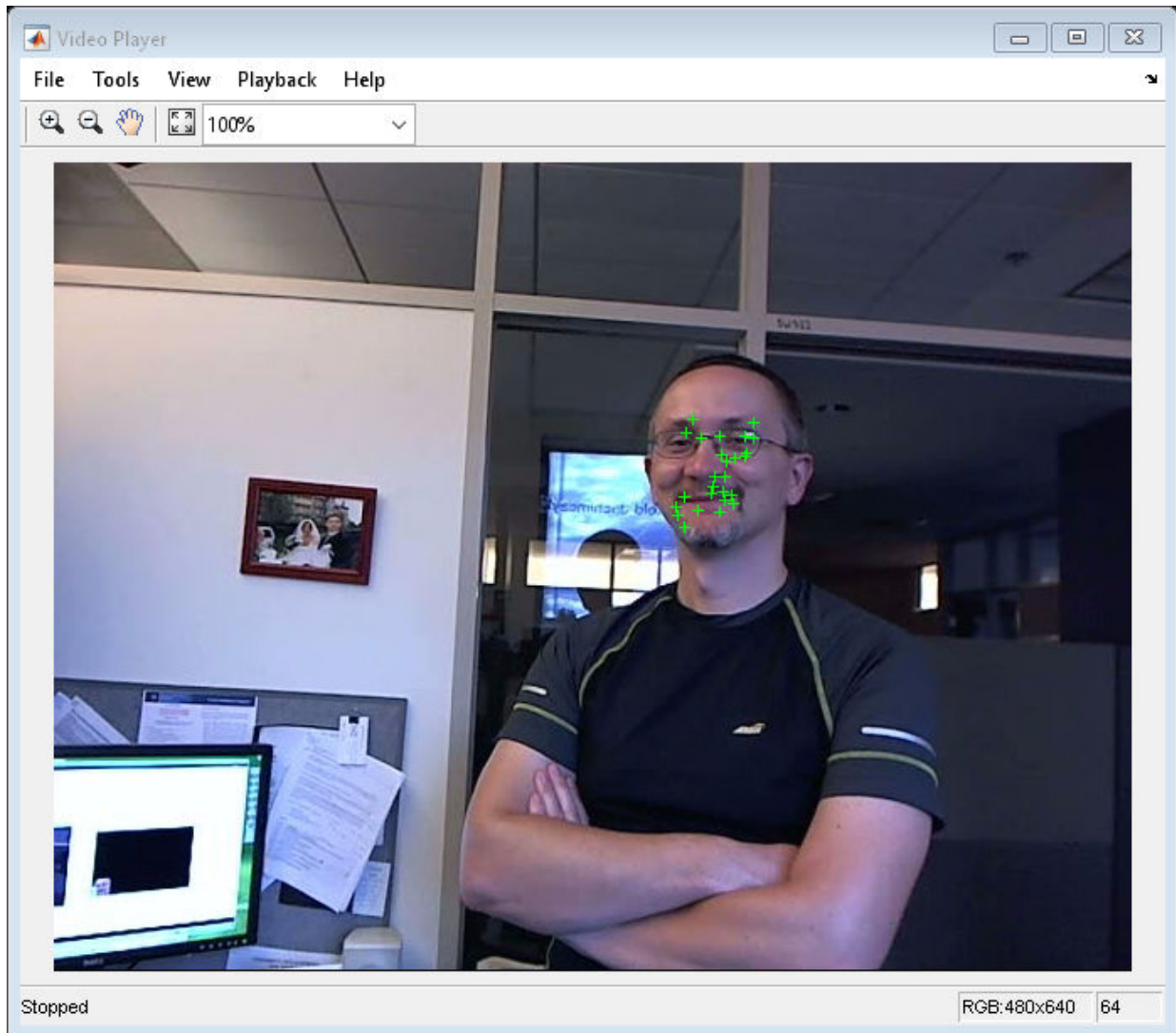
Read, track, display points, and results in each video frame.

```
while ~isDone(videoFileReader)
      frame = videoFileReader();
      [points,validity] = tracker(frame);
      out = insertMarker(frame,points(validity, :),'+');
      videoPlayer(out);
end
```

Release the video reader and player.

```
release(videoPlayer);
```

```
release(videoFileReader);
```

Input Arguments

`pointTracker` — Point tracker
PointTracker object

Point tracker, specified as a `vision.PointTracker` object.

`points` — Points
M-by-2 array

Points, specified as an *M*-by-2 array of [x y] coordinates that correspond to the locations of the points in the input frame, `I`.

`I` — Video frame
grayscale | truecolor (RGB)

Video frame, specified as grayscale or truecolor (RGB) and must be the same size as the images read into the tracker.

Introduced in R2012b

fcnLayers

Create fully convolutional network layers for semantic segmentation

Syntax

```
lgraph = fcnLayers(imageSize,numClasses)
lgraph = fcnLayers(imageSize,numClasses,'type',type)
```

Description

`lgraph = fcnLayers(imageSize,numClasses)` returns a fully convolutional network (FCN), configured as FCN 8s, for semantic segmentation. The FCN is preinitialized using layers and weights from the VGG-16 network.

`fcnLayers` includes a `pixelClassificationLayer` to predict the categorical label for every pixel in an input image. The pixel classification layer only supports RGB images.

This function requires the Neural Network Toolbox *Model for VGG-16 Network* support package. If this support package is not installed, then the `vgg16` function provides a download link.

`lgraph = fcnLayers(imageSize,numClasses,'type',type)` returns an FCN configured as a type specified by `type`.

Examples

Create Fully Convolutional Network 8s

Define the image size and number of classes, then create the network.

```
imageSize = [480 640];
numClasses = 5;
lgraph = fcnLayers(imageSize,numClasses)
```

Display the network.

```
plot(lgraph)
```

Create Fully Convolutional Network 16s

Create a FCN 16s.

```
imageSize = [480 640];
numClasses = 5;
lgraph = fcnLayers(imageSize,numClasses,'type','16s')
```

Display the network.

```
plot(lgraph)
```

Input Arguments

`imageSize` — Network input image size
2-element vector

Network input image size, specified as a 2-element vector in the format [*height*, *width*]. The minimum image size is [224 224] because an FCN is based on the VGG-16 network.

`numClasses` — Number of classes
integer

Number of classes to configure the network to classify, specified as an integer greater than or equal to 2.

`type` — Type of FCN model
'8s' (default) | '16s' | '32s'

Type of FCN model, specified as one of the following:

FCN Model	Description
'32s'	Upsamples the final feature map by a factor of 32. This option provides coarse segmentation with a lower computational cost.
'16s'	Upsamples the final feature map by a factor of 16 after fusing the feature map from the fourth pooling layer. This additional information from earlier layers provides medium-grain segmentation at the cost of additional computation.

FCN Model	Description
'8s'	Upsamples the final feature map by a factor of 8 after fusing feature maps from the third and fourth max pooling layers. This additional information from earlier layers provides finer-grain segmentation at the cost of additional computation.

Output Arguments

`lgraph` — Layers
LayerGraph object

Layers that represent the FCN network architecture, returned as a `layerGraph` object.

All transposed convolution layers are initialized using bilinear interpolation weights. All transposed convolution layer bias terms are fixed to zero.

References

[1] Long, J., E. Shelhamer, and T. Darrell. "Fully Convolutional Networks for Semantic Segmentation." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2015, pp. 3431–3440.

See Also

`layerGraph` | `pixelClassificationLayer` | `pixelLabelImageDatastore` | `segnetLayers` | `semanticseg` | `trainNetwork` | `vgg16`

Topics
"Semantic Segmentation Basics"
"Deep Learning Basics" (Neural Network Toolbox)

Introduced in R2017b

segnetLayers

Create SegNet layers for semantic segmentation

Syntax

```
lgraph = segnetLayers(imageSize,numClasses,model)
lgraph = segnetLayers(imageSize,numClasses,encoderDepth)
lgraph = segnetLayers(imageSize,numClasses,encoderDepth,Name,Value)
```

Description

`lgraph = segnetLayers(imageSize,numClasses,model)` returns SegNet layers, `lgraph`, that is preinitialized with layers and weights from a pretrained `model`.

SegNet is a convolutional neural network for semantic image segmentation. The network uses a `pixelClassificationLayer` to predict the categorical label for every pixel in an input image.

Use `segnetLayers` to create the network architecture for SegNet. You must train the network using the Neural Network Toolbox function `trainNetwork`.

`lgraph = segnetLayers(imageSize,numClasses,encoderDepth)` returns uninitialized SegNet layers configured using the specified encoder depth.

`lgraph = segnetLayers(imageSize,numClasses,encoderDepth,Name,Value)` returns a SegNet layer with additional options specified by one or more `Name,Value` pair arguments.

Examples

Train SegNet

Load training images and pixel labels.

```
dataSetDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
imageDir = fullfile(dataSetDir,'trainingImages');
labelDir = fullfile(dataSetDir,'trainingLabels');
```

Create an image datastore holding the training images.

```
imds = imageDatastore(imageDir);
```

Define the class names and their associated label IDs.

```
classNames = ["triangle", "background"];
labelIDs   = [255 0];
```

Create a pixel label datastore holding the ground truth pixel labels for the training images.

```
pxds = pixelLabelDatastore(labelDir,classNames,labelIDs);
```

Create SegNet layers.

```
imageSize = [32 32];
numClasses = 2;
lgraph = segnetLayers(imageSize,numClasses,2)

lgraph =
  LayerGraph with properties:

         Layers: [31x1 nnet.cnn.layer.Layer]
    Connections: [34x2 table]
```

Create a pixel label image datastore for training a semantic segmentation network.

```
pximds = pixelLabelImageDatastore(imds,pxds);
```

Set up training options.

```
options = trainingOptions('sgdm','InitialLearnRate',1e-3, ...
      'MaxEpochs',20,'VerboseFrequency',10);
```

Train the network.

```
net = trainNetwork(pximds,lgraph,options)

Training on single CPU.
Initializing image normalization.
```

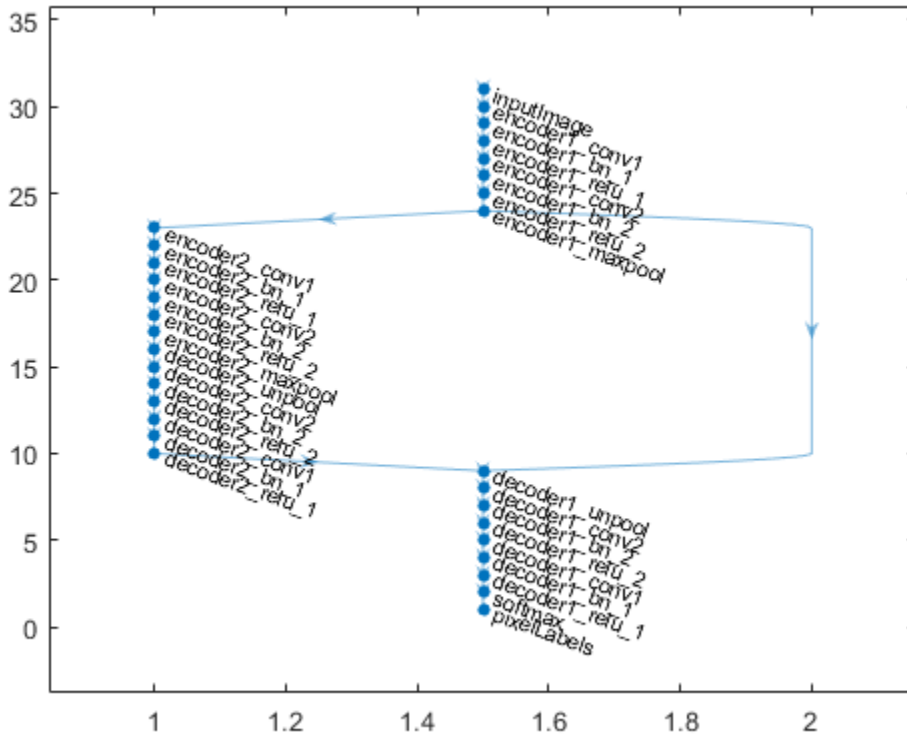```
|===
| Epoch | Iteration | Time Elapsed | Mini-batch | Mini-batch | Base Learning
| | | (hh:mm:ss) | Accuracy | Loss | Rate
|===
| 1 | 1 | 00:00:04 | 39.69% | 0.7640 | 0.001
| 10 | 10 | 00:00:47 | 49.87% | 0.7390 | 0.001
| 20 | 20 | 00:01:28 | 66.56% | 0.6911 | 0.001
|===
```

```
net =
  DAGNetwork with properties:

        Layers: [31x1 nnet.cnn.layer.Layer]
   Connections: [34x2 table]
```

Display the network.

```
plot(lgraph)
```

Create SegNet With Custom Encoder-Decoder Depth

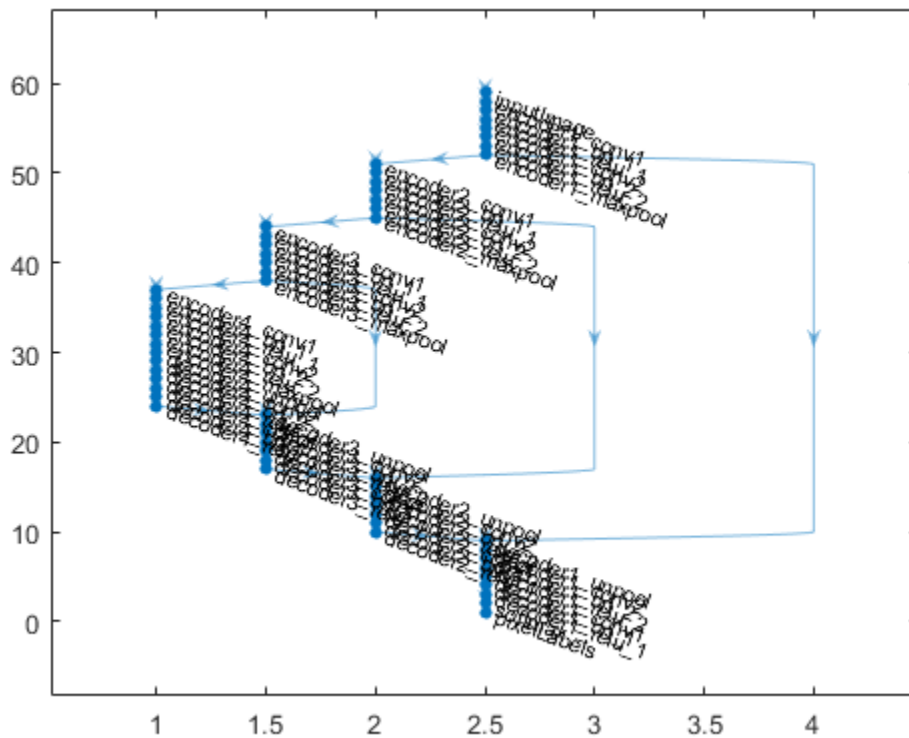Create SegNet layers with an encoder/decoder depth of 4.

```
imageSize = [480 640 3];
numClasses = 5;
encoderDepth = 4;
lgraph = segnetLayers(imageSize,numClasses,encoderDepth)

lgraph =
  LayerGraph with properties:
```

```
        Layers: [59x1 nnet.cnn.layer.Layer]
   Connections: [66x2 table]
```

Display network.

```
figure
plot(lgraph)
```

Input Arguments

`imageSize` — Network input image size
2-element vector | 3-element vector

Network input image size, specified as a:

- 2-element vector in the format [*height*, *width*].
- 3-element vector in the format [*height*, *width*, *depth*]. *depth* is the number of image channels. Set *depth* to 3 for RGB images, 1 for grayscale images, or to the number of channels for multispectral and hyperspectral images.

`numClasses` — Number of classes
integer greater than 1

Number of classes in the semantic segmentation, specified as an integer greater than 1.

`model` — Pretrained network model
`'vgg16'` | `'vgg19'`

Pretrained network model, specified as `'vgg16'` or `'vgg19'`. These models have an encoder depth of 5.

`encoderDepth` — Encoder depth
positive integer

Encoder depth, specified as a positive integer.

SegNet is composed of an encoder and corresponding decoder subnetwork. The depth of these networks determines the number of times the input image is downsampled or upsampled as it is processed. The encoder network downsamples the input image by a factor of 2^D, where D is the value of `encoderDepth`. The decoder network upsamples the encoder network output by a factor of 2^D.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: 'NumConvolutionLayers',1

NumConvolutionLayers — Number of convolutional layer sections
2 (default) | positive integer | vector of positive integers

Number of convolutional layers in each encoder and decoder section, specified as a positive integer or vector of positive integers.

NumConvolutionLayers	Description
scalar	The same number of layers is used for all encoder and decoder sections.
vector	The *k*th element of NumConvolutionLayers is the number of convolution layers in the *k*th encoder section and corresponding decoder section. Typical values are in the range [1, 3].

NumOutputChannels — Number of output channels
64 (default) | positive integer | vector of positive integers

Number of output channels for each section in the SegNet encoder network, specified as a positive integer or vector of positive integers. segnetLayers sets the number of output channels in the decoder to match the corresponding encoder section.

NumOutputChannels	Description
scalar	The same number of output channels is used for all encoder and decoder sections.
vector	The *k*th element of NumOutputChannels is the number of output channels of the *k*th encoder section and corresponding decoder section.

FilterSize — Convolutional layer filter size
3 (default) | positive odd integer | 2-element row vector of positive odd integers

Convolutional layer filter size, specified as a positive odd integer or a 2-element row vector of positive odd integers. Typical values are in the range [3, 7].

FilterSize	Description
scalar	The filter is square.

FilterSize	Description
2-element row vector	The filter has the size [*height width*].

Output Arguments

`lgraph` — Layers
`LayerGraph` object

Layers that represent the SegNet network architecture, returned as a `layerGraph` object.

Tips

- The sections within the SegNet encoder and decoder subnetworks are made up of convolutional, batch normalization, and ReLU layers.

- All convolutional layers are configured such that the bias term is fixed to zero.

- Convolution layer weights in the encoder and decoder subnetworks are initialized using the 'MSRA' weight initialization method. For `'vgg16'` or `'vgg19'` models, only the decoder subnetwork is initialized using MSRA.[1]

References

[1] He, K., X. Zhang, S. Ren, and J. Sun. "Delving Deep Into Rectifiers: Surpassing Human-Level Performance on ImageNet Classification." *Proceedings of the IEEE International Conference on Computer Vision*. 2015, 1026–1034.

[2] Badrinarayanan, V., A. Kendall, and R. Cipolla. "Segnet: A Deep Convolutional Encoder-Decoder Architecture for Image Segmentation." *arXiv*. Preprint arXiv: 1511.0051, 2015.

See Also

DAGNetwork | evaluateSemanticSegmentation | fcnLayers | pixelClassificationLayer | pixelLabelImageDatastore | semanticseg | trainNetwork

Topics
"Semantic Segmentation Basics"
"Deep Learning Basics" (Neural Network Toolbox)

Introduced in R2017b

countEachLabel

Count occurrence of pixel label for data source images

Syntax

```
tbl = countEachLabel(datastore)
```

Description

`tbl = countEachLabel(datastore)` returns a table containing information about the pixel labels and count for the `datastore`.

Examples

Pass Class Weights to Pixel Classification Layer

Set the location of image and pixel label data.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata');
imDir = fullfile(dataDir,'building');
pxDir = fullfile(dataDir,'buildingPixelLabels');
```

Create a pixel label image datastore using the ground truth images in `imds` and the pixel labeled images in `pxds`.

```
imds = imageDatastore(imDir);
classNames = ["sky" "grass" "building" "sidewalk"];
pixelLabelID = [1 2 3 4];
pxds = pixelLabelDatastore(pxDir,classNames,pixelLabelID);
pximds = pixelLabelImageDatastore(imds,pxds);
```

Tabulate pixel label counts in dataset.

```
tbl = countEachLabel(pximds)
```

```
tbl=4×3 table
      Name        PixelCount     ImagePixelCount
    _____    _____     _____

    'sky'         3.1485e+05          1.536e+06
    'grass'       1.5979e+05          1.536e+06
    'building'    1.0312e+06          1.536e+06
    'sidewalk'         25313          9.216e+05
```

Balance classes using uniform prior weighting.

```
prior = 1/numel(classNames);
uniformClassWeights = prior./tbl.PixelCount
```

```
uniformClassWeights = 4×1
10-5 ×

    0.0794
    0.1565
    0.0242
    0.9876
```

Balance classes using inverse frequency weighting.

```
totalNumberOfPixels = sum(tbl.PixelCount);
frequency = tbl.PixelCount / totalNumberOfPixels;
invFreqClassWeights = 1./frequency
```

```
invFreqClassWeights = 4×1

    4.8632
    9.5827
    1.4848
   60.4900
```

Balance classes using median frequency weighting.

```
freq = tbl.PixelCount ./ tbl.ImagePixelCount
```

```
freq = 4×1

    0.2050
    0.1040
```

```
    0.6714
    0.0275
```

```
medFreqClassWeights = median(freq) ./ freq
```

```
medFreqClassWeights = 4×1

    0.7538
    1.4852
    0.2301
    5.6252
```

Pass the class weights using median frequency weighting to the pixel classification layer.

```
layer = pixelClassificationLayer('ClassNames',tbl.Name, ...
  'ClassWeights', medFreqClassWeights)
```

```
layer =
  PixelClassificationLayer with properties:

           Name: ''
      ClassNames: {'sky'  'grass'  'building'  'sidewalk'}
    ClassWeights: [4x1 double]
      OutputSize: 'auto'

   Hyperparameters
    LossFunction: 'crossentropyex'
```

Input Arguments

datastore — Datastore
pixelLabelImageDatastore object | PixelLabelDatastore object

Datastore for training a semantic segmentation network, specified as a
pixelLabelImageDatastore or pixelLabelDatastore object.

Output Arguments

tbl — Pixel label information
table

Pixel label information, returned as a table. The table contains three variables:

Variable	Description
Name	Pixel label class name
PixelCount	Number of pixels in class
ImagePixelCount	Total number of pixels in images that had an instance of a class

Tips

The output of countEachLabel can be used to calculate class weights for class balancing. For example:

- Uniform class balancing weights each class such that each contains a uniform prior probability:

```
numClasses = height(tbl)
prior = 1/numClasses;
classWeights = prior./tbl.PixelCount
```

- Inverse frequency balancing weights each class such that underrepresented classes are given higher weight:

```
totalNumberOfPixels = sum(tbl.PixelCount)
frequency = tbl.PixelCount / totalNumberOfPixels;
classWeights = 1./frequency
```

- Median frequency balancing weights each class using the median frequency. The weight for each class is defined as median($imageFreq$)/$imageFreq$(c), where $imageFreq$(c) represents the number of pixels of the class divided by the total number of pixels in images that had an instance of the class (c):

```
imageFreq = tbl.PixelCount ./ tbl.ImagePixelCount
classWeights = median(imageFreq) ./ imageFreq
```

The calculated class weights can be passed to the pixelClassificationLayer

See Also

pixelClassificationLayer | pixelLabelImageDatastore | trainNetwork

Introduced in R2017b

reset

Reset pixel label datastore to initial state

Syntax

```
reset(pxds)
```

Description

`reset(pxds)` resets the pixel label datastore specified by `pxds` to the state where no data has been read from it. Resetting the pixel label datastore enables you to read from it again.

Input Arguments

pxds — Input pixel label datastore
`PixelLabelDatastore` object

Input pixel label datastore, specified as a `PixelLabelDatastore` object.

See Also
`datastore`

Introduced in R2017b

readimage

Read specified pixel label data file

Syntax

```
C = readimage(pxds,k)
[C,info] = readimage(pxds,k)
```

Description

`C = readimage(pxds,k)` returns the kth file in the pixel label datastore specified by `pxds`.

`[C,info] = readimage(pxds,k)` also returns information about the extracted data in `info`, including metadata.

Input Arguments

pxds — Input pixel label datastore
PixelLabelDatastore object

Input pixel label datastore, specified as a `PixelLabelDatastore` object.

k — File number
positive integer

File number to read from the pixel label datastore, specified as a positive integer.

Output Arguments

C — Output data
categorical matrix

Output data, returned as a categorical matrix.

`info` — Information about read data
structure array

Information about read data, returned as a structure array. The structure array can contain the following fields.

Field Name	Description
Filename	Fully resolved path containing the path string, name of the file, and file extension.
FileSize	Total file size, in bytes.

See Also
datastore

Introduced in R2017b

readall

Read all pixel label data

Syntax

```
data = readall(pxds)
```

Description

`data = readall(pxds)` returns all the data contained in the pixel label datastore specified by `pxds`.

If all the data in the datastore does not fit in memory, then `readall` returns an error.

Input Arguments

pxds — Input pixel label datastore
`PixelLabelDatastore` object

Input pixel label datastore, specified as a `PixelLabelDatastore` object.

Output Arguments

data — All data in the pixel label datastore
cell array of categorical matrices

All data in the pixel label datastore, returned as a cell array of categorical matrices.

After the `readall` function returns all the data, it resets `pxds` to point to the beginning of the pixel label datastore.

See Also
datastore

Introduced in R2017b

read

Read next consecutive file from pixel label datastore

Syntax

```
C = read(pxds)
[C,info] = read(pxds)
```

Description

`C = read(pxds)` returns data from a pixel label datastore. Subsequent calls to the `read` function continue reading from the endpoint of the previous call.

`[C,info] = read(pxds)` also returns information about the extracted data in `info`, including metadata.

Input Arguments

pxds — Input pixel label datastore
PixelLabelDatastore object

Input pixel label datastore, specified as a `PixelLabelDatastore` object.

Output Arguments

C — Output data
categorical matrix | cell array of categorical matrices

Output data, returned as a categorical matrix or a cell array of categorical matrices (when `ReadSize` is greater than 1.)

info — Information about read data
structure array

Information about read data, returned as a structure array. The structure array can contain the following fields.

Field Name	Description
Filename	Fully resolved path containing the path string, name of the file, and file extension. For `PixelLabelDatastore` objects whose `ReadSize` property is greater than 1, `Filename` is a cell array of file names corresponding to each image.
FileSize	Total file size, in bytes. For MAT-files, `FileSize` is the total number of key-value pairs in the file. For `PixelLabelDatastore` objects whose `ReadSize` property is greater than 1, `FileSize` is a vector of file sizes corresponding to each image.

See Also

datastore | pixelLabelDatastore

Introduced in R2017b

preview

Reads first image from pixel label datastore

Syntax

```
C = preview(pxds)
```

Description

`C = preview(pxds)` reads first pixel labeled from datastore `pxds` without changing the current position.

Input Arguments

pxds — Input pixel label datastore
PixelLabelDatastore object

Input pixel label datastore, specified as a `PixelLabelDatastore` object.

Output Arguments

`C` — First pixel label image
categorical matrix

First pixel label image, returned as a categorical matrix.

See Also
datastore

Introduced in R2017b

partition

Partition a pixel label datastore

Syntax

```
subds = partition(pxds,N,index)

subds = partition(pxds,'Files',index)
subds = partition(pxds,'Files',filename)
```

Description

`subds = partition(pxds,N,index)` partitions pixel label datastore `pxds` into *N* parts and returns the partition corresponding to `index`.

`subds = partition(pxds,'Files',index)` partitions the datastore by files and returns the partition corresponding to the file of index `index` in the `Files` property of the datastore.

`subds = partition(pxds,'Files',filename)` partitions the pixel label datastore by files and returns the partition corresponding to the file specified by `filename`.

Input Arguments

pxds — Input pixel label datastore
`PixelLabelDatastore` object

Input pixel label datastore, specified as a `PixelLabelDatastore` object.

N — Number of partitions
positive integer

Number of partitions, specified as a positive integer.

Example: 3

Data Types: `double`

index — Index
positive integer

Index of a file stored within the `Files` property of datastore, specified as a positive integer.

Example: 1

Data Types: `double`

filename — file name
character vector

File name, specified as a character vector.

Example: `'file1.csv'`

Example: `'../dir/data/file1.csv'`

Example: `'hdfs://myserver:7867/data/file1.txt'`

Data Types: `char`

Output Arguments

subds — Output datastore
`datastore` object

Output datastore, returned as a datastore object. The output datastore is of the same type as the input `datastore`, `ds`.

See Also
`datastore`

Introduced in R2017b

numpartitions

Number of partitions for pixel label datastore

Syntax

```
N = numpartitions(pxds)
N = numpartitions(ds,pool)
```

Description

`N = numpartitions(pxds)` returns the default number of partitions for the pixel label datastore `pxds`.

`N = numpartitions(ds,pool)` returns the number of partitions needed to parallelize datastore access over the parallel pool specified by `pool`. To parallelize datastore access, you must have Parallel Computing Toolbox installed.

Input Arguments

pxds — Input pixel label datastore
PixelLabelDatastore object

Input pixel label datastore, specified as a `PixelLabelDatastore` object.

pool — Parallel pool
parallel pool object

Parallel pool object.

Example: `gcp`

See Also

datastore | pixelLabelDatastore

Introduced in R2017b

hasdata

Determine if data is available to read from datastore

Syntax

```
tf = hasdata(pxds)
```

Description

`tf = hasdata(pxds)` returns logical `1` (`true`) if there is data available to read from the datastore specified by `ds`. Otherwise, it returns logical `0` (`false`).

Examples

Determine Pixel Data Available to Read

Check if pixel label data can be read from a datastore.

Set the location of the image and pixel label data.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata');
imDir = fullfile(dataDir,'building');
pxDir = fullfile(dataDir,'buildingPixelLabels');
```

Create an image and pixel label datastore.

```
imds = imageDatastore(imDir);
classNames = ["sky" "grass" "building" "sidewalk"];
pixelLabelID = [1 2 3 4];
pxds = pixelLabelDatastore(pxDir,classNames,pixelLabelID);
```

While data is available in the datastore, read the data.

```
while hasdata(pxds)
    T = read(pxds);
end
```

Input Arguments

pxds — Input pixel label datastore
PixelLabelDatastore object

Input pixel label datastore, specified as a PixelLabelDatastore object.

See Also

datastore | pixelLabelDatastore

Introduced in R2017b

semanticseg

Semantic image segmentation using deep learning

Syntax

```
C = semanticseg(I,network)
[C,score,allScores] = semanticseg(I,network)
[ ___ ] = semanticseg(I,network,roi)

pxds = semanticseg(imds,network)

[ ___ ] = semanticseg( ___ ,Name,Value)
```

Description

`C = semanticseg(I,network)` returns a semantic segmentation of the input image using deep learning. The input `network` must be either a `SeriesNetwork` or `DAGNetwork` object.

`[C,score,allScores] = semanticseg(I,network)` returns a semantic segmentation of the input image with the classification scores for each categorical label in `C`. The scores are returned in a categorical array that corresponds to each pixel in the input image. `allScores` contains the scores for all label categories that the input network can classify.

`[ ___ ] = semanticseg(I,network,roi)` returns a semantic segmentation for a rectangular subregion of the input image.

`pxds = semanticseg(imds,network)` returns the semantic segmentation for a collection of images in `imds`, an `ImageDatastore` object.

This function supports parallel computing using multiple MATLAB workers when processing an `ImageDatastore` object. You can enable parallel computing using the "Computer Vision System Toolbox Preferences" dialog.

`[ ___ ] = semanticseg( ___ ,Name,Value)` returns semantic segmentation with additional options specified by one or more `Name,Value` pair arguments.

Examples

Semantic Image Segmentation

Overlay segmentation results on image and display the results.

Load a pretrained network.

```
data = load('triangleSegmentationNetwork');
net = data.net

net =
  SeriesNetwork with properties:

    Layers: [10x1 nnet.cnn.layer.Layer]
```

List the network layers.

```
net.Layers

ans =
  10x1 Layer array with layers:

     1   'imageinput'       Image Input                32x32x1 images with 'zerocent
     2   'conv_1'           Convolution                64 3x3x1 convolutions with st
     3   'relu_1'           ReLU                       ReLU
     4   'maxpool'          Max Pooling                2x2 max pooling with stride [
     5   'conv_2'           Convolution                64 3x3x64 convolutions with s
     6   'relu_2'           ReLU                       ReLU
     7   'transposed-conv'  Transposed Convolution     64 4x4x64 transposed convolut
     8   'conv_3'           Convolution                2 1x1x64 convolutions with st
     9   'softmax'          Softmax                    softmax
    10   'classoutput'      Pixel Classification Layer Class weighted cross-entropy
```

Read and display the test image.

```
I = imread('triangleTest.jpg');
figure
imshow(I)
```
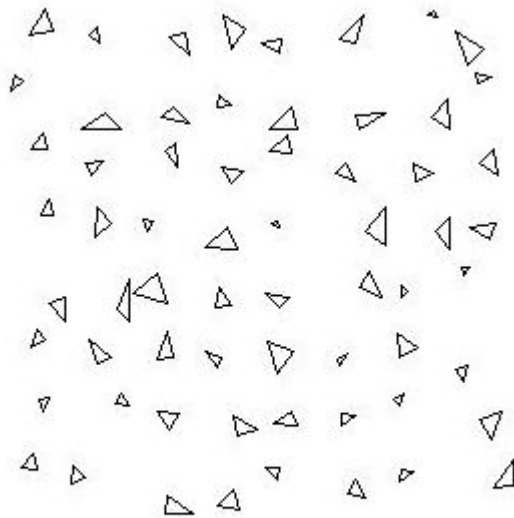
Perform semantic image segmentation.

```
[C,scores] = semanticseg(I,net);
```
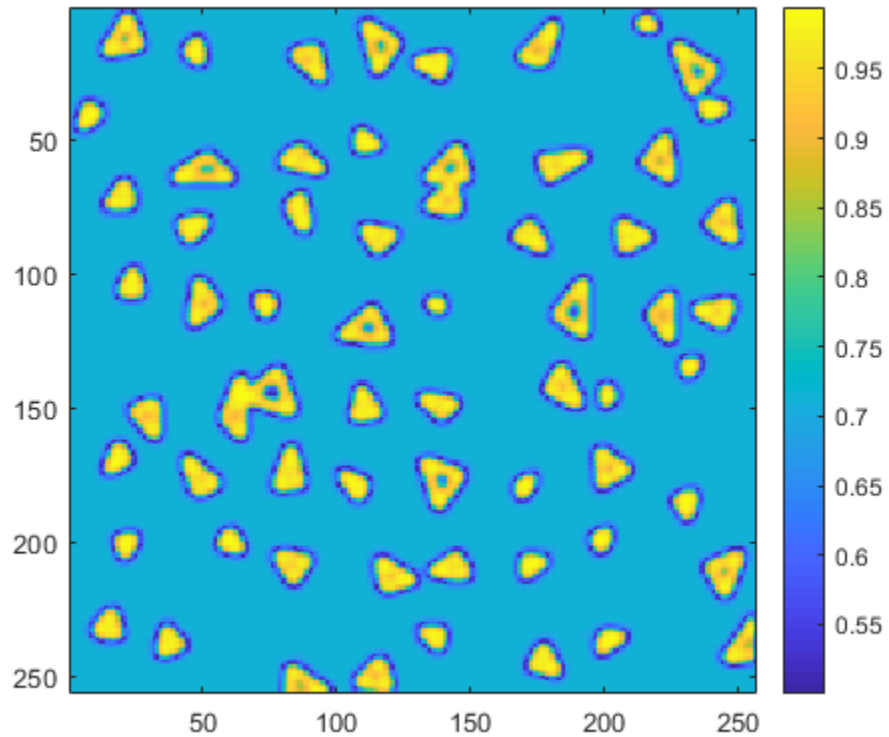
Overlay segmentation results on the image and display the results.

```
B = labeloverlay(I, C);
figure
imshow(B)
```
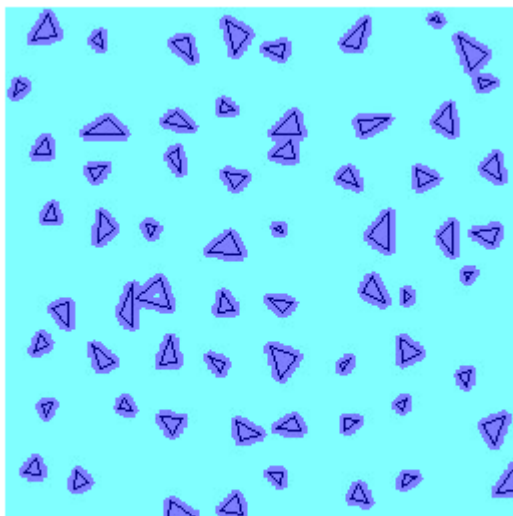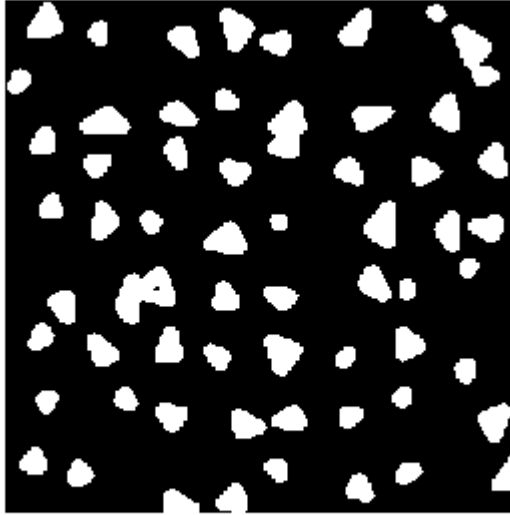
Display the classification scores.

```
figure
imagesc(scores)
axis square
colorbar
```

Create a binary mask with only the triangles.

```
BW = C == 'triangle';
figure
imshow(BW)
```

Evaluate Semantic Segmentation Test Set

Load a pretrained network.

```
data = load('triangleSegmentationNetwork');
net = data.net;
```

Load test images using imageDatastore.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
testImageDir = fullfile(dataDir,'testImages');
imds = imageDatastore(testImageDir)

imds =
  ImageDatastore with properties:

                        Files: {
                                ' ...\toolbox\vision\visiondata\triangleImages\testImages
                                ' ...\toolbox\vision\visiondata\triangleImages\testImages
```

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```
                                  ' ...\toolbox\vision\visiondata\triangleImages\testImages
                                   ... and 97 more
                                  }
         AlternateFileSystemRoots: {}
                         ReadSize: 1
                           Labels: {}
                          ReadFcn: @readDatastoreImage
```

Load ground truth test labels.

```
testLabelDir = fullfile(dataDir,'testLabels');
classNames = ["triangle" "background"];
pixelLabelID = [255 0];
pxdsTruth = pixelLabelDatastore(testLabelDir,classNames,pixelLabelID);
```

Run semantic segmentation on all of the test images.

```
pxdsResults = semanticseg(imds,net,'WriteLocation',tempdir);
```

```
Running semantic segmentation network
-------------------------------------
* Processing 100 images.
* Progress: 100.00%
```

Compare results against ground truth.

```
metrics = evaluateSemanticSegmentation(pxdsResults,pxdsTruth)
```

```
Evaluating semantic segmentation results
-------------------------------------[=============================================
Elapsed time: 00:00:01
Estimated time remaining: 00:00:00
* Finalizing... Done.
* Data set metrics:

    GlobalAccuracy    MeanAccuracy    MeanIoU    WeightedIoU    MeanBFScore
    _____    _____    _____    _____    _____

       0.90624           0.95085      0.61588      0.87529        0.40652

metrics =
  semanticSegmentationMetrics with properties:

             ConfusionMatrix: [2x2 table]
    NormalizedConfusionMatrix: [2x2 table]
```

```
        DataSetMetrics: [1x5 table]
          ClassMetrics: [2x3 table]
          ImageMetrics: [100x5 table]
```

Input Arguments

I — Input image
color image | grayscale image | multispectral image | series of images | `gpuArray` of images

Input image, specified as one of the following. The first three dimensions of the array index the height (M), width (N), and channels (K) of an image. For a series of P images, the fourth dimension indexes the individual image.

Image Type	Data Format
Grayscale image	M-by-N matrix
Color image	M-by-N-by-3 array
Multispectral image	M-by-N-by-K array
Series of grayscale images	M-by-N-by-1-by-P array
Series of color images	M-by-N-by-3-by-P array
Series of multispectral images	M-by-N-by-K-by-P array
`gpuArray` of images	`gpuArray` containing one of the preceding image types (requires Parallel Computing Toolbox).

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`

network — Network
`SeriesNetwork` object | `DAGNetwork` object

Network, specified as either a `SeriesNetwork` or a `DAGNetwork` object.

roi — Region of interest
4-element vector

Region of interest, specified as a 4-element vector in the format [*x*,*y*,*width*,*height*]. The vector defines a rectangular region of interest fully contained in the input image. Image

pixels outside the region of interest are assigned the `<undefined>` categorical label. If you use a 4-D input image, the function applies the same `roi` to all images.

`imds` — **Collection of image data**
`imageDataStore` object

Collection of images, specified as an `ImageDatastore` object. The function returns the semantic segmentation as a categorical array that relates a label to each pixel in the input image.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'ExecutionEnvironment','gpu'`

`OutputType` — **Returned segmentation type**
`'categorical'` (default) | `'double'` | `'uint8'`

Returned segmentation type, specified as either `'categorical'`, `'double'`, or `'uint8'`. When you select `'double'` or `'uint8'`, the function returns the segmentation results as a label matrix containing label IDs. The IDs are integer values that correspond to the class names defined in the `pixelClassificationLayer` used in the input network.

The `OutputType` property cannot be used with an `ImageDatastore` object input.

`MiniBatchSize` — **Group of images**
128 (default) | integer

Group of images, specified as an integer. Images are grouped and processed together as a batch. They are used for processing a large collection of images and they improve computational efficiency. Increasing the `MiniBatchSize` value increases the efficiency, but it also takes up more memory.

`ExecutionEnvironment` — **Hardware resource**
`'auto'` (default) | `'gpu'` | `'cpu'`

Hardware resource used to process images with a network, specified as `'auto'`, `'gpu'`, or `'cpu'`.

ExecutionEnvironment	Description
`'auto'`	Use a GPU if available. Otherwise, use the CPU. To use a GPU, (requires Parallel Computing Toolbox, and a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher.)
`'gpu'`	Use the GPU. If a suitable GPU is not available, the function returns an error message.
`'cpu'`	Use the CPU.

WriteLocation — Folder location
`pwd (current working folder)` (default) | string scalar | character vector

Folder location, specified as `pwd` (your current working folder), a string scalar, or a character vector. The specified folder must exist and have write permissions.

This property applies only when using an `ImageDatastore` object input.

NamePrefix — Prefix applied to output file names
`'pixelLabel'` (default) | string scalar | character vector

Prefix applied to output file names, specified as a string scalar or character vector. The image files are named as follows:

- *prefix_N*.png, where *N* corresponds to the index of the input image file, `imds.Files`(*N*).

This property applies only when using an `ImageDatastore` object input.

Verbose — Display progress information
`'true'` (default) | `'false'`

Display progress information, specified as `'true'` or `'false'`.

This property applies only when using an `ImageDatastore` object input.

Output Arguments

`C` — Categorical labels
categorical array

Categorical labels, returned as a 2-D categorical array. The elements of the label array correspond to the pixel elements of the input image. If you selected an ROI, then the labels are limited to the area within the ROI. Image pixels outside the region of interest are assigned the `<undefined>` categorical label.

`pxds` — Semantic segmentation results
`PixelLabelDatastore` object

Semantic segmentation results, returned as a `pixelLabelDatastore` object. The object contains the semantic segmentation results for all the images contained in the `imds` input object. The result for each image is saved as separate `uint8` label matrices of PNG images. You can use `read(pxds)` to return the categorical labels assigned to the images in `imds`.

`score` — Classification scores
categorical array

Classification scores for each categorical label in `C`, returned as categorical array. The scores represents the confidence in the predicted labels `C`. The classification score of pixel(i,j) relates to `score`(i,j).

`allScores` — Scores for all label categories
4-*D* array

Scores for all label categories the input network is capable of classifying, returned as a 4-*D* array. The first three dimensions represent the height, width, and number of categories in `C`. The fourth dimension indexes each individual image.

See Also
Image Labeler | ImageDatastore | evaluateSemanticSegmentation | labeloverlay | pixelLabelDatastore | trainNetwork

Topics
"Semantic Segmentation Basics"

"Deep Learning Basics" (Neural Network Toolbox)

Introduced in R2017b

detectKAZEFeatures

Detect KAZE features

Syntax

```
points = detectKAZEFeatures(I)
points = detectKAZEFeatures(I,Name,Value)
```

Description

`points = detectKAZEFeatures(I)` returns a `KAZEPoints` object containing information about KAZE keypoints detected in a 2-D grayscale image. The function uses nonlinear diffusion to construct a scale space for the given image. It then detects multiscale corner features from the scale space.

`points = detectKAZEFeatures(I,Name,Value)` returns a `KAZEPoints` object with additional options specified by one or more Name,Value pair arguments

Examples

Detect KAZE Feature Points in Image

Detect and plot KAZE feature points.

Read an image.

```
I = imread('cameraman.tif');
```

Detect KAZE points in the image.

```
points = detectKAZEFeatures(I);
```

Plot the 20 strongest points.

```
imshow(I)
hold on
plot(selectStrongest(points,20))
hold off
```


Detect KAZE Features and Display Specific Points

Detect KAZE features and display set the specific KAZE points you want to plot.

Read an image.

```
I = imread('cameraman.tif');
```

Detect KAZE features in the image.

```
points = detectKAZEFeatures(I);
```

Select and display the last 5 points detected.

```
imshow(I);
hold on;
plot(points(end-4:end));
hold off;
```


Input Arguments

I — Input image
2-D grayscale image

Input image, specified as a 2-D grayscale image.

Data Types: single | double | int16 | uint8 | uint16 | logical

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Diffusion','region'`

Diffusion — Method to compute conductivity
`'region'` (default) | `'sharpedge'` | `'edge'`

Method to compute conductivity, specified as `'region'`, `'sharpedge'`, or `'edge'`. The computation is based on first-order derivatives of a layer in scale space.

Method	Selected Features
`'region'`	Large regions. Uses the Perona and Malik conductivity coefficient, `1/(1 + dL^2/k^2)`.
`'sharpedge'`	High-contrast edges. Uses the Perona and Malik conductivity coefficient, `exp(-|dL|^2/k^2)`.
`'edge'`	Smoothing on both sides of an edge rather than across it. Uses the Weickert conductivity coefficent.

Threshold — Local extrema
`0.0001` (default) | scalar

Local extrema, specified as a scalar greater than or equal to `0`. Increase this value to exclude less significant local extrema.

NumOctaves — Multiscale detection factor
3 (default) | positive integer

Multiscale detection factor, specified as a positive integer. Increase this value to detect larger features. To disable multiscale detection, set `NumOctaves` to 1. When you set the value to 1, the function detects at the scale as the input image. Recommended values are between 1 and 4.

NumScaleLevels — Scale levels
4 (default) | integer

Scale levels, specified as an integer in the range [3,10]. Increase this value to achieve smoother scale changes. Increasing this value also provides additional intermediate scales between octaves. Recommended values are between 1 and 4.

ROI — Rectangular region size
`[1 1 size(I,2) size(I,1)]` (default) | 4-element vector

Rectangular region size for corner detection, specified as a 4-element vector in the format [*y x width height*]. The [*y x*] values are measured from the upper left corner of the rectangle.

Output Arguments

`points` — KAZE points object
`KAZEpoints` object

KAZE points, returned as a `KAZEPoints` object. The object contains information about the feature points detected in the 2-D grayscale input image.

References

[1] Alcantarilla, P.F., A. Bartoli, and A.J. Davison. "KAZE Features." *ECCV 2012, Part VI, LNCS 7577*. 2012, p. 214

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".

See Also

KAZEPoints | MSERRegions | SURFPoints | cornerPoints | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | matchFeatures

Introduced in R2017b

selectUniform

Select uniformly distributed subset of KAZE feature points

Syntax

```
pointsOut = selectUniform(pointsIn,N,imageSize)
```

Description

`pointsOut = selectUniform(pointsIn,N,imageSize)` returns `N` uniformly distributed points from `pointsIn` KAZE points of an image of size `imageSize`.

Examples

Select Uniformly Distributed Subset of KAZE Features

Detect and plot a subset of uniformly distributed KAZE features from an image.

Read an image.

```
im = imread('yellowstone_left.png');
```

Detect and display KAZE features.

```
points1 = detectKAZEFeatures(rgb2gray(im))

points1 =
  7070x1 KAZEPoints array with properties:

        Location: [7070x2 single]
          Metric: [7070x1 single]
           Count: 7070
           Scale: [7070x1 single]
     Orientation: [7070x1 single]
```

```
subplot(1,2,1)
imshow(im)
hold on
plot(points1)
hold off
title('Original Points')
```

Select a uniformly distributed subset of points.

```
numPoints = 100;
points2 = selectUniform(points1,numPoints,size(im))

points2 =
  100x1 KAZEPoints array with properties:

        Location: [100x2 single]
          Metric: [100x1 single]
           Count: 100
           Scale: [100x1 single]
     Orientation: [100x1 single]


subplot(1,2,2)
imshow(im)
hold on
plot(points2)
hold off
title('Uniformly Distributed Points')
```

Original Points
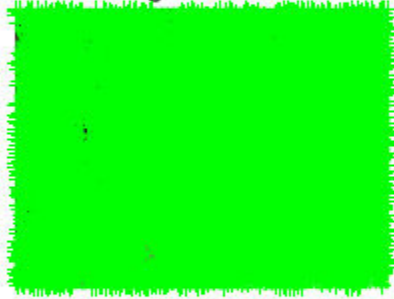
Uniformly Distributed Points

Input Arguments

pointsIn — KAZE points
KAZEPoints object

KAZE points, specified as a KAZEPoints object. This object contains information about KAZE features detected in a grayscale image. To obtain KAZE points, use the detectKAZEFeatures function.

N — Number of points
integer

Number of uniformly distributed points to select, specified as an integer.

`imageSize` — Size of image
2-element vector | 3-element vector

Size of image, specified as a 2-element vector for grayscale images or a 3-element vector for truecolor images.

Introduced in R2017b

size

Return the size of a KAZE points object

Syntax

```
size(KAZEPoints)
```

Description

`size(KAZEPoints)` returns the size of the KAZE points object.

- `sz = size(v)` returns the vector [`length(v)`, 1]
- `sz = size(v, 1)` returns the length of *v*
- `sz = size(v, N)`, for *N* >= 2, returns 1
- [*M*, *N*] = `size(v)` returns `length(v)` for *M* and 1 for *N*

Introduced in R2017b

selectStrongest

Select KAZE points with strongest metrics

Syntax

```
strongestPoints = selectStrongest(points,N)
```

Description

`strongestPoints = selectStrongest(points,N)` returns N number of KAZE points that have the strongest metrics.

Examples

Select Strongest KAZE Features

Create a `KAZEPoints` object holding 50 points.

```
points = KAZEPoints(ones(50,2),'Metric',1:50);
```

Keep the two strongest features.

```
points = selectStrongest(points,2)

points =
  2x1 KAZEPoints array with properties:

        Location: [2x2 single]
          Metric: [2x1 single]
           Count: 2
           Scale: [2x1 single]
     Orientation: [2x1 single]
```

Input Arguments

`points` — KAZE points object
KAZEpoints object

KAZE points, specified as a `KAZEPoints` object. The object contains information about the feature points detected in the 2-D grayscale input image.

N — Number of points
integer

Number of strongest points to select, specified as an integer.

Introduced in R2017b

plot

Plot KAZE points

Syntax

```
plot(KAZEPoints)
plot(KAZEPoints,ax)
plot(KAZEPoints,ax,Name,Value)
```

Description

plot(KAZEPoints) plots KAZE points in the current axis.

plot(KAZEPoints,ax) plots KAZE points in the specified axis.

plot(KAZEPoints,ax,Name,Value) plots KAZE points with additional options specified by one or more Name,Value pair arguments.

Examples

Plot KAZE Points

Detect, extract, and plot KAZE points, including their orientation.

Read an image.

```
I = imread('cameraman.tif');
```

Detect KAZE points from the image.

```
points = detectKAZEFeatures(I);
```

Extract KAZE features from the detected points.

```
[features,valid_points] = extractFeatures(I,points);
```

Plot the 10 strongest points and show their orientations.

```
imshow(I)
hold on
strongestPoints = selectStrongest(valid_points,10);
plot(strongestPoints,'showOrientation',true)
hold off
```
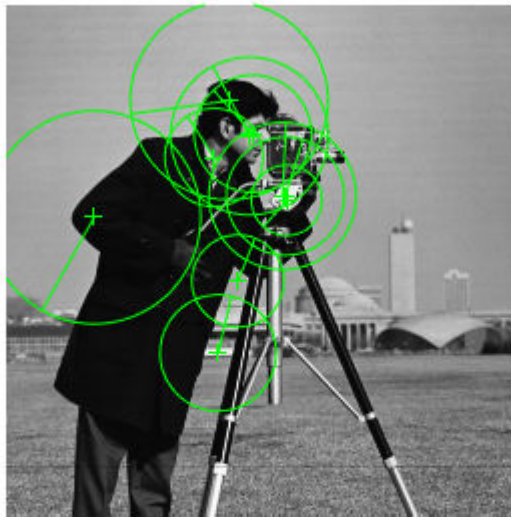

Input Arguments

KAZEPoints — KAZE points object
KAZEpoints object

KAZE points, specified as a `KAZEPoints` object. The object contains information about the feature points detected in the 2-D grayscale input image.

ax — Axes handle
handle

Handle to use for display. You can set the handle using `gca`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'ShowOrientation','true'`

ShowScale — Display scaled circle
`true` (default) | `false`

Display scaled circle, specified as `true` or `false`. When you set this value to `true`, the object draws a circle proportional to the scale of the detected feature, with the feature point located at its center. When you set this value to `false`, the object turns the display of the circle off.

The algorithm represents the scale of the feature with a circle of `6*Scale` radius. The KAZE algorithm uses this equivalent size of circular area to compute the orientation of the feature.

ShowOrientation — Display orientation line
`true` (default) | `false`

Display feature point orientation, specified as `true` or `false`. When you set this value to `true`, the object draws a line corresponding to the point's orientation. The object draws the line from the feature point location to the edge of the circle, indicating the scale.

Introduced in R2017b

length

Number of stored KAZE points

Syntax

```
length(KAZEPoints)
```

Description

length(KAZEPoints) returns the number of stored points in the KAZE points object.

Input Arguments

KAZEPoints — KAZE points object
KAZEpoints object

KAZE points, specified as a KAZEPoints object. The object contains information about the feature points detected in the 2-D grayscale input image. To obtain KAZE points, use the detectKAZEFeatures function.

Introduced in R2017b

isempty

Determine if KAZE points object is empty

Syntax

isempty(KAZEPoints)

Description

isempty(KAZEPoints) returns a `true` value, if the KAZE points object is empty.

Input Arguments

KAZEPoints — KAZE points object
KAZEPoints object

KAZE points, specified as a `KAZEPoints` object. The object contains information about the feature points detected in the 2-D grayscale input image. To obtain KAZE points, use the `detectKAZEFeatures` function.

Introduced in R2017b

assignDetectionsToTracks

Assign detections to tracks for multiobject tracking

Syntax

```
[assignments,unassignedTracks,unassignedDetections] =
assignDetectionsToTracks(costMatrix,costOfNonAssignment)
[assignments,unassignedTracks,unassignedDetections] =
assignDetectionsToTracks(costMatrix, unassignedTrackCost,
unassignedDetectionCost)
```

Description

`[assignments,unassignedTracks,unassignedDetections] = assignDetectionsToTracks(costMatrix,costOfNonAssignment)` assigns detections to tracks in the context of multiple object tracking using the James Munkres's variant of the Hungarian assignment algorithm. It also determines which tracks are missing and which detections should begin new tracks. It returns the indices of assigned and unassigned tracks, and unassigned detections. The `costMatrix` must be an M-by-N matrix. In this matrix, M represents the number of tracks, and N is the number of detections. Each value represents the cost of assigning the Nth detection to the Mth track. The lower the cost, the more likely that a detection gets assigned to a track. The `costOfNonAssignment` scalar input represents the cost of a track or a detection remaining unassigned.

`[assignments,unassignedTracks,unassignedDetections] = assignDetectionsToTracks(costMatrix, unassignedTrackCost, unassignedDetectionCost)` specifies the cost of unassigned tracks and detections separately. The `unassignedTrackCost` must be a scalar value, or an M-element vector, where M represents the number of tracks. For the M-element vector, each element represents the cost of not assigning any detection to that track. The `unassignedDetectionCost` must be a scalar value or an N-element vector, where N represents the number of detections.

Examples

Assign Detections to Tracks in a Single Video Frame

This example shows you how to assign a detection to a track for a single video frame.

Set the predicted locations of objects in the current frame. Obtain predictions using the Kalman filter System object.

```
predictions = [1,1;2,2];
```

Set the locations of the objects detected in the current frame. For this example, there are 2 tracks and 3 new detections. Thus, at least one of the detections is unmatched, which can indicate a new track.

```
detections = [1.1,1.1;2.1,2.1;1.5,3];
```

Preallocate a cost matrix.

```
cost = zeros(size(predictions,1),size(detections,1));
```

Compute the cost of each prediction matching a detection. The cost here, is defined as the Euclidean distance between the prediction and the detection.

```
for i = 1:size(predictions, 1)
     diff = detections - repmat(predictions(i,:),[size(detections,1),1]);
     cost(i, :) = sqrt(sum(diff .^ 2,2));
end
```

Associate detections with predictions. Detection 1 should match to track 1, and detection 2 should match to track 2. Detection 3 should be unmatched.

```
[assignment,unassignedTracks,unassignedDetections] = ...
          assignDetectionsToTracks(cost,0.2);
  figure;
  plot(predictions(:,1),predictions(:,2),'*',detections(:,1),...
          detections(:,2),'ro');
  hold on;
  legend('predictions','detections');
  for i = 1:size(assignment,1)
    text(predictions(assignment(i, 1),1)+0.1,...
          predictions(assignment(i,1),2)-0.1,num2str(i));
    text(detections(assignment(i, 2),1)+0.1,...
```

```
                detections(assignment(i,2),2)-0.1,num2str(i));
    end
    for i = 1:length(unassignedDetections)
      text(detections(unassignedDetections(i),1)+0.1,...
              detections(unassignedDetections(i),2)+0.1,'unassigned');
    end
    xlim([0,4]);
    ylim([0,4]);
```
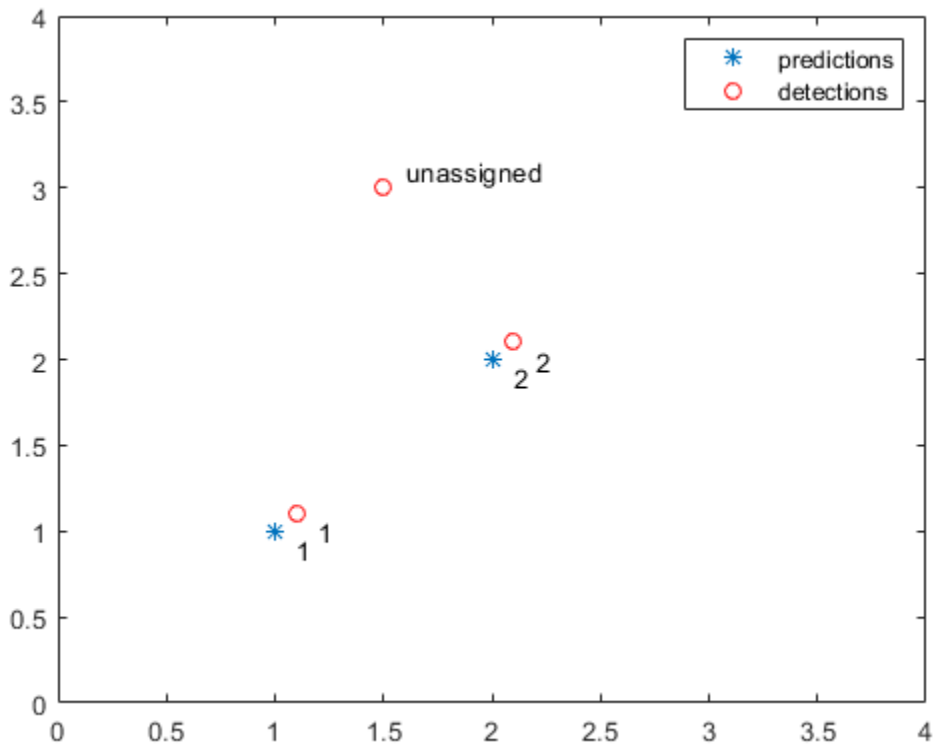
Input Arguments

`costMatrix` — Cost of assigning detection to track
M-by-*N* matrix

Cost of assigning a detection to a track, specified as an *M*-by-*N* matrix, where *M* represents the number of tracks, and *N* is the number of detections. The cost matrix value must be real and nonsparse. The lower the cost, the more likely that a detection gets assigned to a track. Each value represents the cost of assigning the Nth detection to the Mth track. If there is no likelihood of an assignment between a detection and a track, the `costMatrix` input is set to `Inf`. Internally, this function pads the cost matrix with dummy rows and columns to account for the possibility of unassigned tracks and detections. The padded rows represent detections not assigned to any tracks. The padded columns represent tracks not associated with any detections. The function applies the Hungarian assignment algorithm to the padded matrix.
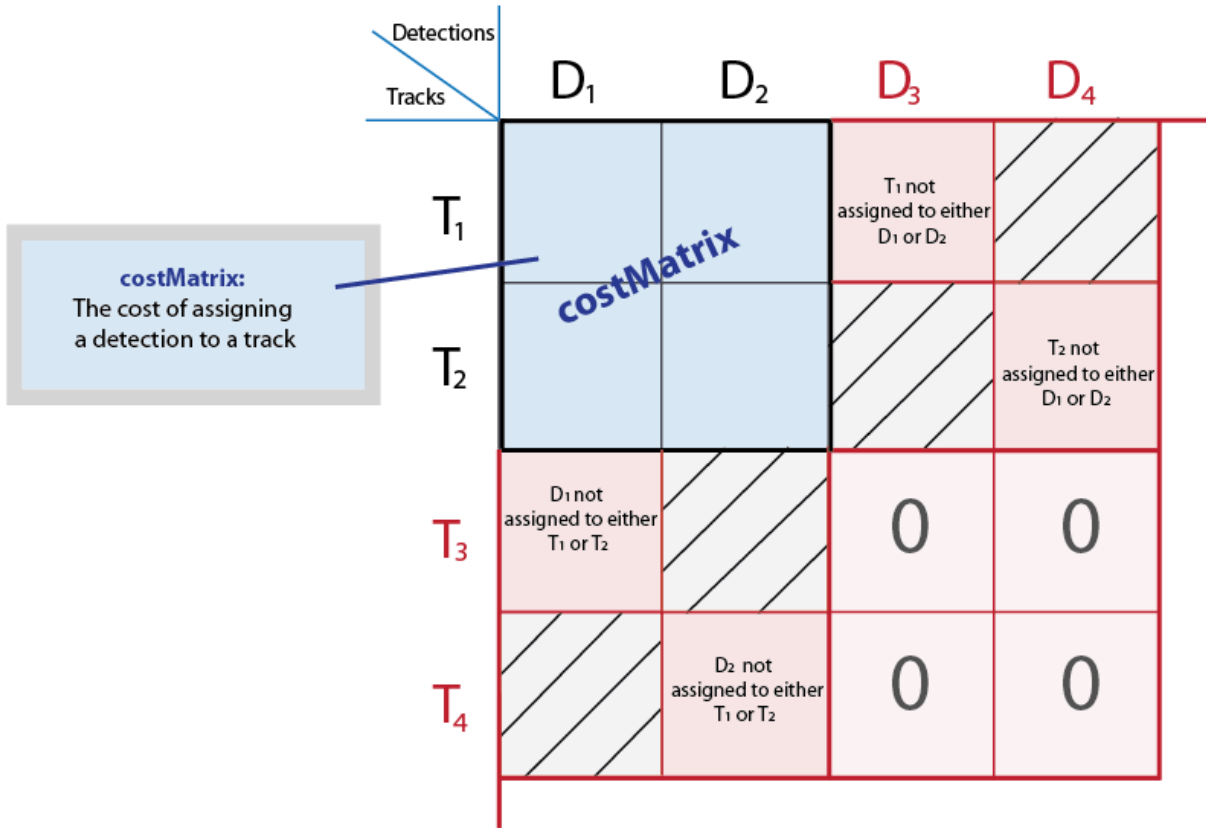
Data Types: `int8` | `uint8` | `int16` | `uint16` | `int32` | `uint32` | `single` | `double`

`costOfNonAssignment` — Cost of not assigning detection to any track or track to any detection
scalar | finite

Cost of not assigning detection to any track or track to detection. You can specify this value as a scalar value representing the cost of a track or a detection remaining unassigned. An unassigned detection may become the start of a new track. If a track is unassigned, the object does not appear. The higher the `costOfNonAssignment` value, the higher the likelihood that every track will be assigned a detection.

Internally, this function pads the cost matrix with dummy rows and columns to account for the possibility of unassigned tracks and detections. The padded rows represent detections not assigned to any tracks. The padded columns represent tracks not associated with any detections. To apply the same value to all elements in both the rows and columns, use the syntax with the `costOfNonAssignment` input. To vary the values for different detections or tracks, use the syntax with the `unassignedTrackCost` and `unassignedDetectionCost` inputs.
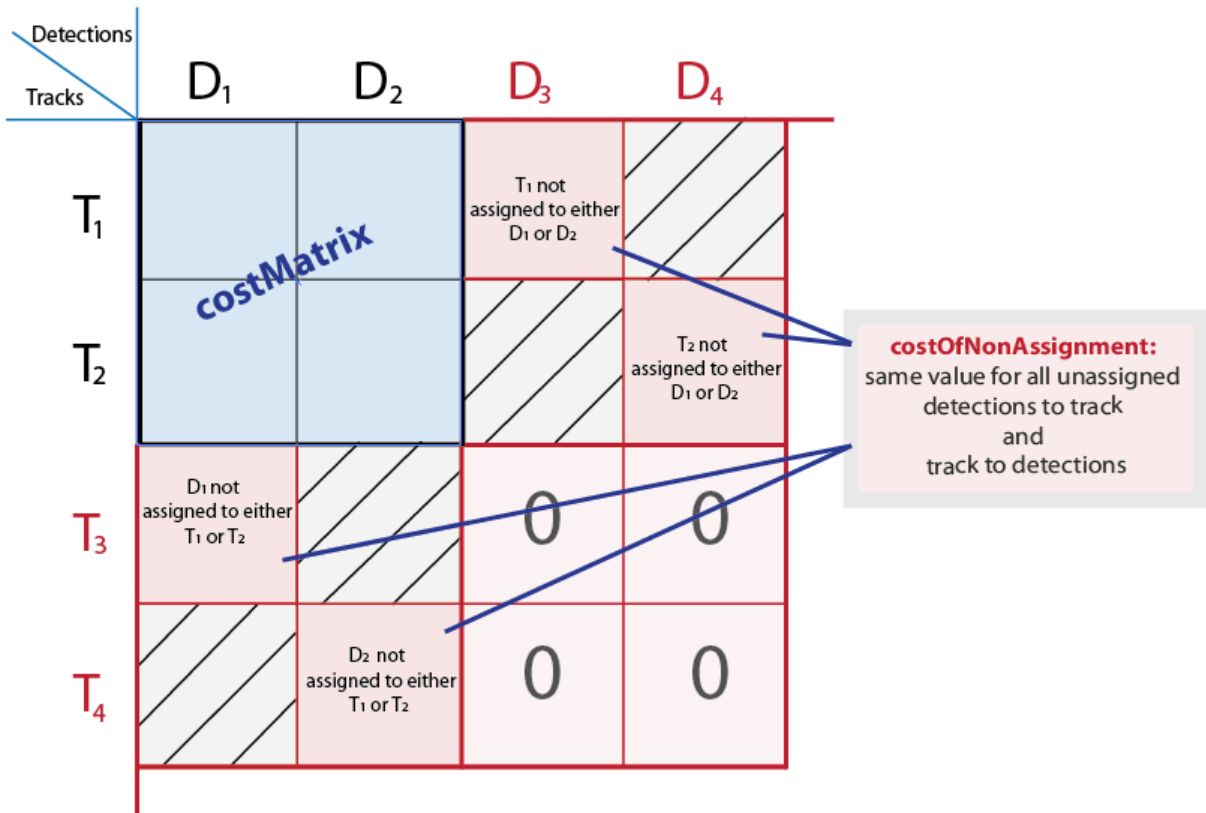
Data Types: `int8` | `uint8` | `int16` | `uint16` | `int32` | `uint32` | `single` | `double`

`unassignedTrackCost` — Cost or likelihood of an unassigned track
M-element vector | scalar | finite

Cost or likelihood of an unassigned track. You can specify this value as a scalar value, or an *M*-element vector, where *M* represents the number of tracks. For the *M*-element vector, each element represents the cost of not assigning any detection to that track. A scalar input represents the same cost of being unassigned for all tracks. The cost may vary depending on what you know about each track and the scene. For example, if an object is about to leave the field of view, the cost of the corresponding track being unassigned should be low.

Internally, this function pads the cost matrix with dummy rows and columns to account for the possibility of unassigned tracks and detections. The padded rows represent detections not assigned to any tracks. The padded columns represent tracks not associated with any detections. To vary the values for different detections or tracks, use the syntax with the `unassignedTrackCost` and `unassignedDetectionCost` inputs. To apply the same value to all elements in both the rows and columns, use the syntax with the `costOfNonAssignment` input.
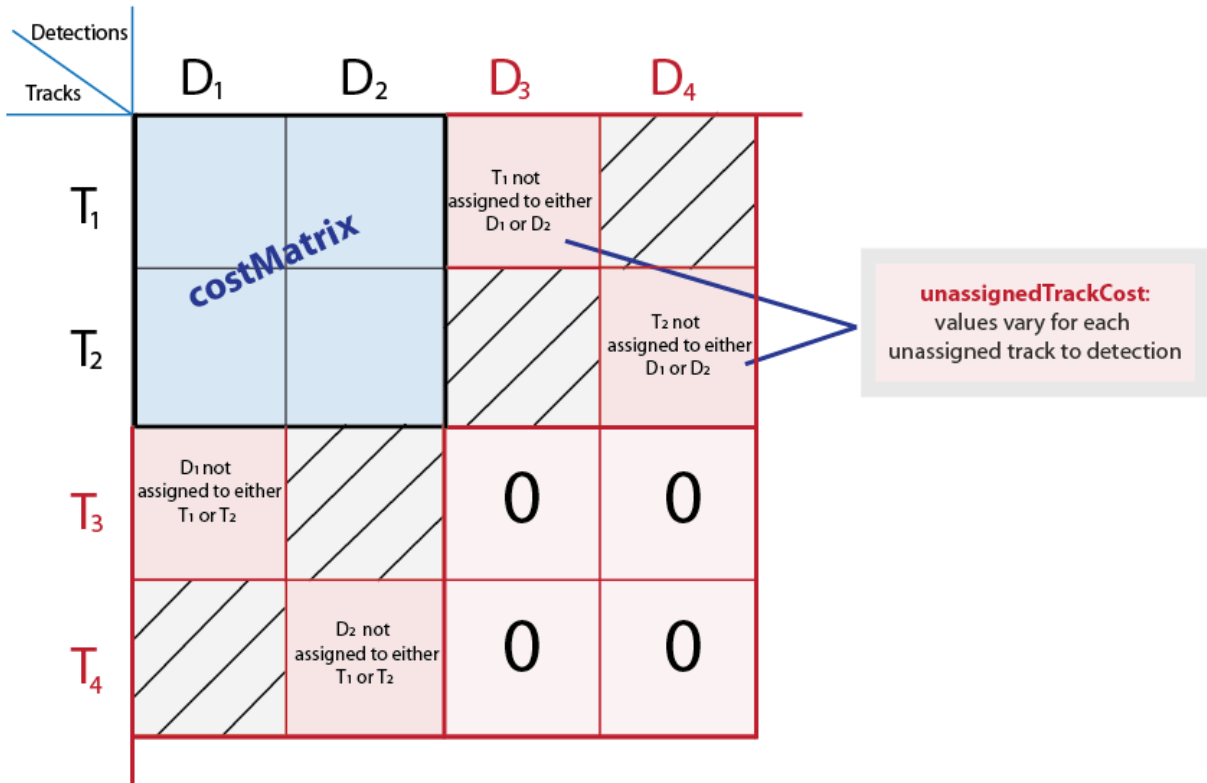
Data Types: `int8` | `uint8` | `int16` | `uint16` | `int32` | `uint32` | `single` | `double`

unassignedDetectionCost — Cost of unassigned detection
N-element vector | scalar | finite

Cost of unassigned detection, specified as a scalar value or an *N*-element vector, where *N* represents the number of detections. For the *N*- element vector, each element represents the cost of starting a new track for that detection. A scalar input represents the same cost of being unassigned for all tracks. The cost may vary depending on what you know about each detection and the scene. For example, if a detection appears close to the edge of the image, it is more likely to be a new object.

Internally, this function pads the cost matrix with dummy rows and columns to account for the possibility of unassigned tracks and detections. The padded rows represent detections not assigned to any tracks. The padded columns represent tracks not

associated with any detections. To vary the values for different detections or tracks, use the syntax with the `unassignedTrackCost` and `unassignedDetectionCost` inputs. To apply the same value to all elements in both the rows and columns, use the syntax with the `costOfNonAssignment` input.

The matrix shows Detections (columns D_1, D_2, D_3, D_4) and Tracks (rows T_1, T_2, T_3, T_4).

costMatrix occupies the T_1, T_2 rows and D_1, D_2 columns.

- T_1 not assigned to either D_1 or D_2
- T_2 not assigned to either D_1 or D_2
- D_1 not assigned to either T_1 or T_2
- D_2 not assigned to either T_1 or T_2

0 0
0 0

unassignedDetectionCost: values vary for each unassigned detecion to track

Data Types: `int8` | `uint8` | `int16` | `uint16` | `int32` | `uint32` | `single` | `double`

Output Arguments

`assignments` — Index pairs of tracks and corresponding detections
L-by-2 matrix

Index pairs of tracks and corresponding detections. This value is returned as an *L*-by-2 matrix of index pairs, with *L* number of pairs. The first column represents the track index and the second column represents the detection index.

Data Types: `uint32`

`unassignedTracks` — Unassigned tracks
P-element vector

Unassigned tracks, returned as a *P*-element vector. *P* represents the number of unassigned tracks. Each element represents a track to which no detections are assigned.

Data Types: `uint32`

`unassignedDetections` — Unassigned detections
Q-element vector

Unassigned detections, returned as a *Q*-element vector, where *Q* represents the number of unassigned detections. Each element represents a detection that was not assigned to any tracks. These detections can begin new tracks.

Data Types: `uint32`

References

[1] Miller, Matt L., Harold S. Stone, and Ingemar J. Cox, "Optimizing Murty's Ranked Assignment Method," *IEEE Transactions on Aerospace and Electronic Systems*, 33(3), 1997.

[2] Munkres, James, "Algorithms for Assignment and Transportation Problems," *Journal of the Society for Industrial and Applied Mathematics*, Volume 5, Number 1, March, 1957.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
configureKalmanFilter | vision.KalmanFilter

Topics
"Multiple Object Tracking"

External Websites
Munkres' Assignment Algorithm Modified for Rectangular Matrices

Introduced in R2012b

bbox2points

Convert rectangle to corner points list

Syntax

```
points = bbox2points(rectangle)
```

Description

`points = bbox2points(rectangle)` converts the input rectangle, specified as [*x y width height*] into a list of four [*x y*] corner points. The `rectangle` input must be either a single bounding box or a set of bounding boxes.

Examples

Convert Bounding Box to List of Points and Apply Rotation

Define a bounding box.

```
bbox = [10,20,50,60];
```

Convert the bounding box to a list of four points.

```
points = bbox2points(bbox);
```

Define a rotation transformation.

```
theta = 10;
tform = affine2d([cosd(theta) -sind(theta) 0; sind(theta) cosd(theta) 0; 0 0 1]);
```

Apply the rotation.

```
points2 = transformPointsForward(tform,points);
```

Close the polygon for display.

```
points2(end+1,:) = points2(1,:);
```

Plot the rotated box.

```
plot(points2(:,1),points2(:,2), '*-');
```
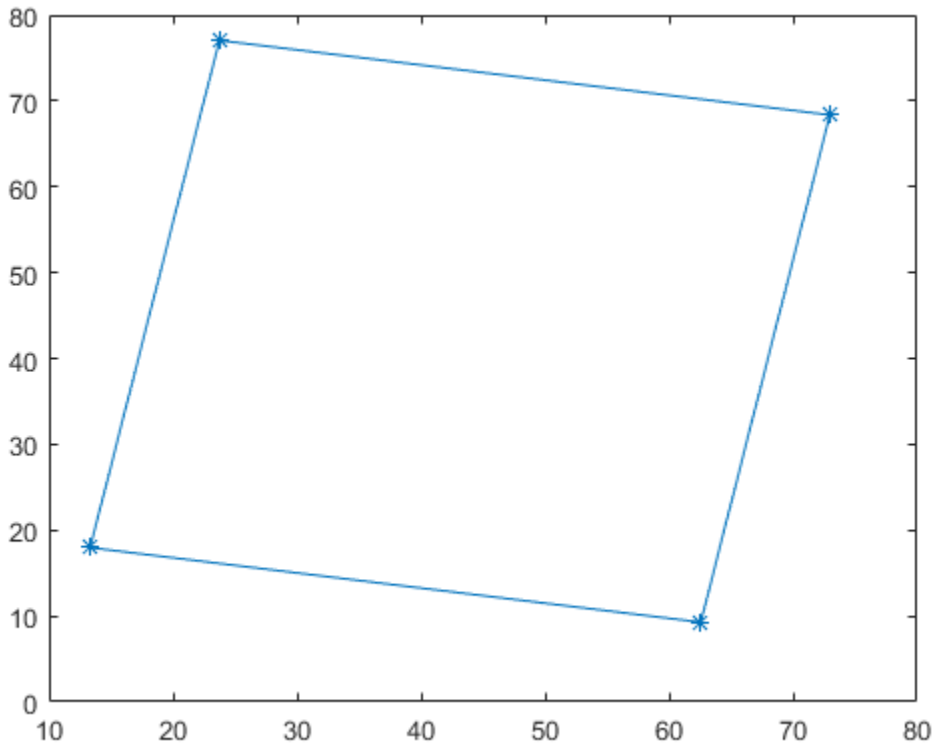

Input Arguments

rectangle — Bounding box
4-element vector | *M*-by-4 matrix

Bounding box, specified as a 4-element vector, [*x y width height*], or a set of bounding boxes, specified as an *M*-by-4 matrix.

Data Types: `single` | `double` | `int16` | `int32` | `uint16` | `uint32`

Output Arguments

`points` — Rectangle corner coordinates
4-by-2 matrix | 4-by-2-by-*M* array

List of rectangle corners, returned as a 4-by-2 matrix of [*x,y*] coordinates, or a 4-by-2-by-*M* array of [*x,y*] coordinates. The output points for the rectangle are listed counterclockwise starting from the upper-left corner.

- For a single input bounding box, the function returns the 4-by-2 matrix.
- For multiple input bounding boxes, the function returns the 4-by-2-*M* array for *M* bounding boxes.

Data Types: `single` | `double` | `int16` | `int32` | `uint16` | `uint32`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`affine2d` | `projective2d`

Introduced in R2014b

bboxOverlapRatio

Compute bounding box overlap ratio

Syntax

```
overlapRatio = bboxOverlapRatio(bboxA,bboxB)
overlapRatio = bboxOverlapRatio(bboxA, bboxB, ratioType)
```

Description

`overlapRatio = bboxOverlapRatio(bboxA,bboxB)` returns the overlap ratio between each pair of bounding boxes `bboxA` and `bboxB`. The function returns the `overlapRatio` value between `0` and `1`, where `1` implies a perfect overlap.

`overlapRatio = bboxOverlapRatio(bboxA, bboxB, ratioType)` additionally lets you specify the method to use for computing the ratio. You must set the `ratioType` to either `'Union'` or `'Min'`.

Examples

Compute the Overlap Ratio Between Two Bounding Boxes

Define two bounding boxes in the format [x y width height].

```
bboxA = [150,80,100,100];
bboxB = bboxA + 50;
```

Display the bounding boxes on an image.

```
I = imread('peppers.png');
RGB = insertShape(I,'FilledRectangle',bboxA,'Color','green');
RGB = insertShape(RGB,'FilledRectangle',bboxB,'Color','yellow');
imshow(RGB)
```

Compute the overlap ratio between the two bounding boxes.

```
overlapRatio = bboxOverlapRatio(bboxA,bboxB)
```

```
overlapRatio = 0.0833
```

Compute Overlap Ratio Between Each Pair of Bounding Boxes

Randomly generate two sets of bounding boxes.

```
bboxA = 10*rand(5,4);
bboxB = 10*rand(10,4);
```

Ensure that the width and height of the boxes are positive.

```
bboxA(:,3:4) = bboxA(:,3:4) + 10;
bboxB(:,3:4) = bboxB(:,3:4) + 10;
```

Compute the overlap ratio between each pair.

```
overlapRatio = bboxOverlapRatio(bboxA,bboxB)
```

overlapRatio = *5×10*

```
    0.2431    0.2329    0.3418    0.5117    0.7972    0.1567    0.1789    0.4339    0.0
    0.3420    0.1655    0.7375    0.5188    0.2786    0.3050    0.2969    0.4350    0.2
    0.4844    0.3290    0.3448    0.1500    0.1854    0.4976    0.5629    0.4430    0.5
    0.3681    0.0825    0.3499    0.0840    0.0658    0.5921    0.6498    0.1930    0.7
    0.3752    0.1114    0.3114    0.0696    0.0654    0.5408    0.6234    0.2046    0.7
```

Input Arguments

bboxA — Bounding box
M-by-4 matrix

Bounding box, specified as an *M*-by-4 matrix. Each row of bboxA contains a vector in the format [*x y width height*], where *x* and *y* correspond to the upper left corner of the bounding box. Bounding boxes inputs bboxA and bboxB must be real, finite, and nonsparse.

Data Types: single | double | int8 | int16 | int32 | uint8 | uint16 | uint32

bboxB — Bounding box
M-by-4 matrix

Bounding box, specified as an *M*-by-4 matrix. Each row of bboxB contains a vector in the format [*x y width height*], where *x* and *y* correspond to the upper left corner of the bounding box. Bounding boxes inputs bboxA and bboxB must be real, finite, and nonsparse.

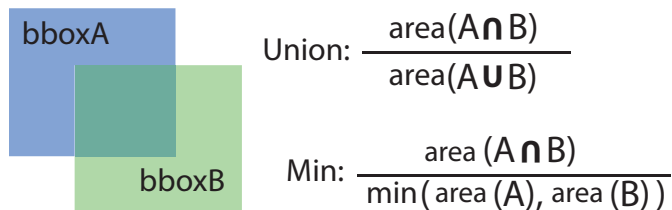Data Types: single | double | int8 | int16 | int32 | uint8 | uint16 | uint32

ratioType — Ratio type
'Union' (default) | 'Min'

Ratio type, specified as the character vector `'Union'` or `'Min'`.

- Set the ratio type to `'Union'` to compute the ratio as the area of intersection between bboxA and bboxB, divided by the area of the union of the two.

- Set the ratio type to `'Min'` to compute the ratio as the area of intersection between bboxA and bboxB, divided by the minimum area of the two bounding boxes.
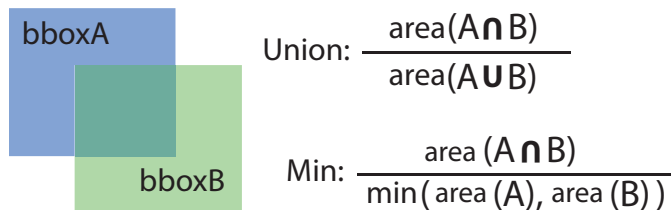

$$\text{Union:} \quad \frac{\text{area}(A \cap B)}{\text{area}(A \cup B)}$$

$$\text{Min:} \quad \frac{\text{area}(A \cap B)}{\min(\text{area}(A),\ \text{area}(B))}$$

Data Types: `char`

Output Arguments

`overlapRatio` — Overlap ratio between two bounding boxes
M-by-*N* matrix

Overlap ratio between two bounding boxes, returned as an *M*-by-*N* matrix. Each (I, J) element in the output matrix corresponds to the overlap ratio between row I in bboxA and row J in bboxB. The function returns `overlapRatio` in the between 0 and 1, where 1 implies a perfect overlap. If either bboxA or bboxB is double, then the function returns `overlapRatio` as `double`. Otherwise, the function returns it as `single`.

The function computes the overlap ratio based on the ratio type. You can set `ratioType` to `'Union'` or `'Min'`:

$$\text{Union:} \quad \frac{\text{area}(A \cap B)}{\text{area}(A \cup B)}$$

$$\text{Min:} \quad \frac{\text{area}(A \cap B)}{\min(\text{area}(A),\ \text{area}(B))}$$

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

See Also
bboxPrecisionRecall | selectStrongestBbox

Topics
"Multiple Object Tracking"

Introduced in R2014b

bboxPrecisionRecall

Compute bounding box precision and recall against ground truth

Syntax

```
[precision,recall] = bboxPrecisionRecall(bboxes,groundTruthBboxes)
[precision,recall] = bboxPrecisionRecall(bboxes,groundTruthBboxes,
threshold)
```

Description

`[precision,recall] = bboxPrecisionRecall(bboxes,groundTruthBboxes)` measures the accuracy of bounding box overlap between `bboxes` and `groundTruthBboxes`. Precision is a ratio of true positive instances to all positive instances of objects in the detector, based on the ground truth. Recall is a ratio of true positive instances to the sum of true positives and false negatives in the detector, based on the ground truth.

If the bounding box is associated with a class label, `precision` and `recall` contain metrics for each class. If the bounding box is also associated with a confidence score for ranking, use the `evaluateDetectionPrecision` function.

`[precision,recall] = bboxPrecisionRecall(bboxes,groundTruthBboxes, threshold)` specifies the overlap threshold for assigning a given box to a ground truth box.

Examples

Evaluate Bounding Box Overlap Accuracy

Create two ground truth boxes.

```
groundTruthBoxes = [2 2 10 20; 80 80 30 40];
```

Create three boxes for evaluation.

```
boundingBoxes = [4 4 10 20; 50 50 30 10; 90 90 40 50];
```

Plot the boxes.

```
figure
hold on
for i=1:2
    rectangle('Position',groundTruthBoxes(i,:),'EdgeColor','r');
end
for i=1:3
    rectangle('Position',boundingBoxes(i,:),'EdgeColor','b');
end
```
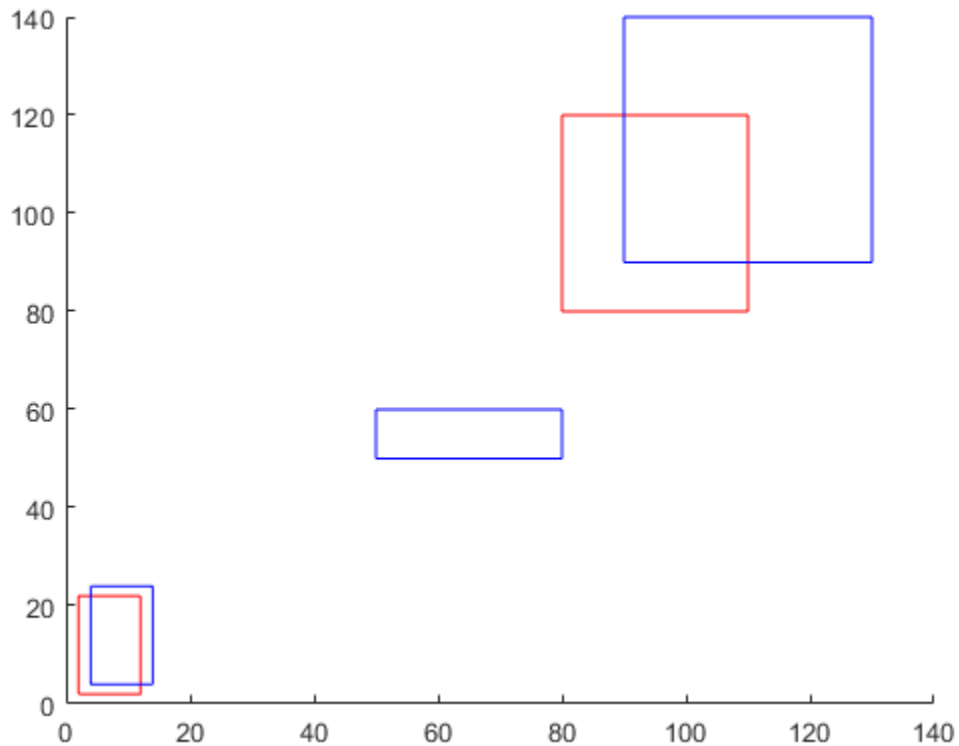
Evaluate the overlap accuracy against the ground truth data.

```
[precision,recall] = bboxPrecisionRecall(boundingBoxes,groundTruthBoxes)

precision = 0.3333

recall = 0.5000
```

Input Arguments

bboxes — Bounding boxes
M-by-4 matrix | table with *M* rows

Bounding boxes, specified as one of the following. *M* is the number of bounding boxes.

- For single-class bounding boxes, bboxes can be an *M*-by-4 matrix, or a table with *M* rows and one column. Each row of the matrix or element in the table represents a bounding box, specified in the format [*x y width height*], where *x* and *y* correspond to the upper left corner of the bounding box.

- For multi-class bounding boxes, bboxes is a table with *M* rows and two columns. Each element in the first column represents a bounding box, specified in the format [*x y width height*]. The second column contains the predicted label for each box. The label must be a categorical type defined by the variable (column) names of the groundTruthBboxes table.

Data Types: single | double | int8 | int16 | int32 | uint8 | uint16 | uint32

groundTruthBboxes — Ground truth bounding boxes
M-by-4 matrix | table with *M* rows

Ground truth bounding boxes, specified as one of the following. *M* is the number of ground truth bounding boxes.

- For single-class bounding boxes, groundTruthBboxes can be an *M*-by-4 matrix, or a table with *M* rows and one column. Each row of the matrix or element in the table represents a bounding box, specified in the format [*x y width height*], where *x* and *y* correspond to the upper left corner of the bounding box.

- For multi-class bounding boxes, groundTruthBboxes is a table with *M* rows and multiple columns. Each column represents a different class, and the column name specifies the class label. Each element in the table has the format [*x y width height*].

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32`

`threshold` — Overlap threshold
`0.5` | numeric scalar

Overlap threshold for assigned a detection to a ground truth box, specified as a numeric scalar. The overlap ratio is computed as the intersection over union.

Output Arguments

`precision` — Precision values from each detection
numeric scalar | numeric vector

Precision values from each detection, returned as a numeric scalar for single-class bounding boxes. For multi-class bounding boxes, `precision` is returned as a numeric vector consisting of metrics for each class. The class order follows the same column order as the `groundTruthBboxes` table.

`recall` — Recall values from each detection
numeric scalar | numeric vector

Recall values from each detection, returned as a numeric scalar for single-class bounding boxes. For multi-class bounding boxes, `recall` is returned as a numeric vector consisting of metrics for each class. The class order follows the same column order as the `groundTruthBboxes` table.

See Also

`bboxOverlapRatio` | `evaluateDetectionPrecision`

Introduced in R2018a

bundleAdjustment

Refine camera poses and 3-D points

Syntax

```
[xyzRefinedPoints,refinedPoses] = bundleAdjustment(xyzPoints,
pointTracks,cameraPoses,cameraParams)
[ ___ ,reprojectionErrors] = bundleAdjustment( ___ )
[ ___ ] = bundleAdjustment( ___ ,Name,Value)
```

Description

`[xyzRefinedPoints,refinedPoses] = bundleAdjustment(xyzPoints,` `pointTracks,cameraPoses,cameraParams)` returns the refined 3-D points and camera poses that minimize reprojection errors. The refinement procedure is a variant of the Levenberg-Marquardt algorithm.

`[ ___ ,reprojectionErrors] = bundleAdjustment( ___ )` additionally returns reprojection errors for each 3-D world point using the arguments from the previous syntax.

`[ ___ ] = bundleAdjustment( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

Code Generation Support:
Supports Code Generation: No
Supports MATLAB Function block: No
"Code Generation Support, Usage Notes, and Limitations"

Examples

Refine Camera Poses and 3-D Points

Load data for initialization.

```
load('sfmGlobe');
```

Refine the camera poses and points.

```
[xyzRefinedPoints,refinedPoses] = ...
    bundleAdjustment(xyzPoints,pointTracks,cameraPoses,cameraParams);
```

Display the refined camera poses and 3-D world points.

```
cameraSize = 0.1;
for j = 1:height(refinedPoses)
    id = refinedPoses.ViewId(j);
    loc = refinedPoses.Location{j};
    orient = refinedPoses.Orientation{j};
    plotCamera('Location',loc,'Orientation',orient,'Size',...
        cameraSize,'Color','r','Label',num2str(id),'Opacity',.5);
    hold on
end
pcshow(xyzRefinedPoints,'VerticalAxis','y','VerticalAxisDir',...
    'down','MarkerSize',45);
grid on
```
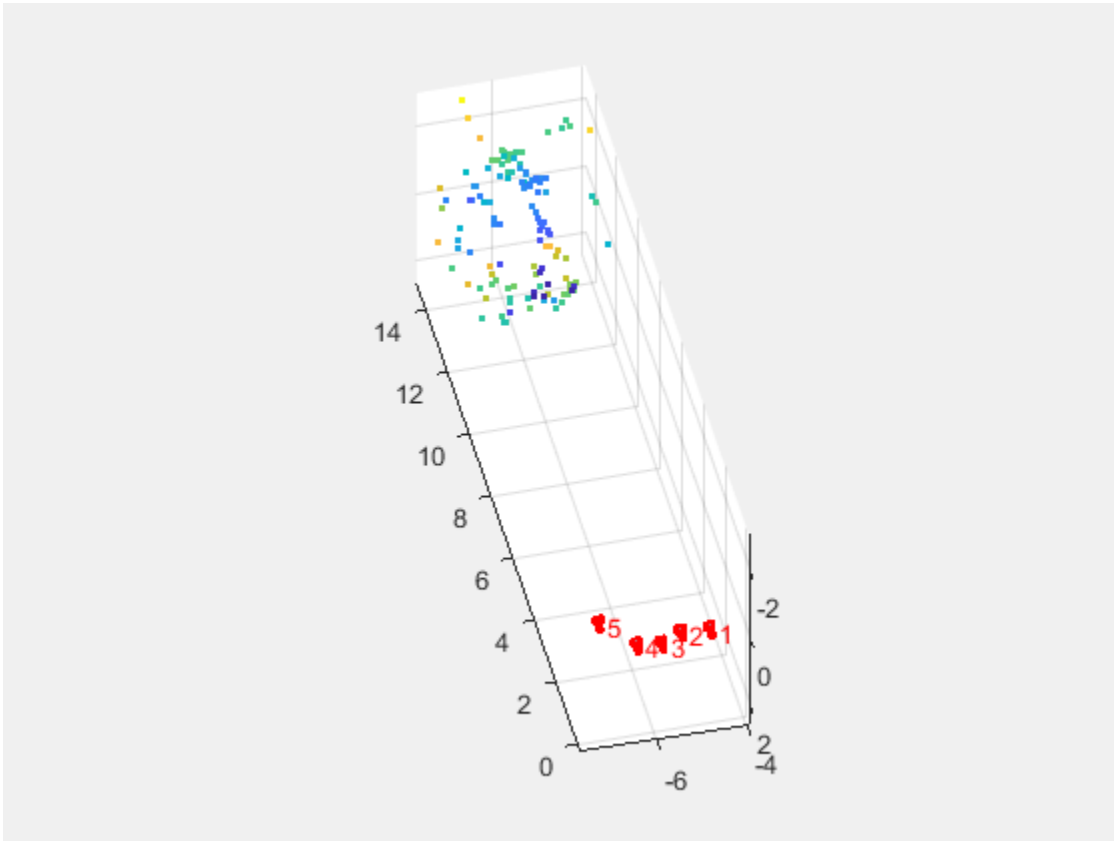
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

xyzPoints — Unrefined 3-D points
M-by-3 matrix

Unrefined 3-D points, specified as an *M*-by-3 matrix of [*x*,*y*,*z*] locations.

pointTracks — Matching points across multiple images
N-element array of `pointTrack` objects

Matching points across multiple images, specified as an *N*-element array of `pointTrack` objects. Each element contains two or more matching points across multiple images.

cameraPoses — Camera pose information
three-column table

Camera pose `ViewId`, `Orientation`, and `Location` information, specified as a three-column table. The view IDs relate to the IDs in the `pointTracks` object. The orientations are specified as 3-by-3 rotation matrices. The locations are specified as a three-element vectors.

cameraParams — Object for storing camera parameters
`cameraParameters` object | `cameraIntrinsics` object

Camera parameters, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: `'MaxIterations','50'`

MaxIterations — Maximum number of iterations
50 (default) | positive integer

Maximum number of iterations before the Levenberg-Marquardt algorithm stops, specified as the comma-separated pair consisting of '`MaxIterations`' and a positive integer.

AbsoluteTolerance — Absolute termination tolerance
1.0 (default) | positive scalar

Absolute termination tolerance of the mean squared reprojection error in pixels, specified as the comma-separated pair consisting of 'AbsoluteTolerance' and a positive scalar.

RelativeTolerance — Relative termination tolerance
1e-5 (default) | positive scalar

Relative termination tolerance of the reduction in reprojection error between iterations, specified as the comma-separated pair consisting of 'RelativeTolerance' and a positive scalar.

PointsUndistorted — Flag to indicate lens distortion
false (default) | true

Flag to indicate lens distortion, specified as the comma-separated pair consisting of 'PointsUndistorted' and either false or true. When you set PointsUndistorted to false, the 2-D points in pointTracks must be from images with lens distortion. To use undistorted points, use the undistortImage function first, then set PointsUndistorted to true.

FixedViewIDs — View IDs for fixed camera pose
[] (default) | vector of nonnegative integers

View IDs for fixed camera pose, specified as the comma-separated pair consisting of 'FixedViewIDs' and a vector of nonnegative integers. Each ID corresponds to the ViewId of a fixed camera pose in cameraPoses. An empty value for FixedViewIDs means that all camera poses are optimized.

Verbose — Display progress information
False (default) | true

Display progress information, specified as the comma-separated pair consisting of 'Verbose' and either false or true.

Output Arguments

xyzRefinedPoints — 3-D locations of refined world points
M-by-3 matrix

3-D locations of refined world points, returned as an *M*-by-3 matrix of [*x*,*y*, *z*] locations.

Data Types: single | double

`refinedPoses` — Refined camera poses
three-column table

Refined camera poses, returned as a table. The table contains three columns for `'ViewId'`, `'Orientation'`, and `'Location'`.

`reprojectionErrors` — Reprojection errors
M-by-1 vector

Reprojection errors, returned as an *M*-by-1 vector. The function projects each world point back into each camera. Then in each image, the function calculates the reprojection error as the distance between the detected and the reprojected point. The `reprojectionErrors` vector contains the average reprojection error for each world point.
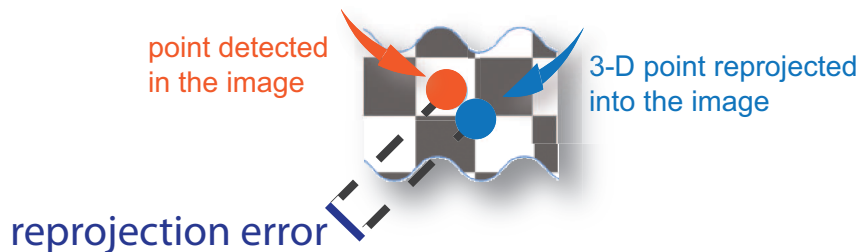
References

[1] Lourakis, M.I.A., and A.A. Argyros. "SBA: A Software Package for Generic Sparse Bundle Adjustment." *ACM Transactions on Mathematical Software*. 2009.

[2] Hartley, R., and A. Zisserman. *Multiple View Geometry in Computer Vision*. Cambridge University Press, 2003.

[3] Triggs, B., P. McLauchlan, R. Hartley, and A. Fitzgibbon. "Bundle Adjustment: A Modern Synthesis." *Proceedings of the International Workshop on Vision Algorithms*. Springer-Verlag. 1999, pp. 298-372.

See Also

cameraIntrinsics | cameraMatrix | cameraParameters | pointTrack | relativeCameraPose | triangulateMultiview | undistortImage | undistortPoints | viewSet

Topics

"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Code Generation for Depth Estimation From Stereo Video"
"Structure from Motion"

Introduced in R2016a

OCR Trainer

Train an optical character recognition model to recognize a specific set of characters

Description

The **OCR Trainer** app allows you to label character data for OCR training interactively and to generate an OCR language data file for use with the `ocr` function.

Open the OCR Trainer App

- MATLAB Toolstrip: On the **Apps** tab, under **Image Processing and Computer Vision**, click the app icon.
- MATLAB command prompt: Enter `ocrTrainer`.

Programmatic Use

`ocrTrainer` opens the OCR Trainer app.

`ocrTrainer(sessionFile)` opens the app and loads a saved OCR training session. `sessionFile` is the path to the MAT file containing the saved session.

See Also

`ocr`

Topics

"Train Optical Character Recognition for Custom Fonts"

Introduced in R2016a

listTrueTypeFonts

List available TrueType fonts

Syntax

```
fontNames = listTrueTypeFonts
```

Description

`fontNames = listTrueTypeFonts` returns a cell array of sorted TrueType font names installed on the system.

Examples

List Available TrueType Fonts

```
listTrueTypeFonts

ans = 388x1 cell array
    {'Agency FB'                }
    {'Agency FB Bold'           }
    {'Algerian'                 }
    {'Arial'                    }
    {'Arial Black'              }
    {'Arial Bold'               }
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    {'Arial Narrow Bold Italic' }
    {'Arial Narrow Italic'      }
    {'Arial Rounded MT Bold'    }
    {'Arial Unicode MS'         }
    {'Baskerville Old Face'     }
    {'Bauhaus 93'               }
```

```
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```

```
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```

```
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```

```
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{'Yu Gothic UI Regular'          }
{'Yu Gothic UI Semibold'         }
{'Yu Gothic UI Semilight'        }
{'YuGothic'                      }
{'YuGothic Bold'                 }
```

List All TrueType 'Lucida' Fonts

```
fontNames = listTrueTypeFonts;
LucidaFonts = fontNames(~cellfun(@isempty,regexp(fontNames,'^Lucida')))
```

```
LucidaFonts = 28x1 cell array
    {'Lucida Bright'                }
    {'Lucida Bright Demibold'       }
    {'Lucida Bright Demibold Italic' }
    {'Lucida Bright Italic'         }
    {'Lucida Calligraphy Italic'    }
    {'Lucida Console'               }
    {'Lucida Fax Demibold'          }
    {'Lucida Fax Demibold Italic'   }
    {'Lucida Fax Italic'            }
    {'Lucida Fax Regular'           }
    {'Lucida Handwriting Italic'    }
    {'Lucida Sans Demibold Italic'  }
    {'Lucida Sans Demibold Roman'   }
    {'Lucida Sans Italic'           }
```

```
{'Lucida Sans Regular'             }
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{'LucidaBrightRegular'             }
{'LucidaSansDemiBold'              }
{'LucidaSansRegular'               }
{'LucidaTypewriterBold'            }
{'LucidaTypewriterRegular'         }
```

Output Arguments

`fontNames` — Available TrueType fonts on system
cell array

Available TrueType fonts on system, returned as a cell array of sorted TrueType font names.

See Also

`insertObjectAnnotation` | `insertText` | `listfonts`

Introduced in R2015b

pcfromkinect

Point cloud from Kinect for Windows

Syntax

```
ptCloud = pcfromkinect(depthDevice,depthImage)
ptCloud = pcfromkinect(depthDevice,depthImage,colorImage)
ptCloud = pcfromkinect(depthDevice,depthImage,colorImage,alignment)
```

Description

ptCloud = pcfromkinect(depthDevice,depthImage) returns a point cloud from a Kinect depth image. The depthDevice input can be either a videoinput object or an imaq.VideoDevice object configured for Kinect (Versions 1 and 2) for Windows.

This function requires the Image Acquisition Toolbox™ software, which supports Kinect for Windows.

ptCloud = pcfromkinect(depthDevice,depthImage,colorImage) adds color to the returned point cloud, specified by the colorImage input.

The Kinect for Windows system, designed for gaming, produces depthImage and colorImage as mirror images of the scene. The returned point cloud is corrected to match the actual scene.

ptCloud = pcfromkinect(depthDevice,depthImage,colorImage,alignment) additionally returns the color point cloud with the origin specified at the center of the depth camera.

Examples

Plot Color Point Cloud from Kinect for Windows

Plot a color point cloud from Kinect images. This example requires the Image Acquisition Toolbox software and the Kinect camera and a connection to the camera.

Create a System object for the color device.

```
colorDevice = imaq.VideoDevice('kinect',1)
```

Create a System object for the depth device.

```
depthDevice = imaq.VideoDevice('kinect',2)
```

Initialize the camera.

```
step(colorDevice);
step(depthDevice);
```

Load one frame from the device.

```
colorImage = step(colorDevice);
depthImage = step(depthDevice);
```

Extract the point cloud.

```
ptCloud = pcfromkinect(depthDevice,depthImage,colorImage);
```

Initialize a point cloud player to visualize 3-D point cloud data. The axis is set appropriately to visualize the point cloud from Kinect.

```
player = pcplayer(ptCloud.XLimits,ptCloud.YLimits,ptCloud.ZLimits,...
    'VerticalAxis','y','VerticalAxisDir','down');

xlabel(player.Axes,'X (m)');
ylabel(player.Axes,'Y (m)');
zlabel(player.Axes,'Z (m)');
```

Acquire and view 500 frames of live Kinect point cloud data.

```
for i = 1:500
   colorImage = step(colorDevice);
   depthImage = step(depthDevice);

   ptCloud = pcfromkinect(depthDevice,depthImage,colorImage);
```

```
    view(player,ptCloud);
end
```
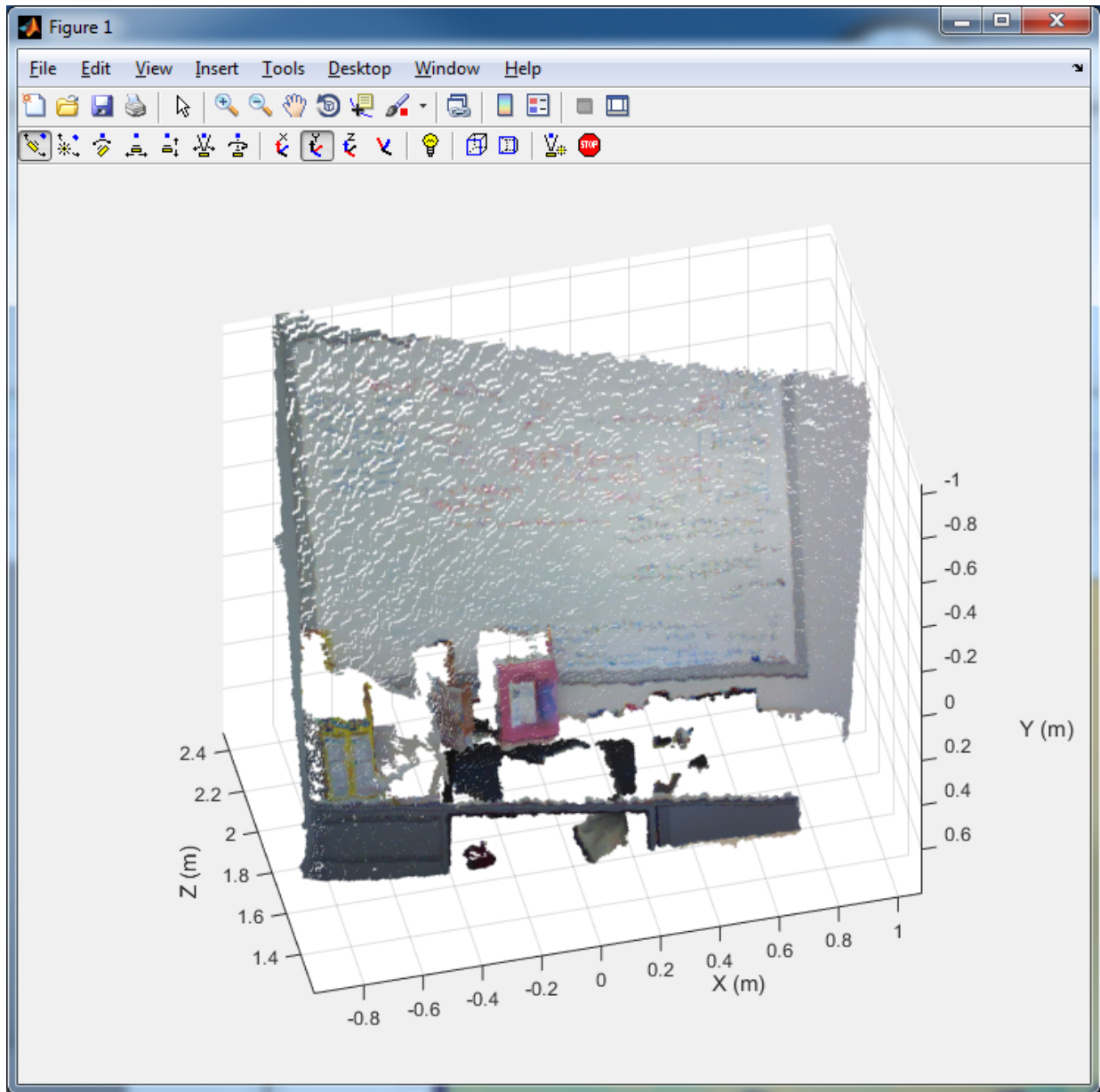
Release the objects.

```
release(colorDevice);
release(depthDevice);
```

*   "Structure From Motion From Two Views"
*   "Depth Estimation From Stereo Video"

Input Arguments

depthDevice — Input video object
videoinput object | imaq.VideoDevice object

Input video object, specified as either a videoinput object or an imaq.VideoDevice object configured for Kinect for Windows.

depthImage — Depth image
M-by-*N* matrix

Depth image, specified as an *M*-by-*N* pixel matrix. The original images, depthImage and colorImage, from Kinect are mirror images of the scene.

The Kinect depth camera has limited range. The limited range of the Kinect depth camera can cause pixel values in the depth image to not have corresponding 3-D coordinates. These missing pixel values are set to NaN in the Location property of the returned point cloud.

Data Types: uint16

colorImage — Color image
M-by-*N*-by-3 RGB truecolor image

Color image, specified as an *M*-by-*N*-by-3 RGB truecolor image that the Kinect returns. The original images, depthImage and colorImage, from Kinect are mirror images of the scene.

Data Types: uint8

alignment — Direction of the image coordinate system
'colorCentric' (default) | 'depthCentric'

Direction of the image coordinate system, specified as the character vector 'colorCentric' or 'depthCentric'. Set this value to 'colorCentric' to align

depthImage with `colorImage`. Set `alignment` to `'depthCentric'` to align `colorImage` with `depthImage`.

The origin of a right-handed world coordinate system is at the center of the depth camera. The *x*-axis of the coordinate system points to the right, the *y*-axis points downward, and the *z*-axis points from the camera.
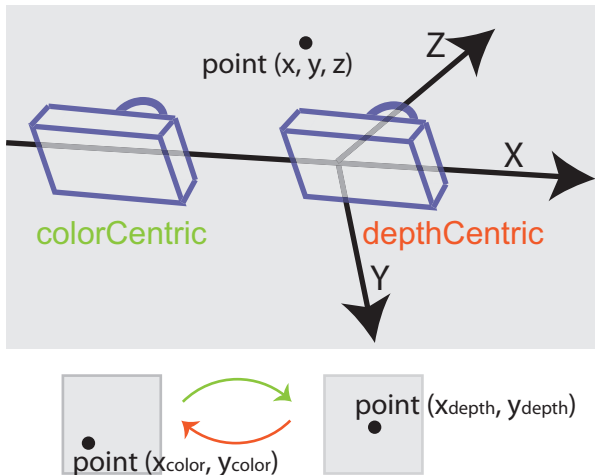
Note For consistency across Computer Vision System Toolbox use of coordinates systems, the coordinate system defined by this function is different from the one defined by Kinect Skeletal metadata.

Output Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, returned as a `pointCloud` object. The origin of the coordinate system of the returned point cloud is at the center of the depth camera.

See Also

pcdenoise | pcdownsample | pcfitplane | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pcwrite | planeModel | plot3 | pointCloud | reconstructScene | scatter3 | triangulate

Topics

"Structure From Motion From Two Views"
"Depth Estimation From Stereo Video"
"Coordinate Systems"

Introduced in R2015b

Camera Calibrator

Estimate geometric parameters of a single camera

Description

The **Camera Calibrator** app allows you to estimate camera intrinsics, extrinsics, and lens distortion parameters. You can use these camera parameters for various computer vision applications. These applications include removing the effects of lens distortion from an image, measuring planar objects, or reconstructing 3-D scenes from multiple cameras.

Open the Camera Calibrator App

- MATLAB Toolstrip: On the **Apps** tab, under **Image Processing and Computer Vision**, click the app icon.
- MATLAB command prompt: Enter `cameraCalibrator`.

Examples

Open Camera Calibrator App

This example shows you the two ways to open the Camera Calibrator app.

Type `cameraCalibrator` on the MATLAB command line or select it from the MATLAB desktop **Apps** tab.

- "Evaluating the Accuracy of Single Camera Calibration"
- "Measuring Planar Objects with a Calibrated Camera"
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"
- "Depth Estimation From Stereo Video"

Programmatic Use

`cameraCalibrator` opens the Camera Calibrator app, which enables you to compute parameters needed to remove the effects of lens distortion from an image.

`cameraCalibrator(imageFolder,squareSize)` invokes the camera calibration app and loads calibration images from the `imageFolder`. The `squareSize` input must be a scalar in millimeters that specifies the size of the checkerboard square in the calibration pattern.

`cameraCalibrator(sessionFile)` invokes the app and loads a saved camera calibration session. Set the `sessionFile` to the name of the saved session file. The name must include the path to the MAT file containing the saved session.

See Also

Apps
Stereo Camera Calibrator

Classes
`cameraParameters` | `stereoParameters`

Functions
`detectCheckerboardPoints` | `estimateCameraParameters` | `extrinsics` | `generateCheckerboardPoints` | `rectifyStereoImages` | `showExtrinsics` | `showReprojectionErrors` | `triangulate` | `undistortImage`

Topics
"Evaluating the Accuracy of Single Camera Calibration"
"Measuring Planar Objects with a Calibrated Camera"
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Depth Estimation From Stereo Video"
"What Is Camera Calibration?"
"Single Camera Calibrator App"
"Stereo Camera Calibrator App"

Introduced in R2013b

Stereo Camera Calibrator

Estimate geometric parameters of a stereo camera

Description

The **Stereo Camera Calibrator** app allows you to estimate the intrinsic and extrinsic parameters of each camera in a stereo pair. You can also use the app to estimate the translation and rotation between the two cameras.

Open the Stereo Camera Calibrator App

- MATLAB Toolstrip: On the **Apps** tab, under **Image Processing and Computer Vision**, click the app icon.
- MATLAB command prompt: Enter `stereoCameraCalibrator`.

Examples

Open Stereo Camera Calibrator App

This example shows you the two ways to open the Stereo Camera Calibrator app.

Type `stereocameraCalibrator` on the MATLAB command line or select it from the MATLAB desktop **Apps** tab.

- "Evaluating the Accuracy of Single Camera Calibration"
- "Measuring Planar Objects with a Calibrated Camera"
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"
- "Depth Estimation From Stereo Video"

Programmatic Use

`stereoCameraCalibrator` opens the Stereo Camera Calibrator app. You can use this app to estimate the intrinsic and extrinsic parameters of each camera in a stereo pair. You can also use the app to estimate the translation and rotation between the two cameras.

`stereoCameraCalibrator(folder1,folder2,squareSize)` opens the Stereo Camera Calibrator app and loads the stereo calibration images. The app uses the checkerboard square size specified by the `squareSize` input. It also uses `folder1` images for camera 1 and `folder2` for camera 2.

`stereoCameraCalibrator(folder1,folder2,squareSize,squareSizeUnits)` additionally specifies the units of the square size. If you do not specify units, the app sets `squareSizeUnits` to `'millimeters'`. Units can be `'millimeters'`, `'centimeters'`, or `'inches'`.

`stereoCameraCalibrator(sessionFile)` opens the app and loads a saved stereo calibration session. Set the `sessionFile` to the name of the saved session MAT-file.

See Also
Camera Calibrator | cameraParameters | detectCheckerboardPoints | estimateCameraParameters | generateCheckerboardPoints | showExtrinsics | showReprojectionErrors | stereoParameters | undistortImage

Topics
"Evaluating the Accuracy of Single Camera Calibration"
"Measuring Planar Objects with a Calibrated Camera"
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Depth Estimation From Stereo Video"
"What Is Camera Calibration?"
"Single Camera Calibrator App"
"Stereo Camera Calibrator App"

Introduced in R2014b

cameraMatrix

Camera projection matrix

Syntax

```
camMatrix = cameraMatrix(cameraParams,rotationMatrix,
translationVector)
```

Description

`camMatrix = cameraMatrix(cameraParams,rotationMatrix, translationVector)` returns a 4-by-3 camera projection matrix. You can use this matrix to project 3-D world points in homogeneous coordinates into an image.

Examples

Compute Camera Matrix

Create a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','slr'));
```

Detect the checkerboard corners in the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate the world coordinates of the checkerboard corners in the pattern-centric coordinate system, with the upper-left corner at (0,0). The square size is in millimeters.

```
squareSize = 29;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the camera.

```
I = readimage(images,1);
imageSize = [size(I,1),size(I,2)];
cameraParams = estimateCameraParameters(imagePoints,worldPoints, ...
                                        'ImageSize',imageSize);
```

Load image at new location.

```
imOrig = imread(fullfile(matlabroot,'toolbox','vision','visiondata', ...
    'calibration','slr','image9.jpg'));
figure; imshow(imOrig);
title('Input Image');
```


Input Image

Undistort image.

```
im = undistortImage(imOrig,cameraParams);
```

Find reference object in new image.

```
[imagePoints,boardSize] = detectCheckerboardPoints(im);
```

Compute new extrinsics.

```
[rotationMatrix,translationVector] = extrinsics(...
    imagePoints,worldPoints,cameraParams);
```

Calculate camera matrix

```
P = cameraMatrix(cameraParams,rotationMatrix,translationVector)
```

```
P =

  1.0e+05 *

    0.0157   -0.0271    0.0000
    0.0404   -0.0046   -0.0000
    0.0199    0.0387    0.0000
    8.9399    9.4399    0.0072
```

- "Evaluating the Accuracy of Single Camera Calibration"
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"
- "Depth Estimation From Stereo Video"
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

cameraParams — Object for storing camera parameters
cameraParameters object | cameraIntrinsics object

Camera parameters, specified as a cameraParameters or cameraIntrinsics object. You can return the cameraParameters object using the estimateCameraParameters function. The cameraParameters object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

rotationMatrix — Rotation of camera
3-by-3 matrix

Rotation of camera, specified as a 3-by-3 matrix. You can obtain this matrix using the `extrinsics` function. You can also obtain the matrix using the `relativeCameraPose` function by transposing its `orientation` output. The `rotationMatrix` and `translationVector` inputs must be real, nonsparse, and of the same class.

translationVector — Translation of camera
1-by-3 vector

Translation of camera, specified as a 1-by-3 vector. The translation vector describes the transformation from the world coordinates to the camera coordinates. You can obtain this vector using the `extrinsics` function. You can also obtain the vector using the `location` and `orientation` outputs of the `relativeCameraPose` function:

- `translationVector = -relativeLocation * relativeOrientation'`

The `translationVector` inputs must be real, nonsparse, and of the same class.

Output Arguments

camMatrix — Camera projection matrix
4-by-3 matrix

Camera projection matrix, returned as a 4-by-3 matrix. The matrix contains the 3-D world points in homogenous coordinates that are projected into the image. When you set `rotationMatrix` and `translationVector` to `double`, the function returns `camMatrix` as `double`. Otherwise it returns `camMatrix` as `single`.

The function computes `camMatrix` as follows:

`camMatrix` = [`rotationMatrix`; `translationVector`] × K.
K: the intrinsic matrix

Then, using the camera matrix and homogeneous coordinates, you can project a world point onto the image.

w × [x,y,1] = [X,Y,Z,1] × `camMatrix`.

(*X*,*Y*,*Z*): world coordinates of a point
(*x*,*y*): coordinates of the corresponding image point
w: arbitrary scale factor

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

See Also
Camera Calibrator | `estimateCameraParameters` | `extrinsics` |
`relativeCameraPose` | `triangulate`

Topics
"Evaluating the Accuracy of Single Camera Calibration"
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Depth Estimation From Stereo Video"
"Code Generation for Depth Estimation From Stereo Video"
"What Is Camera Calibration?"
"Single Camera Calibrator App"
"Stereo Camera Calibrator App"

Introduced in R2014b

cameraPose

Compute relative rotation and translation between camera poses

Syntax

```
cameraPose
```

Description

`cameraPose` returns the camera extrinsics.

Note `cameraPose` was renamed to `relativeCameraPose`. Please use the new function in place of `cameraPose`.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

Introduced in R2015b

relativeCameraPose

Compute relative rotation and translation between camera poses

Syntax

```
[relativeOrientation,relativeLocation] = relativeCameraPose(M,
cameraParams,inlierPoints1,inlierPoints2)
[relativeOrientation,relativeLocation] = relativeCameraPose(M,
cameraParams1,cameraParams2,inlierPoints1,inlierPoints2)
[relativeOrientation,relativeLocation,validPointsFraction] =
relativeCameraPose(M, ___ )
```

Description

`[relativeOrientation,relativeLocation] = relativeCameraPose(M,
cameraParams,inlierPoints1,inlierPoints2)` returns the orientation and location of a calibrated camera relative to its previous pose. The two poses are related by `M`, which must be either a fundamental matrix or an essential matrix. The function computes the camera location up to scale and returns `relativeLocation` as a unit vector.

`[relativeOrientation,relativeLocation] = relativeCameraPose(M,
cameraParams1,cameraParams2,inlierPoints1,inlierPoints2)` returns the orientation and location of the second camera relative to the first one.

`[relativeOrientation,relativeLocation,validPointsFraction] =
relativeCameraPose(M, ___)` additionally returns the fraction of the inlier points that project in front of both cameras.

Input Arguments

`M` — Fundamental or essential matrix
3-by-3 matrix

Fundamental matrix, specified as a 3-by-3 matrix. You can obtain this matrix using the `estimateFundamentalMatrix` or the `estimateEssentialMatrix`function.

Data Types: `single` | `double`

cameraParams — Object for storing camera parameters
`cameraParameters` object | `cameraIntrinsics` object

Camera parameters, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

cameraParams1 — Camera parameters for camera 1
`cameraParameters` object | `cameraIntrinsics` object

Camera parameters for camera 1, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

cameraParams2 — Camera parameters for camera 2
`cameraParameters` object | `cameraIntrinsics` object

Camera parameters for camera 2, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

inlierPoints1 — Coordinates of corresponding points in view 1
SURFPoints | cornerPoints | MSERRegions | *M*-by-2 matrix of [*x*,*y*] coordinates

Coordinates of corresponding points in view 1, specified as an *M*-by-2 matrix of *M* number of [*x*,*y*] coordinates, or as a SURFPoints, MSERRegions, or `cornerPoints` object. You can obtain these points using the `estimateFundamentalMatrix` function or the `estimateEssentialMatrix`.

inlierPoints2 — Coordinates of corresponding points in view 2
SURFPoints | cornerPoints | MSERRegions | *M*-by-2 matrix of [*x*,*y*] coordinates

Coordinates of corresponding points in view 2, specified as an *M*-by-2 matrix of *M* number of [*x*,*y*] coordinates, or as a SURFPoints, MSERRegions, or `cornerPoints` object. You can obtain these points using the `estimateFundamentalMatrix` function or the `estimateEssentialMatrix`.

Output Arguments

relativeOrientation — Orientation of camera
3-by-3 matrix

Orientation of camera, returned as a 3-by-3 matrix. If you use only one camera, the matrix describes the orientation of the second camera pose relative to the first camera pose. If you use two cameras, the matrix describes the orientation of camera 2 relative to camera 1.

Data Types: `single` | `double`

relativeLocation — Location of camera
1-by-3 vector

Location of camera, returned as a 1-by-3 unit vector. If you use only one camera, the vector describes the location of the second camera pose relative to the first camera pose. If you use two cameras, the vector describes the location of camera 2 relative to camera 1.

Data Types: `single` | `double`

validPointsFraction — Fraction of valid inlier points
scalar

Fraction of valid inlier points that project in front of both cameras, returned as a scalar. If `validPointsFraction` is too small, e.g. less than 0.9, it can indicate that the fundamental matrix is incorrect.

Tips

- You can compute the camera extrinsics, `rotationMatrix` and `translationVector`, corresponding to the camera pose, from `relativeOrientation` and `relativeLocation`:

  `[rotationMatrix,translationVector] = cameraPoseToExtrinsics(relativeOrientation,rela`

  The orientation of the previous camera pose is the identity matrix, `eye(3)`, and its location is, `[0,0,0]`.
- You can then use `rotationMatrix` and `translationVector` as inputs to the `cameraMatrix` function.

- You can compute four possible combinations of orientation and location from the input fundamental matrix. Three of the combinations are not physically realizable, because they project 3-D points behind one or both cameras. The `relativeCameraPose` function uses `inlierPoints1` and `inlierPoints2` to determine the realizable combination.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

See Also
Camera Calibrator | cameraMatrix | cameraPoseToExtrinsics | estimateCameraParameters | estimateEssentialMatrix | estimateFundamentalMatrix | estimateWorldCameraPose | plotCamera | triangulate | triangulateMultiview

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Point Feature Types"
"Single Camera Calibrator App"
"Stereo Camera Calibrator App"
"Structure from Motion"

Introduced in R2016b

extractLBPFeatures

Extract local binary pattern (LBP) features

Syntax

```
features = extractLBPFeatures(I)
features = extractLBPFeatures(I,Name,Value)
```

Description

`features = extractLBPFeatures(I)` returns extracted uniform local binary pattern (LBP) from a grayscale image. The LBP features encode local texture information.

`features = extractLBPFeatures(I,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Using LBP Features to Differentiate Images by Texture

Read images that contain different textures.

```
brickWall = imread('bricks.jpg');
rotatedBrickWall = imread('bricksRotated.jpg');
carpet = imread('carpet.jpg');
```

Display the images.

```
figure
imshow(brickWall)
title('Bricks')
```

Bricks
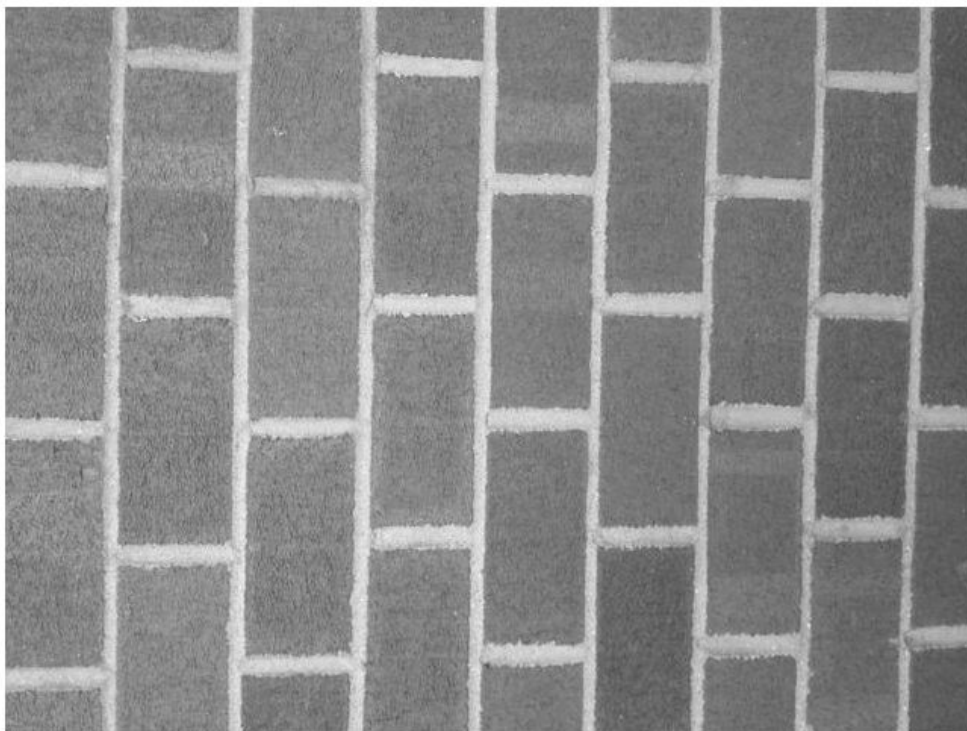
```
figure
imshow(rotatedBrickWall)
title('Rotated Bricks')
```

Rotated Bricks
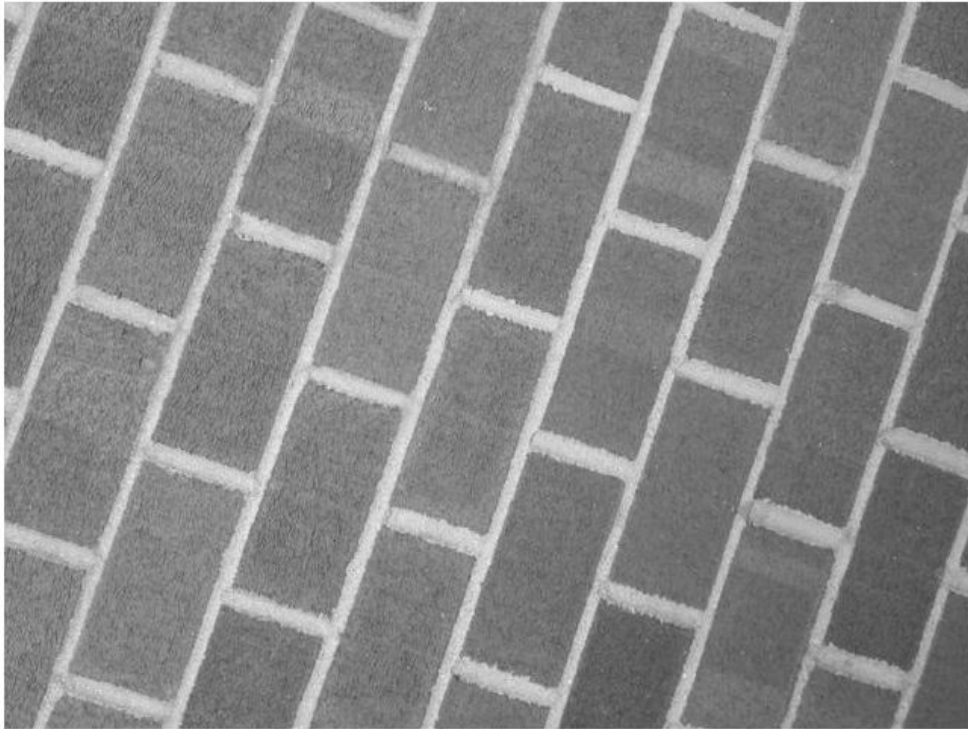

```
figure
imshow(carpet)
title('Carpet')
```

Carpet
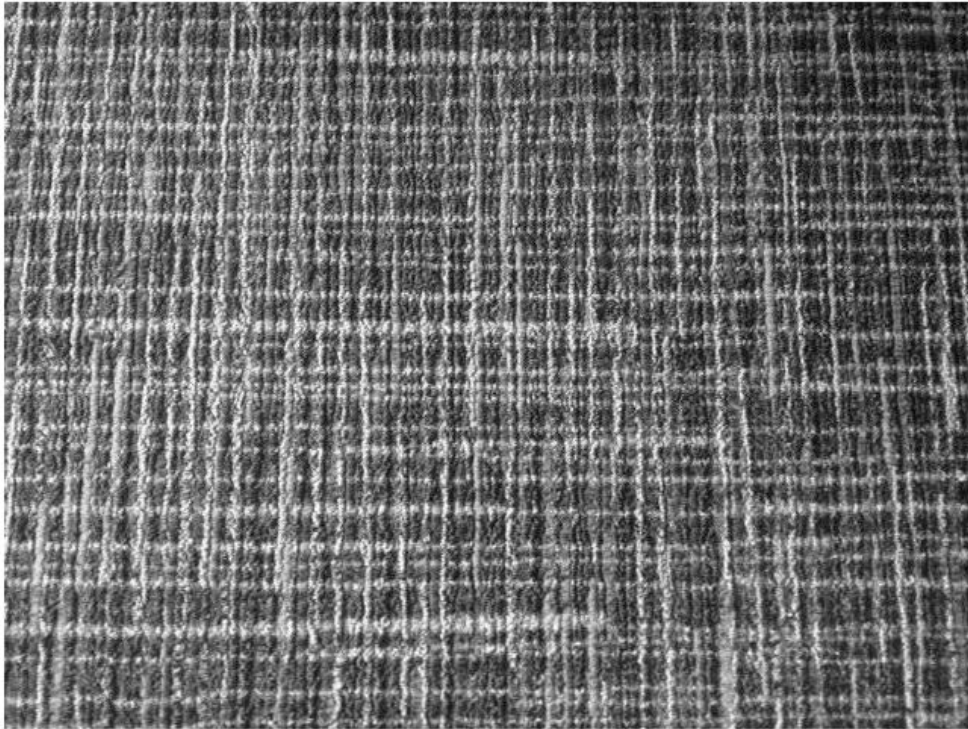
Extract LBP features from the images to encode their texture information.

```
lbpBricks1 = extractLBPFeatures(brickWall,'Upright',false);
lbpBricks2 = extractLBPFeatures(rotatedBrickWall,'Upright',false);
lbpCarpet = extractLBPFeatures(carpet,'Upright',false);
```

Gauge the similarity between the LBP features by computing the squared error between them.

```
brickVsBrick = (lbpBricks1 - lbpBricks2).^2;
brickVsCarpet = (lbpBricks1 - lbpCarpet).^2;
```

Visualize the squared error to compare bricks versus bricks and bricks versus carpet. The squared error is smaller when images have similar texture.

```
figure
bar([brickVsBrick; brickVsCarpet]','grouped')
title('Squared Error of LBP Histograms')
xlabel('LBP Histogram Bins')
legend('Bricks vs Rotated Bricks','Bricks vs Carpet')
```
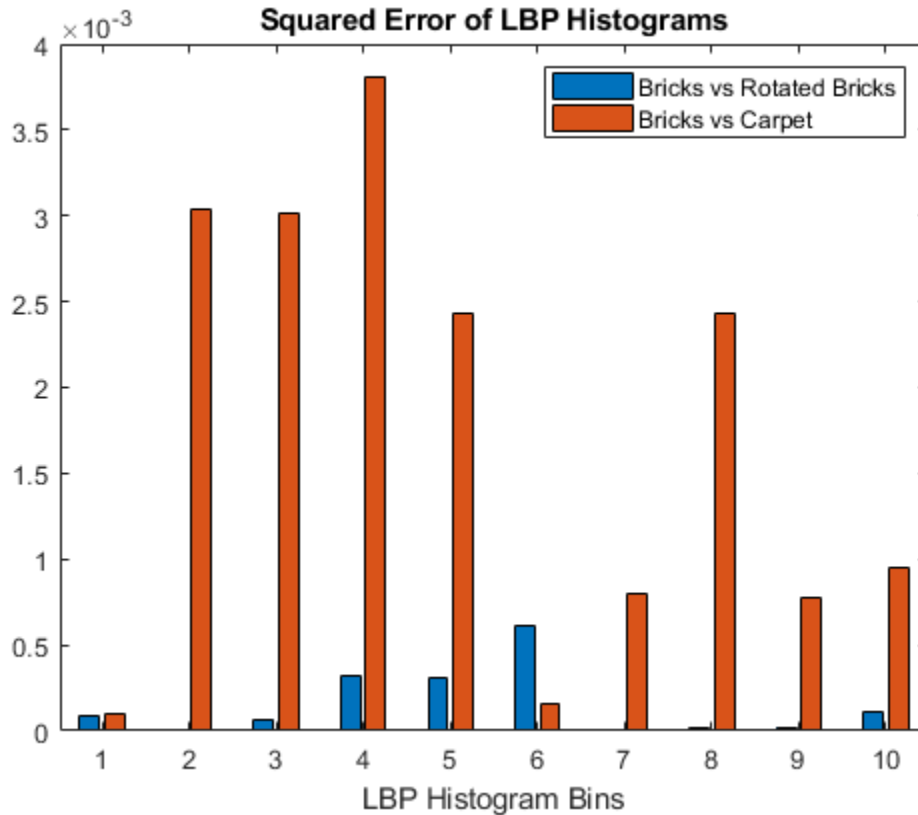

Apply L1 Normalization to LBP Features

Read in a sample image and convert it to grayscale.

```
I = imread('gantrycrane.png');
I = rgb2gray(I);
```

Extract unnormalized LBP features so that you can apply a custom normalization.

```
lbpFeatures = extractLBPFeatures(I,'CellSize',[32 32],'Normalization','None');
```

Reshape the LBP features into a *number of neighbors* -by- *number of cells* array to access histograms for each individual cell.

```
numNeighbors = 8;
numBins = numNeighbors*(numNeighbors-1)+3;
lbpCellHists = reshape(lbpFeatures,numBins,[]);
```

Normalize each LBP cell histogram using L1 norm.

```
lbpCellHists = bsxfun(@rdivide,lbpCellHists,sum(lbpCellHists));
```

Reshape the LBP features vector back to 1-by- *N* feature vector.

```
lbpFeatures = reshape(lbpCellHists,1,[]);
```

Input Arguments

I — Input image
M-by-*N* 2-D grayscale image

Input image, specified as an *M*-by-*N* 2-D grayscale image that is real, and non-sparse.

Data Types: logical | single | double | int16 | uint8 | uint16

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name, Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'NumNeighbors',8

Algorithm Parameters
The LBP algorithm parameters control how local binary patterns are computed for each pixel in the input image.

NumNeighbors — Number of neighbors
8 (default) | positive integer

Number of neighbors used to compute the LBP for each pixel in the input image, specified as the comma-separated pair consisting of 'NumNeighbors' and a positive integer. The set of neighbors is selected from a circularly symmetric pattern around each pixel. Increase the number of neighbors to encode greater detail around each pixel. Typical values range from 4 to 24.

Radius — Radius of circular pattern to select neighbors
1 (default) | positive integer

Radius of circular pattern used to select neighbors for each pixel in the input image, specified as the comma-separated pair consisting of 'Radius' and a positive integer. To capture detail over a larger spatial scale, increase the radius. Typical values range from 1 to 5.

Upright — Rotation invariance flag
true | logical scalar

Rotation invariance flag, specified as the comma-separated pair consisting of 'Upright' and a logical scalar. When you set this property to true, the LBP features do not encode rotation information. Set 'Upright' to false when rotationally invariant features are required.

Interpolation — Interpolation method
'Linear' (default) | 'Nearest'

Interpolation method used to compute pixel neighbors, specified as the comma-separated pair consisting of 'Interpolation' and the character vector 'Linear' or 'Nearest'. Use 'Nearest' for faster computation, but with less accuracy.

Histogram Parameters
The histogram parameters determine how the distribution of binary patterns is aggregated over the image to produce the output features.

CellSize — Cell size
size(I) (default) | 2-element vector

Cell size, specified as the comma-separated pair consisting of 'CellSize' and a 2-element vector. The number of cells is calculated as floor(size(I)/CellSize).

Normalization — Type of normalization
'L2' (default) | 'None'

Type of normalization applied to each LBP cell histogram, specified as the comma-separated pair consisting of 'Normalization' and the character vector 'L2' or 'None'. To apply a custom normalization method as a post-processing step, set this value to 'None'.

Output Arguments

features — LBP feature vector
1-by-*N* vector

LBP feature vector, returned as a 1-by-*N* vector of length *N* representing the number of features. LBP features encode local texture information, which you can use for tasks such as classification, detection, and recognition. The function partitions the input image into non-overlapping cells. To collect information over larger regions, select larger cell sizes . However, when you increase the cell size, you lose local detail. *N*, depends on the number of cells in the image, *numCells*, the number of neighbors, *P*, and the Upright parameter.

The number of cells is calculated as:
numCells = prod(floor(size(I)/CellSize))

The figure shows an image with nine cell histograms. Each histogram describes an LBP feature.

Image

cells
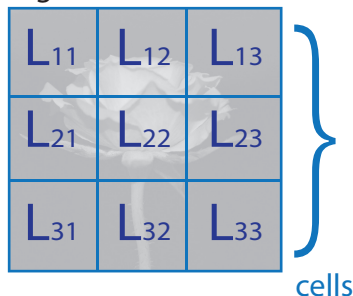
The size of the histogram in each cell is [1,*B*], where *B* is the number of bins in the histogram. The number of bins depends on the Upright property and the number of neighbors, *P*.

Upright	Number of Bins
true	(P x P–1) + 3)
false	(P + 2)

The overall LBP feature length, N, depends on the number of cells and the number of bins, B:

$N = numCells \times B$

LBP features = size(L_{YX}) = [1, B]
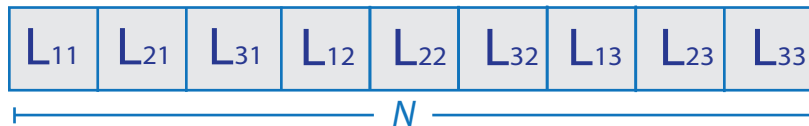
References

[1] Ojala, T., M. Pietikainen, and T. Maenpaa. "Multiresolution Gray Scale and Rotation Invariant Texture Classification With Local Binary Patterns." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 24, Issue 7, July 2002, pp. 971-987.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Does not generate a platform-dependent library.

See Also

MSERRegions | SURFPoints | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | extractHOGFeatures | matchFeatures

Topics
"Local Feature Detection and Extraction"

Introduced in R2015b

configureKalmanFilter

Create Kalman filter for object tracking

Syntax

```
kalmanFilter = configureKalmanFilter(MotionModel,InitialLocation,
InitialEstimateError,MotionNoise,MeasurementNoise)
```

Description

`kalmanFilter = configureKalmanFilter(MotionModel,InitialLocation, InitialEstimateError,MotionNoise,MeasurementNoise)` returns a `vision.KalmanFilter` object configured to track a physical object. This object moves with constant velocity or constant acceleration in an *M*-dimensional Cartesian space. The function determines the number of dimensions, *M*, from the length of the `InitialLocation` vector.

This function provides a simple approach for configuring the `vision.KalmanFilter` object for tracking a physical object in a Cartesian coordinate system. The tracked object may move with either constant velocity or constant acceleration. The statistics are the same along all dimensions. If you need to configure a Kalman filter with different assumptions, use the `vision.KalmanFilter` object directly.

Examples

Track an Occluded Object

Detect and track a ball using Kalman filtering, foreground detection, and blob analysis.

Create System objects to read the video frames, detect foreground physical objects, and display results.

```
videoReader = vision.VideoFileReader('singleball.mp4');
videoPlayer = vision.VideoPlayer('Position',[100,100,500,400]);
```

```
foregroundDetector = vision.ForegroundDetector('NumTrainingFrames',10,...
                'InitialVariance',0.05);
blobAnalyzer = vision.BlobAnalysis('AreaOutputPort',false,...
                'MinimumBlobArea',70);
```

Process each video frame to detect and track the ball. After reading the current video frame, the example searches for the ball by using background subtraction and blob analysis. When the ball is first detected, the example creates a Kalman filter. The Kalman filter determines the ball's location, whether it is detected or not. If the ball is detected, the Kalman filter first predicts its state at the current video frame. The filter then uses the newly detected location to correct the state, producing a filtered location. If the ball is missing, the Kalman filter solely relies on its previous state to predict the ball's current location.

```
kalmanFilter = []; isTrackInitialized = false;
 while ~isDone(videoReader)
   colorImage  = step(videoReader);

   foregroundMask = step(foregroundDetector, rgb2gray(colorImage));
   detectedLocation = step(blobAnalyzer,foregroundMask);
   isObjectDetected = size(detectedLocation, 1) > 0;

   if ~isTrackInitialized
     if isObjectDetected
       kalmanFilter = configureKalmanFilter('ConstantAcceleration',...
               detectedLocation(1,:), [1 1 1]*1e5, [25, 10, 10], 25);
       isTrackInitialized = true;
     end
     label = ''; circle = zeros(0,3);
   else
     if isObjectDetected
       predict(kalmanFilter);
       trackedLocation = correct(kalmanFilter, detectedLocation(1,:));
       label = 'Corrected';
     else
       trackedLocation = predict(kalmanFilter);
       label = 'Predicted';
     end
     circle = [trackedLocation, 5];
   end

   colorImage = insertObjectAnnotation(colorImage,'circle',...
               circle,label,'Color','red');
```

```
        step(videoPlayer,colorImage);
    end
```
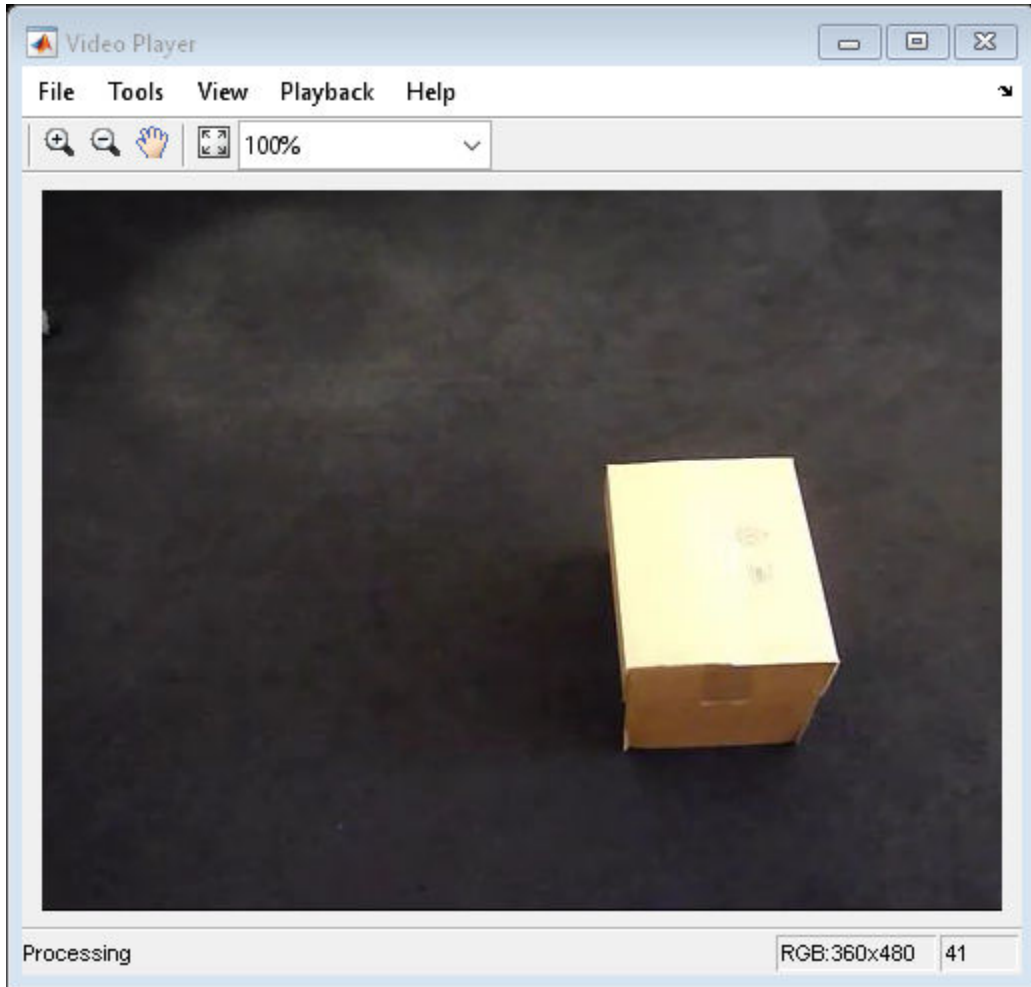

Release resources.

```
release(videoPlayer);
release(videoReader);
```
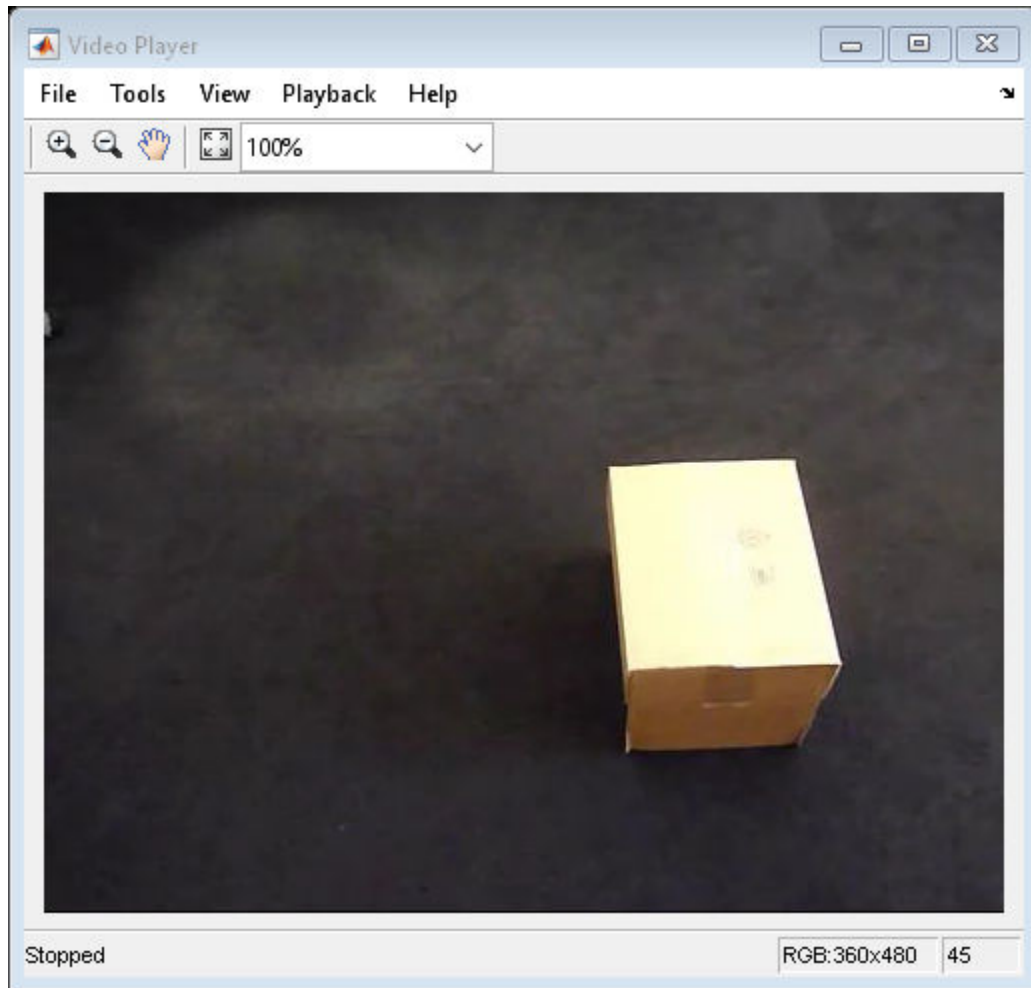
- "Using Kalman Filter for Object Tracking"

Input Arguments

MotionModel — Motion model
`'ConstantVelocity'` | `'ConstantAcceleration'`

Motion model, specified as the character vector `'ConstantVelocity'` or `'ConstantAcceleration'`. The motion model you select applies to all dimensions. For example, for the 2-D Cartesian coordinate system. This mode applies to both *X* and *Y* directions.

Data Types: `char`

InitialLocation — Initial location of object
vector

Initial location of object, specified as a numeric vector. This argument also determines the number of dimensions for the coordinate system. For example, if you specify the initial location as a two-element vector, $[x_0, y_0]$, then a 2-D coordinate system is assumed.

Data Types: `double` | `single` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

InitialEstimateError — Initial estimate uncertainty variance
2-element vector | 3-element vector

Initial estimate uncertainty variance, specified as a two- or three-element vector. The initial estimate error specifies the variance of the initial estimates of location, velocity, and acceleration of the tracked object. The function assumes a zero initial velocity and acceleration for the object, at the location you set with the `InitialLocation` property. You can set the `InitialEstimateError` to an approximated value:
(*assumed values – actual values*)^2 + *the variance of the values*

The value of this property affects the Kalman filter for the first few detections. Later, the estimate error is determined by the noise and input data. A larger value for the initial estimate error helps the Kalman filter to adapt to the detection results faster. However, a larger value also prevents the Kalman filter from removing noise from the first few detections.

Specify the initial estimate error as a two-element vector for constant velocity or a three-element vector for constant acceleration:

MotionModel	InitialEstimateError
`ConstantVelocity`	[*LocationVariance, VelocityVariance*]
`ConstantAcceleration`	[*LocationVariance, VelocityVariance, AccelerationVariance*]

Data Types: `double` | `single`

MotionNoise — Deviation of selected and actual model
2-element vector | 3-element vector

Deviation of selected and actual model, specified as a two- or three-element vector. The motion noise specifies the tolerance of the Kalman filter for the deviation from the chosen model. This tolerance compensates for the difference between the object's actual motion and that of the model you choose. Increasing this value may cause the Kalman filter to change its state to fit the detections. Such an increase may prevent the Kalman filter from removing enough noise from the detections. The values of this property stay constant and therefore may affect the long-term performance of the Kalman filter.

MotionModel	InitialEstimateError
ConstantVelocity	[*LocationVariance*, *VelocityVariance*]
ConstantAcceleration	[*LocationVariance*, *VelocityVariance*, *AccelerationVariance*]

Data Types: `double` | `single`

MeasurementNoise — Variance inaccuracy of detected location
scalar

Variance inaccuracy of detected location, specified as a scalar. It is directly related to the technique used to detect the physical objects. Increasing the `MeasurementNoise` value enables the Kalman filter to remove more noise from the detections. However, it may also cause the Kalman filter to adhere too closely to the motion model you chose, putting less emphasis on the detections. The values of this property stay constant, and therefore may affect the long-term performance of the Kalman filter.

Data Types: `double` | `single`

Output Arguments

kalmanFilter — Configured Kalman filter tracking
object

Configured Kalman filter, returned as a `vision.KalmanFilter` object for tracking.

Algorithms

This function provides a simple approach for configuring the vision.KalmanFilter object for tracking. The Kalman filter implements a discrete time, linear State-Space System. The `configureKalmanFilter` function sets the `vision.KalmanFilter` object properties.

The `InitialLocation` property corresponds to the measurement vector used in the Kalman filter state-space model. This table relates the measurement vector, M, to the state-space model for the Kalman filter.
State transition model, A, and Measurement model, H
The state transition model, A, and the measurement model, H of the state-space model, are set to block diagonal matrices made from M identical submatrices As and Hs, respectively: $A = $ `blkdiag`$(As\_1, As\_2, ..., As\_M)$ $H = $ `blkdiag`$(Hs\_1, Hs\_2, ..., Hs\_M)$
The submatrices As and Hs are described below:

MotionModel	As	Hs
`'ConstantVelocity'`	[1 1; 0 1]	[1 0]
`'ConstantAcceleration'`	[1 1 0.5; 0 1 1; 0 0 1]	[1 0 0]

The Initial State, x:

MotionModel	Initial state, x
`'ConstantVelocity'`	[InitialLocation(1), 0, ..., InitialLocation(M), 0]
`'ConstantAcceleration'`	[InitialLocation(1), 0, 0, ..., InitialLocation(M), 0, 0]

The initial state estimation error covariance matrix, P:
$P = $ `diag(repmat(InitialError, [1, M]))`

The process noise covariance, Q:
$Q = \mathrm{diag}(\mathrm{repmat}(\mathrm{MotionNoise}, [1, M]))$
The measurement noise covariance, R:
$R = \mathrm{diag}(\mathrm{repmat}(\mathrm{MeasurementNoise}, [1, M]))$.

See Also

vision.BlobAnalysis | vision.ForegroundDetector | vision.KalmanFilter

Topics

"Using Kalman Filter for Object Tracking"
"Multiple Object Tracking"

Introduced in R2012b

detectBRISKFeatures

Detect BRISK features and return `BRISKPoints` object

Syntax

```
points = detectBRISKFeatures(I)
points = detectBRISKFeatures(I,Name,Value)
```

Description

`points = detectBRISKFeatures(I)` returns a `BRISKPoints` object, `points`. The object contains information about BRISK features detected in a 2-D grayscale input image, `I`. The `detectBRISKFeatures` function uses a Binary Robust Invariant Scalable Keypoints (BRISK) algorithm to detect multiscale corner features.

`points = detectBRISKFeatures(I,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Detect BRISK Points in an Image and Mark Their Locations

Read the image.

```
I = imread('cameraman.tif');
```

Find the BRISK points.

```
points = detectBRISKFeatures(I);
```

Display the results.

```
imshow(I); hold on;
plot(points.selectStrongest(20));
```

Input Arguments

I — Input image
M-by-*N* 2-D grayscale image

Input image, specified in 2-D grayscale. The input image must be real and nonsparse.

Example:

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MinQuality',0.1,'ROI', [50,150,100,200]` specifies that the detector must use a 10% minimum accepted quality of corners within the designated region of interest. This region of interest is located at x=50, y=150. The ROI has a width of 100 pixels and a height of 200 pixels.

`MinContrast` — Minimum intensity difference
0.2 (default) | scalar

Minimum intensity difference between a corner and its surrounding region, specified as the comma-separated pair consisting of `'MinContrast'` and a scalar in the range (0 1). The minimum contrast value represents a fraction of the maximum value of the image class. Increase this value to reduce the number of detected corners.

`MinQuality` — Minimum accepted quality of corners
0.1 (default) | scalar

Minimum accepted quality of corners, specified as the comma-separated pair consisting of `'MinQuality'` and a scalar value in the range [0,1]. The minimum accepted quality of corners represents a fraction of the maximum corner metric value in the image. Increase this value to remove erroneous corners.

`NumOctaves` — Number of octaves
4 (default) | scalar

Number of octaves to implement, specified as a comma-separated pair consisting of `'NumOctaves'` and an integer scalar, greater than or equal to 0. Increase this value to detect larger blobs. Recommended values are between 1 and 4. When you set `NumOctaves` to 0, the function disables multiscale detection. It performs the detection at the scale of the input image, `I`.

`ROI` — Rectangular region
[1 1 `size(I,2) size(I,1)`] (default) | vector

Rectangular region for corner detection, specified as a comma-separated pair consisting of `'ROI'` and a vector of the format [x y *width height*]. The first two integer values [x y] represent the location of the upper-left corner of the region of interest. The last two integer values represent the width and height.

Output Arguments

points — Brisk points
BRISKPoints object

Brisk points, returned as a BRISKPoints object. The object contains information about the feature points detected in the 2-D grayscale input image.

References

[1] Leutenegger, S., M. Chli and R. Siegwart. "BRISK: Binary Robust Invariant Scalable Keypoints", *Proceedings of the IEEE International Conference*, ICCV, 2011.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".

See Also
BRISKPoints | MSERRegions | SURFPoints | binaryFeatures | cornerPoints | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | extractHOGFeatures | matchFeatures

Topics
"Point Feature Types"

Introduced in R2014a

detectCheckerboardPoints

Detect checkerboard pattern in image

Syntax

```
[imagePoints,boardSize] = detectCheckerboardPoints(I)

[imagePoints,boardSize,imagesUsed] = detectCheckerboardPoints(
imageFileNames)
[imagePoints,boardSize,imagesUsed] = detectCheckerboardPoints(
images)

[imagePoints,boardSize,pairsUsed] = detectCheckerboardPoints(
imageFileNames1,imageFileNames2)
[imagePoints,boardSize,pairsUsed] = detectCheckerboardPoints(
images1,images2)

[imagePoints,boardSize,pairsUsed] = detectCheckerboardPoints( ___ ,
Name,Value
```

Description

`[imagePoints,boardSize] = detectCheckerboardPoints(I)` detects a black and white checkerboard of size greater than 4-by-4 squares in a 2-D truecolor or grayscale image. The function returns the detected points and dimensions of the checkerboard.

`[imagePoints,boardSize,imagesUsed] = detectCheckerboardPoints(imageFileNames)` detects a checkerboard pattern in a set of input images, provided as an array of file names.

`[imagePoints,boardSize,imagesUsed] = detectCheckerboardPoints(images)` detects a checkerboard pattern in a set of input images, provided as an array of grayscale or truecolor images.

`[imagePoints,boardSize,pairsUsed] = detectCheckerboardPoints(`
`imageFileNames1,imageFileNames2)` detects a checkerboard pattern in stereo pairs
of images, provided as cell arrays of file names.

`[imagePoints,boardSize,pairsUsed] = detectCheckerboardPoints(`
`images1,images2)` detects a checkerboard pattern in stereo pairs of images, provided
as arrays of grayscale or truecolor images.

`[imagePoints,boardSize,pairsUsed] = detectCheckerboardPoints( ___ ,`
`Name,Value` sets additional options specified by one or more `Name,Value` pair
arguments.

Examples

Detect Checkerboard in a Set of Image Files

Create a cell array of file names of calibration images.

```
for i = 1:5
  imageFileName = sprintf('image%d.tif', i);
  imageFileNames{i} = fullfile(matlabroot,'toolbox','vision',...
      'visiondata','calibration','webcam',imageFileName);
end
```

Detect calibration pattern in the images.

```
[imagePoints,boardSize,imagesUsed] = detectCheckerboardPoints(imageFileNames);
```

Display the detected points.

```
imageFileNames = imageFileNames(imagesUsed);
for i = 1:numel(imageFileNames)
  I = imread(imageFileNames{i});
  subplot(2, 2, i);
  imshow(I);
  hold on;
  plot(imagePoints(:,1,i),imagePoints(:,2,i),'ro');
end
```

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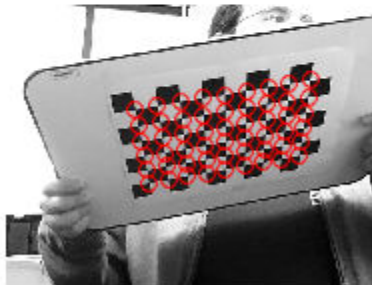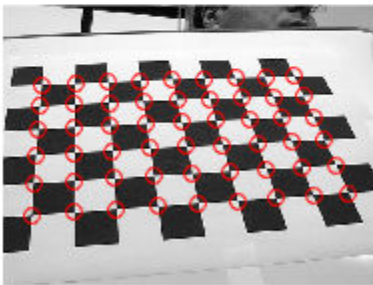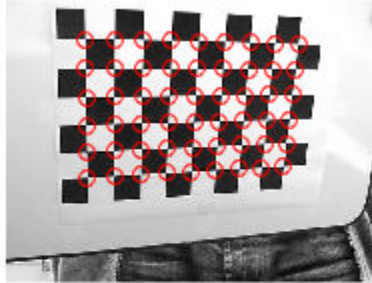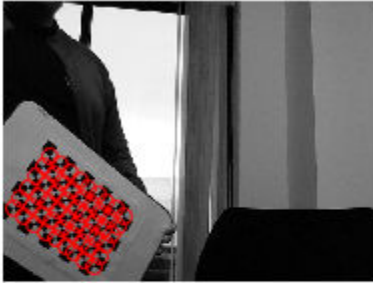
Detect Checkerboard in Stereo Images

Read in stereo images.

```
numImages = 4;
images1 = cell(1, numImages);
images2 = cell(1, numImages);
for i = 1:numImages
    images1{i} = fullfile(matlabroot,'toolbox','vision',...
        'visiondata','calibration','stereo','left',sprintf('left%02d.png',i));
    images2{i} = fullfile(matlabroot,'toolbox','vision',...
```

```
        'visiondata','calibration','stereo','right',sprintf('right%02d.png',i));
end
```

Detect the checkerboards in the images.

```
[imagePoints,boardSize,pairsUsed] = ...
    detectCheckerboardPoints(images1,images2);
```

Display points from images1.

```
images1 = images1(pairsUsed);
figure;
for i = 1:numel(images1)
    I = imread(images1{i});
    subplot(2,2,i);
    imshow(I);
    hold on;
    plot(imagePoints(:,1,i,1),imagePoints(:,2,i,1),'ro');
end
annotation('textbox',[0 0.9 1 0.1],'String','Camera 1',...
    'EdgeColor','none','HorizontalAlignment','center')
```

Camera 1
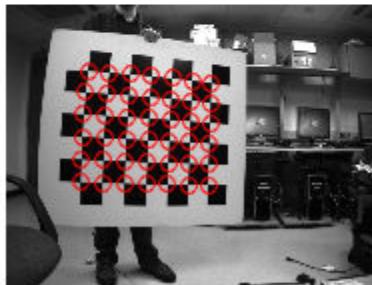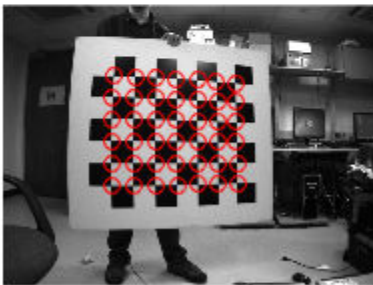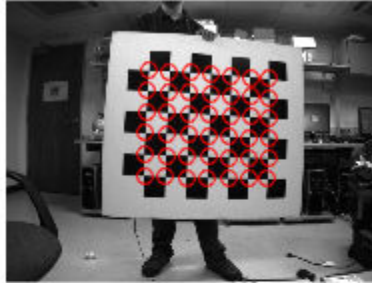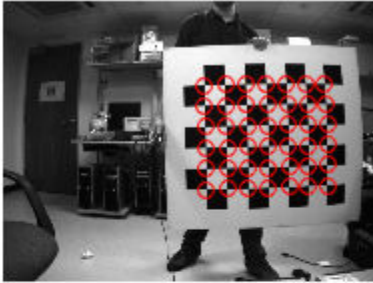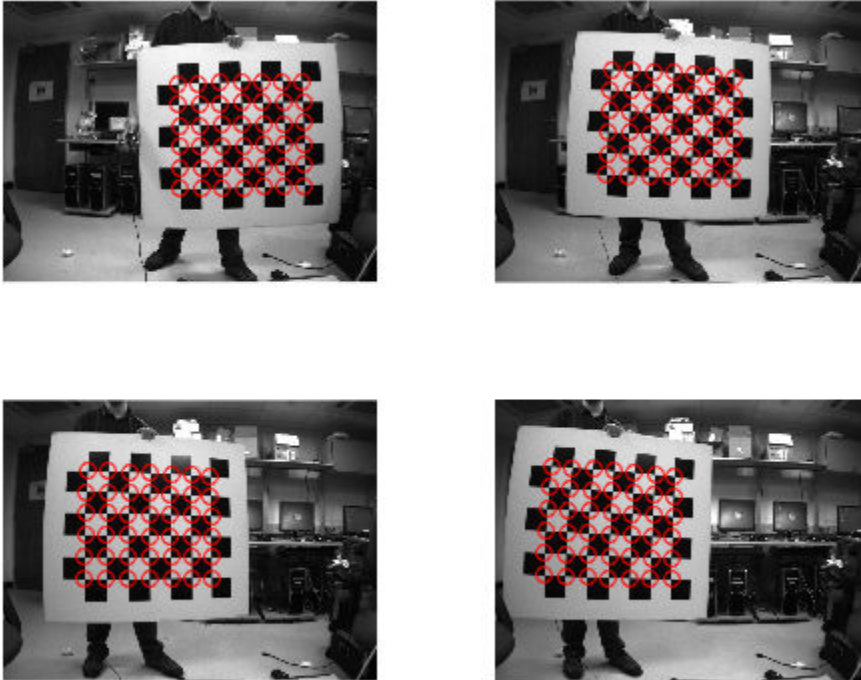
Display points from images2.

```
images2 = images2(pairsUsed);
figure;
for i = 1:numel(images2)
    I = imread(images2{i});
    subplot(2, 2, i);
    imshow(I);
    hold on;
    plot(imagePoints(:,1,i,2),imagePoints(:,2,i,2),'ro');
end
annotation('textbox',[0 0.9 1 0.1],'String','Camera 2',...
    'EdgeColor','none','HorizontalAlignment','center')
```

Input Arguments

I — Input image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input image, specified in either an *M*-by-*N*-by-3 truecolor or *M*-by-*N* 2-D grayscale. The input image must be real and nonsparse. The function can detect checkerboards with a minimum size of 4-by-4 squares.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

imageFileNames — Image file names
N-element cell array

Image file names, specified as an *N*-element cell array of *N* file names.

imageFileNames1 — File names for camera 1 images
N-element cell array

File names for camera 1 images, specified as an *N*-element cell array of *N* file names. The images contained in this array must be in the same order as images contained in `imageFileNames2`, forming stereo pairs.

imageFileNames2 — File names for camera 2 images
N-element cell array

File names for camera 2 images, specified as an *N*-element cell array of *N* file names. The images contained in this array must be in the same order as images contained in `imageFileNames1`, forming stereo pairs.

images — Images
height-by-*width*-by-*color channel*-by-*number of frames* array

Images, specified as an *H*-by-*W*-by-*B*-by-*F* array containing a set of grayscale or truecolor images. The input dimensions are:
H represents the image height.
W represents the image width.
B represents the color channel. A value of 1 indicates a grayscale image, and a value of 3 indicates a truecolor image.
F represents the number of image frames.

images1 — Stereo pair images 1
height-by-*width*-by-*color channel*-by-*number of frames* array

Images, specified as an *H*-by-*W*-by-*B*-by-*F* array containing a set of grayscale or truecolor images. The input dimensions are:
H represents the image height.
W represents the image width.
B represents the color channel. A value of 1 indicates a grayscale image, and a value of 3 indicates a truecolor image.
F represents the number of image frames.

images2 — Stereo pair images 2
height-by-*width*-by-*color channel*-by-*number of frames* array

Images, specified as an *H*-by-*W*-by-*B*-by-*F* array containing a set of grayscale or truecolor images. The input dimensions are:
H represents the image height.
W represents the image width.
B represents the color channel. A value of 1 indicates a grayscale image, and a value of 3 indicates a truecolor image.
F represents the number of image frames.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MinCornerMetric',0.15`.

MinCornerMetric — Corner metric threshold
`0.15` (default) | nonnegative scalar

Corner metric threshold, specified as a nonnegative scalar. When the image is noisy or highly textured, increase this value to reduce the number of false corners.

Output Arguments

imagePoints — Detected checkerboard corner coordinates
M-by-2 matrix | *M*-by-2-by- *number of images* array | *M*-by-2-by-*number of pairs of images*-by-*number of cameras* array

Detected checkerboard corner coordinates, returned as an *M*-by-2 matrix for one image. For multiple images, points are returned as an *M*-by-2-by-*number of images* array, and for stereo pairs of images, the function returns points as an *M*-by-2-by-*number of pairs*-by-*number of cameras* array.

For stereo pairs, `imagePoints`(:,:,:,1) are the points from the first set of images, and `imagePoints`(:,:,:,2) are the points from the second set of images. The output contains *M* number of [*x y*] coordinates. Each coordinate represents a point where square corners are

detected on the checkerboard. The number of points the function returns depends on the value of `boardSize`, which indicates the number of squares detected. The function detects the points with sub-pixel accuracy.

The function calculates the number of points, *M*, as follows:
M = `prod(boardSize-1)`.
If the checkerboard cannot be detected:
`imagePoints = []`
`boardSize = [0,0]`

When you specify the `imageFileNames` input, the function can return `imagePoints` as an *M*-by-2-by-*N* array. In this array, *N* represents the number of images in which a checkerboard is detected.
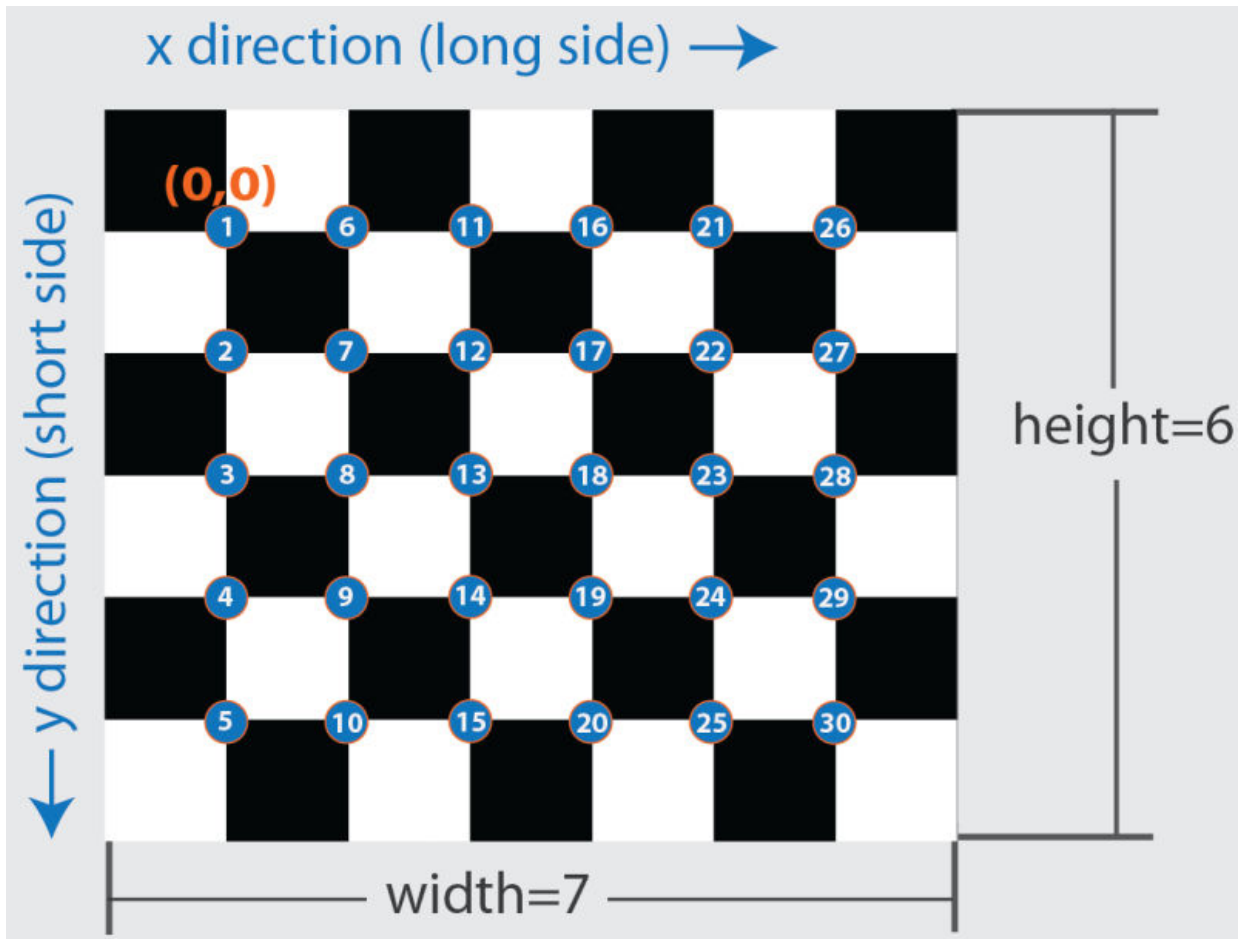
boardSize — Checkerboard dimensions
2-element [*height*, *width*] vector

Checkerboard dimensions, returned as a 2-element [*height*, *width*] vector. The dimensions of the checkerboard are expressed in terms of the number of squares.
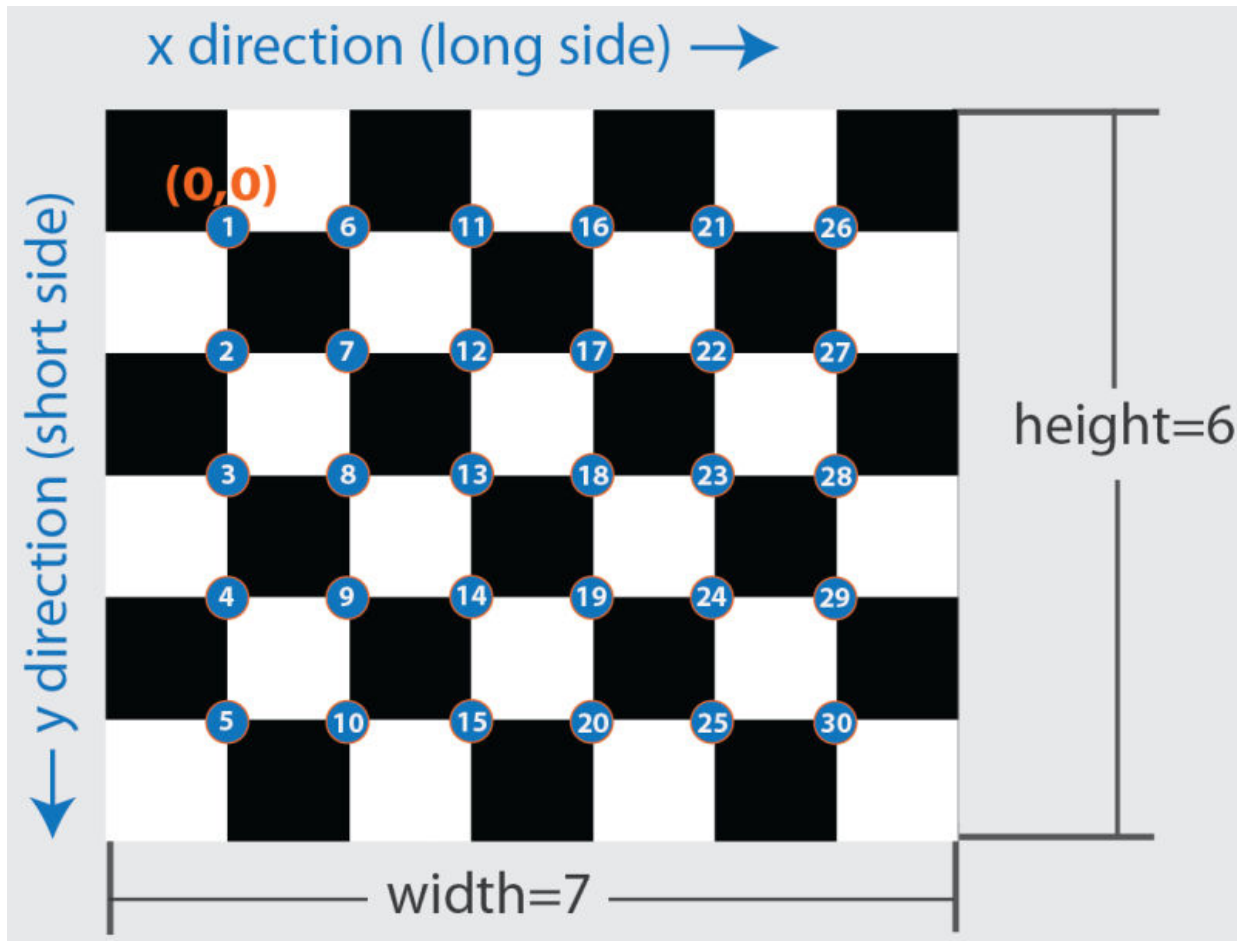
imagesUsed — Pattern detection flag
N-by-1 logical vector

Pattern detection flag, returned as an *N*-by-1 logical vector of *N* logicals. The function outputs the same number of logicals as there are input images. A `true` value indicates that the pattern was detected in the corresponding image. A `false` value indicates that the function did not detect a pattern.

pairsUsed — Stereo pair pattern detection flag
N-by-1 logical vector

Stereo pair pattern detection flag, returned as an *N*-by-1 logical vector of *N* logicals. The function outputs the same number of logicals as there are input images. A `true` value indicates that the pattern is detected in the corresponding stereo image pair. A `false` value indicates that the function does not detect a pattern.

References

[1] Geiger, A., F. Moosmann, O. Car, and B. Schuster. "Automatic Camera and Range Sensor Calibration using a Single Shot," *International Conference on Robotics and Automation (ICRA)*, St. Paul, USA, May 2012.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Code generation will not support specifying images as file names or cell arrays of file names. It supports only checkerboard detection in a single image or stereo pair of images. For example, these syntaxes are supported:

  - `detectCheckerboardPoints(I1)`
  - `detectCheckerobarPoints(I1,I2)`

  `I1` and `I2` are single grayscale or RGB images.

See Also
Camera Calibrator | cameraParameters | estimateCameraParameters | generateCheckerboardPoints | stereoParameters

Topics
"Single Camera Calibrator App"

Introduced in R2014a

detectFASTFeatures

Detect corners using FAST algorithm and return `cornerPoints` object

Syntax

```
points = detectFASTFeatures(I)
points = detectFASTFeatures(I,Name,Value)
PointsGPU = detectFASTFeatures(gpuI, ___ )
```

Description

`points = detectFASTFeatures(I)` returns a `cornerPoints` object, `points`. The object contains information about the feature points detected in a 2-D grayscale input image, `I`. The `detectFASTFeatures` function uses the Features from Accelerated Segment Test (FAST) algorithm to find feature points.

`points = detectFASTFeatures(I,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

`PointsGPU = detectFASTFeatures(gpuI, ___ )` perform operation on a graphics processing unit (GPU), where gpuI is a `gpuArray` object that contains a 2-D grayscale input image. The output is a `cornerPoints` object. This syntax requires the Parallel Computing Toolbox.

Examples

Find Corner Points in an Image Using the FAST Algorithm

Read the image.

```
I = imread('cameraman.tif');
```

Find the corners.

```
corners = detectFASTFeatures(I);
```

Display the results.

```
imshow(I); hold on;
plot(corners.selectStrongest(50));
```


- "Find Corner Points Using the Eigenvalue Algorithm" on page 3-185
- "Find Corner Points Using the Harris-Stephens Algorithm" on page 3-180

Input Arguments

I — Input image
M-by-*N* 2-D grayscale image

Input image, specified in 2-D grayscale. The input image must be real and nonsparse.

Example:

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

gpuI — Input image
M-by-*N* 2-D grayscale image

Input image stored on the GPU, specified in 2-D grayscale. The input image must be real and nonsparse.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MinQuality','0.01','ROI', [50,150,100,200]` specifies that the detector must use a 1% minimum accepted quality of corners within the designated region of interest. This region of interest is located at $x=50$, $y=150$. The ROI has a width of 100 pixels, and a height of 200 pixels.

MinQuality — Minimum accepted quality of corners
0.1 (default)

Minimum accepted quality of corners, specified as the comma-separated pair consisting of `'MinQuality'` and a scalar value in the range [0,1].

The minimum accepted quality of corners represents a fraction of the maximum corner metric value in the image. Larger values can be used to remove erroneous corners.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

MinContrast — Minimum intensity
0.2 (default)

Minimum intensity difference between corner and surrounding region, specified as the comma-separated pair consisting of `'MinContrast'` and a scalar value in the range (0,1).

The minimum intensity represents a fraction of the maximum value of the image class. Increasing the value reduces the number of detected corners.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ROI — Rectangular region
[1 1 size(I,2) size(I,1)] (default) | vector

Rectangular region for corner detection, specified as a comma-separated pair consisting of 'ROI' and a vector of the format [*x y width height*]. The first two integer values [*x y*] represent the location of the upper-left corner of the region of interest. The last two integer values represent the width and height.

Example: 'ROI', [50,150,100,200]

Output Arguments

points — Corner points
cornerPoints object

Corner points object, returned as a cornerPoints object. The object contains information about the feature points detected in the 2-D grayscale input image.

PointsGPU — Corner points
cornerPoints object

Corner points object, returned as a cornerPoints object. The object contains information about the feature points detected in the 2-D grayscale input image. The underlying feature point data of this object is stored on the GPU. Use the gather method of the cornerPoints object and the PointsGPU output to copy data back to the CPU.

```
pointsCPU = gather(pointsGPU);
```

References

[1] Rosten, E., and T. Drummond. "Fusing Points and Lines for High Performance Tracking," *Proceedings of the IEEE International Conference on Computer Vision*, Vol. 2 (October 2005): pp. 1508–1511.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".

See Also
BRISKPoints | MSERRegions | SURFPoints | binaryFeatures | cornerPoints | detectBRISKFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | extractHOGFeatures | matchFeatures

Topics
"Find Corner Points Using the Eigenvalue Algorithm" on page 3-185
"Find Corner Points Using the Harris-Stephens Algorithm" on page 3-180
"Point Feature Types"

Introduced in R2013a

detectHarrisFeatures

Detect corners using Harris–Stephens algorithm and return `cornerPoints` object

Syntax

```
points = detectHarrisFeatures(I)
points = detectHarrisFeatures(I,Name,Value)
PointsGPU = detectHarrisFeatures(gpuI,___ )
```

Description

`points = detectHarrisFeatures(I)` returns a `cornerPoints` object, `points`. The object contains information about the feature points detected in a 2-D input image, `I`. The `detectHarrisFeatures` function uses the Harris–Stephens algorithm to find these feature points.

`points = detectHarrisFeatures(I,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

`PointsGPU = detectHarrisFeatures(gpuI, ___ )` perform operation on a graphics processing unit (GPU), where gpuI is a `gpuArray` object that contains a 2-D input image, and the output is a `cornerPoints` object. This syntax requires the Parallel Computing Toolbox.

Examples

Find Corner Points Using the Harris-Stephens Algorithm

Read the image.

```
I = checkerboard;
```

Find the corners.

```
corners = detectHarrisFeatures(I);
```

Display the results.

```
imshow(I); hold on;
plot(corners.selectStrongest(50));
```
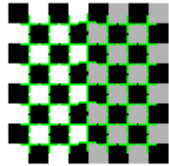

- "Find Corner Points Using the Eigenvalue Algorithm" on page 3-185
- "Find Corner Points in an Image Using the FAST Algorithm" on page 3-175

Input Arguments

`I` — Input image
M-by-*N* 2-D image

Input image, specified is an *M*-by-*N* 2-D image. The input image must be real and nonsparse.

Example:

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

`gpuI` — Input image
M-by-*N* 2-D image

Input image stored on the GPU, specified as an *M*-by-*N* 2-D image. The input image must be real and nonsparse.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MinQuality','0.01','ROI',[50,150,100,200]` specifies that the detector must use a 1% minimum accepted quality of corners within the designated region of interest. This region of interest is located at $x=50$, $y=150$. The ROI has a width of `100` pixels and a height of `200` pixels.

`MinQuality` — Minimum accepted quality of corners
0.01 (default)

Minimum accepted quality of corners, specified as the comma-separated pair consisting of '`MinQuality`' and a scalar value in the range [0,1].

The minimum accepted quality of corners represents a fraction of the maximum corner metric value in the image. Larger values can be used to remove erroneous corners.

Example: `'MinQuality', 0.01`

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`FilterSize` — Gaussian filter dimension
5 (default)

Gaussian filter dimension, specified as the comma-separated pair consisting of '`FilterSize`' and an odd integer value in the range [3, `min(size(I))`].

The Gaussian filter smooths the gradient of the input image.

The function uses the `FilterSize` value to calculate the filter's dimensions, `FilterSize`-by-`FilterSize`. It also defines the standard deviation of the Gaussian filter as `FilterSize`/3.

Example: `'FilterSize', 5`

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ROI — Rectangular region
[1 1 size(I,2) size(I,1)] (default) | vector

Rectangular region for corner detection, specified as a comma-separated pair consisting of 'ROI' and a vector of the format [*x y width height*]. The first two integer values [*x y*] represent the location of the upper-left corner of the region of interest. The last two integer values represent the width and height.

Example: 'ROI', [50,150,100,200]

Output Arguments

points — Corner points
cornerPoints object

Corner points object, returned as a cornerPoints object. The object contains information about the feature points detected in the 2-D input image.

PointsGPU — Corner points
cornerPoints object

Corner points object, returned as a cornerPoints object. The object contains information about the feature points detected in the 2-D input image. The underlying feature point data of this object is stored on the GPU. Use the gather method and PointsGPU output to copy data back to the CPU.

```
pointsCPU = gather(pointsGPU);
```

References

[1] Harris, C., and M. Stephens, "A Combined Corner and Edge Detector," *Proceedings of the 4th Alvey Vision Conference*, August 1988, pp. 147-151.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.
- `'FilterSize'` must be a compile-time constant.
- Generated code for this function uses a precompiled platform-specific shared library.

See Also

BRISKPoints | MSERRegions | SURFPoints | binaryFeatures | cornerPoints | detectBRISKFeatures | detectFASTFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | extractHOGFeatures | matchFeatures

Topics

"Find Corner Points Using the Eigenvalue Algorithm" on page 3-185
"Find Corner Points in an Image Using the FAST Algorithm" on page 3-175
"Point Feature Types"

Introduced in R2013a

detectMinEigenFeatures

Detect corners using minimum eigenvalue algorithm and return `cornerPoints` object

Syntax

```
points = detectMinEigenFeatures(I)
points = detectMinEigenFeatures(I,Name,Value)
```

Description

`points = detectMinEigenFeatures(I)` returns a `cornerPoints` object, `points`. The object contains information about the feature points detected in a 2-D grayscale input image, `I`. The `detectMinEigenFeatures` function uses the minimum eigenvalue algorithm developed by Shi and Tomasi to find feature points.

`points = detectMinEigenFeatures(I,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Find Corner Points Using the Eigenvalue Algorithm

Read the image.

```
I = checkerboard;
```

Find the corners.

```
corners = detectMinEigenFeatures(I);
```

Display the results.

```
imshow(I); hold on;
plot(corners.selectStrongest(50));
```

- "Find Corner Points Using the Harris-Stephens Algorithm" on page 3-180
- "Find Corner Points in an Image Using the FAST Algorithm" on page 3-175

Input Arguments

I — Input image
M-by-*N* 2-D grayscale image

Input image, specified in 2-D grayscale. The input image must be real and nonsparse.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MinQuality','0.01','ROI', [50,150,100,200]` specifies that the detector must use a 1% minimum accepted quality of corners within the designated region of interest. This region of interest is located at *x*=50, *y*=150. The ROI has a width of 100 pixels, and a height of 200 pixels.

MinQuality — Minimum accepted quality of corners
0.01 (default)

Minimum accepted quality of corners, specified as the comma-separated pair consisting of 'MinQuality' and a scalar value in the range [0,1].

The minimum accepted quality of corners represents a fraction of the maximum corner metric value in the image. Larger values can be used to remove erroneous corners.

Example: 'MinQuality', 0.01

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

FilterSize — Gaussian filter dimension
5 (default)

Gaussian filter dimension, specified as the comma-separated pair consisting of 'FilterSize' and an odd integer value in the range [3, inf).

The Gaussian filter smooths the gradient of the input image.

The function uses the FilterSize value to calculate the filter's dimensions, FilterSize-by-FilterSize. It also defines the standard deviation as FilterSize/3.

Example: 'FilterSize', 5

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

ROI — Rectangular region
[1 1 size(I,2) size(I,1)] (default) | vector

Rectangular region for corner detection, specified as a comma-separated pair consisting of 'ROI' and a vector of the format [*x y width height*]. The first two integer values [*x y*] represent the location of the upper-left corner of the region of interest. The last two integer values represent the width and height.

Example: 'ROI', [50,150,100,200]

Output Arguments

points — Corner points
cornerPoints object

Corner points, returned as a `cornerPoints` object. The object contains information about the feature points detected in the 2-D grayscale input image.

References

[1] Shi, J., and C. Tomasi, "Good Features to Track," *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, June 1994, pp. 593–600.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.
- `'FilterSize'` must be a compile-time constant.
- Generated code for this function uses a precompiled platform-specific shared library.

See Also
BRISKPoints | MSERRegions | SURFPoints | binaryFeatures | cornerPoints | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectSURFFeatures | extractFeatures | extractHOGFeatures | matchFeatures

Topics
"Find Corner Points Using the Harris-Stephens Algorithm" on page 3-180
"Find Corner Points in an Image Using the FAST Algorithm" on page 3-175
"Point Feature Types"

Introduced in R2013a

detectMSERFeatures

Detect MSER features and return `MSERRegions` object

Syntax

```
regions = detectMSERFeatures(I)
[regions,cc] = detectMSERFeatures(I)
[ ___ ] = detectMSERFeatures(I,Name,Value)
```

Description

`regions = detectMSERFeatures(I)` returns an `MSERRegions` object, `regions`, containing information about MSER features detected in the 2-D grayscale input image, `I`. This object uses Maximally Stable Extremal Regions (MSER) algorithm to find regions.

`[regions,cc] = detectMSERFeatures(I)` optionally returns MSER regions in a connected component structure.

`[ ___ ] = detectMSERFeatures(I,Name,Value)` sets additional options specified by one or more `Name,Value` pair arguments.

Examples

Find MSER Regions in an Image

Read image and detect MSER regions.

```
I = imread('cameraman.tif');
regions = detectMSERFeatures(I);
```

Visualize MSER regions which are described by pixel lists stored inside the returned 'regions' object.

```
figure; imshow(I); hold on;
plot(regions,'showPixelList',true,'showEllipses',false);
```

Display ellipses and centroids fit into the regions. By default, plot displays ellipses and centroids.

```
figure; imshow(I);
hold on;
plot(regions);
```

Find circular MSER regions

Detect MSER regions.

```
I = imread('coins.png');
[regions,mserCC] = detectMSERFeatures(I);
```

Show all detected MSER Regions.

```
figure
imshow(I)
hold on
plot(regions,'showPixelList',true,'showEllipses',false)
```
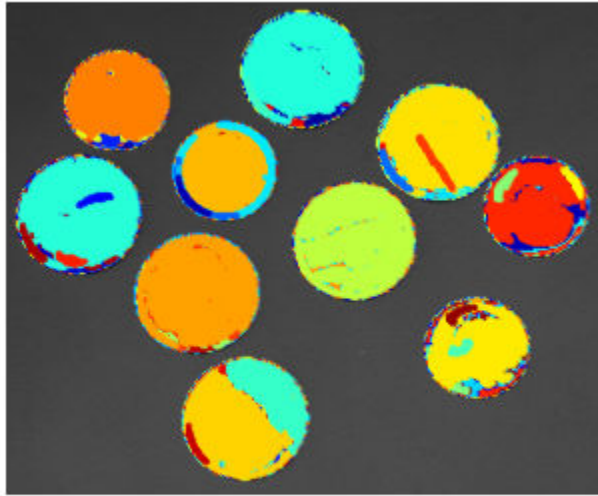
Measure the MSER region eccentricity to gauge region circularity.

```
stats = regionprops('table',mserCC,'Eccentricity');
```

Threshold eccentricity values to only keep the circular regions. (Circular regions have low eccentricity.)

```
eccentricityIdx = stats.Eccentricity < 0.55;
circularRegions = regions(eccentricityIdx);
```

Show the circular regions.

```
figure
imshow(I)
hold on
plot(circularRegions,'showPixelList',true,'showEllipses',false)
```
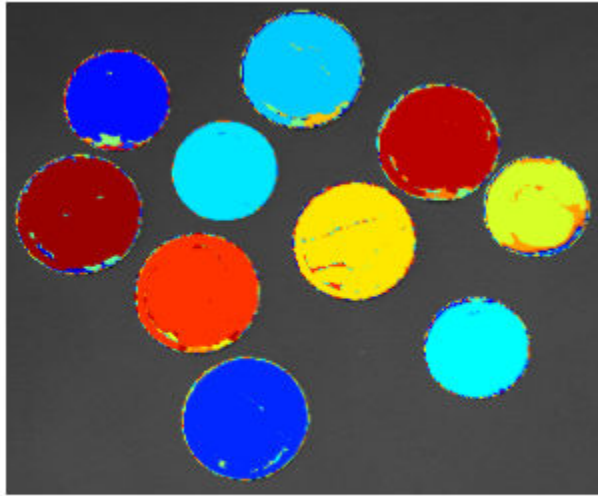
- "Automatically Detect and Recognize Text in Natural Images"

Input Arguments

I — Input image
M-by-*N* 2-D grayscale image

Input image, specified in grayscale. It must be real and nonsparse.

Data Types: `uint8` | `int16` | `uint16` | `single` | `double` | `logical`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'   '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: 'RegionAreaRange',[30 14000], specifies the size of the region in pixels.

ThresholdDelta — Step size between intensity threshold levels
2 (default) | percent numeric value

Step size between intensity threshold levels, specified as the comma-separated pair consisting of 'ThresholdDelta' and a numeric value in the range (0,100]. This value is expressed as a percentage of the input data type range used in selecting extremal regions while testing for their stability. Decrease this value to return more regions. Typical values range from 0.8 to 4.

RegionAreaRange — Size of the region
[30 14000] (default) | two-element vector

Size of the region in pixels, specified as the comma-separated pair consisting of 'RegionAreaRange' and a two-element vector. The vector, [*minArea maxArea*], allows the selection of regions containing pixels to be between *minArea* and *maxArea*, inclusive.

MaxAreaVariation — Maximum area variation between extremal regions
0.25 (default) | positive scalar

Maximum area variation between extremal regions at varying intensity thresholds, specified as the comma-separated pair consisting of 'MaxAreaVariation' and a positive scalar value. Increasing this value returns a greater number of regions, but they may be less stable. Stable regions are very similar in size over varying intensity thresholds. Typical values range from 0.1 to 1.0.

ROI — Rectangular region of interest
[1 1 size(I,2) size(I,1)] (default) | vector

Rectangular region of interest, specified as a vector. The vector must be in the format [*x y width height*]. When you specify an ROI, the function detects corners within the area located at [*x y*] of size specified by [*width height*] . The [*x y*] elements specify the upper left corner of the region.

Output Arguments

regions — MSER regions object
MSERRegions object (default)

MSER regions object, returned as a `MSERRegions` object. The object contains information about MSER features detected in the grayscale input image.

`cc` — Connected component structure
structure

Connected component structure, returned as a structure with four fields. The connected component structure is useful for measuring region properties using the `regionprops` function. The four fields:

Field	Description
`Connectivity`	Connectivity of the MSER regions. Default: **8**
`ImageSize`	Size of `I`.
`NumObjects`	Number of MSER regions in `I`.
`PixelIdxList`	1-by-`NumObjects` cell array containing `NumObjects` vectors. Each vector represents the linear indices of the pixels in the element's corresponding MSER region.

Algorithms

Intensity Threshold Levels

The MSER detector incrementally steps through the intensity range of the input image to detect stable regions. The `ThresholdDelta` parameter determines the number of increments the detector tests for stability. You can think of the threshold delta value as the size of a cup to fill a bucket with water. The smaller the cup, the more number of increments it takes to fill up the bucket. The bucket can be thought of as the intensity profile of the region.
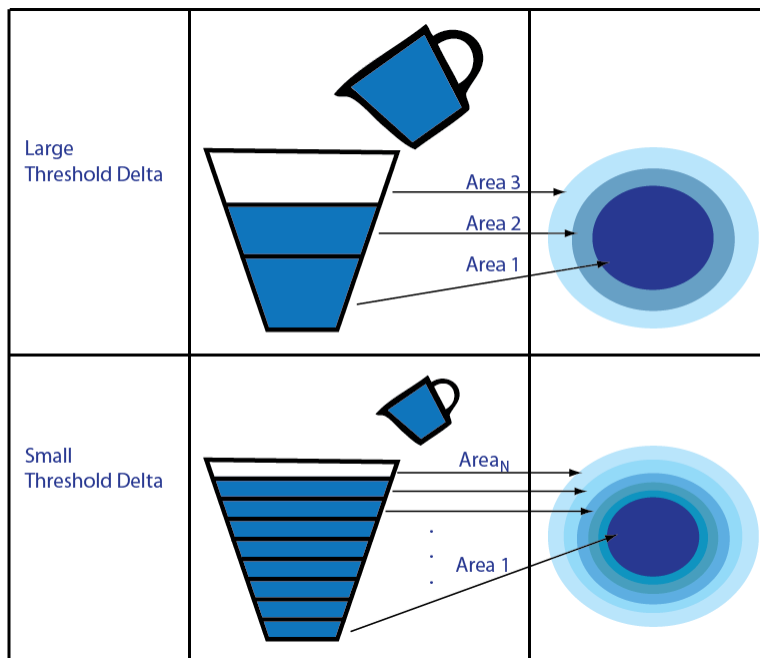
The MSER object checks the variation of the region area size between different intensity thresholds. The variation must be less than the value of the `MaxAreaVariation` parameter to be considered stable.

At a high level, MSER can be explained, by thinking of the intensity profile of an image representing a series of buckets. Imagine the tops of the buckets flush with the ground, and a hose turned on at one of the buckets. As the water fills into the bucket, it overflows and the next bucket starts filling up. Smaller regions of water join and become bigger bodies of water, and finally the whole area gets filled. As water is filling up into a bucket, it is checked against the MSER stability criterion. Regions appear, grow and merge at different intensity thresholds.

References

[1] Nister, D., and H. Stewenius, "Linear Time Maximally Stable Extremal Regions", *Lecture Notes in Computer Science*. 10th European Conference on Computer Vision, Marseille, France: 2008, no. 5303, pp. 183–196.

[2] Matas, J., O. Chum, M. Urba, and T. Pajdla. "Robust wide baseline stereo from maximally stable extremal regions." *Proceedings of British Machine Vision Conference*, pages 384-396, 2002.

[3] Obdrzalek D., S. Basovnik, L. Mach, and A. Mikulik. "Detecting Scene Elements Using Maximally Stable Colour Regions," *Communications in Computer and Information Science*, La Ferte-Bernard, France; 2009, vol. 82 CCIS (2010 12 01), pp 107–115.

[4] Mikolajczyk, K., T. Tuytelaars, C. Schmid, A. Zisserman, T. Kadir, and L. Van Gool, "*A Comparison of Affine Region Detectors*"; International Journal of Computer Vision, Volume 65, Numbers 1–2 / November, 2005, pp 43–72 .

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".

• For code generation, the function outputs `regions.PixelList` as an array. The region sizes are defined in `regions.Lengths`.

See Also
`BRISKPoints` | `MSERRegions` | `SURFPoints` | `binaryFeatures` | `cornerPoints` | `detectBRISKFeatures` | `detectFASTFeatures` | `detectHarrisFeatures` | `detectMinEigenFeatures` | `detectSURFFeatures` | `extractFeatures` | `extractHOGFeatures` | `matchFeatures`

Topics
"Automatically Detect and Recognize Text in Natural Images"
"Point Feature Types"

Introduced in R2012a

detectPeopleACF

Detect people using aggregate channel features (ACF)

Note detectPeopleACF will be removed in a future release. Use `peopleDetectorACF` instead.

Syntax

```
bboxes = detectPeopleACF(I)
[bboxes,scores] = detectPeopleACF(I)
[ ___ ] = detectPeopleACF(I,roi)
[ ___ ] = detectPeopleACF(Name,Value)
```

Description

`bboxes = detectPeopleACF(I)` returns a matrix, `bboxes`, that contains the locations of detected upright people in the input image, `I`. The locations are represented as bounding boxes. The function uses the aggregate channel features (ACF) algorithm.

`[bboxes,scores] = detectPeopleACF(I)` also returns the detection scores for each bounding box.

`[ ___ ] = detectPeopleACF(I,roi)` detects people within the rectangular search region specified by `roi`, using either of the previous syntaxes.

`[ ___ ] = detectPeopleACF(Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments. Unspecified properties have default values.

Code Generation Support:
Supports Code Generation: No
Supports MATLAB Function block: No
"Code Generation Support, Usage Notes, and Limitations"

Examples

Detect People Using Aggregated Channel Features

Read an image.

```
I = imread('visionteam1.jpg');
```

Detect people in the image and store results as bounding boxes and score.

```
[bboxes,scores] = detectPeopleACF(I);
```

Annotate the detected upright people in the image.

```
I = insertObjectAnnotation(I,'rectangle',bboxes,scores);
```

Display the results with annotation.

```
figure
imshow(I)
title('Detected people and detection scores')
```

Detected people and detection scores
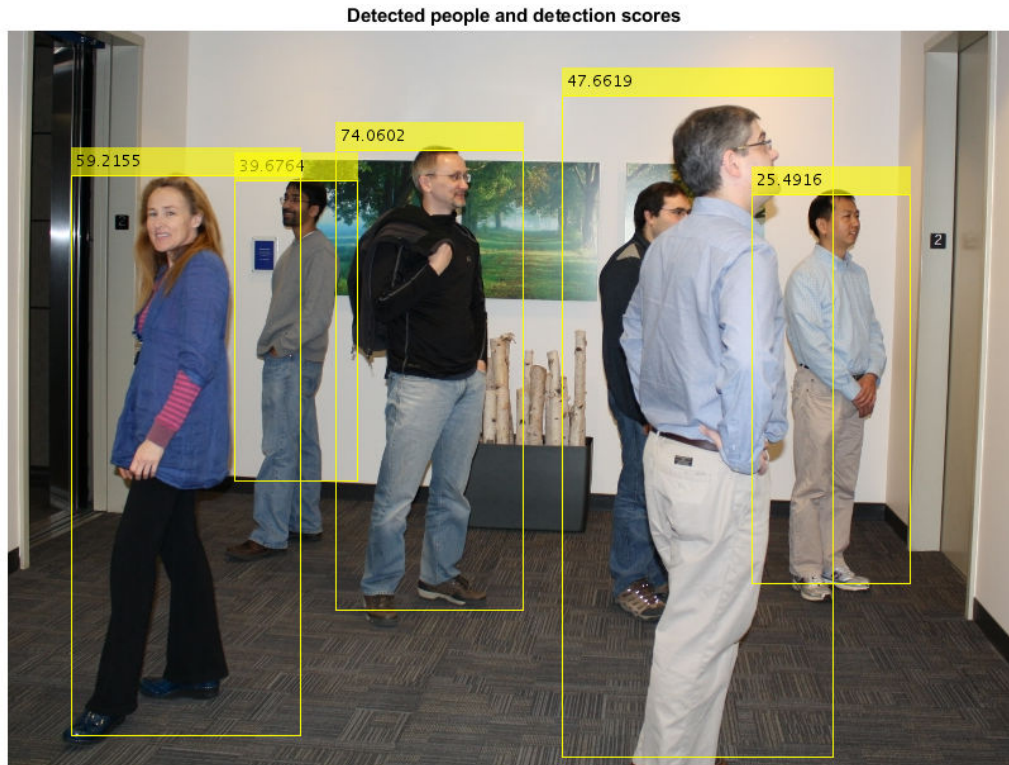
- "Tracking Pedestrians from a Moving Car"

Input Arguments

I — Input image
truecolor image

Input image, specified as a truecolor image. The image must be real and nonsparse.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single`

`roi` — Rectangular search region
four-element vector

Rectangular search region, specified as a four-element vector, [*x*,*y*,*width*,*height*]. The `roi` must be fully contained in `I`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Threshold',-1`

`Model` — ACF classification model
`'inria-100x41'` (default) | `'caltech-50x21'`

ACF classification model, specified as the comma-separated pair consisting of `'Model'` and the character vector `'inria-100x41'` or `'caltech-50x21'`. The `'inria-100x41'` model was trained using the INRIA Person dataset. The `'caltech-50x21'` model was trained using the Caltech Pedestrian dataset.

`NumScaleLevels` — Number of scale levels per octave
8 (default) | integer

Number of scale levels per octave, specified as the comma-separated pair consisting of `'NumScaleLevels'`, and an integer. Each octave is a power-of-two downscaling of the image. Increase this number to detect people at finer scale increments. Recommended values are in the range [4,8].

`WindowStride` — Window stride for sliding window
4 (default) | integer

Window stride for sliding window, specified as the comma-separated pair consisting of `'WindowStride'`, and an integer. Set this value to the amount you want to move the window, in the *x* and *y* directions. The sliding window scans the images for object detection. The function uses the same stride for the *x* and *y* directions.

`SelectStrongest` — Select strongest bounding box
true (default) | `false`

Select strongest bounding box, specified as the comma-separated pair consisting of `'SelectStrongest'` and either `true` or `false`. The process, often referred to as nonmaximum suppression, eliminates overlapping bounding boxes based on their scores. Set this property to `true` to use the `selectStrongestBbox` function to select the strongest bounding box. Set this property to `false`, to perform a custom selection operation. Setting this property to `false` returns detected bounding boxes.

`MinSize` — Minimum region size
two-element vector [*height width*] | `[50 21]` | `[100 41]`

Minimum region size in pixels, specified as the comma-separated pair consisting of `'MinSize'`, and a two-element vector [*height width*]. You can set this property to `[50 21]` for the `'caltech-50x21'` model or `[100 41]` for the `'inria-100x41'` model. You can reduce computation time by setting this value to the known minimum region size for detecting a person. By default, `MinSize` is set to the smallest region size possible to detect an upright person for the classification model selected.

`MaxSize` — Maximum region size
`size(I)` (default) | two-element vector [*height width*]

Maximum region size in pixels, specified as the comma-separated pair consisting of `'MaxSize'`, and a two-element vector, [*height width*]. You can reduce computation time by setting this value to the known region size for detecting a person. If you do not set this value, by default the function determines the height and width of the image using the size of `I`.

`Threshold` — Classification accuracy threshold
−1 (default) | numeric value

Classification accuracy threshold, specified as the comma-separated pair consisting of `'Threshold'` and a numerical value. Typical values are in the range [–1,1]. During multiscale object detection, the threshold value controls the person or nonperson classification accuracy and speed. Increase this threshold to speed up the performance at the risk of missing true detections.

Output Arguments

bboxes — Locations of detected people
M-by-4 matrix

Locations of people detected using the aggregate channel features (ACF) algorithm, returned as an *M*-by-4 matrix. The locations are represented as bounding boxes. Each row in bboxes contains a four-element vector, [*x*,*y*,*width*,*height*]. This vector specifies the upper-left corner and size of a bounding box, in pixels, for a detected person.

scores — Confidence value
M-by-1 vector

Confidence value for the detections, returned as an *M*-by-1 vector. The vector contains a value for each bounding box in bboxes. The score for each detection is the output of a soft-cascade classifier. The range of score values is [-inf inf]. Greater scores indicate a higher confidence in the detection.

References

[1] Dollar, P., R. Appel, S. Belongie, and P. Perona. "Fast feature pyramids for object detection." *Pattern Analysis and Machine Intelligence, IEEE Transactions*. Vol. 36, Issue 8, 2014, pp. 1532–1545.

[2] Dollar, C. Wojeck, B. Shiele, and P. Perona. "Pedestrian detection: An evaluation of the state of the art." *Pattern Analysis and Machine Intelligence, IEEE Transactions*.Vol. 34, Issue 4, 2012, pp. 743–761.

[3] Dollar, C., Wojeck, B. Shiele, and P. Perona. "Pedestrian detection: A benchmark." *IEEE Conference on Computer Vision and Pattern Recognition*. 2009.

See Also
selectStrongestBbox | vision.CascadeObjectDetector | vision.PeopleDetector

Topics
"Tracking Pedestrians from a Moving Car"
"Point Feature Types"

Introduced in R2016a

detectSURFFeatures

Detect SURF features and return `SURFPoints` object

Syntax

```
points = detectSURFFeatures(I)
points = detectSURFFeatures(I,Name,Value)
```

Description

`points = detectSURFFeatures(I)` returns a `SURFPoints` object, `points`, containing information about SURF features detected in the 2-D grayscale input image I. The `detectSURFFeatures` function implements the Speeded-Up Robust Features (SURF) algorithm to find blob features.

`points = detectSURFFeatures(I,Name,Value)` Additional control for the algorithm requires specification of parameters and corresponding values. An additional option is specified by one or more `Name,Value` pair arguments.

Input Arguments

I — Input image
M-by-*N* 2-D grayscale image

Input image, specified as an *M*-by-*N* 2-D grayscale. The input image must be a real nonsparse value.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

MetricThreshold — Strongest feature threshold
1000.0 (default) | non-negative scalar

Strongest feature threshold, specified as the comma-separated pair consisting of 'MetricThreshold' and a non-negative scalar. To return more blobs, decrease the value of this threshold.

NumOctaves — Number of octaves
3 (default) | scalar, greater than or equal to 1

Number of octaves to implement, specified as the comma-separated pair consisting of 'NumOctaves' and an integer scalar, greater than or equal to 1. Increase this value to detect larger blobs. Recommended values are between 1 and 4.

Each octave spans a number of scales that are analyzed using varying size filters:

Octave	Filter sizes
1	9-by-9, 15-by-15, 21-by-21, 27-by-27, ...
2	15-by-15, 27-by-27, 39-by-39, 51-by-51, ...
3	27-by-27, 51-by-51, 75-by-75, 99-by-99, ...
4	....

Higher octaves use larger filters and subsample the image data. Larger number of octaves will result in finding larger size blobs. Set the NumOctaves parameter appropriately for the image size. For example, a 50-by-50 image should not require you to set the NumOctaves parameter, greater than 2. The NumScaleLevels parameter controls the number of filters used per octave. At least three levels are required to analyze the data in a single octave.

NumScaleLevels — Number of scale levels per octave
4 (default) | integer scalar, greater than or equal to 3

Number of scale levels per octave to compute, specified as the comma-separated pair consisting of 'NumScaleLevels' and an integer scalar, greater than or equal to 3. Increase this number to detect more blobs at finer scale increments. Recommended values are between 3 and 6.

ROI — Rectangular region of interest
[1 1 size(I,2) size(I,1)] (default) | vector

Rectangular region of interest, specified as a vector. The vector must be in the format [*x y width height*]. When you specify an `ROI`, the function detects corners within the area located at [*x y*] of size specified by [*width height*] . The [*x y*] elements specify the upper left corner of the region.

Output Arguments

`points` — SURF features
`SURFPoints` object

SURF features, returned as a `SURFPoints` object. This object contains information about SURF features detected in a grayscale image.

Examples

Detect SURF Interest Points in a Grayscale Image

Read image and detect interest points.

```
I = imread('cameraman.tif');
points = detectSURFFeatures(I);
```

Display locations of interest in image.

```
imshow(I); hold on;
plot(points.selectStrongest(10));
```

- "Detect MSER Features in an Image" on page 2-236
- "Combine MSER Region Detector with SURF Descriptors" on page 2-238

References

[1] Bay, H., A. Ess, T. Tuytelaars, and L. Van Gool. "SURF:Speeded Up Robust Features." *Computer Vision and Image Understanding (CVIU)*.Vol. 110, No. 3, pp. 346–359, 2008.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".

See Also
BRISKPoints | MSERRegions | SURFPoints | binaryFeatures | cornerPoints | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | extractFeatures | extractHOGFeatures | matchFeatures

Topics
"Detect MSER Features in an Image" on page 2-236
"Combine MSER Region Detector with SURF Descriptors" on page 2-238
"Point Feature Types"

Introduced in R2011b

disparity

Disparity map between stereo images

Syntax

```
disparityMap = disparity(I1,I2)
disparityMap = disparity(I1,I2,Name,Value)
```

Description

`disparityMap = disparity(I1,I2)` returns the disparity map, `disparityMap`, for a pair of stereo images, `I1` and `I2`.

`disparityMap = disparity(I1,I2,Name,Value)` provides additional control for the disparity algorithm by using one or more `Name,Value` pair arguments.

Examples

Compute Disparity Map for a Pair of Stereo Images

Load the images and convert them to grayscale.

```
I1 = imread('scene_left.png');
I2 = imread('scene_right.png');
```

Show stereo anaglyph. Use red-cyan stereo glasses to view image in 3-D.

```
figure
imshow(stereoAnaglyph(I1,I2));
title('Red-cyan composite view of the stereo images');
```

Red-cyan composite view of the stereo images

Compute the disparity map.

```
disparityRange = [-6 10];
disparityMap = disparity(rgb2gray(I1),rgb2gray(I2),'BlockSize',...
    15,'DisparityRange',disparityRange);
```

Display the disparity map. For better visualization, use the disparity range as the display range for imshow.

```
figure
imshow(disparityMap,disparityRange);
title('Disparity Map');
colormap(gca,jet)
colorbar
```
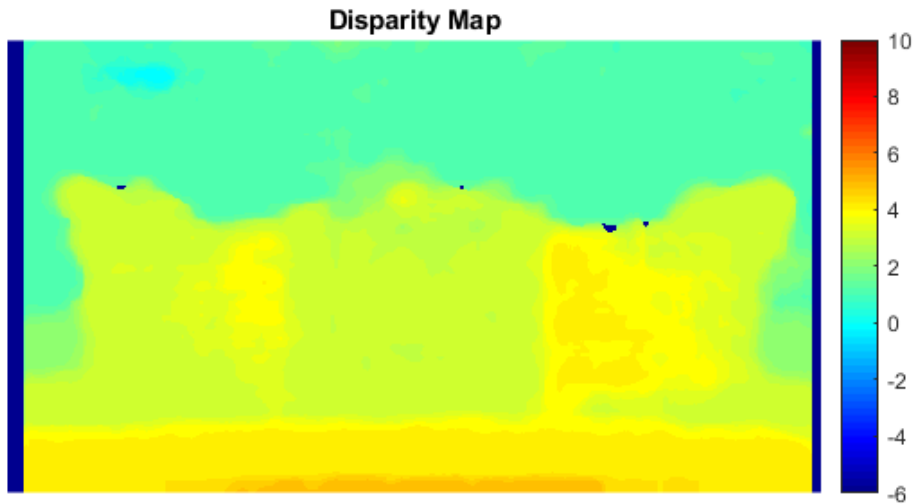
Disparity Map

- "Depth Estimation From Stereo Video"
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"
- "Uncalibrated Stereo Image Rectification"

Input Arguments

I1 — Input image 1
M-by-*N* 2-D grayscale image

Input image referenced as `I1` corresponding to camera 1, specified in 2-D grayscale. The stereo images, `I1` and `I2`, must be rectified such that the corresponding points are located on the same rows. You can perform this rectification with the `rectifyStereoImages` function.

You can improve the speed of the function by setting the class of `I1` and `I2` to `uint8`, and the number of columns to be divisible by 4. Input images `I1` and `I2` must be real, finite, and nonsparse. They must be the same class.

Data Types: `uint8` | `uint16` | `int16` | `single` | `double`

I2 — Input image 2
M-by-*N* 2-D grayscale image

Input image referenced as `I2` corresponding to camera 2, specified in 2-D grayscale. The input images must be rectified such that the corresponding points are located on the same rows. You can improve the speed of the function by setting the class of `I1` and `I2` to `uint8`, and the number of columns to be divisible by 4. Input images `I1` and `I2` must be real, finite, and nonsparse. They must be the same class.

Data Types: `uint8` | `uint16` | `int16` | `single` | `double`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Method','BlockMatching'`, specifies the `'Method'` property be set to `'BlockMatching'`.

Method — Disparity estimation algorithm
`'SemiGlobal'` (default) | `'BlockMatching'`

Disparity estimation algorithm, specified as the comma-separated pair consisting of `'Method'` and the character vector `'BlockMatching'` or `'SemiGlobal'`. The disparity function implements the basic Block Matching[1] and the Semi-Global Block Matching[3] algorithms. In the `'BlockMatching'` method, the function computes disparity by comparing the sum of absolute differences (SAD) of each block of pixels in the image. In the `'SemiGlobal'` matching method, the function additionally forces similar disparity on neighboring blocks. This additional constraint results in a more complete disparity estimate than in the `'BlockMatching'` method.

The algorithms perform these steps:

1   Compute a measure of contrast of the image by using the Sobel filter.

2   Compute the disparity for each pixel in `I1`.

3   Mark elements of the disparity map, `disparityMap`, that were not computed reliably. The function uses `–realmax('single')` to mark these elements.

DisparityRange — Range of disparity
[0 64] (default) | two-element vector

Range of disparity, specified as the comma-separated pair consisting of `'DisparityRange'` and a two-element vector. The two-element vector must be in the format [*MinDisparity*, *MaxDisparity*]. Both elements must be an integer and can be negative. *MinDisparity* and *MaxDisparity* must be in the range [-*image width*, *image width*]. The difference between *MaxDisparity* and *MinDisparity* must be divisible by 16. `DisparityRange` must be real, finite, and nonsparse. If the camera used to take `I1` was to the right of the camera used to take `I2`, then *MinDisparity* must be negative.

The disparity range depends on the distance between the two cameras and the distance between the cameras and the object of interest. Increase the `DisparityRange` when the cameras are far apart or the objects are close to the cameras. To determine a reasonable disparity for your configuration, display the stereo anaglyph of the input images in `imtool` and use the Distance tool to measure distances between pairs of corresponding points. Modify the *MaxDisparity* to correspond to the measurement.
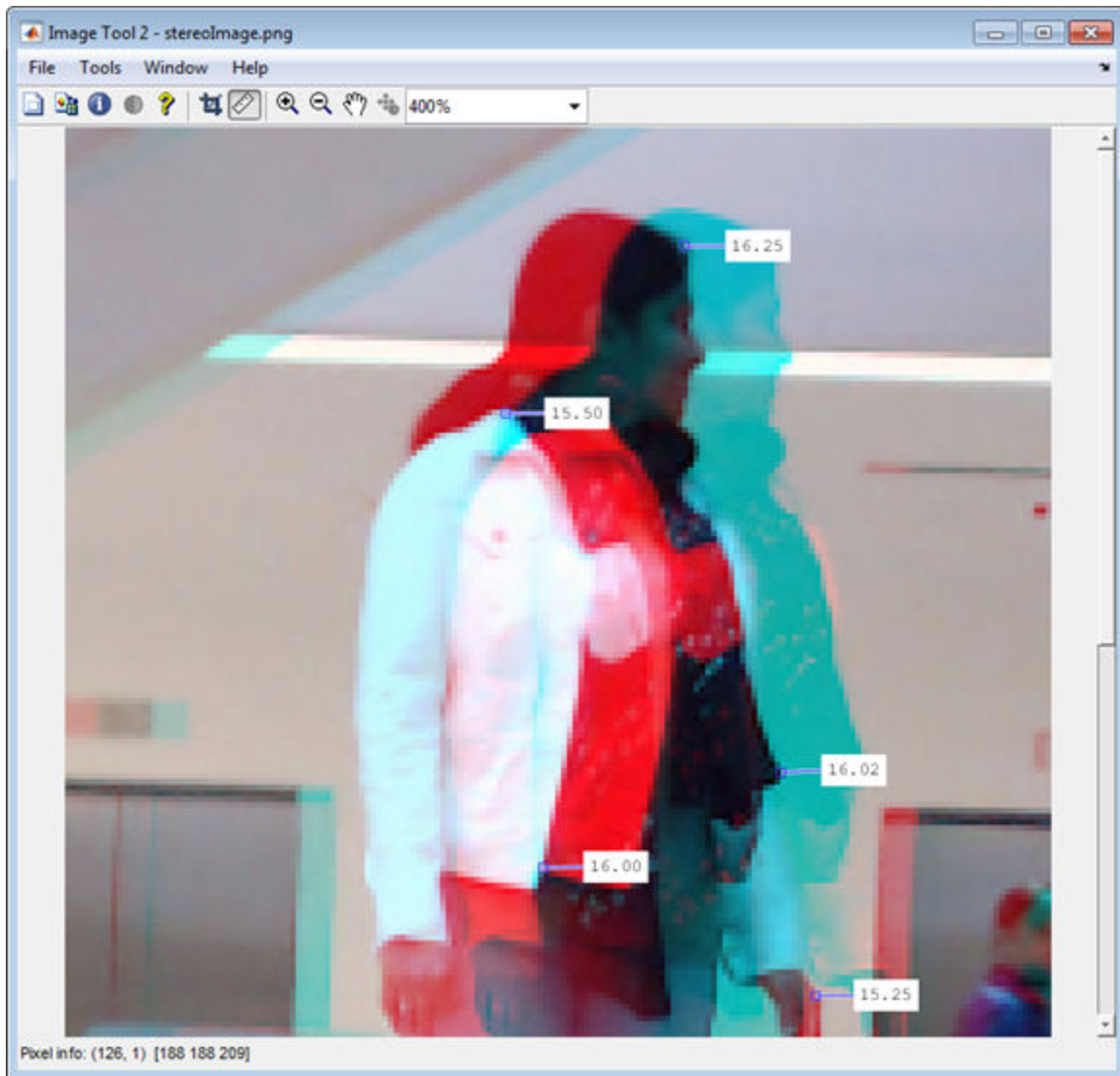
BlockSize — Square block size
15 (default) | odd integer

Square block size, specified as the comma-separated pair consisting of `'BlockSize'` and an odd integer in the range [5,255]. This value sets the width for the square block size.

The function uses the square block of pixels for comparisons between `I1` and I2. `BlockSize` must be real, finite, and nonsparse.

`ContrastThreshold` — Contrast threshold range
`0.5` (default) | scalar value

Contrast threshold range, specified as the comma-separated pair consisting of `'ContrastThreshold'` and a scalar value in the range (0,1]. The contrast threshold defines an acceptable range of contrast values. Increasing this parameter results in fewer pixels being marked as unreliable.`ContrastThreshold` must be real, finite, and nonsparse.

`UniquenessThreshold` — Minimum value of uniqueness
`15` (default) | non-negative integer

Minimum value of uniqueness, specified as the comma-separated pair consisting of `'UniquenessThreshold'` and a nonnegative integer. Increasing this parameter results in the function marking more pixels unreliable. When the uniqueness value for a pixel is low, the disparity computed for it is less reliable. Setting the threshold to `0` disables uniqueness thresholding. `UniquenessThreshold` must be real, finite, and nonsparse.

The function defines uniqueness as a ratio of the optimal disparity estimation and the less optimal disparity estimation. For example:
Let K be the best estimated disparity, and let V be the corresponding SAD (Sum of Absolute Difference) value.
Consider V as the smallest SAD value over the whole disparity range, and v as the smallest SAD value over the whole disparity range, excluding K, K-1, and K+1.
If $v < V * (1+0.01*$`UniquenessThreshold`$)$, then the function marks the disparity for the pixel as unreliable.

`DistanceThreshold` — Maximum distance for left-to-right image checking
`[ ]` (disabled) (default) | non-negative integer

Maximum distance for left-to-right image checking between two points, specified as the comma-separated pair consisting of `'DistanceThreshold'` and a nonnegative integer. Increasing this parameter results in fewer pixels being marked as unreliable. Conversely, when you decrease the value of the distance threshold, you increase the reliability of the disparity map. You can set this parameter to an empty matrix `[ ]` to disable it. `DistanceThreshold` must be real, finite, and nonsparse.

The distance threshold specifies the maximum distance between a point in `I1` and the same point found from `I2`. The function finds the distance and marks the pixel in the following way:

Let p_1 be a point in image I_1.

Step 1: The function searches for point p_1's best match in image I_2 (left-to-right check) and finds point p_2.

Step 2: The function searches for p_2's best match in image I_1 (right-to-left check) and finds point p_3.

If the search returns a distance between p_1 and p_3 greater than `DistanceThreshold`, the function marks the disparity for the point p_1 as unreliable.

TextureThreshold — Minimum texture threshold
`0.0002` (default) | scalar value

Minimum texture threshold, specified as the comma-separated pair consisting of `'TextureThreshold'` and a scalar value in the range [0, 1). The texture threshold defines the minimum texture value for a pixel to be reliable. The lower the texture for a block of pixels, the less reliable the computed disparity is for the pixels. Increasing this parameter results in more pixels being marked as unreliable. You can set this parameter to `0` to disable it. This parameter applies only when you set `Method` to `'BlockMatching'`.

The texture of a pixel is defined as the sum of the saturated contrast computed over the `BlockSize`-by-`BlockSize` window around the pixel. The function considers the disparity computed for the pixel unreliable and marks it, when the texture falls below the value defined by:

$$Texture < X * \text{TextureThreshold} * \text{BlockSize}^2$$

X represents the maximum value supported by the class of the input images, `I1` and `I2`.

`TextureThreshold` must be real, finite, and nonsparse.

Output Arguments

disparityMap — Disparity map
M-by-*N* 2-D grayscale image

Disparity map for a pair of stereo images, returned as an *M*-by-*N* 2-D grayscale image. The function returns the disparity map with the same size as the input images, `I1` and `I2`.

Each element of the output specifies the disparity for the corresponding pixel in the image references as `I1`. The returned disparity values are rounded to $\frac{1}{16}$ th pixel.

The function computes the disparity map in three steps:

1 Compute a measure of contrast of the image by using the Sobel filter.
2 Compute the disparity for each of the pixels by using block matching and the sum of absolute differences (SAD).
3 Optionally, mark the pixels which contain unreliable disparity values. The function sets the pixel to the value returned by `-realmax('single')`.

Tips

If your resulting disparity map looks noisy, try modifying the `DisparityRange`. The disparity range depends on the distance between the two cameras and the distance between the cameras and the object of interest. Increase the `DisparityRange` when the cameras are far apart or the objects are close to the cameras. To determine a reasonable disparity for your configuration, display the stereo anaglyph of the input images in `imtool` and use the Distance tool to measure distances between pairs of corresponding points. Modify the *MaxDisparity* to correspond to the measurement.
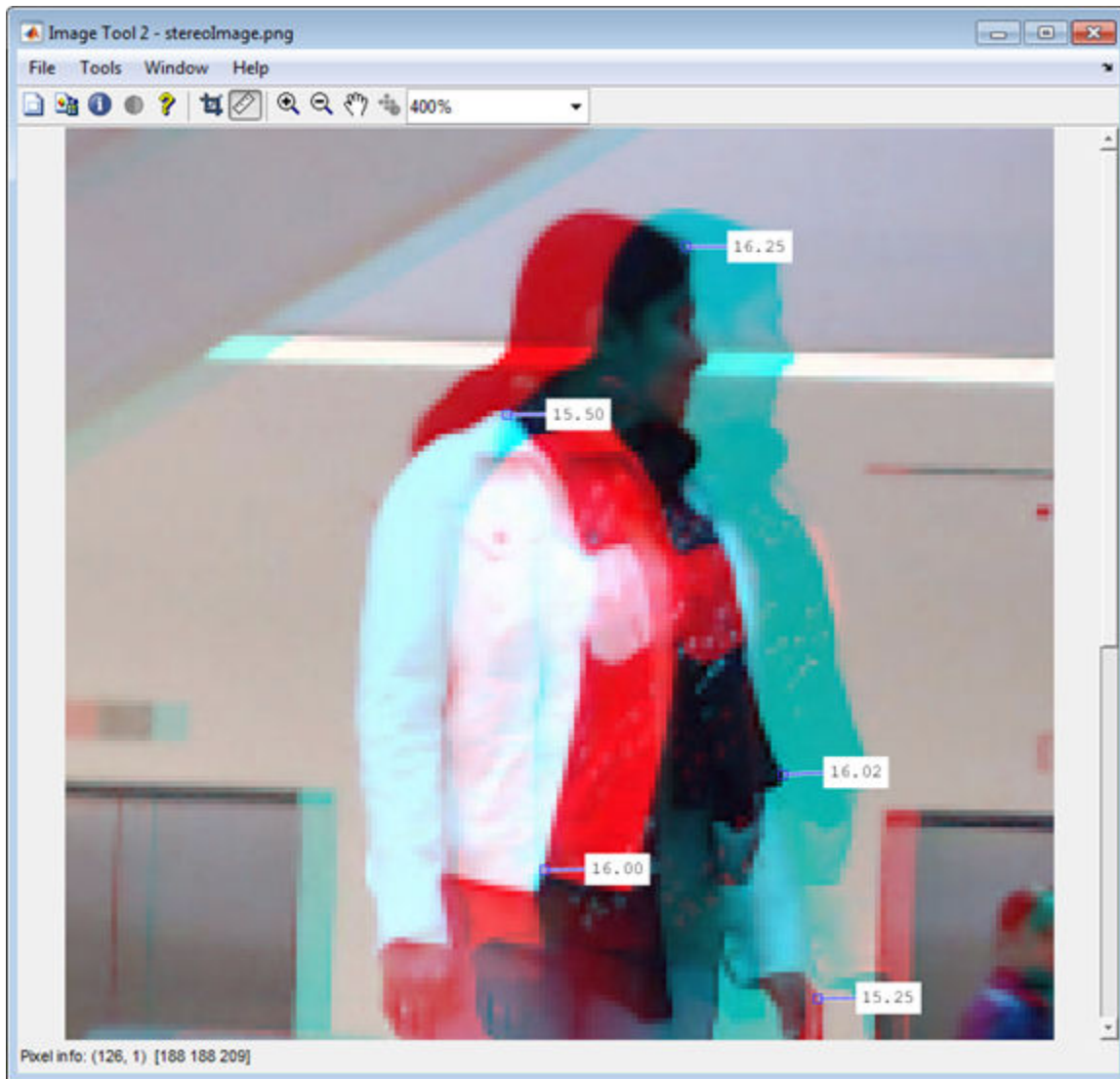
References

[1] Konolige, K., *Small Vision Systems: Hardware and Implementation*, Proceedings of the 8th International Symposium in Robotic Research, pages 203-212, 1997.

[2] Bradski, G. and A. Kaehler, *Learning OpenCV : Computer Vision with the OpenCV Library*, O'Reilly, Sebastopol, CA, 2008.

[3] Hirschmuller, H., *Accurate and Efficient Stereo Processing by Semi-Global Matching and Mutual Information*, International Conference on Computer Vision and Pattern Recognition, 2005.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- `'Method'` must be a compile-time constant.
- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries. See "Portable C Code Generation for Functions That Use OpenCV Library".

See Also
Stereo Camera Calibrator | estimateCameraParameters | estimateUncalibratedRectification | reconstructScene | rectifyStereoImages

Topics
"Depth Estimation From Stereo Video"
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Uncalibrated Stereo Image Rectification"

Introduced in R2011b

epipolarLine

Compute epipolar lines for stereo images

Syntax

```
lines = epipolarLine(F,points)
lines = epipolarLine(F',points)
```

Description

`lines = epipolarLine(F,points)` returns an *M*-by-3 matrix, `lines`. The matrix represents the computed epipolar lines in the second image corresponding to the points, `points`, in the first image. The input F represents the fundamental matrix that maps points in the first image to the epipolar lines in the second image.

`lines = epipolarLine(F',points)` returns an *M*-by-3 matrix `lines`. The matrix represents the computed epipolar lines of the first image corresponding to the points, `points`, in the second image.

Input Arguments

F

A 3-by-3 fundamental matrix. F must be double or single. If *P*1 represents a point in the first image *I*1 that corresponds to *P*2, a point in the second image *I*2, then:
$[P_2,1] * F * [P_1,1]' = 0$

In computer vision, the fundamental matrix is a 3-by-3 matrix which relates corresponding points in stereo images. When two cameras view a 3-D scene from two distinct positions, there are a number of geometric relations between the 3-D points and their projections onto the 2-D images that lead to constraints between the image points. Two images of the same scene are related by epipolar geometry.

points

An *M*-by-2 matrix, where each row contains the x and y coordinates of a point in the image. *M* represents the number of points.

`points` must be a double, single, or integer value.

Output Arguments

lines

An *M*-by-3 matrix, where each row must be in the format, [*A*,*B*,*C*]. This corresponds to the definition of the line:
A * *x* + *B* * *y* + *C* = 0.
M represents the number of lines.

Examples

Compute Fundamental Matrix

This example shows you how to compute the fundamental matrix. It uses the least median of squares method to find the inliers.

The points, matched_points1 and matched_points2, have been putatively matched.

```
load stereoPointPairs
[fLMedS,inliers] = estimateFundamentalMatrix(matchedPoints1,...
    matchedPoints2,'NumTrials',4000);
```

Show the inliers in the first image.

```
I1 = imread('viprectification_deskLeft.png');
figure;
subplot(121);
imshow(I1);
title('Inliers and Epipolar Lines in First Image'); hold on;
plot(matchedPoints1(inliers,1),matchedPoints1(inliers,2),'go')
```

Inliers and Epipolar Lines in First Image

Compute the epipolar lines in the first image.

```
epiLines = epipolarLine(fLMedS',matchedPoints2(inliers,:));
```

Compute the intersection points of the lines and the image border.

```
points = lineToBorderPoints(epiLines,size(I1));
```

Show the epipolar lines in the first image

```
line(points(:,[1,3])',points(:,[2,4])');
```

Inliers and Epipolar Lines in First Image
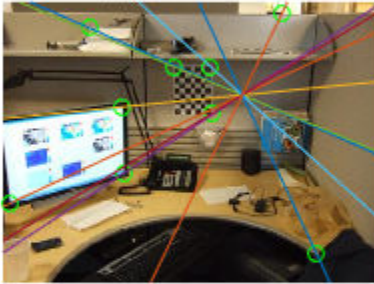
Show the inliers in the second image.

```
I2 = imread('viprectification_deskRight.png');
subplot(122);
imshow(I2);
title('Inliers and Epipolar Lines in Second Image'); hold on;
plot(matchedPoints2(inliers,1),matchedPoints2(inliers,2),'go')
```

Inliers and Epipolar Lines in First Image Inliers and Epipolar Lines in Second Image
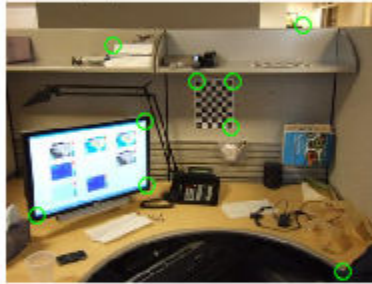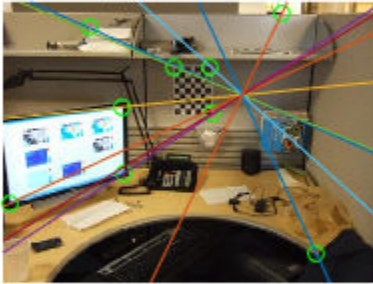
Compute and show the epipolar lines in the second image.

```
epiLines = epipolarLine(fLMedS,matchedPoints1(inliers,:));
points = lineToBorderPoints(epiLines,size(I2));
line(points(:,[1,3])',points(:,[2,4])');
truesize;
```
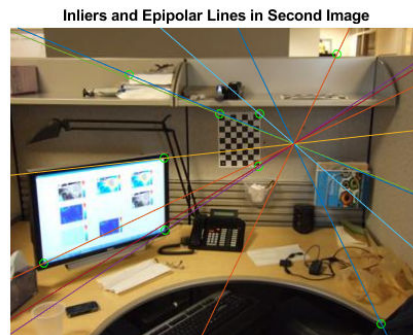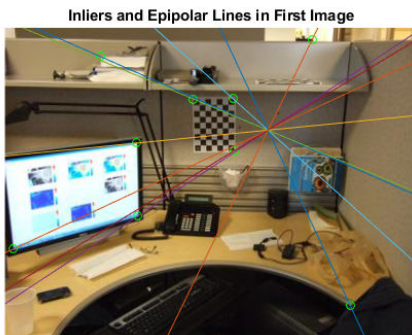
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`estimateFundamentalMatrix` | `insertShape` | `isEpipoleInImage` | `line` | `lineToBorderPoints` | `size`

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

Introduced in R2011a

estimateCameraParameters

Calibrate a single or stereo camera

Syntax

```
[cameraParams,imagesUsed,estimationErrors] =
estimateCameraParameters(imagePoints,worldPoints)
```

```
[stereoParams,pairsUsed,estimationErrors] =
estimateCameraParameters(imagePoints,worldPoints)
```

```
cameraParams = estimateCameraParameters( ___ ,Name,Value)
```

Description

`[cameraParams,imagesUsed,estimationErrors] =
estimateCameraParameters(imagePoints,worldPoints)` returns `cameraParams`, a `cameraParameters` object containing estimates for the intrinsic and extrinsic parameters and the distortion coefficients of a single camera. The function also returns the images you used to estimate the camera parameters and the standard estimation errors for the single camera calibration.

`[stereoParams,pairsUsed,estimationErrors] =
estimateCameraParameters(imagePoints,worldPoints)` returns `stereoParams`, a `stereoParameters` object containing the parameters of the stereo camera. The function also returns the images you used to estimate the stereo parameters and the standard estimation errors for the stereo camera calibration.

`cameraParams = estimateCameraParameters( ___ ,Name,Value)` configures the `cameraParams` object properties specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes. Unspecified properties have their default values.

Examples

Single Camera Calibration

Create a set of calibration images.

```
images = imageSet(fullfile(toolboxdir('vision'),'visiondata',...
            'calibration','mono'));
imageFileNames = images.ImageLocation;
```

Detect the calibration pattern.

```
[imagePoints, boardSize] = detectCheckerboardPoints(imageFileNames);
```

Generate the world coordinates of the corners of the squares.

```
squareSizeInMM = 29;
worldPoints = generateCheckerboardPoints(boardSize,squareSizeInMM);
```

Calibrate the camera.

```
I = readimage(images,1);
imageSize = [size(I, 1),size(I, 2)];
params = estimateCameraParameters(imagePoints,worldPoints, ...
                                'ImageSize',imageSize);
```
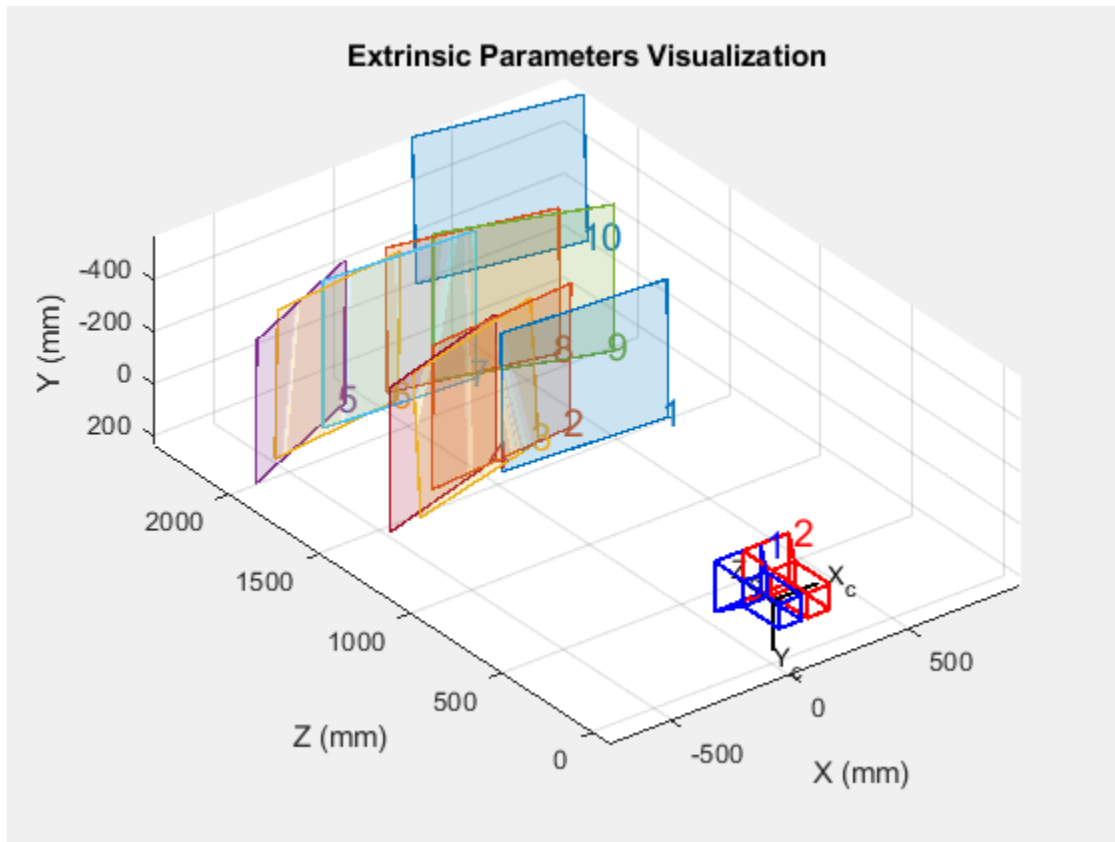
Visualize the calibration accuracy.

```
showReprojectionErrors(params);
```
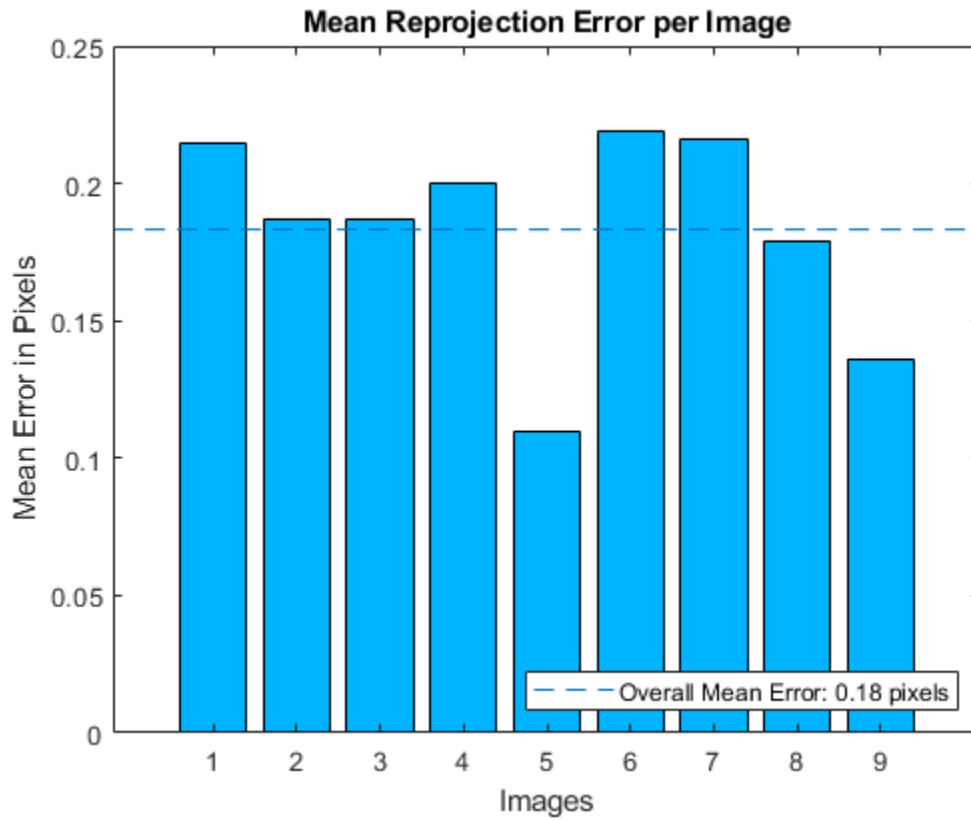
Visualize camera extrinsics.

```
figure;
showExtrinsics(params);
```
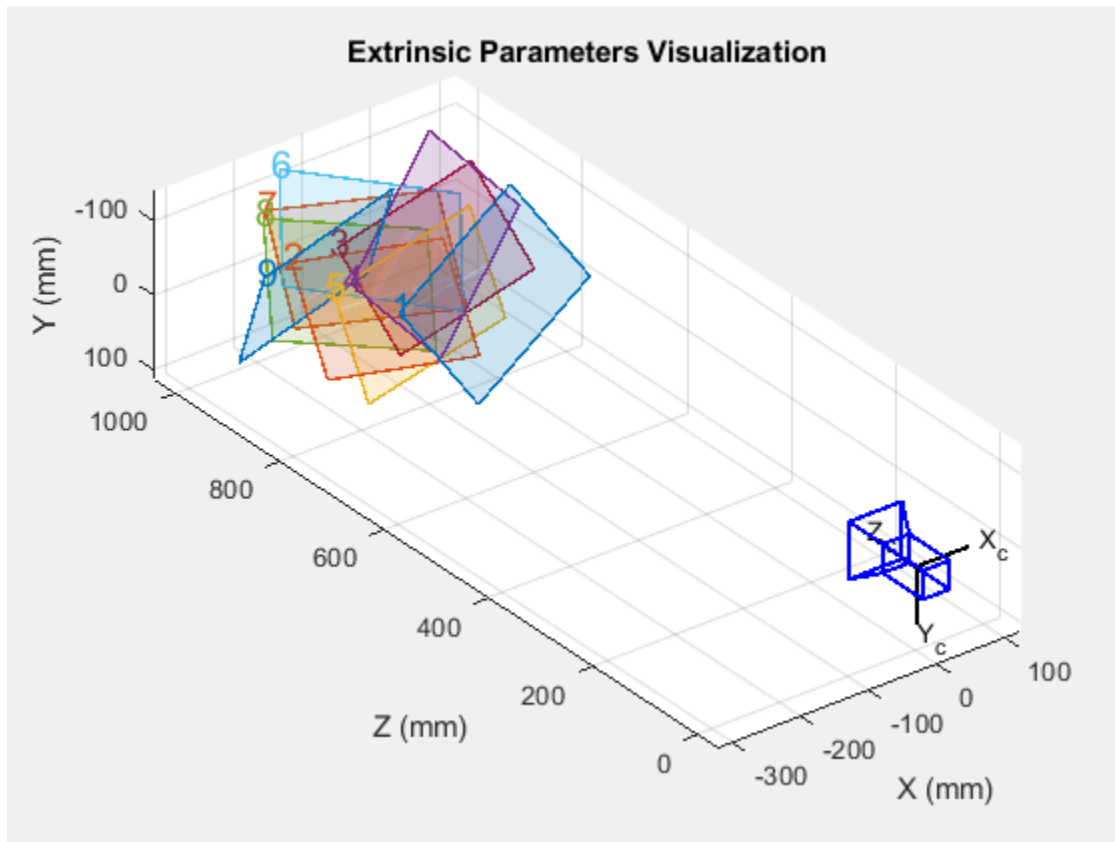
drawnow;

Plot detected and reprojected points.

```
figure;
imshow(imageFileNames{1});
hold on;
plot(imagePoints(:,1,1), imagePoints(:,2,1),'go');
plot(params.ReprojectedPoints(:,1,1),params.ReprojectedPoints(:,2,1),'r+');
legend('Detected Points','ReprojectedPoints');
hold off;
```

Stereo Camera Calibration

Specify calibration images.

```
leftImages = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','stereo','left'));
rightImages = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','stereo','right'));
```

Detect the checkerboards.

```
[imagePoints,boardSize] = ...
  detectCheckerboardPoints(leftImages.Files,rightImages.Files);
```

Specify the world coordinates of the checkerboard keypoints. Square size is in millimeters.

```
squareSize = 108;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the stereo camera system. Both cameras have the same resolution.

```
I = readimage(leftImages,1);
imageSize = [size(I,1),size(I,2)];
params = estimateCameraParameters(imagePoints,worldPoints, ...
                                  'ImageSize',imageSize);
```

Visualize the calibration accuracy.

```
showReprojectionErrors(params);
```

Mean Reprojection Error per Image

Visualize camera extrinsics.

```
figure;
showExtrinsics(params);
```

- "Evaluating the Accuracy of Single Camera Calibration"

Input Arguments

`imagePoints` — Key points of calibration pattern
M-by-2-by-*numImages* | *M*-by-2-by-*numPairs*-by-2 array

Key points of calibration pattern, specified as an array of [*x,y*] intrinsic image coordinates.

Calibration	Input Array of [*x*,*y*] Key Points
Single Camera	*M*-by-2-by-*numImages* array of [*x*,*y*] points. • The number of images, *numImages*, must be greater than 2. • The number of keypoint coordinates in each pattern, *M*, must be greater than 3.
Stereo Camera	*M*-by-2-by-*numPairs*-by-2 array of [*x*,*y*] points. • *numPairs* is the number of stereo image pairs containing the calibration pattern. • The number of keypoint coordinates in each pattern, *M*, must be greater than 3. • `imagePoints(:,:,:,1)` are the points from camera 1. • `imagePoints(:,:,:,2)` are the points from camera 2.

Data Types: `single` | `double`

worldPoints — Key points of calibration pattern in world coordinates
M-by-2 array

Key points of calibration pattern in world coordinates, specified as an *M*-by-2 array of *M* number of [*x*,*y*] world coordinates. The pattern must be planar; therefore, *z*-coordinates are zero.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'WorldUnits','mm'` sets the world point units to millimeters.

WorldUnits — World points units
`'mm'` (default) | character vector

World points units, specified as the comma-separated pair consisting of `'WorldUnits'` and a character vector representing units.

EstimateSkew — Estimate skew
`false` (default) | logical scalar

Estimate skew, specified as the comma-separated pair consisting of `'EstimateSkew'` and a logical scalar. When you set this property to `true`, the function estimates the image axes skew. When set to `false`, the image axes are exactly perpendicular and the function sets the skew to zero.
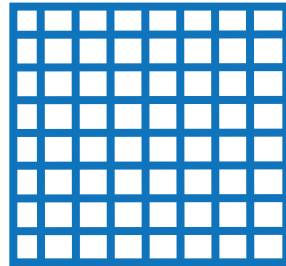
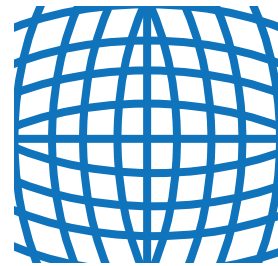**NumRadialDistortionCoefficients — Number of radial distortion coefficients**
2 (default) | 3

Number of radial distortion coefficients to estimate, specified as the comma-separated pair consisting of `'NumRadialDistortionCoefficients'` and the value 2 or 3. Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion.
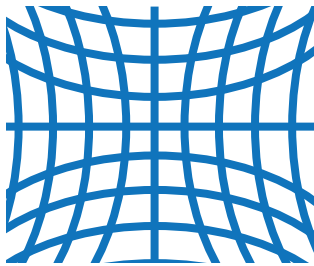
Negative radial distortion "pincushion"   No distortion   Positive radial distortion "barrel"

The radial distortion coefficients model this type of distortion. The distorted points are denoted as $(x_{distorted}, y_{distorted})$:

$$x_{distorted} = x(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

$$y_{distorted} = y(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

- x, y — Undistorted pixel locations. x and y are in normalized image coordinates. Normalized image coordinates are calculated from pixel coordinates by translating to the optical center and dividing by the focal length in pixels. Thus, x and y are dimensionless.
- k_1, k_2, and k_3 — Radial distortion coefficients of the lens.
- r^2: $x^2 + y^2$

Typically, two coefficients are sufficient for calibration. For severe distortion, such as in wide-angle lenses, you can select 3 coefficients to include k_3.

EstimateTangentialDistortion — Tangential distortion flag
false (default) | logical scalar

Tangential distortion flag, specified as the comma-separated pair consisting of, 'EstimateTangentialDistortion' and a logical scalar. When you set this property to true, the function estimates the tangential distortion. When you set it to false, the tangential distortion is negligible.

Tangential distortion occurs when the lens and the image plane are not parallel. The tangential distortion coefficients model this type of distortion.
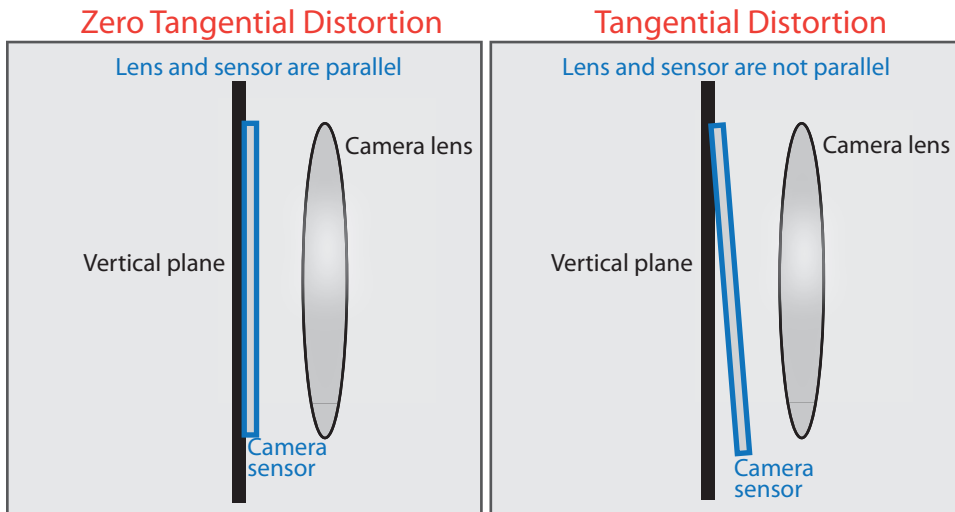
The distorted points are denoted as $(x_{distorted}, y_{distorted})$:

$x_{distorted} = x + [2 * p_1 * x * y + p_2 * (r^2 + 2 * x^2)]$

$y_{distorted} = y + [p_1 * (r^2 + 2 *y^2) + 2 * p_2 * x * y]$

- x, y — Undistorted pixel locations. x and y are in normalized image coordinates. Normalized image coordinates are calculated from pixel coordinates by translating to the optical center and dividing by the focal length in pixels. Thus, x and y are dimensionless.

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- p_1 and p_2 — Tangential distortion coefficients of the lens.
- r^2: $x^2 + y^2$

`InitialIntrinsicMatrix` — Initial guess for camera intrinsics
[] (default) | 3-by-3 matrix

Initial guess for camera intrinsics, specified as the comma-separated pair consisting of `'InitialIntrinsicMatrix'` and a 3-by-3 matrix. If you do not provide an initial value, the function computes the initial intrinsic matrix using linear least squares.

`InitialRadialDistortion` — Initial guess for radial distortion coefficients
[] (default) | 2-element vector | 3-element vector

Initial guess for radial distortion coefficients, specified as the comma-separated pair consisting of `'InitialRadialDistortion'` and a 2- or 3-element vector. If you do not provide an initial value, the function uses 0 as the initial value for all the coefficients.

`ImageSize` — Image size produced by camera
1-by-2 [*mrows, ncols*] vector | []

Image size produced by camera, specified as the comma-separated pair consisting of `'ImageSize'` and as 1-by-2 [*mrows, ncols*] vector.

Output Arguments

`cameraParams` — Camera parameters
`cameraParameters` object

Camera parameters, returned as a `cameraParameters` object.

`imagesUsed` — Images used to estimate camera parameters
P-by-1 logical array

Images you use to estimate camera parameters, returned as a *P*-by-1 logical array. *P* corresponds to the number of images. The array indicates which images you used to estimate the camera parameters. A logical `true` value in the array indicates which images you used to estimate the camera parameters.

The function computes a homography between the world points and the points detected in each image. If the homography computation fails for an image, the function issues a

warning. The points for that image are not used for estimating the camera parameters. The function also sets the corresponding element of imagesUsed to false.

estimationErrors — Standard errors of estimated parameters
cameraCalibrationErrors object | stereoCalibrationErrors object

Standard errors of estimated parameters, returned as a cameraCalibrationErrors object or a stereoCalibrationErrors object.

stereoParams — Camera parameters for stereo system
stereoParameters object

Camera parameters for stereo system, returned as a stereoParameters object. The object contains the intrinsic, extrinsic, and lens distortion parameters of the stereo camera system.

pairsUsed — Image pairs used to estimate camera parameters
P-by-1 logical array

Image pairs used to estimate camera parameters, returned as a *P*-by-1 logical array. *P* corresponds to the number of image pairs. A logical true value in the array indicates which image pairs you used to estimate the camera parameters.

Algorithms

Calibration Algorithm

You can use the Camera Calibrator app with cameras up to a field of view (FOV) of 95 degrees.

The calibration algorithm assumes a pinhole camera model:

$$w[x \quad y \quad 1] = [X \quad Y \quad Z \quad 1]\begin{bmatrix} R \\ t \end{bmatrix} K$$

(*X*,*Y*,*Z*): world coordinates of a point
(*x*,*y*): coordinates of the corresponding image point
w: arbitrary scale factor
K: camera intrinsic matrix

R: matrix representing the 3-D rotation of the camera
t: translation of the camera relative to the world coordinate system

Camera calibration estimates the values of the intrinsic parameters, the extrinsic parameters, and the distortion coefficients. There are two steps involved in camera calibration:

1   Solve for the intrinsics and extrinsics in closed form, assuming that lens distortion is zero. [1]

2   Estimate all parameters simultaneously including the distortion coefficients using nonlinear least-squares minimization (Levenberg–Marquardt algorithm). Use the closed form solution from the preceding step as the initial estimate of the intrinsics and extrinsics. Then set the initial estimate of the distortion coefficients to zero. [1] [2]

References

[1] Zhang, Z. "A Flexible New Technique for Camera Calibration". *IEEE Transactions on Pattern Analysis and Machine Intelligence*.Vol. 22, No. 11, 2000, pp. 1330–1334.

[2] Heikkila, J, and O. Silven. "A Four-step Camera Calibration Procedure with Implicit Image Correction", *IEEE International Conference on Computer Vision and Pattern Recognition*, 1997.

[3] Bouguet, J.Y. "Camera Calibration Toolbox for Matlab", Computational Vision at the California Institute of Technology. Camera Calibration Toolbox for MATLAB.

[4] Bradski, G., and A. Kaehler. *Learning OpenCV : Computer Vision with the OpenCV Library*. Sebastopol, CA: O'Reilly, 2008.

See Also

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Classes
cameraCalibrationErrors | cameraParameters | stereoCalibrationErrors | stereoParameters

Functions
detectCheckerboardPoints | disparity | estimateFundamentalMatrix |
estimateStereoBaseline | estimateUncalibratedRectification |
generateCheckerboardPoints | reconstructScene | rectifyStereoImages |
showExtrinsics | showReprojectionErrors | undistortImage |
undistortPoints

Topics
"Evaluating the Accuracy of Single Camera Calibration"
"What Is Camera Calibration?"
"Single Camera Calibrator App"
"Coordinate Systems"

Introduced in R2014b

estimateFundamentalMatrix

Estimate fundamental matrix from corresponding points in stereo images

Syntax

```
estimateFundamentalMatrix
F = estimateFundamentalMatrix(matchedPoints1,matchedPoints2)
[F,inliersIndex] = estimateFundamentalMatrix(matchedPoints1,
matchedPoints2)
[F,inliersIndex,status] = estimateFundamentalMatrix(matchedPoints1,
matchedPoints2)
[F,inliersIndex,status] = estimateFundamentalMatrix(matchedPoints1,
matchedPoints2,Name,Value)
```

Description

`estimateFundamentalMatrix` estimates the fundamental matrix from corresponding points in stereo images. This function can be configured to use all corresponding points or to exclude outliers. You can exclude outliers by using a robust estimation technique such as random-sample consensus (RANSAC). When you use robust estimation, results may not be identical between runs because of the randomized nature of the algorithm.

`F = estimateFundamentalMatrix(matchedPoints1,matchedPoints2)` returns the 3-by-3 fundamental matrix, `F`, using the least median of squares (LMedS) method. The input points can be *M*-by-2 matrices of *M* number of [x y] coordinates, or `SURFPoints`, `MSERRegions`, or `cornerPoints` object.

`[F,inliersIndex] = estimateFundamentalMatrix(matchedPoints1, matchedPoints2)` additionally returns logical indices, `inliersIndex`, for the inliers used to compute the fundamental matrix. The `inliersIndex` output is an *M*-by-1 vector. The function sets the elements of the vector to `true` when the corresponding point was used to compute the fundamental matrix. The elements are set to `false` if they are not used.

`[F,inliersIndex,status] = estimateFundamentalMatrix(matchedPoints1, matchedPoints2)` additionally returns a status code.

[F,inliersIndex,status] = estimateFundamentalMatrix(matchedPoints1, matchedPoints2,Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Compute Fundamental Matrix

The RANSAC method requires that the input points are already putatively matched. We can, for example, use the `matchFeatures` function for this. Using the RANSAC algorithm eliminates any outliers which may still be contained within putatively matched points.

Load stereo points.

```
load stereoPointPairs
```

Estimate the fundamental matrix.

```
fRANSAC = estimateFundamentalMatrix(matchedPoints1,...
    matchedPoints2,'Method','RANSAC',...
    'NumTrials',2000,'DistanceThreshold',1e-4)
```

fRANSAC = *3×3*

```
    0.0000   -0.0004    0.0348
    0.0004    0.0000   -0.0937
   -0.0426    0.0993    0.9892
```

Use the Least Median of Squares Method to Find Inliers

Load the putatively matched points.

```
load stereoPointPairs
[fLMedS, inliers] = estimateFundamentalMatrix(matchedPoints1,matchedPoints2,'NumTrials
```

fLMedS = *3×3*

```
    0.0000   -0.0004    0.0349
```

```
    0.0004    0.0000   -0.0938
   -0.0426    0.0994    0.9892


inliers = 18x1 logical array

    1
    1
    1
    1
    1
    1
    0
    1
    0
    0
     ⋮
```
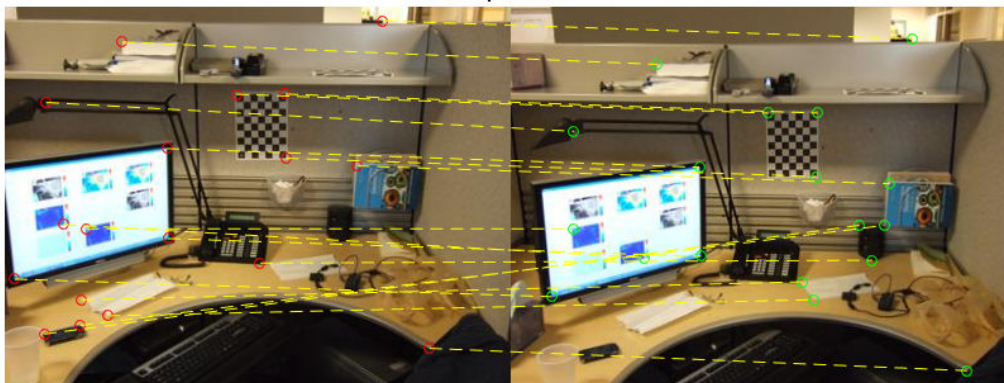
Load the stereo images.

```
I1 = imread('viprectification_deskLeft.png');
I2 = imread('viprectification_deskRight.png');
```

Show the putatively matched points.

```
figure;
showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2,'montage','PlotOptions',{'ro',
title('Putative point matches');
```
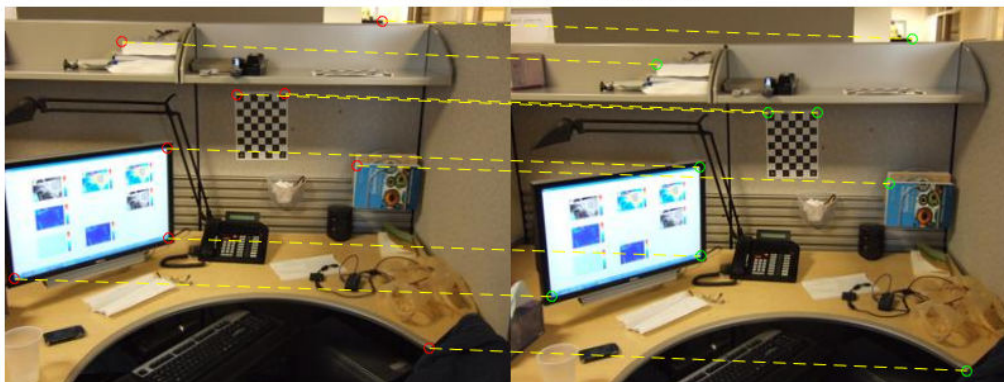
Putative point matches

Show the inlier points.

```
figure;
showMatchedFeatures(I1, I2, matchedPoints1(inliers,:),matchedPoints2(inliers,:),'montag
title('Point matches after outliers were removed');
```


Point matches after outliers were removed

Use the Normalized Eight-Point Algorithm to Compute the Fundamental Matrix

Load the stereo point pairs.

```
load stereoPointPairs
```

Compute the fundamental matrix for input points which do not contain any outliers.

```
inlierPts1 = matchedPoints1(knownInliers,:);
inlierPts2 = matchedPoints2(knownInliers,:);
fNorm8Point = estimateFundamentalMatrix(inlierPts1,inlierPts2,'Method','Norm8Point')
```

fNorm8Point = *3×3*

```
    0.0000   -0.0004    0.0348
    0.0004    0.0000   -0.0937
   -0.0426    0.0993    0.9892
```

- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Input Arguments

matchedPoints1 — Coordinates of corresponding points
SURFPoints | cornerPoints | MSERRegions | *M*-by-2 matrix of [*x*,*y*] coordinates

Coordinates of corresponding points in image one, specified as an *M*-by-2 matrix of *M* number of [x y] coordinates, or as a SURFPoints, MSERRegions, or cornerPoints object. The matchedPoints1 input must contain points which do not lie on a single planar surface, (e.g., a wall, table, or book) and are putatively matched by using a function such as matchFeatures.

matchedPoints2 — Coordinates of corresponding points
SURFPoints | cornerPoints | MSERRegions | *M*-by-2 matrix of [*x*,*y*] coordinates

Coordinates of corresponding points in image one, specified as an *M*-by-2 matrix of *M* number of [x y] coordinates, or as a SURFPoints, MSERRegions, or cornerPoints object. The matchedPoints2 input must contain points which do not lie on a single planar surface, (e.g., a wall, table, or book) and are putatively matched by using a function such as matchFeatures

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Method'`, `'RANSAC'` specifies RANSAC as the method to compute the fundamental matrix.

Method — Method used to compute the fundamental matrix
LMedS (default) | Norm8Point | RANSAC | MSAC | LTS

Method used to compute the fundamental matrix, specified as the comma-separated pair consisting of '`Method`' and one of the five character vectors:

Norm8Point	Normalized eight-point algorithm. To produce reliable results, the inputs, `matchedPoints1` and `matchedPoints2` must match precisely.
LMedS	Least Median of Squares. Select this method if you know that at least 50% of the points in `matchedPoints1` and `matchedPoints2` are inliers.
RANSAC	RANdom SAmple Consensus. Select this method if you would like to set the distance threshold for the inliers.
MSAC	M-estimator SAmple Consensus. Select the M-estimator SAmple Consensus method if you would like to set the distance threshold for the inliers. Generally, the MSAC method converges more quickly than the RANSAC method.
LTS	Least Trimmed Squares. Select the Least Trimmed Squares method if you know a minimum percentage of inliers in `matchedPoints1` and `matchedPoints2`. Generally, the LTS method converges more quickly than the LMedS method.

To produce reliable results using the `Norm8Point` algorithm, the inputs, `matchedPoints1` and `matchedPoints2`, must match precisely. The other methods can tolerate outliers and therefore only require putatively matched input points. You can obtain putatively matched points by using the `matchFeatures` function.

OutputClass — Fundamental matrix class
'double' (default) | 'single'

Fundamental matrix class, specified as the comma-separated pair consisting of
`'OutputClass'` and either the character vector `'double'` or `'single'`. This specifies
the class for the fundamental matrix and the function's internal computations.

NumTrials — Number of random trials for finding the outliers
500 (default) | integer

Number of random trials for finding the outliers, specified as the comma-separated pair
consisting of `'NumTrials'` and an integer value. This parameter applies when you set the
`Method` parameter to LMedS, RANSAC, MSAC, or LTS.

When you set the `Method` parameter to either LMedS or LTS, the function uses the actual
number of trials as the parameter value.

When you set the `Method` parameter to either RANSAC or MSAC, the function uses the
maximum number of trials as the parameter value. The actual number of trials depends
on `matchedPoints1`, `matchedPoints2`, and the value of the `Confidence` parameter.

Select the number of random trials to optimize speed and accuracy.

DistanceType — Algebraic or Sampson distance type
`'Sampson'` (default) | `'Algebraic'`

Algebraic or Sampson distance type, specified as the comma-separated pair consisting of
`'DistanceType'` and either the `Algebraic` or `Sampson` character vector. The distance
type determines whether a pair of points is an inlier or outlier. This parameter applies
when you set the `Method` parameter to LMedS, RANSAC, MSAC, or LTS.

Note For faster computations, set this parameter to `Algebraic`. For a geometric
distance, set this parameter to `Sampson`.

Data Types: `char`

DistanceThreshold — Distance threshold for finding outliers
0.01 (default)

Distance threshold for finding outliers, specified as the comma-separated pair consisting
of `'DistanceThreshold'` and a positive value. This parameter applies when you set the
`Method` parameter to RANSAC or MSAC.

Confidence — Desired confidence for finding maximum number of inliers
99 (default) | scalar

Desired confidence for finding maximum number of inliers, specified as the comma-separated pair consisting of 'Confidence' and a percentage scalar value in the range (0 100). This parameter applies when you set the Method parameter to RANSAC or MSAC.

InlierPercentage — Minimum percentage of inliers in input points
50 (default) | scalar

Minimum percentage of inliers in input points, specified as the comma-separated pair consisting of 'InlierPercentage' and percentage scalar value in the range (0 100). Specify the minimum percentage of inliers in matchedPoints1 and matchedPoints2. This parameter applies when you set the Method parameter to LTS.

ReportRuntimeError — Report runtime error
true (default) | false

Report runtime error, specified as the comma-separated pair consisting of 'ReportRuntimeError' and a logical value. Set this parameter to true to report run-time errors when the function cannot compute the fundamental matrix from matchedPoints1 and matchedPoints2. When you set this parameter to false, you can check the status output to verify validity of the fundamental matrix.

Output Arguments

F — Fundamental matrix
3-by-3 matrix

Fundamental matrix, returns as a 3-by-3 matrix that is computed from the points in the inputs matchedPoints1 and matchedPoints2.

$$\begin{bmatrix} P_2 & 1 \end{bmatrix} * FundamentalMatrix * \begin{bmatrix} P_1 & 1 \end{bmatrix}' = 0$$

P_1, the point in matchedPoints1 of image 1 in pixels, corresponds to the point, P_2, the point in matchedPoints2 in image 2.

In computer vision, the fundamental matrix is a 3-by-3 matrix which relates corresponding points in stereo images. When two cameras view a 3-D scene from two distinct positions, there are a number of geometric relations between the 3-D points and

their projections onto the 2-D images that lead to constraints between the image points. Two images of the same scene are related by epipolar geometry.

`inliersIndex` — Inliers index
M-by-1 logical vector

Inliers index, returned as an *M*-by-1 logical index vector. An element set to `true` means that the corresponding indexed matched points in `matchedPoints1` and `matchedPoints2` were used to compute the fundamental matrix. An element set to `false` means the indexed points were not used for the computation.

Data Types: `logical`

`status` — Status code
`0` | `1` | `2`

Status code, returned as one of the following possible values:

status	Value
0:	No error.
1:	`matchedPoints1` and `matchedPoints2` do not contain enough points. `Norm8Point`, `RANSAC`, and `MSAC` require at least 8 points, `LMedS` 16 points, and `LTS` requires `ceil(800/InlierPercentage)`.
2:	Not enough inliers found.

Data Types: `int32`

Tips

Use `estimateEssentialMatrix` when you know the camera intrinsics. You can obtain the intrinsics using the **Camera Calibrator** app. Otherwise, you can use the `estimateFundamentalMatrix` function that does not require camera intrinsics. Note that the fundamental matrix cannot be estimated from coplanar world points.

Algorithms

Computing the Fundamental Matrix

This function computes the fundamental matrix using the normalized eight-point algorithm [1]

When you choose the `Norm8Point` method, the function uses all points in `matchedPoints1` and `matchedPoints2` to compute the fundamental matrix.

When you choose any other method, the function uses the following algorithm to exclude outliers and compute the fundamental matrix from inliers:

1 Initialize the fundamental matrix, *F*, to a 3-by-3 matrix of zeros.
2 Set the loop counter *n*, to zero, and the number of loops *N*, to the number of random trials specified.
3 Loop through the following steps while *n* < *N*:

   a Randomly select 8 pairs of points from `matchedPoints1` and `matchedPoints2`.
   b Use the selected 8 points to compute a fundamental matrix, *f*, by using the normalized 8-point algorithm.
   c Compute the fitness of *f* for all points in `matchedPoints1` and `matchedPoints2`.
   d If the fitness of *f* is better than *F*, replace *F* with *f*.

      For `RANSAC` and `MSAC`, update *N*.
   e *n* = *n* + 1

Number of Random Samplings for RANSAC and MSAC Methods

The RANSAC and MSAC methods update the number of random trials *N*, for every iteration in the algorithm loop. The function resets *N*, according to the following:

$$N = \min\left(N, \ \frac{\log(1-p)}{\log(1-r^8)} \right).$$

Where, *p* represents the confidence parameter you specified, and *r* is calculated as follows:

$$\sum_{i}^{N} \text{sgn}(du_i, v_i), t) / N \, , \text{ where } \text{sgn}(a,b) = 1 \text{ if } a \le b \text{ and } 0 \text{ otherwise.}$$

When you use RANSAC or MSAC, results may not be identical between runs because of the randomized nature of the algorithm.

Distance Types

The function provides two distance types, algebraic distance and Sampson distance, to measure the distance of a pair of points according to a fundamental matrix. The following equations are used for each type, with u representing `matchedPoints1` and v representing `matchedPoints2`.

Algebraic distance:
$$d(u_i, v_i) = (v_i F u_i^T)^2$$

Sampson distance:
$$d(u_i, v_i) = (v_i F u_i^T)^2 \left[\frac{1}{(F u_i^T)_1^2 + (F u_i^T)_2^2} + \frac{1}{(v_i F)_1^2 + (v_i F)_2^2} \right]$$

where i represents the index of the corresponding points, and $\left(F u_i^T \right)_j^2$, the square of the j-th entry of the vector $F u_i^T$.

Fitness of Fundamental Matrix for Corresponding Points

The following table summarizes how each method determines the fitness of the computed fundamental matrix:

Method	Measure of Fitness
LMedS	$median(d(u_i, v_i); i = 1 : N)$, the number of input points. The smaller the value, the better the fitness.

Method	Measure of Fitness
RANSAC	$\sum\limits_{i}^{N} \mathrm{sgn}(du_i, v_i), t)\,/\,N$, where $\mathrm{sgn}(a,b) = 1$ if $a \le b$ and 0 otherwise, t represents the specified threshold. The greater the value, the better the fitness.
MSAC	$\sum\limits_{i}^{N} \min(d(u_i, v_i), t)$. The smaller the value, the better the fitness.
LTS	$\sum\limits_{\Omega} d(u_i, v_i)$, where Ω is the first lowest value of an (N x q) pair of points. Where q represents the inlier percentage you specified. The smaller the value, the better the fitness.

References

[1] Hartley, R., A. Zisserman, *Multiple View Geometry in Computer Vision*, Cambridge University Press, 2003.

[2] Rousseeuw, P., A. Leroy, *Robust Regression and Outlier Detection*, John Wiley & Sons, 1987.

[3] Torr, P. H. S., and A. Zisserman, *MLESAC: A New Robust Estimator with Application to Estimating Image Geometry*, Computer Vision and Image Understanding, 2000.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- `'Method'`, `'OutputClass'`, `'DistanceType'`, and `'ReportRuntimeError'` must be compile-time constants.

See Also

detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | epipolarline | estimateUncalibratedRectification | extractFeatures | matchFeatures | relativeCameraPose

Topics

"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Point Feature Types"
"Structure from Motion"
"Coordinate Systems"

Introduced in R2012b

estimateEssentialMatrix

Estimate essential matrix from corresponding points in a pair of images

Syntax

```
E = estimateEssentialMatrix(matchedPoints1,matchedPoints2,
cameraParams)
E = estimateEssentialMatrix(matchedPoints1,matchedPoints2,
cameraParams1,cameraParams2)
[E,inliersIndex] = estimateEssentialMatrix(matchedPoints1,
matchedPoints2)
[E,inliersIndex,status] = estimateEssentialMatrix(matchedPoints1,
matchedPoints2)
[E,inliersIndex,status] = estimateEssentialMatrix( ___ ,Name,Value)
```

Description

`E = estimateEssentialMatrix(matchedPoints1,matchedPoints2, cameraParams)` returns the 3-by-3 essential matrix, E, using the M-estimator sample consensus (MSAC) algorithm. The input points can be *M*-by-2 matrices of *M* number of [*x,y*] coordinates, or a SURFPoints, MSERRegions, BRISKPoints, or `cornerPoints` object. The `cameraParams` object contains the parameters of the camera used to take the images.

`E = estimateEssentialMatrix(matchedPoints1,matchedPoints2, cameraParams1,cameraParams2)` returns the essential matrix relating two images taken by different cameras. `cameraParams1` and `cameraParams2` are `cameraParameters` objects containing the parameters of camera 1 and camera 2 respectively.

`[E,inliersIndex] = estimateEssentialMatrix(matchedPoints1, matchedPoints2)` additionally returns an *M*-by-1 logical vector, `inliersIndex`, used to compute the essential matrix. The function sets the elements of the vector to `true` when the corresponding point was used to compute the fundamental matrix. The elements are set to `false` if they are not used.

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[E,inliersIndex,status] = estimateEssentialMatrix(matchedPoints1, matchedPoints2) additionally returns a status code to indicate the validity of points.

[E,inliersIndex,status] = estimateEssentialMatrix(___ ,Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Estimate Essential Matrix from A Pair of Images

Load precomputed camera parameters.

```
load upToScaleReconstructionCameraParameters.mat
```

Read and undistort two images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata',...
    'upToScaleReconstructionImages');
images = imageDatastore(imageDir);
I1 = undistortImage(readimage(images,1),cameraParams);
I2 = undistortImage(readimage(images,2),cameraParams);
I1gray = rgb2gray(I1);
I2gray = rgb2gray(I2);
```

Detect feature points each image.

```
imagePoints1 = detectSURFFeatures(I1gray);
imagePoints2 = detectSURFFeatures(I2gray);
```

Extract feature descriptors from each image.

```
features1 = extractFeatures(I1gray,imagePoints1,'Upright',true);
features2 = extractFeatures(I2gray,imagePoints2,'Upright',true);
```

Match features across the images.

```
indexPairs = matchFeatures(features1,features2);
matchedPoints1 = imagePoints1(indexPairs(:,1));
matchedPoints2 = imagePoints2(indexPairs(:,2));
figure
showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2);
title('Putative Matches')
```
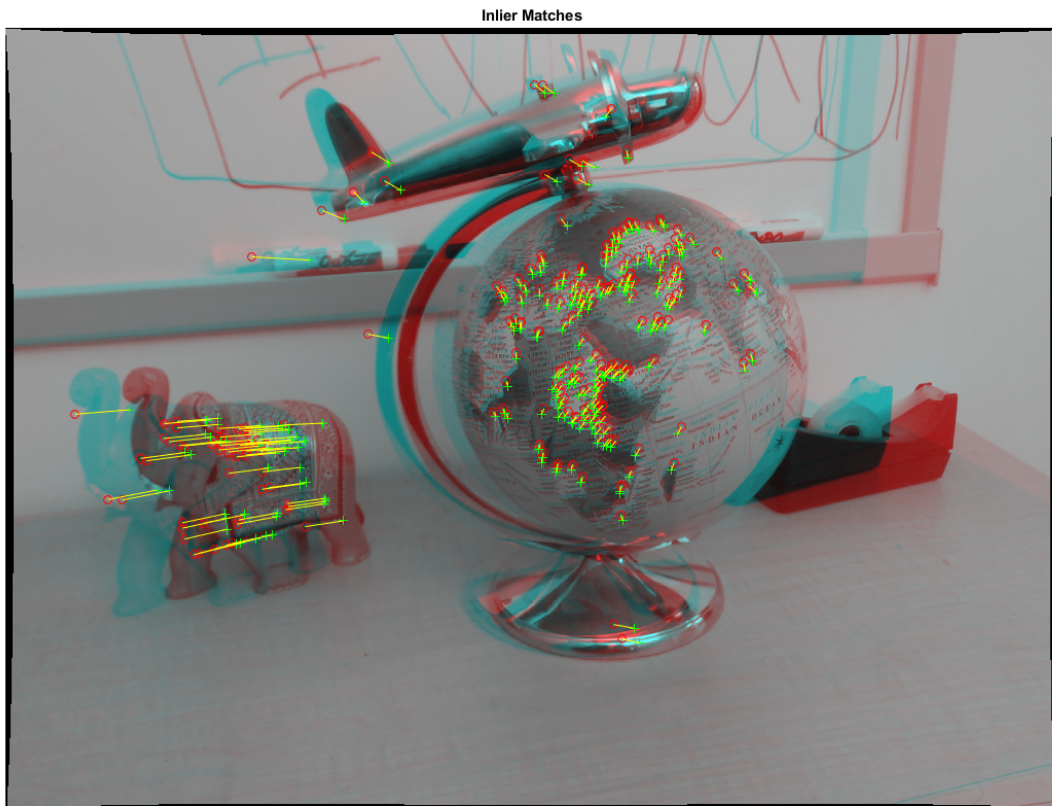
Putative Matches
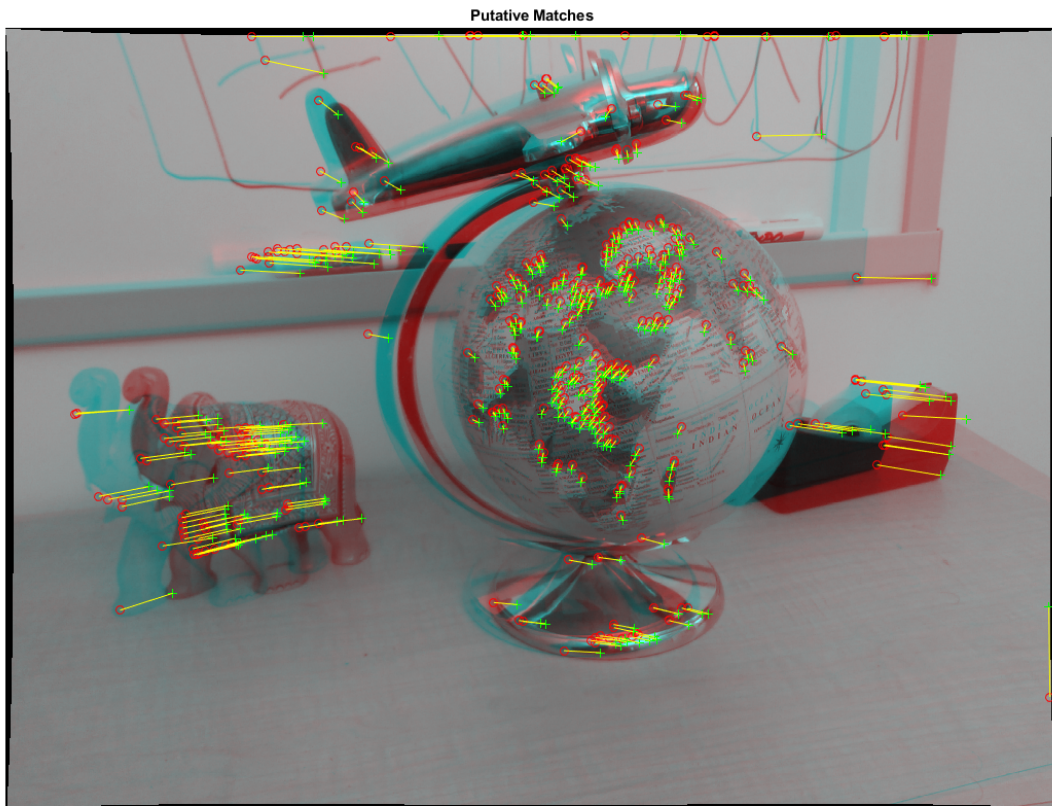
Estimate the essential matrix.

```
[E,inliers] = estimateEssentialMatrix(matchedPoints1,matchedPoints2,...
 cameraParams);
```

Display the inlier matches.

```
inlierPoints1 = matchedPoints1(inliers);
inlierPoints2 = matchedPoints2(inliers);
figure
showMatchedFeatures(I1,I2,inlierPoints1,inlierPoints2);
title('Inlier Matches')
```

Inlier Matches

- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Input Arguments

matchedPoints1 — Coordinates of corresponding points

M-by-2 matrix of [*x,y*] coordinates | SURFPoints | BRISKPoints | MSERRegions | cornerPoints

Coordinates of corresponding points in image 1, specified as an *M*-by-2 matrix of *M* of [*x,y*] coordinates, or as a SURFPoints, BRISKPoints, MSERRegions, or cornerPoints object. The matchedPoints1 input must contain at least five points, which are putatively matched by using a function such as matchFeatures.

matchedPoints2 — Coordinates of corresponding points
SURFPoints | cornerPoints | MSERRegions | BRISKPoints | *M*-by-2 matrix of [*x,y*] coordinates

Coordinates of corresponding points in image 1, specified as an *M*-by-2 matrix of *M* of [*x,y*] coordinates, or as a SURFPoints, MSERRegions, BRISKPoints,or cornerPoints object. The matchedPoints2 input must contain at least five points, which are putatively matched by using a function such as matchFeatures.

cameraParams — Object for storing camera parameters
cameraParameters object | cameraIntrinsics object

Camera parameters, specified as a cameraParameters or cameraIntrinsics object. You can return the cameraParameters object using the estimateCameraParameters function. The cameraParameters object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

cameraParams1 — Camera parameters for camera 1
cameraParameters object | cameraIntrinsics object

Camera parameters for camera 1, specified as a cameraParameters or cameraIntrinsics object. You can return the cameraParameters object using the estimateCameraParameters function. The cameraParameters object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

cameraParams2 — Camera parameters for camera 2
cameraParameters object | cameraIntrinsics object

Camera parameters for camera 2, specified as a cameraParameters or cameraIntrinsics object. You can return the cameraParameters object using the estimateCameraParameters function. The cameraParameters object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single

quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MaxNumTrials',500`

MaxNumTrials — Maximum number of random trials for finding the outliers
500 (default) | positive integer

Maximum number of random trials for finding outliers, specified as the comma-separated pair consisting of `'MaxNumTrials'` and a positive integer. The actual number of trials depends on `matchedPoints1`, `matchedPoints2`, and the value of the `Confidence` parameter. To optimize speed and accuracy, select the number of random trials.

Confidence — Desired confidence for finding maximum number of inliers
99 (default) | scalar

Desired confidence for finding the maximum number of inliers, specified as the comma-separated pair consisting of `'Confidence'` and a percentage scalar value in the range (0,100). Increasing this value improves the robustness of the output but increases the amount of computations.

MaxDistance — Sampson distance threshold
0.1 (default) | scalar

Sampson distance threshold, specified as the comma-separated pair consisting of `'MaxDistance'` and a scalar value. The function uses the threshold to find outliers returned in pixels squared. The Sampson distance is a first-order approximation of the squared geometric distance between a point and the epipolar line. Increase this value to make the algorithm converge faster, but this can also adversely affect the accuracy of the result.

Output Arguments

E — Essential matrix
3-by-3 matrix

Essential matrix, returned as a 3-by-3 matrix that is computed from the points in the `matchedPoints1` and `matchedPoints2` inputs.

$$[P_2 \quad 1] * EssentialMatrix * [P_1 \quad 1]^{'} = 0$$

The P_1 point in image 1, in normalized image coordinates, corresponds to the , P_2 point in image 2.

In computer vision, the essential matrix is a 3-by-3 matrix which relates corresponding points in stereo images which are in normalized image coordinates. When two cameras view a 3-D scene from two distinct positions, the geometric relations between the 3-D points and their projections onto the 2-D images lead to constraints between image points. The two images of the same scene are related by epipolar geometry.

Data Types: `double`

`inliersIndex` — Inliers index
M-by-1 logical vector

Inliers index, returned as an *M*-by-1 logical index vector. An element set to `true` indicates that the corresponding indexed matched points in `matchedPoints1` and `matchedPoints2` were used to compute the essential matrix. An element set to `false` means the indexed points were not used for the computation.

Data Types: `logical`

`status` — Status code
0 | 1 | 2

Status code, returned as one of the following possible values:

status	Value
0:	No error.
1:	`matchedPoints1` and `matchedPoints2` do not contain enough points. At least five points are required.
2:	Not enough inliers found. A least five inliers are required.

Data Types: `int32`

Tips

Use `estimateEssentialMatrix` when you know the camera intrinsics. You can obtain the intrinsics using the **Camera Calibrator** app. Otherwise, you can use the `estimateFundamentalMatrix` function that does not require camera intrinsics. The fundamental matrix cannot be estimated from coplanar world points.

References

[1] Kukelova, Z., M. Bujnak, and T. Pajdla *Polynomial Eigenvalue Solutions to the 5-pt and 6-pt Relative Pose Problems.* Leeds, UK: BMVC, 2008.

[2] Nister, D.. "An Efficient Solution to the Five-Point Relative Pose Problem." *IEEE Transactions on Pattern Analysis and Machine Intelligence.*Volume 26, Issue 6, June 2004.

[3] Torr, P. H. S., and A. Zisserman. "MLESAC: A New Robust Estimator with Application to Estimating Image Geometry." *Computer Vision and Image Understanding.* Volume 78, Issue 1, April 2000, pp. 138-156.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

• Use in a MATLAB Function block is not supported.

See Also

Apps
Camera Calibrator

Functions
estimateCameraParameters | estimateFundamentalMatrix | estimateWorldCameraPose | relativeCameraPose

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"
"Point Feature Types"

"Structure from Motion"
"Coordinate Systems"

Introduced in R2016b

estimateStereoBaseline

Estimate baseline of stereo camera

Syntax

```
[stereoParams,pairsUsed,estimationErrors] = estimateStereoBaseline(
imagePoints,worldPoints,intrinsics1,intrinsics2)
[stereoParams,pairsUsed,estimationErrors] = estimateStereoBaseline(
imagePoints,worldPoints,intrinsics1,intrinsics2,'WorldUnits',units)
```

Description

`[stereoParams,pairsUsed,estimationErrors] = estimateStereoBaseline(`
`imagePoints,worldPoints,intrinsics1,intrinsics2)` estimates the translation
and orientation between two cameras of the same resolution. The
`estimateStereoBaseline` function is best used for a stereo system with a wide
baseline.

`[stereoParams,pairsUsed,estimationErrors] = estimateStereoBaseline(`
`imagePoints,worldPoints,intrinsics1,intrinsics2,'WorldUnits',units)`
specifies the units in which `worldPoints` are measured.

Examples

Estimate Baseline of a Stereo System

Load camera intrinsic parameters.

```
ld = load('wideBaselineStereo');
```

Specify stereo calibration images.

```
leftImages = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','wideBaseline','left'));
```

```
rightImages = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','wideBaseline','right'));
```

Detect the checkerboards.

```
[imagePoints, boardSize] = ...
    detectCheckerboardPoints(leftImages.Files,rightImages.Files);
```

Specify world coordinates of checkerboard keypoints.

```
squareSize = 29; % in millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the baseline and extrinsic parameters.

```
params = estimateStereoBaseline(imagePoints,worldPoints, ...
    ld.intrinsics1,ld.intrinsics2)
```

```
params =
  stereoParameters with properties:

    Parameters of Two Cameras
        CameraParameters1: [1x1 cameraParameters]
        CameraParameters2: [1x1 cameraParameters]

    Inter-camera Geometry
        RotationOfCamera2: [3x3 double]
     TranslationOfCamera2: [-978.9732 55.2644 547.8081]
        FundamentalMatrix: [3x3 double]
          EssentialMatrix: [3x3 double]

    Accuracy of Estimation
     MeanReprojectionError: 0.2664

    Calibration Settings
               NumPatterns: 6
               WorldPoints: [54x2 double]
                WorldUnits: 'mm'
```

Visualize calibration accuracy.

```
figure
showReprojectionErrors(params)
```
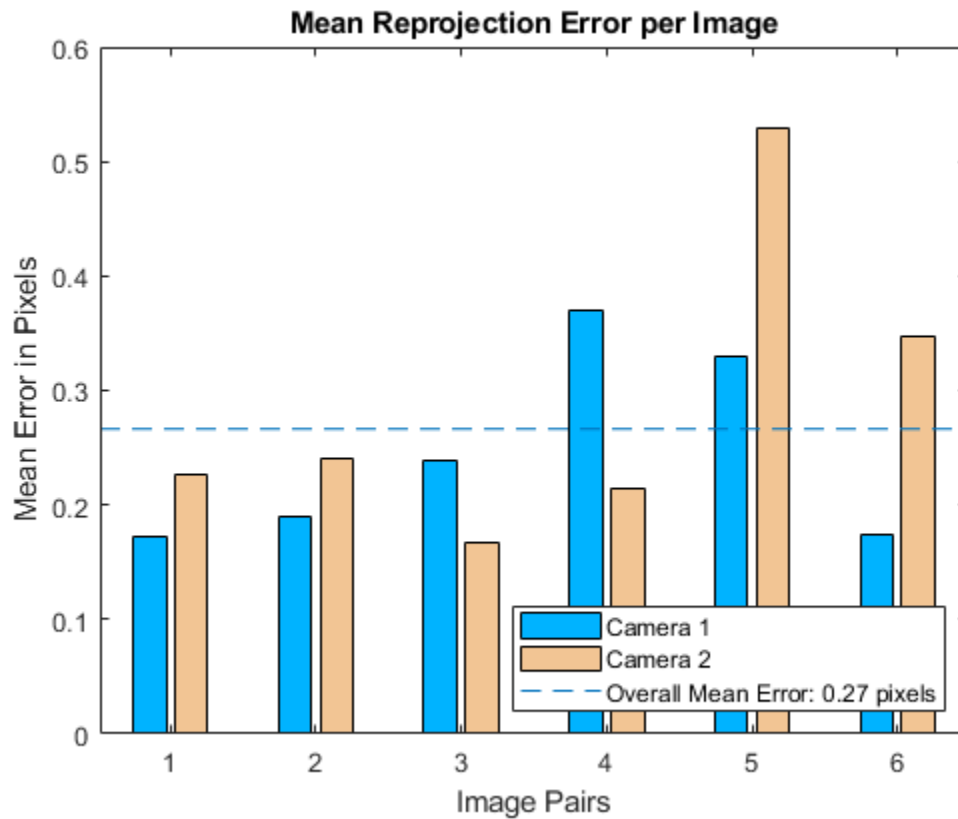
Visualize camera extrinsics.

```
figure
showExtrinsics(params)
```
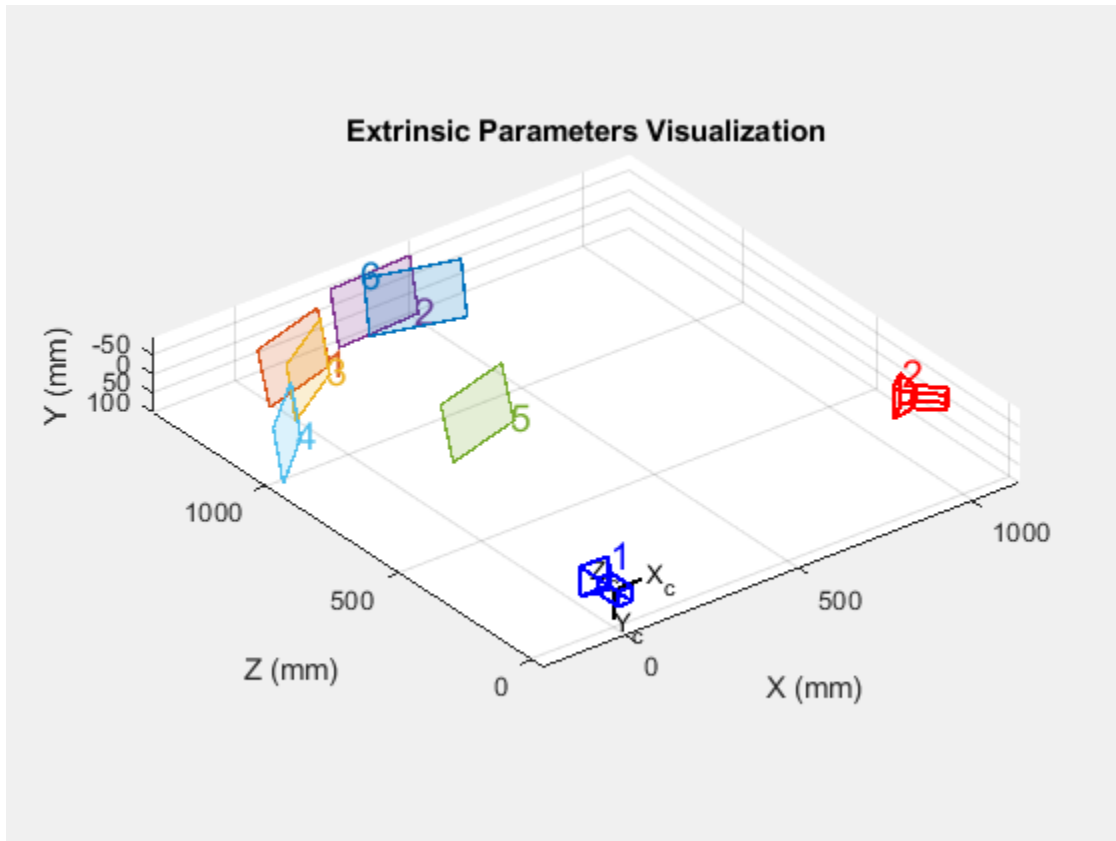
Input Arguments

`imagePoints` — Key points of calibration pattern
M-by-2-by-*numPairs*-by-2 array

Key points of calibration pattern, specified as an *M*-by-2-by-*numPairs*-by-2 array. The array contains the [*x*,*y*] intrinsic image coordinates of key points in the calibration pattern.

- *numPairs* is the number of stereo image pairs containing the calibration pattern.

- The number of keypoint coordinates in each pattern, *M*, must be greater than 3.
- `imagePoints(:,:,:,1)` are the points from camera 1.
- `imagePoints(:,:,:,2)` are the points from camera 2.

Data Types: `single` | `double`

worldPoints — Key points of calibration pattern in world coordinates
M-by-2 array

Key points of calibration pattern in world coordinates, specified as an *M*-by-2 array of *M* number of [*x*,*y*] world coordinates. The pattern must be planar; therefore, *z*-coordinates are zero.

Data Types: `single` | `double`

intrinsics1 — Intrinsic parameters of camera 1
`cameraIntrinsics` object

Intrinsic parameters of camera 1, specified as a `cameraIntrinsics` object. The intrinsics object stores information about a camera's intrinsic calibration parameters, including lens distortion.

intrinsics2 — Intrinsic parameters of camera 2
`cameraIntrinsics` object

Intrinsic parameters of camera 2, specified as a `cameraIntrinsics` object. The intrinsics object stores information about a camera's intrinsic calibration parameters, including lens distortion.

units — World points units
`'mm'` (default) | string

World points units, specified as a string representing units.

Output Arguments

stereoParams — Camera parameters for stereo system
`stereoParameters` object

Camera parameters for stereo system, returned as a `stereoParameters` object. The object contains the intrinsic, extrinsic, and lens distortion parameters of the stereo camera system.

pairsUsed — Image pairs used to estimate camera parameters
numPairs-by-1 logical vector

Image pairs used to estimate camera parameters, returned as a *numPairs*-by-1 logical array. A logical `true` value in the vector indicates which that the image pairs was used to estimate the camera parameters. An image pair will not be used for estimation if the algorithm fails to estimate a homography between the world points and the points detected in that pair of images.

estimationErrors — Standard errors of estimated parameters
`stereoCalibrationErrors` object

Standard errors of estimated parameters, returned as a `stereoCalibrationErrors` object.

See Also

Apps
Stereo Camera Calibrator

Classes
`cameraCalibrationErrors` | `cameraIntrinsics` | `cameraParameters` | `stereoCalibrationErrors` | `stereoParameters`

Functions
`detectCheckerboardPoints` | `estimateCameraParameters` | `generateCheckerboardPoints` | `showExtrinsics` | `showReprojectionErrors` | `undistortImage`

Introduced in R2018a

estimateWorldCameraPose

Estimate camera pose from 3-D to 2-D point correspondences

Syntax

```
[worldOrientation,worldLocation] = estimateWorldCameraPose(
imagePoints,worldPoints,cameraParams)
[ ___ ,inlierIdx] = estimateWorldCameraPose(imagePoints,worldPoints,
cameraParams)
[ ___ ,status] = estimateWorldCameraPose(imagePoints,worldPoints,
cameraParams)
[ ___ ] = estimateWorldCameraPose( ___ ,Name,Value)
```

Description

`[worldOrientation,worldLocation] = estimateWorldCameraPose(imagePoints,worldPoints,cameraParams)` returns the orientation and location of a calibrated camera in a world coordinate system. The input `worldPoints` must be defined in the world coordinate system.

This function solves the perspective-*n*-point (PnP) problem using the perspective-three-point (P3P) algorithm [1]. The function also eliminates spurious correspondences using the M-estimator sample consensus (MSAC) algorithm.

`[ ___ ,inlierIdx] = estimateWorldCameraPose(imagePoints,worldPoints,cameraParams)` returns the indices of the inliers used to compute the camera pose, in addition to the arguments from the previous syntax.

`[ ___ ,status] = estimateWorldCameraPose(imagePoints,worldPoints,cameraParams)` additionally returns a status code to indicate whether there were enough points.

`[ ___ ] = estimateWorldCameraPose( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

Examples

Determine Camera Pose from World-to-Image Correspondences

Load previously calculated world-to-image correspondences.

```
data = load('worldToImageCorrespondences.mat');
```

Estimate the world camera pose.

```
[worldOrientation,worldLocation] = estimateWorldCameraPose(...
     data.imagePoints,data.worldPoints,data.cameraParams);
```

Plot the world points.

```
pcshow(data.worldPoints,'VerticalAxis','Y','VerticalAxisDir','down', ...
     'MarkerSize',30);
hold on
plotCamera('Size',10,'Orientation',worldOrientation,'Location',...
     worldLocation);
hold off
```
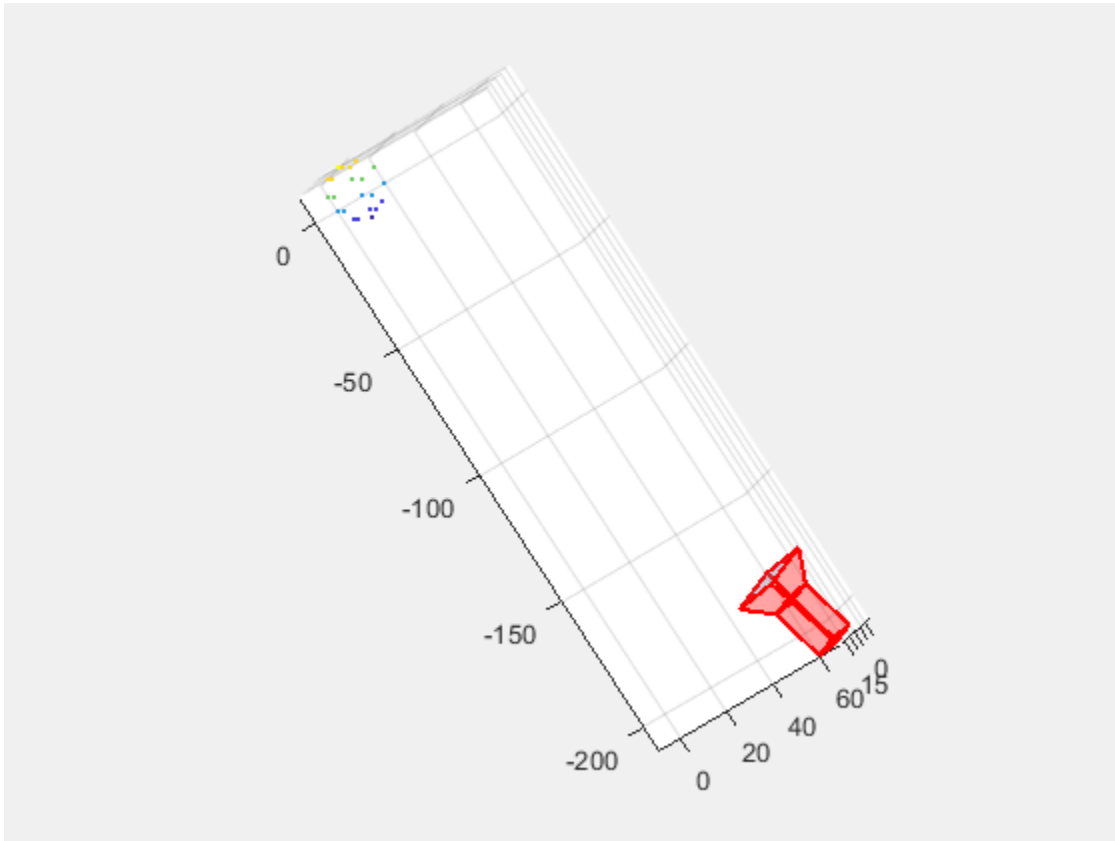
Input Arguments

`imagePoints` — Coordinates of undistorted image points
M-by-2 array

Coordinates of undistorted image points, specified as an *M*-by-2 array of [*x*,*y*] coordinates. The number of image points, *M*, must be at least four.

The function does not account for lens distortion. You can either undistort the images using the `undistortImage` function before detecting the image points, or you can undistort the image points themselves using the `undistortPoints` function.

Data Types: `single` | `double`

worldPoints — Coordinates of world points
M-by-3 array

Coordinates of world points, specified as an *M*-by-3 array of [*x*,*y*,*z*] coordinates.

Data Types: `single` | `double`

cameraParams — Object for storing camera parameters
`cameraParameters` object | `cameraIntrinsics` object

Camera parameters, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MaxNumTrials',1000`

MaxNumTrials — Maximum number of random trials
1000 (default) | positive integer scalar

Maximum number of random trials, specified as the comma-separated pair consisting of `'MaxNumTrials'` and a positive integer scalar. The actual number of trials depends on the number of image and world points, and the values for the `MaxReprojectionError` and `Confidence` properties. Increasing the number of trials improves the robustness of the output at the expense of additional computation.

Confidence — Confidence for finding maximum number of inliers
99 (default) | scalar in the range (0,100)

Confidence for finding maximum number of inliers, specified as the comma-separated pair consisting of `'Confidence'` and a scalar in the range (0,100). Increasing this value improves the robustness of the output at the expense of additional computation.

MaxReprojectionError — Reprojection error threshold
1 (default) | positive numeric scalar

Reprojection error threshold for finding outliers, specified as the comma-separated pair consisting of `'Confidence'` and a positive numeric scalar in pixels. Increasing this value makes the algorithm converge faster, but can reduce the accuracy of the result.

Output Arguments

worldOrientation — Orientation of camera in world coordinates
3-by-3 matrix

Orientation of camera in world coordinates, returned as a 3-by-3 matrix.

Data Types: `double`

worldLocation — Location of camera
1-by-3 vector

Location of camera, returned as a 1-by-3 unit vector.

Data Types: `double`

inlierIdx — Indices of inlier points
M-by-1 logical vector

Indices of inlier points, returned as an *M*-by-1 logical vector. A logical true value in the vector corresponds to inliers represented in `imagePoints` and `worldPoints`.

status — Status code
integer value

Status code, returned as `0`, `1`, or `2`.

Status code	Status
0	No error
1	`imagePoints` and `worldPoints` do not contain enough points. A minimum of four points are required.
2	Not enough inliers found. A minimum of 4 inliers are required.

References

[1] Gao, X.-S., X.-R. Hou, J. Tang, and H.F. Cheng. "Complete Solution Classification for the Perspective-Three-Point Problem." *IEEE Transactions on Pattern Analysis and Machine Intelligence.* Volume 25,Issue 8, pp. 930–943, August 2003.

[2] Torr, P. H. S., and A. Zisserman. "MLESAC: A New Robust Estimator with Application to Estimating Image Geometry." *Computer Vision and Image Understanding.* Volume 78, Issue 1, April 2000, pp. 138-156.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

See Also

Functions
bundleAdjustment | cameraPoseToExtrinsics | extrinsics | pcshow | plotCamera | relativeCameraPose | triangulateMultiview | viewSet

Topics
"Structure from Motion"

Introduced in R2016b

cameraPoseToExtrinsics

Convert camera pose to extrinsics

Syntax

```
[rotationMatrix,translationVector] = cameraPoseToExtrinsics(
orientation,location)
```

Description

`[rotationMatrix,translationVector] = cameraPoseToExtrinsics(orientation,location)` returns the camera extrinsics, `rotationMatrix` and `translationVector`, which represent the coordinate system transformation from world coordinates to camera coordinates. The inputs, `orientation` and `location`, represent the 3-D camera pose in the world coordinates.

Examples

Convert World Coordinates to Camera Coordinates

```
orientation = eye(3);
location = [0 0 10];
[R,t] = cameraPoseToExtrinsics(orientation,location)
```

R = *3×3*

```
    1     0     0
    0     1     0
    0     0     1
```

t = *1×3*

```
    0     0    -10
```

- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Input Arguments

`orientation` — 3-D orientation
3-by-3 matrix

3-D orientation of the camera in world coordinates, specified as a 3-by-3 matrix. The `orientation` and `location` inputs must be the same data type.

Data Types: `double` | `single`

`location` — 3-D location
three-element vector

3-D location of the camera in world coordinates, specified as a three-element vector. The `orientation` and `location` inputs must be the same data type.

Data Types: `double` | `single`

Output Arguments

`rotationMatrix` — 3-D rotation
3-by-3 matrix

3-D rotation , returned as a 3-by-3 matrix. The rotation matrix, together with the translation vector allows you to transform points from the world coordinate system to the camera coordinate system.

$$[x\ y\ z] = [X\ Y\ Z]R + t$$

- camera coordinates: $[x\ y\ z]$
- world coordinates: $[X\ Y\ Z]$
- rotation matrix: R
- translation vector: t

The relationship between the rotation matrix and the input orientation matrix is:
`rotationMatrix = orientation'`

`translationVector` — **3-D translation**
1-by-3 vector

3-D translation, returned as a 1-by-3 vector. The translation vector together with the rotation matrix, enables you to transform points from the world coordinate system to the camera coordinate system.

$$[x\ y\ z]\ =\ [X\ Y\ Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

The relationship between the translation vector and the input orientation matrix is :
`translationVector = -location*orientation'`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`estimateWorldCameraPose` | `extrinsics` | `extrinsicsToCameraPose` | `relativeCameraPose`

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

Introduced in R2016b

extrinsicsToCameraPose

Convert extrinsics to camera pose

Syntax

```
[orientation,location] = extrinsicsToCameraPose(rotationMatrix,
translationVector)
```

Description

`[orientation,location] = extrinsicsToCameraPose(rotationMatrix, translationVector)` returns 3-D camera pose orientation and location in world coordinates. The inputs, `rotationMatrix` and `translationVector`, represent the transformation from world coordinates to camera coordinates.

Examples

Convert Camera Coordinates to World Coordinates

```
R = eye(3);
t = [0 0 -10];
[orientation,location] = extrinsicsToCameraPose(R,t)

orientation = 3×3

     1     0     0
     0     1     0
     0     0     1


location = 1×3

     0     0    10
```

- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Input Arguments

`rotationMatrix` — 3-D rotation
3-by-3 matrix

3-D rotation , specified as a 3-by-3 matrix. The rotation matrix, together with the translation vector allows you to transform points from the world coordinate system to the camera coordinate system.

$$[x\ y\ z] = [X\ Y\ Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

The relationship between the rotation matrix and the input orientation matrix is:
`rotationMatrix = orientation'`

Data Types: `double` | `single`

`translationVector` — 3-D translation
1-by-3 vector

3-D translation, specified as a 1-by-3 vector. The translation vector together with the rotation matrix, enables you to transform points from the world coordinate system to the camera coordinate system.

$$[x\ y\ z] = [X\ Y\ Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

The relationship between the translation vector and the input orientation matrix is :
`translationVector = -location*orientation'`

Data Types: `double` | `single`

Output Arguments

`orientation` — 3-D orientation
3-by-3 matrix

3-D orientation of the camera in world coordinates, returned as a 3-by-3 matrix.

`location` — 3-D location
3-element vector

3-D location of the camera in world coordinates, specified as a three-element vector.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
cameraPoseToExtrinsics | estimateWorldCameraPose | extrinsics | relativeCameraPose

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

Introduced in R2016b

trainACFObjectDetector

Train ACF object detector

Syntax

```
detector = trainACFObjectDetector(trainingData)
detector = trainACFObjectDetector(trainingData,Name,Value)
```

Description

`detector = trainACFObjectDetector(trainingData)` returns a trained aggregate channel features (ACF) object detector. The function uses positive instances of objects in images given in the `trainingData` table and automatically collects negative instances from the images during training. To create a ground truth table, use the **Image Labeler** app.

`detector = trainACFObjectDetector(trainingData,Name,Value)` returns a `detector` object with additional options specified by one or more `Name,Value` pair arguments.

Examples

Train a Stop Sign Detector Using an ACF Object Detector

Use the `trainACFObjectDetector` with training images to create an ACF object detector that can detect stop signs. Test the detector with a separate image.

Load the training data.

```
load('stopSignsAndCars.mat')
```

Select the ground truth for stop signs. These ground truth is the set of known locations of stop signs in the images.

```
stopSigns = stopSignsAndCars(:,1:2);
```

Add the full path to the image files.

```
stopSigns.imageFilename = fullfile(toolboxdir('vision'),...
    'visiondata',stopSigns.imageFilename);
```

Train the ACF detector. You can turn off the training progress output by specifying `'Verbose',false` as a `Name,Value` pair.

```
acfDetector = trainACFObjectDetector(stopSigns,'NegativeSamplesFactor',2);
```

```
ACF Object Detector Training
The training will take 4 stages. The model size is 34x31.
Sample positive examples(~100% Completed)
Compute approximation coefficients...Completed.
Compute aggregated channel features...Completed.
--------------------------------------------
Stage 1:
Sample negative examples(~100% Completed)
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 19 weak learners.
--------------------------------------------
Stage 2:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 20 weak learners.
--------------------------------------------
Stage 3:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 54 weak learners.
--------------------------------------------
Stage 4:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 61 weak learners.
```
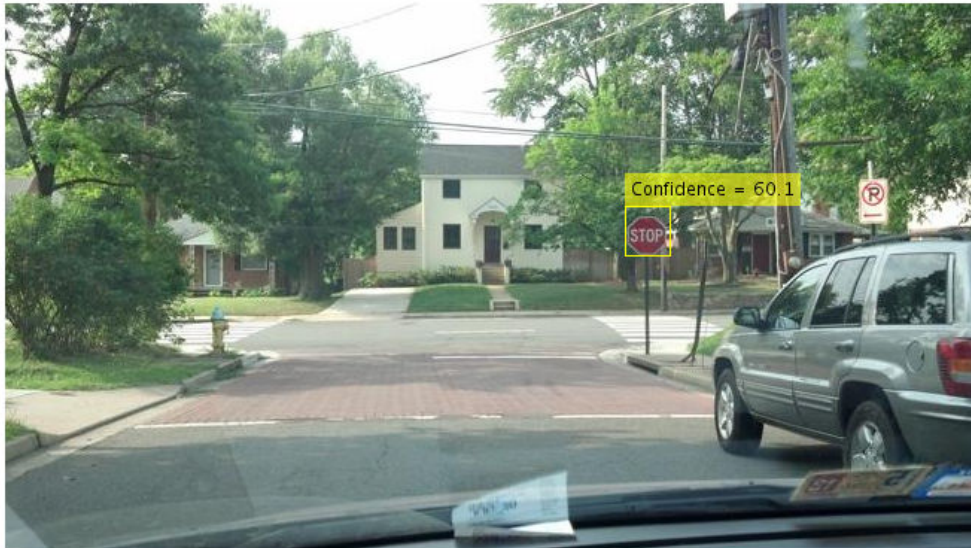
```
----------------------------------------------
ACF object detector training is completed. Elapsed time is 31.7646 seconds.
```

Test the ACF detector on a test image.

```
img = imread('stopSignTest.jpg');

[bboxes,scores] = detect(acfDetector,img);
```

Display the detection results and insert the bounding boxes for objects into the image.

```
for i = 1:length(scores)
   annotation = sprintf('Confidence = %.1f',scores(i));
   img = insertObjectAnnotation(img,'rectangle',bboxes(i,:),annotation);
end

figure
imshow(img)
```

Input Arguments

`trainingData` — Labeled ground truth images
table

Labeled ground truth images, specified as a table with two columns. The first column must contain paths and file names to grayscale or truecolor (RGB) images. Although, ACF-based detectors work best with truecolor images. The second column contains M-by-4 matrices, that contain the locations of the bounding boxes related to the corresponding image. The locations are in the format, [x,y,$width$,$height$]. The second column represents a positive instance of a single object class, such as a car, dog, flower, or stop sign. Negative instances are automatically collected from images during the training process.

	stopSigns ☒	
⊞	27x2 table	
	1 imageFilename	**2** stopSign
1	'stopSignImages/image005.jpg'	[980,393,31,56]
2	'stopSignImages/image006.jpg'	[1.0408e+03,354.7500,73,72]
3	'stopSignImages/image009.jpg'	[635,254,65,63]
4	'stopSignImages/image013.jpg'	[398.2050,261.2996,349.6806,385.6992]
5	'stopSignImages/image014.jpg'	[365.1880,306.3229,357.1845,421.7178]
6	'stopSignImages/image020.jpg'	[653.7500,307.7500,73.0000,76]
7	'stopSignImages/image021.jpg'	[589.7500,239.7500,181,196.0000]
8	'stopSignImages/image022.jpg'	[509.7500,470.7500,43,73]
9		

Each bounding box must be in the format [x,y,$width$,$height$]. The format specifies the upper-left corner location and the size of the object in the corresponding image. The table variable (column) name defines the object class name. To create the ground truth table, use the **Image Labeler** app.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single

quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'ObjectTrainingSize',[100 100]`

`ObjectTrainingSize` — Size of training images
`'Auto'` (default) | [*height width*] vector

Size of training images, specified as the comma-separated pair consisting of `'ObjectTrainingSize'` and either `'Auto'` or a [*height width*] vector. The minimum value of *height* and *width* is 8. During the training process, all images are resized to this height and width during the training process. Increasing the size can improve detection accuracy, but also increases training and detection times.

When you specify `'Auto'`, the size is set based on the median width-to-height ratio of the positive instances.

Example: [100,100]

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`NumStages` — Number of training stages
4 (default) | positive integer

Number of training stages for the iterative training process, specified as the comma-separated pair consisting of `'NumStages'` and a positive integer. Increasing this number can improve the detector and reduce training errors, at the expense of longer training time.

Data Types: `double`

`NegativeSamplesFactor` — Negative sample factor
5 (default) | real-valued scalar

Negative sample factor, specified as the comma-separated pair consisting of `'NegativeSamplesFactor'` and a real-valued scalar. The number of negative samples to use at each stage is equal to

`NegativeSamplesFactor` × *number of positive samples used at each stage*

Data Types: `double`

MaxWeakLearners — Maximum number of weak learners
2048 (default) | positive integer scalar | vector of positive integers

Maximum number of weak learners for the last stage, specified as the comma-separated pair consisting of 'MaxWeakLearners' and a positive integer scalar or vector of positive integers. If the input is a scalar, MaxWeakLearners specifies the maximum number for the last stage. If the input is a vector, MaxWeakLearners specifies the maximum number for each of the stages and must have a length equal to 'NumStages'. These values typically increase throughout the stages. The ACF object detector uses the boosting algorithm to create an ensemble of weaker learners. You can use higher values to improve the detection accuracy, at the expense of reduced detection performance speeds. Recommended values range from 300 to 5000.

Data Types: double

Verbose — Display progress information
true (default) | false

Option to display progress information for the training process, specified as the comma-separated pair consisting of 'Verbose' and true or false.

Data Types: logical

Output Arguments

detector — Trained ACF-based object detector
acfObjectDetector object

Trained ACF-based object detector, returned as an acfObjectDetector object.

See Also

Apps
Image Labeler

Functions
acfObjectDetector | detectPeopleACF | trainCascadeObjectDetector | trainRCNNObjectDetector

Introduced in R2017a

trainRCNNObjectDetector

Train an R-CNN deep learning object detector

Syntax

```
detector = trainRCNNObjectDetector(trainingData,network,options)
detector = trainRCNNObjectDetector( ___ ,Name,Value)
detector = trainRCNNObjectDetector( ___ ,'
RegionProposalFcn',proposalFcn)
[detector,info] = trainRCNNObjectDetector( ___ )
```

Description

`detector = trainRCNNObjectDetector(trainingData,network,options)` returns an R-CNN (regions with convolutional neural networks) based object detector. The function uses deep learning to train the detector for multiclass object detection. Specify your ground truth training data, your network, and training options. The network can be a pretrained series network such as `alexnet` or `vgg16` for training using transfer learning, or you can train a network from scratch using an array of `Layer` objects with uninitialized weights.

This function requires that you have Neural Network Toolbox and Statistics and Machine Learning Toolbox. It is recommended that you also have Parallel Computing Toolbox to use with a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher.

`detector = trainRCNNObjectDetector( ___ ,Name,Value)` returns a `detector` object with optional input properties specified by one or more `Name,Value` pair arguments.

`detector = trainRCNNObjectDetector( ___ ,'RegionProposalFcn',proposalFcn)` optionally trains an R-CNN detector using a custom region proposal function.

`[detector,info] = trainRCNNObjectDetector( ___ )` additionally returns information on the training progress, such as training loss and accuracy, for each iteration.

Examples

Train R-CNN Stop Sign Detector

Load training data and network layers.

```
load('rcnnStopSigns.mat', 'stopSigns', 'layers')
```

Add the image directory to the MATLAB path.

```
imDir = fullfile(matlabroot, 'toolbox', 'vision', 'visiondata',...
  'stopSignImages');
addpath(imDir);
```

Set network training options to use mini-batch size of 32 to reduce GPU memory usage. Lower the InitialLearningRate to reduce the rate at which network parameters are changed. This is beneficial when fine-tuning a pre-trained network and prevents the network from changing too rapidly.

```
options = trainingOptions('sgdm', ...
  'MiniBatchSize', 32, ...
  'InitialLearnRate', 1e-6, ...
  'MaxEpochs', 10);
```

Train the R-CNN detector. Training can take a few minutes to complete.

```
rcnn = trainRCNNObjectDetector(stopSigns, layers, options, 'NegativeOverlapRange', [0 (
```

```
********************************************************************
Training an R-CNN Object Detector for the following object classes:

* stopSign

Step 1 of 3: Extracting region proposals from 27 training images...done.

Step 2 of 3: Training a neural network to classify objects in training data...
```

Epoch	Iteration	Time Elapsed (seconds)	Mini-batch Loss	Mini-batch Accuracy	Base Learn Rate
3	50	9.27	0.2895	96.88%	0.0000
5	100	14.77	0.2443	93.75%	0.0000

```
|             8 |          150 |        20.29 |       0.0013 |      100.00% |      0.0000
|            10 |          200 |        25.94 |       0.1524 |       96.88% |      0.0000
|========================================================================================

Network training complete.

Step 3 of 3: Training bounding box regression models for each object class...100.00%..

R-CNN training complete.
********************************************************************
```

Test the R-CNN detector on a test image.

```
img = imread('stopSignTest.jpg');

[bbox, score, label] = detect(rcnn, img, 'MiniBatchSize', 32);
```

Display strongest detection result.

```
[score, idx] = max(score);

bbox = bbox(idx, :);
annotation = sprintf('%s: (Confidence = %f)', label(idx), score);

detectedImg = insertObjectAnnotation(img, 'rectangle', bbox, annotation);

figure
imshow(detectedImg)
```

Remove the image directory from the path.

```
rmpath(imDir);
```

Resume Training an R-CNN Object Detector

Resume training an R-CNN object detector using additional data. To illustrate this procedure, half the ground truth data will be used to initially train the detector. Then, training is resumed using all the data.

Load training data and initialize training options.

```
load('rcnnStopSigns.mat', 'stopSigns', 'layers')

stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);

options = trainingOptions('sgdm', ...
```

```
    'MiniBatchSize', 32, ...
    'InitialLearnRate', 1e-6, ...
    'MaxEpochs', 10, ...
    'Verbose', false);
```

Train the R-CNN detector with a portion of the ground truth.

```
rcnn = trainRCNNObjectDetector(stopSigns(1:10,:), layers, options, 'NegativeOverlapRang
```

Get the trained network layers from the detector. When you pass in an array of network layers to `trainRCNNObjectDetector`, they are used as-is to continue training.

```
network = rcnn.Network;
layers = network.Layers;
```

Resume training using all the training data.

```
rcnnFinal = trainRCNNObjectDetector(stopSigns, layers, options);
```

Create a network for multiclass R-CNN object detection

Create an R-CNN object detector for two object classes: dogs and cats.

```
objectClasses = {'dogs','cats'};
```

The network must be able to classify both dogs, cats, and a "background" class in order to be trained using `trainRCNNObjectDetector`. In this example, a one is added to include the background.

```
numClassesPlusBackground = numel(objectClasses) + 1;
```

The final fully connected layer of a network defines the number of classes that the network can classify. Set the final fully connected layer to have an output size equal to the number of classes plus a background class.

```
layers = [ ...
    imageInputLayer([28 28 1])
    convolution2dLayer(5,20)
    fullyConnectedLayer(numClassesPlusBackground);
    softmaxLayer()
    classificationLayer()];
```

These network layers can now be used to train an R-CNN two-class object detector.

Use A Saved Network In R-CNN Object Detector

Create an R-CNN object detector and set it up to use a saved network checkpoint. A network checkpoint is saved every epoch during network training when the `trainingOptions` 'CheckpointPath' parameter is set. Network checkpoints are useful in case your training session terminates unexpectedly.

Load the stop sign training data.

```
load('rcnnStopSigns.mat','stopSigns','layers')
```

Add full path to image files.

```
stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);
```

Set the 'CheckpointPath' using the `trainingOptions` function.

```
checkpointLocation = tempdir;
options = trainingOptions('sgdm','Verbose',false, ...
    'CheckpointPath',checkpointLocation);
```

Train the R-CNN object detector with a few images.

```
rcnn = trainRCNNObjectDetector(stopSigns(1:3,:),layers,options);
```

Load a saved network checkpoint.

```
wildcardFilePath = fullfile(checkpointLocation,'convnet_checkpoint__*.mat');
contents = dir(wildcardFilePath);
```

Load one of the checkpoint networks.

```
filepath = fullfile(contents(1).folder,contents(1).name);
checkpoint = load(filepath);
```

```
checkpoint.net
```

```
ans =

  SeriesNetwork with properties:
```

```
    Layers: [15×1 nnet.cnn.layer.Layer]
```

Create a new R-CNN object detector and set it up to use the saved network.

```
rcnnCheckPoint = rcnnObjectDetector();
rcnnCheckPoint.RegionProposalFcn = @rcnnObjectDetector.proposeRegions;
```

Set the Network to the saved network checkpoint.

```
rcnnCheckPoint.Network = checkpoint.net
```

```
rcnnCheckPoint =

  rcnnObjectDetector with properties:

              Network: [1×1 SeriesNetwork]
           ClassNames: {'stopSign'  'Background'}
    RegionProposalFcn: @rcnnObjectDetector.proposeRegions
```

- "Image Category Classification Using Deep Learning"

Input Arguments

trainingData — Labeled ground truth images
table

Labeled ground truth images, specified as a table with two or more columns. The first column must contain path and file names to images that are either grayscale or true color (RGB). The remaining columns must contain bounding boxes related to the corresponding image. Each column represents a single object class, such as a car, dog, flower, or stop sign.

	1 imageFilename	2 stopSign
1	'stopSignImages/image005.jpg'	[980,393,31,56]
2	'stopSignImages/image006.jpg'	[1.0408e+03,354.7500,73,72]
3	'stopSignImages/image009.jpg'	[635,254,65,63]
4	'stopSignImages/image013.jpg'	[398.2050,261.2996,349.6806,385.6992]
5	'stopSignImages/image014.jpg'	[365.1880,306.3229,357.1845,421.7178]
6	'stopSignImages/image020.jpg'	[653.7500,307.7500,73.0000,76]
7	'stopSignImages/image021.jpg'	[589.7500,239.7500,181,196.0000]
8	'stopSignImages/image022.jpg'	[509.7500,470.7500,43,73]
9		

stopSigns ✕

27x2 table

Each bounding box must be in the format [*x*,*y*,*width*,*height*]. The format specifies the upper-left corner location and size of the object in the corresponding image. The table variable name defines the object class name. To create the ground truth table, use the **Image Labeler** app. Boxes smaller than 32-by-32 are not used for training.

network — Network
SeriesNetwork object | array of Layer objects

Network, specified as one of the following. The network is trained to classify object classes defined in the trainingData table.

- A SeriesNetwork object, including pretrained networks such as alexnet or vgg16. When the network is a SeriesNetwork, the network layers are automatically adjusted to support the number of object classes defined within the groundTruth training data. The background is added as an additional class.

- An array of Layer objects. For example,

```
layers = [imageInputLayer([28 28 3])
        convolution2dLayer([5 5],10)
        reluLayer()
        fullyConnectedLayer(10)
        softmaxLayer()
        classificationLayer()];
```

When the network is an array of `Layer` objects, the network must have a classification layer that supports the number of object classes, plus a background class. Use this input type to customize the learning rates of each layer. You can also use this input type to resume training from a previous session. Resuming the training is useful when the network requires additional rounds of fine-tuning, and when you want to train with additional training data.

Note `trainRCNNObjectDetector` does not support DAG networks, such as ResNet-50, Inception-v3, or GoogLeNet. Additionally, you cannot pass a Layers array from a DAG network to the training function, because the Layers property from a DAG network does not contain the connection information.

options — Training options
`trainingOptionsSGDM` object

Training options of the neural network, specified as an `TrainingOptionsSGDM` object. You can obtain this object by using the `trainingOptions` function with the `'sgdm'` solver name.

To fine-tune a pretrained network for detection, lower the initial learning rate to avoid changing the model parameters too rapidly. You can use the following syntax to adjust the learning rate:

```
options = trainingOptions('sgdm', ...
                          'InitialLearningRate',1e-6, ...
                          'CheckpointPath',tempdir);
```

```
detector = trainRCNNObjectDetector(trainingData,network,options);
```

Because network training can take a few hours, use the `'CheckpointPath'` property of `trainingOptions` to save your progress periodically.

Note `trainRCNNObjectDetector` does not support these training options:

- The `ExecutionEnvironment` values: `'multi-gpu'` or `'parallel'`
- The `Plots` value: `'training-progress'`
- The `ValidationData`, `ValidationFrequency`, or `ValidationPatience` options
- ADAM and RMSProp solvers

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'PositiveOverlapRange',[0.5 1]`.

PositiveOverlapRange — Positive training sample ratios for range of bounding box overlap
`[0.5 1]` (default) | two-element vector

Positive training sample ratios for range of bounding box overlap, specified as the comma-separated pair consisting of `'PositiveOverlapRange'` and a two-element vector. The vector contains values in the range [0,1]. Region proposals that overlap with ground truth bounding boxes within the specified range are used as positive training samples.

The overlap ratio used for both the `PositiveOverlapRange` and `NegativeOverlapRange` is defined as:

$$\frac{area(A \text{ I } B)}{area(A \text{ U } B)}$$

A and *B* are bounding boxes.

NegativeOverlapRange — Negative training sample ratios for range of bounding box overlap
`[0.1 0.5]` (default) | two-element vector

Negative training sample ratios for range of bounding box overlap, specified as the comma-separated pair consisting of `'NegativeOverlapRange'` and a two-element vector. The vector contains values in the range [0,1]. Region proposals that overlap with the ground truth bounding boxes within the specified range are used as negative training samples.

NumStrongestRegions — Maximum number of strongest region proposals
`2000` (default) | integer

Maximum number of strongest region proposals to use for generating training samples, specified as the comma-separated pair consisting of `'NumStrongestRegions'` and an

integer. Reduce this value to speed up processing time, although doing so decreases training accuracy. To use all region proposals, set this value to `inf`.

RegionProposalFcn — Custom region proposal
function handle

Custom region proposal function handle, specified as the comma-separated pair consisting of 'RegionProposalFcn' and the function name. If you do not specify a custom region proposal function, the default variant of the Edge Boxes algorithm [3] , set in `rcnnObjectDetector`, is used. A custom `proposalFcn` must have the following functional form:

```
[bboxes,scores] = proposalFcn(I)
```

The input, `I`, is an image defined in the `groundTruth` table. The function must return rectangular bounding boxes in an *M*-by-4 array. Each row of `bboxes` contains a four-element vector, [*x*,*y*,*width*,*height*], that specifies the upper–left corner and size of a bounding box in pixels. The function must also return a score for each bounding box in an *M*-by-1 vector. Higher scores indicate that the bounding box is more likely to contain an object. The scores are used to select the strongest regions, which you can specify in `NumStrongestRegions`.

Output Arguments

detector — Trained R-CNN-based object detector
`rcnnObjectDetector` object

Trained R-CNN-based object detector, returned as an `rcnnObjectDetector` object. You can train an R-CNN detector to detect multiple object classes.

info — Training information
structure

Training information, returned as a structure with the following fields. Each field is a numeric vector with one element per training iteration. Values that have not been calculated at a specific iteration are represented by `NaN`.

- `TrainingLoss` — Training loss at each iteration. This is the combination of the classification and regression loss used to train the R-CNN network.
- `TrainingAccuracy` — Training set accuracy at each iteration

- `BaseLearnRate` — Learning rate at each iteration

Limitations

- This implementation of R-CNN does not train an SVM classifier for each object class.

Tips

- To accelerate data preprocessing for training, `trainRCNNObjectDetector` automatically creates and uses a parallel pool based on your parallel preference settings. This requires Parallel Computing Toolbox.

- If you have a large network (such as VGG-16) or large images, you may encounter an "Out of Memory" error. To avoid this error for large images, manually resize the images along with the bounding box ground truth data before calling `trainRCNNObjectDetector`.

- Transfer learning is supported for series networks such as AlexNet and VGG-16. Passing a network or an array of Layers to the training function preserves the weights of the pretrained network. You can perform transfer learning using code such as this.

```
net = alexnet;
detector = trainRCNNObjectDetector(trainingData,net,options);
```

For more information, see "Get Started with Transfer Learning" (Neural Network Toolbox) and "Transfer Learning Using AlexNet" (Neural Network Toolbox).

- Use the `trainingOptions` function to enable or disable verbose printing.

References

[1] Girshick, R., J. Donahue, T. Darrell, and J. Malik. "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation."*Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition.* 2014, pp. 580–587.

[2] Girshick, R. "Fast R-CNN." *Proceedings of the IEEE International Conference on Computer Vision.* 2015, pp. 1440–1448.

[3] Zitnick, C. Lawrence, and P. Dollar. "Edge Boxes: Locating Object Proposals from Edges." *Computer Vision-ECCV, Springer International Publishing.* 2014, pp. 391–405.

See Also

Apps
Image Labeler

Functions
Layer | SeriesNetwork | imageCategoryClassifier | rcnnObjectDetector |
trainFastRCNNObjectDetector | trainFasterRCNNObjectDetector |
trainingOptions

Topics
"Image Category Classification Using Deep Learning"
"Choose Among R-CNN, Fast R-CNN, or Faster R-CNN Object Detectors"

Introduced in R2016b

estimateGeometricTransform

Estimate geometric transform from matching point pairs

Syntax

```
tform = estimateGeometricTransform(matchedPoints1,matchedPoints2,
transformType)

[tform,inlierpoints1,inlierpoints2] = estimateGeometricTransform(
matchedPoints1,matchedPoints2,transformType)
[ ___ ,status] = estimateGeometricTransform(matchedPoints1,
matchedPoints2,transformType)

[ ___ ] = estimateGeometricTransform(matchedPoints1,matchedPoints2,
transformType, Name,Value)
```

Description

`tform = estimateGeometricTransform(matchedPoints1,matchedPoints2, transformType)` returns a 2-D geometric transform object, `tform`. The `tform` object maps the inliers in `matchedPoints1` to the inliers in `matchedPoints2`.

The function excludes outliers using the M-estimator SAmple Consensus (MSAC) algorithm. The MSAC algorithm is a variant of the Random Sample Consensus (RANSAC) algorithm. Results may not be identical between runs because of the randomized nature of the MSAC algorithm.

`[tform,inlierpoints1,inlierpoints2] = estimateGeometricTransform( matchedPoints1,matchedPoints2,transformType)` returns the corresponding inlier points in `inlierpoints1` and `inlierpoints2`.

`[ ___ ,status] = estimateGeometricTransform(matchedPoints1, matchedPoints2,transformType)` returns a status code of `0`, `1`, or `2`. If you do not request the `status` code output, the function returns an error for conditions that cannot produce results.

[___] = estimateGeometricTransform(matchedPoints1,matchedPoints2, transformType, Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Recover a Transformed Image Using SURF Feature Points

Read and display an image and a transformed image.

```
original  = imread('cameraman.tif');
imshow(original);
title('Base image');
```

Base image


```
distorted = imresize(original,0.7);
distorted = imrotate(distorted,31);
```

```
figure; imshow(distorted);
title('Transformed image');
```

Transformed image

Detect and extract features from both images.

```
ptsOriginal  = detectSURFFeatures(original);
ptsDistorted = detectSURFFeatures(distorted);
[featuresOriginal,validPtsOriginal] = ...
    extractFeatures(original,ptsOriginal);
[featuresDistorted,validPtsDistorted] = ...
    extractFeatures(distorted,ptsDistorted);
```

Match features.

```
index_pairs = matchFeatures(featuresOriginal,featuresDistorted);
matchedPtsOriginal  = validPtsOriginal(index_pairs(:,1));
matchedPtsDistorted = validPtsDistorted(index_pairs(:,2));
figure;
showMatchedFeatures(original,distorted,...
```

```
    matchedPtsOriginal,matchedPtsDistorted);
title('Matched SURF points,including outliers');
```

Matched SURF points,including outliers

Exclude the outliers, and compute the transformation matrix.

```
[tform,inlierPtsDistorted,inlierPtsOriginal] = ...
    estimateGeometricTransform(matchedPtsDistorted,matchedPtsOriginal,...
    'similarity');
figure;

showMatchedFeatures(original,distorted,...
    inlierPtsOriginal,inlierPtsDistorted);
title('Matched inlier points');
```

Matched inlier points

Recover the original image from the distorted image.

```
outputView = imref2d(size(original));
Ir = imwarp(distorted,tform,'OutputView',outputView);
figure; imshow(Ir);
title('Recovered image');
```

Recovered image

- "Feature Based Panoramic Image Stitching"

Input Arguments

matchedPoints1 — Matched points from image 1
cornerPoints object | SURFPoints object | MSERRegions object | *M*-by-2 matrix of [*x*,*y*] coordinates

Matched points from image 1, specified as either a cornerPoints object, SURFPoints object, MSERRegions object, or an *M*-by-2 matrix of [x,y] coordinates. The function excludes outliers using the M-estimator SAmple Consensus (MSAC) algorithm. The MSAC algorithm is a variant of the Random Sample Consensus (RANSAC) algorithm.

matchedPoints2 — Matched points from image 2
cornerPoints object | SURFPoints object | MSERRegions object | *M*-by-2 matrix of [*x*,*y*] coordinates

Matched points from image 2, specified as either a `cornerPoints` object, `SURFPoints` object, `MSERRegions` object, or an *M*-by-2 matrix of [x,y] coordinates. The function excludes outliers using the M-estimator SAmple Consensus (MSAC) algorithm. The MSAC algorithm is a variant of the Random Sample Consensus (RANSAC) algorithm.

`transformType` — Transform type
`'similarity'` | `'affine'` | `'projective'`

Transform type, specified as one of three character strings. You can set the transform type to either `'similarity'`, `'affine'`, or `'projective'`. The greater the number of matched pairs of points, the greater the accuracy of the estimated transformation. The minimum number of matched pairs of points for each transform type:

Transform Type	Minimum Number of Matched Pairs of Points
`'similarity'`	2
`'affine'`	3
`'projective'`	4

Data Types: `char`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Confidence'`,99 sets the confidence value to 99.

`MaxNumTrials` — Maximum random trials
1000 (default) | positive integer

Maximum number of random trials for finding the inliers, specified as the comma-separated pair consisting of `'MaxNumTrials'` and a positive integer scalar. Increasing this value improves the robustness of the results at the expense of additional computations.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`Confidence` — Confidence of finding maximum number of inliers
99 (default) | positive numeric scalar

Confidence of finding the maximum number of inliers, specified as the comma-separated pair consisting of `'Confidence'` and a percentage numeric scalar in the range (0 100). Increasing this value improves the robustness of the results at the expense of additional computations.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`MaxDistance` — Maximum distance from point to projection
1.5 (default) | positive numeric scalar

Maximum distance in pixels, from a point to the projection of its corresponding point, specified as the comma-separated pair consisting of `'MaxDistance'` and a positive numeric scalar. The corresponding projection is based on the estimated transform.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`
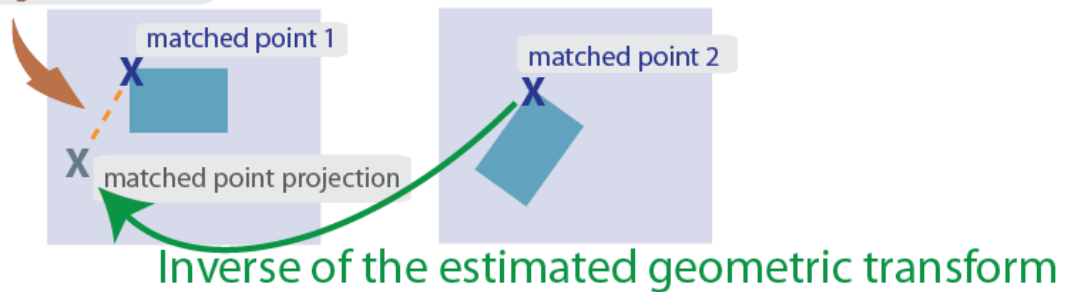
Output Arguments

`tform` — Geometric transformation
`affine2d` object | `projective2d` object

Geometric transformation, returned as either an `affine2d` object or a `projective2d` object.

The returned geometric transformation matrix maps the inliers in `matchedPoints1` to the inliers in `matchedPoints2`. When you set the `transformType` input to either `'similarity'` or `'affine'`, the function returns an `affine2d` object. Otherwise, it returns a `projective2d` object.

status — Status code
`0 | 1 | 2`

Status code, returned as the value `0`, `1`, or `2`.

status	Description
0	No error.
1	`matchedPoints1` and `matchedPoints2` inputs do not contain enough points.
2	Not enough inliers found.

If you do not request the `status` code output, the function will throw an error for the two conditions that cannot produce results.

Data Types: `double`

inlierpoints1 — Inlier points in image 1
inlier points

Inlier points in image 1, returned as the same type as the input matching points.

inlierpoints2 — Inlier points in image 2
inlier points

Inlier points in image 2, returned as the same type as the input matching points.

References

[1] Hartley, R., and A. Zisserman, "Multiple View Geometry in Computer Vision," *Cambridge University Press*, 2003.

[2] Torr, P. H. S., and A. Zisserman, "MLESAC: A New Robust Estimator with Application to Estimating Image Geometry," *Computer Vision and Image Understanding*, 2000.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

See Also
MSERRegions | SURFPoints | cornerPoints | detectFASTFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | estimateFundamentalMatrix | extractFeatures | fitgeotrans | matchFeatures

Topics
"Feature Based Panoramic Image Stitching"
"Point Feature Types"
"Coordinate Systems"
"2-D and 3-D Geometric Transformation Process Overview" (Image Processing Toolbox)

Introduced in R2013a

estimateUncalibratedRectification

Uncalibrated stereo rectification

Syntax

```
[T1,T2] = estimateUncalibratedRectification(F,inlierPoints1,
inlierPoints2,imagesize)
```

Description

`[T1,T2] = estimateUncalibratedRectification(F,inlierPoints1,`
`inlierPoints2,imagesize)` returns projective transformations for rectifying stereo images. This function does not require either intrinsic or extrinsic camera parameters. The input points can be M-by-2 matrices of M number of [x y] coordinates, or `SURFPoints`, `MSERRegions`, or `cornerPoints` object. F is a 3-by-3 fundamental matrix for the stereo images.

Examples

Find Fundamental Matrix Describing Epipolar Geometry

This example shows how to compute the fundamental matrix from corresponding points in a pair of stereo images.

Load the stereo images and feature points which are already matched.

```
I1 = imread('yellowstone_left.png');
I2 = imread('yellowstone_right.png');
load yellowstone_inlier_points;
```

Display point correspondences. Notice that the matching points are in different rows, indicating that the stereo pair is not rectified.

```
showMatchedFeatures(I1, I2,inlier_points1,inlier_points2,'montage');
title('Original images and matching feature points');
```

Original images and matching feature points
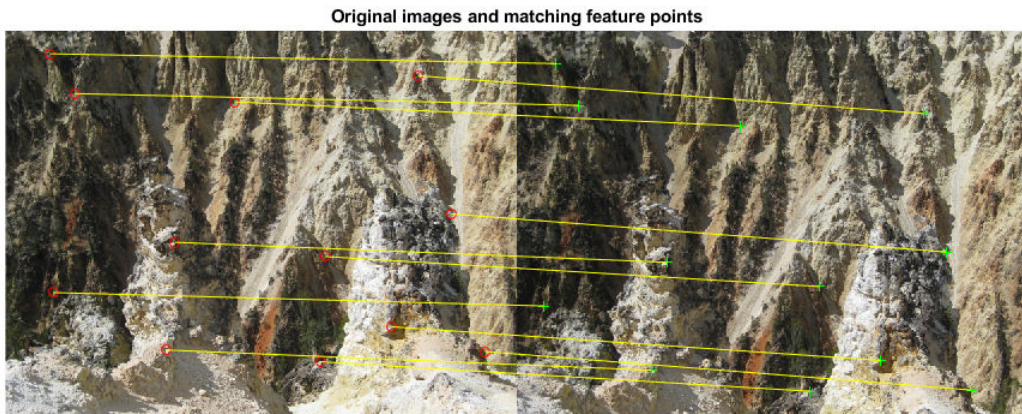
Compute the fundamental matrix from the corresponding points.

```
f = estimateFundamentalMatrix(inlier_points1,inlier_points2,...
    'Method','Norm8Point');
```

Compute the rectification transformations.

```
[t1, t2] = estimateUncalibratedRectification(f,inlier_points1,...
    inlier_points2,size(I2));
```

Rectify the stereo images using projective transformations t1 and t2.

```
[I1Rect,I2Rect] = rectifyStereoImages(I1,I2,t1,t2);
```

Display the stereo anaglyph, which can also be viewed with 3-D glasses.

```
figure;
imshow(stereoAnaglyph(I1Rect,I2Rect));
```

- Image Rectification

Input Arguments

F — Fundamental matrix for the stereo images
3-by-3 matrix

Fundamental matrix for the stereo images, specified as a 3-by-3 fundamental matrix. The fundamental matrix satisfies the following criteria:
If P_1, a point in image 1, corresponds to P_2, a point in image 2, then:
$[P_2,1] * F * [P_1,1]' = 0$

F must be double or single.

`inlierPoints1` — Coordinates of corresponding points
`SURFPoints` | `cornerPoints` | `MSERRegions` | *M*-by-2 matrix of [*x,y*] coordinates

Coordinates of corresponding points in image one, specified as an *M*-by-2 matrix of *M* number of [x y] coordinates, or as a `SURFPoints`, `MSERRegions`, or `cornerPoints` object.

inlierPoints2 — Coordinates of corresponding points
`SURFPoints` | `cornerPoints` | `MSERRegions` | *M*-by-2 matrix of [*x*,*y*] coordinates

Coordinates of corresponding points in image one, specified as an *M*-by-2 matrix of *M* number of [x y] coordinates, or as a `SURFPoints`, `MSERRegions`, or `cornerPoints` object.

imagesize — Input image size
single | double | integer

Second input image size, specified as a double, single, or integer value and in the format returned by the `size` function. The size of input image 2 corresponds to `inlierPoints2`.

Output Arguments

T1 — Projective transformation one
3-by-3 matrix

Projective transformation, returned as a 3-by-3 matrix describing the projective transformations for input image `T1`.

T2 — Projective transformation two
3-by-3 matrix

Projective transformation, returned as a 3-by-3 matrix describing the projective transformations for input image `T2`.

Tips

- An epipole may be located in the first image or the second image. Applying the output uncalibrated rectification of `T1` (or `T2`) to image 1 (or image 2) may result in an undesired distortion. You can check for an epipole within an image by applying the `isEpipoleInImage` function.

References

[1] Hartley, R. and A. Zisserman, "Multiple View Geometry in Computer Vision," *Cambridge University Press*, 2003.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Classes
cameraParameters | stereoParameters

Functions
cameraMatrix | detectHarrisFeatures | detectHarrisFeatures | detectMinEigenFeatures | estimateCameraParameters | estimateFundamentalMatrix | extractFeatures | imwarp | isEpipoleInImage | matchFeatures | reconstructScene | size | undistortImage

Topics
Image Rectification
"Point Feature Types"
"Coordinate Systems"

Introduced in R2012b

evaluateDetectionMissRate

Evaluate miss rate metric for object detection

Syntax

```
logAverageMissRate = evaluateDetectionMissRate(detectionResults,
groundTruthData)
[logAverageMissRate,fppi,missRate] = evaluateDetectionMissRate( ___ )
[ ___ ] = evaluateDetectionMissRate( ___ ,threshold)
```

Description

logAverageMissRate = evaluateDetectionMissRate(detectionResults,
groundTruthData) returns the log-average miss rate of the detectionResults
compared to groundTruthTable, which is used to measure the performance of the
object detector. For a multiclass detector, the log-average miss rate is a vector of scores
for each object class in the order specified by groundTruthTable.

[logAverageMissRate,fppi,missRate] = evaluateDetectionMissRate(___)
returns data points for plotting the log miss rate–false positives per image (FPPI) curve,
using input arguments from the previous syntax.

[___] = evaluateDetectionMissRate(___ ,threshold) specifies the overlap
threshold for assigning a detection to a ground truth box.

Examples

Evaluate a Stop Sign Detector

Load a ground truth table.

```
load('stopSignsAndCars.mat')
stopSigns = stopSignsAndCars(:, 1:2);
```

```
stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);
```

Train an ACF based detector.

```
detector = trainACFObjectDetector(stopSigns,'NegativeSamplesFactor',2);
```

```
ACF Object Detector Training
The training will take 4 stages. The model size is 34x31.
Sample positive examples(~100% Completed)
Compute approximation coefficients...Completed.
Compute aggregated channel features...Completed.
--------------------------------------------
Stage 1:
Sample negative examples(~100% Completed)
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 19 weak learners.
--------------------------------------------
Stage 2:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 20 weak learners.
--------------------------------------------
Stage 3:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 54 weak learners.
--------------------------------------------
Stage 4:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 61 weak learners.
--------------------------------------------
ACF object detector training is completed. Elapsed time is 31.7672 seconds.
```

Create a struct array to store the results.

```
numImages = height(stopSigns);
results(numImages) = struct('Boxes', [], 'Scores', []);
```

Run the detector on the training images.

```
for i = 1 : numImages
    I = imread(stopSigns.imageFilename{i});
    [bboxes, scores] = detect(detector, I);
    results(i).Boxes = bboxes;
    results(i).Scores = scores;
end
```

```
results = struct2table(results);
```

Evaluate the results against the ground truth data.

```
[am, fppi, missRate] = evaluateDetectionMissRate(results, stopSigns(:, 2));
```

Plot log-miss-rate/FPPI curve.

```
figure
loglog(fppi, missRate);
grid on
title(sprintf('log Average Miss Rate = %.1f', am))
```

Input Arguments

`detectionResults` — Object locations and scores
table

Object locations and scores, specified as a two-column table containing the bounding boxes and scores for each detected object. For multiclass detection, a third column contains the predicted label for each detection.

When detecting objects, you can create the detection results table by using `struct2table` to combine the `bboxes` and `scores` outputs:

```
    for i = 1:numImages
        I = imread(imageFilename{i});
        [bboxes,scores] = detect(detector,I);
        results(i).Boxes = bboxes;
        results(i).Scores = scores;
    end
 results = struct2table(results);
```

Data Types: `table`

groundTruthData — Training data
table

Training data, specified as a table with one or more columns. The table contains one column for single-class data and multiple columns for multiclass data. Each column contains *M*-by-4 matrices of [*x*,*y*,*width*,*height*] bounding boxes that specify object locations. The format specifies the upper-left corner location and the size of the object. The column name specifies the class label.

threshold — Overlap threshold
0.5 | numeric scalar

Overlap threshold for a detection assigned to a ground truth box, specified as a numeric scalar. The overlap ratio is computed as the intersection over union.

Output Arguments

logAverageMissRate — Log-average miss rate metric
numeric scalar | vector

Log-average miss rate metric, returned as either a numeric scalar or vector. For a multiclass detector, the log-average miss rate is returned as a vector of values that correspond to the data points for each class.

fppi — False positives per image
vector of numeric scalars | cell array

False positives per image, returned as either a vector of numeric scalars or as a cell array. For a multiclass detector, the FPPI and log miss rate are cell arrays, where each cell contains the data points for each object class.

`missRate` — Log miss rate
vector of numeric scalars | cell array

Log miss rate, returned as either a vector of numeric scalars or as a cell array. For a multiclass detector, the FPPI and log miss rate are cell arrays, where each cell contains the data points for each object class.

See Also

Image Labeler | `acfObjectDetector` | `evaluateDetectionPrecision` | `trainACFObjectDetector`

Introduced in R2017a

evaluateDetectionPrecision

Evaluate precision metric for object detection

Syntax

```
averagePrecision = evaluateDetectionPrecision(detectionResults,
groundTruthData)
[averagePrecision,recall,precision] = evaluateDetectionPrecision( ___
)
[ ___ ] = evaluateDetectionPrecision( ___ ,threshold)
```

Description

`averagePrecision = evaluateDetectionPrecision(detectionResults,
groundTruthData)` returns the average precision, of the `detectionResults` compared to the `groundTruthData`. You can use the average precision to measure the performance of an object detector. For a multiclass detector, the function returns `averagePrecision` as a vector of scores for each object class in the order specified by `groundTruthData`.

`[averagePrecision,recall,precision] = evaluateDetectionPrecision(___
)` returns data points for plotting the precision–recall curve, using input arguments from the previous syntax.

`[ ___ ] = evaluateDetectionPrecision( ___ ,threshold)` specifies the overlap threshold for assigning a detection to a ground truth box.

Examples

Evaluate Precision of Stop Sign Detector

Train an ACF-based detector using pre-loaded ground truth information. Run the detector on the training images. Evaluate the detector and display the precision-recall curve.

Load the ground truth table.

```
load('stopSignsAndCars.mat')
stopSigns = stopSignsAndCars(:,1:2);
stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);
```

Train an ACF-based detector.

```
detector = trainACFObjectDetector(stopSigns,'NegativeSamplesFactor',2);
```

```
ACF Object Detector Training
The training will take 4 stages. The model size is 34x31.
Sample positive examples(~100% Completed)
Compute approximation coefficients...Completed.
Compute aggregated channel features...Completed.
--------------------------------------------
Stage 1:
Sample negative examples(~100% Completed)
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 19 weak learners.
--------------------------------------------
Stage 2:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 20 weak learners.
--------------------------------------------
Stage 3:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 54 weak learners.
--------------------------------------------
Stage 4:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 61 weak learners.
--------------------------------------------
ACF object detector training is completed. Elapsed time is 32.7165 seconds.
```

Create a table to store the results.

```
numImages = height(stopSigns);
results(numImages) = struct('Boxes',[],'Scores',[]);
```

Run the detector on the training images. Store the results as a table.

```
for i = 1:numImages
    I = imread(stopSigns.imageFilename{i});
    [bboxes,scores] = detect(detector,I);
    results(i).Boxes = bboxes;
    results(i).Scores = scores;
end
```

```
results = struct2table(results);
```

Evaluate the results against the ground truth data. Get the precision statistics.

```
[ap,recall,precision] = evaluateDetectionPrecision(results,stopSigns(:,2));
```

Plot the precision-recall curve.

```
figure
plot(recall,precision)
grid on
title(sprintf('Average Precision = %.1f',ap))
```

Average Precision = 0.7

Input Arguments

detectionResults — Object locations and scores
table

Object locations and scores, specified as a two-column table containing the bounding boxes and scores for each detected object. For multiclass detection, a third column contains the predicted label for each detection.

When detecting objects, you can create the detection results table by using `struct2table` to combine the `bboxes` and `scores` outputs:

```
    for i = 1:numImages
        I = imread(imageFilename{i});
        [bboxes,scores] = detect(detector,I);
        results(i).Boxes = bboxes;
        results(i).Scores = scores;
    end
 results = struct2table(results);
```

Data Types: `table`

groundTruthData — Training data
table

Training data, specified as a table with one or more columns. The table contains one column for single-class data and multiple columns for multiclass data. Each column contains *M*-by-4 matrices of [*x*,*y*,*width*,*height*] bounding boxes that specify object locations. The format specifies the upper-left corner location and the size of the object. The column name specifies the class label.

threshold — Overlap threshold
`0.5` | numeric scalar

Overlap threshold for assigned a detection to a ground truth box, specified as a numeric scalar. The overlap ratio is computed as the intersection over union.

Output Arguments

averagePrecision — Average precision
numeric scalar | vector

Average precision over all the detection results, returned as a numeric scalar or vector. Precision is a ratio of true positive instances to all positive instances of objects in the detector, based on the ground truth. For a multiclass detector, the average precision is a vector of average precision scores for each object class.

recall — Recall values from each detection
vector of numeric scalars | cell array

Recall values from each detection, returned as a vector of numeric scalars or as a cell array. Recall is a ratio of true positive instances to the sum of true positives and false negatives in the detector, based on the ground truth. For a multiclass detector, `recall`

and `precision` are cell arrays, where each cell contains the data points for each object class.

`precision` — Precision values from each detection
vector of numeric scalars | cell array

Precision values from each detection, returned as a vector of numeric scalars or as a cell array. Precision is a ratio of true positive instances to all positive instances of objects in the detector, based on the ground truth. For a multi-class detector, `recall` and `precision` are cell arrays, where each cell contains the data points for each object class.

See Also

Image Labeler | `acfObjectDetector` | `evaluateDetectionMissRate` | `trainACFObjectDetector`

Introduced in R2017a

evaluateImageRetrieval

Evaluate image search results

Syntax

```
averagePrecision = evaluateImageRetrieval(queryImage,imageIndex,
expectedIDs)
[averagePrecision,imageIDs,scores] = evaluateImageRetrieval(
queryImage,imageIndex,expectedIDs)
[averagePrecision,imageIDs,scores] = evaluateImageRetrieval( ___ ,
Name,Value)
```

Description

`averagePrecision = evaluateImageRetrieval(queryImage,imageIndex,
expectedIDs)` returns the average precision metric for measuring the accuracy of
image search results for the `queryImage`. The `expectedIDs` input contains the indices
of images within `imageIndex` that are known to be similar to the query image.

`[averagePrecision,imageIDs,scores] = evaluateImageRetrieval(
queryImage,imageIndex,expectedIDs)` optionally returns the indices corresponding
to images within `imageIndex` that are visually similar to the query image. It also returns
the corresponding similarity scores.

`[averagePrecision,imageIDs,scores] = evaluateImageRetrieval(___ ,
Name,Value)` uses additional options specified by one or more `Name,Value` pair
arguments, using any of the preceding syntaxes.

Examples

Evaluate Image Retrieval Results

Define a set of images.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata','bookCovers');
bookCovers = imageDatastore(dataDir);
```

Display the set of images.

```
thumbnailGallery = [];
for i = 1:length(bookCovers.Files)
    img = readimage(bookCovers,i);
    thumbnail = imresize(img,[300 300]);
    thumbnailGallery = cat(4,thumbnailGallery,thumbnail);
end
figure
montage(thumbnailGallery);
```

Index the images. This will take a few minutes.

```
imageIndex = indexImages(bookCovers);
```

```
Creating an inverted image index using Bag-Of-Features.
-------------------------------------------------------

Creating Bag-Of-Features.
-------------------------

* Selecting feature point locations using the Detector method.
* Extracting SURF features from the selected feature point locations.
** detectSURFFeatures is used to detect key points for feature extraction.

* Extracting features from 58 images...done. Extracted 29216 features.

* Keeping 80 percent of the strongest features from each category.

* Balancing the number of features across all image categories to improve clustering.
** Image category 1 has the least number of strongest features: 23373.
** Using the strongest 23373 features from each of the other image categories.

* Using K-Means clustering to create a 20000 word visual vocabulary.
* Number of features        : 23373
* Number of clusters (K)     : 20000

* Initializing cluster centers...100.00%.
* Clustering...completed 11/100 iterations (~1.77 seconds/iteration)...converged in 11

* Finished creating Bag-Of-Features


Encoding images using Bag-Of-Features.
--------------------------------------

* Encoding 58 images...done.
Finished creating the image index.
```

Select and display the query image.

```
queryDir = fullfile(dataDir,'queries',filesep);
query = imread([queryDir 'query2.jpg']);

figure
imshow(query)
```
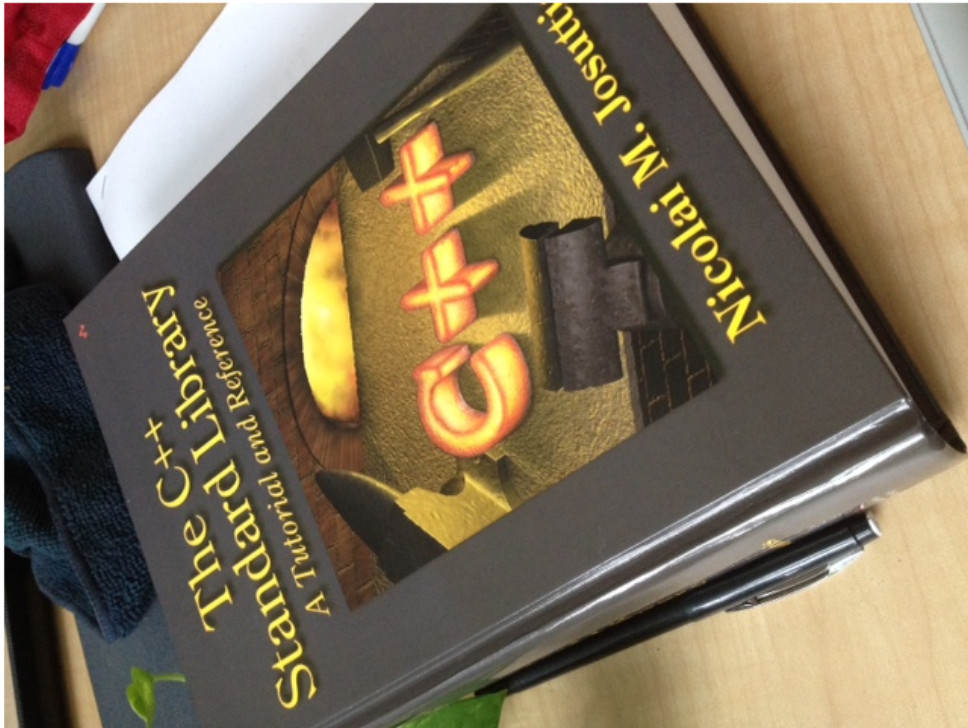
Evaluation requires knowing the expected results. Here, the query image is known to be the 3rd book in the imageIndex.

```
expectedID = 3;
```

Find and report the average precision score.

```
[averagePrecision,actualIDs] = evaluateImageRetrieval(query,...
    imageIndex,expectedID);

fprintf('Average Precision: %f\n\n',averagePrecision)
```

```
Average Precision: 0.043478
```

Show the query and best match side-by-side.

```
bestMatch = actualIDs(1);
bestImage = imread(imageIndex.ImageLocation{bestMatch});

figure
imshowpair(query,bestImage,'montage')
```


Compute Mean Average Precision (MAP) for Image Retrieval

Create an image set of book covers.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata','bookCovers');
bookCovers = imageDatastore(dataDir);
```

Index the image set. The indexing may take a few minutes.

```
imageIndex = indexImages(bookCovers,'Verbose',false);
```

Create a set of query images.

```
queryDir = fullfile(dataDir,'queries',filesep);
querySet = imageDatastore(queryDir);
```

Specify the expected search results for each query image.

```
    expectedIDs = [1 2 3];
```

Evaluate each query image and collect average precision scores.

```
    for i = 1:numel(querySet.Files)
        query = readimage(querySet,i);
        averagePrecision(i) = evaluateImageRetrieval(query, imageIndex, expectedIDs(i));
    end
```

Compute mean average precision (MAP).

```
    map = mean(averagePrecision)
```

map = 0.8333

- "Image Retrieval Using Customized Bag of Features"

Input Arguments

queryImage — Input query image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input query image, specified as either an *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-D grayscale image.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

imageIndex — Image search index
`invertedImageIndex` object

Image search index, specified as an `invertedImageIndex` object. The `indexImages` function creates the `invertedImageIndex` object, which stores the data used for the image search.

expectedIDs — Image indices
row or column vector

Image indices, specified as a row or column vector. The indices correspond to the images within `imageIndex` that are known to be similar to the query image.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NumResults',25`

NumResults — Maximum number of search results to evaluate
`Inf` (default) | positive integer value

Maximum number of search results to evaluate, specified as the comma-separated pair consisting of `'NumResults'` and a positive integer value. The function evaluates the top `NumResults` and returns the average-precision-at-`NumResults` metric.

ROI — Rectangular search region
`[1 1 size(queryImage,2) size(queryImage,1)]` (default) | [*x y width height*] vector

Rectangular search region within the query image, specified as the comma-separated pair consisting of `'ROI'` and a [*x y width height*] formatted vector.

Output Arguments

averagePrecision — Average precision metric
scalar value in the range [0 1]

Average precision metric, returned as a scalar value in the range [0 1]. The average precision metric represents the accuracy of image search results for the query image.

imageIDs — Ranked index of retrieved images
M-by-1 vector

Ranked index of retrieved images, returned as an *M*-by-1 vector. The image IDs are returned in ranked order, from the most to least similar matched image.

scores — Similarity metric
N-by-1 vector

Similarity metric, returned as an *N*-by-1 vector. This output contains the scores that correspond to the retrieved images in the `imageIDs` output. The scores are computed using the cosine similarity and range from 0 to 1.

See Also

bagOfFeatures | imageDatastore | indexImages | invertedImageIndex | retrieveImages

Topics

"Image Retrieval Using Customized Bag of Features"
"Image Retrieval with Bag of Visual Words"

Introduced in R2015a

evaluateSemanticSegmentation

Evaluate semantic segmentation data set against ground truth

Syntax

```
ssm = evaluateSemanticSegmentation(pxdsResults,pxdsTruth)
ssm = evaluateSemanticSegmentation(pxdsResults,pxdsTruth,Name,Value)
```

Description

ssm = evaluateSemanticSegmentation(pxdsResults,pxdsTruth) computes various metrics to evaluate the quality of the semantic segmentation results, pxdsResults, against the ground truth segmentation, pxdsTruth.

ssm = evaluateSemanticSegmentation(pxdsResults,pxdsTruth,Name,Value) computes semantic segmentation metrics using one or more Name,Value pair arguments to control the evaluation.

Examples

Evaluate Semantic Segmentation Results

Evaluate the results of semantic segmentation by computing a confusion matrix and metrics for each class, each image, and the entire data set.

Perform Semantic Segmentation

Label each pixel in a series of images either as an object or as the background. This example uses the triangleImages data set, which has 100 test images of triangles with ground truth labels.

Define the location of the data set, test images, and ground truth labels.

```
dataSetDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
testImagesDir = fullfile(dataSetDir,'testImages');
testLabelsDir = fullfile(dataSetDir,'testLabels');
```

Create an image datastore holding the test images.

```
imds = imageDatastore(testImagesDir);
```

Define the class names and their associated label IDs.

```
classNames = ["triangle","background"];
labelIDs = [255 0];
```

Create a pixel label datastore holding the ground truth pixel labels for the test images.

```
pxdsTruth = pixelLabelDatastore(testLabelsDir,classNames,labelIDs);
```

Load a semantic segmentation network that has been trained on the training images of noisy shapes.

```
net = load('triangleSegmentationNetwork');
net = net.net;
```

Run the network on the test images. Predicted labels are written to disk in a temporary folder and returned as a `pixelLabelDatastore`.

```
pxdsResults = semanticseg(imds,net,"WriteLocation",tempdir);
```

```
Running semantic segmentation network
-------------------------------------
* Processing 100 images.
* Progress: 100.00%
```

Compute Confusion Matrix and Segmentation Metrics

Evaluate the prediction results against the ground truth. By default, `evaluateSemanticSegmentation` computes all available metrics, including the confusion matrix, normalized confusion matrix, data set metrics, class metrics, and image metrics.

```
metrics = evaluateSemanticSegmentation(pxdsResults,pxdsTruth)
```

```
Evaluating semantic segmentation results
----------------------------------------[==================================================]
Elapsed time: 00:00:02
```

```
Estimated time remaining: 00:00:00
* Finalizing... Done.
* Data set metrics:

    GlobalAccuracy     MeanAccuracy     MeanIoU     WeightedIoU     MeanBFScore
    _____     _____     _____     _____     _____

       0.90624           0.95085        0.61588       0.87529         0.40652

metrics =
  semanticSegmentationMetrics with properties:

            ConfusionMatrix: [2x2 table]
  NormalizedConfusionMatrix: [2x2 table]
             DataSetMetrics: [1x5 table]
               ClassMetrics: [2x3 table]
               ImageMetrics: [100x5 table]
```

To explore the results, display the classification accuracy, the intersection over union, and the boundary F-1 score for each class. These values are stored in the `ClassMetrics` property. Also, display the normalized confusion matrix.

```
metrics.ClassMetrics
```

ans=*2×3 table*

	Accuracy	IoU	MeanBFScore
triangle	1	0.33005	0.028664
background	0.9017	0.9017	0.78438

```
metrics.NormalizedConfusionMatrix
```

ans=*2×2 table*

	triangle	background
triangle	1	0

```
   background      0.0983        0.9017
```

Evaluate Results of Semantic Segmentation

The `triangleImages` data set has 100 test images with ground truth labels. Define the location of the data set.

```
dataSetDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
```

Define the location of the test images.

```
testImagesDir = fullfile(dataSetDir,'testImages');
```

Define the location of the ground truth labels.

```
testLabelsDir = fullfile(dataSetDir,'testLabels');
```

Create an imageDatastore holding the test images.

```
imds = imageDatastore(testImagesDir);
```

Define the class names and their associated label IDs.

```
classNames = ["triangle","background"];
labelIDs   = [255 0];
```

Create a pixelLabelDatastore holding the ground truth pixel labels for the test images.

```
pxdsTruth = pixelLabelDatastore(testLabelsDir,classNames,labelIDs);
```

Load a semantic segmentation network that has been trained on the training images of `noisyShapes`.

```
net = load('triangleSegmentationNetwork');
net = net.net;
```

Run the network on the test images. Predicted labels are written to disk in a temporary directory and returned as a pixelLabelDatastore.

```
pxdsResults = semanticseg(imds,net,"WriteLocation",tempdir);
```

```
Running semantic segmentation network
-------------------------------------
* Processing 100 images.
* Progress: 100.00%
```

3-341

Evaluate the prediction results against the ground truth.

```
metrics = evaluateSemanticSegmentation(pxdsResults,pxdsTruth);
```

```
Evaluating semantic segmentation results
--------------------------------[================================================]
Elapsed time: 00:00:02
Estimated time remaining: 00:00:00
* Finalizing... Done.
* Data set metrics:

    GlobalAccuracy     MeanAccuracy     MeanIoU     WeightedIoU     MeanBFScore
    _____     _____     _____     _____     _____

       0.90624          0.95085         0.61588      0.87529          0.40652
```

Display the classification accuracy, the intersection over union, and the boundary F-1 score for each class.

```
metrics.ClassMetrics
```

```
ans=2×3 table
                  Accuracy       IoU       MeanBFScore
                  _____     _____     _____

    triangle          1        0.33005      0.028664
    background      0.9017      0.9017        0.78438
```

Input Arguments

pxdsResults — Predicted pixel labels
PixelLabelDatastore object | cell array of PixelLabelDatastore objects

Predicted pixels labels resulting from semantic segmentation, specified as a PixelLabelDatastore object or a cell array of PixelLabelDatastore objects.

pxdsTruth — Ground truth pixel labels
PixelLabelDatastore object | cell array of PixelLabelDatastore objects

Ground truth pixel labels, specified as a PixelLabelDatastore object or a cell array of PixelLabelDatastore objects.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `metrics = evaluateSemanticSegmentation(pxdsResults,pxdsTruth,'Metrics',"bfscore")` computes only the mean BF score of each class, each image, and the entire data set.

Metrics — Segmentation metrics
"all" (default) | vector of strings

Segmentation metrics in `semanticSegmentationMetrics` to compute, specified as the comma-separated pair consisting of `'Metrics'` and a vector of strings. This argument specifies which variables in the `DataSetMetrics`, `ClassMetrics`, and `ImageMetrics` tables to compute. `ConfusionMatrix` and `NormalizedConfusionMatrix` are computed regardless of the value of `'Metric'`.
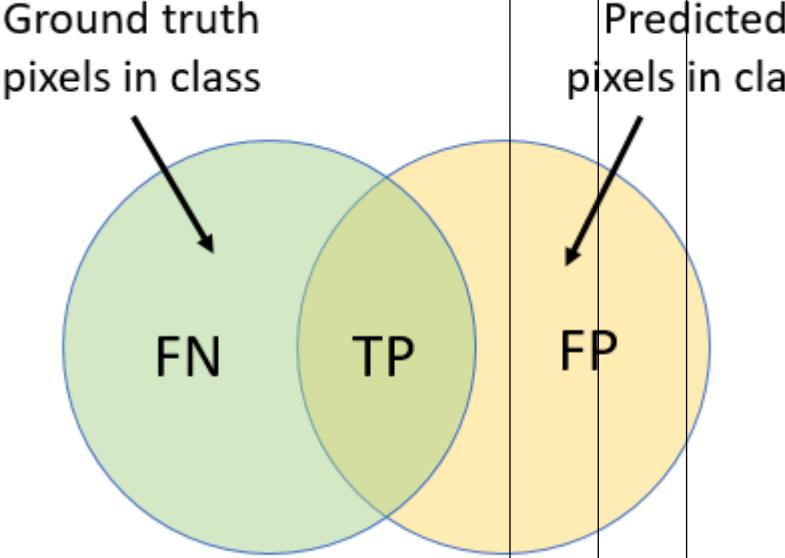
Value	Description	Aggregate Data Set Metric	Image Metric	Class Metric
"all"	Evaluate all semantic segmentation metrics.	All aggregate data set metrics	All image metrics	All class metrics

Value	Description	Aggregate Data Set Metric	Image Metric	Class Metric
`"accuracy"`	Accuracy indicates the percentage of correctly identified pixels for each class. Use the accuracy metric if you want to know how well each class correctly identifies pixels. • For each class, `Accuracy` is the ratio of correctly classified pixels to the total number of pixels in that class, according to the ground truth. In other words, Accuracy score = TP / (TP + FN) TP is the number of true positives and FN is the number of false negatives. • For the aggregate data set, `MeanAccuracy` is the average `Accuracy` of all classes in all images. • For each image, `MeanAccuracy` is the average `Accuracy` of all classes in that particular image. The class accuracy is a simple metric analogous to global accuracy, but it can be misleading. For example, labeling all pixels "car" gives a perfect score for the "car" class (although not for the other classes). Use class accuracy in conjuction with IoU for a more complete evaluation of segmentation results.	Mean Accuracy	Mean Accuracy	Accuracy

Value	Description	Aggregate Data Set Metric	Image Metric	Class Metric
"bfscore"	The boundary F1 (BF) contour matching score indicates how well the predicted boundary of each class aligns with the true boundary. Use the BF score if you want a metric that tends to correlate better with human qualitative assessment than the IoU metric. • For each class, MeanBFScore is the average BF score of that class over all images. • For each image, MeanBFScore is the average BF score of all classes in that particular image. • For the aggregate data set, MeanBFScore is the average BF score of all classes in all images. For more information, see bfscore.	Mean BFScore	Mean BFScore	MeanBFScore
"global-accuracy"	GlobalAccuracy is the ratio of correctly classified pixels, regardless of class, to the total number of pixels. Use the global accuracy metric if you want a quick and computationally inexpensive estimate of the percentage of correctly classified pixels.	GlobalAccuracy	GlobalAccuracy	none

Value	Description	Aggregate Data Set Metric	Image Metric	Class Metric
`"iou"`	Intersection over union (IoU), also known as the Jaccard similarity coefficient, is the most commonly used metric. Use the IoU metric if you want a statistical accuracy measurement that penalizes false positives. • For each class, `IoU` is the ratio of correctly classified pixels to the total number of ground truth and predicted pixels in that class. In other words, IoU score = TP / (TP + FP + FN) The image describes the true positives (TP), false positives (FP), and false negatives (FN).	Mean IoU	Mean IoU	IoU

Value	Description	Aggregate Data Set Metric	Image Metric	Class Metric
	Ground truth pixels in class · Predicted pixels in class · FN · TP · FP • For each image, MeanIoU is the average IoU score of all classes in that particular image. • For the aggregate data set, MeanIoU is the average IoU score of all classes in all images. For more information, see jaccard.			

Value	Description	Aggregate Data Set Metric	Image Metric	Class Metric
"weighted-iou"	Average IoU of each class, weighted by the number of pixels in that class. Use this metric if images have disproportionally sized classes, to reduce the impact of errors in the small classes on the aggregate quality score.	Weighted IoU	Weighted IoU	none

Example: `metrics = evaluateSemanticSegmentation(pxdsResults, pxdsTruth,'Metrics',["global-accuracy","iou"])` calculates the global accuracy and IoU metrics across the data set, images, and classes.

Data Types: `string`

Verbose — Flag to display evaluation progress
1 (default) | 0

Flag to display evaluation progress information in the command window, specified as the comma-separated pair consisting of `'Verbose'` and either 1 (`true`) or 0 (`false`).

The displayed information includes a progress bar, elapsed time, estimated time remaining, and data set metrics.

Example: `metrics = evaluateSemanticSegmentation(pxdsResults, pxdsTruth,'Verbose',0)` calculates segmentation metrics without displaying progress information.

Data Types: `logical`

Output Arguments

ssm — Semantic segmentation metrics
semanticSegmentationMetrics object

Semantic segmentation metrics, returned as a `semanticSegmentationMetrics` object.

References

[1] Csurka, G., D. Larlus, and F. Perronnin. "What is a good evaluation measure for semantic segmentation?" *Proceedings of the British Machine Vision Conference*, 2013, pp. 32.1–32.11.

See Also

PixelLabelDatastore | bfscore | jaccard | plotconfusion |
semanticSegmentationMetrics | semanticseg

Topics
"Semantic Segmentation Basics"
"Deep Learning Basics" (Neural Network Toolbox)

Introduced in R2017b

extractFeatures

Extract interest point descriptors

Syntax

```
[features,validPoints] = extractFeatures(I,points)
[features,validPoints] = extractFeatures(I,points,Name,Value)
```

Description

`[features,validPoints] = extractFeatures(I,points)` returns extracted feature vectors, also known as descriptors, and their corresponding locations, from a binary or intensity image.

The function derives the descriptors from pixels surrounding an interest point. The pixels represent and match features specified by a single-point location. Each single-point specifies the center location of a neighborhood. The method you use for descriptor extraction depends on the class of the input `points`.

`[features,validPoints] = extractFeatures(I,points,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Extract Corner Features from an Image.

Read the image.

```
I = imread('cameraman.tif');
```

Find and extract corner features.

```
corners = detectHarrisFeatures(I);
[features, valid_corners] = extractFeatures(I, corners);
```

Display image.

```
figure; imshow(I); hold on
```


Plot valid corner points.

```
plot(valid_corners);
```

Extract SURF Features from an Image

Read image.

```
I = imread('cameraman.tif');
```

Find and extract features.

```
points = detectSURFFeatures(I);
[features, valid_points] = extractFeatures(I, points);
```

Display and plot ten strongest SURF features.

```
figure; imshow(I); hold on;
plot(valid_points.selectStrongest(10),'showOrientation',true);
```
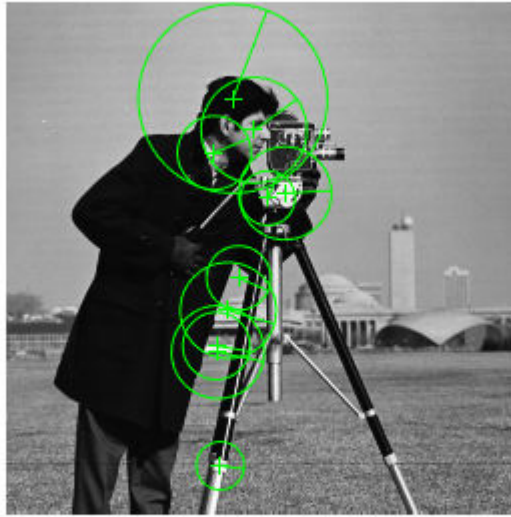
Extract MSER Features from an Image

Read image.

```
I = imread('cameraman.tif');
```

Find features using MSER with SURF feature descriptor.

```
regions = detectMSERFeatures(I);
[features, valid_points] = extractFeatures(I,regions,'Upright',true);
```

Display SURF features corresponding to the MSER ellipse centers.

```
figure; imshow(I); hold on;
plot(valid_points,'showOrientation',true);
```

Input Arguments

I — Input image
binary image | *M*-by-*N* 2-D grayscale image

Input image, specified as either a binary or 2-D grayscale image.

Data Types: `logical` | `single` | `double` | `int16` | `uint8` | `uint16`

points — Center location point
BRISKPoints object | cornerPoints object | SURFPoints object | KAZEPoints object | MSERRegions object | *M*-by-2 matrix of [x,y] coordinates

Center location point of a square neighborhood, specified as either a BRISKPoints, SURFPoints, KAZEPoints, MSERRegions, or cornerPoints object, or an *M*-by-2 matrix of *M* number of [x y] coordinates. The table lists the possible input classes of points that can be used for extraction.

Class of Points	
BRISKPoints	Binary Robust Invariant Scalable Keypoints (BRISK)
SURFPoints object	Speeded-Up Robust Features (SURF)
MSERRegions object	Maximally Stable Extremal Regions (MSER)
cornerPoints	Features from Accelerated Segment Test (FAST), Minimum eigen-value, or Harris
KAZEPoints	Non-linear image pyramid-based rotation and orientation invariant features. Similar to SURF, but contains less noisy points.
M-by-2 matrix of [x y] coordinates	Simple square neighborhood around [x y] point locations

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'Method','Block' specifies the Block method for descriptor extraction.

Method — Descriptor extraction method
'Auto' (default) | 'BRISK' | 'FREAK' | 'SURF' | 'KAZE' | 'Block'

Descriptor extraction method, specified as a comma-separated pair consisting of 'Method' and the character vector 'FREAK', 'SURF', 'Block', or 'Auto'.

The table describes how the function implements the descriptor extraction methods.

Method	Feature Vector (Descriptor)
BRISK	Binary Robust Invariant Scalable Keypoints (BRISK). The function sets the Orientation property of the validPoints output object to the orientation of the extracted features, in radians.

Method	Feature Vector (Descriptor)
FREAK	Fast Retina Keypoint (FREAK). The function sets the Orientation property of the validPoints output object to the orientation of the extracted features, in radians.
SURF	Speeded-Up Robust Features (SURF). The function sets the Orientation property of the validPoints output object to the orientation of the extracted features, in radians. When you use an MSERRegions object with the SURF method, the Centroid property of the object extracts SURF descriptors. The Axes property of the object selects the scale of the SURF descriptors such that the circle representing the feature has an area proportional to the MSER ellipse area. The scale is calculated as 1/4*sqrt((majorAxes/2).*(minorAxes/2)) and saturated to 1.6, as required by the SURFPoints object.
KAZE	Non-linear pyramid-based features. The function sets the Orientation property of the validPoints output object to the orientation of the extracted features, in radians. When you use an MSERRegions object with the KAZE method, the Location property of the object is used to extract KAZE descriptors. The Axes property of the object selects the scale of the KAZE descriptors such that the circle representing the feature has an area proportional to the MSER ellipse area.
Block	Simple square neighbhorhood. The Block method extracts only the neighborhoods fully contained within the image boundary. Therefore, the output, validPoints, can contain fewer points than the input POINTS.

Method	Feature Vector (Descriptor)
`Auto`	The function selects the `Method`, based on the class of the input points and implements: The `FREAK` method for a `cornerPoints` input object. The `SURF` method for a `SURFPoints` or `MSERRegions` input object. The `BRISK` method for a `BRISKPoints` input object. For an *M*-by-2 input matrix of [*x y*] coordinates, the function implements the `Block` method.

BlockSize — Block size
11 (default) | odd integer scalar

Block size, specified as an odd integer scalar. This value defines the local square neighborhood **BlockSize**-by-**BlockSize**, centered at each interest point. This option applies only when the function implements the `Block` method.

Upright — Rotation invariance flag
`false` | logical scalar

Rotation invariance flag, specified a logical scalar. When you set this property to `true`, the orientation of the feature vectors are not estimated and the feature orientation is set to pi/2. Set this to `true` when you do not need the image descriptors to capture rotation information. When you set this property to `false`, the orientation of the features is estimated and the features are then invariant to rotation.

FeatureSize — Length of feature vector
64 (default) | 128

Length of the SURF or KAZE feature vector (descriptor), specified as `64` or `128`. This option applies only when the function implements the `SURF` or `KAZE` method. The larger feature size of `128` provides greater accuracy, but decreases the feature matching speed.

Output Arguments

features — Feature vectors
M-by-*N* matrix | `binaryFeatures` object

Feature vectors, returned as a `binaryFeatures` object or an *M*-by-*N* matrix of *M* feature vectors, also known as descriptors. Each descriptor is of length *N*.

validPoints — Valid points
BRISKPoints object | `cornerPoints` object | SURFPoints object | KAZEPoints object | MSERRegions object | *M*-by-2 matrix of [x,y] coordinates

Valid points associated with each output feature vector (descriptor) in `features`, returned in the same format as the input. Valid points can be a `BRISKPoints`, `cornerPoints`, `SURFPoints`, `KAZEPoints`, `MSERRegions` object, or an *M*-by-2 matrix of [x,y] coordinates.

The function extracts descriptors from a region around each interest point. If the region lies outside of the image, the function cannot compute a feature descriptor for that point. When the point of interest lies too close to the edge of the image, the function cannot compute the feature descriptor. In this case, the function ignores the point. The point is not included in the valid points output.

References

[1] G. Bradski and A. Kaehler, *Learning OpenCV : Computer Vision with the OpenCV Library*, O'Reilly, Sebastopol, CA, 2008.

[2] Herbert Bay, Andreas Ess, Tinne Tuytelaars, Luc Van Gool, *SURF: Speeded Up Robust Features*"*, Computer Vision and Image Understanding (CVIU)*, Vol. 110, No. 3, pp. 346--359, 2008

[3] Bay, Herbert, Andreas Ess, Tinne Tuytelaars, and Luc Van Gool, "SURF: Speeded Up Robust Features", *Computer Vision and Image Understanding (CVIU)*, Vol. 110, No. 3, pp. 346--359, 2008.

[4] Alahi, Alexandre, Ortiz, Raphael, and Pierre Vandergheynst, "FREAK: Fast Retina Keypoint", *IEEE Conference on Computer Vision and Pattern Recognition*, 2012.

[5] Alcantarilla, P.F., A. Bartoli, and A.J. Davison. "KAZE Features", *ECCV 2012, Part VI, LNCS 7577* pp. 214, 2012

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- `'Method'` must be a compile-time constant.
- Supports MATLAB Function block for BRISK, FREAK, and SURF methods only.
- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries for BRISK, FREAK, and SURF Methods. See "Portable C Code Generation for Functions That Use OpenCV Library".
- The KAZE method and the `detectKAZEFeatures` function do not support code generation.

See Also
KAZEPoints | MSERRegions | SURFPoints | binaryFeatures | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectKAZEFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractHOGFeatures | extractLBPFeatures | matchFeatures

Topics
"Point Feature Types"
"Local Feature Detection and Extraction"

Introduced in R2011a

extractHOGFeatures

Extract histogram of oriented gradients (HOG) features

Syntax

```
features = extractHOGFeatures(I)
[features,validPoints] = extractHOGFeatures(I,points)
[ ___ , visualization] = extractHOGFeatures(I, ___ )
[ ___ ] = extractHOGFeatures( ___ ,Name,Value)
```

Description

`features = extractHOGFeatures(I)` returns extracted HOG features from a truecolor or grayscale input image, `I`. The features are returned in a 1-by-N vector, where N is the HOG feature length. The returned features encode local shape information from regions within an image. You can use this information for many tasks including classification, detection, and tracking.

`[features,validPoints] = extractHOGFeatures(I,points)` returns HOG features extracted around specified point locations. The function also returns `validPoints`, which contains the input point locations whose surrounding region is fully contained within `I`. Scale information associated with the points is ignored.

`[ ___ , visualization] = extractHOGFeatures(I, ___ )` optionally returns a HOG feature visualization, using any of the preceding syntaxes. You can display this visualization using `plot(visualization)`.

`[ ___ ] = extractHOGFeatures( ___ ,Name,Value)` uses additional options specified by one or more Name,Value pair arguments, using any of the preceding syntaxes.

Examples

Extract and Plot HOG Features

Read the image of interest.

```
img = imread('cameraman.tif');
```

Extract HOG features.

```
[featureVector,hogVisualization] = extractHOGFeatures(img);
```

Plot HOG features over the original image.

```
figure;
imshow(img);
hold on;
plot(hogVisualization);
```
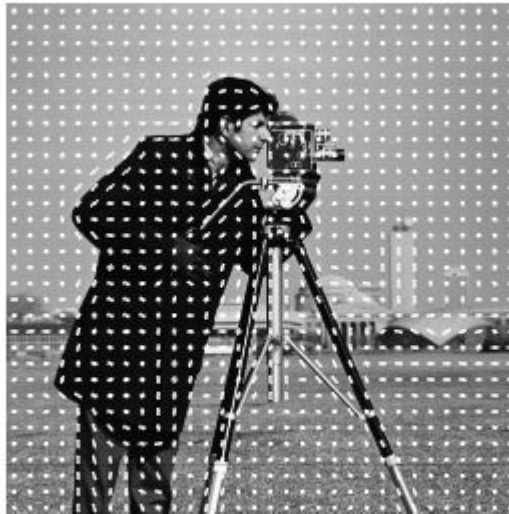
Extract HOG Features using CellSize

Read the image of interest.

```
I1 = imread('gantrycrane.png');
```

Extract HOG features.

```
[hog1,visualization] = extractHOGFeatures(I1,'CellSize',[32 32]);
```

Display the original image and the HOG features.

```
subplot(1,2,1);
imshow(I1);
subplot(1,2,2);
plot(visualization);
```
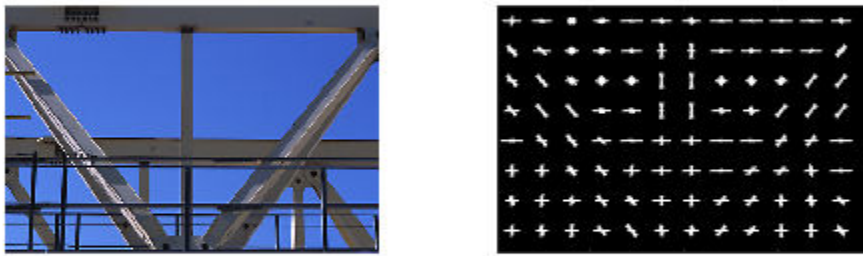
Extract HOG Features Around Corner Points

Read in the image of interest.

```
I2 = imread('gantrycrane.png');
```

Detect and select the strongest corners in the image.

```
corners   = detectFASTFeatures(rgb2gray(I2));
strongest = selectStrongest(corners,3);
```

Extract HOG features.

```
[hog2, validPoints,ptVis] = extractHOGFeatures(I2,strongest);
```

Display the original image with an overlay of HOG features around the strongest corners.

```
figure;
imshow(I2);
hold on;
plot(ptVis,'Color','green');
```


- "Digit Classification Using HOG Features"

Input Arguments

I — Input image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input image, specified in either *M*-by-*N*-by-3 truecolor or *M*-by-*N* 2-D grayscale. The input image must be a real, nonsparse value. If you have tightly cropped images, you may lose shape information that the HOG function can encode. You can avoid losing this information by including an extra margin of pixels around the patch that contains background pixels.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

points — Center location point
`BRISKPoints` object | `cornerPoints` object | `SURFPoints` object | `MSERRegions` object | *M*-by-2 matrix of [*x*, *y*] coordinates

Center location point of a square neighborhood, specified as either a `BRISKPoints`, `SURFPoints`, `MSERRegions`, or `cornerPoints` object, or an *M*-by-2 matrix of *M* number of [*x*, *y*] coordinates. The function extracts descriptors from the neighborhoods that are fully contained within the image boundary. You can set the size of the neighborhood with the `BlockSize` parameter. Only neighborhoods fully contained within the image are used to determine the valid output points. The function ignores scale information associated with these points.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'BlockSize',[2 2]` sets the `BlockSize` to be a 2-by-2 square block.

CellSize — Size of HOG cell
`[8 8]` (default) | 2-element vector

Size of HOG cell, specified in pixels as a 2-element vector. To capture large-scale spatial information, increase the cell size. When you increase the cell size, you may lose small-scale detail.

BlockSize — Number of cells in block
`[2 2]` (default) | 2-element vector

Number of cells in a block, specified as a 2-element vector. A large block size value reduces the ability to suppress local illumination changes. Because of the number of pixels in a large block, these changes may get lost with averaging. Reducing the block

size helps to capture the significance of local pixels. Smaller block size can help suppress illumination changes of HOG features.

BlockOverlap — Number of overlapping cells between adjacent blocks
ceil(BlockSize/2) (default)

Number of overlapping cells between adjacent blocks, specified as a 2-element vector. To ensure adequate contrast normalization, select an overlap of at least half the block size. Large overlap values can capture more information, but they produce larger feature vector size. This property applies only when you are extracting HOG features from regions and not from point locations. When you are extracting HOG features around a point location, only one block is used, and thus, no overlap occurs.

NumBins — Number of orientation histogram bins
9 (default) | positive scalar

Number of orientation histogram bins, specified as positive scalar. To encode finer orientation details, increase the number of bins. Increasing this value increases the size of the feature vector, which requires more time to process.

UseSignedOrientation — Selection of orientation values
false (default) | logical scalar

Selection of orientation values, specified as a logical scalar. When you set this property to true, orientation values are evenly spaced in bins between -180 and 180 degrees. When you set this property to false, they are evenly spaced from 0 through 180. In this case, values of theta that are less than 0 are placed into a theta + 180 value bin. Using signed orientation can help differentiate light-to-dark versus dark-to-light transitions within an image region.

Output Arguments

features — Extracted HOG features
1-by-N vector | P-by-Q matrix

Extracted HOG features, returned as either a 1-by-N vector or a P-by-Q matrix. The features encode local shape information from regions or from point locations within an image. You can use this information for many tasks including classification, detection, and tracking.

features output	Description
1-by-*N* vector	HOG feature length, *N*, is based on the image size and the function parameter values. *N* = prod([*BlocksPerImage*, BlockSize, NumBins]) *BlocksPerImage* = floor((size(I)./CellSize – BlockSize)./ (BlockSize – BlockOverlap) + 1)
P-by-*Q* matrix	*P* is the number of valid points whose surrounding region is fully contained within the input image. You provide the points input value for extracting point locations. The surrounding region is calculated as: CellSize.*BlockSize. The feature vector length, *Q*, is calculated as: prod([NumBins,BlockSize]).

Example 3.1. Arrangement of Histograms in HOG Feature Vectors

The figure below shows an image with six cells.

If you set the BlockSize to [2 2], it would make the size of each HOG block, 2-by-2 cells. The size of the cells are in pixels. You can set it with the CellSize property.

HOG block: 2-by-2 cells
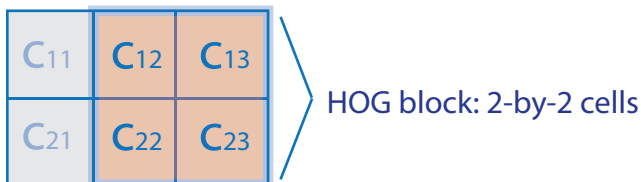
The HOG feature vector is arranged by HOG blocks. The cell histogram, H(C_{yx}), is 1-by-NumBins.
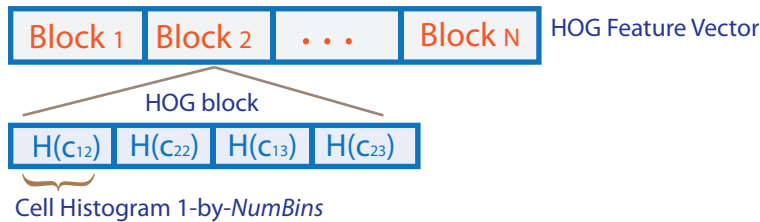
The figure below shows the HOG feature vector with a 1-by-1 cell overlap between blocks.
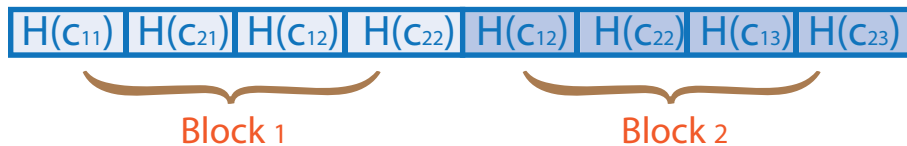
validPoints — Valid points
cornerPoints object | BRISKPoints object | SURFPoints object | MSERRegions object | *M*-by-2 matrix of [*x,y*] coordinates

Valid points associated with each `features` descriptor vector output. This output can be returned as either a `cornerPoints` object, `BRISKPoints`, `SURFPoints` object, `MSERRegions` object, or an *M*-by-2 matrix of [*x,y*] coordinates. The function extracts *M* number of descriptors from valid interest points in a region of size equal to [`CellSize.*BlockSize`]. The extracted descriptors are returned as the same type of object or matrix as the input. The region must be fully contained within the image.

visualization — HOG feature visualization
object

HOG feature visualization, returned as an object. The function outputs this optional argument to visualize the extracted HOG features. You can use the `plot` method with the `visualization` output. See the "Extract and Plot HOG Features" on page 3-360 example.

HOG features are visualized using a grid of uniformly spaced `rose` plots. The cell size and the size of the image determines the grid dimensions. Each rose plot shows the distribution of gradient orientations within a HOG cell. The length of each petal of the rose plot is scaled to indicate the contribution each orientation makes within the cell histogram. The plot displays the edge directions, which are normal to the gradient directions. Viewing the plot with the edge directions allows you to better understand the shape and contours encoded by HOG. Each rose plot displays two times `NumBins` petals.

You can use the following syntax to plot the HOG features:

`plot(visualization)` plots the HOG features as an array of rose plots.

`plot(visualization,AX)` plots HOG features into the axes AX.

`plot(___, 'Color',Colorspec)` Specifies the color used to plot HOG features, where `Colorspec` represents the color.

References

[1] Dalal, N. and B. Triggs. "Histograms of Oriented Gradients for Human Detection", *IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, Vol. 1 (June 2005), pp. 886–893.

See Also

MSERRegions | SURFPoints | binaryFeatures | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | extractFeatures | extractLBPFeatures | matchFeatures | rose

Topics

"Digit Classification Using HOG Features"
"Local Feature Detection and Extraction"
"Point Feature Types"

Introduced in R2013b

extrinsics

Compute location of calibrated camera

Syntax

```
[rotationMatrix,translationVector] = extrinsics(imagePoints,
worldPoints,cameraParams)
```

Description

`[rotationMatrix,translationVector] = extrinsics(imagePoints,`
`worldPoints,cameraParams)` returns the 3-D rotation matrix and the 3-D translation vector to allow you to transform points from the world coordinate to the camera coordinate system.

Examples

Compute Camera Extrinsics

Create a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration', 'slr'));
```

Detect the checkerboard corners in the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate the world coordinates of the checkerboard corners in the pattern-centric coordinate system, with the upper-left corner at (0,0). The square size is in millimeters.

```
squareSize = 29;
worldPoints = generateCheckerboardPoints(boardSize, squareSize);
```

Calibrate the camera.

```
I = readimage(images,1);
imageSize = [size(I,1), size(I,2)];
cameraParams = estimateCameraParameters(imagePoints,worldPoints, ...
                                'ImageSize',imageSize);
```

Load image at new location.

```
imOrig = imread(fullfile(matlabroot,'toolbox','vision','visiondata', ...
    'calibration','slr','image9.jpg'));
figure
imshow(imOrig);
title('Input Image');
```


Input Image

Undistort image.

```
[im,newOrigin] = undistortImage(imOrig,cameraParams,'OutputView','full');
```

Find reference object in new image.

```
[imagePoints,boardSize] = detectCheckerboardPoints(im);
```

Compensate for image coordinate system shift.

```
imagePoints = [imagePoints(:,1) + newOrigin(1), ...
               imagePoints(:,2) + newOrigin(2)];
```

Compute new extrinsics.

```
[rotationMatrix, translationVector] = extrinsics(...
imagePoints,worldPoints,cameraParams);
```

Compute camera pose.

```
[orientation, location] = extrinsicsToCameraPose(rotationMatrix, ...
  translationVector);
figure
plotCamera('Location',location,'Orientation',orientation,'Size',20);
hold on
pcshow([worldPoints,zeros(size(worldPoints,1),1)], ...
  'VerticalAxisDir','down','MarkerSize',40);
```
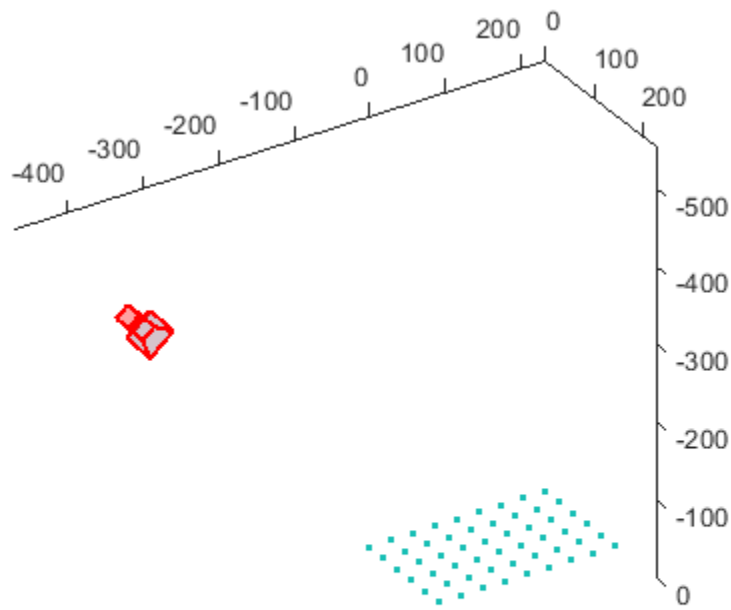
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

`imagePoints` — Image coordinates of points
M-by-2 array

Image coordinates of points, specified as an *M*-by-2 array. The array contains *M* number of [*x*, *y*] coordinates. The `imagePoints` and `worldPoints` inputs must both be `double` or both be `single`.

Data Types: `single` | `double`

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worldPoints — World coordinates corresponding to image coordinates
M-by-2 matrix

World coordinates corresponding to image coordinates, specified as an *M*-by-2 matrix. The `imagePoints` and `worldPoints` inputs must both be `double` or both be `single`. The function assumes that the points are coplanar with $z = 0$ and the number of points, *M*, must be at least 4.

Data Types: `single` | `double`

cameraParams — Camera parameters
`cameraParameters` object | `cameraIntrinsics` object | `fisheyeIntrinsics` object

Object for storing camera parameters, specified as a `cameraParameters`, `cameraIntrinsics`, or `fisheyeIntrinsics` object. These objects are returned by the `estimateCameraParameters` function, the `estimateFisheyeParameters` function, or the **Camera Calibrator** app. The object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

Output Arguments

rotationMatrix — 3-D rotation
3-by-3 matrix

3-D rotation, returned as a 3-by-3 matrix. The rotation matrix together with the translation vector allows you to transform points from the world coordinate to the camera coordinate system.

$$[x\ y\ z] \ = \ [X\ Y\ Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

If you set the `imagePoints` and `worldPoints` inputs to class `double`, then the function returns the `rotationMatrix` and `translationVector` as `double`. Otherwise, they are `single`.

translationVector — 3-D translation
3-D translation, returned as a 1-by-3 vector. The rotation matrix together with the translation vector allows you to transform points from the world coordinate to the camera coordinate system.

3-D translation, returned as a 1-by-3 vector.

$$[x\ y\ z]\ =\ [X\ Y\ Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

If you set the `imagePoints` and `worldPoints` inputs to class `double`, then the function returns the `rotationMatrix` and `translationVector` as `double`. Otherwise, they are `single`.

Algorithms

The `extrinsics` function uses two different algorithms to compute the extrinsics depending on whether `worldPoints` are specified as an *M*-by-2 or an *M*-by-3 matrix. The algorithm for the *M*-by-3 case requires the points to be non-coplanar. It will produce incorrect results if the `worldPoints` are coplanar. Use an *M*-by-2 matrix for coplanar points where $z = 0$.

The `extrinsics` function computes the rotation matrix and translation vector for a single image in closed form. During calibration, the extrinsics are estimated numerically to minimize the reprojection errors for all calibration images. Therefore, using the `extrinsics` function on one of the calibration images returns rotation matrix and translation vector slightly different from the ones obtained during calibration.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.
- Use of a `fisheyeIntrinsics` object as the `cameraParams` input is not supported.

See Also

Camera Calibrator | cameraIntrinsics | cameraMatrix | cameraParameters | estimateCameraParameters | estimateFisheyeParameters | fisheyeIntrinsics | plotCamera

Topics
"Code Generation for Depth Estimation From Stereo Video"

Introduced in R2014a

generateCheckerboardPoints

Generate checkerboard corner locations

Syntax

```
[worldPoints] = generateCheckerboardPoints(boardSize,squareSize)
```

Description

[worldPoints] = generateCheckerboardPoints(boardSize,squareSize)
returns an *M*-by-2 matrix containing *M* [*x, y*] corner coordinates for the squares on a
checkerboard. The point [0,0] corresponds to the lower-right corner of the top-left square
of the board.

Examples

Generate and Plot Corners of an 8-by-8 Checkerboard

Generate the checkerboard, and obtain world coordinates.

```
I = checkerboard;
squareSize = 10;
worldPoints = generateCheckerboardPoints([8 8], squareSize);
```

**Offset the points, placing the first point at the lower-right corner of the first
square.**

```
imshow(insertMarker(I, worldPoints + squareSize));
```
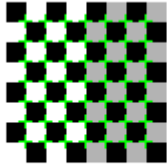
• "Measuring Planar Objects with a Calibrated Camera"

Input Arguments

boardSize — Generated checkerboard dimensions
2-element [*height, width*] vector

Generated checkerboard dimensions, specified as a 2-element [*height, width*] vector. You express the dimensions of the checkerboard in number of squares.
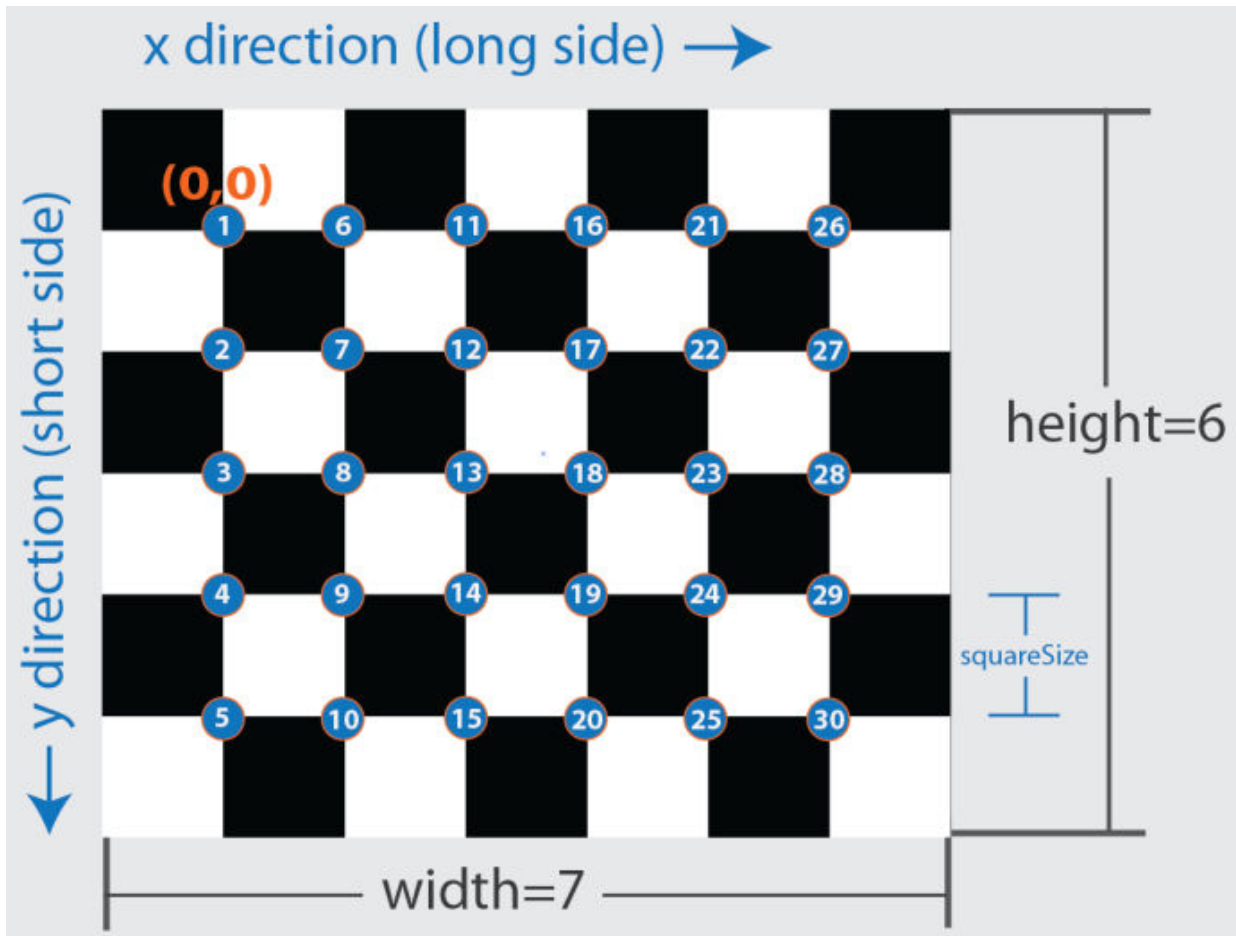
squareSize — Generated checkerboard square side length
scalar

Checkerboard square side length, specified as a scalar in world units. You express world units as a measurement, such as millimeters or inches.
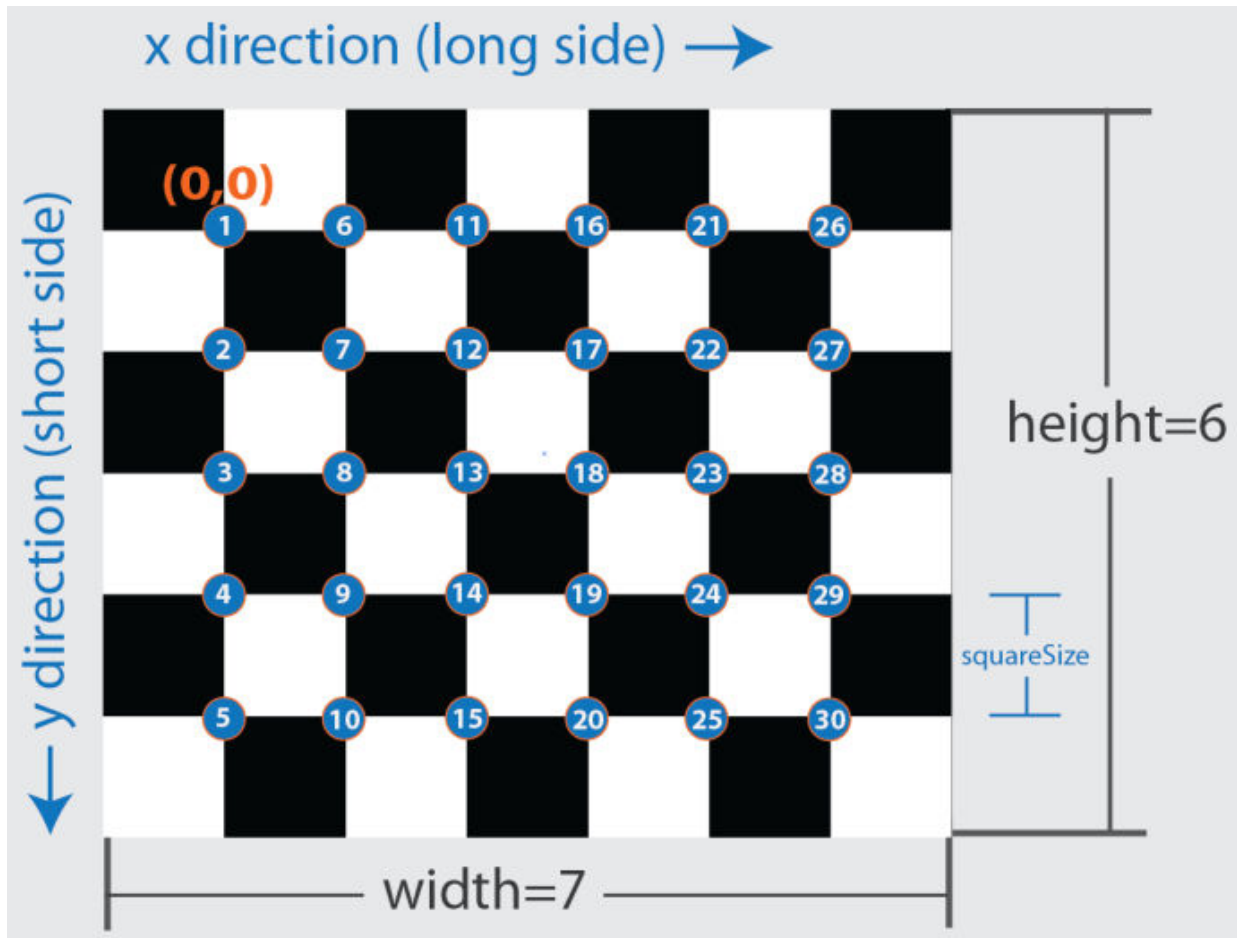
Output Arguments

worldPoints — Generated checkerboard corner coordinates
M-by-2 matrix

Generated checkerboard corner coordinates, returned as an *M*-by-2 matrix of *M* number of [*x y*] coordinates. The coordinates represent the corners of the squares on the checkerboard. The point [0,0] corresponds to the lower-right corner of the top-left square

of the board. The number of points, *M*, that the function returns are based on the number of squares on the checkerboard. This value is set with the `boardSize` parameter.
$M = (\texttt{boardSize(1)-1}) * (\texttt{boardSize(2)-1})$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

See Also
Camera Calibrator | cameraParameters | detectCheckerboardPoints | estimateCameraParameters | stereoParameters

Topics
"Measuring Planar Objects with a Calibrated Camera"
"Single Camera Calibrator App"

Introduced in R2013b

indexImages

Create image search index

Syntax

```
imageIndex = indexImages(imds)

imageIndex = indexImages(imds,bag)
imageIndex = indexImages( ___ ,Name,Value)
```

Description

`imageIndex = indexImages(imds)` creates an `invertedImageIndex` object, `imageIndex`, that contains a search index for `imds`. Use `imageIndex` with the `retrieveImages` function to search for images.

`imageIndex = indexImages(imds,bag)` returns a search index that uses a custom `bagOfFeatures` object, `bag`. Use this syntax with the `bag` you created when you want to modify the number of visual words or the feature type used to create the image search index for `imds`.

`imageIndex = indexImages( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

This object supports parallel computing using multiple MATLAB workers. Enable parallel computing from the "Computer Vision System Toolbox Preferences" dialog box. To open Computer Vision System Toolbox preferences, on the **Home** tab, in the **Environment** section, click **Preferences**. Then select **Computer Vision System Toolbox**.

Examples

Search Image Set Using a Query Image

Create an image set.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets','cups');
imds = imageDatastore(setDir);
```

Index the image set.

```
imageIndex = indexImages(imds)
```

```
Creating an inverted image index using Bag-Of-Features.
--------------------------------------------------------

Creating Bag-Of-Features.
-------------------------

* Selecting feature point locations using the Detector method.
* Extracting SURF features from the selected feature point locations.
** detectSURFFeatures is used to detect key points for feature extraction.

* Extracting features from 6 images...done. Extracted 1708 features.

* Keeping 80 percent of the strongest features from each category.

* Balancing the number of features across all image categories to improve clustering.
** Image category 1 has the least number of strongest features: 1366.
** Using the strongest 1366 features from each of the other image categories.

* Using K-Means clustering to create a 20000 word visual vocabulary.
* Number of features      : 1366
* Number of clusters (K)   : 1366

* Initializing cluster centers...100.00%.
* Clustering...completed 1/100 iterations (~0.11 seconds/iteration)...converged in 1 it

* Finished creating Bag-Of-Features


Encoding images using Bag-Of-Features.
--------------------------------------

* Encoding 6 images...done.
Finished creating the image index.

imageIndex =
  invertedImageIndex with properties:

        ImageLocation: {6x1 cell}
```

```
        ImageWords: [6x1 vision.internal.visualWords]
     WordFrequency: [1x1366 double]
     BagOfFeatures: [1x1 bagOfFeatures]
    MatchThreshold: 0.0100
WordFrequencyRange: [0.0100 0.9000]
```

Display the image set using the `montage` function.

```
thumbnailGallery = [];
for i = 1:length(imds.Files)
    I = readimage(imds,i);
    thumbnail = imresize(I,[300 300]);
    thumbnailGallery = cat(4,thumbnailGallery,thumbnail);
end

figure
montage(thumbnailGallery);
```

Select a query image.

```
queryImage = readimage(imds,2);
figure
imshow(queryImage)
```

Search the image set for similar image using query image. The best result is first.

```
indices = retrieveImages(queryImage,imageIndex)

indices = 5×1

     2
     1
     4
     3
     5


bestMatchIdx = indices(1);
```

Display the best match from the image set.

```
bestMatch = imageIndex.ImageLocation{bestMatchIdx}

bestMatch =
'B:\matlab\toolbox\vision\visiondata\imageSets\cups\blueCup.jpg'

figure
imshow(bestMatch)
```

Create Search Index Using Custom Bag of Features

Create an image set.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets','cups');
imgSets = imageSet(setDir, 'recursive');
```

Display image set.

```
thumbnailGallery = [];
for i = 1:imgSets.Count
    I = read(imgSets, i);
    thumbnail = imresize(I, [300 300]);
    thumbnailGallery = cat(4, thumbnailGallery, thumbnail);
end

figure
montage(thumbnailGallery);
```

Train a bag of features using a custom feature extractor.

```
extractor = @exampleBagOfFeaturesExtractor;
bag = bagOfFeatures(imgSets,'CustomExtractor',extractor);
```

```
Creating Bag-Of-Features.
-------------------------
* Image category 1: cups
* Extracting features using a custom feature extraction function: exampleBagOfFeatures
* Extracting features from 6 images in image set 1...done. Extracted 115200 features.

* Keeping 80 percent of the strongest features from each category.

* Using K-Means clustering to create a 500 word visual vocabulary.
* Number of features         : 92160
```

```
* Number of clusters (K)      : 500

* Initializing cluster centers...100.00%.
* Clustering...completed 16/100 iterations (~0.34 seconds/iteration)...converged in 16

* Finished creating Bag-Of-Features
```

Use the trained bag of features to index the image set.

```
imageIndex = indexImages(imgSets,bag,'Verbose',false)

imageIndex =
  invertedImageIndex with properties:

          ImageLocation: {6x1 cell}
             ImageWords: [6x1 vision.internal.visualWords]
          WordFrequency: [1x500 double]
          BagOfFeatures: [1x1 bagOfFeatures]
         MatchThreshold: 0.0100
     WordFrequencyRange: [0.0100 0.9000]
```

```
queryImage = read(imgSets,4);

figure
imshow(queryImage)
```

Search for the image from image index using query image.

```
indices = retrieveImages(queryImage,imageIndex);
bestMatch = imageIndex.ImageLocation{indices(1)};
figure
imshow(bestMatch)
```

- "Image Retrieval Using Customized Bag of Features"

Input Arguments

imds — Images
`imageDatastore` object

Images, specified as an `imageDatastore` object. The object stores a collection of images.

bag — Bag of visual words
`bagOfFeatures` object

Bag of visual words, specified as a `bagOfFeatures` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Verbose',true` sets the `'Verbose'` property to `true`

SaveFeatureLocations — Save feature locations
`true` (default) | `false`

Save feature locations, specified as the comma-separated pair consisting of `'SaveFeatureLocations'` and a logical scalar. When set to `true`, the image feature locations are saved in the `imageIndex` output object. Use location data to verify spatial or geometric image search results. If you do not require feature locations, set this property to false to reduce memory consumption.

Verbose — Display progress information
`true` (default) | `false`

Display progress information, specified as the comma-separated pair consisting of `'Verbose'` and a logical scalar.

Output Arguments

imageIndex — Image search index
invertedImageIndex object

Image search index, returned as an invertedImageIndex object.

Algorithms

imageIndex uses the bag-of-features framework with the speeded-up robust features (SURF) detector and extractor to learn a vocabulary of 20,000 visual words. The visual words are then used to create an index that maps visual words to the images in imds. You can use the index to search for images within imds that are similar to a given query image.

See Also
bagOfFeatures | evaluateImageRetrieval | imageDatastore | invertedImageIndex | retrieveImages

Topics
"Image Retrieval Using Customized Bag of Features"
"Image Retrieval with Bag of Visual Words"

Introduced in R2015a

integralFilter

Filter using integral image

Syntax

```
J = integralFilter(intI,H)
```

Description

`J = integralFilter(intI,H)` filters an image, given its integral image, `intI`, and filter object, `H`. The `integralKernel` function returns the filter object used for the input to the `integralFilter`.

This function uses integral images for filtering an image with box filters. You can obtain the integral image, `intI`, by calling the `integralImage` function. The filter size does not affect the speed of the filtering operation. Thus, the `integralFilter` function is ideally suited to use for fast analysis of images at different scales, as demonstrated by the Viola-Jones algorithm [1].

Tips

Because the `integralFilter` function uses correlation for filtering, the filter is not rotated before computing the result.

Input Arguments

intI

Integral image. You can obtain the integral image, `intI`, by calling the `integralImage` function. The class for this value can be `double` or `single`.

H

Filter object. You can obtain the filter object, `H`, by calling the `integralKernel` function.

Output Arguments

`J`

Filtered image. The filtered image, `J`, returns only the parts of correlation that are computed without padding. This results in `size(J) = size(intI) – H.Size` for an upright filter, and `size(J) = size(intI) – H.Size – [0 1]` for a rotated filter. This function uses correlation for filtering.

Examples

Blur an Image Using an Average Filter

Read and display the input image.

```
I = imread('pout.tif');
imshow(I);
```

Compute the integral image.

```
intImage = integralImage(I);
```

Apply a 7-by-7 average filter.

```
avgH = integralKernel([1 1 7 7], 1/49);
J = integralFilter(intImage, avgH);
```

Cast the result back to the same class as the input image.

```
J = uint8(J);
figure
imshow(J);
```

Find Vertical and Horizontal Edges in Image

Construct Haar-like wavelet filters to find vertical and horizontal edges in an image.

Read the input image and compute the integral image.

```
I = imread('pout.tif');
intImage = integralImage(I);
```

Construct Haar-like wavelet filters. Use the dot notation to find the vertical filter from the horizontal filter.

```
horiH = integralKernel([1 1 4 3; 1 4 4 3],[-1, 1]);
vertH = horiH.'
```

```
vertH =
  integralKernel with properties:

    BoundingBoxes: [2x4 double]
          Weights: [-1 1]
     Coefficients: [4x6 double]
           Center: [2 3]
             Size: [4 6]
      Orientation: 'upright'
```

Display the horizontal filter.

```
imtool(horiH.Coefficients, 'InitialMagnification','fit');
```
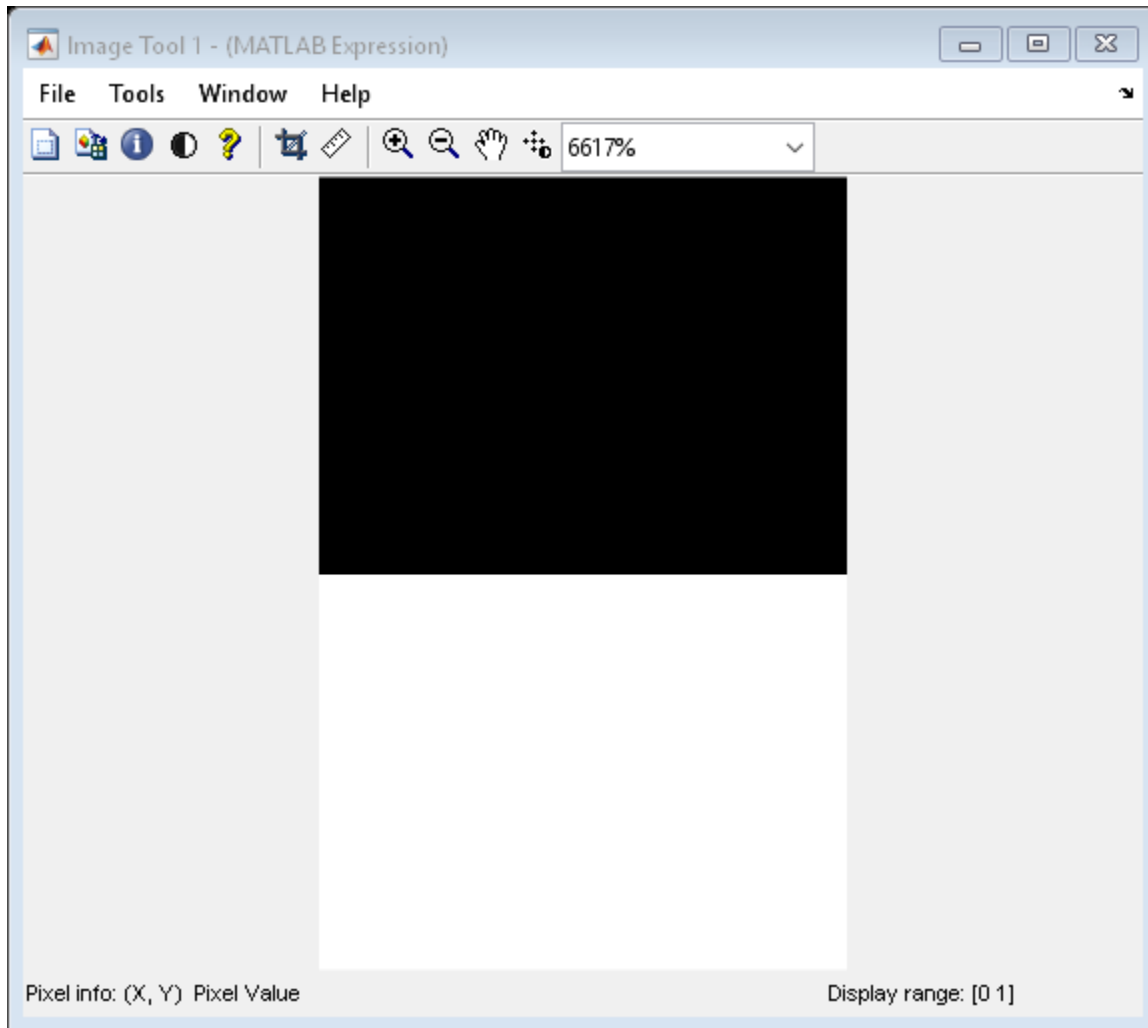
Compute the filter responses.

```
horiResponse = integralFilter(intImage,horiH);
vertResponse = integralFilter(intImage,vertH);
```

Display the results.

```
figure;
imshow(horiResponse,[]);
title('Horizontal edge responses');
```

Horizontal edge responses
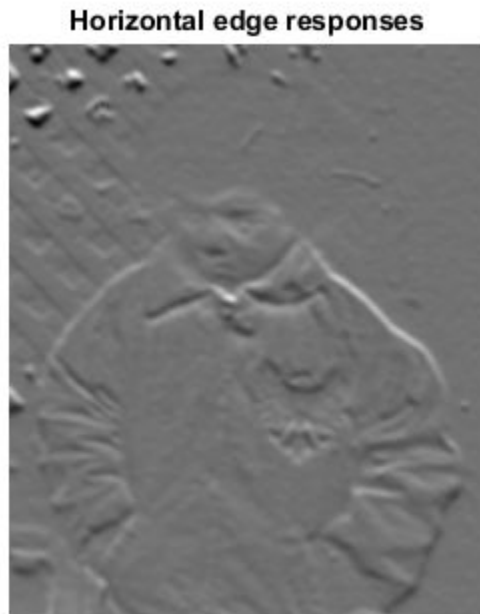

```
figure;
imshow(vertResponse,[]);
title('Vertical edge responses');
```

Vertical edge responses
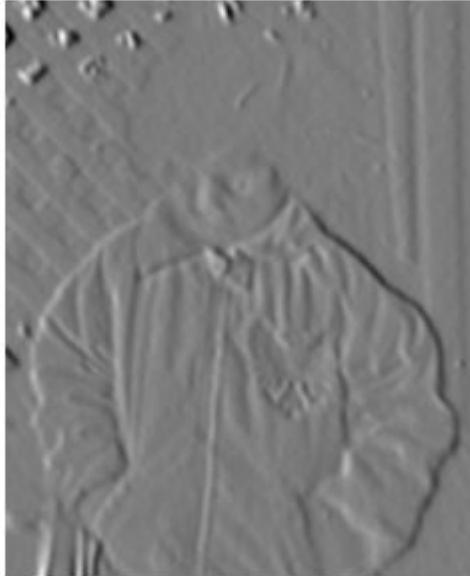
Compute a Rotated Edge Response Using Integral Filter

Read the input image.

```
I = imread('pout.tif');
```

Compute 45 degree edge responses of the image.

```
intImage = integralImage(I,'rotated');
figure;
imshow(I);
title('Original Image');
```

Original Image

Construct 45 degree rotated Haar-like wavelet filters.

```
rotH = integralKernel([2 1 2 2;4 3 2 2],[1 -1],'rotated');
rotHTrans = rotH.';
```

Visualize the filter rotH.

```
figure;
imshow(rotH.Coefficients, [],'InitialMagnification','fit');
```

Compute filter responses.

```
rotHResponse = integralFilter(intImage,rotH);
rotHTransResponse = integralFilter(intImage,rotHTrans);
```

Display results.

```
figure;
imshow(rotHResponse, []);
title('Response for SouthWest-NorthEast edges');
```

Response for SouthWest-NorthEast edges
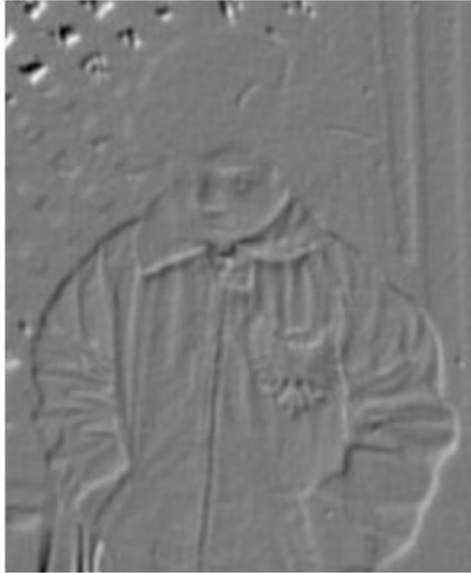

```
figure;
imshow(rotHTransResponse, []);
title('Response for NorthWest-SouthEast edges');
```

Response for NorthWest-SouthEast edges
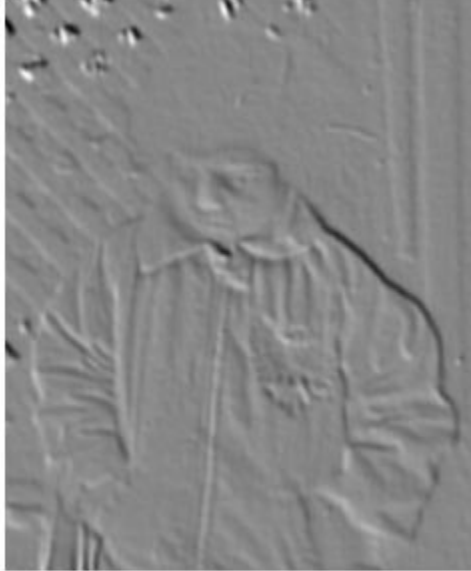
- "Compute an Integral Image" on page 3-411

References

[1] Viola, Paul and Michael J. Jones, "Rapid Object Detection using a Boosted Cascade of Simple Features", *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2001. Volume: 1, pp.511–518.

See Also

`cumsum` | `integralImage` | `integralKernel`

Topics

"Compute an Integral Image" on page 3-411

Introduced in R2012a

integralImage

Integral image

Syntax

```
J = integralImage(I)
J = integralImage(I,orientation)
```

Description

`J = integralImage(I)` computes an integral image of the input intensity image, `I`. The function zero-pads the top and left side of the output integral image, `J`.

`J = integralImage(I,orientation)` computes the integral image with the specified orientation.

An integral image lets you rapidly calculate summations over image subregions. Use of integral images was popularized by the Viola-Jones algorithm [1]. Integral images facilitate summation of pixels and can be performed in constant time, regardless of the neighborhood size.

Input Arguments

I — Intensity image

Intensity image, specified as an *M*-by-*N* grayscale image. This value can be any numeric class.

orientation — Image orientation
`'upright'` (default) | `'rotated'`

Image orientation, specified as `'upright'` or `'rotated'`. If you set the orientation to `'rotated'`, `integralImage` returns the integral image for computing sums over rectangles rotated by 45 degrees. To facilitate easy computation of pixel sums along all image boundaries, the output integral images are padded as follows:

Upright integral image — Zero-padded on top and left, resulting in `size(J) = size(I) + 1`

Rotated integral image — Zero-padded at the top, left, and right, resulting in `size(J) = size(I) + [1 2]`

Output Arguments

J

Integral image. The function zero-pads the top and left side of the integral image. The class of the output is `double`. The resulting size of the output integral image equals:

`size(J) = size(I) + 1`

Such sizing facilitates easy computation of pixel sums along all image boundaries. The integral image, `J`, is essentially a padded version of the value `cumsum(cumsum(I,2))`.

Examples

Compute an Integral Image

Compute the integral image and use it to compute the sum of pixels over a rectangular region of an intensity image.

Create an image matrix.

```
I = magic(5)

I = 5×5

    17    24     1     8    15
    23     5     7    14    16
     4     6    13    20    22
    10    12    19    21     3
    11    18    25     2     9
```

Define rectangular region as [startingRow, startingColumn, endingRow, endingColumn].

```
[sR sC eR eC] = deal(1,3,2,4);
```

Compute the sum over the region using the integral image.

```
J = integralImage(I);
regionSum = J(eR+1,eC+1) - J(eR+1,sC) - J(sR,eC+1) + J(sR,sC)

regionSum = 30
```

- "Blur an Image Using an Average Filter"
- "Find Vertical and Horizontal Edges in Image"

Algorithms

How Integral Image Summation Works

An integral image helps you rapidly calculate summations over image subregions. Every pixel in an integral image is the summation of the pixels above and to the left of it.

input image   integral image
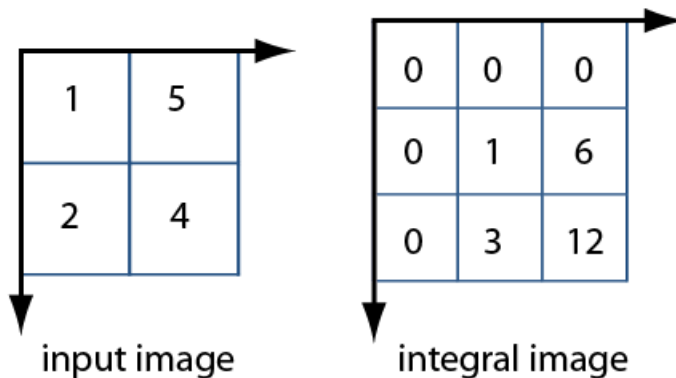
To calculate the summation of a subregion of an image, you can use the corresponding region of its integral image. For example, in the input image below, the summation of the shaded region becomes a simple calculation using four reference values of the rectangular region in the corresponding integral image. The calculation becomes, 46 – 22 – 20 + 10 = 14. The calculation subtracts the regions above and to the left of the shaded region. The area of overlap is added back to compensate for the double subtraction.

input image   integral image
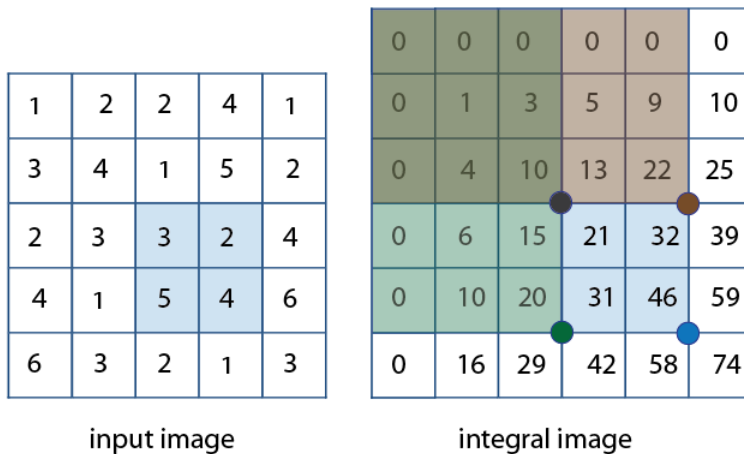
In this way, you can calculate summations in rectangular regions rapidly, irrespective of the filter size.

References

[1] Viola, Paul and Michael J. Jones, "Rapid Object Detection using a Boosted Cascade of Simple Features", *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2001. Volume: 1, pp.511–518.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`cumsum` | `integralFilter` | `integralKernel`

Topics
"Blur an Image Using an Average Filter"

"Find Vertical and Horizontal Edges in Image"

Introduced in R2012a

insertMarker

Insert markers in image or video

Syntax

```
RGB = insertMarker(I,position)
RGB = insertMarker(I,position,marker)
RGB = insertMarker(___,Name,Value)
```

Description

RGB = insertMarker(I,position) returns a truecolor image with inserted plus (+) markers. The input image, I, can be either a truecolor or grayscale image. You draw the markers by overwriting pixel values. The input position can be either an *M*-by-2 matrix of *M* number of [*x y*] pairs or one of the "Point Feature Types".

RGB = insertMarker(I,position,marker) returns a truecolor image with the marker type of markers inserted.

RGB = insertMarker(___,Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Draw Markers on an Image

Read the image.

```
I = imread('peppers.png');
```

Insert a plus (+) marker.

```
RGB = insertMarker(I,[147 279]);
```

Draw four x-marks.

```
pos   = [120 248;195 246;195 312;120 312];
color = {'red','white','green','magenta'};
RGB = insertMarker(RGB,pos,'x','color',color,'size',10);
```

Display the image.

```
imshow(RGB);
```


- "Insert Circle and Filled Shapes on an Image" on page 3-429
- "Insert Numbers and Text on Image" on page 3-437

Input Arguments

`I` — Input image
M-by-*N*-by-3 truecolor | *M*-by-*N* 2-D grayscale image

Input image, specified in truecolor or 2-D grayscale.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16`

`position` — Position of marker
M-by-2 matrix | vector

Position of marker, specified as either an *M*-by-2 matrix of *M* number of [*x y*] pairs or one of the "Point Feature Types". The center positions for the markers are defined by the [*xy*] pairs of the matrix or by the `Location` property of the point feature object.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`marker` — Type of marker
`'plus'` (default) | character vector

Type of marker, specified as a character vector. The vector can be full text or the corresponding symbol.

Character Vector	Symbol
`'circle'`	`'o'`
`'x-mark'`	`'x'`
`'plus'`	`'+'`
`'star'`	`'*'`
`'square'`	`'s'`

Data Types: `char`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: `'Color','yellow'` specifies yellow for the marker color.

Size — Size of marker
3 (default) | scalar value

Size of marker in pixels, specified as the comma-separated pair consisting of `'Size'` and a scalar value in the range [1, inf).

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Color — Marker color
`'green'` (default) | character vector | cell array of character vectors | vector | matrix

Marker color, specified as the comma-separated pair consisting of `'Color'` and either a character vector, cell array of character vectors, vector, or matrix. You can specify a different color for each marker or one color for all markers.

To specify a color for each marker, set `Color` to a cell array of color character vectors or an *M*-by-3 matrix of *M* number of RGB (red, green, and blue) color values.

To specify one color for all markers, set `Color` to either a color character vector or an [R G B] vector. The [R G B] vector contains the red, green, and blue values.

Supported colors are: `'blue'`, `'green'`, `'red'`, `'cyan'`, `'magenta'`, `'yellow'`, `'black'`, and `'white'`.

Data Types: `cell` | `char` | `uint8` | `uint16` | `int16` | `double` | `single`

Output Arguments

RGB — Output image
M-by-*N*-by-3 truecolor

Output image, returned as a truecolor image.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- `'Shape'` and `'Color'` must be compile-time constants.

See Also
"Point Feature Types" | BRISKPoints | MSERRegions | SURFPoints | cornerPoints | insertObjectAnnotation | insertShape | insertText

Topics

Introduced in R2013a

insertObjectAnnotation

Annotate truecolor or grayscale image or video stream

Syntax

```
RGB = insertObjectAnnotation(I,shape,position,label)
RGB = insertObjectAnnotation(I,shape,position,label,Name,Value)

insertObjectAnnotation(I,'rectangle',position,label)
insertObjectAnnotation(I,'circle',position,label)
```

Description

`RGB = insertObjectAnnotation(I,shape,position,label)` returns a truecolor image annotated with `shape` and `label` at the location specified by `position`.

`RGB = insertObjectAnnotation(I,shape,position,label,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

`insertObjectAnnotation(I,'rectangle',position,label)` inserts rectangles and labels at the location indicated by the position matrix.

`insertObjectAnnotation(I,'circle',position,label)` inserts circles and corresponding labels at the location indicated by the position matrix.

Examples

Annotate Image with Numbers and Strings

Read image.

```
I = imread('board.tif');
```

Create labels of floating point numbers. The floating point numbers relate to confidence value labels.

```
label_str = cell(3,1);
conf_val = [85.212 98.76 78.342];
for ii=1:3
    label_str{ii} = ['Confidence: ' num2str(conf_val(ii),'%0.2f') '%'];
end
```

Set the position for the rectangles as [x y width height].

```
position = [23 373 60 66;35 185 77 81;77 107 59 26];
```

Insert the labels.

```
RGB = insertObjectAnnotation(I,'rectangle',position,label_str,...
    'TextBoxOpacity',0.9,'FontSize',18);
```

Display the annotated image.

```
figure
imshow(RGB)
title('Annotated chips');
```

Annotated chips
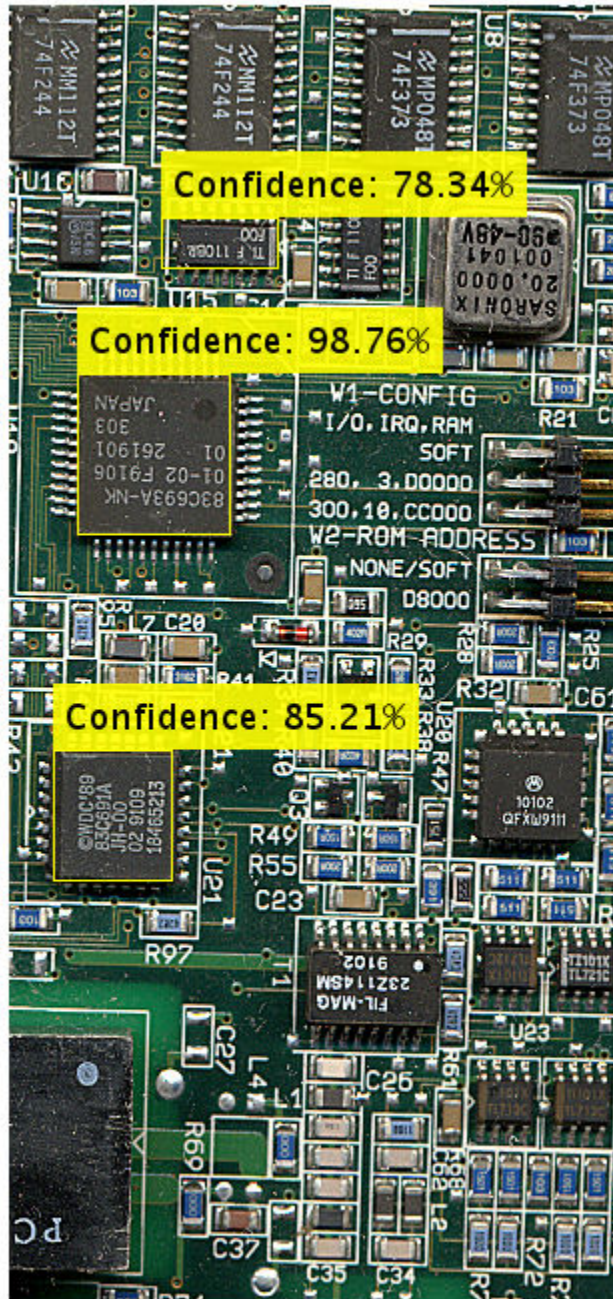
Annotate Image with Integer Numbers

Read image.

```
I = imread('coins.png');
```

Set positions for the circles. The first two values represents the center at (x,y) and the third value is the radius.

```
position = [96 146 31;236 173 26];
```

Set the label to display the integers 5 and 10 (U.S. cents).

```
label = [5 10];
```

Insert the annotations.

```
RGB = insertObjectAnnotation(I,'circle',position,label,'LineWidth',3,'Color',{'cyan','y
```

Display.

```
figure
imshow(RGB)
title('Annotated coins');
```

Annotated coins

Input Arguments

I — Truecolor or grayscale image
M-by-*N*-by-3 truecolor | *M*-by-*N* 2-D grayscale image

Truecolor or grayscale image, specified as an image or video stream. The input image can be either an *M*-by-*N*-by-3 truecolor or a *M*-by-*N* 2-D grayscale image.

Data Types: `double` | `single` | `uint8` | `uint16` | `int16`

shape — Rectangle or circle annotation
'rectangle' | 'circle'

Rectangle or circle annotation, specified as a character vector indicating the annotation shape.

Data Types: `char`

`position` — Location and size of the annotation shape
M-by-3 matrix | *M*-by-4 matrix

Location and size of the annotation shape, specified as an *M*-by-3 or *M*-by-4 matrix. When you specify a rectangle, the position input matrix must be an *M*-by-4 matrix. Each row, *M*, specifies a rectangle as a four-element vector, [*x y width height*]. The elements, *x* and *y*, indicate the upper-left corner of the rectangle, and the *width* and *height* specify the size.

When you specify a circle, the position input matrix must be an *M*-by-3 matrix, where each row, *M*, specifies a three-element vector [*x y r*]. The elements, *x* and *y*, indicate the center of the circle and *r* specifies the radius.

Example: `position = [50 120 75 75]`

A rectangle with top-left corner located at *x*=50, *y*=120, with a width and height of 75 pixels.

Example: `position = [96 146 31]`

A circle with center located at *x*=96, *y*=146 and a radius of 31 pixels.

Example: `position = [23 373 60 66;35 185 77 81;77 107 59 26]`

Location and size for three rectangles.

`label` — A character vector label to associate with a shape
numeric scalar | numeric vector | ASCII character vector | cell array of ASCII character vectors

A character vector label to associate with a shape, specified as a numeric vector or a cell array. The input can be a numeric vector of length *M*. It can also be a cell array of ASCII character vectors of length *M*, where *M* is the number of shape positions. You can also specify a single numeric scalar or character vector label for all shapes.

Example: label = [5 10], where the function marks the first shape with the label, 5, and the second shape with the label, 10.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Color'`, `'white'` sets the color for the label text box to white.

Font — Font face of text
`'LucidaSansRegular'` (default) | character vector

Font face of text, specified as the comma-separated pair consisting of `'Font'` and a character vector. The font face must be one of the available truetype fonts installed on your system. To get a list of available fonts on your system, type `listTrueTypeFonts` at the MATLAB command prompt.

Data Types: `char`

FontSize — Label text font size
12 (default) | integer in the range of [8 72]

Label text font size, specified as the comma-separated pair consisting of `'FontSize'` and an integer corresponding to points in the range of [8 72].

Data Types: `double` | `single` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

LineWidth — Shape border line width
1 (default)

Shape border line width, specified as the comma-separated pair consisting of `'LineWidth'` and a positive scalar integer in pixels.

Color — Color for shape and corresponding label text box
`'yellow'` (default) | color character vector | [R G B] vector | cell array | *M*-by-3 matrix

Color for shape and for corresponding label text box, specified as the comma-separated pair consisting of `'Color'` and either a character vector, an [R G B] vector, a cell array, or an *M*-by-3 matrix.

To specify one color for all shapes, set this parameter to either a character vector or an [R G B] vector. To specify a color for each of the *M* shapes, set this parameter to a cell array of *M* character vectors. Alternatively, you can specify an *M*-by-3 matrix of RGB values for each annotation. RGB values must be in the range of the input image data type.

Supported colors: `'blue'`, `'green'`, `'cyan'`, `'red'`, `'magenta'`, `'black'`, and `'white'`.

Data Types: `char` | `uint8` | `uint16` | `int16` | `double` | `single` | `cell`

TextColor — Color of text in text label
'black' (default) | color character vector | [R G B] vector | cell array | *M*-by-3 matrix

Color of text in text label, specified as the comma-separated pair consisting of 'TextColor' and either a character vector, an [R G B] vector, a cell array, or an *M*-by-3 matrix. To specify one color for all text, set this parameter to either a character vector or an [R G B] vector. To specify a color for each of the *M* text labels, set this parameter to a cell array of *M* character vectors. Alternatively, you can specify an *M*-by-3 matrix of RGB values for each annotation. RGB values must be in the range of the input image data type.

Supported colors: 'blue', 'green', 'cyan', 'red', 'magenta', 'yellow', and 'white'.

Data Types: char | uint8 | uint16 | int16 | double | single | cell

TextBoxOpacity — Opacity of text label box background
0.6 (default) | range of [0 1]

Opacity of text label box background, specified as the comma-separated pair consisting of 'TextBoxOpacity' and a scalar defining the opacity of the background of the label text box. Specify this value in the range of 0 to 1.

Data Types: double | single | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Output Arguments

RGB — Truecolor or grayscale image with annotation
M-by-*N*-by-3 truecolor

Truecolor image with annotation, returned as an image or video stream.

Data Types: double | single | uint8 | uint16 | int16

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Input image must be bounded. See "Specify Upper Bounds for Variable-Size Arrays" (MATLAB Coder).
- See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

insertMarker | insertShape | insertText

Introduced in R2012b

insertShape

Insert shapes in image or video

Syntax

```
RGB = insertShape(I,shape,position)
RGB = insertShape( ___ ,Name,Value)
```

Description

`RGB = insertShape(I,shape,position)` returns a truecolor image with `shape` inserted. The input image, `I`, can be either a truecolor or grayscale image. You draw the shapes by overwriting pixel values.

`RGB = insertShape( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Insert Circle and Filled Shapes on an Image

Read the image.

```
I = imread('peppers.png');
```

Draw a circle with a border line width of 5.

```
RGB = insertShape(I,'circle',[150 280 35],'LineWidth',5);
```

Draw a filled triangle and a filled hexagon.

```
pos_triangle = [183 297 302 250 316 297];
pos_hexagon = [340 163 305 186 303 257 334 294 362 255 361 191];
RGB = insertShape(RGB,'FilledPolygon',{pos_triangle,pos_hexagon},...
    'Color', {'white','green'},'Opacity',0.7);
```

Display the image.

```
imshow(RGB);
```


- "Draw Markers on an Image" on page 3-415
- "Insert Numbers and Text on Image" on page 3-437

Input Arguments

I — Input image
M-by-*N*-by-3 truecolor | *M*-by-*N* 2-D grayscale image

Input image, specified in truecolor or 2-D grayscale.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16`

shape — Type of shape
character vector
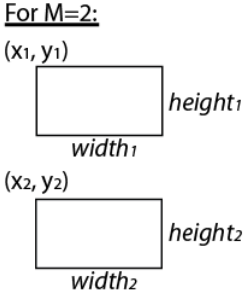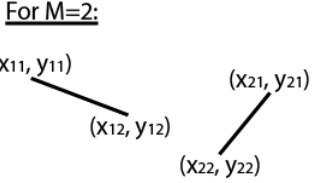
Type of shape, specified as a character vector. The vector can be, `'Rectangle'`, `'FilledRectangle'`, `'Line'`, `'Polygon'`, `'FilledPolygon'`, `'Circle'`, or `'FilledCircle'`.

Data Types: `char`
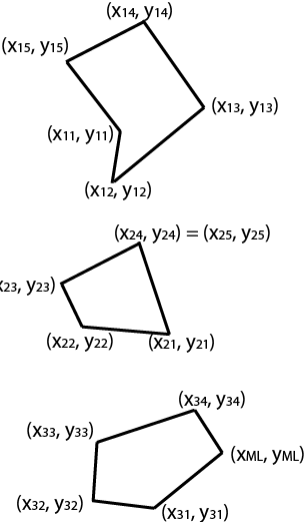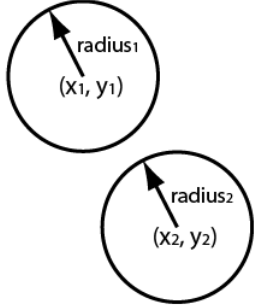
`position` — Position of shape
matrix | vector | cell array

Position of shape, specified according to the type of shape, described in the table.

Shape	Position	Shape Drawn
`'Rectangle'` `'FilledRectangle'`	M-by-4 matrix where each row specifies a rectangle as $\begin{bmatrix} x & y & width & height \end{bmatrix}$. $$\begin{bmatrix} x_1 & y_1 & width_1 & height_1 \\ x_2 & y_2 & width_2 & height_2 \\ \vdots & \vdots & \vdots & \vdots \\ x_M & y_M & width_M & height_M \end{bmatrix}$$	
`'Line'`	For one or more disconnected lines, an M-by-4 matrix, where each four-element vector $[x_1, y_1, x_2, y_2]$, describe a line with endpoints, $[x_1\ y_1]$ and $[x_2\ y_2]$. $$\begin{bmatrix} x_{11} & y_{11} & x_{12} & y_{12} \\ x_{21} & y_{21} & x_{22} & y_{22} \\ \vdots & \vdots & \vdots & \vdots \\ x_{M1} & y_{M1} & x_{M2} & x_{M2} \end{bmatrix}$$	

Shape	Position	Shape Drawn
	For one or more line segments, an *M*-by-2*L* matrix, where each row is a vector representing a polyline with *L* number of vertices.	For M=2:

The polyline always contains (*L*-1) number of segments because the first and last vertex points do not connect. For lines with fewer segments, repeat the ending coordinates to fill the matrix.

You can also specify the shapes as a cell array of *M* vectors.

$$\{[x_{11},y_{11},x_{12},y_{12},...,x_{1p},y_{1p}],$$
$$[x_{21},y_{21},x_{22},y_{22},......,x_{2q},y_{2q}], ...$$
$$[x_{M1},y_{M1},x_{M2},y_{M2},.......,x_{Mr},y_{Mr}]\}$$

p, *q*, and *r* specify the number of vertices.

Shape	Position	Shape Drawn
`'Polygon'` `'FilledPolygon'`	An *M*-by-2*L* matrix, where each row represents a polygon with *L* number of vertices. Each row of the matrix corresponds to a polygon. For polygons with fewer segments, repeat the ending coordinates to fill the matrix. You can also specify the shapes as a cell array of *M* vectors: $\{[x_{11}, y_{11}, x_{12}, y_{12}, ..., x_{1p}, y_{1p}],$ $[x_{21}, y_{21}, x_{22}, y_{22}, ..., x_{2q}, y_{2q}], ...$ $[x_{M1}, y_{M1}, x_{M2}, y_{M2}, ..., x_{Mr}, y_{Mr}]\}$ *p*, *q*, and *r* specify the number of vertices.	
`'Circle'` `'FilledCircle'`	An *M*-by-3 matrix, where each row is a vector specifying a circle as $\begin{bmatrix} x & y & radius \end{bmatrix}$. The $\begin{bmatrix} x & y \end{bmatrix}$ coordinates represent the center of the circle. $$\begin{bmatrix} x_1 & y_1 & radius_1 \\ x_2 & y_2 & radius_2 \\ \vdots & \vdots & \vdots \\ x_M & y_M & radius_M \end{bmatrix}$$	

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Color','yellow'` specifies yellow for the shape color.

`LineWidth` — Shape border line width
1 (default) | positive scalar integer

Shape border line width, specified in pixels, as a positive scalar integer. This property only applies to the `'Rectangle'`, `'Line'`, `'Polygon'`, or `'Circle'` shapes.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single`

`Color` — Shape color
`'yellow'` (default) | character vector | cell array of character vectors | [R G B] vector | *M*-by-3 matrix

Shape color, specified as the comma-separated pair consisting of `'Color'` and either a character vector, cell array of character vector, or matrix. You can specify a different color for each shape, or one color for all shapes.

To specify a color for each shape, set `Color` to a cell array of color character vectors or an *M*-by-3 matrix of *M* number of RGB (red, green, and blue) color values.

To specify one color for all shapes, set `Color` to either a color character vector or an [R G B] vector. The [R G B] vector contains the red, green, and blue values.

Supported colors: `'blue'`, `'green'`, `'red'`, `'cyan'`, `'magenta'`, `'black'`,`'black'`, and `'white'`.

Data Types: `cell` | `char` | `uint8` | `uint16` | `int16` | `double` | `single`

`Opacity` — Opacity of filled shape
0.6 (default) | range of [0 1]

Opacity of filled shape, specified as the comma-separated pair consisting of `'Opacity'` and a scalar value in the range [0 1]. The `Opacity` property applies for the `FilledRectangle`, `FilledPolygon`, and `FilledCircle` shapes.

Data Types: `double` | `single` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

SmoothEdges — Smooth shape edges
`true` (default) | `false`

Smooth shape edges, specified as the comma-separated pair consisting of `'SmoothEdges'` and a logical value of `true` or `false`. A `true` value enables an anti-aliasing filter to smooth shape edges. This value applies only to nonrectangular shapes. Enabling anti-aliasing requires additional time to draw the shapes.

Data Types: `logical`

Output Arguments

RGB — Output image
M-by-*N*-by-3 truecolor

Output image, returned as a truecolor image.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- `'Color'` and `'SmoothEdges'` must be compile-time constants.

See Also
`insertMarker` | `insertObjectAnnotation` | `insertText`

Topics

Introduced in R2014a

insertText

Insert text in image or video

Syntax

```
RGB = insertText(I,position,text)
RGB = insertText(I,position,numericValue)
RGB = insertText( ___ ,Name,Value)
```

Description

`RGB = insertText(I,position,text)` returns a truecolor image with text character vectors inserted. The input image, `I`, can be either a truecolor or grayscale image. The text character vectors are drawn by overwriting pixel values.

`RGB = insertText(I,position,numericValue)` returns a truecolor image with numeric values inserted.

`RGB = insertText( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Insert Numbers and Text on Image

Read the image.

```
I = imread('board.tif');
```

Create texts that contain fractions.

```
text_str = cell(3,1);
conf_val = [85.212 98.76 78.342];
for ii=1:3
```

```
    text_str{ii} = ['Confidence: ' num2str(conf_val(ii),'%0.2f') '%'];
end
```

Define the positions and colors of the text boxes.

```
position = [23 373;35 185;77 107];
box_color = {'red','green','yellow'};
```
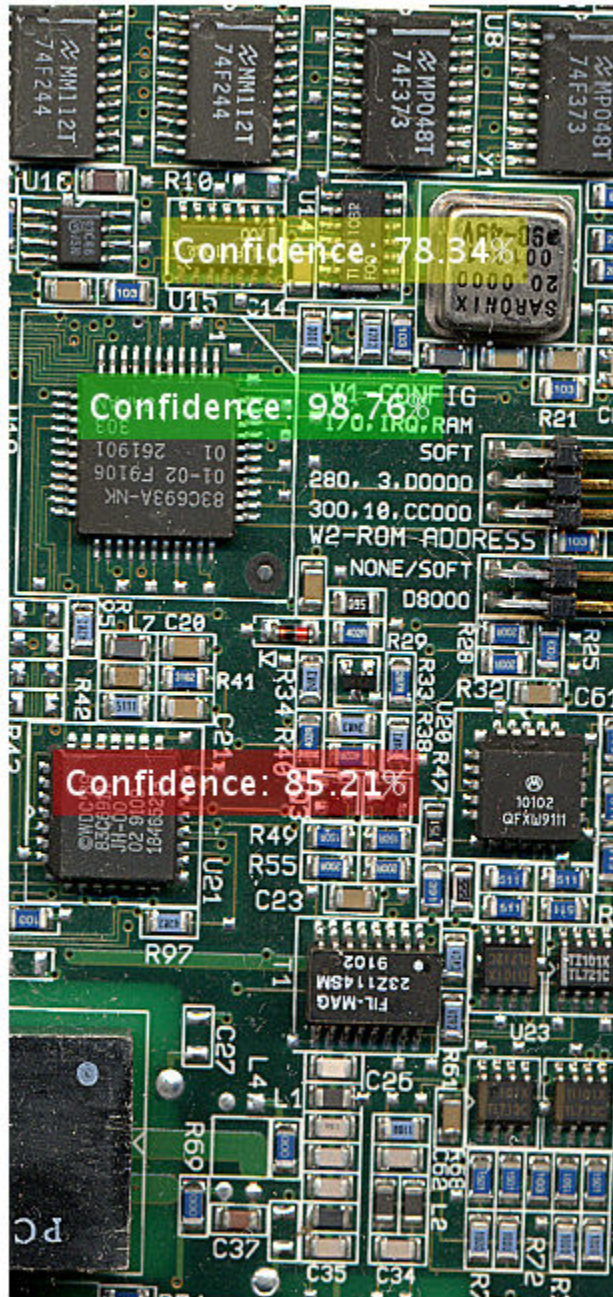
Insert the text with new font size, box color, opacity, and text color.

```
RGB = insertText(I,position,text_str,'FontSize',18,'BoxColor',...
    box_color,'BoxOpacity',0.4,'TextColor','white');
```

Display the image.

```
figure
imshow(RGB)
title('Board');
```

Board

Insert Numeric Text on Image

Read the image.

```
I = imread('peppers.png');
```

Define the (*x,_y_*) position for the text and the value.

```
position =  [1 50; 100 50];
value = [555 pi];
```

Insert text using the bottom-left as the anchor point.

```
RGB = insertText(I,position,value,'AnchorPoint','LeftBottom');
```

Display the image with the numeric text inserted.

```
figure
imshow(RGB),title('Numeric values');
```

Numeric values

Display non-ASCII character (U+014C)

```
OWithMacron=native2unicode([hex2dec('C5') hex2dec('8C')],'UTF-8');
RGB = insertText(RGB,[256 50],OWithMacron,'Font','LucidaBrightRegular','BoxColor','w');
```

Display the image with the numeric text inserted.

```
figure
imshow(RGB),title('Numeric values');
```

- "Draw Markers on an Image" on page 3-415
- "Insert Circle and Filled Shapes on an Image" on page 3-429

Input Arguments

I — Input image
M-by-*N*-by-3 truecolor | *M*-by-*N* 2-D grayscale image

Input image, specified as *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-D grayscale image.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16`

text — Unicode text character vector

text character vector | cell array of text character vectors

Unicode text, specified as a text character vector or a cell array of Unicode text character vectors. The length of the cell array must equal the number of rows in the `position` matrix. If you specify a single text character vector, that vector is used for all positions in the `position` matrix. Most unicode fonts contain ASCII characters. You can display non-English and English characters, including English numeric values, with a single font.

Data Types: `char`

numericValue — Numeric value text

scalar | vector

Numeric value text, specified as a scalar or a vector. If you specify a scalar value, that value is used for all positions. The vector length must equal the number of rows in the `position` matrix. Numeric values are converted to a character vector using the `sprintf` format `'%0.5g'`.

Data Types: `char`

position — Position of inserted text

vector | matrix

Position of inserted text, specified as a vector or an M-by-2 matrix of [x y] coordinates. Each row represents the [x y] coordinate for the `AnchorPoint` of the text bounding box.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'AnchorPoint','LeftTop'`

Font — Font face of text

`'LucidaSansRegular'` (default) | character vector

Font face of text, specified as the comma-separated pair consisting of `'Font'` and a character vector. The font face must be one of the available truetype fonts installed on

your system. To get a list of available fonts on your system, type `listTrueTypeFonts` at the MATLAB command prompt.

Data Types: `char`

FontSize — Font size
12 (default) | positive integer in the range [1,200]

Font size, specified as the comma-separated pair consisting of `'FontSize'` and a positive integer in the range [1,200].

Data Types: `double` | `single` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

TextColor — Text color
`'black'` (default) | character vector | cell array of character vectors | [R G B] vector | *M*-by-3 matrix

Text color, specified as the comma-separated pair consisting of `'TextColor'` and a character vector, cell array of character vectors, or matrix. You can specify a different color for each character vector or one color for all character vectors.

- To specify a color for each text character vector, set `TextColor` to a cell array of *M* number of color character vectors. Or, you can set it to an *M*-by-3 matrix of RGB character vector color values.
- To specify one color for all text character vectors, set `TextColor` to either a color character vector or an [R G B] vector of red, green, and blue values.
- RGB values must be in the range of the image data type. Supported colors: `'blue'`, `'green'`, `'red'`, `'cyan'`, `'magenta'`, `'yellow'`,`'black'`, and `'white'`.

Data Types: `cell` | `char` | `uint8` | `uint16` | `int16` | `double` | `single`

BoxColor — Text box color
`'yellow'` (default) | character vector | cell array of character vectors | [R G B] vector | *M*-by-3 matrix

Text box color, specified as the comma-separated pair consisting of `'BoxColor'` and a character vector, cell array of character vector, or matrix. You can specify a different color for each text box or one color for all the boxes.

- To specify a color for each text box, set `BoxColor` to a cell array of *M* number of color character vectors. Or, you can set it to an *M*-by-3 matrix of *M* number of RGB (red, green, and blue) character vector color values.

- To specify one color for all the text boxes, set `BoxColor` to either a color character vector or an [R G B] vector. The [R G B] vector contains the red, green, and blue values.

- RGB values must be in the range of the image data type. Supported colors: `'blue'`, `'green'`, `'red'`, `'cyan'`, `'magenta'`, `'yellow'`,`'black'`, and `'white'`.

Data Types: `cell` | `char` | `uint8` | `uint16` | `int16` | `double` | `single`

BoxOpacity — Opacity of text box
0.6 (default) | scalar value in the range of [0 1]

Opacity of text box, specified as the comma-separated pair consisting of `'BoxOpacity'` and a scalar value in the range [0,1]. A value of `0` corresponds to a fully transparent text box, or no box. A value of `1` corresponds to a fully opaque text box.

Data Types: `double` | `single` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

AnchorPoint — Text box reference point
`'LeftTop'` (default) | `'LeftCenter'` | `'LeftBottom'` | `'CenterTop'` | `'Center'` | `'CenterBottom'` | `'RightTop'` | `'RightCenter'` | `'RightBottom'`

Text box reference point, specified as the comma-separated pair consisting of `'AnchorPoint'` and a character vector value. The anchor point defines a relative location on the text box. You can position the text box by placing its anchor point at the [*x,y*] coordinate defined by the corresponding `position` for the text. For example, to place the center of the text box to be at the [*x,y*] coordinate you specified with the `position` input, then set `AnchorPoint` to `Center`.

Supported positions are `LeftTop`, `LeftCenter`, `LeftBottom`, `CenterTop`, `Center`, `CenterBottom`, `RightTop`, `RightCenter`, and `RightBottom`.

Data Types: `char`

Output Arguments

RGB — Output image
M-by-*N*-by-3 truecolor image

Output image, returned as an *M*-by-*N*-by-3 truecolor image with the specified text inserted.

Limitations

- If you do not see characters in the output image, it means that the font did not contain the character. Select a different font. To get a list of available fonts on your system, at the MATLAB prompt, type `listTrueTypeFonts`.

- Increasing the font size also increases the preprocessing time and memory usage.

- The `insertText` function does not work for certain composite characters. For example, you cannot insert text when the rendering of one glyph corresponding to a character code influences the position, shape, or size of the adjacent glyph.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- `Font`, `FontSize` must be compile-time constants.
- Non-ASCII characters are not supported.

See Also
insertMarker | insertObjectAnnotation | insertShape | listTrueTypeFonts

Topics
"Draw Markers on an Image" on page 3-415
"Insert Circle and Filled Shapes on an Image" on page 3-429

Introduced in R2013a

isEpipoleInImage

Determine whether image contains epipole

Syntax

```
isIn = isEpipoleInImage(F,imageSize)
isIn = isEpipoleInImage(F',imageSize)
[isIn,epipole] = isEpipoleInImage( ___ )
```

Description

`isIn = isEpipoleInImage(F,imageSize)` determines whether the first stereo image associated with the fundamental matrix `F` contains an epipole. `imageSize` is the size of the first image, and is in the format returned by the function `size`.

`isIn = isEpipoleInImage(F',imageSize)` determines whether the second stereo image associated with the fundamental matrix `F'` contains an epipole.

`[isIn,epipole] = isEpipoleInImage( ___ )` also returns the epipole.

Input Arguments

F

A 3-by-3 fundamental matrix computed from stereo images. `F` must be double or single. If P_1 represents a point in the first image I_1 that corresponds to P_2, a point in the second image I_2, then:
$[P_2,1] * F * [P_1,1]' = 0$

In computer vision, the fundamental matrix is a 3-by-3 matrix which relates corresponding points in stereo images. When two cameras view a 3-D scene from two distinct positions, there are a number of geometric relations between the 3-D points and their projections onto the 2-D images that lead to constraints between the image points. Two images of the same scene are related by epipolar geometry.
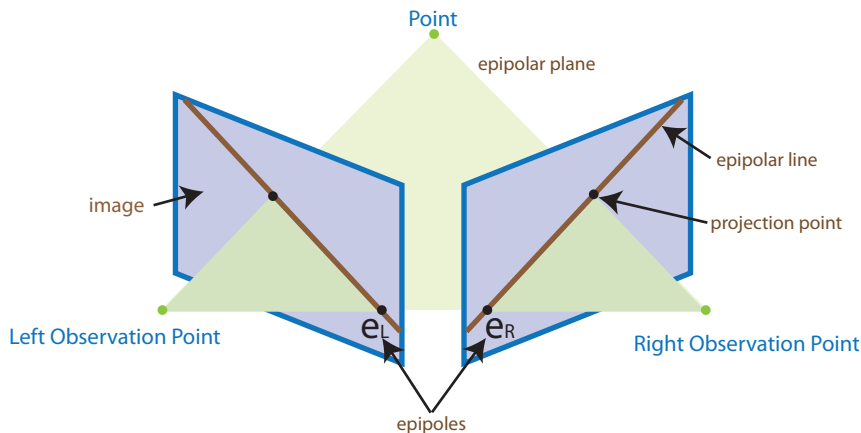
imageSize

The size of the image, and in the format returned by the function `size`.

Output Arguments

isIn

Logical value set to `true` when the image contains an epipole, and set to `false` when the image does not contain an epipole.

When the image planes are at a great enough angle to each other, you can expect the epipole to be located in the image.

When the image planes are at a more subtle angle to each other, you can expect the epipole to be located outside of the image, (but still in the image plane).
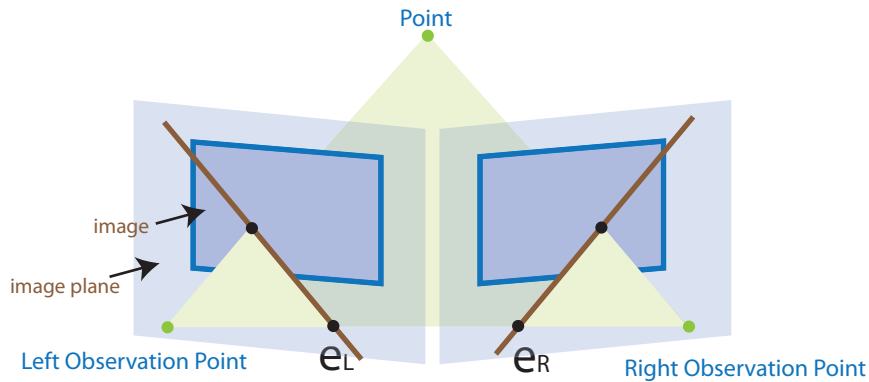
epipole

A 1-by-2 vector indicating the location of the epipole.

Examples

Determine Epipole Location in an Image

```
% Load stereo point pairs.
    load stereoPointPairs
    f = estimateFundamentalMatrix(matchedPoints1, matchedPoints2, 'NumTrials', 2000);
    imageSize = [200 300];

% Determine whether the image contains epipole and epipole location.
    [isIn,epipole] = isEpipoleInImage(f,imageSize)

isIn = logical
   1


epipole = 1×2

  256.5465  100.0140
```

Determine Whether Image Contains Epipole

```
f = [0 0 1; 0 0 0; -1 0 0];
imageSize = [200, 300];
[isIn,epipole] = isEpipoleInImage(f',imageSize)
```

```
isIn = logical
   0
```

```
epipole = 1×2
10^308 ×

          0    1.7977
```

- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
epipolarLine | estimateFundamentalMatrix |
estimateUncalibratedRectification

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

Introduced in R2011a

isfilterseparable

Determine whether filter coefficients are separable

Syntax

```
S = isfilterseparable(H)
[S, HCOL, HROW] = isfilterseparable(H)
```

Description

`S = isfilterseparable(H)` takes in the filter kernel *H* and returns `1` (true) when the filter is separable, and `0` (false) otherwise.

`[S, HCOL, HROW] = isfilterseparable(H)` uses the filter kernel, `H`, to return its vertical coefficients `HCOL` and horizontal coefficients `HROW` when the filter is separable. Otherwise, `HCOL` and `HROW` are empty.

Input Arguments

H

H numeric or logical, 2-D, and nonsparse.

Output Arguments

HCOL

HCOL is the same data type as input H when H is either single or double floating point. Otherwise, HCOL becomes double floating point. If S is true, HCOL is a vector of vertical filter coefficients. Otherwise, HCOL is empty.

HROW

HROW is the same data type as input H when H is either single or double floating point. Otherwise, HROW becomes double floating point. If S is true, HROW is a vector of horizontal filter coefficients. Otherwise, HROW is empty.

S

Logical variable that is set to `true`, when the filter is separable, and `false`, when it is not.

Examples

Determine if Gaussian Filter is Separable

Determine if the Gaussian filter created using the `fspecial` function is separable.

Create a Gaussian filter.

```
twoDimensionalFilter = fspecial('gauss');
```

Test the filter.

```
[isseparable,hcol,hrow] = isfilterseparable(twoDimensionalFilter)
```

```
isseparable = logical
   1
```

```
hcol = 3×1

   -0.1065
   -0.7870
   -0.1065
```

```
hrow = 1×3

   -0.1065   -0.7870   -0.1065
```

Definitions

Separable two dimensional filters

Separable two-dimensional filters reflect the outer product of two vectors. Separable filters help reduce the number of calculations required.

A two-dimensional convolution calculation requires a number of multiplications equal to the *width* $\times$ *height* for each output pixel. The general case equation for a two-dimensional convolution is:

$$Y(m,n) = \sum_{k} \sum_{l} H(k,l) U(m-k, n-l)$$

If the filter H is separable then,

$$H(k,l) = H_{row}(k) H_{col}(l)$$

Shifting the filter instead of the image, the two-dimensional equation becomes:

$$Y(m,n) = \sum_{k} H_{row}(k) \sum_{l} H_{col}(l) U(m-k, n-l)$$

This calculation requires only (width + height) number of multiplications for each pixel.

Algorithms

The `isfilterseparable` function uses the singular value decomposition `svd` function to determine the rank of the matrix.

See Also

2-D FIR Filter | `rank` | `svd`

External Websites

MATLAB Central — Separable Convolution

Introduced in R2006a

lineToBorderPoints

Intersection points of lines in image and image border

Syntax

```
points = lineToBorderPoints(lines,imageSize)
```

Description

`points = lineToBorderPoints(lines,imageSize)` computes the intersection points between one or more lines in an image with the image border.

Input Arguments

lines

Line matrix. An *M*-by-3 matrix, where each row must be in the format, [*A*,*B*,*C*]. This matrix corresponds to the definition of the line:
$A * x + B * y + C = 0$.
M represents the number of lines.

`lines` must be `double` or `single`.

imageSize

Image size. This input must be in the format returned by the `size` function.

`imageSize` must be `double`, `single`, or `integer`.

Output Arguments

points

Output intersection points. An *M*-by-4 matrix. The function returns the matrix in the format of [x_1, y_1, x_2, y_2]. In this matrix, [x_1 y_1] and [x_2 y_2] are the two intersection points.

When a line in the image and the image border do not intersect, the function returns `[-1,-1,-1,-1]`.

Examples

Find Intersection Points Between a Line and Image Border

Load and display an image.

```
I = imread('rice.png');
figure;
imshow(I);
hold on;
```
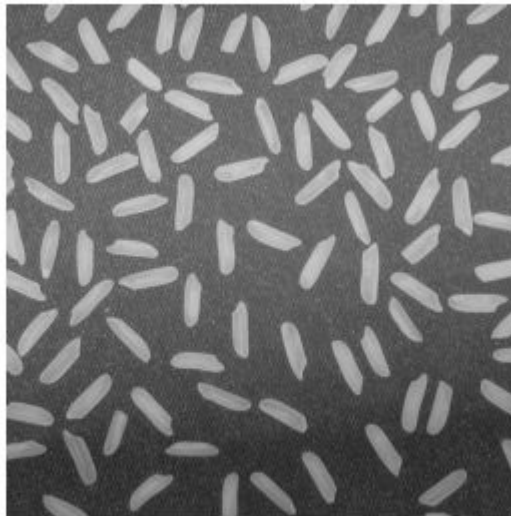

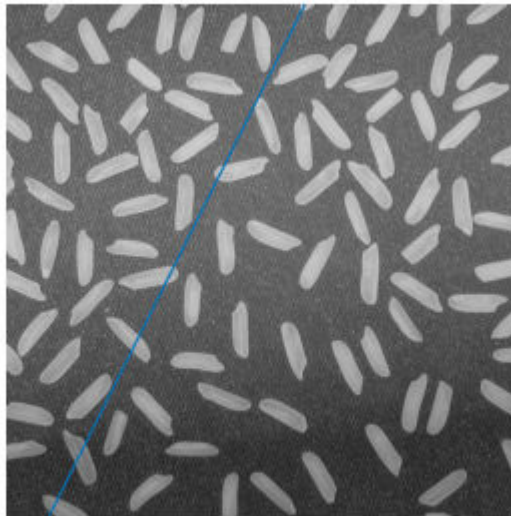Define a line with the equation, 2 * x + y - 300 = 0.

```
aLine = [2,1,-300];
```

Compute the intersection points of the line and the image border.

```
points = lineToBorderPoints(aLine,size(I))

points = 1×4

  149.7500    0.5000   21.7500  256.5000


line(points([1,3]),points([2,4]));
```


Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

epipolarLine | line | size

Introduced in R2011a

matchFeatures

Find matching features

Syntax

```
indexPairs = matchFeatures(features1,features2)
[indexPairs,matchmetric] = matchFeatures(features1,features2)
[indexPairs,matchmetric] = matchFeatures(features1,features2,
Name,Value)
```

Description

`indexPairs = matchFeatures(features1,features2)` returns indices of the matching features in the two input feature sets. The input feature must be either `binaryFeatures` objects or matrices.

`[indexPairs,matchmetric] = matchFeatures(features1,features2)` also returns the distance between the matching features, indexed by `indexPairs`.

`[indexPairs,matchmetric] = matchFeatures(features1,features2,
Name,Value)` includes additional options specified by one or more `Name,Value` pair arguments.

Examples

Find Corresponding Interest Points Between Pair of Images

Find corresponding interest points between a pair of images using local neighbhorhoods and the Harris algorithm.

Read the stereo images.

```
I1 = rgb2gray(imread('viprectification_deskLeft.png'));
I2 = rgb2gray(imread('viprectification_deskRight.png'));
```

Find the corners.

```
points1 = detectHarrisFeatures(I1);
points2 = detectHarrisFeatures(I2);
```

Extract the neighborhood features.

```
[features1,valid_points1] = extractFeatures(I1,points1);
[features2,valid_points2] = extractFeatures(I2,points2);
```
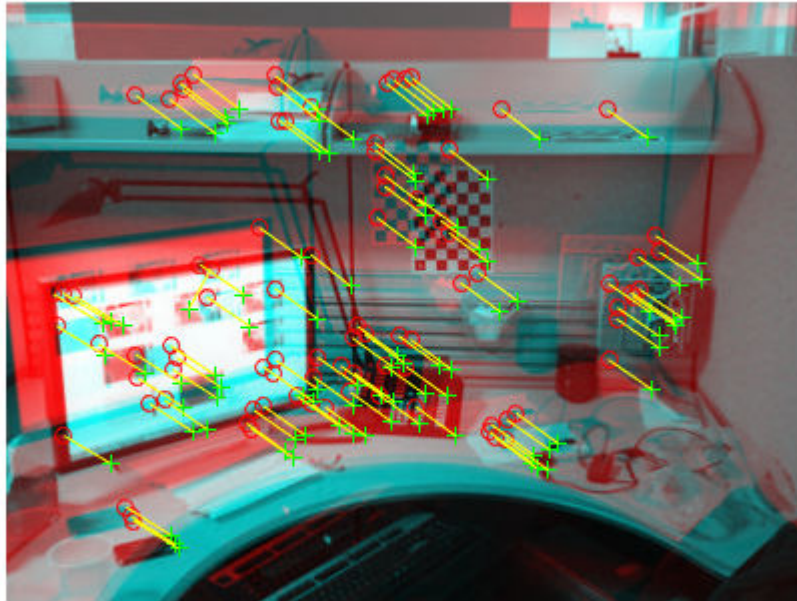
Match the features.

```
indexPairs = matchFeatures(features1,features2);
```

Retrieve the locations of the corresponding points for each image.

```
matchedPoints1 = valid_points1(indexPairs(:,1),:);
matchedPoints2 = valid_points2(indexPairs(:,2),:);
```

Visualize the corresponding points. You can see the effect of translation between the two images despite several erroneous matches.

```
figure; showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2);
```

Find Corresponding Points Using SURF Features

Use the SURF local feature detector function to find the corresponding points between two images that are rotated and scaled with respect to each other.

Read the two images.

```
I1 = imread('cameraman.tif');
I2 = imresize(imrotate(I1,-20),1.2);
```

Find the SURF features.

```
points1 = detectSURFFeatures(I1);
points2 = detectSURFFeatures(I2);
```

Extract the features.

```
[f1,vpts1] = extractFeatures(I1,points1);
[f2,vpts2] = extractFeatures(I2,points2);
```

Retrieve the locations of matched points.

```
indexPairs = matchFeatures(f1,f2) ;
matchedPoints1 = vpts1(indexPairs(:,1));
matchedPoints2 = vpts2(indexPairs(:,2));
```

Display the matching points. The data still includes several outliers, but you can see the effects of rotation and scaling on the display of matched features.

```
figure; showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2);
legend('matched points 1','matched points 2');
```

Input Arguments

features1 — Feature set 1
binaryFeatures object | M_1-by-N matrix

Features set 1, specified as a binaryFeatures object or an M_1-by-N matrix. The matrix contains M_1 features, and N corresponds to the length of each feature vector. You can

obtain the `binaryFeatures` object using the `extractFeatures` function with the fast retina keypoint (FREAK) or binary robust invariant scalable keypoints (BRISK) descriptor method.

features2 — Feature set 2
M_2-by-N matrix | `binaryFeatures` object

Features set 2, specified as a `binaryFeatures` object or an M_2-by-N matrix. The matrix contains M_2 features and N corresponds to the length of each feature vector. You can obtain the `binaryFeatures` object using the `extractFeatures` function with the fast retina keypoint (FREAK) or binary robust invariant scalable keypoints (BRISK) descriptor method.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Metric','SSD'` specifies the sum of squared differences for the feature matching metric.

Method — Matching method
`'Exhaustive'` (default) | `'Approximate'`

Matching method, specified as the comma-separated pair consisting of `'Method'` and either `'Exhaustive'` or `'Approximate'`. The method specifies how nearest neighbors between `features1` and `features2` are found. Two feature vectors match when the distance between them is less than the threshold set by the `MatchThreshold` parameter.

`'Exhaustive'`	Compute the pairwise distance between feature vectors in `features1` and `features2`.
`'Approximate'`	Use an efficient approximate nearest neighbor search. Use this method for large feature sets. [3]

MatchThreshold — Matching threshold
`10.0` or `1.0` (default) | percent value in the range (0, 100]

Matching threshold threshold, specified as the comma-separated pair consisting of `'MatchThreshold'` and a scalar percent value in the range (0,100]. The default values

are set to either `10.0` for binary feature vectors or to `1.0` for nonbinary feature vectors. You can use the match threshold for selecting the strongest matches. The threshold represents a percent of the distance from a perfect match.

Two feature vectors match when the distance between them is less than the threshold set by `MatchThreshold`. The function rejects a match when the distance between the features is greater than the value of `MatchThreshold`. Increase the value to return more matches.

Inputs that are `binaryFeatures` objects typically require a larger value for the match threshold. The `extractFeatures` function returns the `binaryFeatures` objects when extracting FREAK or BRISK descriptors.

MaxRatio — Ratio threshold
`0.6` (default) | ratio in the range (0,1]

Ratio threshold, specified as the comma-separated pair consisting of '`MaxRatio`' and a scalar ratio value in the range (0,1]. Use the max ratio for rejecting ambiguous matches. Increase this value to return more matches.

Metric — Feature matching metric
'`SSD`' (default) | '`SAD`'

Feature matching metric, specified as the comma-separated pair consisting of '`Metric`' and either '`SAD`' or '`SSD`'.

|	
'`SAD`'	Sum of absolute differences
'`SSD`'	Sum of squared differences

This property applies when the input feature sets, `features1` and `features2`, are not `binaryFeatures` objects. When you specify the features as `binaryFeatures` objects, the function uses the Hamming distance to compute the similarity metric.

Unique — Unique matches
`false` (default) | `true`

Unique matches, specified as the comma-separated pair consisting of '`Unique`' and either `false` or `true`. Set this value to `true` to return only unique matches between `features1` and `features2`.

When you set `Unique` to `false`, the function returns all matches between `features1` and `features2`. Multiple features in `features1` can match to one feature in `features2`.
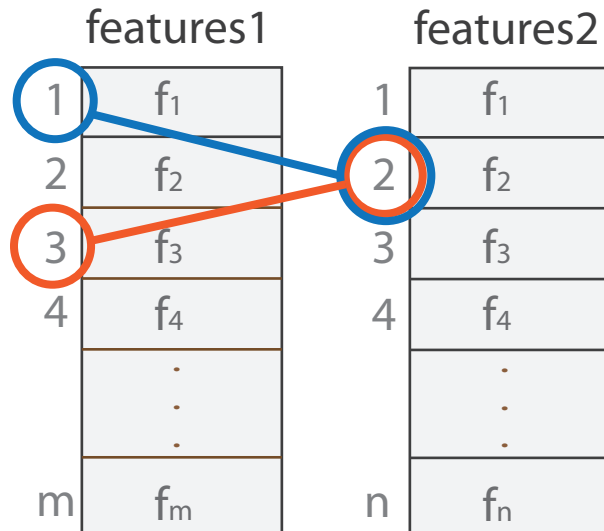
When you set `Unique` to `true`, the function performs a forward-backward match to select a unique match. After matching `features1` to `features2`, it matches `features2` to `features1` and keeps the best match.

Output Arguments

`indexPairs` — Indices to corresponding features
P-by-2 matrix

Indices of corresponding features between the two input feature sets, returned as a *P*-by-2 matrix of *P* number of indices. Each index pair corresponds to a matched feature between the `features1` and `features2` inputs. The first element indexes the feature in `features1`. The second element indexes the matching feature in `features2`.
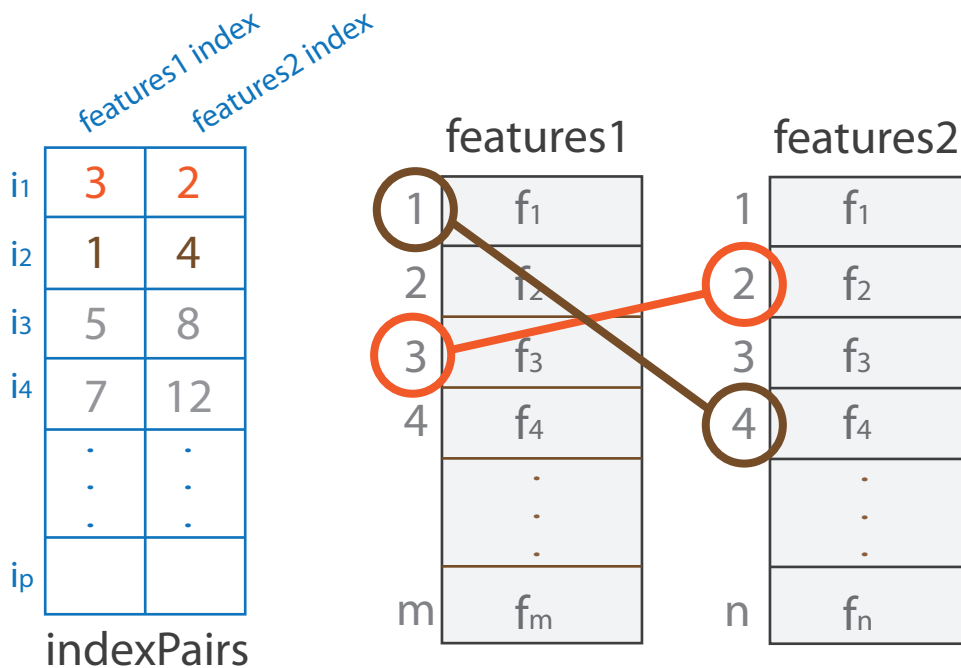
matchmetric — Distance between matching features
p-by-1 vector

Distance between matching features, returned as a *p*-by-1 vector. The value of the distances are based on the metric selected. Each *i*th element in `matchmetric` corresponds to the *i*th row in the `indexPairs` output matrix. When `Metric` is set to either `SAD` or `SSD`, the feature vectors are normalized to unit vectors before computation.

Metric	Range	Perfect Match Value
SAD	[0, 2*sqrt(size(features1, 2))].	0
SSD	[0,4]	0
Hamming	[0, features1.NumBits]	0

Note You cannot select the `Hamming` metric. It is invoked automatically when `features1` and `features2` inputs are `binaryFeatures`.

References

[1] Lowe, David G. "Distinctive Image Features from Scale-Invariant Keypoints." *International Journal of Computer Vision*. Volume 60, Number 2, pp. 91–110.

[2] Muja, M., and D. G. Lowe. "Fast Matching of Binary Features. "*Conference on Computer and Robot Vision*. CRV, 2012.

[3] Muja, M., and D. G. Lowe. "Fast Approximate Nearest Neighbors with Automatic Algorithm Configuration." *International Conference on Computer Vision Theory and Applications*.VISAPP, 2009.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Generates platform-dependent library for MATLAB host only when using the `Exhaustive` method.

- Generates portable C code for non-host target only when using the `Exhaustive` method.

- Generates portable C code using a C++ compiler that links to OpenCV (Version 3.1.0) libraries when not using the `Exhaustive` method. See "Portable C Code Generation for Functions That Use OpenCV Library".

- `'Method'` and `'Metric'` must be compile-time constants.

See Also
binaryFeatures | detectBRISKFeatures | detectFASTFeatures | detectHarrisFeatures | detectMSERFeatures | detectMinEigenFeatures | detectSURFFeatures | estimateFundamentalMatrix | estimateGeometricTransform | extractFeatures | showMatchedFeatures

Topics
"Structure from Motion"

Introduced in R2011a

mplay

View video from MATLAB workspace, multimedia file, or Simulink model.

Syntax

Description

Note The mplay function will be removed in a future release. Use the implay function with functionality identical to mplay.

Introduced in R2006a

ocr

Recognize text using optical character recognition

Syntax

```
txt = ocr(I)
txt = ocr(I, roi)

[ ___ ] = ocr( ___ ,Name,Value)
```

Description

`txt = ocr(I)` returns an `ocrText` object containing optical character recognition information from the input image, `I`. The object contains recognized text, text location, and a metric indicating the confidence of the recognition result.

`txt = ocr(I, roi)` recognizes text in `I` within one or more rectangular regions. The `roi` input contains an *M*-by-4 matrix, with *M* regions of interest.

`[ ___ ] = ocr( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

Examples

Recognize Text Within an Image

```
    businessCard   = imread('businessCard.png');
    ocrResults     = ocr(businessCard)

ocrResults =
  ocrText with properties:

                    Text: '' MathWorks®...'
    CharacterBoundingBoxes: [103x4 double]
```

```
CharacterConfidences: [103x1 single]
               Words: {16x1 cell}
   WordBoundingBoxes: [16x4 double]
      WordConfidences: [16x1 single]
```

```
recognizedText = ocrResults.Text;
figure;
imshow(businessCard);
text(600, 150, recognizedText, 'BackgroundColor', [1 1 1]);
```


Recognize Text in Regions of Interest (ROI)

Read image.

```
I = imread('handicapSign.jpg');
```

Define one or more rectangular regions of interest within I.

```
roi = [360 118 384 560];
```

You may also use IMRECT to select a region using a mouse: figure; imshow(I); roi = round(getPosition(imrect))

```
ocrResults = ocr(I, roi);
```

Insert recognized text into original image

```
Iocr = insertText(I,roi(1:2),ocrResults.Text,'AnchorPoint',...
    'RightTop','FontSize',16);
figure; imshow(Iocr);
```

Display Bounding Boxes of Words and Recognition Confidences

```
businessCard = imread('businessCard.png');
ocrResults   = ocr(businessCard)
```

```
ocrResults =
  ocrText with properties:

                     Text: '' MathWorks®...'
    CharacterBoundingBoxes: [103x4 double]
```

```
  CharacterConfidences: [103x1 single]
                Words: {16x1 cell}
    WordBoundingBoxes: [16x4 double]
       WordConfidences: [16x1 single]


Iocr            = insertObjectAnnotation(businessCard, 'rectangle', ...
                        ocrResults.WordBoundingBoxes, ...
                        ocrResults.WordConfidences);
figure; imshow(Iocr);
```
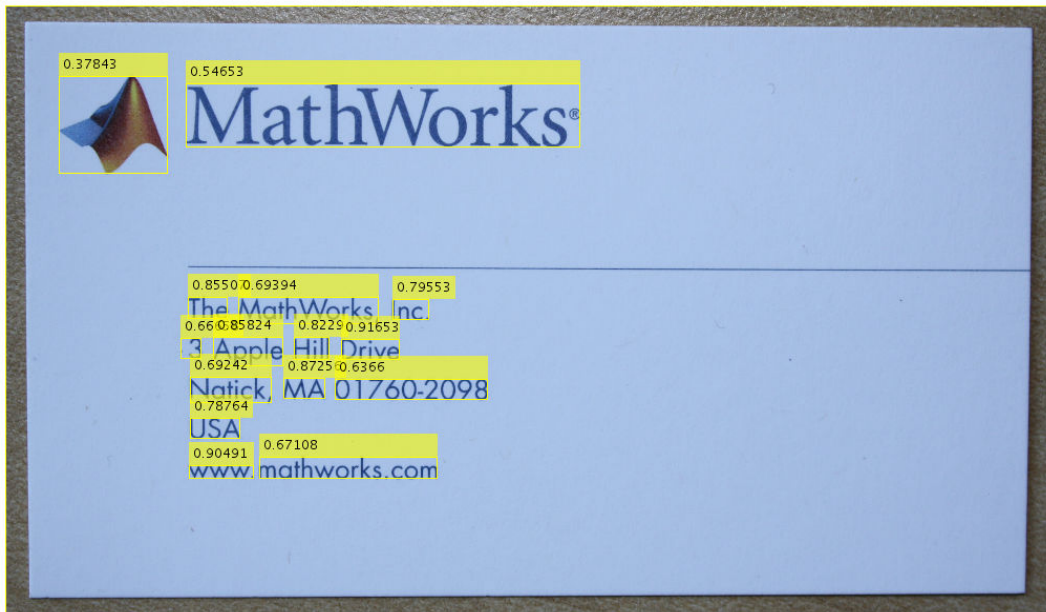

Find and Highlight Text in an Image

```
businessCard = imread('businessCard.png');
ocrResults = ocr(businessCard);
bboxes = locateText(ocrResults, 'MathWorks', 'IgnoreCase', true);
```

```
Iocr = insertShape(businessCard, 'FilledRectangle', bboxes);
figure; imshow(Iocr);
```


- "Automatically Detect and Recognize Text in Natural Images"
- "Recognize Text Using Optical Character Recognition (OCR)"

Input Arguments

I — Input image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image | *M*-by-*N* binary image

Input image, specified in *M*-by-*N*-by-3 truecolor, *M*-by-*N* 2-D grayscale, or binary format. The input image must be a real, nonsparse value. The function converts truecolor or grayscale input images to a binary image, before the recognition process. It uses the Otsu's thresholding technique for the conversion. For best ocr results, the height of a

lowercase 'x', or comparable character in the input image, must be greater than 20 pixels. From either the horizontal or vertical axes, remove any text rotations greater than +/- 10 degrees, to improve recognition results.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

roi — Region of interest
M-by-4 element matrix

One or more rectangular regions of interest, specified as an *M*-by-4 element matrix. Each row, *M*, specifies a region of interest within the input image, as a four-element vector, [*x y width height*]. The vector specifies the upper-left corner location, [*x y*], and the size of a rectangular region of interest, [*width height*], in pixels. Each rectangle must be fully contained within the input image, `I`. Before the recognition process, the function uses the Otsu's thresholding to convert truecolor and grayscale input regions of interest to binary regions. The function returns text recognized in the rectangular regions as an array of objects.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example:

TextLayout — Input text layout
`'Auto'` (default) | `'Block'` | `'Line'` | `'Word'`

Input text layout, specified as the comma-separated pair consisting of `'TextLayout'` and the character vector `'Auto'`, `'Block'`, `'Line'`, or `'Word'`.

The table lists how the function treats the text for each `TextLayout` setting.

TextLayout	Text Treatment
`'Auto'`	Determines the layout and reading order of text blocks within the input image.
`'Block'`	Treats the text in the image as a single block of text.

TextLayout	Text Treatment
`'Line'`	Treats the text in the image as a single line of text.
`'Word'`	Treats the text in the image as a single word of text.

Use the automatic layout analysis to recognize text from a scanned document that contains a specific format, such as a double column. This setting preserves the reading order in the returned text. You may get poor results if your input image contains a few regions of text or the text is located in a cluttered scene. If you get poor OCR results, try a different layout that matches the text in your image. If the text is located in a cluttered scene, try specifying an ROI around the text in your image in addition to trying a different layout.

Language — Language
`'English'` (default) | `'Japanese'` | character vector | cell array of character vectors

Language to recognize, specified as the comma-separated pair consisting of `'Language'` and the character vector `'English'`, `'Japanese'`, or a cell array of character vectors. You can also install the "Install OCR Language Data Files" package for additional languages or add a custom language. Specifying multiple languages enables simultaneous recognition of all the selected languages. However, selecting more than one language may reduce the accuracy and increase the time it takes to perform ocr.

To specify any of the additional languages which are contained in the "Install OCR Language Data Files" package, use the language character vector the same way as the built-in languages. You do not need to specify the path.

```
txt = ocr(img,'Language','Finnish');
```

List of Support Package OCR Languages

- `'Afrikaans'`
- `'Albanian'`
- `'AncientGreek'`
- `'Arabic'`
- `'Azerbaijani'`
- `'Basque'`

- 'Belarusian'
- 'Bengali'
- 'Bulgarian'
- 'Catalan'
- 'Cherokee'
- 'ChineseSimplified'
- 'ChineseTraditional'
- 'Croatian'
- 'Czech'
- 'Danish'
- 'Dutch'
- 'English'
- 'Esperanto'
- 'EsperantoAlternative'
- 'Estonian'
- 'Finnish'
- 'Frankish'
- 'French'
- 'Galician'
- 'German'
- 'Greek'
- 'Hebrew'
- 'Hindi'
- 'Hungarian'
- 'Icelandic'
- 'Indonesian'
- 'Italian'
- 'ItalianOld'
- 'Japanese'
- 'Kannada'

- `'Korean'`
- `'Latvian'`
- `'Lithuanian'`
- `'Macedonian'`
- `'Malay'`
- `'Malayalam'`
- `'Maltese'`
- `'MathEquation'`
- `'MiddleEnglish'`
- `'MiddleFrench'`
- `'Norwegian'`
- `'Polish'`
- `'Portuguese'`
- `'Romanian'`
- `'Russian'`
- `'SerbianLatin'`
- `'Slovakian'`
- `'Slovenian'`
- `'Spanish'`
- `'SpanishOld'`
- `'Swahili'`
- `'Swedish'`
- `'Tagalog'`
- `'Tamil'`
- `'Telugu'`
- `'Thai'`
- `'Turkish'`
- `'Ukrainian'`

To use your own custom languages, specify the path to the trained data file as the language character vector. You must name the file in the format,

<language>.`traineddata`. The file must be located in a folder named '`tessdata`'. For example:

```
txt = ocr(img,'Language','path/to/tessdata/eng.traineddata');
```

You can load multiple custom languages as a cell array of character vectors:

```
txt = ocr(img,'Language', ...
                {'path/to/tessdata/eng.traineddata',...
                 'path/to/tessdata/jpn.traineddata'});
```

The containing folder must always be the same for all the files specified in the cell array. In the preceding example, all of the `traineddata` files in the cell array are contained in the folder '`path/to/tessdata`'. Because the following code points to two different containing folders, it does not work.

```
txt = ocr(img,'Language', ...
                {'path/one/tessdata/eng.traineddata',...
                 'path/two/tessdata/jpn.traineddata'});
```

Some language files have a dependency on another language. For example, Hindi training depends on English. If you want to use Hindi, the English `traineddata` file must also exist in the same folder as the Hindi `traineddata` file. The `ocr` only supports `traineddata` files created using `tesseract-ocr` 3.02 or using the **OCR Trainer**.

For deployment targets generated by MATLAB Coder: Generated ocr executable and language data file folder must be colocated. The `tessdata` folder must be named `tessdata`:

- For English: `C:/path/tessdata/eng.traineddata`
- For Japanese: `C:/path/tessdata/jpn.traineddata`
- For custom data files: `C:/path/tessdata/customlang.traineddata`
- `C:/path/ocr_app.exe`

You can copy the English and Japanese trained data files from:

```
fullfile(matlabroot, 'toolbox','vision','visionutilities','tessdata');
```

CharacterSet — Character subset
'' all characters (default) | character vector

Character subset, specified as the comma-separated pair consisting of '`CharacterSet`' and a character vector. By default, `CharacterSet` is set to the empty character vector,

`''`. The empty vector sets the function to search for all characters in the language specified by the `Language` property. You can set this property to a smaller set of known characters to constrain the classification process.

The `ocr` function selects the best match from the `CharacterSet`. Using deducible knowledge about the characters in the input image helps to improve text recognition accuracy. For example, if you set `CharacterSet` to all numeric digits, `'0123456789'`, the function attempts to match each character to only digits. In this case, a non-digit character can incorrectly get recognized as a digit.

Output Arguments

`txt` — Recognized text and metrics
`ocrText` object

Recognized text and metrics, returned as an `ocrText` object. The object contains the recognized text, the location of the recognized text within the input image, and the metrics indicating the confidence of the results. The confidence values range is [0 1] and represents a percent probability. When you specify an *M*-by-4 `roi`, the function returns `ocrText` as an *M*-by-1 array of `ocrText` objects.

If your `ocr` results are not what you expect, try one or more of the following options:

• Increase the image 2-to-4 times the original size.

• If the characters in the image are too close together or their edges are touching, use morphology to thin out the characters. Using morphology to thin out the characters separates the characters.

• Use binarization to check for non-uniform lighting issues. Use the `graythresh` and `imbinarize` functions to binarize the image. If the characters are not visible in the results of the binarization, it indicates a potential non-uniform lighting issue. Try top hat, using the `imtophat` function, or other techniques that deal with removing non-uniform illumination.

• Use the region of interest `roi` option to isolate the text. Specify the `roi` manually or use text detection.

• If your image looks like a natural scene containing words, like a street scene, rather than a scanned document, try using an ROI input. Also, you can set the `TextLayout` property to `'Block'` or `'Word'`.

References

[1] R. Smith. *An Overview of the Tesseract OCR Engine*, Proceedings of the Ninth International Conference on Document Analysis and Recognition (ICDAR 2007) Vol 2 (2007), pp. 629-633.

[2] Smith, R., D. Antonova, and D. Lee. *Adapting the Tesseract Open Source OCR Engine for Multilingual OCR*. Proceedings of the International Workshop on Multilingual OCR, (2009).

[3] R. Smith. *Hybrid Page Layout Analysis via Tab-Stop Detection*. Proceedings of the 10th international conference on document analysis and recognition. 2009.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- `'TextLayout'`, `'Language'`, and `'CharacterSet'` must be compile-time constants.
- Generated code for this function uses a precompiled platform-specific shared library.

See Also
OCR Trainer | graythresh | imbinarize | imtophat | insertShape | ocrText

Topics
"Automatically Detect and Recognize Text in Natural Images"
"Recognize Text Using Optical Character Recognition (OCR)"
"Train Optical Character Recognition for Custom Fonts"
"Install OCR Language Data Files"
"Install Computer Vision System Toolbox Add-on Support Files"

Introduced in R2014a

pcdenoise

Remove noise from 3-D point cloud

Syntax

```
ptCloudOut = pcdenoise(ptCloudIn)
[ptCloudOut,inlierIndices,outlierIndices] = pcdenoise(ptCloudIn)
[ptCloudOut, ___ ] = pcdenoise( ___ Name,Value)
```

Description

`ptCloudOut = pcdenoise(ptCloudIn)` returns a filtered point cloud that removes outliers.

`[ptCloudOut,inlierIndices,outlierIndices] = pcdenoise(ptCloudIn)` additionally returns the linear indices to the points that are identified as inliers and outliers.

`[ptCloudOut, ___ ] = pcdenoise( ___ Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

Examples

Remove Outliers from Noisy Point Cloud

Create a plane point cloud.

```
gv = 0:0.01:1;
[X,Y] = meshgrid(gv,gv);
ptCloud = pointCloud([X(:),Y(:),0.5*ones(numel(X),1)]);

figure
pcshow(ptCloud);
title('Original Data');
```

Original Data
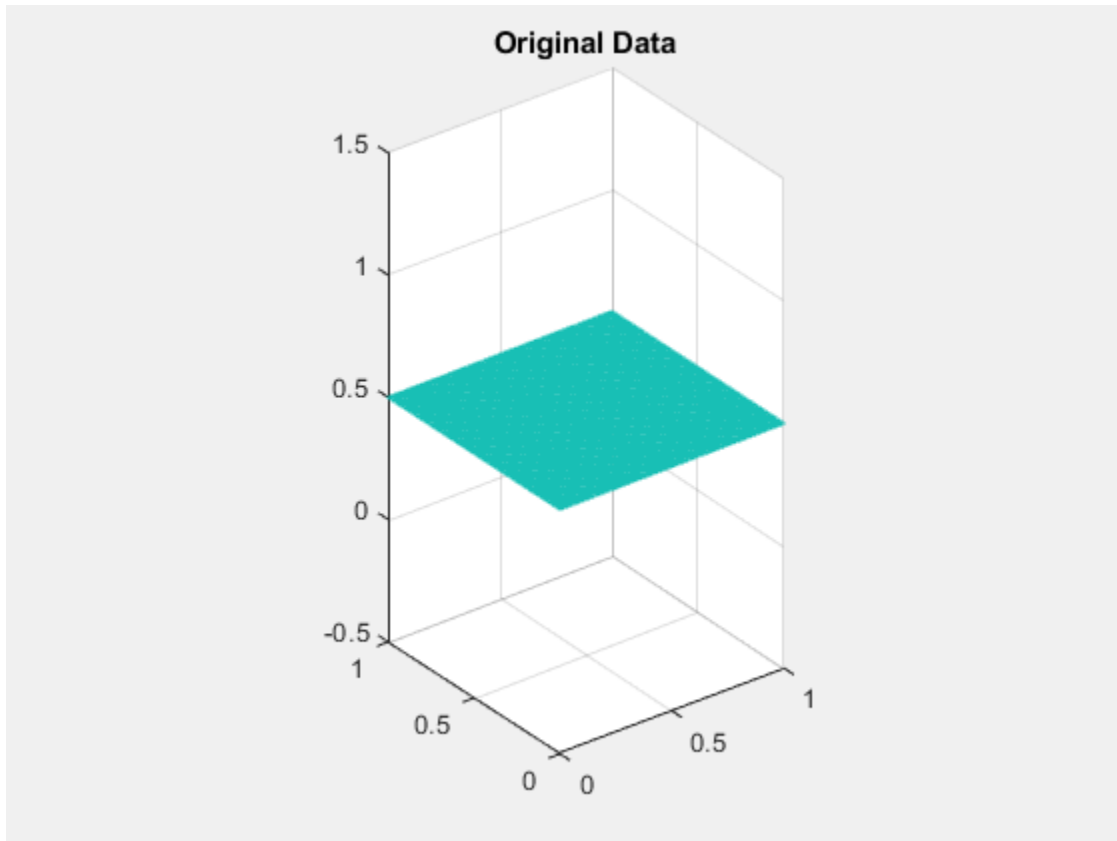
Add uniformly distributed random noise.

```
noise = rand(500, 3);
ptCloudA = pointCloud([ptCloud.Location; noise]);

figure
pcshow(ptCloudA);
title('Noisy Data');
```
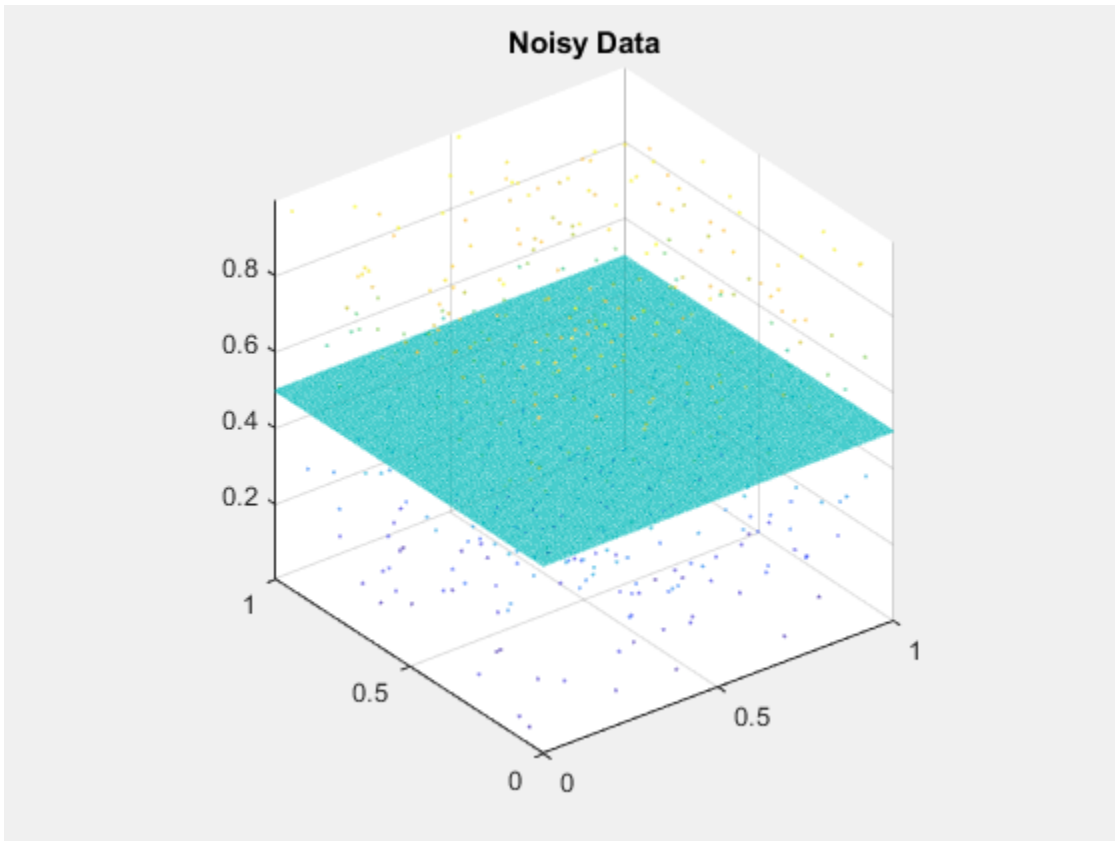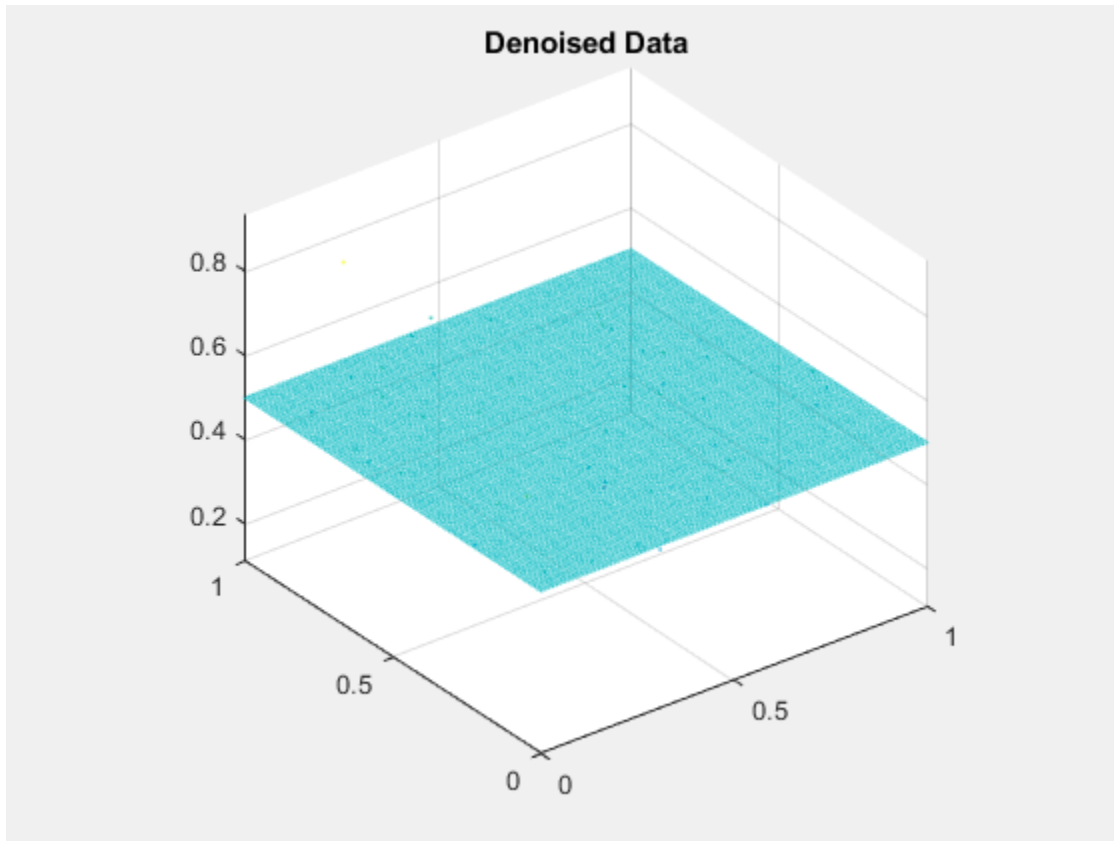
Remove outliers.

```
ptCloudB = pcdenoise(ptCloudA);

figure;
pcshow(ptCloudB);
title('Denoised Data');
```

Denoised Data

•   "3-D Point Cloud Registration and Stitching"

Input Arguments

ptCloudIn — Point cloud
pointCloud object

Point cloud, specified as a pointCloud object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Threshold','1.0'` sets the threshold to `1.0`.

NumNeighbors — Number of nearest neighbor points
4 (default) | positive integer

Number of nearest neighbor points, specified as the comma-separated pair consisting of `'NumNeighbors'` and a positive integer in pixels. The value is used to estimate the mean of the average distance to neighbors of all points. Decreasing this value makes the filter more sensitive to noise. Increasing this value increases the number of computations.

Threshold — Outlier threshold
1.0 (default) | scalar

Outlier threshold, specified as the comma-separated pair consisting of `'Threshold'` and a scalar. By default, the threshold is one standard deviation from the mean of the average distance to neighbors of all points. A point is considered to be an outlier if the average distance to its *k*-nearest neighbors is above the specified threshold.

Output Arguments

ptCloudOut — Filtered point cloud
`pointCloud` object

Filtered point cloud, returned as a `pointCloud` object.

inlierIndices — Linear index of inlier points
1-by-*N* vector

Linear index of inlier points, returned as a 1-by-*N* vector.

Data Types: `uint32`

outlierIndices — Linear index of outlier points
1-by-*N* vector

Linear index of outlier points, returned as a 1-by-*N* vector of linear indices.

Data Types: `uint32`

References

[1] Rusu, R. B., Z. C. Marton, N. Blodow, M. Dolha, and M. Beetz. "Towards 3D Point Cloud Based Object Maps for Household Environments". *Robotics and Autonomous Systems Journal*. 2008.

See Also

affine3d | pcdownsample | pcfitplane | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics

"3-D Point Cloud Registration and Stitching"

Introduced in R2015a

pcmerge

Merge two 3-D point clouds

Syntax

```
ptCloudOut = pcmerge(ptCloudA,ptCloudB,gridStep)
```

Description

ptCloudOut = pcmerge(ptCloudA,ptCloudB,gridStep) returns a merged point cloud using a box grid filter. gridStep specifies the size of the 3-D box for the filter.

Examples
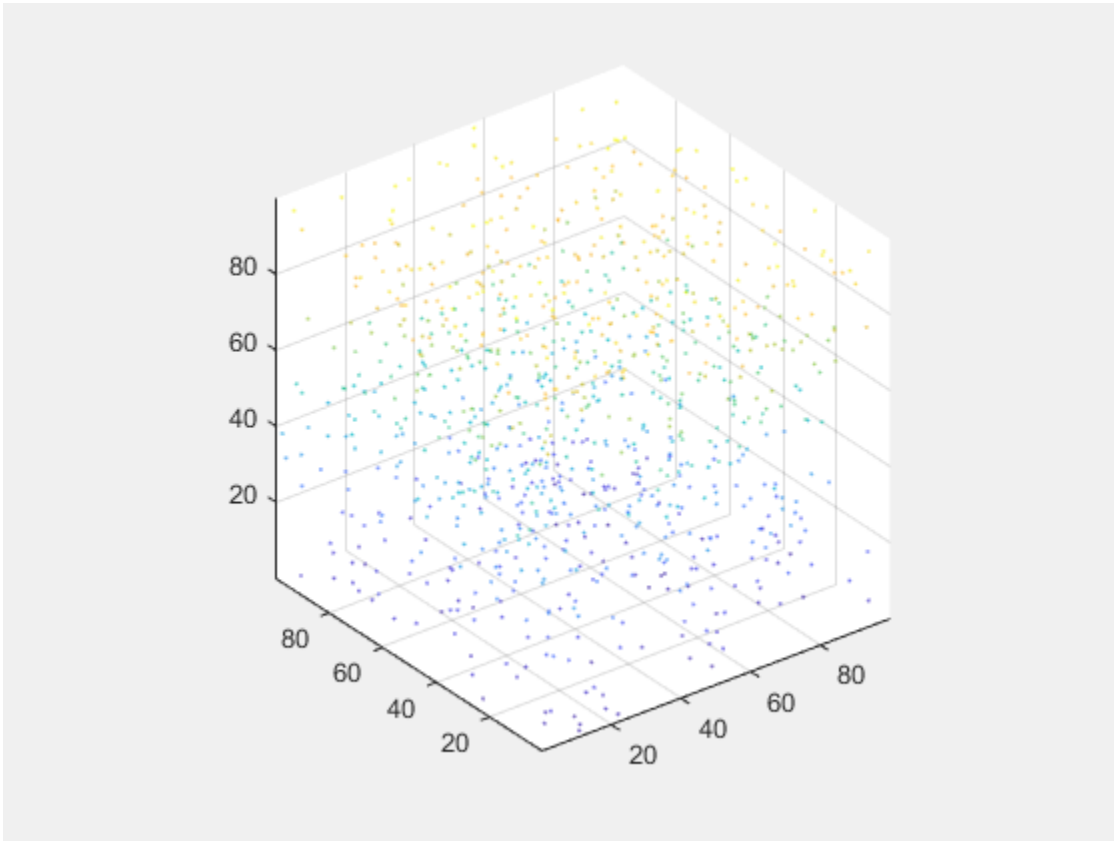
Merge Two Identical Point Clouds Using Box Grid Filter

Create two identical point clouds.

```
ptCloudA = pointCloud(100*rand(1000,3));
ptCloudB = copy(ptCloudA);
```

Merge the two point clouds.

```
ptCloud = pcmerge(ptCloudA,ptCloudB,1);
pcshow(ptCloud);
```

- "3-D Point Cloud Registration and Stitching"

Input Arguments

ptCloudA — Point cloud A
pointCloud object

Point cloud A, specified as a pointCloud object.

ptCloudB — Point cloud B
pointCloud object

Point cloud B, specified as a `pointCloud` object.

gridStep — Size of 3-D box for grid filter
numeric value

Size of 3-D box for grid filter, specified as a numeric value. Increase the size of `gridStep` when there are not enough resources to construct a large fine-grained grid.

Data Types: `single` | `double`

Output Arguments

`ptCloudOut` — Merged point cloud
`pointCloud` object

Merged point cloud, returned as a `pointCloud` object. The function computes the axis-aligned bounding box for the overlapped region between two point clouds. The bounding box is divided into grid boxes of the size specified by `gridStep`. Points within each grid box are merged by averaging their locations, colors, and normals. Points outside the overlapped region are untouched.

See Also

`pcdenoise` | `pcdownsample` | `pcfitplane` | `pcplayer` | `pcread` | `pcregistericp` | `pcshow` | `pctransform` | `pcwrite` | `planeModel` | `pointCloud`

Topics
"3-D Point Cloud Registration and Stitching"

Introduced in R2015a

pcdownsample

Downsample a 3-D point cloud

Syntax

```
ptCloudOut = pcdownsample(ptCloudIn,'random',percentage)
ptCloudOut = pcdownsample(ptCloudIn,'gridAverage',gridStep)
ptCloudOut = pcdownsample(ptCloudIn,'nonuniformGridSample',
maxNumPoints)
```

Description

ptCloudOut = pcdownsample(ptCloudIn,'random',percentage) returns a downsampled point cloud with random sampling and without replacement. The percentage input specifies the portion of the input to return to the output.

ptCloudOut = pcdownsample(ptCloudIn,'gridAverage',gridStep) returns a downsampled point cloud using a box grid filter. The gridStep input specifies the size of a 3-D box.

ptCloudOut = pcdownsample(ptCloudIn,'nonuniformGridSample', maxNumPoints) returns a downsampled point cloud using nonuniform box grid filter. You must set the maximum number of points in the grid box, maxNumPoints, to at least 6.

Examples

Downsample Point Cloud Using Box Grid Filter

Read a point cloud.
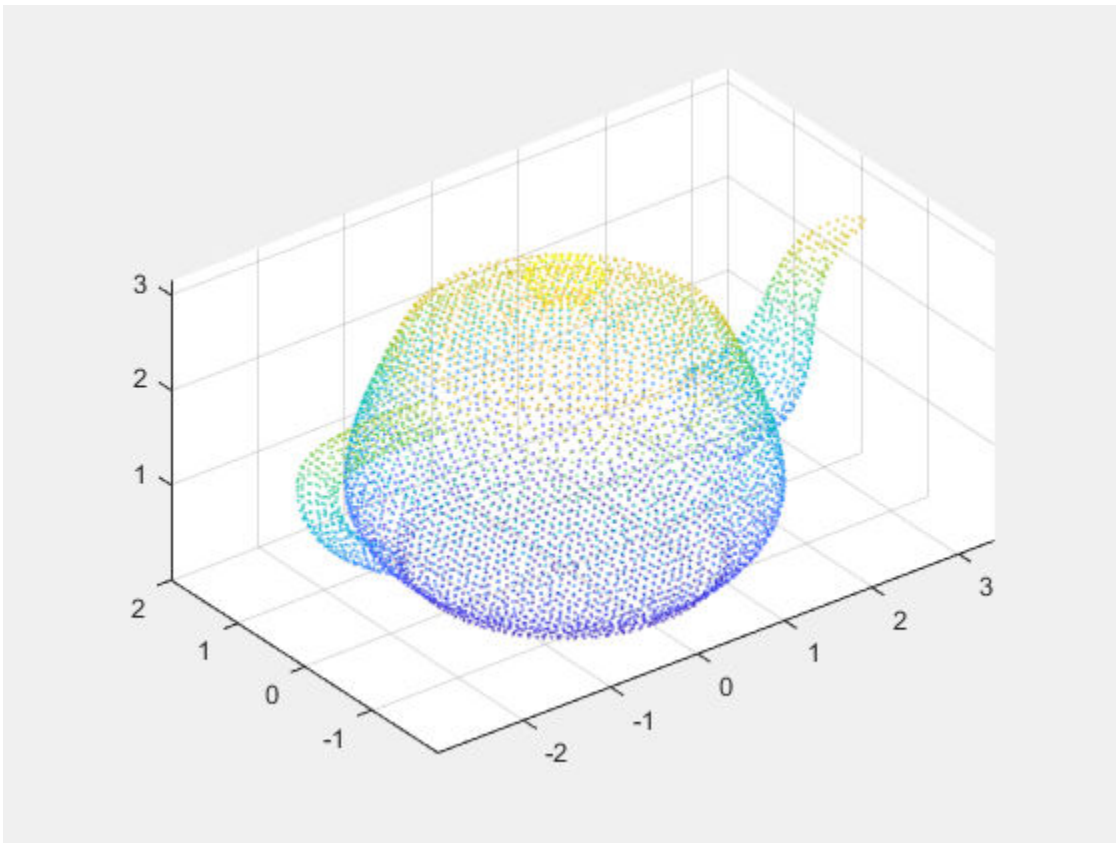
```
ptCloud = pcread('teapot.ply');
```

Set the 3-D resolution to be (0.1 x 0.1 x 0.1).

```
gridStep = 0.1;
ptCloudA = pcdownsample(ptCloud,'gridAverage',gridStep);
```
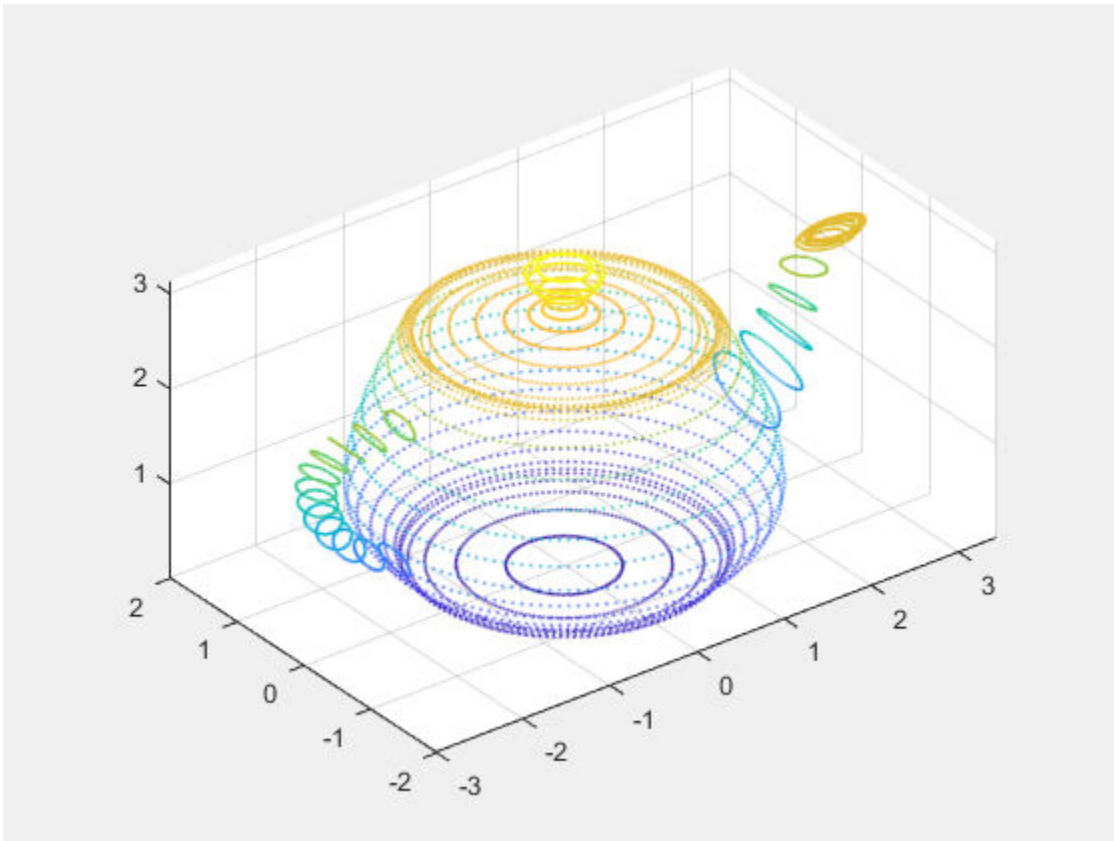
Visualize the downsampled data.

```
figure;
pcshow(ptCloudA);
```


Compare the point cloud to data that is downsampled using a fixed step size.

```
stepSize = floor(ptCloud.Count/ptCloudA.Count);
indices = 1:stepSize:ptCloud.Count;
ptCloudB = select(ptCloud, indices);
```

```
figure;
pcshow(ptCloudB);
```


Remove Redundant Points from Point Cloud

Create a point cloud with all points sharing the same coordinates.

```
ptCloud = pointCloud(ones(100,3));
```

Set the 3-D resolution to a small value.

```
gridStep = 0.01;
```

The output now contains only one unique point.

```
ptCloudOut = pcdownsample(ptCloud,'gridAverage',gridStep)

ptCloudOut =
  pointCloud with properties:

     Location: [1 1 1]
        Color: [0x3 uint8]
       Normal: [0x3 double]
    Intensity: []
        Count: 1
       XLimits: [1 1]
       YLimits: [1 1]
       ZLimits: [1 1]
```

- "3-D Point Cloud Registration and Stitching"

Input Arguments

ptCloudIn — Point cloud
pointCloud object

Point cloud, specified as a pointCloud object.

'random' — Random downsample method
'random'

Random downsample method, specified as the character vector, 'random'. This method is more efficient than the 'gridAverage' downsample method, especially when it is applied before point cloud registration.

Downsample the point cloud using 'random', 'gridAverage', or 'nonuniformGridSample' inputs, according to the Metric you use in the pcregistericp function for registration.

Metric	Point Cloud A Downsample Method	Point Cloud B Downsample Method
'pointToPoint'	'random'	'random'

Metric	Point Cloud A Downsample Method	Point Cloud B Downsample Method
	`'gridAverage'`	`'gridAverage'`
`'pointToPlane'`	`'gridAverage'`	`'gridAverage'`
	`'random'`	`'nonuniformGridSample'`

percentage — Percentage of input
positive scalar

Percentage of input, specified as a positive scalar in the range [0, 1]. The `percentage` input specifies the portion of the input for the function to return.

`'gridAverage'` — Grid average downsample method
`'gridAverage'`

Grid average downsample method, specified as the character vector, `'gridAverage'`. Points within the same box are merged to a single point in the output. Their color and normal properties are averaged accordingly. This method preserves the shape of the point cloud better than the `'random'` downsample method.

The function computes the axis-aligned bounding box for the entire point cloud. The bounding box is divided into grid boxes of size specified by `gridStep`. Points within each grid box are merged by averaging their locations, colors, and normals.

Downsample the point cloud using `'random'`, `'gridAverage'`, or `'nonuniformGridSample'` inputs, according to the `Metric` you use in the `pcregistericp` function for registration.

Metric	Point Cloud A Downsample Method	Point Cloud B Downsample Method
`'pointToPoint'`	`'random'`	`'random'`
	`'gridAverage'`	`'gridAverage'`
`'pointToPlane'`	`'gridAverage'`	`'gridAverage'`
	`'random'`	`'nonuniformGridSample'`

gridStep — Size of 3-D box for grid filter
numeric value

Size of 3-D box for grid filter, specified as a numeric value. Increase the size of `gridStep` when there are not enough resources to construct a large fine-grained grid.

Data Types: `single` | `double`

`'nonuniformGridSample'` — Nonuniform grid sample method
`'nonuniformGridSample'`

Nonuniform grid sample method, specified as the character vector `'nonuniformGridSample'`. The best use of this method is to apply it as a preprocessing step to the `pcregistericp` function for point cloud registration, when you use the `'pointToPlane'` metric. When you use the `'nonuniformGridSample'` algorithm, the normals are computed on the original data prior to downsampling. The downsampled output preserves more accurate normals.

Downsample the point cloud using `'random'`, `'gridAverage'`, or `'nonuniformGridSample'` inputs, according to the `Metric` you use in the `pcregistericp` function for registration.

Metric	Point Cloud A Downsample Method	Point Cloud B Downsample Method
`'pointToPoint'`	`'random'`	`'random'`
	`'gridAverage'`	`'gridAverage'`
`'pointToPlane'`	`'gridAverage'`	`'gridAverage'`
	`'random'`	`'nonuniformGridSample'`

`maxNumPoints` — Maximum number of points in grid box
integer

Maximum number of points in grid box, specified as an integer greater than 6. The method randomly selects a single point from each box. If the normal was not provided in the input point cloud, this method automatically fills in the normal property in the `ptCloudOut` output.

Output Arguments

`ptCloudOut` — Filtered point cloud
`pointCloud` object

Filtered point cloud, returned as a `pointCloud` object.

References

[1] Pomerleau, F., F. Colas, R. Siegwart, and S. Magnenat. "Comparing ICP variants on real-world data sets." *Autonomous Robots*. Vol. 34, Issue 3, April 2013, pp. 133–148.

See Also

affine3d | pcdenoise | pcfitplane | pcmerge | pcplayer | pcread | pcregistericp | pcregisterndt | pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics

"3-D Point Cloud Registration and Stitching"

Introduced in R2015a

pcread

Read 3-D point cloud from PLY or PCD file

Syntax
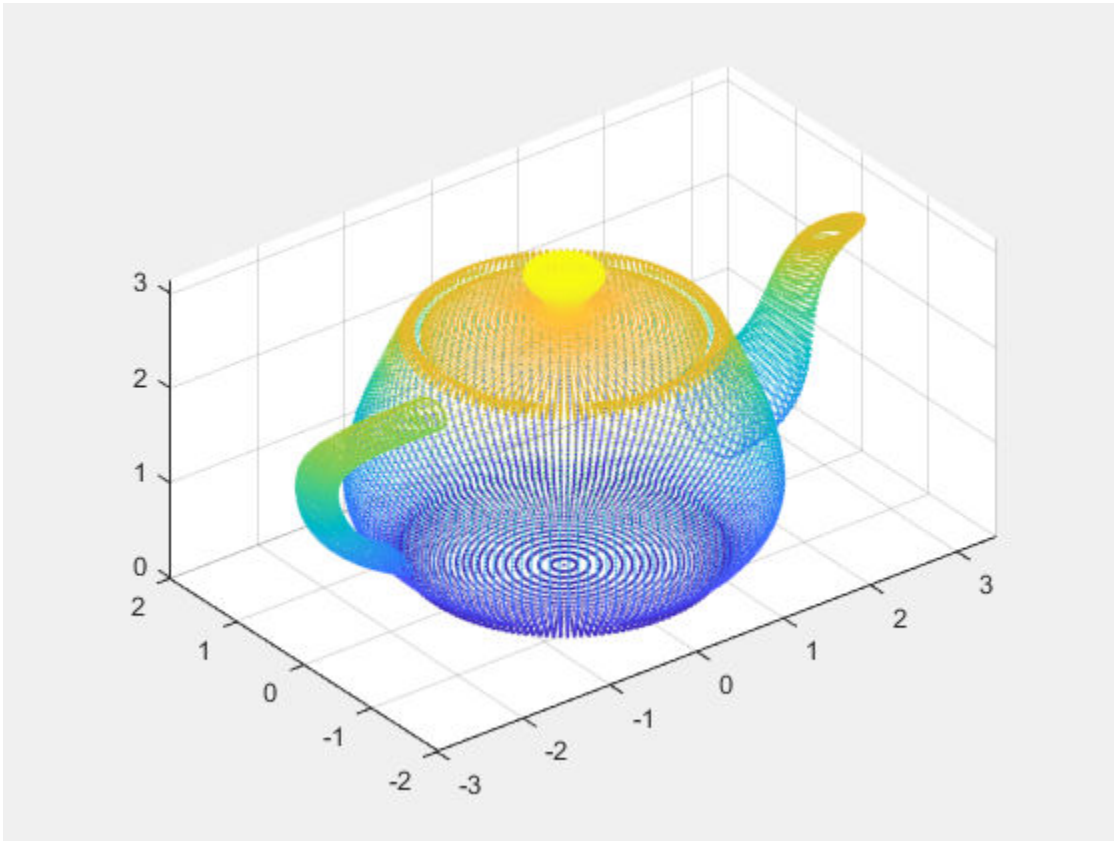
```
ptCloud = pcread(filename)
```

Description

`ptCloud = pcread(filename)` reads a point cloud from the PLY or PCD file specified by the input `filename` character vector. The function returns a `pointCloud` object, `ptCloud`.

Examples

Read Point Cloud from a PLY File

```
ptCloud = pcread('teapot.ply');
pcshow(ptCloud);
```

- "3-D Point Cloud Registration and Stitching"

Input Arguments

filename — File name
character vector

File name, specified as a character vector. The input file type must be a PLY or a PCD format file.

The polygon (PLY) file format , also known as the Stanford triangle format stores three-dimensional data from 3-D scanners. It is a format for storing graphical objects that are

described as a collection of polygons. A PLY file consists of a header, followed by a list of vertices and then, a list of polygons. The header specifies how many vertices and polygons are in the file. It also states what properties are associated with each vertex, such as (*x*,*y*,*z*) coordinates, normals, and color. The file format has two sub-formats: an ASCII representation and a binary version for compact storage and for rapid saving and loading. The header of both ASCII and binary files is ASCII text. Only the numeric data that follows the header is different between the two versions. See "The PLY Format" for details on the contents of a PLY file.

The point cloud data (PCD) file format also stores three-dimensional data. It was created by the authors of the widely used point cloud library (PCL) to accommodate additional point cloud data requirements. See The PCD (Point Cloud Data) file format.

Note This function only supports PCD file formats saved in version 0.7 (PCD_V7). It also only supports the header entries with the `COUNT` entry set to 1. It does not support the `COUNT` entry set to a feature descriptor.

Output Arguments

`ptCloud` — Object for storing point cloud
`pointCloud` object

Object for storing point cloud, returned as a `pointCloud` object that contains the following PLY or PCD fields:

- `Location` property, stores the *x*, *y*, and *z* values.
- `Color` property, stores the red, green, and blue values.
- `Normal` property, stores the normal vectors for each point.
- `Intensity` property, stores the grayscale intensity for each point.

See Also
pcdenoise | pcdownsample | pcfitplane | pcmerge | pcplayer | pcregistericp | pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics
"3-D Point Cloud Registration and Stitching"

"The PLY Format"

External Websites
The PCD (Point Cloud Data) file format

Introduced in R2015a

pcregistericp

Register two point clouds using ICP algorithm

Syntax

```
tform = pcregistericp(moving,fixed)
[tform,movingReg] = pcregistericp(moving,fixed)
[ ___ ,rmse] = pcregistericp(moving,fixed)
[ ___ ] = pcregistericp(moving,fixed,Name,Value)
```

Description

`tform = pcregistericp(moving,fixed)` returns a rigid transformation that registers a moving point cloud to a fixed point cloud.

The registration algorithm is based on the "iterative closest point" (ICP) algorithm. Best performance of this iterative process requires adjusting properties for your data. Consider downsampling point clouds using `pcdownsample` before using `pcregistericp` to improve accuracy and efficiency of registration.

Point cloud normals are required by the registration algorithm when you select the `'pointToPlane'` metric. Therefore, if the input point cloud's `Normal` property is empty, the function fills it. When the function fills the `Normal` property, it uses 6 points to fit the local plane. Six points may not work under all circumstances. If registration with the `'pointToPlane'` metric fails, consider calling the `pcnormals` function which allows you to select the number of points to use.

`[tform,movingReg] = pcregistericp(moving,fixed)` additionally returns the transformed point cloud that aligns with the fixed point cloud.

`[ ___ ,rmse] = pcregistericp(moving,fixed)` additionally returns the root mean squared error of the Euclidean distance between the aligned point clouds, using any of the preceding syntaxes.
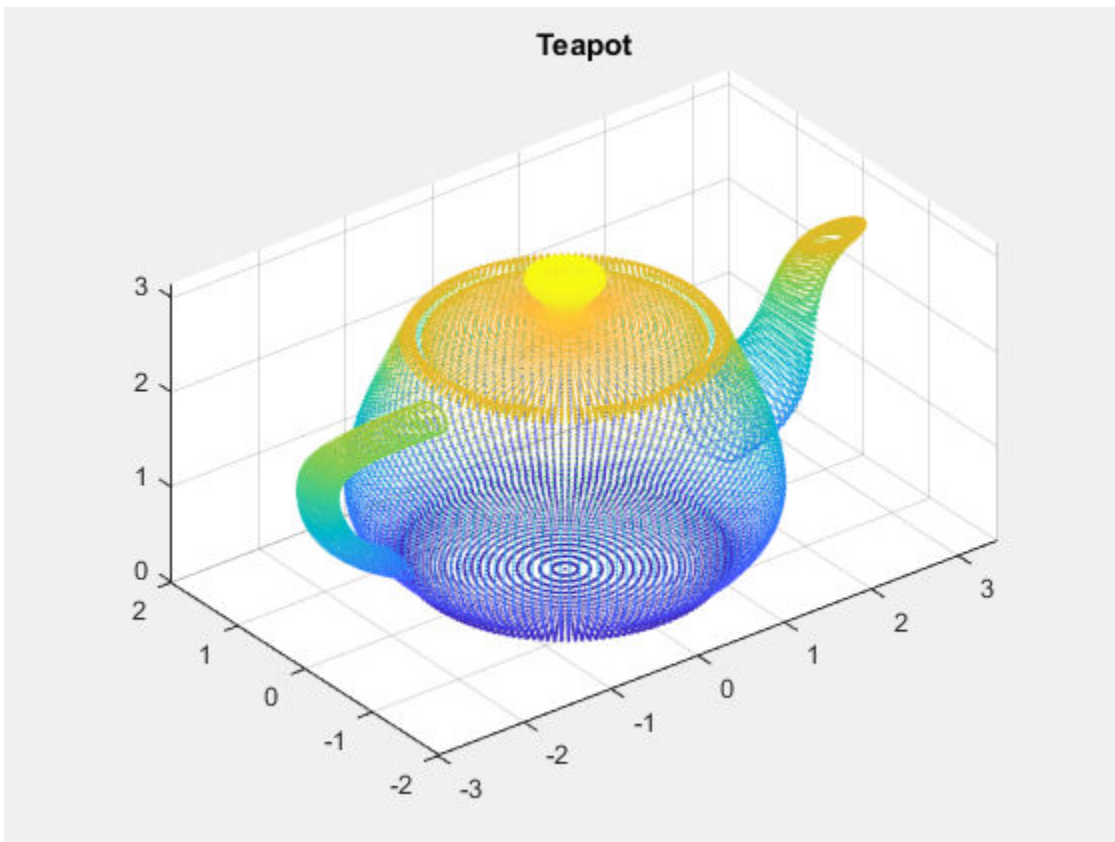
`[ ___ ] = pcregistericp(moving,fixed,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Align Two Point Clouds Using ICP Algorithm

Load point cloud data.

```
ptCloud = pcread('teapot.ply');
```

```
pcshow(ptCloud);
title('Teapot');
```
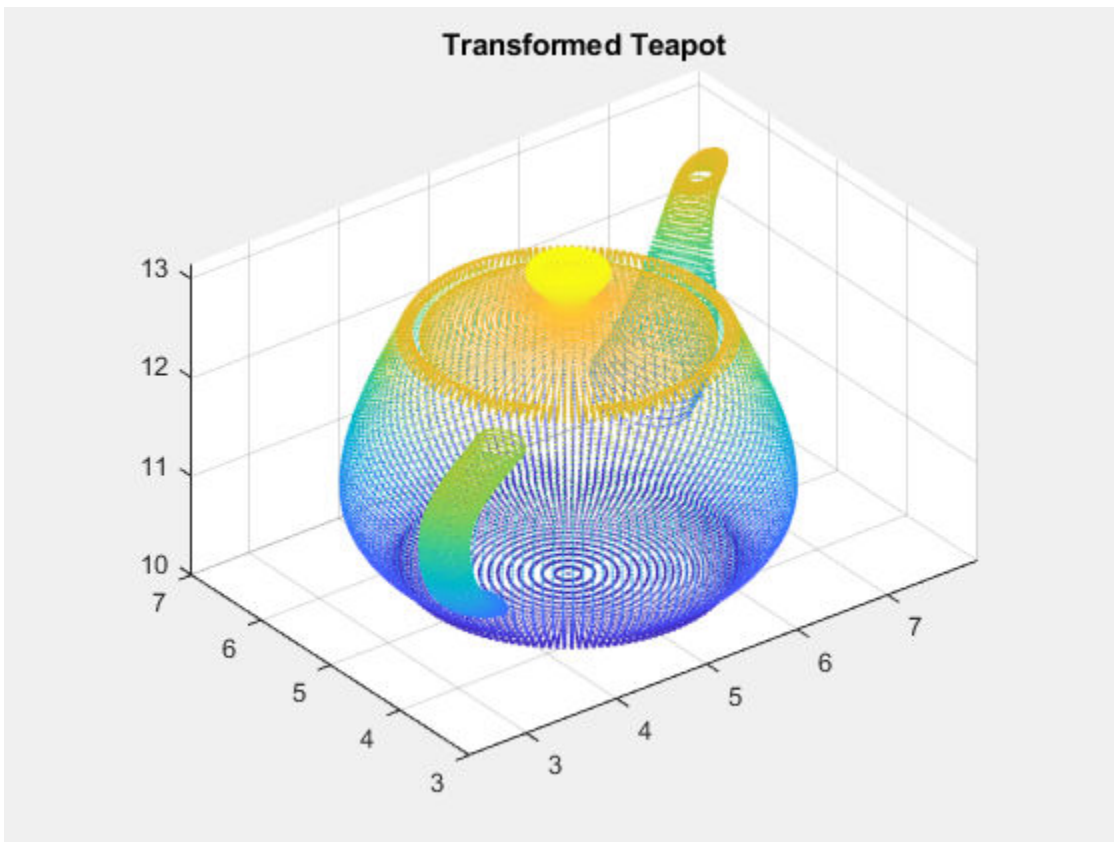

Teapot

Create a transform object with 30 degree rotation along z -axis and translation [5,5,10].

```
A = [cos(pi/6) sin(pi/6) 0 0; ...
    -sin(pi/6) cos(pi/6) 0 0; ...
            0          0 1 0; ...
            5          5 10 1];
tform1 = affine3d(A);
```

Transform the point cloud.

```
ptCloudTformed = pctransform(ptCloud,tform1);
```

```
pcshow(ptCloudTformed);
title('Transformed Teapot');
```


Apply the rigid registration.

```
tform = pcregistericp(ptCloudTformed,ptCloud,'Extrapolate',true);
```

Compare the result with the true transformation.

```
disp(tform1.T);
```

```
    0.8660    0.5000         0         0
   -0.5000    0.8660         0         0
         0         0    1.0000         0
    5.0000    5.0000   10.0000    1.0000
```

```
tform2 = invert(tform);
disp(tform2.T);
```

```
    0.8660    0.5000    0.0000         0
   -0.5000    0.8660    0.0000         0
    0.0000   -0.0000    1.0000         0
    5.0000    5.0000   10.0000    1.0000
```

- "3-D Point Cloud Registration and Stitching"

Input Arguments

moving — Moving point cloud
pointCloud object

Moving point cloud, specified as a `pointCloud` object.

fixed — Fixed point cloud
pointCloud object

Fixed point cloud, specified as a `pointCloud` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Metric','pointToPoint'` sets the metric for the ICP algorithm to the `'pointToPoint'` character vector.

Metric — Minimization metric
'pointToPoint' (default) | 'pointToPlane'

Minimization metric, specified as the comma-separated pair consisting of 'Metric' and the 'pointToPoint' or 'pointToPlane' character vector. The rigid transformation between the moving and fixed point clouds are estimated by the iterative closest point (ICP) algorithm. The ICP algorithm minimizes the distance between the two point clouds according to the given metric.

Setting 'Metric' to 'pointToPlane' can reduce the number of iterations to process. However, this metric requires extra algorithmic steps within each iteration. The 'pointToPlane' metric improves the registration of planar surfaces.

Downsample Method Selection:
Downsample the point clouds using the pcdownsample function. Use either the 'random' or 'gridAverage' input for the pcdownsample function according to the Metric table below.

Metric	Point Cloud A Downsample Method	Point Cloud B Downsample Method
'pointToPoint'	'random'	'random'
	'gridAverage'	'gridAverage'
'pointToPlane'	'gridAverage'	'gridAverage'
	'random'	'nonuniformGridSample'

Extrapolate — Extrapolation
false (default) | true

Extrapolation, specified as the comma-separated pair consisting of 'Extrapolate' and the boolean true or false. When you set this property to true, the function adds an extrapolation step that traces out a path in the registration state space, that is described in [2]. Setting this property to true can reduce the number of iterations to converge.

InlierRatio — Percentage of inliers
1 (default) | scalar

Percentage of inliers, specified as the comma-separated pair consisting of 'InlierRatio' and a scalar value. Use this value to set a percentage of matched pairs as inliers. A pair of matched points is considered an inlier if its Euclidean distance falls within the percentage set of matching distances. By default, all matching pairs are used.

MaxIterations — Maximum number of iterations
20 (default) | positive integer

Maximum number of iterations, specified as the comma-separated pair consisting of 'MaxIterations' and a positive integer. This value specifies the maximum number of iterations before ICP stops.

Tolerance — Tolerance between consecutive ICP iterations
[0.01, 0.05] (default) | 2-element vector

Tolerance between consecutive ICP iterations, specified as the comma-separated pair consisting of 'Tolerance' and a 2-element vector. The 2-element vector, [*Tdiff*, *Rdiff*], represents the tolerance of absolute difference in translation and rotation estimated in consecutive ICP iterations. *Tdiff* measures the Euclidean distance between two translation vectors. *Rdiff* measures the angular difference in degrees. The algorithm stops when the average difference between estimated rigid transformations in the three most recent consecutive iterations falls below the specified tolerance value.

InitialTransform — Initial rigid transformation
affine3d() object (default)

Initial rigid transformation, specified as the comma-separated pair consisting of 'InitialTransform' and an affine3d object. The initial rigid transformation is useful when you provide an external coarse estimation.

Verbose — Display progress information
true (default) | false

Display progress information, specified as the comma-separated pair consisting of 'Verbose' and a logical scalar. Set Verbose to true to display progress information.

Output Arguments

tform — Rigid transformation
affine3d object

Rigid transformation, returned as an affine3d object. The rigid transformation registers a moving point cloud to a fixed point cloud. The affine3d object describes the rigid 3-D transform. The iterative closest point (ICP) algorithm estimates the rigid transformation between the moving and fixed point clouds.

movingReg — Transformed point cloud
`pointCloud` object

Transformed point cloud, returned as a `pointCloud` object. The transformed point cloud is aligned with the fixed point cloud.

rmse — Root mean square error
positive numeric

Root mean square error, returned as the Euclidean distance between the aligned point clouds.

Algorithms

References

[1] Chen, Y. and G. Medioni. "Object Modelling by Registration of Multiple Range Images." *Image Vision Computing*. Butterworth-Heinemann . Vol. 10, Issue 3, April 1992, pp. 145-155.

[2] Besl, Paul J., N. D. McKay. "A Method for Registration of 3-D Shapes." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Los Alamitos, CA: IEEE Computer Society. Vol. 14, Issue 2, 1992, pp. 239-256.

See Also

affine3d | pcdenoise | pcdownsample | pcfitplane | pcmerge | pcplayer | pcread | pcregisterndt | pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics
"3-D Point Cloud Registration and Stitching"

Introduced in R2018a

pcregisterndt

Register two point clouds using NDT algorithm

Syntax

```
tform = pcregisterndt(moving,fixed,gridStep)
[tform,movingReg] = pcregisterndt(moving,fixed,gridStep)
[ ___ ,rmse] = pcregisterndt(moving,fixed,gridStep)
[ ___ ] = pcregisterndt(moving,fixed,gridStep,Name,Value)
```

Description

`tform = pcregisterndt(moving,fixed,gridStep)` returns the rigid transformation that registers the moving point cloud with the fixed point cloud. The point clouds are voxelized into cubes of size `gridStep`.

The registration algorithm is based on the normal-distributions transform (NDT) algorithm [1] [2]. Best performance of this iterative process requires adjusting properties for your data. To improve accuracy and efficiency of registration, consider downsampling the point clouds by using `pcdownsample` before using `pcregisterndt`.

`[tform,movingReg] = pcregisterndt(moving,fixed,gridStep)` also returns the transformed point cloud that aligns with the fixed point cloud.

`[ ___ ,rmse] = pcregisterndt(moving,fixed,gridStep)` also returns the root mean square error of the Euclidean distance between the aligned point clouds, using any of the preceding syntaxes.
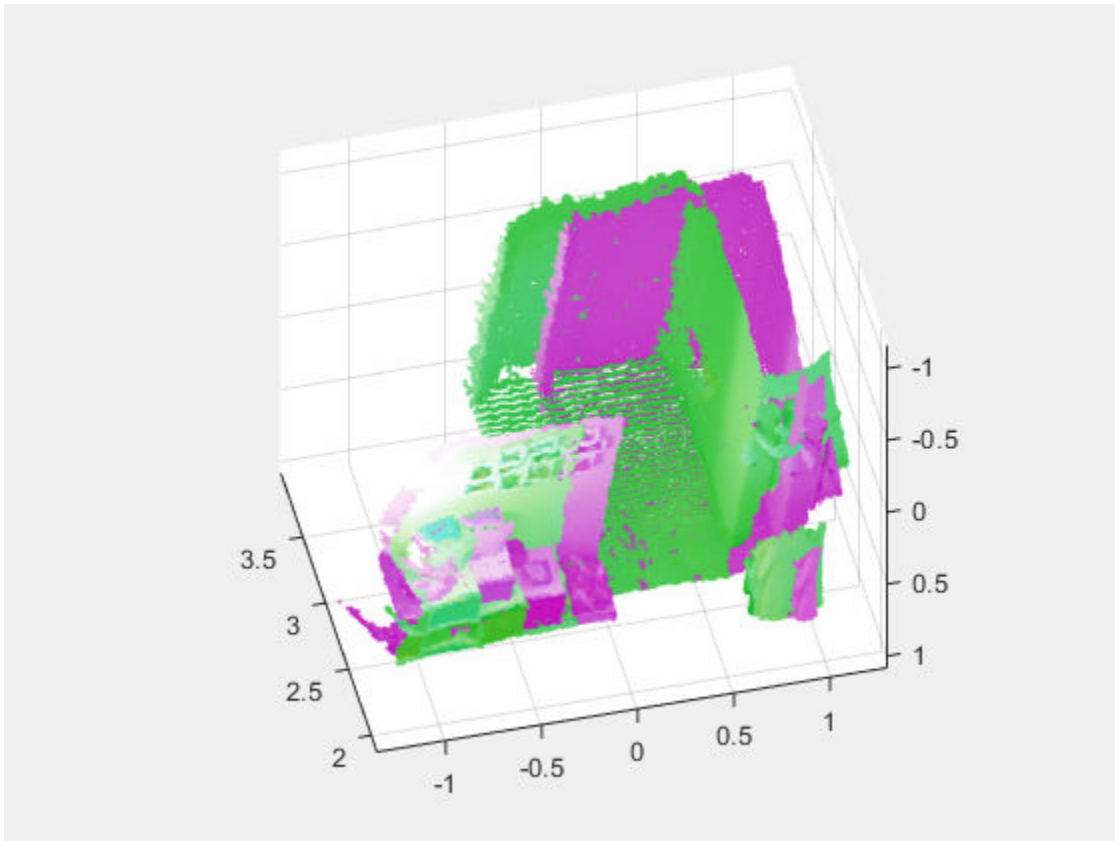
`[ ___ ] = pcregisterndt(moving,fixed,gridStep,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Align Two Point Clouds Using NDT Algorithm

Load point cloud data.

```
ld = load('livingRoom.mat');
moving = ld.livingRoomData{1};
fixed = ld.livingRoomData{2};
pcshowpair(moving,fixed,'VerticalAxis','Y','VerticalAxisDir','Down')
```


To improve the efficiency and accuracy of the NDT registration algorithm, downsample the moving point cloud.

```
movingDownsampled = pcdownsample(moving,'gridAverage',0.1);
```

Voxelize the point cloud into cubes of sidelength 0.5. Apply the rigid registration using the NDT algorithm.

```
gridStep = 0.5;
tform = pcregisterndt(movingDownsampled,fixed,gridStep);
```

Visualize the alignment.

```
movingReg = pctransform(moving,tform);
pcshowpair(movingReg,fixed,'VerticalAxis','Y','VerticalAxisDir','Down')
```
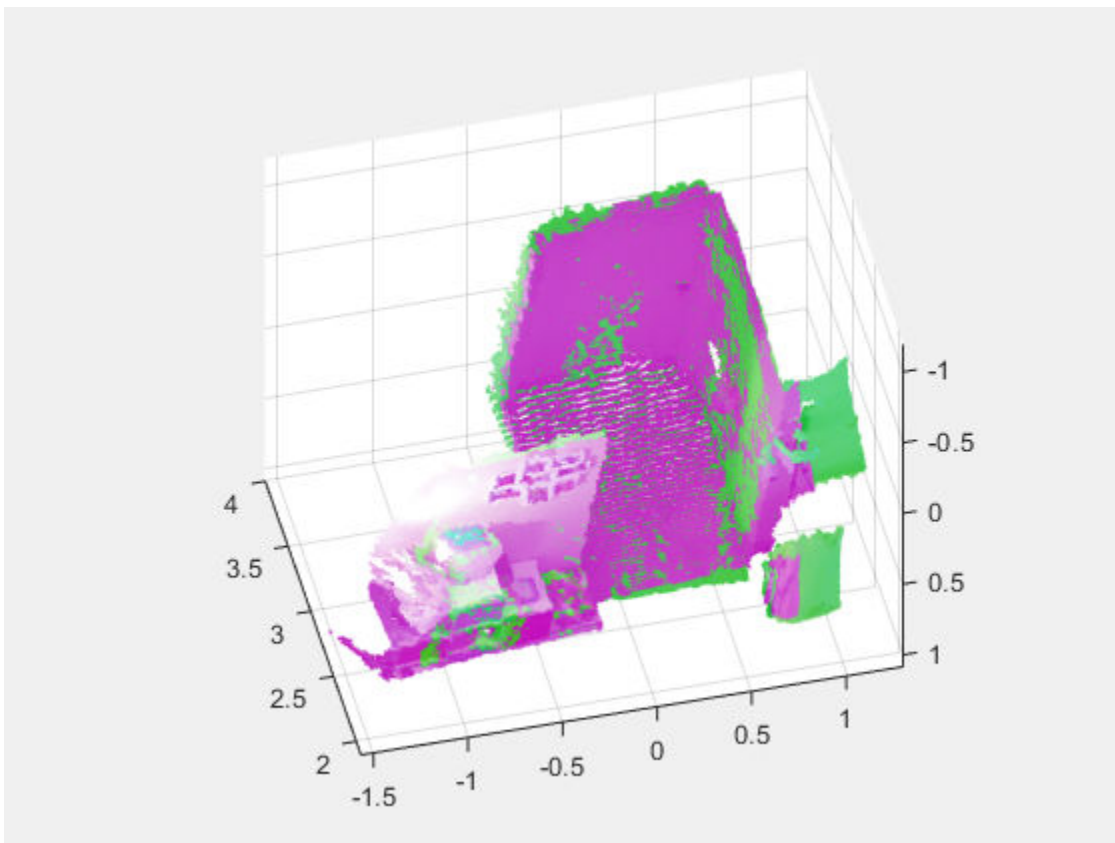
Input Arguments

`moving` — Moving point cloud
`pointCloud` object

Moving point cloud, specified as a `pointCloud` object.

`fixed` — Fixed point cloud
`pointCloud` object

Fixed point cloud, specified as a `pointCloud` object.

`gridStep` — Size of voxels
positive scalar

Size of the 3-D cube that voxelizes the fixed point cloud, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MaxIterations',20` stops the NDT algorithm after 20 iterations.

`InitialTransform` — Initial rigid transformation
`affine3d` object

Initial rigid transformation, specified as the comma-separated pair consisting of `'InitialTransform'` and an `affine3d` object. The initial rigid transformation is useful when you provide an external coarse estimation.

`OutlierRatio` — Percentage of outliers
`0.55` (default) | scalar in the range [0, 1)

Expected percentage of outliers with respect to a normal distribution, specified as the comma-separated pair consisting of `'OutlierRatio'` and a scalar in the range [0, 1). The NDT algorithm assumes a point is generated by a mixture of a normal distribution for

inliers and a uniform distribution for outliers. A larger value of 'OutlierRatio' reduces the influence of outliers.

Data Types: single | double

MaxIterations — Maximum number of iterations
30 (default) | nonnegative integer

Maximum number of iterations before NDT stops, specified as the comma-separated pair consisting of 'MaxIterations' and a nonnegative integer.

Data Types: single | double

Tolerance — Tolerance between consecutive NDT iterations
[0.01 0.5] (default) | 2-element vector

Tolerance between consecutive NDT iterations, specified as the comma-separated pair consisting of 'Tolerance' and a 2-element vector with nonnegative values. The vector, [*Tdiff Rdiff*], represents the tolerance of absolute difference in translation and rotation estimated in consecutive NDT iterations. *Tdiff* measures the Euclidean distance between two translation vectors. *Rdiff* measures the angular difference in degrees. The algorithm stops when the difference between estimated rigid transformations in the most recent consecutive iterations falls below the specified tolerance value.

Data Types: single | double

Verbose — Display progress information
false (default) | true

Display progress information, specified as the comma-separated pair consisting of 'Verbose' and a logical scalar. Set Verbose to true to display progress information.

Data Types: logical

Output Arguments

tform — Rigid transformation
affine3d object

Rigid transformation, returned as an affine3d object. tform describes the rigid 3-D transformation that registers the moving point cloud, moving, to the fixed point cloud, fixed.

**movingReg — Transformed point cloud**
`pointCloud` object

Transformed point cloud, returned as a `pointCloud` object. The transformed point cloud is aligned with the fixed point cloud, `fixed`.

rmse — Root mean square error
positive number

Root mean square error, returned as a positive number. `rmse` is the Euclidean distance between the aligned point clouds.

Algorithms

Complete Point Cloud Registration Workflow
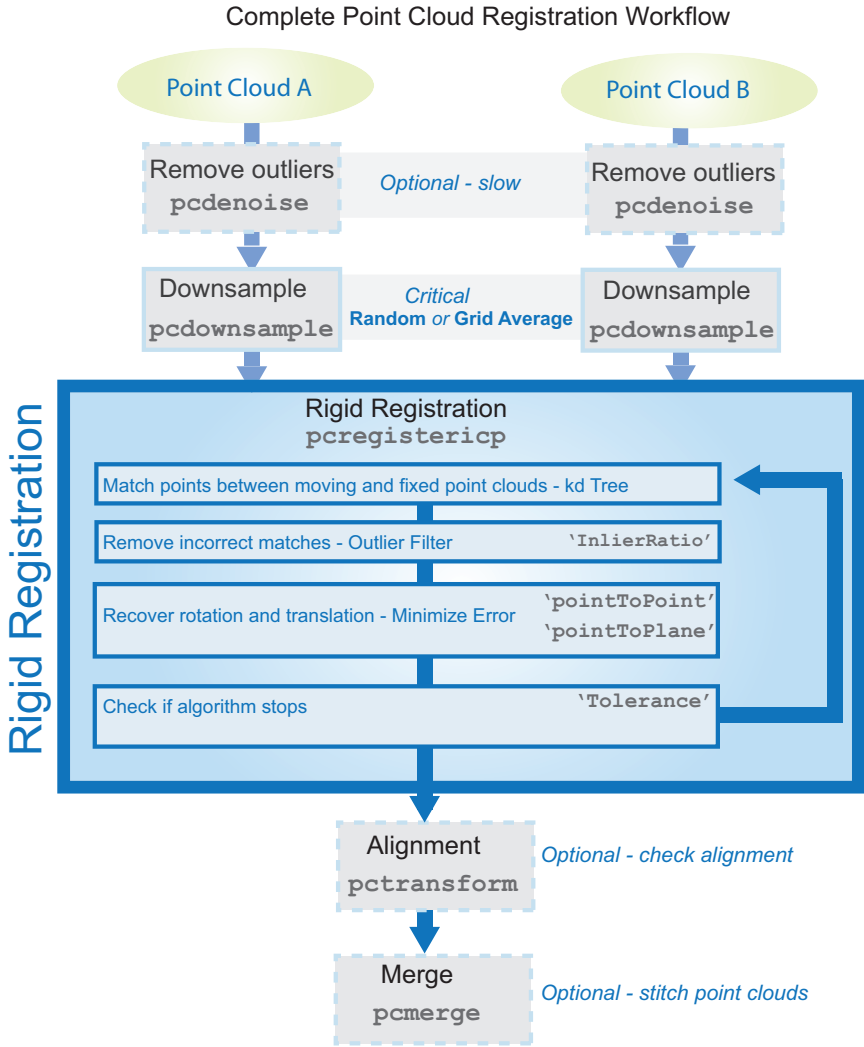
References

[1] Biber, P., and W. Straßer. "The Normal Distributions Transform: A New Approach to Laser Scan Matching." *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. Las Vegas, NV. Vol. 3, November 2003, pp. 2743–2748.

[2] Magnusson, M. "The Three-Dimensional Normal-Distributions Transform — an Efficient Representation for Registration, Surface Analysis, and Loop Detection." Ph.D. Thesis. Örebro University, Örebro, Sweden, 2013.

See Also

affine3d | pcdenoise | pcdownsample | pcmerge | pcregistericp | pcshow | pcshowpair | pctransform | pointCloud

Introduced in R2018a

pcregrigid

Register two point clouds using ICP algorithm

Note `pcregrigid` is not recommended. Use `pcregistericp` instead.

Syntax

```
tform = pcregrigid(moving,fixed)
[tform,movingReg] = pcregrigid(moving,fixed)
[ ___ ,rmse] = pcregrigid(moving,fixed)
[ ___ ] = pcregrigid(moving,fixed,Name,Value)
```

Description

`tform = pcregrigid(moving,fixed)` returns a rigid transformation that registers a moving point cloud to a fixed point cloud.

The registration algorithm is based on the "iterative closest point" (ICP) algorithm. Best performance of this iterative process requires adjusting properties for your data. Consider downsampling point clouds using `pcdownsample` before using `pcregrigid` to improve accuracy and efficiency of registration.

Point cloud normals are required by the registration algorithm when you select the `'pointToPlane'` metric. Therefore, if the input point cloud's `Normal` property is empty, the function fills it. When the function fills the `Normal` property, it uses 6 points to fit the local plane. Six points may not work under all circumstances. If registration with the `'pointToPlane'` metric fails, consider calling the `pcnormals` function which allows you to select the number of points to use.

`[tform,movingReg] = pcregrigid(moving,fixed)` additionally returns the transformed point cloud that aligns with the fixed point cloud.

`[ ___ ,rmse] = pcregrigid(moving,fixed)` additionally returns the root mean squared error of the Euclidean distance between the aligned point clouds, using any of the preceding syntaxes.
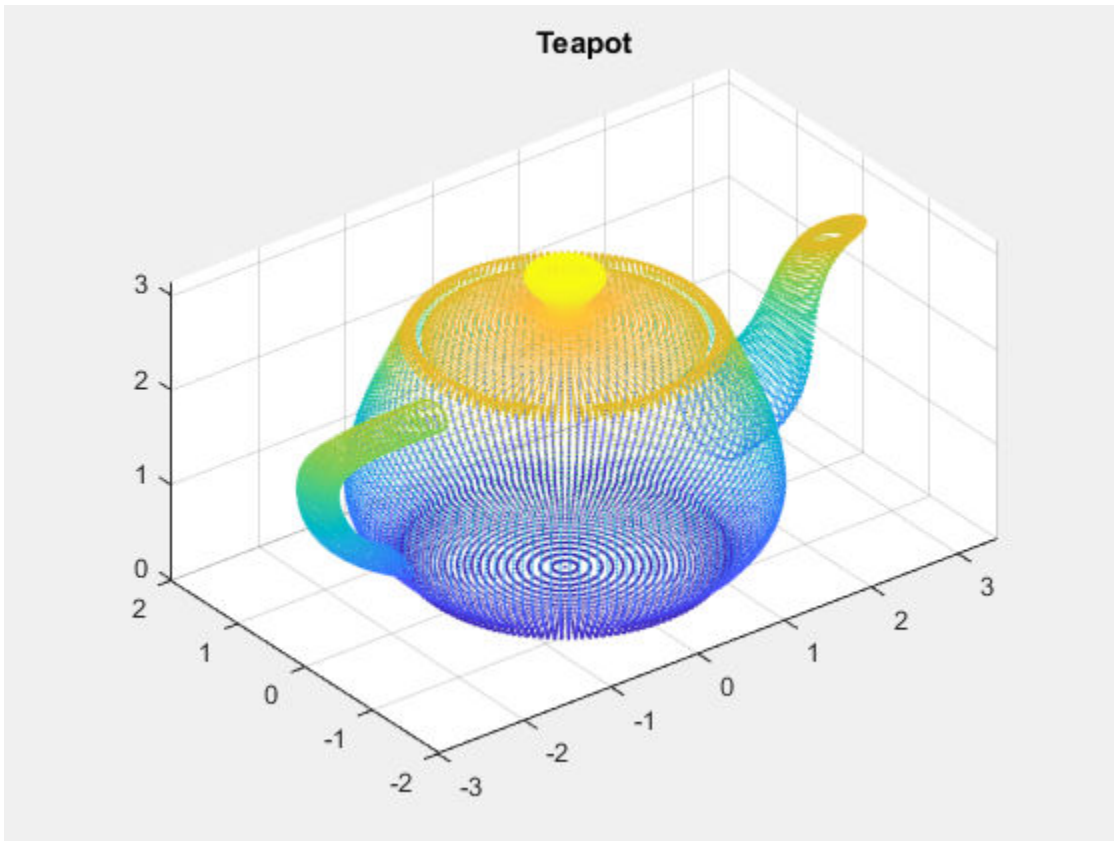
[___] = pcregrigid(moving,fixed,Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Align Two Point Clouds

Load point cloud data.

```
ptCloud = pcread('teapot.ply');
figure
pcshow(ptCloud);
title('Teapot');
```

Teapot

Create a transform object with 30 degree rotation along z-axis and translation [5,5,10].
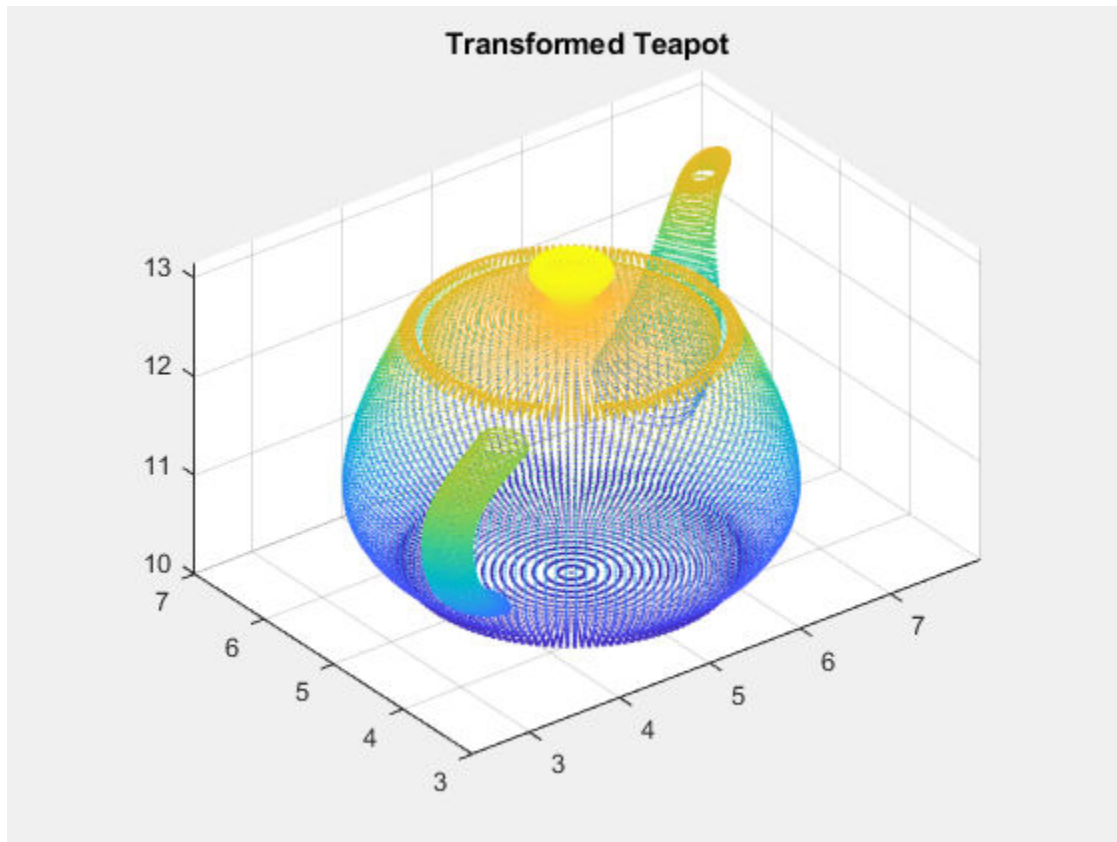
```
A = [cos(pi/6) sin(pi/6) 0 0; ...
    -sin(pi/6) cos(pi/6) 0 0; ...
            0         0  1 0; ...
            5         5 10 1];
tform1 = affine3d(A);
```

Transform the point cloud.

```
ptCloudTformed = pctransform(ptCloud,tform1);

figure
pcshow(ptCloudTformed);
title('Transformed Teapot');
```

Apply the rigid registration.

```
tform = pcregrigid(ptCloudTformed,ptCloud,'Extrapolate',true);
```

Compare the result with the true transformation.

```
disp(tform1.T);
```

```
    0.8660    0.5000         0         0
   -0.5000    0.8660         0         0
         0         0    1.0000         0
    5.0000    5.0000   10.0000    1.0000
```

```
tform2 = invert(tform);
disp(tform2.T);
```

```
  0.8660    0.5000    0.0000         0
 -0.5000    0.8660    0.0000         0
  0.0000   -0.0000    1.0000         0
  5.0000    5.0000   10.0000    1.0000
```

- "3-D Point Cloud Registration and Stitching"

Input Arguments

moving — Moving point cloud
pointCloud object

Moving point cloud, specified as a pointCloud object.

fixed — Fixed point cloud
pointCloud object

Fixed point cloud, specified as a pointCloud object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'Metric','pointToPoint' sets the metric for the ICP algorithm to the 'pointToPoint' character vector.

Metric — Minimization metric
'pointToPoint' (default) | 'pointToPlane'

Minimization metric, specified as the comma-separated pair consisting of 'Metric' and the 'pointToPoint' or 'pointToPlane' character vector. The rigid transformation between the moving and fixed point clouds are estimated by the iterative closest point (ICP) algorithm. The ICP algorithm minimizes the distance between the two point clouds according to the given metric.

Setting 'Metric' to 'pointToPlane' can reduce the number of iterations to process. However, this metric requires extra algorithmic steps within each iteration. The 'pointToPlane' metric improves the registration of planar surfaces.

Downsample Method Selection:
Downsample the point clouds using the pcdownsample function. Use either the 'random' or 'gridAverage' input for the pcdownsample function according to the Metric table below.

Metric	Point Cloud A Downsample Method	Point Cloud B Downsample Method
'pointToPoint'	'random'	'random'
	'gridAverage'	'gridAverage'
'pointToPlane'	'gridAverage'	'gridAverage'
	'random'	'nonuniformGridSample'

Extrapolate — Extrapolation
false (default) | true

Extrapolation, specified as the comma-separated pair consisting of 'Extrapolate' and the boolean true or false. When you set this property to true, the function adds an extrapolation step that traces out a path in the registration state space, that is described in [2]. Setting this property to true can reduce the number of iterations to converge.

InlierRatio — Percentage of inliers
1 (default) | scalar

Percentage of inliers, specified as the comma-separated pair consisting of 'InlierRatio' and a scalar value. Use this value to set a percentage of matched pairs as inliers. A pair of matched points is considered an inlier if its Euclidean distance falls within the percentage set of matching distances. By default, all matching pairs are used.

MaxIterations — Maximum number of iterations
20 (default) | positive integer

Maximum number of iterations, specified as the comma-separated pair consisting of 'MaxIterations' and a positive integer. This value specifies the maximum number of iterations before ICP stops.

Tolerance — Tolerance between consecutive ICP iterations
[0.01, 0.009] (default) | 2-element vector

Tolerance between consecutive ICP iterations, specified as the comma-separated pair consisting of 'Tolerance' and a 2-element vector. The 2-element vector, [*Tdiff*, *Rdiff*], represents the tolerance of absolute difference in translation and rotation estimated in consecutive ICP iterations. *Tdiff* measures the Euclidean distance between two translation vectors. *Rdiff* measures the angular difference in radians. The algorithm stops when the average difference between estimated rigid transformations in the three most recent consecutive iterations falls below the specified tolerance value.

InitialTransform — Initial rigid transformation
affine3d() object (default)

Initial rigid transformation, specified as the comma-separated pair consisting of 'InitialTransform' and an affine3d object. The initial rigid transformation is useful when you provide an external coarse estimation.

Verbose — Display progress information
true (default) | false

Display progress information, specified as the comma-separated pair consisting of 'Verbose' and a logical scalar. Set Verbose to true to display progress information.

Output Arguments

tform — Rigid transformation
affine3d object

Rigid transformation, returned as an affine3d object. The rigid transformation registers a moving point cloud to a fixed point cloud. The affine3d object describes the rigid 3-D transform. The iterative closest point (ICP) algorithm estimates the rigid transformation between the moving and fixed point clouds.
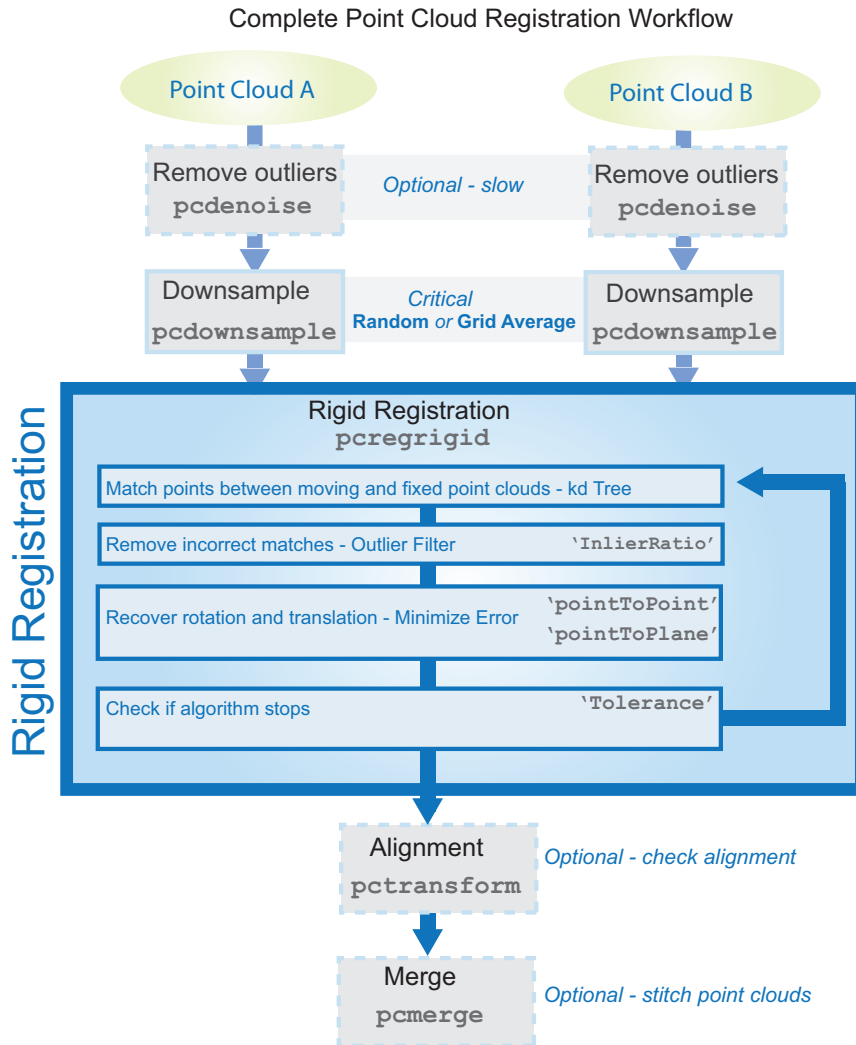
movingReg — Transformed point cloud
pointCloud object

Transformed point cloud, returned as a pointCloud object. The transformed point cloud is aligned with the fixed point cloud.

`rmse` — Root mean square error
positive numeric

Root mean square error, returned as the Euclidean distance between the aligned point clouds.

Algorithms

Complete Point Cloud Registration Workflow

Point Cloud A

Point Cloud B

Remove outliers
pcdenoise

Optional - slow

Remove outliers
pcdenoise

Downsample
pcdownsample

Critical
Random *or* **Grid Average**

Downsample
pcdownsample

Rigid Registration

Rigid Registration
pcregrigid

Match points between moving and fixed point clouds - kd Tree

Remove incorrect matches - Outlier Filter   `'InlierRatio'`

Recover rotation and translation - Minimize Error   `'pointToPoint'`
        `'pointToPlane'`

Check if algorithm stops   `'Tolerance'`

Alignment
pctransform

Optional - check alignment

Merge
pcmerge

Optional - stitch point clouds

References

[1] Chen, Y. and G. Medioni. "Object Modelling by Registration of Multiple Range Images." *Image Vision Computing*. Butterworth-Heinemann . Vol. 10, Issue 3, April 1992, pp. 145-155.

[2] Besl, Paul J., N. D. McKay. "A Method for Registration of 3-D Shapes." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Los Alamitos, CA: IEEE Computer Society. Vol. 14, Issue 2, 1992, pp. 239-256.

See Also

pcregistericp | pcregisterndt | pointCloud

Topics

"3-D Point Cloud Registration and Stitching"

Introduced in R2015a

pcsegdist

Segment point cloud into clusters based on Euclidean distance

Syntax

```
labels = pcsegdist(ptCloud,minDistance)
[labels,numClusters] = pcsegdist(ptCloud,minDistance)
```

Description

`labels = pcsegdist(ptCloud,minDistance)` segments a point cloud into clusters, with a minimum Euclidean distance of `minDistance` between points from different clusters. `pcsegdist` assigns an integer cluster label to each point in the point cloud, and returns the `labels` of all points.
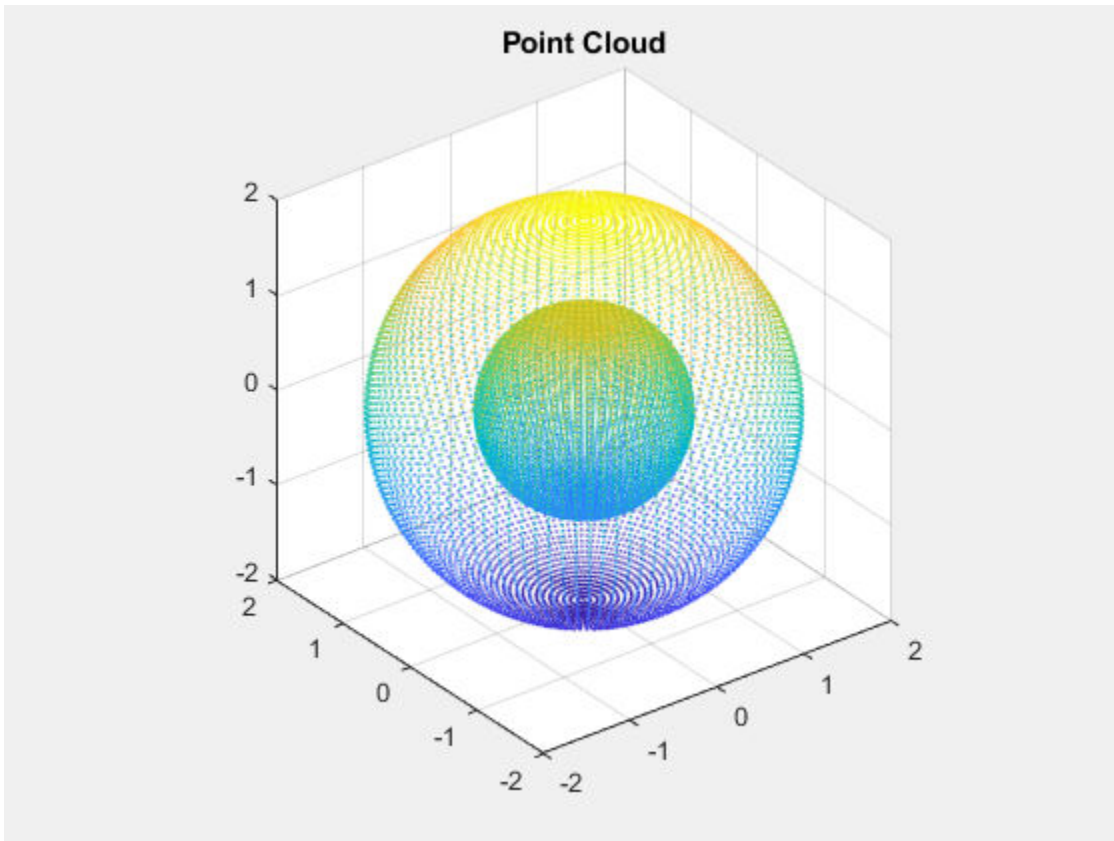
`[labels,numClusters] = pcsegdist(ptCloud,minDistance)` also returns the number of clusters.

Examples

Cluster Point Cloud Based on Euclidean Distance

Create two concentric spheres and combine them into a point cloud.

```
[X,Y,Z] = sphere(100);
loc1 = [X(:),Y(:),Z(:)];
loc2 = 2*loc1;
ptCloud = pointCloud([loc1;loc2]);
pcshow(ptCloud)
title('Point Cloud')
```

Set the minimum Euclidean distance between clusters.
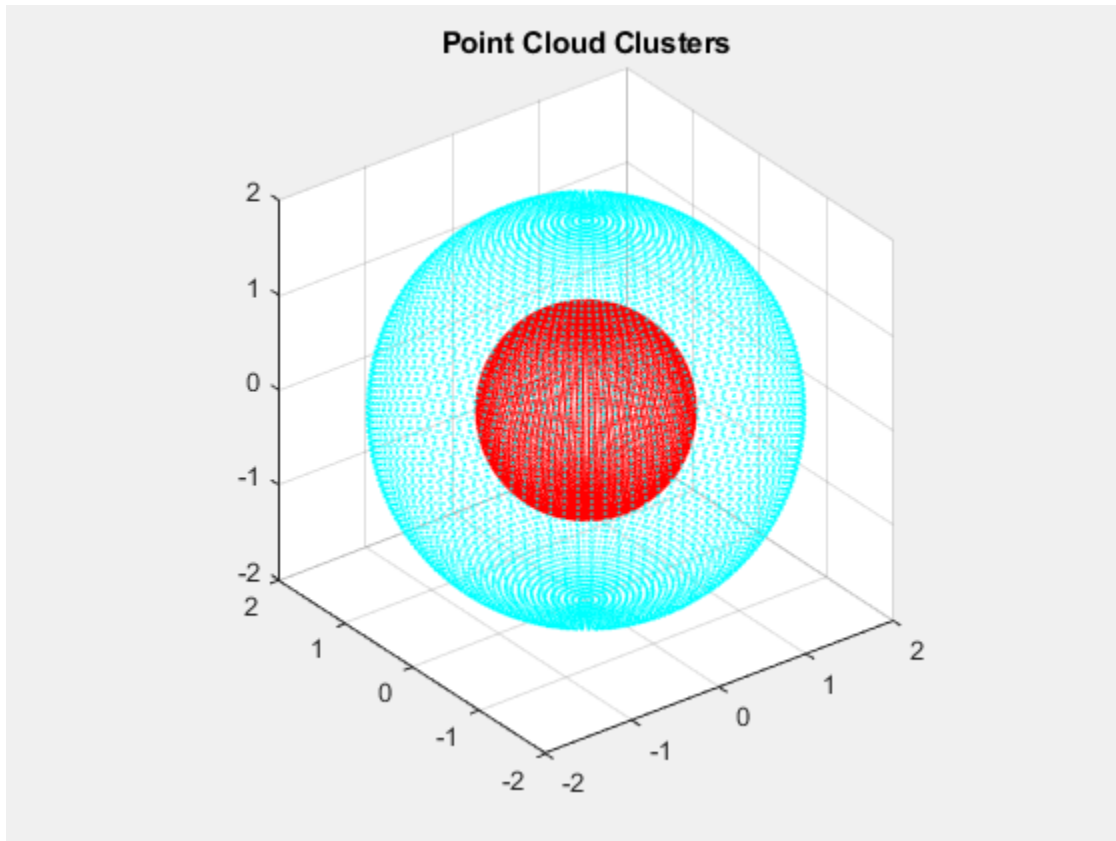
```
minDistance = 0.5;
```

Segment the point cloud.

```
[labels,numClusters] = pcsegdist(ptCloud,minDistance);
```

Plot the labeled results. The points are grouped into two clusters.

```
pcshow(ptCloud.Location,labels)
colormap(hsv(numClusters))
title('Point Cloud Clusters')
```
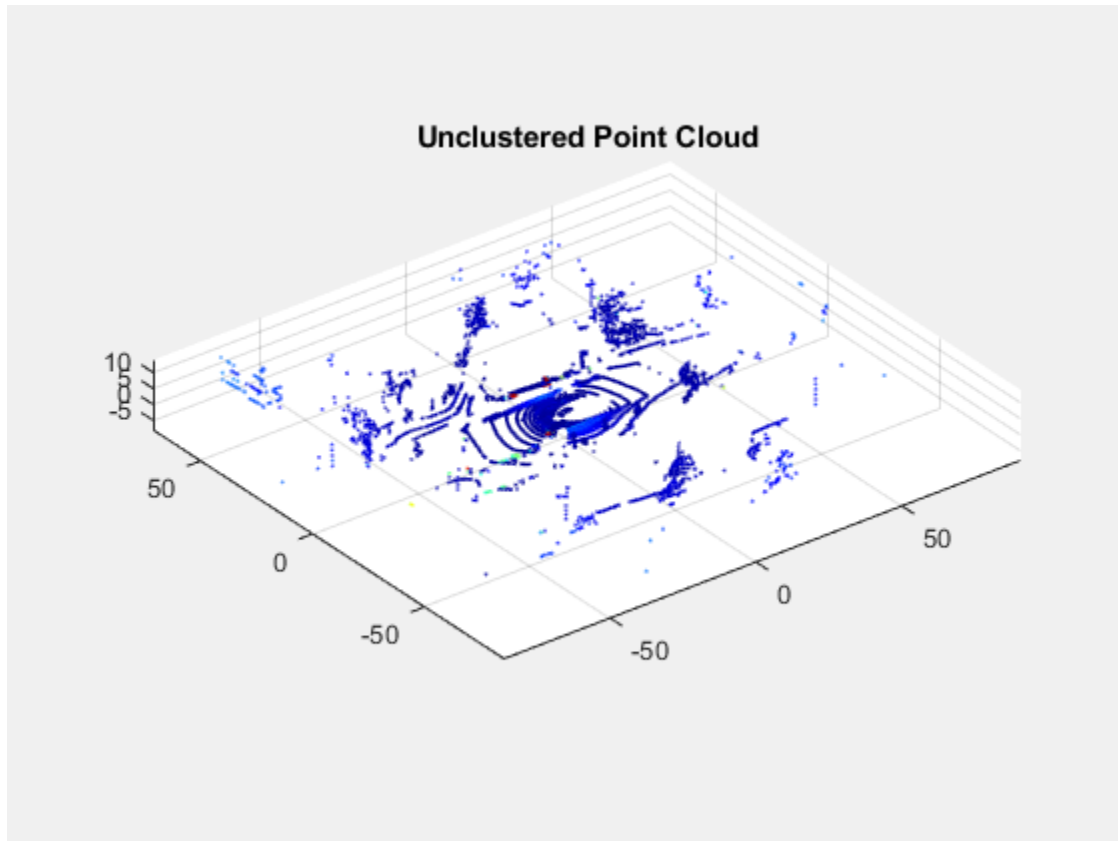
Point Cloud Clusters

Cluster Lidar Point Cloud Based on Euclidean Distance

Load an organized lidar point cloud named ptCloud.

```
load('drivingLidarPoints.mat')
pcshow(ptCloud)
title('Unclustered Point Cloud')
```

Detect the ground plane and store the points in `inliers`. Distance is measured in meters.

```
maxDistance = 0.3;
referenceVector = [0,0,1];
[~,inliers,outliers] = pcfitplane(ptCloud,maxDistance,referenceVector);
```

Cluster the points, ignoring the ground plane points. Specify a minimum Euclidean distance of 0.5 meters between clusters.

```
ptCloudWithoutGround = select(ptCloud,outliers,'OutputSize','full');
distThreshold = 0.5;
[labels,numClusters] = pcsegdist(ptCloudWithoutGround,distThreshold);
```

Add an additional label for the ground plane.

```
numClusters = numClusters+1;
labels(inliers) = numClusters;
```

Plot the labeled results. Display the ground plane in black.

```
labelColorIndex = labels+1;
pcshow(ptCloud.Location,labelColorIndex)
colormap([hsv(numClusters);[0 0 0]])
title('Point Cloud Clusters')
```
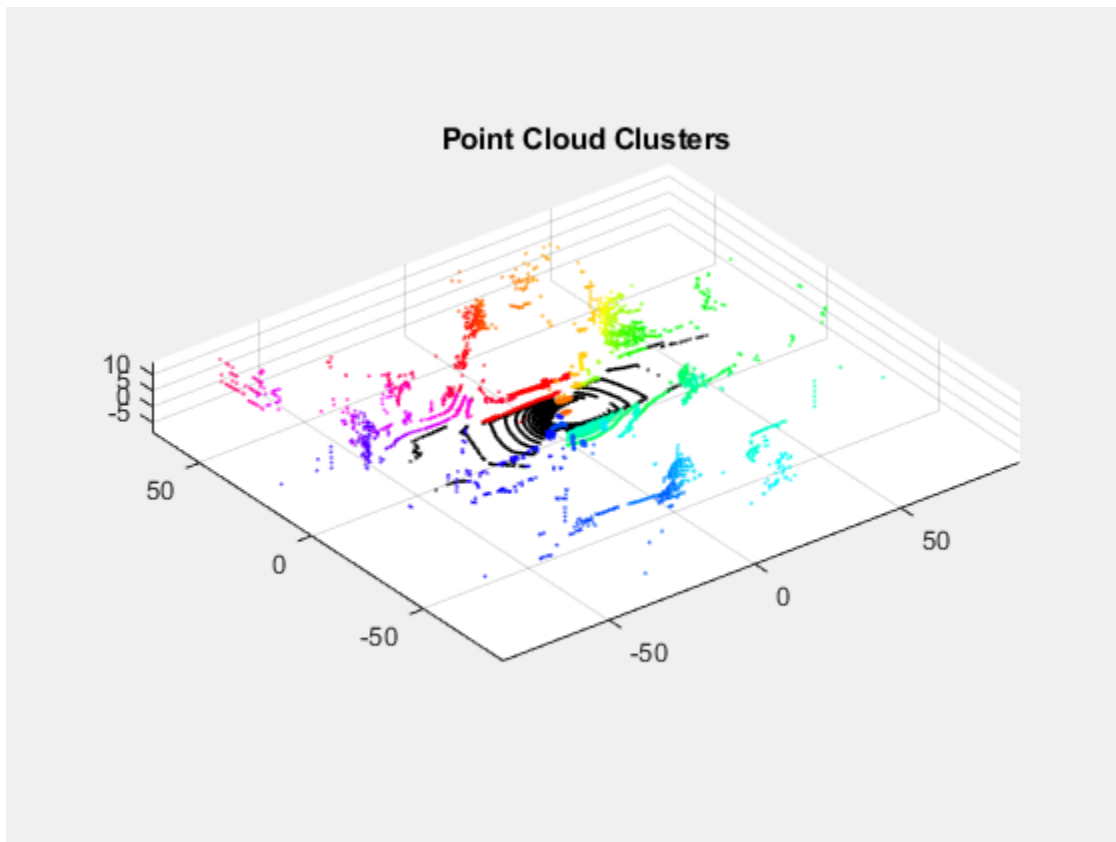
Input Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object.

minDistance — Minimum Euclidean distance
positive scalar

Minimum Euclidean distance between points from two different clusters, specified as a positive scalar.

Data Types: `single` | `double`

Output Arguments

labels — Cluster labels
M-by-1 vector | *M*-by-*N* matrix

Cluster labels, returned as one of the following.

* If the point cloud, `ptCloud`, stores point locations as an unorganized *M*-by-3 matrix, then `labels` is an *M*-by-1 vector.
* If the point cloud, `ptCloud`, stores point locations as an organized *M*-by-*N*-by-3 array, then `labels` is an *M*-by-*N* matrix.

Each point in the point cloud has a cluster label, specified by the corresponding element in `labels`. The value of each label is an integer from 0 to the number of clusters of valid points, `numClusters`. The value 0 is reserved for invalid points, such as points with `Inf` or `NaN` coordinates.

numClusters — Number of clusters
positive integer

Number of clusters, returned as a positive integer. The number of clusters does not include the cluster corresponding to invalid points.

See Also

pcdenoise | pcfitplane | pcshow | pointCloud

Introduced in R2018a

pcwrite

Write 3-D point cloud to PLY or PCD file

Syntax

```
pcwrite(ptCloud,filename)
pcwrite(ptCloud,filename,'Encoding',encodingType)
```

Description

pcwrite(ptCloud,filename) writes the point cloud object, ptCloud, to the PLY or PCD file specified by the input filename character vector.

pcwrite(ptCloud,filename,'Encoding',encodingType) writes a pointCloud object, ptCloud, to a PLY file that is in the specified format.
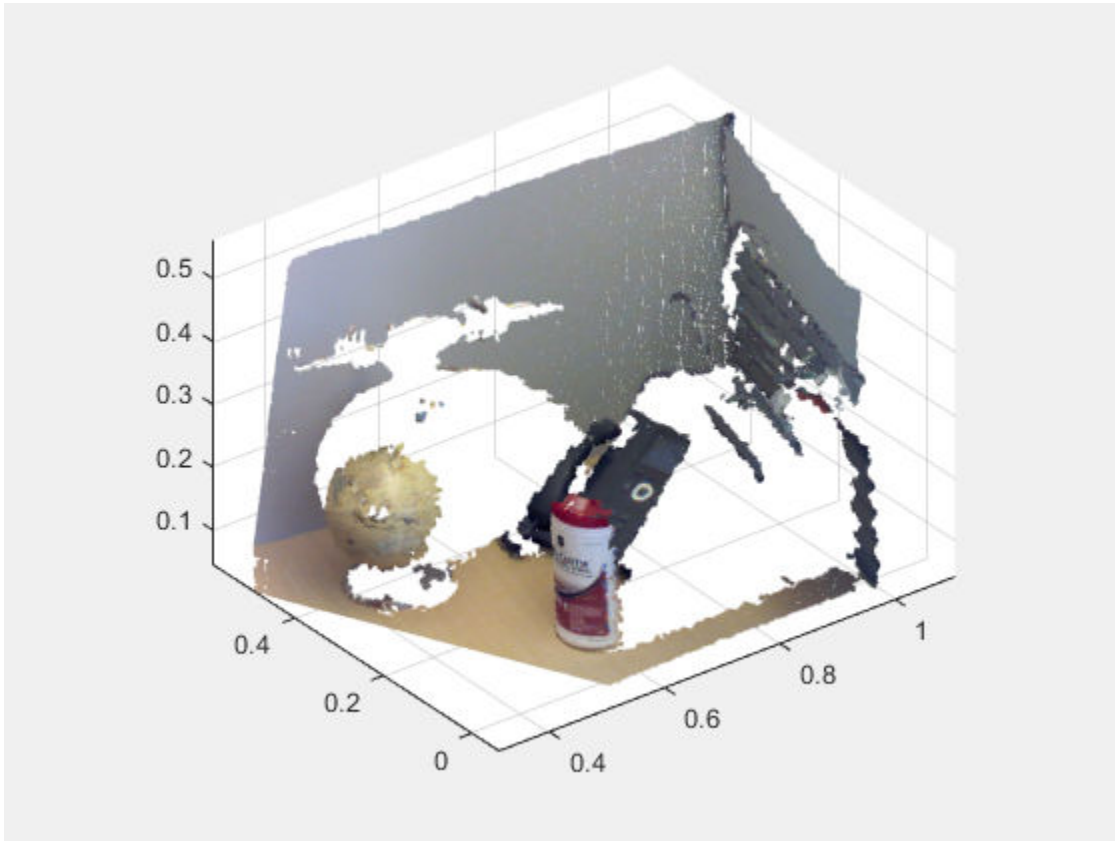
Examples

Write 3-D Point Cloud to PLY File

```
ptCloud = pcread('teapot.ply');
pcshow(ptCloud);
```
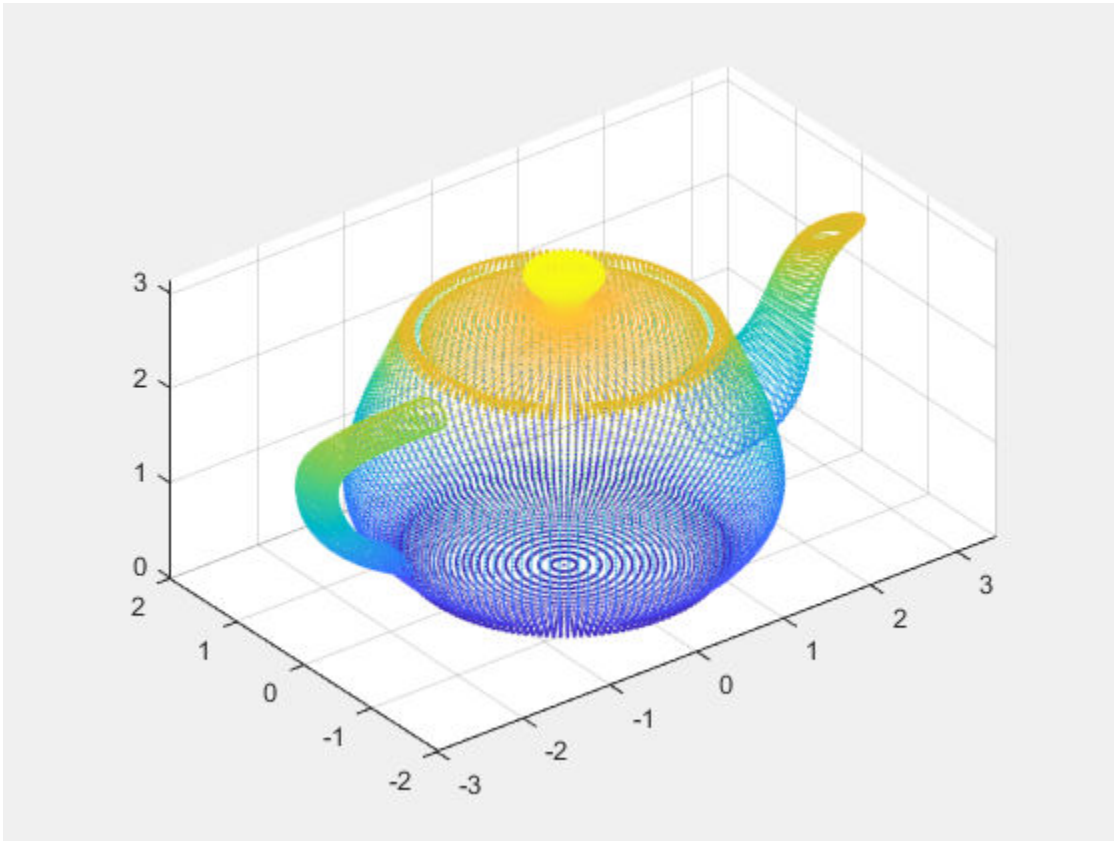
```
pcwrite(ptCloud,'teapotOut','PLYFormat','binary');
```

Write 3-D Organized Point Cloud to PCD File

```
load('object3d.mat');
pcwrite(ptCloud,'object3d.pcd','Encoding','ascii');
pc = pcread('object3d.pcd');
pcshow(pc);
```

- "3-D Point Cloud Registration and Stitching"

Input Arguments

`filename` — File name
character vector

File name, specified as a character vector. The input file type must be a PLY or PCD format file.

For a PLY-file, the `pcwrite` function converts an organized M-by-N-by-3 point cloud to an unorganized M-by-3 format. It converts the format because PLY files do not support

organized point clouds. To preserve the organized format, you can save the point cloud as a PCD-file.

If you do not specify the file name with an extension, the function writes the file in a PLY-format.

ptCloud — Object for storing point cloud
pointCloud object

Object for storing point cloud, specified as a `pointCloud` object.

encodingType — PLY or PCD file
'ascii' (default) | 'ascii' | 'binary' | 'compressed'

PLY or PCD formatted file, specified as the comma-separated pair consisting of the character vector `'Encoding'`, and a character vector for the file format.

File Format	Valid Encodings
PLY	`'ascii'`, `'binary'`
PCD	`'ascii'`, `'binary'`, or `'compressed'`

See Also
pcdenoise | pcdownsample | pcfitplane | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pctransform | planeModel | pointCloud

Topics
"3-D Point Cloud Registration and Stitching"

Introduced in R2015a

pctransform

Rigid transform of 3-D point cloud

Syntax

```
ptCloudOut = pctransform(ptCloudIn,tform)
```

Description

`ptCloudOut = pctransform(ptCloudIn,tform)` applies the specified forward rigid transform to the input point cloud.

Examples
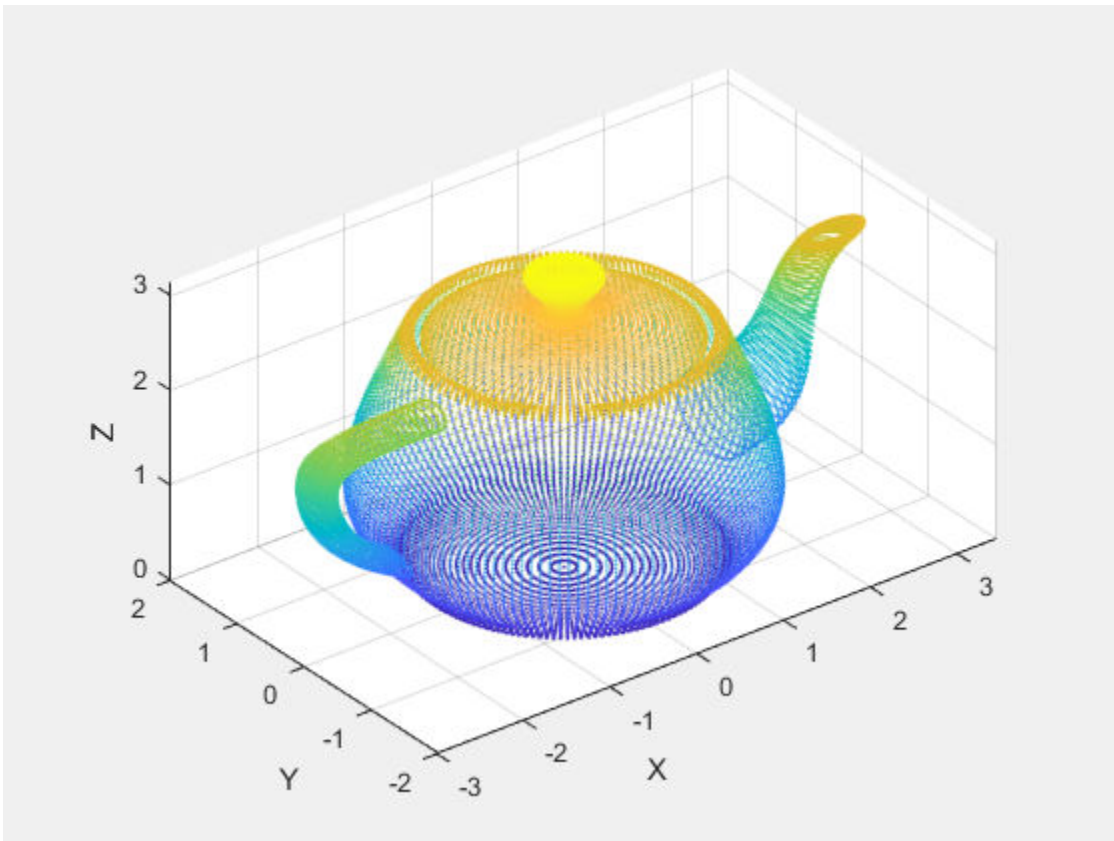
Rotate 3-D Point Cloud

Read a point cloud.

```
ptCloud = pcread('teapot.ply');
```

Plot the original data.

```
figure
pcshow(ptCloud);
xlabel('X');
ylabel('Y');
zlabel('Z');
```

Create a transform object with a 45 degrees rotation along the z-axis.

```
A = [cos(pi/4) sin(pi/4) 0 0; ...
     -sin(pi/4) cos(pi/4) 0 0; ...
     0 0 1 0; ...
     0 0 0 1];
tform = affine3d(A);
```
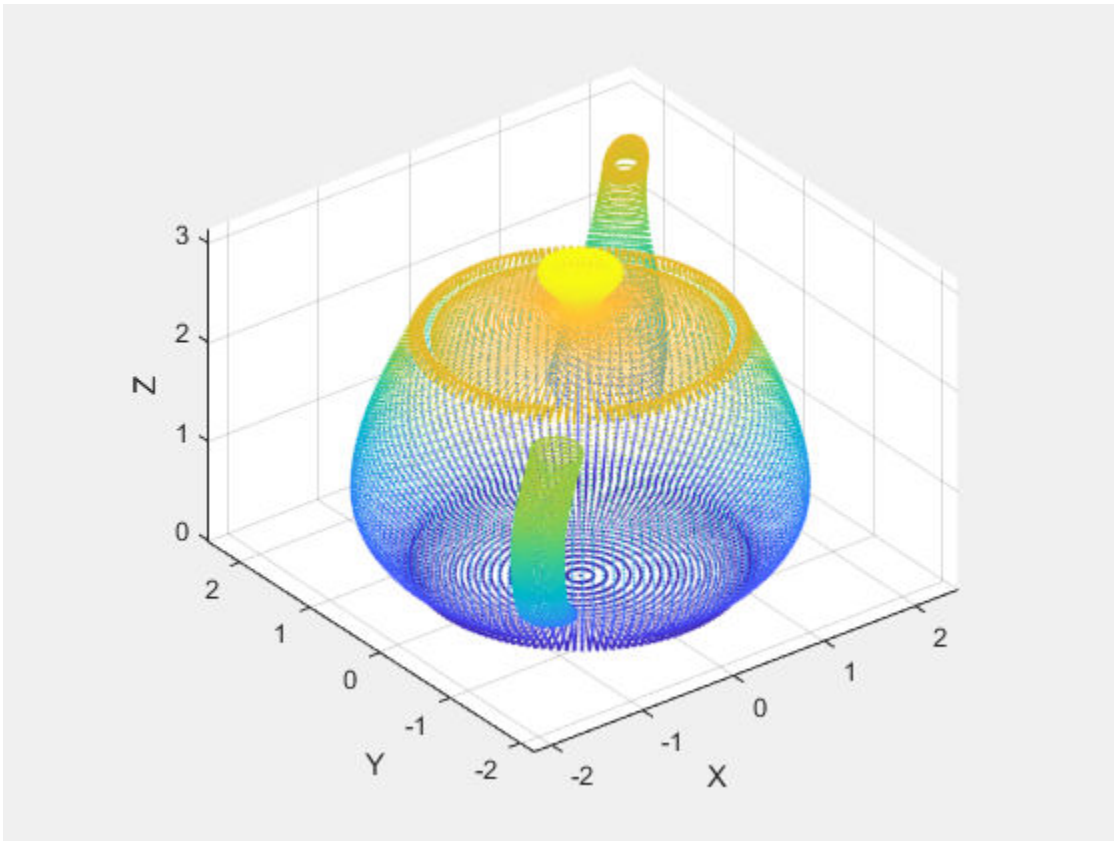
Transform the point cloud.

```
ptCloudOut = pctransform(ptCloud,tform);
```

Plot the transformed point cloud.

```
figure
pcshow(ptCloudOut);
xlabel('X');
ylabel('Y');
zlabel('Z');
```


- "3-D Point Cloud Registration and Stitching"

Input Arguments

ptCloudIn — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object.

tform — 3-D affine geometric transformation
`affine3d` object

3-D affine geometric transformation, specified as a rigid transform `affine3d` object. The `tform` input must be a valid rigid transform (rotation and translation only). See "Using a Transformation Matrix" (Image Processing Toolbox), for details on how to set up the `tform` object.

Output Arguments

ptCloudOut — Transformed point cloud
`pointCloud` object

Transformed point cloud, returned as a `pointCloud` object. The transformation applies to the coordinates of points and their normal vectors.

See Also

`affine3d` | `pcdenoise` | `pcdownsample` | `pcfitplane` | `pcmerge` | `pcplayer` | `pcread` | `pcregistericp` | `pcshow` | `pcwrite` | `planeModel` | `pointCloud`

Topics
"3-D Point Cloud Registration and Stitching"

Introduced in R2015a

pcnormals

Estimate normals for point cloud

Syntax

```
normals = pcnormals(ptCloud)
normals = pcnormals(ptCloud,k)
```

Description

`normals = pcnormals(ptCloud)` returns a matrix that stores a normal for each point in the input `ptCloud`. The function uses six neighboring points to fit a local plane to determine each normal vector.

`normals = pcnormals(ptCloud,k)` additionally specifies k, the number of points used for local plane fitting.

Examples

Estimate Normals of Point Cloud

Load a point cloud.

```
load('object3d.mat');
```

Estimate the normal vectors.

```
normals = pcnormals(ptCloud);

figure
pcshow(ptCloud)
title('Estimated Normals of Point Cloud')
hold on
```

Estimated Normals of Point Cloud
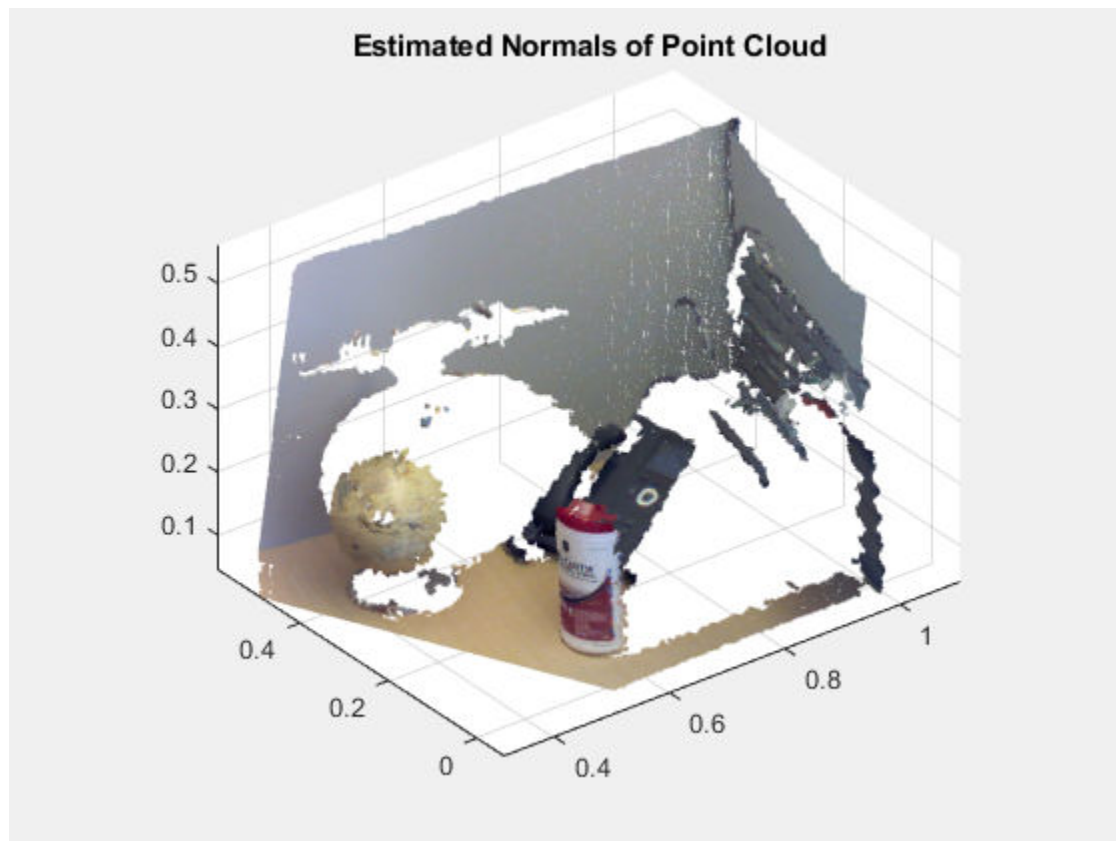

```
x = ptCloud.Location(1:10:end,1:10:end,1);
y = ptCloud.Location(1:10:end,1:10:end,2);
z = ptCloud.Location(1:10:end,1:10:end,3);
u = normals(1:10:end,1:10:end,1);
v = normals(1:10:end,1:10:end,2);
w = normals(1:10:end,1:10:end,3);
```

Plot the normal vectors.

```
quiver3(x,y,z,u,v,w);
hold off
```

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Estimated Normals of Point Cloud
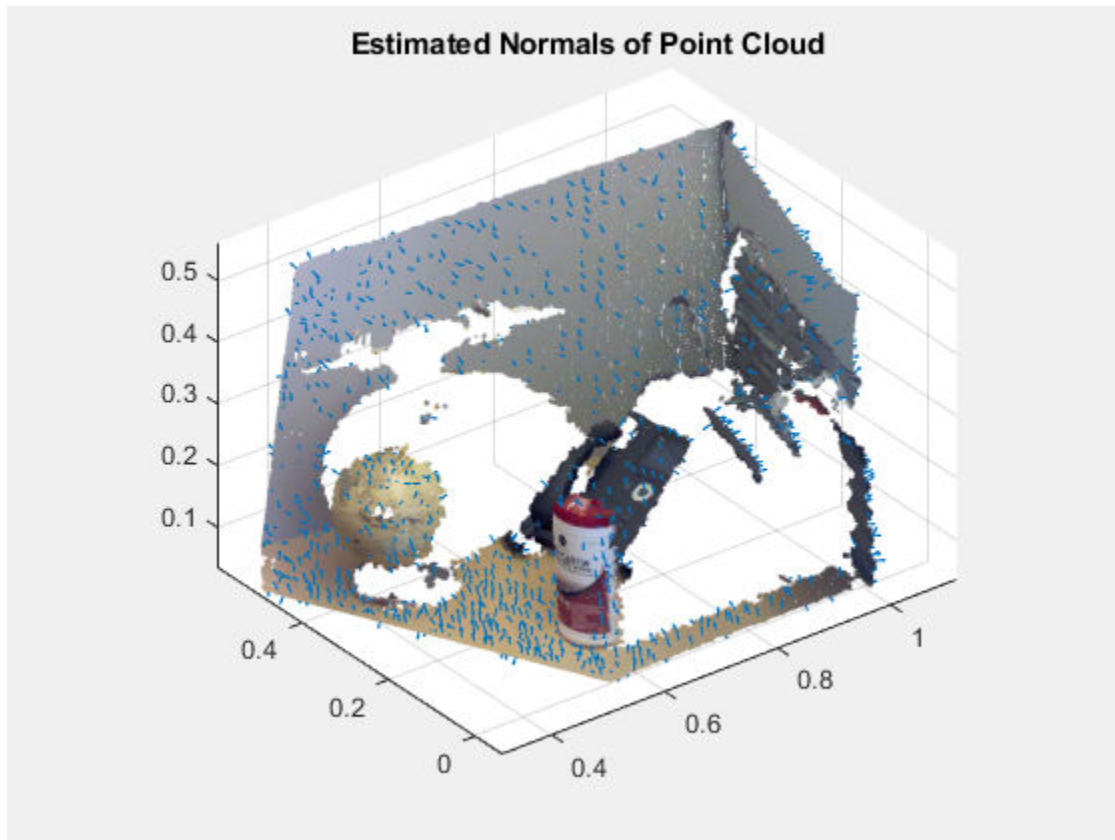
Flip the normals to point towards the sensor location. This step is necessary only for determining the inward or outward direction of the surface. The sensor center is set in x, y, z coordinates.

```
sensorCenter = [0,-0.3,0.3];
for k = 1 : numel(x)
   p1 = sensorCenter - [x(k),y(k),z(k)];
   p2 = [u(k),v(k),w(k)];
   % Flip the normal vector if it is not pointing towards the sensor.
   angle = atan2(norm(cross(p1,p2)),p1*p2');
   if angle > pi/2 || angle < -pi/2
       u(k) = -u(k);
       v(k) = -v(k);
       w(k) = -w(k);
```
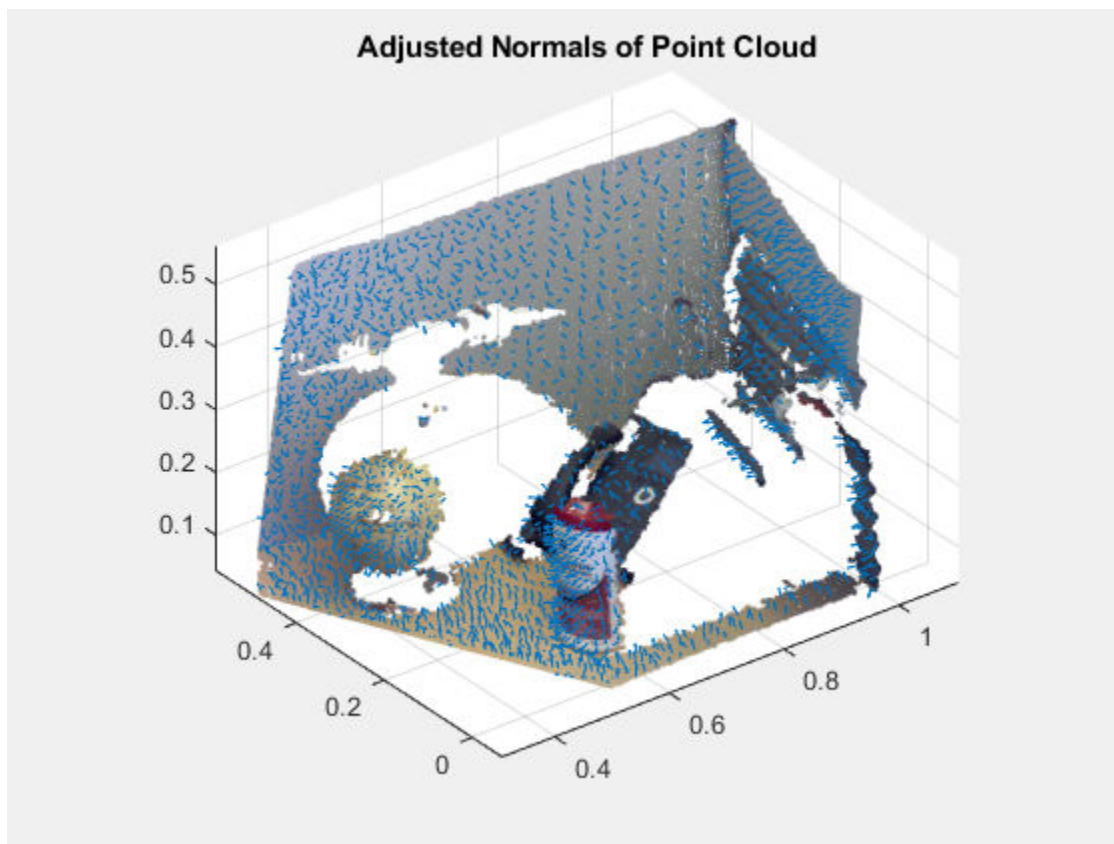
```
    end
end
```

Plot the adjusted normals.

```
figure
pcshow(ptCloud)
title('Adjusted Normals of Point Cloud')
hold on
quiver3(x, y, z, u, v, w);
hold off
```


Adjusted Normals of Point Cloud

- "3-D Point Cloud Registration and Stitching"

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Input Arguments

`ptCloud` — Object for storing point cloud
pointCloud object

Object for storing point cloud, returned as a `pointCloud` object.

k — Number of points used for local plane fitting
integer greater than or equal to 3

Number of points used for local plane fitting, specified as an integer greater than or equal to 3. Increasing this value improves accuracy but slows down computation time.

Output Arguments

`normals` — Normals used to fit a local plane
M-by-3 | *M*-by-*N*-by-3

Normals used to fit a local plane, returned as an *M*-by-3 or an *M*-by-*N*-by-3 vector. The normal vectors are computed locally using six neighboring points. The direction of each normal vector can be set based on how you acquired the points. The "Estimate Normals of Point Cloud" on page 3-544 example, shows how to set the direction when the normal vectors are pointing towards the sensor.

References

[1] Hoppe, H., T. DeRose, T. Duchamp, J. Mcdonald, and W. Stuetzle. "Surface Reconstruction from Unorganized Points". *Computer Graphics (SIGGRAPH 1992 Proceedings).* 1992, pp. 71–78.

See Also

pcdenoise | pcdownsample | pcfitplane | pcmerge | pcplayer | pcregistericp | pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics
"3-D Point Cloud Registration and Stitching"
"The PLY Format"

Introduced in R2015b

pcfitcylinder

Fit cylinder to 3-D point cloud

Syntax

```
model = pcfitcylinder(ptCloudIn,maxDistance)
model = pcfitcylinder(ptCloudIn,maxDistance,referenceVector)
model = pcfitcylinder(ptCloudIn,maxDistance,referenceVector,
maxAngularDistance)

[model,inlierIndices,outlierIndices] = pcfitcylinder(ptCloudIn,
maxDistance)
[ ___ ,meanError] = pcfitcylinder(ptCloudIn,maxDistance)
[ ___ ] = pcfitcylinder( ___ ,Name,Value)
```

Description

`model = pcfitcylinder(ptCloudIn,maxDistance)` fits a cylinder to a point cloud with a maximum allowable distance from an inlier point to the cylinder. This function uses the M-estimator SAmple Consensus (MSAC) algorithm to find the cylinder.

`model = pcfitcylinder(ptCloudIn,maxDistance,referenceVector)` fits a cylinder to the point cloud with additional orientation constraints specified by the 1-by-3 reference orientation input vector.

`model = pcfitcylinder(ptCloudIn,maxDistance,referenceVector, maxAngularDistance)` additionally specifies the maximum allowed absolute angular distance.

`[model,inlierIndices,outlierIndices] = pcfitcylinder(ptCloudIn, maxDistance)` additionally returns linear indices to the inlier and outlier points in the point cloud input.

`[ ___ ,meanError] = pcfitcylinder(ptCloudIn,maxDistance)` additionally returns the mean error of the distance of the inlier points to the model.

[___] = pcfitcylinder(___ ,Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Extract Cylinder from Point Cloud

Load the point cloud.

```
load('object3d.mat');
```

Display the point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Original Point Cloud')
```

Set the maximum point-to-cylinder distance (5 mm) for cylinder fitting.

```
maxDistance = 0.005;
```

Set the region of interest to constrain the search.

```
roi = [0.4,0.6,-inf,0.2,0.1,inf];
sampleIndices = findPointsInROI(ptCloud,roi);
```

Set the orientation constraint.

```
referenceVector = [0,0,1];
```

Detect the cylinder and extract it from the point cloud by specifying the inlier points.

```
[model,inlierIndices] = pcfitcylinder(ptCloud,maxDistance,...
        referenceVector,'SampleIndices',sampleIndices);
pc = select(ptCloud,inlierIndices);
```

Plot the extracted cylinder.
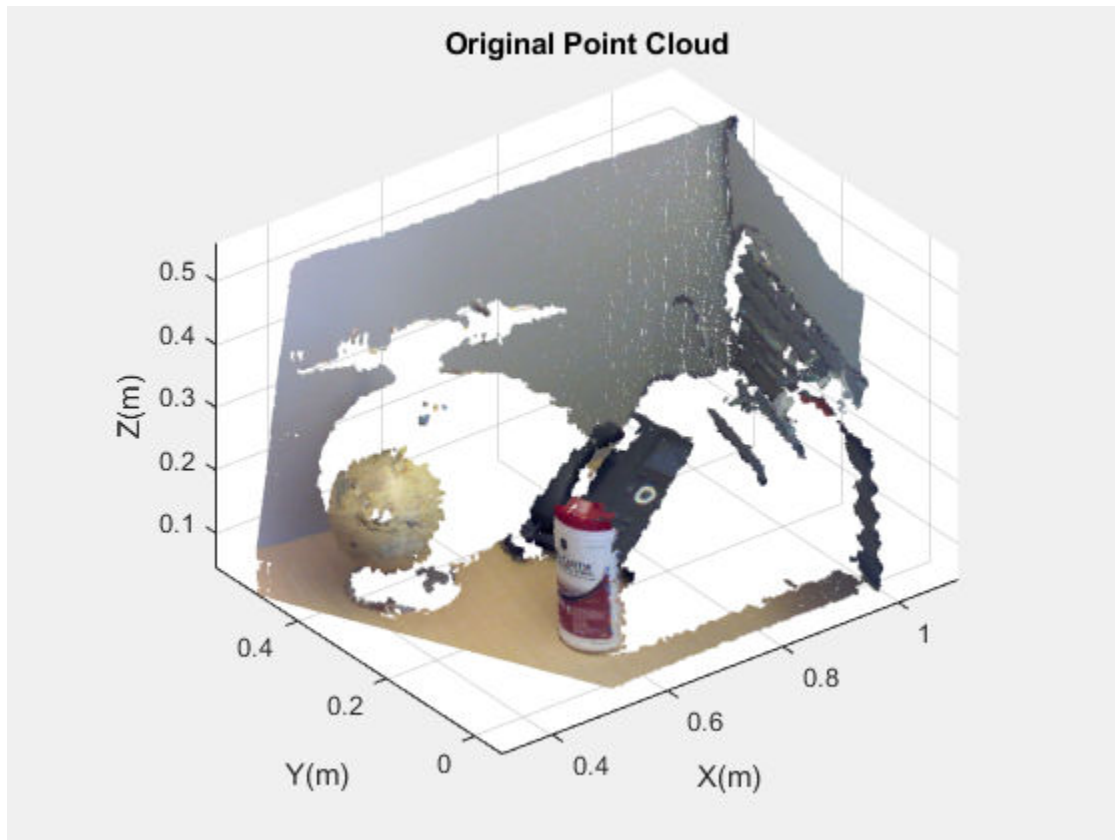
```
figure
pcshow(pc)
title('Cylinder Point Cloud')
```

Detect Cylinder in Point Cloud

Load the point cloud.

```
load('object3d.mat');
```

Display point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Detect a Cylinder in a Point Cloud')
```

Set the maximum point-to-cylinder distance (5 mm) for the cylinder fitting.

```
maxDistance = 0.005;
```

Set the region of interest to constrain the search.

```
roi = [0.4,0.6;-inf,0.2;0.1,inf];
sampleIndices = findPointsInROI(ptCloud,roi);
```
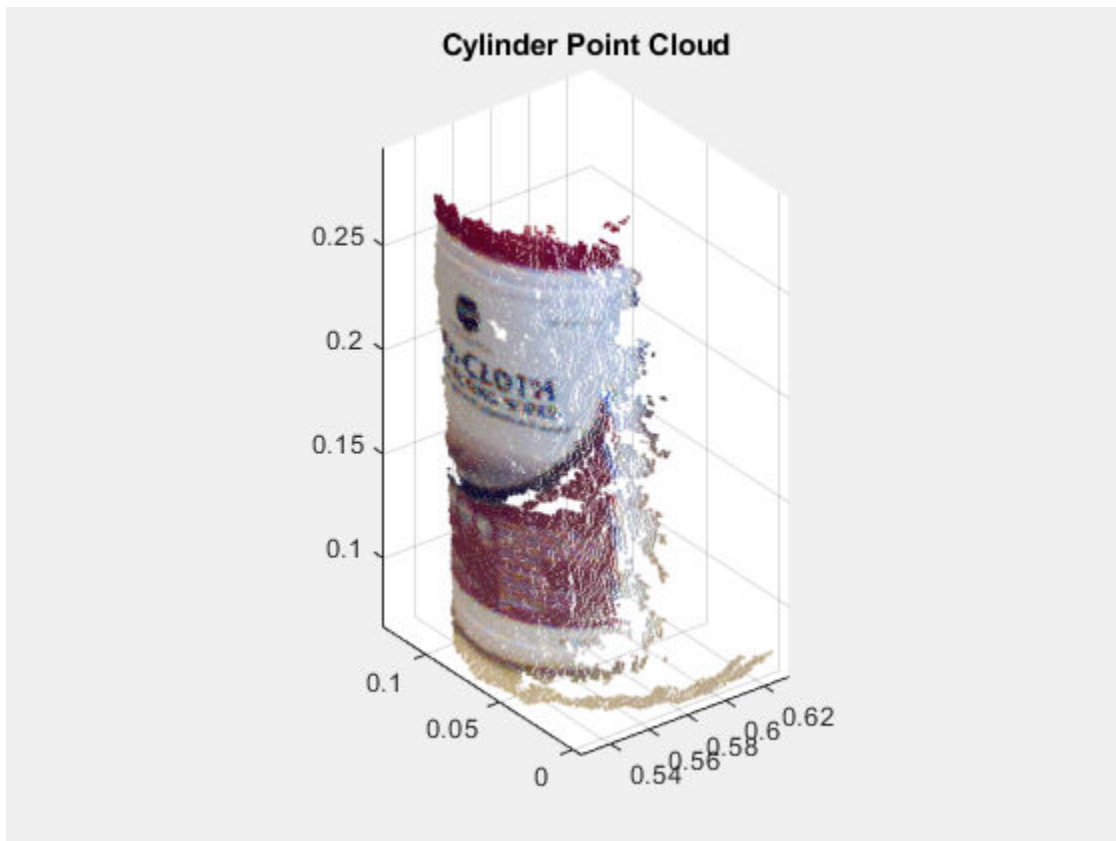
Set the orientation constraint.

```
referenceVector = [0,0,1];
```

Detect the cylinder in the point cloud and extract it.

```
model = pcfitcylinder(ptCloud,maxDistance,referenceVector,...
        'SampleIndices',sampleIndices);
```

Plot the cylinder.

```
hold on
plot(model)
```

Detect a Cylinder in a Point Cloud

- "3-D Point Cloud Registration and Stitching"

Input Arguments

ptCloudIn — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object. If the `Normal` property of the input `ptCloud` is empty, the function populates it with values to meet the requirements of the fitting algorithm.

`maxDistance` — Maximum distance from an inlier point to the cylinder
scalar value

Maximum distance from an inlier point to the cylinder, specified as a scalar value. Specify the distance in units that are consistent with the units you are using for the point cloud.

Data Types: `single` | `double`

`referenceVector` — Reference orientation
1-by-3 vector

Reference orientation, specified as a 1-by-3 vector.

`maxAngularDistance` — Maximum absolute angular distance
5 (default) | scalar value

Maximum absolute angular distance, specified as a scalar value. The maximum angular distance is measured in degrees between the direction of the fitted cylinder and the reference orientation.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'SampleIndices',[]`.

`SampleIndices` — Linear indices of points to sample
[] (default) | column vector

Linear indices of points to sample in the input point cloud, specified as the comma-separated pair consisting of `'SampleIndices'` and a column vector. An empty vector means that all points are candidates to sample when fitting the cylinder during the RANSAC iteration. If you specify a subset of points, the function fits the model by sampling only those points in the subset. Providing a subset of points can significantly speed up the process by reducing the number of trials. You can generate the indices vector using the `findPointsInROI` method of the `pointCloud` object.

`MaxNumTrials` — Maximum number of random trials
1000 (default) | positive integer

Maximum number of random trials for finding inliers, specified as the comma-separated pair consisting of `'MaxNumTrials'` and a positive integer. To improve robustness of the output, increase this value. However, doing so adds additional computations.

Confidence — Percentage for finding maximum number of inliers
99 (default) | numeric scalar in the range (0,100)

Percentage for finding maximum number of inliers, specified as the comma-separated pair consisting of `'Confidence'` and a numeric scalar, in the range (0 100). To improve the robustness of the output, increase this value. However, doing so adds additional computations.

Output Arguments

`model` — Geometric model of cylinder
`cylinderModel` object.

Geometric model of cylinder, returned as a `cylinderModel` object.

The coefficients for the output model are set to zero when:

- The input point cloud does not contain enough valid points.
- The algorithm cannot find enough inlier points.

`inlierIndices` — Linear indices of inlier points
column vector

Linear indices of the inlier points in the input point cloud, returned as a column vector.

`outlierIndices` — Linear indices of outlier points
column vector

Linear indices of the outlier points in the input point cloud returned as a column vector.

`meanError` — Mean square error
scalar value

Mean error of the distance of inlier points to the model, returned as a scalar value.

Algorithms

The function returns a geometric model that describes the cylinder. This function uses the M-estimator SAmple Consensus (MSAC) algorithm to find the cylinder. The MSAC algorithm is a variant of the RANdom SAmple Consensus (RANSAC) algorithm.

The fitting algorithm for the `pcfitcylinder` function requires point cloud normals. Therefore, if the `Normal` property for the input point cloud is empty, the function fills it. When the function fills the `Normal` property, it uses six points to fit the local cylinder. If six points do not work and the fitting fails, consider calling the `pcnormals` function which enables you to select the number of points to use.

References

[1] Torr, P. H. S., and A. Zisserman. "MLESAC: A New Robust Estimator with Application to Estimating Image Geometry." *Computer Vision and Image Understanding*. Volume 78, Issue 1, April 2000, pp. 138-156.

See Also

affine3d | cylinderModel | pcdenoise | pcfitplane | pcfitsphere | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics

"3-D Point Cloud Registration and Stitching"

Introduced in R2015b

pcfitplane

Fit plane to 3-D point cloud

Syntax

```
model = pcfitplane(ptCloudIn,maxDistance)
model = pcfitplane(ptCloudIn,maxDistance,referenceVector)
model = pcfitplane(ptCloudIn,maxDistance,referenceVector,
maxAngularDistance)

[model,inlierIndices,outlierIndices] = pcfitplane(ptCloudIn,
maxDistance)
[___,meanError] = pcfitplane(ptCloudIn,maxDistance)
[___] = pcfitplane(ptCloudIn,maxDistance,Name,Value)
```

Description

`model = pcfitplane(ptCloudIn,maxDistance)` fits a plane to a point cloud that has a maximum allowable distance from an inlier point to the plane. The function returns a geometrical model that describes the plane.

This function uses the M-estimator SAmple Consensus (MSAC) algorithm to find the plane. The MSAC algorithm is a variant of the RANdom SAmple Consensus (RANSAC) algorithm.

`model = pcfitplane(ptCloudIn,maxDistance,referenceVector)` fits a plane to a point cloud that has additional orientation constraints specified by the 1-by-3 `referenceVector` input.

`model = pcfitplane(ptCloudIn,maxDistance,referenceVector, maxAngularDistance)` fits a plane to a point cloud that has a specified maximum angular distance.

`[model,inlierIndices,outlierIndices] = pcfitplane(ptCloudIn, maxDistance)` additionally returns the linear indices to the inlier and outlier points in the point cloud input.

[___ ,meanError] = pcfitplane(ptCloudIn,maxDistance) additionally returns the mean error of the distance of inlier points to the model, using any of the preceding syntaxes.

[___] = pcfitplane(ptCloudIn,maxDistance,Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Detect Multiple Planes from Point Cloud

Load the point cloud.

```
load('object3d.mat')
```

Display and label the point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Original Point Cloud')
```

Original Point Cloud

Set the maximum point-to-plane distance (2cm) for plane fitting.

```
maxDistance = 0.02;
```

Set the normal vector of the plane.

```
referenceVector = [0,0,1];
```

Set the maximum angular distance to 5 degrees.

```
maxAngularDistance = 5;
```

Detect the first plane, the table, and extract it from the point cloud.

```
[model1,inlierIndices,outlierIndices] = pcfitplane(ptCloud,...
            maxDistance,referenceVector,maxAngularDistance);
```

```
plane1 = select(ptCloud,inlierIndices);
remainPtCloud = select(ptCloud,outlierIndices);
```

Set the region of interest to constrain the search for the second plane, left wall.

```
roi = [-inf,inf;0.4,inf;-inf,inf];
sampleIndices = findPointsInROI(remainPtCloud,roi);
```

Detect the left wall and extract it from the remaining point cloud.

```
[model2,inlierIndices,outlierIndices] = pcfitplane(remainPtCloud,...
            maxDistance,'SampleIndices',sampleIndices);
plane2 = select(remainPtCloud,inlierIndices);
remainPtCloud = select(remainPtCloud,outlierIndices);
```

Plot the two planes and the remaining points.

```
figure
pcshow(plane1)
title('First Plane')
```

First Plane

```
figure
pcshow(plane2)
title('Second Plane')
```

Second Plane

```
figure
pcshow(remainPtCloud)
title('Remaining Point Cloud')
```

Remaining Point Cloud

- "3-D Point Cloud Registration and Stitching"

Input Arguments

ptCloudIn — Point cloud
pointCloud object

Point cloud, specified as a pointCloud object.

maxDistance — Maximum distance from an inlier point to the plane
scalar value

Maximum distance from an inlier point to the plane, specified as a scalar value. Specify the distance in units that are consistent with the units you are using for the point cloud.

Data Types: `single` | `double`

referenceVector — Reference orientation constraint
1-by-3 vector

Reference orientation constraint, specified as a 1-by-3 vector.

Data Types: `single` | `double`

maxAngularDistance — Maximum absolute angular distance
5 degrees (default) | scalar value

Maximum absolute angular distance between the normal vector of the fitted plane and the reference orientation, specified as a scalar value in degrees.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: `'SampleIndices',[]`.

SampleIndices — Linear indices of points to be sampled
[ ] (default) | column vector

Linear indices of points to sample in the input point cloud, specified as the comma-separated pair consisting of `'SampleIndices'` and a column vector. An empty vector means that all points are candidates to sample in the RANSAC iteration to fit the plane. When you specify a subset, only points in the subset are sampled to fit a model.

Providing a subset of points can significantly speed up the process and reduce the number of trials. You can generate the indices vector using the `findPointsInROI` method of the `pointCloud` object.

MaxNumTrials — Maximum number of random trials
1000 (default) | positive integer

Maximum number of random trials for finding inliers, specified as the comma-separated pair consisting of `'MaxNumTrials'` and a positive integer. Increasing this value makes the output more robust but adds additional computations.

`Confidence` — Confidence percentage for finding maximum number of inliers
99 (default) | numeric scalar

Confidence percentage for finding maximum number of inliers, specified as the comma-separated pair consisting of `'Confidence'` and a numeric scalar, in the range [0 100]. Increasing this value makes the output more robust but adds additional computations.

Output Arguments

`model` — Geometric model of plane
`planeModel` object

Geometric model of plane, returned as a `planeModel` object.

When the input point cloud does not contain enough valid points, or when the function cannot find enough inlier points, the coefficients for the output model are set to zero.

`inlierIndices` — Linear indices of inlier points
column vector

Linear indices of inlier points within the input point cloud, returned as a column vector.

`outlierIndices` — Linear indices of outlier points
column vector

Linear indices of outlier points within the input point cloud, returned as a column vector.

`meanError` — Mean square error
scalar value

Mean error of the distance of inlier points to the model, returned as a scalar value.

References

[1] Torr, P. H. S., and A. Zisserman. "MLESAC: A New Robust Estimator with Application to Estimating Image Geometry." *Computer Vision and Image Understanding*. 2000.

See Also

affine3d | pcdenoise | pcfitcylinder | pcfitsphere | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pctransform | pcwrite | planeModel | pointCloud

Topics

"3-D Point Cloud Registration and Stitching"

Introduced in R2015b

pcfitsphere

Fit sphere to 3-D point cloud

Syntax

```
model = pcfitsphere(ptCloudIn,maxDistance)
[model,inlierIndices,outlierIndices] = pcfitsphere(ptCloudIn,
maxDistance)
[ ___ ,meanError] = pcfitsphere(ptCloudIn,maxDistance)
[ ___ ] = pcfitsphere( ___ ,Name,Value)
```

Description

`model = pcfitsphere(ptCloudIn,maxDistance)` fits a sphere to a point cloud tha has a maximum allowable distance from an inlier point to the sphere. The function returns a geometrical model that describes the sphere.

This function uses the M-estimator SAmple Consensus (MSAC) algorithm to find the sphere. The MSAC algorithm is a variant of the RANdom SAmple Consensus (RANSAC) algorithm.

`[model,inlierIndices,outlierIndices] = pcfitsphere(ptCloudIn, maxDistance)` additionally returns linear indices to the inlier and outlier points in the point cloud input.

`[ ___ ,meanError] = pcfitsphere(ptCloudIn,maxDistance)` additionally returns the mean error of the distance of inlier points to the model, using any of the preceding syntaxes.

`[ ___ ] = pcfitsphere( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Detect Sphere from Point Cloud

Load data file.

```
load('object3d.mat');
```

Display original point cloud.

```
figure
pcshow(ptCloud)
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
title('Original Point Cloud')
```
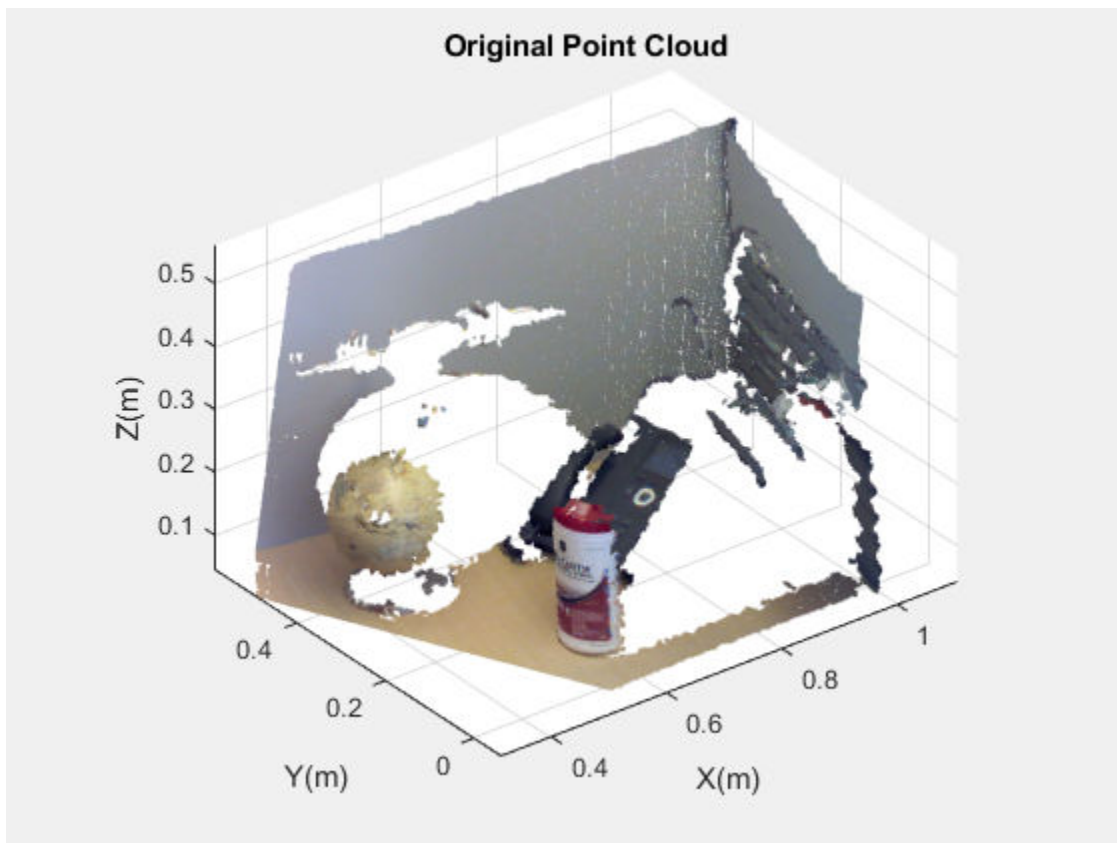
Set a maximum point-to-sphere distance of 1cm for sphere fitting.

```
maxDistance = 0.01;
```

Set the roi to constrain the search.

```
roi = [-inf,0.5,0.2,0.4,0.1,inf];
sampleIndices = findPointsInROI(ptCloud,roi);
```

Detect the sphere, a globe, and extract it from the point cloud.

```
[model,inlierIndices] = pcfitsphere(ptCloud,maxDistance,...
            'SampleIndices',sampleIndices);
globe = select(ptCloud,inlierIndices);
```

Plot the globe.

```
hold on
plot(model)
```

Original Point Cloud
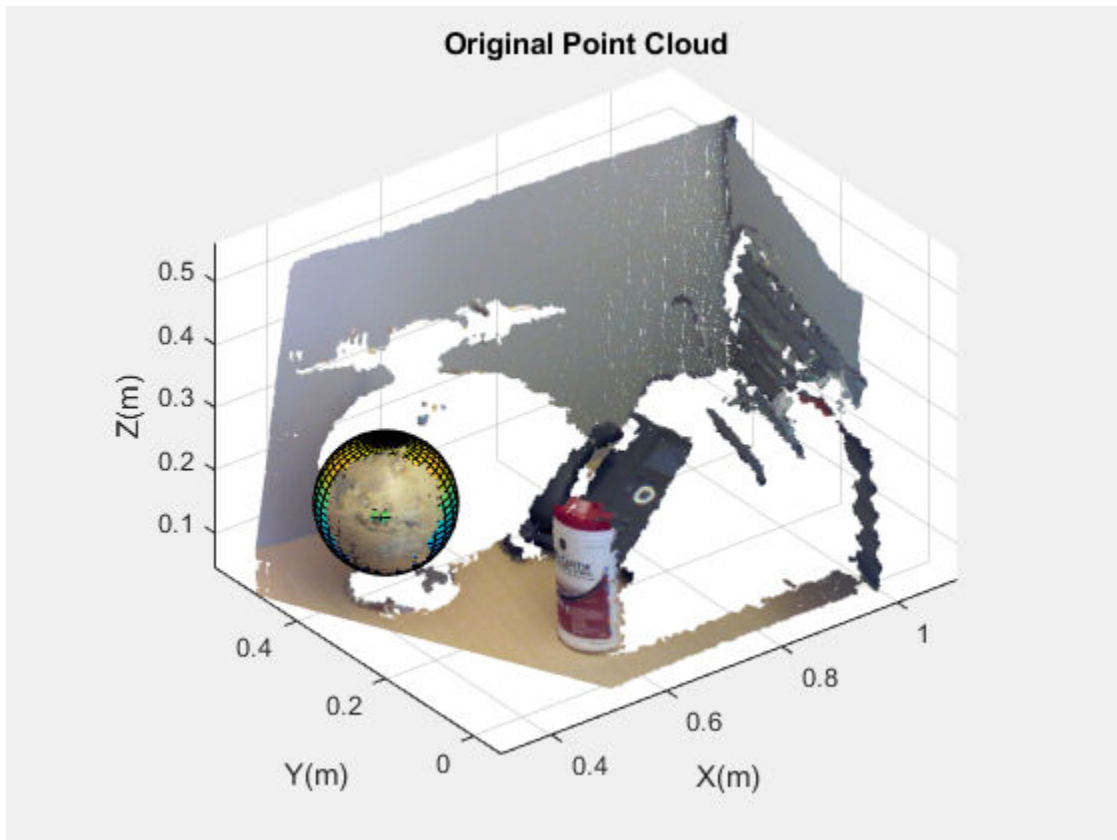
```
figure
pcshow(globe)
title('Globe Point Cloud')
```
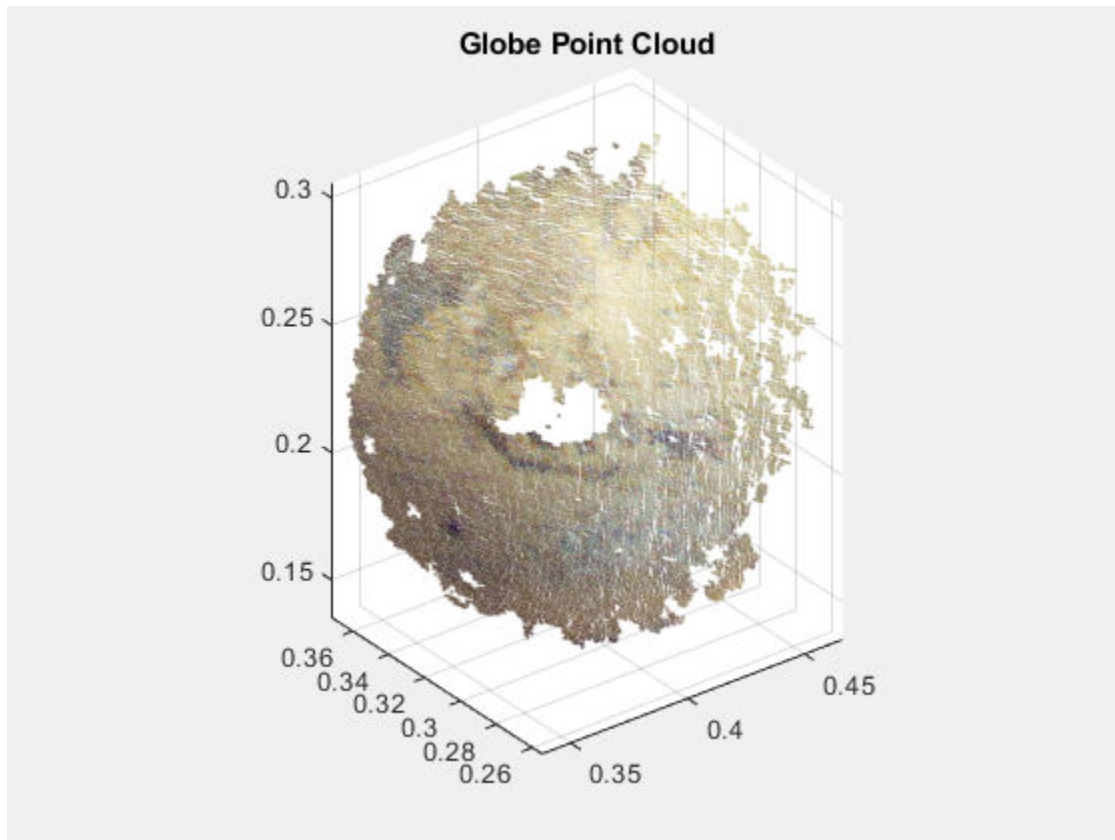
- "3-D Point Cloud Registration and Stitching"

Input Arguments

ptCloudIn — Point cloud
pointCloud object

Point cloud, specified as a pointCloud object.

maxDistance — Maximum distance from an inlier point to the sphere
scalar value

Maximum distance from an inlier point to the sphere, specified as a scalar value. Specify the distance in units that are consistent with the units you are using for the point cloud.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'SampleIndices',[]`.

SampleIndices — Linear indices of points to be sampled
`[]` (default) | column vector

Linear indices of points to sample in the input point cloud, specified as the comma-separated pair consisting of `'SampleIndices'` and a column vector. An empty vector means that all points are candidates to sample in the RANSAC iteration to fit the sphere. When you specify a subset, only points in the subset are sampled to fit a model. Providing a subset of points can significantly speed up the process and reduce the number of trials. You can generate the indices vector using the `findPointsInROI` method of the `pointCloud` object.

MaxNumTrials — Maximum number of random trials
`1000` (default) | positive integer

Maximum number of random trials for finding inliers, specified as the comma-separated pair consisting of `'MaxNumTrials'` and a positive integer. Increasing this value makes the output more robust but adds additional computations.

Confidence — Confidence percentage for finding maximum number of inliers
`99` (default) | numeric scalar in the range [0,100]

Confidence percentage for finding maximum number of inliers, specified as the comma-separated pair consisting of `'Confidence'` and a numeric scalar representing percentage, in the range [0,100]. Increasing this value makes the output more robust but adds additional computations.

Output Arguments

`model` — Geometric model of sphere
`sphereModel` object

Geometric model of sphere, returned as a `sphereModel` object.

When the input point cloud does not contain enough valid points, or when the function cannot find enough inlier points, the coefficients for the output model are set to zero.

`inlierIndices` — Linear indices of inlier points
column vector

Linear indices of inlier points within the input point cloud, returned as a column vector.

`outlierIndices` — Linear indices of outlier points
column vector

Linear indices of outlier points within the input point cloud, returned as a column vector.

`meanError` — Mean square error
scalar value

Mean error of the distance of inlier points to the model, returned as a scalar value.

References

[1] Torr, P. H. S. and A. Zisserman. "MLESAC: A New Robust Estimator with Application to Estimating Image Geometry." *Computer Vision and Image Understanding*. 2000.

See Also

`affine3d` | `pcdenoise` | `pcfitcylinder` | `pcfitplane` | `pcmerge` | `pcplayer` | `pcread` | `pcregistericp` | `pcshow` | `pctransform` | `pcwrite` | `planeModel` | `pointCloud`

Topics
"3-D Point Cloud Registration and Stitching"

Introduced in R2015b

pixelLabelImageSource

(To be removed) Create datastore for semantic segmentation networks

---

Note `pixelLabelImageSource` will be removed in a future release. Create a pixel label image datastore using the `pixelLabelImageDatastore` function instead.

Syntax

```
pximds = pixelLabelImageSource(gTruth)
pximds = pixelLabelImageSource(imds,pxds)
pximds = pixelLabelImageSource( ___ ,Name,Value)
```

Description

`pximds = pixelLabelImageSource(gTruth)` returns a pixel label image datastore for training a semantic segmentation network based on the input array of `groundTruth` objects. Use the output `pixelLabelImageDatastore` object with the Neural Network Toolbox function `trainNetwork` to train convolutional neural networks for semantic segmentation.

`pximds = pixelLabelImageSource(imds,pxds)` returns a pixel label image datastore based on the input image datastore and the pixel label datastore objects. `imds` is an `ImageDatastore` object that represents the training input to the network. `pxds` is a `PixelLabelDatastore` object that represents the required network output.

`pximds = pixelLabelImageSource( ___ ,Name,Value)` sets properties of the returned pixel label image datastore using name-value pairs. You can specify multiple name-value pairs. Enclose each argument name in quotes.

Examples

Augment Data While Training Using Pixel Label Image Source

Configure a pixel label image datastore to augment data while training. This example uses the `pixelLabelImageSource` function to create a pixel label image datastore object. See "Augment Data While Training" on page 2-12 for an example of the recommended workflow, which uses the `pixelLabelImageDatastore` function to create a pixel label image datastore object.

Load training images and pixel labels.

```
dataSetDir = fullfile(toolboxdir('vision'),'visiondata','triangleImages');
imageDir = fullfile(dataSetDir,'trainingImages');
labelDir = fullfile(dataSetDir,'trainingLabels');
```

Create an `imageDatastore` object to hold the training images.

```
imds = imageDatastore(imageDir);
```

Define the class names and their associated label IDs.

```
classNames = ["triangle","background"];
labelIDs   = [255 0];
```

Create a `pixelLabelDatastore` object to hold the ground truth pixel labels for the training images.

```
pxds = pixelLabelDatastore(labelDir, classNames, labelIDs);
```

Create an `imageDataAugmenter` object to randomly rotate and mirror image data.

```
augmenter = imageDataAugmenter('RandRotation',[-10 10],'RandXReflection',true)

augmenter =
  imageDataAugmenter with properties:

           FillValue: 0
     RandXReflection: 1
     RandYReflection: 0
        RandRotation: [-10 10]
          RandXScale: [1 1]
          RandYScale: [1 1]
          RandXShear: [0 0]
          RandYShear: [0 0]
     RandXTranslation: [0 0]
```

```
    RandYTranslation: [0 0]
```

Use the `pixelLabelImageSource` function to create a `pixelLabelImageDatastore` object that can be used to train the network with augmented data.

```
plimds = pixelLabelImageSource(imds,pxds,'DataAugmentation',augmenter)

plimds =
  pixelLabelImageDatastore with properties:

                 Images: {200x1 cell}
         PixelLabelData: {200x1 cell}
             ClassNames: {2x1 cell}
       DataAugmentation: [1x1 imageDataAugmenter]
      ColorPreprocessing: 'none'
             OutputSize: []
         OutputSizeMode: 'resize'
          MiniBatchSize: 1
        NumObservations: 200
    DispatchInBackground: 0
```

Input Arguments

gTruth — Ground truth data
groundTruth object

Ground truth data, specified as a `groundTruth` object. You can use the **Image Labeler** to create a `groundTruth` object for training a semantic segmentation network.

imds — Collection of images
ImageDatastore object

Collection of images, specified as an `ImageDatastore` object.

pxds — Collection of pixel labeled images
PixelLabelDatastore object

Collection of pixel labeled images, specified as a `PixelLabelDatastore` object. The object contains the pixel labeled images for each image contained in the `imds` input object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'ColorProcessing','rgb2gray'`

DataAugmentation — Image data augmentation
`'none'` (default) | `imageDataAugmenter` object

Image data augmentation, specified as `'none'` or an `imageDataAugmenter` object. This argument sets the `DataAugmentation` on page 2-0 property of the returned pixel label image datastore, `pximds`.

ColorPreprocessing — Color channel preprocessing
`'none'` (default) | `'gray2rgb'` | `'rgb2gray'`

Color channel preprocessing, specified as `'none'`, `'gray2rgb'`, or `'rgb2gray'`. This argument sets the `ColorPreprocessing` on page 2-0 property of the returned pixel label image datastore, `pximds`. Use this property when you need the image data created by the data source must be only color or grayscale, but the training set includes both. Suppose you need to train a network that expects color images but some of your training images are grayscale. Set `ColorPreprocessing` to `'gray2rgb'` to replicate the color channels of the grayscale images in the input image set. Using the `'gray2rgb'` option creates M-by-N-by-3 output images.

OutputSize — Size of images produced by data source
`[]` (default) | 2-element vector

Size of images produced by data source, specified as a 2-element vector indicating the number of rows and columns. This argument sets the `OutputSize` on page 2-0 property of the returned pixel label image datastore, `pximds`. When you specify the `OutputSize`, image sizes are adjusted as necessary. By default, this property is empty, which means that the images are not adjusted.

OutputSizeMode — Technique used to adjust image sizes
`'false'` (default) | `'resize'` | `'centercrop'` | `'randcrop'`

Technique used to adjust image sizes, specified as `'false'`, `'resize'`, `'centercrop'`, or `'randcrop'`. This argument sets the `OutputSizeMode` on page 2-0 property

of the returned pixel label image datastore, `pximds`. This property applies only when you set `OutputSize` to a value other than `[]`.

BackgroundExecution — Preprocess images in parallel
`false` (default) | `true`

Preprocess images in parallel, specified as `false` or `true`. This argument sets the `DispatchInBackground` on page 2-0 property of the returned pixel label image datastore object, `pximds`. If `BackgroundExecution` is `true` and you have Parallel Computing Toolbox, then the pixel label image datastore asynchronously reads, augments, and queues pixel labeled images for use in training.

Output Arguments

pximds — Pixel label image datastore
`pixelLabelImageDatastore` object

Pixel label image datastore, returned as a `pixelLabelImageDatastore` object.

See Also
`pixelLabelImageDatastore`

Introduced in R2017b

pixelLabelTrainingData

Create training data for semantic segmentation from ground truth

Syntax

```
[imds,pxds] = pixelLabelTrainingData(gTruth)
[imds,pxds] = pixelLabelTrainingData(gTruth,Name,Value)
```

Description

`[imds,pxds] = pixelLabelTrainingData(gTruth)` creates image datastore `imds` and pixel label datastore `pxds` from the specified ground truth. Use these datastores with the `trainNetwork` function to train deep learning segmentation networks, or with the `evaluateSemanticSegmentation` function to evaluate the result from deep learning or classical segmentation methods.

This function supports parallel computing using multiple MATLAB workers. Enable parallel computing using the "Computer Vision System Toolbox Preferences" dialog box.

`[imds,pxds] = pixelLabelTrainingData(gTruth,Name,Value)` returns image and pixel label datastores with additional options specified by one or more name-value pair arguments.

- If the `groundTruth` objects in `gTruth` were created using a video file or a custom data source, then you can specify any combination of name-value pair arguments.

- If the `groundTruth` objects were created from an image collection or image sequence data source, then you can specify only the `SamplingFactor` name-value pair argument

Examples

Prepare Data for Evaluating Semantic Segmentation Algorithm

Load a `groundTruth` object named `gTruth`. The ground truth contains pixel labels for triangles and background, annotated on a video with 100 frames.

```
visiondataPath = fullfile(matlabroot,'toolbox','vision','visiondata');
addpath(fullfile(visiondataPath,'triangleImages','testImages'));
load(fullfile(visiondataPath,'triangleImages','triangleGroundTruth.mat'));
```

Create a temporary folder.

```
tempf = 'C:\temp\';
mkdir(tempf)
```

Create an `imageDatastore` and a `pixelLabelDatastore` from the video file and corresponding pixel labels. Write every fifth image to the temporary folder.

```
[imds,pxdsTruth] = pixelLabelTrainingData(gTruth,...
    'SamplingFactor',5,'WriteLocation',tempf);

Write images extracted for training to folder:
    C:\temp\

Writing 20 images extracted from triangleVideo.avi...Completed.
```

Confirm that the temporary folder contains every fifth image.

```
imds.Files

ans = 20×1 cell array
    {'C:\temp\triangleVideo01.png'}
    {'C:\temp\triangleVideo06.png'}
    {'C:\temp\triangleVideo11.png'}
    {'C:\temp\triangleVideo16.png'}
    {'C:\temp\triangleVideo21.png'}
    {'C:\temp\triangleVideo26.png'}
    {'C:\temp\triangleVideo31.png'}
    {'C:\temp\triangleVideo36.png'}
    {'C:\temp\triangleVideo41.png'}
    {'C:\temp\triangleVideo46.png'}
    {'C:\temp\triangleVideo51.png'}
    {'C:\temp\triangleVideo56.png'}
    {'C:\temp\triangleVideo61.png'}
    {'C:\temp\triangleVideo66.png'}
    {'C:\temp\triangleVideo71.png'}
```

```
{'C:\temp\triangleVideo76.png'}
{'C:\temp\triangleVideo81.png'}
{'C:\temp\triangleVideo86.png'}
{'C:\temp\triangleVideo91.png'}
{'C:\temp\triangleVideo96.png'}
```

Remove the video and images from the path.

```
rmpath(fullfile(visiondataPath,'triangleImages','testImages'));
delete([tempf,'triangleVideo*.png'])
```

Input Arguments

gTruth — Ground truth data
scalar groundTruth object | array of groundTruth objects

Ground truth data, specified as a scalar groundTruth object or an array of groundTruth objects. When gTruth is an array of groundTruth objects, the LabelDefinitions property of each object must contain the same pixel label names.

If you use custom data sources in gTruth with parallel computing enabled, then the reader function is expected to work with a pool of MATLAB workers to read images from the data source in parallel.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'SamplingFactor',5

SamplingFactor — Factor at which to subsample images
1 (default) | integer | vector of integers

Factor at which to subsample images in the ground truth data source, specified as the comma-separated pair consisting of 'SamplingFactor' and an integer or a vector of integers. For a sampling factor of *N*, the returned image datastore imds includes every

*N*th image in the ground truth data source. Ground truth images with empty pixel labels are ignored.

SamplingFactor	Sampling Factor Applied
Integer	All ground truth data sources in `gTruth` are sampled with the same sampling factor, *N*.
Vector of integers	The *k*th ground truth data source in `gTruth` is sampled with a sampling factor of *N*(*k*).

WriteLocation — Folder name
pwd (current working folder) (default) | string scalar | character vector

Folder name to which extracted images are written, specified as the comma-separated pair consisting of `'WriteLocation'` and a string scalar or character vector. The specified folder must exist and have write permissions. This argument applies only for `groundTruth` objects created using a video file or a custom data source.

ImageFormat — Image file format
PNG (default) | string scalar | character vector

Image file format, specified as the comma-separated pair consisting of `'ImageFormat'` and a string scalar or character vector. File formats must be supported by `imwrite`. This argument applies only for `groundTruth` objects created using a video file or a custom data source.

NamePrefix — Prefix applied to file names
string scalar | character vector

Prefix applied to file names of the output images, specified as the comma-separated pair consisting of `'NamePrefix'` and a string scalar or character vector. The image files are named as:

```
<name_prefix><image_number>.<image_format>
```

The default value of `NamePrefix` is the name of the video file or data source containing the images. This argument applies only for `groundTruth` objects created using a video file or a custom data source.

Verbose — Display training progress
true (default) | false

Display training progress on the MATLAB command line, specified as the comma-separated pair consisting of `'Verbose'` and `true` or `false`. This argument applies only for `groundTruth` objects created using a video file or a custom data source.

Output Arguments

imds — Collection of images
ImageDatastore object

Collection of images extracted from the ground truth, `gTruth`, returned as an `ImageDatastore` object. Each image in `imds` has annotations with at least one class of pixel labels. `imds` ignores images that with no annotations.

pxds — Collection of pixel-labeled images
PixelLabelDatastore object

Collection of pixel-labeled images extracted from the ground truth, `gTruth`, returned as a `PixelLabelDatastore` object. The object contains a categorical matrix of pixel labels for each image contained in the image datastore, `imds`. Labels that do not correspond to pixel labels are ignored.

See Also

Apps
Ground Truth Labeler | **Image Labeler**

Functions
evaluateSemanticSegmentation | objectDetectorTrainingData | semanticseg

Objects
ImageDatastore | PixelLabelDatastore | PixelLabelImageDatastore | groundTruth

Introduced in R2018a

plotCamera

Plot a camera in 3-D coordinates

Syntax

```
cam = plotCamera()
cam = plotCamera(cameraTable)
cam = plotCamera(Name,Value)
```

Description

`cam = plotCamera()` creates a camera visualization object rendered in the current axes.

`cam = plotCamera(cameraTable)` returns an array of camera visualization objects rendered in the current axes.

`cam = plotCamera(Name,Value)` creates a camera visualization object with the property values specified by one or more `Name,Value` pair arguments.

Examples

Create Animated Camera Plot

Plot a camera pointing along the *y*-axis.

```
R = [1     0     0;
     0     0    -1;
     0     1     0];
```

Set the opacity of the camera to zero for faster animation.

```
cam = plotCamera('Location',[10 0 20],'Orientation',R,'Opacity',0);
```
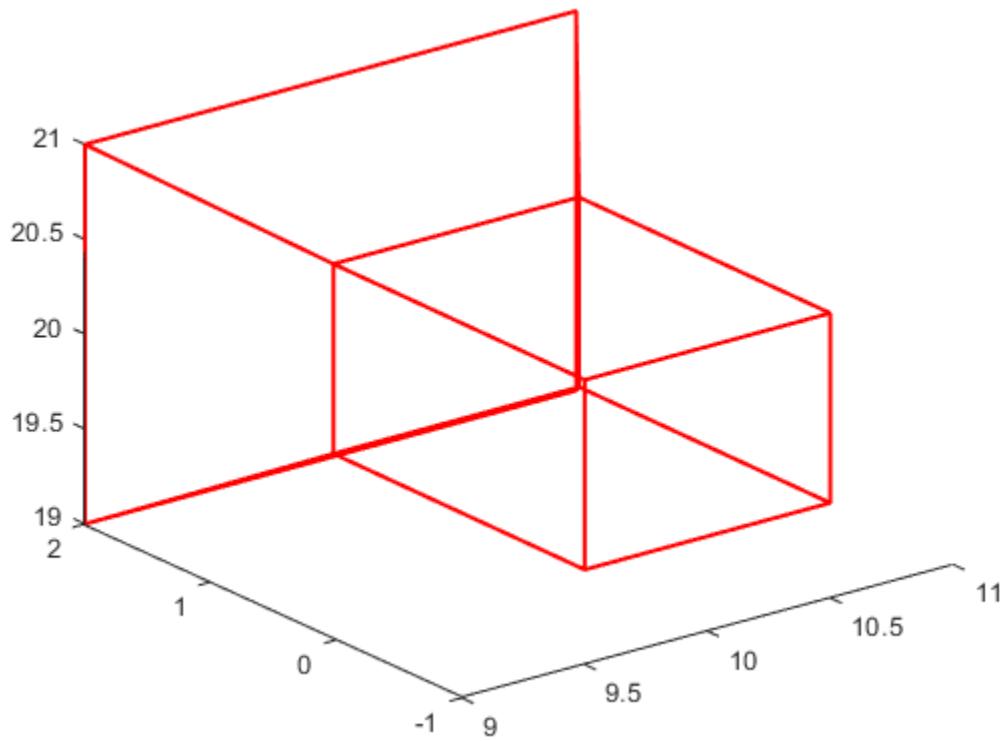
Set the view properties.

```
grid on
axis equal
axis manual
```
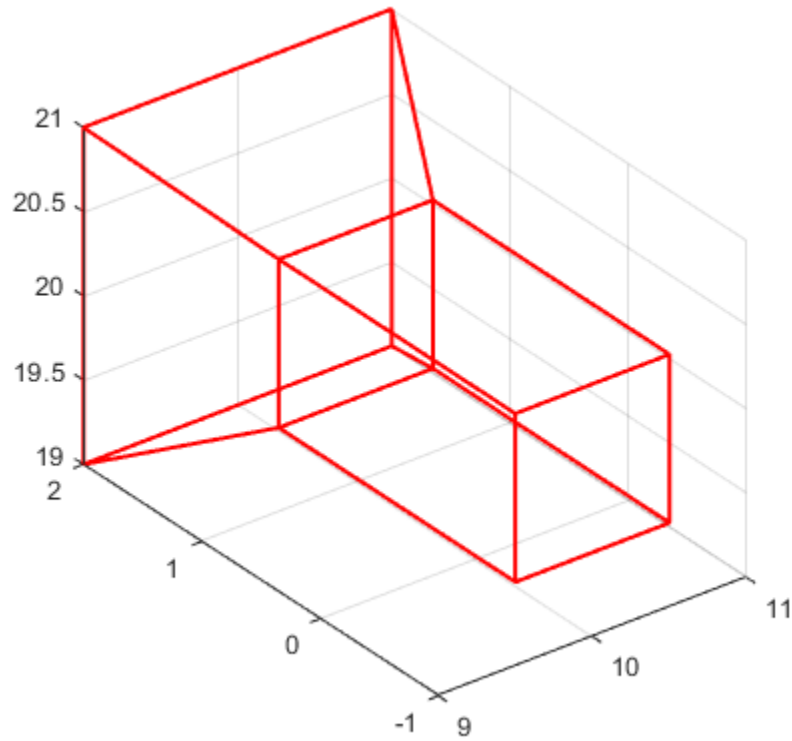
Make the space large enough for the animation.

```
xlim([-15,20]);
ylim([-15,20]);
zlim([15,25]);
```
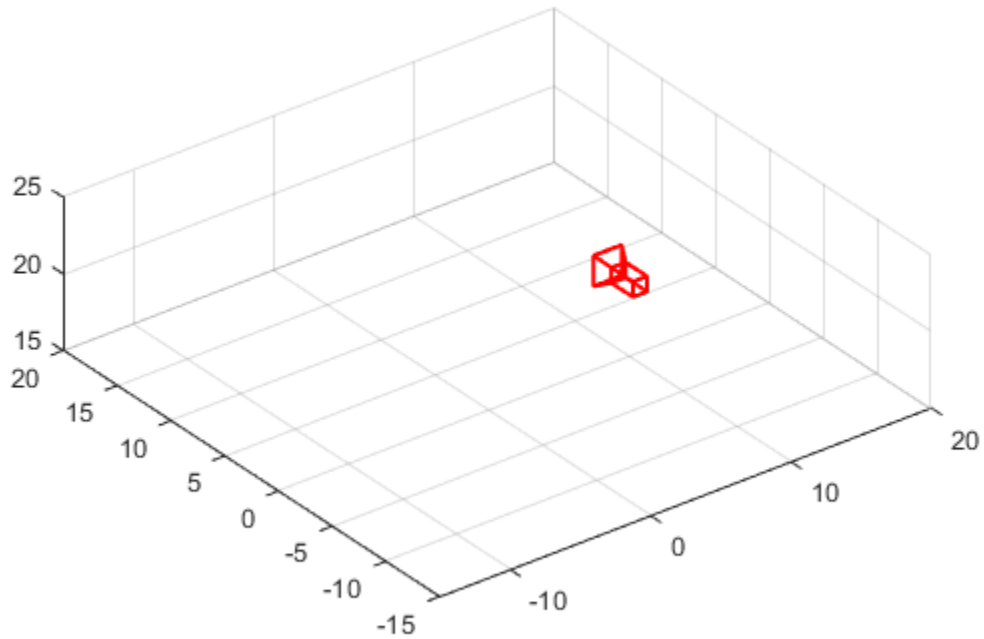
Rotate the camera about the camera's *y*-axis.

```
for theta = 0:pi/64:10*pi
    T = [cos(theta)  0  sin(theta);
            0        1     0;
        -sin(theta) 0  cos(theta)];
    cam.Orientation = T * R;
    cam.Location = [10 * cos(theta),10 * sin(theta),20];
    drawnow();
end
```
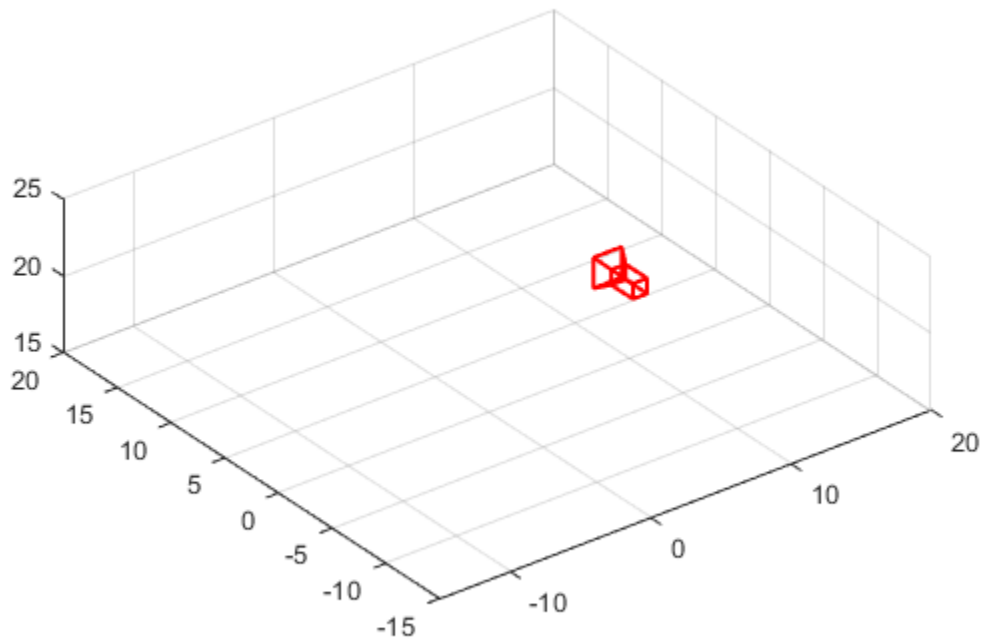
Visualize Camera Extrinsics

Create a set of calibration images.

```
images = imageSet(fullfile(toolboxdir('vision'),'visiondata',...
    'calibration','slr'));
```

Detect the checkerboard corners in the images.

```
[imagePoints, boardSize] = detectCheckerboardPoints(images.ImageLocation);
```

Generate the world coordinates of the checkerboard corners in the pattern-centric coordinate system, with the upper-left corner at (0,0). Set the square size to 29 mm.

```
squareSize = 29;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the camera.

```
cameraParams = estimateCameraParameters(imagePoints,worldPoints);
```

Load an image at its new location.

```
imOrig = imread(fullfile(toolboxdir('vision'),'visiondata',...
    'calibration','slr','image9.jpg'));
figure; imshow(imOrig,'InitialMagnification',50);
title('Input Image');
```


Input Image
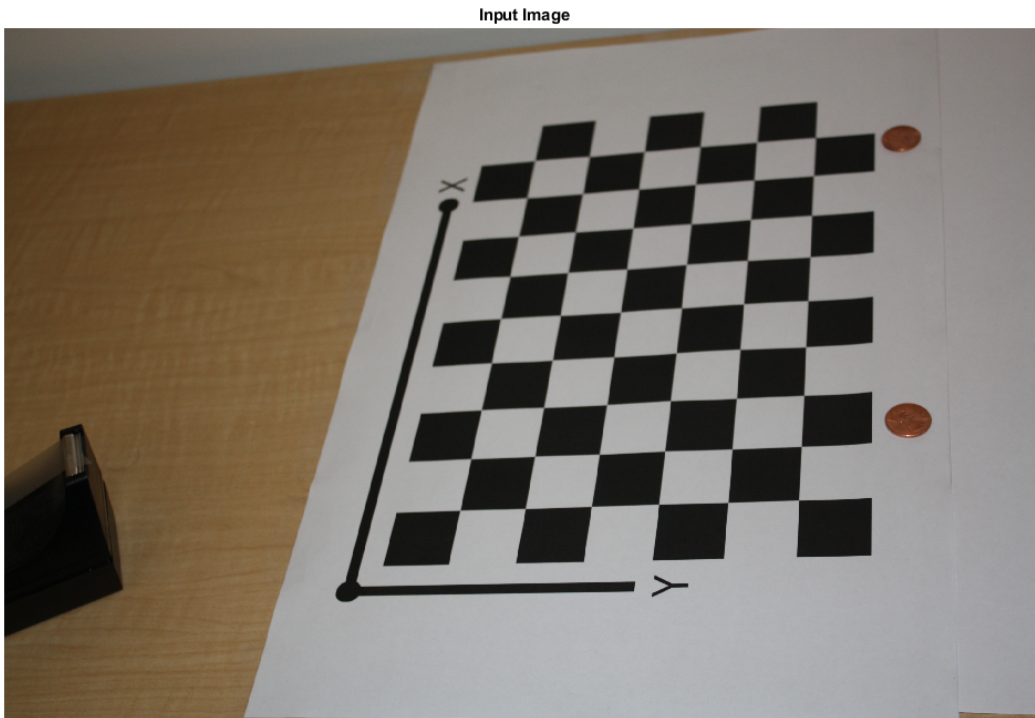
Undistort the image.

```
im = undistortImage(imOrig,cameraParams);
```

Find the reference object in the new image.

```
[imagePoints,boardSize] = detectCheckerboardPoints(im);
```

Compute the new extrinsics.

```
[rotationMatrix,translationVector] = extrinsics(imagePoints,...
    worldPoints,cameraParams);
```

Plot the world points.

```
figure;
plot3(worldPoints(:,1),worldPoints(:,2),zeros(size(worldPoints, 1),1),'*');
hold on
```
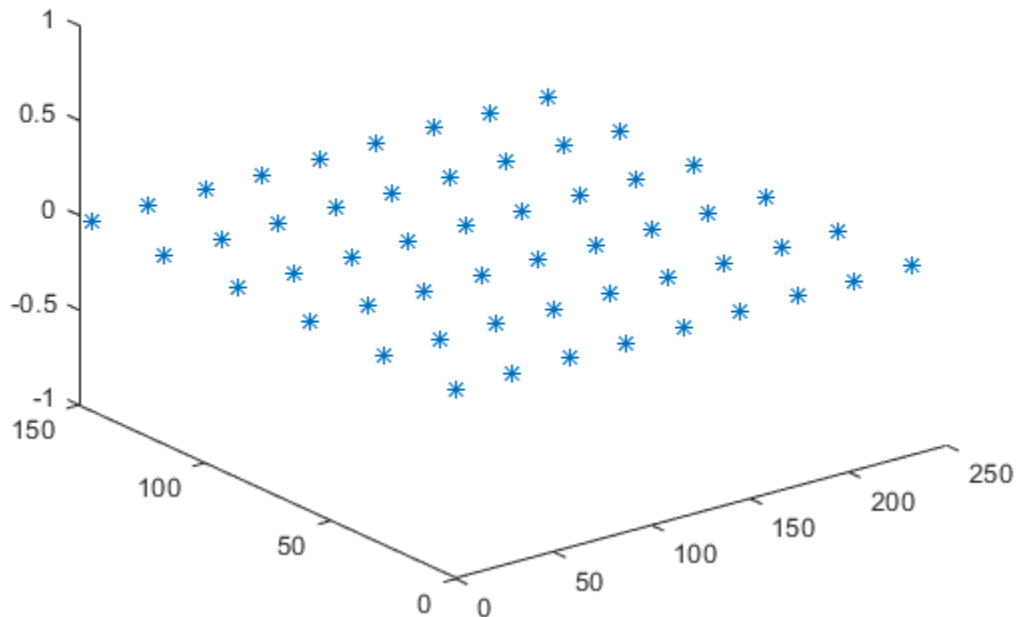
Mark the origin.

```
plot3(0,0,0,'g*');
```
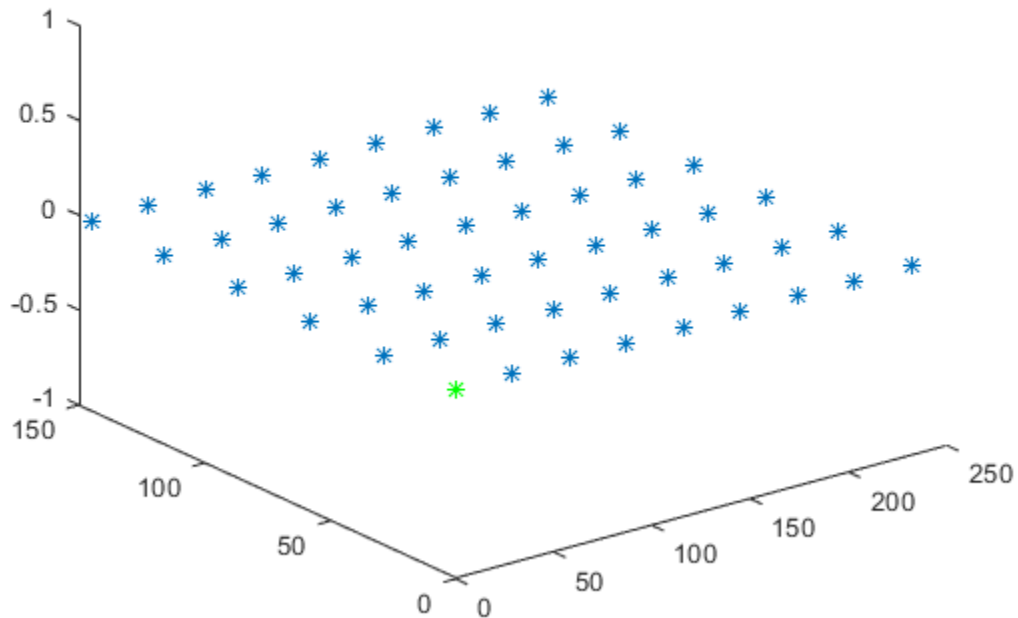

Compute the camera location and orientation.

```
orientation = rotationMatrix';
location = -translationVector * orientation;
```

Plot the camera.

```
cam = plotCamera('Location',location,'Orientation',orientation,'Size',20);
```
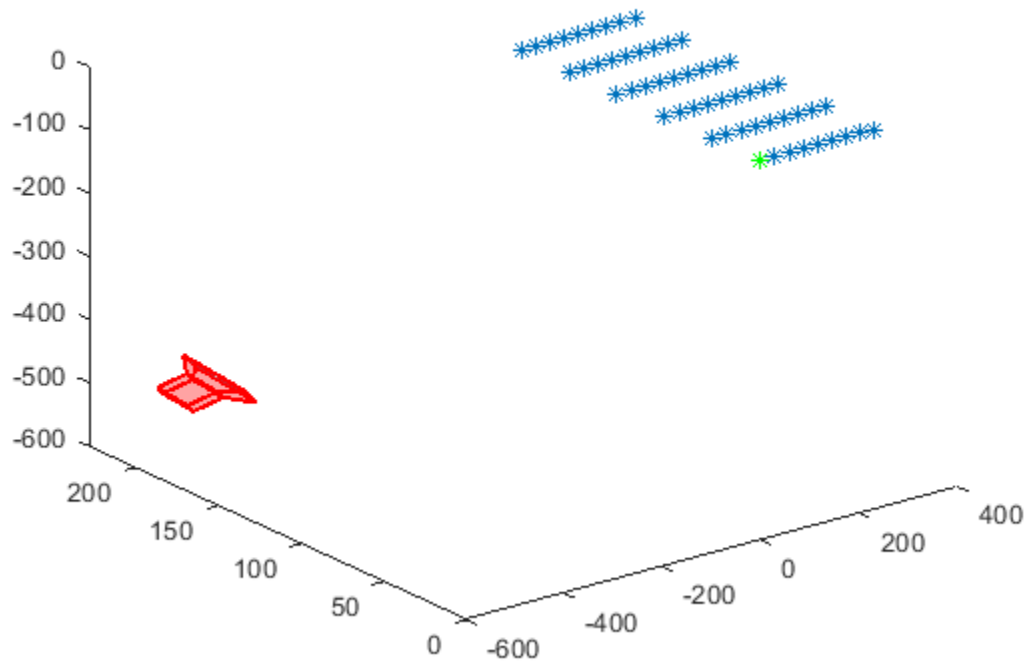
Make the z-axis point down.

```
set(gca,'CameraUpVector',[0 0 -1]);
```
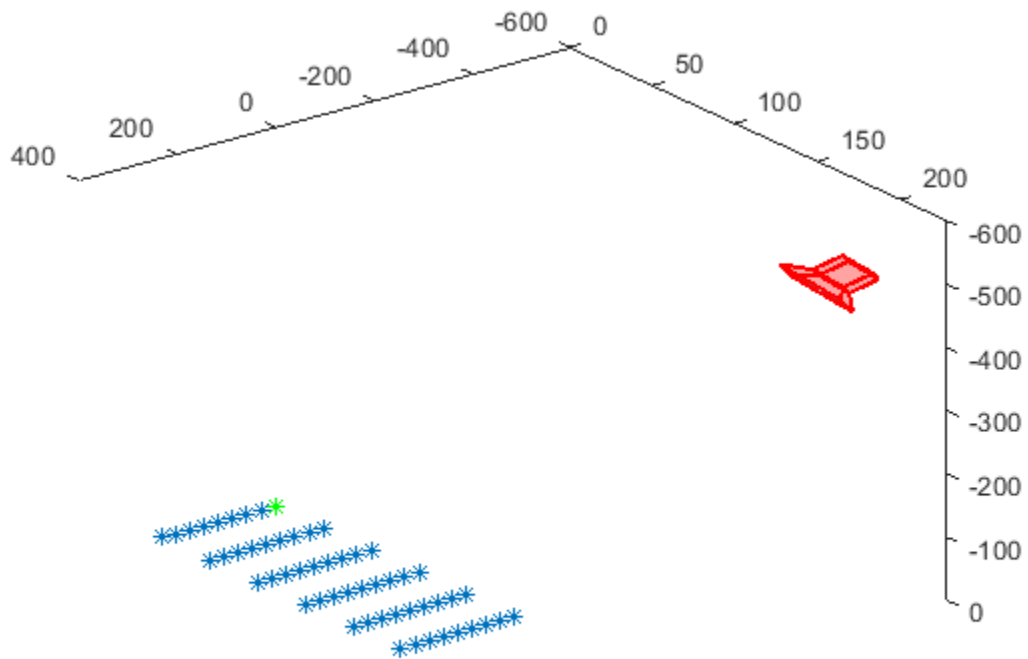
Set the view parameters.

```
camorbit(gca,-110,60,'data',[0 0 1]);
axis equal
grid on
```

3-597
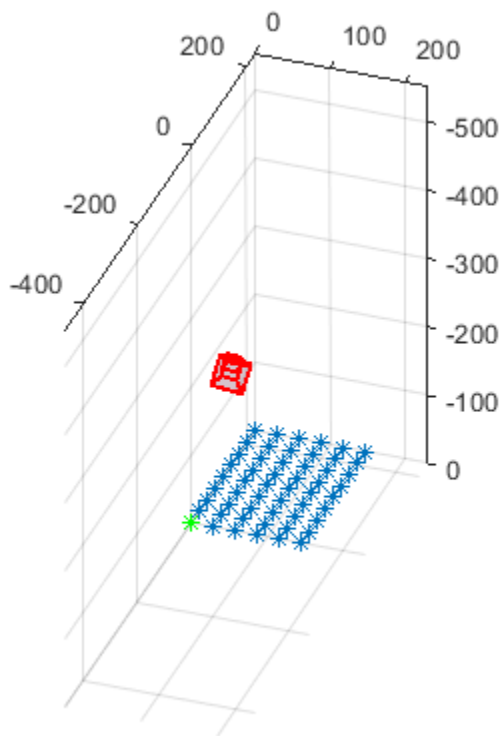
Turn on 3-D rotation.

```
cameratoolbar('SetMode','orbit');
```
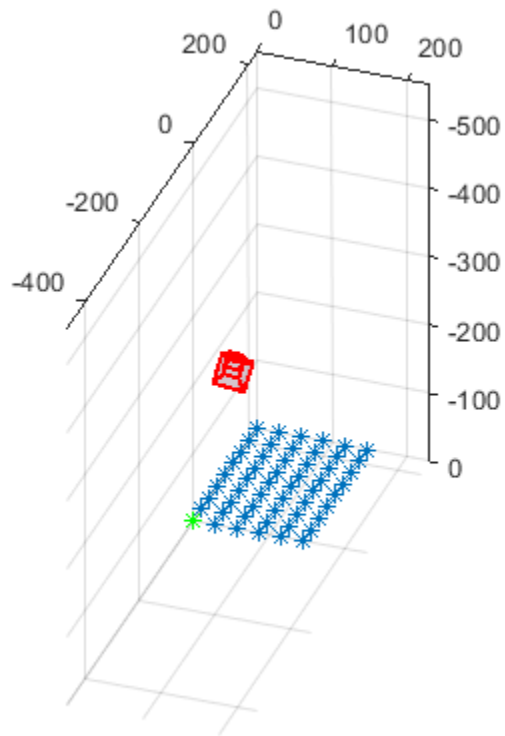
Label the axes.

```
xlabel('X (mm)');
ylabel('Y (mm)');
zlabel('Z (mm)');
```
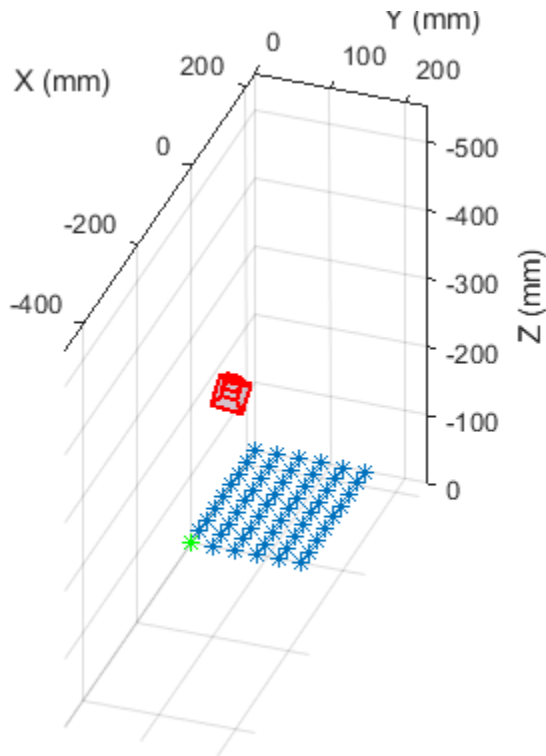
• "Structure From Motion From Two Views"

Input Arguments

cameraTable — Camera visualization object properties
table

Camera visualization object properties, specified as a table. The columns contain the
Name,Value properties of the camera visualization object except for Parent, which
specifies the axes for display. If the table contains a 'ViewId' column, then the view IDs
are used as camera labels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Location',[0,0,0]`

Location — Camera location coordinates
`[0,0,0]` (default) | three-element vector

Camera location coordinates, specified as the comma-separated pair consisting of `'Location'` and a three-element vector. The [x, y, z] coordinates are specified in the data units of the parent axes.

Orientation — Matrix orientation
`eye(3)` (default) | 3-by-3 3-D rotation matrix

Matrix orientation, specified as the comma-separated pair consisting of `'Orientation'` and a 3-by-3 3-D rotation matrix.

Size — Camera base width
`1` | scalar

Camera base width, specified as the comma-separated pair consisting of `'Size'` and a scalar.

Label — Camera label
`' '` (default) | character vector

Camera label, specified as the comma-separated pair consisting of `'Label'` and a character vector.

Color — Camera color
`[1 0 0]` (default) | character vector | three-element vector

Camera color, specified as the comma-separated pair consisting of `'Color'` and a character vector or a three-element vector of RGB values in the range [0 1]. See `colorspec` for more information on how to specify an RGB color.

Opacity — Camera opacity
`0.2` | scalar in the range [0 1]

Camera opacity, specified as the comma-separated pair consisting of `'Opacity'` and a scalar in the range [0 1].

`Visible` — Camera visibility
`true` (default) | `false`

Camera visibility, specified as the comma-separated pair consisting of `'Visible'` and the logical `true` or `false`.

`AxesVisible` — Camera axes visibility
`false` (default) | `true`

Camera axes visibility, specified as the comma-separated pair consisting of `'AxesVisible'` and the logical `true` or `false`.

`ButtonDownFcn` — Callback function
`''` | function name

Callback function, specified as the comma-separated pair consisting of `'ButtonDownFcn'` and a function name that executes when you click the camera.

`Parent` — Output axes
`gca` handle

Output axes, specified as the comma-separated pair consisting of `'Parent'` and an axes handle. The default is set to the current axes handle, `gca`.

See Also

extrinsics | showExtrinsics

Topics
"Structure From Motion From Two Views"
"3-D Coordinate Systems"
"Single Camera Calibrator App"
"Stereo Camera Calibrator App"

Introduced in R2015a

reconstructScene

Reconstruct 3-D scene from disparity map

Syntax

```
xyzPoints = reconstructScene(disparityMap,stereoParams)
```

Description

`xyzPoints = reconstructScene(disparityMap,stereoParams)` returns an array of 3-D world point coordinates that reconstruct a scene from a disparity map. The `stereoParams` input must be the same input that you use to rectify the stereo images corresponding to the disparity map.

Examples

Reconstruct 3-D Scene from Disparity Map

Load the stereo parameters.

```
load('webcamsSceneReconstruction.mat');
```

Read in the stereo pair of images.

```
I1 = imread('sceneReconstructionLeft.jpg');
I2 = imread('sceneReconstructionRight.jpg');
```

Rectify the images.

```
[J1, J2] = rectifyStereoImages(I1,I2,stereoParams);
```

Display the images after rectification.

```
figure
imshow(cat(3,J1(:,:,1),J2(:,:,2:3)),'InitialMagnification',50);
```

Compute the disparity.

```
disparityMap = disparity(rgb2gray(J1), rgb2gray(J2));
figure
imshow(disparityMap,[0,64],'InitialMagnification',50);
```

Reconstruct the 3-D world coordinates of points corresponding to each pixel from the disparity map.

```
xyzPoints = reconstructScene(disparityMap,stereoParams);
```

Segment out a person located between 3.2 and 3.7 meters away from the camera.

```
Z = xyzPoints(:,:,3);
mask = repmat(Z > 3200 & Z < 3700,[1,1,3]);
J1(~mask) = 0;
imshow(J1,'InitialMagnification',50);
```

- "Structure From Motion From Two Views"
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

disparityMap — Disparity image
2-*D* array

Disparity image, specified as a 2-D array of disparity values for pixels in image 1 of a stereo pair. The `disparity` function provides the input disparity map.

The map can contain invalid values marked by `-realmax('single')`. These values correspond to pixels in image 1, which the `disparity` function did not match in image 2. The function sets the world coordinates corresponding to invalid disparity to `NaN`.

Pixels with zero disparity correspond to world points that are too far away to measure, given the resolution of the camera. The function sets the world coordinates corresponding to zero disparity to `Inf`.

When you specify the `disparityMap` input as a `double`, the function returns the `pointCloud` as a `double`. Otherwise, the function returns the coordinates as `single`.

Data Types: `single` | `double`

`stereoParams` — Stereo camera system parameters
`stereoParameters` object

Stereo camera system parameters, specified as a `stereoParameters` object.

Data Types: `uint8` | `uint16` | `int16` | `single` | `double`

Output Arguments

`xyzPoints` — Coordinates of world points
M-by-*N*-by-3 array

Coordinates of world points, returned as an *M*-by-*N*-by-3 array. The 3-D world coordinates are relative to the optical center of camera 1 in the stereo system represented by `stereoParams`.

The output array contains the [*x*, *y*, *z*] coordinates of world points that correspond to the pixels in the `disparityMap` input. `xyzPoints`(:, :, 1) contains the *x* world coordinates of points corresponding to the pixels in the disparity map. `xyzPoints`(:, :, 2) contains the *y* world coordinates, and `xyzPoints`(:, :, 3) contains the *z* world coordinates. The 3-D world coordinates are relative to the optical center of camera 1 in the stereo system.

When you specify the `disparityMap` input as `double`, the function returns the `xyzPoints` output as `double`. Otherwise, the function returns it as `single`.

Data Types: `single` | `double`

References

[1] G. Bradski and A. Kaehler, *Learning OpenCV : Computer Vision with the OpenCV Library*, Sebastopol, CA: O'Reilly, 2008.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

See Also
cameraParameters | disparity | estimateCameraParameters |
lineToBorderPoints | rectifyStereoImages | size | stereoParameters

Topics
"Structure From Motion From Two Views"
"Code Generation for Depth Estimation From Stereo Video"
"Coordinate Systems"

Introduced in R2014a

rectifyStereoImages

Rectify a pair of stereo images

Syntax

```
[J1,J2] = rectifyStereoImages(I1,I2,stereoParams)
[J1,J2] = rectifyStereoImages(I1,I2,tform1,tform2)

[J1,J2] = rectifyStereoImages( ___ ,interp)
[J1,J2] = rectifyStereoImages( ___ ,Name,Value)
```

Description

[J1,J2] = rectifyStereoImages(I1,I2,stereoParams) returns undistorted and rectified versions of I1 and I2 input images using the stereo parameters stored in the stereoParams object.

Stereo image rectification projects images onto a common image plane in such a way that the corresponding points have the same row coordinates. This image projection makes the image appear as though the two cameras are parallel. Use the disparity function to compute a disparity map from the rectified images for 3-D scene reconstruction.

[J1,J2] = rectifyStereoImages(I1,I2,tform1,tform2) returns rectified versions of I1 and I2 input images by applying projective transformations tform1 and tform2. The projective transformations are returned by the estimateUncalibratedRectification function.

[J1,J2] = rectifyStereoImages(___ ,interp) additionally specifies the interpolation method to use for rectified images. You can specify the method as 'nearest', 'linear', or 'cubic'.

[J1,J2] = rectifyStereoImages(___ ,Name,Value) uses additional options specified by one or more Name,Value pair arguments.

Examples

Rectify Stereo Images

Specify images containing a checkerboard for calibration.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','stereo');
leftImages = imageDatastore(fullfile(imageDir,'left'));
rightImages = imageDatastore(fullfile(imageDir,'right'));
```

Detect the checkerboards.

```
[imagePoints,boardSize] = detectCheckerboardPoints(...
    leftImages.Files,rightImages.Files);
```

Specify world coordinates of checkerboard keypoints.

```
squareSizeInMillimeters = 108;
worldPoints = generateCheckerboardPoints(boardSize,squareSizeInMillimeters);
```

Read in the images.

```
I1 = readimage(leftImages,1);
I2 = readimage(rightImages,1);
imageSize = [size(I1,1),size(I1,2)];
```

Calibrate the stereo camera system.

```
stereoParams = estimateCameraParameters(imagePoints,worldPoints, ...
                                        'ImageSize',imageSize);
```

Rectify the images using 'full' output view.

```
[J1_full,J2_full] = rectifyStereoImages(I1,I2,stereoParams, ...
  'OutputView','full');
```

Display the result for 'full' output view.

```
figure;
imshow(stereoAnaglyph(J1_full,J2_full));
```
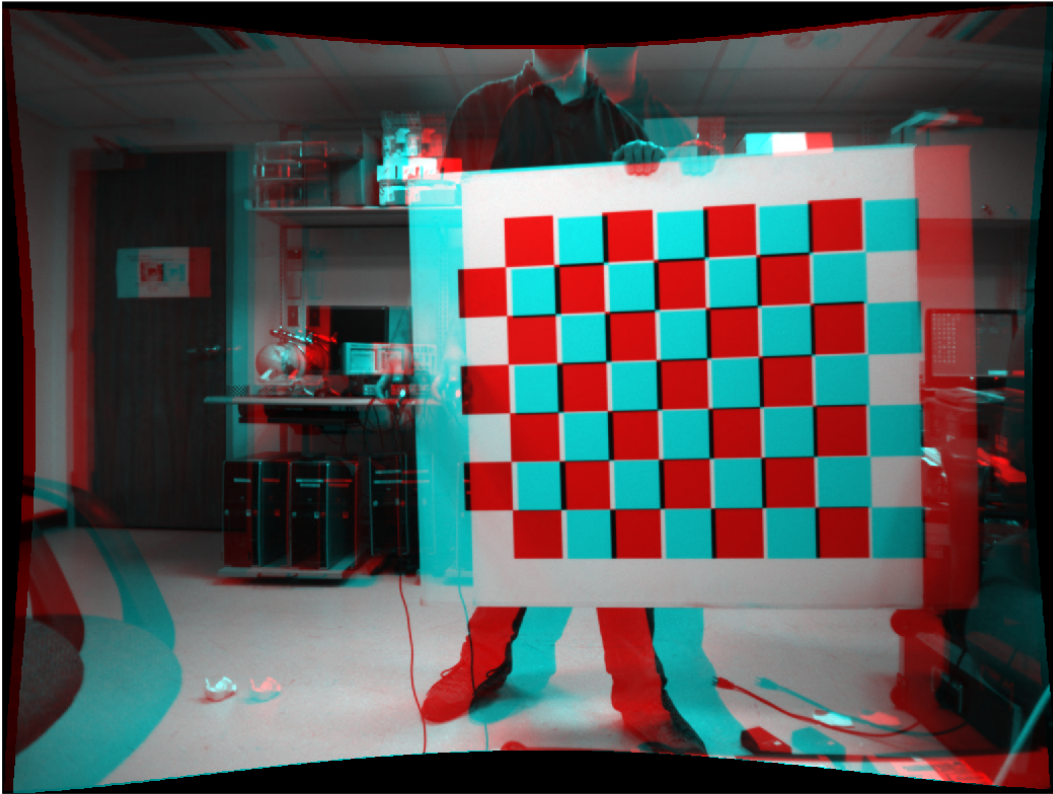
Rectify the images using 'valid' output view. This is most suitable for computing disparity.

```
[J1_valid,J2_valid] = rectifyStereoImages(I1,I2,stereoParams, ...
    'OutputView','valid');
```

Display the result for 'valid' output view.

```
figure;
imshow(stereoAnaglyph(J1_valid,J2_valid));
```
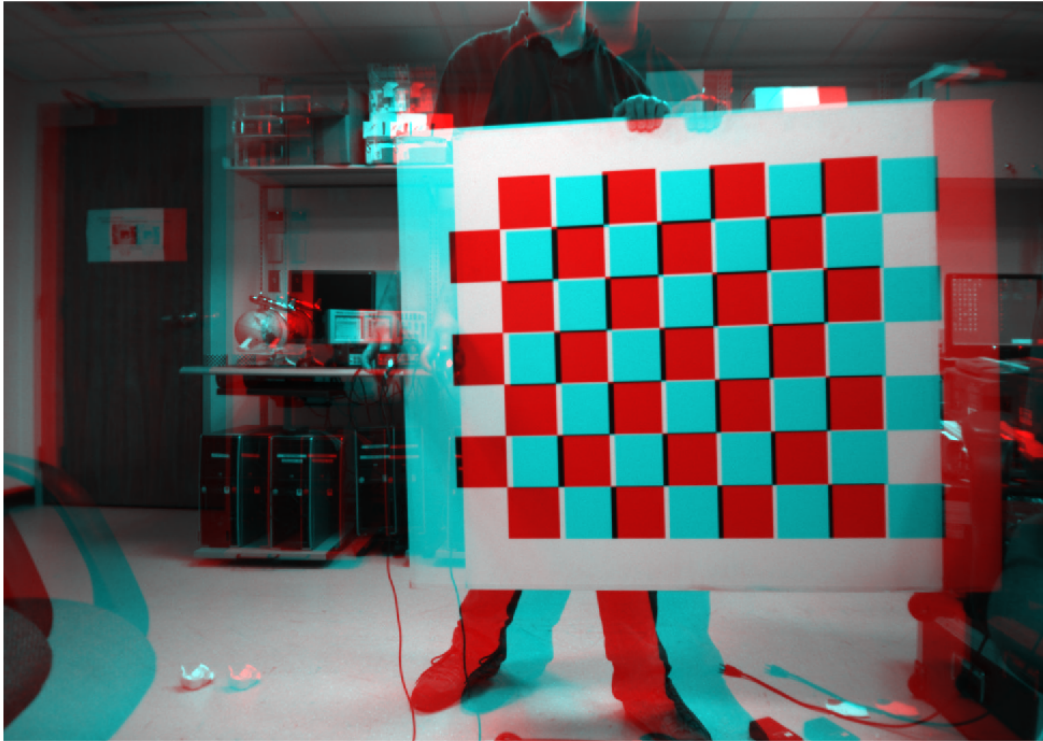
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"
- "Uncalibrated Stereo Image Rectification"
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

I1 — Input image 1
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input image corresponding to camera 1, specified as an *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-D grayscale array. Input images I1 and I2 must also be real, finite, and nonsparse. The input images must be the same class.

Data Types: uint8 | uint16 | int16 | single | double

I2 — Input image 2
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D truecolor image

Input image corresponding to camera 2, specified as an *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-D grayscale array. Input images I1 and I2 must be real, finite, and nonsparse. The input images must also be the same class.

Data Types: uint8 | uint16 | int16 | single | double

stereoParams — Stereo camera system parameters
stereoParameters object

Stereo camera system parameters, specified as a stereoParameters object.

Data Types: uint8 | uint16 | int16 | single | double

tform1 — Projective transformation
3-by-3 matrix | projective2d object

Projective transformations for image 1, specified as a 3-by-3 matrix returned by the estimateUncalibratedRectification function or a projective2d object.

tform2 — Projective transformation
3-by-3 matrix | projective2d object

Projective transformations for image 2, specified as a 3-by-3 matrix returned by the estimateUncalibratedRectification function or a projective2d object.

interp — Interpolation method
'linear' (default) | 'nearest' | 'cubic'

Interpolation method, specified as the character vector 'linear', 'nearest', or 'cubic' character vector.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single

quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'OutputView'`, `'valid'` sets the `'OutputView'` property to the character vector `'valid'`.

`OutputView` — Size of rectified images
`'valid'` (default) | character vector

Size of rectified images, specified as the comma-separated pair consisting of `'OutputView'` and the character vector `'full'` or `'valid'`. When you set this parameter to `'full'`, the rectified images include all pixels from the original images. When you set this value to `'valid'`, the output images are cropped to the size of the largest common rectangle containing valid pixels.

When there is no overlap between rectified images, set the `OutputView` to `'full'`.

`FillValues` — Output pixel fill values
array of scalar values

Output pixel fill values, specified as the comma-separated pair consisting of `'FillValues'` and an array of one or more scalar values. When the corresponding inverse-transformed location in the input image is completely outside the input image boundaries, use the fill values for output pixels. If `I1` and `I2` are 2-D grayscale images, then you must set `'FillValues'` to a scalar. If `I1` and `I2` are truecolor images, then you can set `'FillValues'` to a scalar or a 3-element vector of RGB values.

Output Arguments

J1 — Undistorted and rectified image 1
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Undistorted and rectified version of `I1`, returned as an *M*-by-*N*-by-3 truecolor image or as an *M*-by-*N* 2-D grayscale image.

Stereo image rectification projects images onto a common image plane in such a way that the corresponding points have the same row coordinates. This image projection makes the image appear as though the two cameras are parallel. Use the `disparity` function to compute a disparity map from the rectified images for 3-D scene reconstruction.

J2 — Undistorted and rectified image 2
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Undistorted and rectified version of I2, returned as an *M*-by-*N*-by-3 truecolor image or as an *M*-by-*N* 2-D grayscale image.

Stereo image rectification projects images onto a common image plane in such a way that the corresponding points have the same row coordinates. This image projection makes the image appear as though the two cameras are parallel. Use the `disparity` function to compute a disparity map from the rectified images for 3-D scene reconstruction.

References

[1] G. Bradski and A. Kaehler, *Learning OpenCV : Computer Vision with the OpenCV Library*. Sebastopol, CA: O'Reilly, 2008.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.
- `'interp'` and `'OutputView'` must be compile-time constants.

See Also
Camera Calibrator | **Stereo Camera Calibrator** | disparity | estimateCameraParameters | estimateUncalibratedRectification | reconstructScene | stereoParameters

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

"Uncalibrated Stereo Image Rectification"
"Code Generation for Depth Estimation From Stereo Video"
"Coordinate Systems"

Introduced in R2014a

retrieveImages

Search image set for similar image

Syntax

```
imageIDs = retrieveImages(queryImage,imageIndex)
[imageIDs,scores] = retrieveImages(queryImage,imageIndex)
[imageIDs,scores,imageWords] = retrieveImages(queryImage,imageIndex)
[imageIDs, ___ ] = retrieveImages(queryImage,imageIndex,Name,Value)
```

Description

`imageIDs = retrieveImages(queryImage,imageIndex)` returns the indices corresponding to images within `imageIndex` that are visually similar to the query image. The `imageIDs` output contains the indices in ranked order, from the most to least similar match.

`[imageIDs,scores] = retrieveImages(queryImage,imageIndex)` optionally returns the similarity scores used to rank the image retrieval results. The `scores` output contains the corresponding scores from 0 to 1.

`[imageIDs,scores,imageWords] = retrieveImages(queryImage,imageIndex)` optionally returns the visual words in `queryImage` that are used to search for similar images.

`[imageIDs, ___ ] = retrieveImages(queryImage,imageIndex,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

Examples

Search Image Set Using Query Image

Create an image set of book covers.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata','bookCovers');
bookCovers = imageDatastore(dataDir);
```

Display the data set.

```
thumbnailGallery = [];
for i = 1:length(bookCovers.Files)
    I = readimage(bookCovers,i);
    thumbnail = imresize(I,[300 300]);
    thumbnailGallery = cat(4,thumbnailGallery,thumbnail);
end

figure
montage(thumbnailGallery);
```

Index the image set. This step may take a few minutes.

```
imageIndex = indexImages(bookCovers);
```

```
Creating an inverted image index using Bag-Of-Features.
-------------------------------------------------------

Creating Bag-Of-Features.
-------------------------

* Selecting feature point locations using the Detector method.
* Extracting SURF features from the selected feature point locations.
** detectSURFFeatures is used to detect key points for feature extraction.

* Extracting features from 58 images...done. Extracted 29216 features.

* Keeping 80 percent of the strongest features from each category.

* Balancing the number of features across all image categories to improve clustering.
** Image category 1 has the least number of strongest features: 23373.
** Using the strongest 23373 features from each of the other image categories.

* Using K-Means clustering to create a 20000 word visual vocabulary.
* Number of features        : 23373
* Number of clusters (K)     : 20000

* Initializing cluster centers...100.00%.
* Clustering...completed 11/100 iterations (~1.52 seconds/iteration)...converged in 11

* Finished creating Bag-Of-Features


Encoding images using Bag-Of-Features.
--------------------------------------

* Encoding 58 images...done.
Finished creating the image index.
```

Select and display the query image.

```
queryDir = fullfile(dataDir,'queries',filesep);
queryImage = imread([queryDir 'query3.jpg']);

imageIDs = retrieveImages(queryImage,imageIndex);
```

Show the query image and its best match, side-by-side.

```
bestMatch = imageIDs(1);
bestImage = imread(imageIndex.ImageLocation{bestMatch});
```

```
figure
imshowpair(queryImage,bestImage,'montage')
```
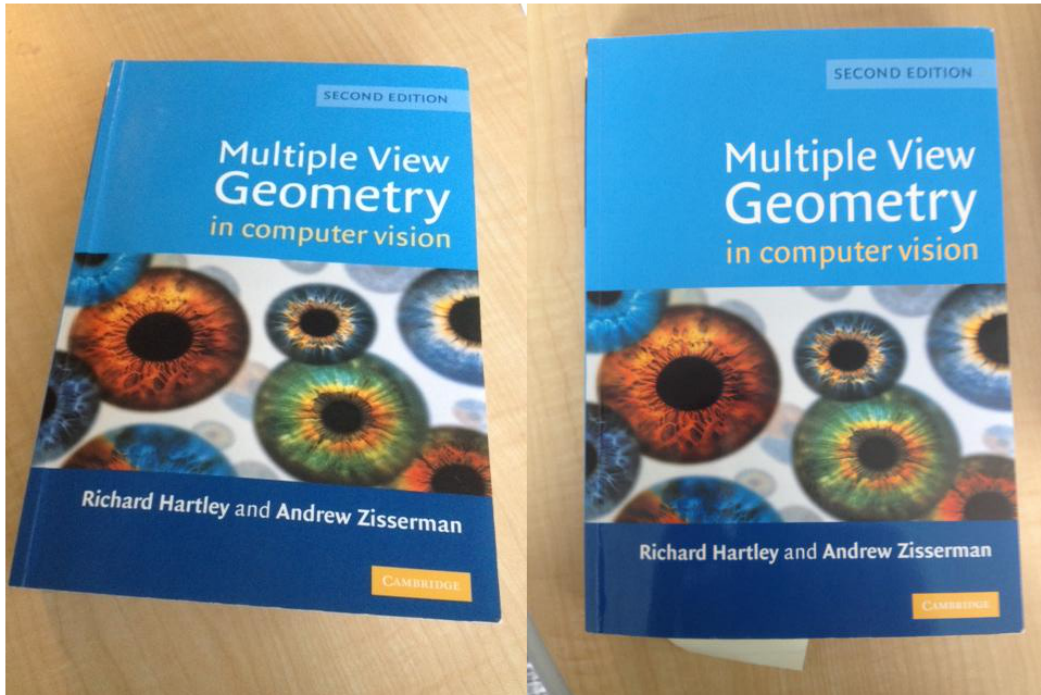

Search Image Set for Specific Object Using ROIs

Search an image set for an object using a region of interest (ROI) for the query image.

Define a set of images to search.

```
imageFiles = ...
  {'elephant.jpg', 'cameraman.tif', ...
  'peppers.png',  'saturn.png',...
  'pears.png',     'stapleRemover.jpg', ...
```

```
    'football.jpg', 'mandi.tif',...
    'kids.tif',     'liftingbody.png', ...
    'office_5.jpg', 'gantrycrane.png',...
    'moon.tif',     'circuit.tif', ...
    'tape.png',     'coins.png'};

imds = imageDatastore(imageFiles);
```

Create a search index.

```
 imageIndex = indexImages(imds);
```

```
Creating an inverted image index using Bag-Of-Features.
-------------------------------------------------------

Creating Bag-Of-Features.
-------------------------

* Selecting feature point locations using the Detector method.
* Extracting SURF features from the selected feature point locations.
** detectSURFFeatures is used to detect key points for feature extraction.

* Extracting features from 16 images...done. Extracted 3680 features.

* Keeping 80 percent of the strongest features from each category.

* Balancing the number of features across all image categories to improve clustering.
** Image category 1 has the least number of strongest features: 2944.
** Using the strongest 2944 features from each of the other image categories.

* Using K-Means clustering to create a 20000 word visual vocabulary.
* Number of features        : 2944
* Number of clusters (K)     : 2944

* Initializing cluster centers...100.00%.
* Clustering...completed 1/100 iterations (~0.18 seconds/iteration)...converged in 1 it

* Finished creating Bag-Of-Features


Encoding images using Bag-Of-Features.
--------------------------------------

* Encoding 16 images...done.
Finished creating the image index.
```

Specify a query image and an ROI. The ROI outlines the object, an elephant, for the search.

```
queryImage = imread('clutteredDesk.jpg');
queryROI = [130 175 330 365];

figure
imshow(queryImage)
rectangle('Position',queryROI,'EdgeColor','yellow')
```


You can also use the `imrect` function to select an ROI interactively. For example, `queryROI = getPosition(imrect)`

Find images that contain the object.

```
imageIDs = retrieveImages(queryImage,imageIndex,'ROI',queryROI)
```

imageIDs = *12×1*

```
     1
    11
     6
    12
     3
    14
     2
     8
    10
    13
     ⋮
```

Display the best match.

```
bestMatch = imageIDs(1);
```

```
figure
imshow(imageIndex.ImageLocation{bestMatch})
```

Geometric Verification Using `estimateGeometricTransform` Function

Use the locations of visual words to verify the best search result. To rerank the search results based on geometric information, repeat this procedure for the top *N* search results.

Specify the location of the images.

```
dataDir = fullfile(toolboxdir('vision'),'visiondata','bookCovers');
bookCovers = imageDatastore(dataDir);
```

Index the image set. This process can take a few minutes.

```
imageIndex = indexImages(bookCovers);
```

```
Creating an inverted image index using Bag-Of-Features.
-------------------------------------------------------

Creating Bag-Of-Features.
-------------------------

* Selecting feature point locations using the Detector method.
* Extracting SURF features from the selected feature point locations.
** detectSURFFeatures is used to detect key points for feature extraction.

* Extracting features from 58 images...done. Extracted 29216 features.

* Keeping 80 percent of the strongest features from each category.

* Balancing the number of features across all image categories to improve clustering.
** Image category 1 has the least number of strongest features: 23373.
** Using the strongest 23373 features from each of the other image categories.

* Using K-Means clustering to create a 20000 word visual vocabulary.
* Number of features        : 23373
* Number of clusters (K)     : 20000

* Initializing cluster centers...100.00%.
* Clustering...completed 11/100 iterations (~1.96 seconds/iteration)...converged in 11

* Finished creating Bag-Of-Features


Encoding images using Bag-Of-Features.
--------------------------------------

* Encoding 58 images...done.
Finished creating the image index.
```

Select and display the query image.

```
queryDir = fullfile(dataDir,'queries',filesep);
queryImage = imread([queryDir 'query3.jpg']);
```

```
figure
imshow(queryImage)
```
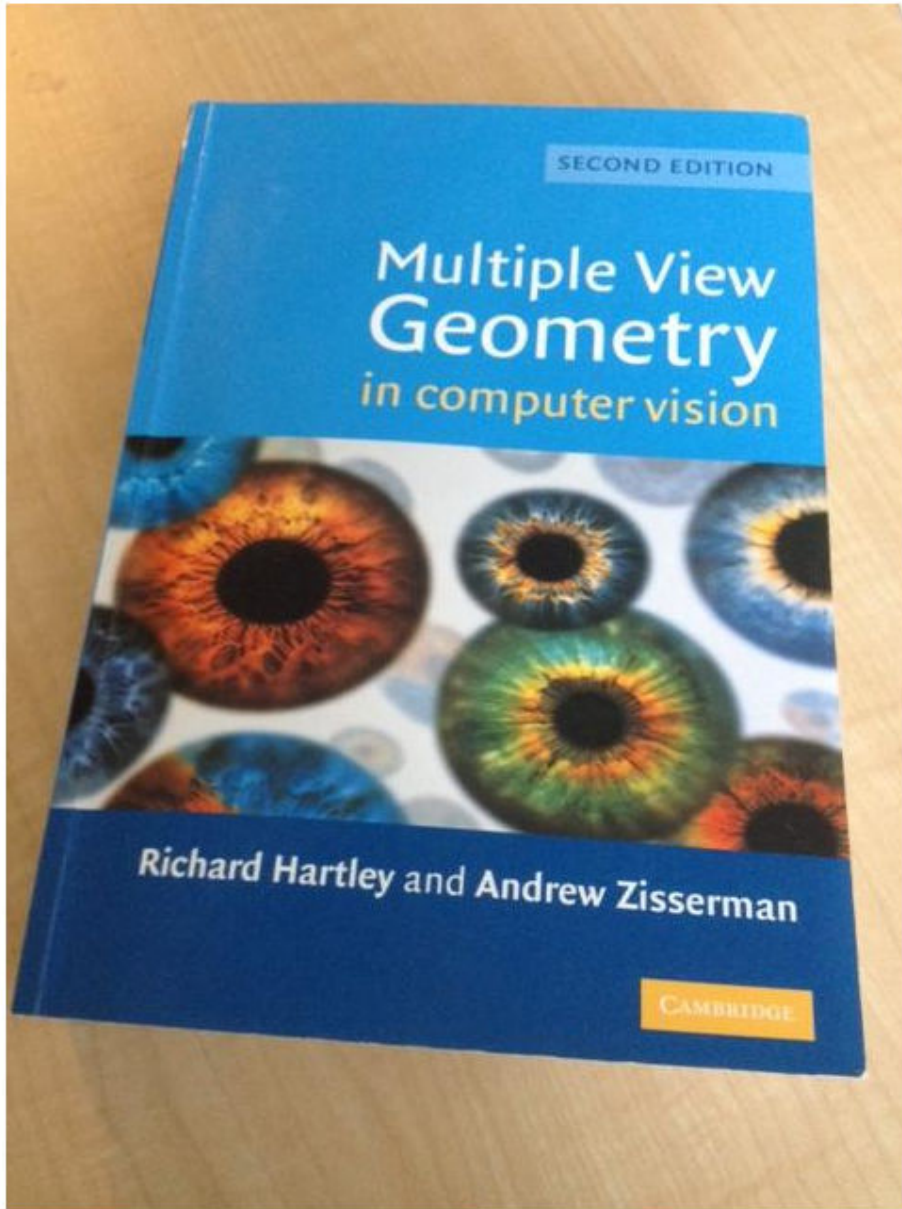
Retrieve the best matches. The `queryWords` output contains visual word locations information for the query image. Use this information to verify the search results.

```
[imageIDs, ~, queryWords] = retrieveImages(queryImage,imageIndex);
```

Find the best match for the query image by extracting the visual words from the image index. The image index contains the visual word information for all images in the index.

```
bestMatch = imageIDs(1);
bestImage = imread(imageIndex.ImageLocation{bestMatch});
bestMatchWords = imageIndex.ImageWords(bestMatch);
```

Generate a set of tentative matches based on visual word assignments. Each visual word in the query can have multiple matches due to the hard quantization used to assign visual words.

```
queryWordsIndex     = queryWords.WordIndex;
bestMatchWordIndex  = bestMatchWords.WordIndex;

tentativeMatches = [];
for i = 1:numel(queryWords.WordIndex)

    idx = find(queryWordsIndex(i) == bestMatchWordIndex);

    matches = [repmat(i, numel(idx), 1) idx];

    tentativeMatches = [tentativeMatches; matches];

end
```

Show the point locations for the tentative matches. There are many poor matches.

```
points1 = queryWords.Location(tentativeMatches(:,1),:);
points2 = bestMatchWords.Location(tentativeMatches(:,2),:);

figure
showMatchedFeatures(queryImage,bestImage,points1,points2,'montage')
```
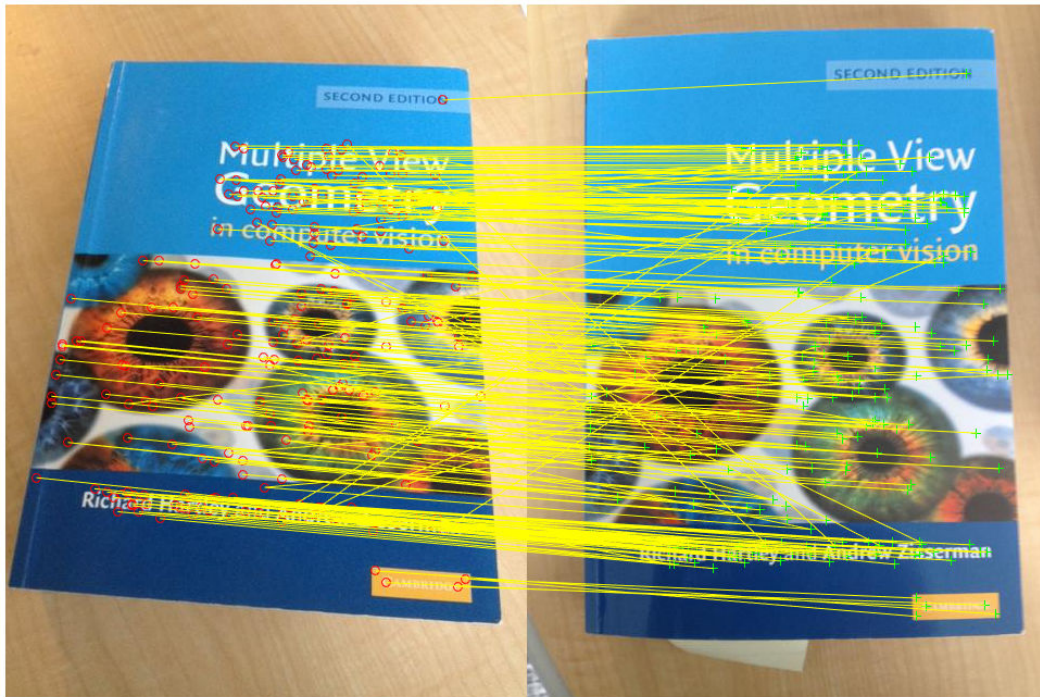
Remove poor visual word assignments using `estimateGeometricTransform` function. Keep the assignments that fit a valid geometric transform.

```
[tform,inlierPoints1,inlierPoints2] = ...
    estimateGeometricTransform(points1,points2,'affine',...
        'MaxNumTrials',2000);
```

Rerank the search results by the percentage of inliers. Do this when the geometric verification procedure is applied to the top *N* search results. Those images with a higher percentage of inliers are more likely to be relevant.

```
percentageOfInliers = size(inlierPoints1,1)./size(points1,1);

figure
showMatchedFeatures(queryImage,bestImage,inlierPoints1,...
    inlierPoints2,'montage')
```
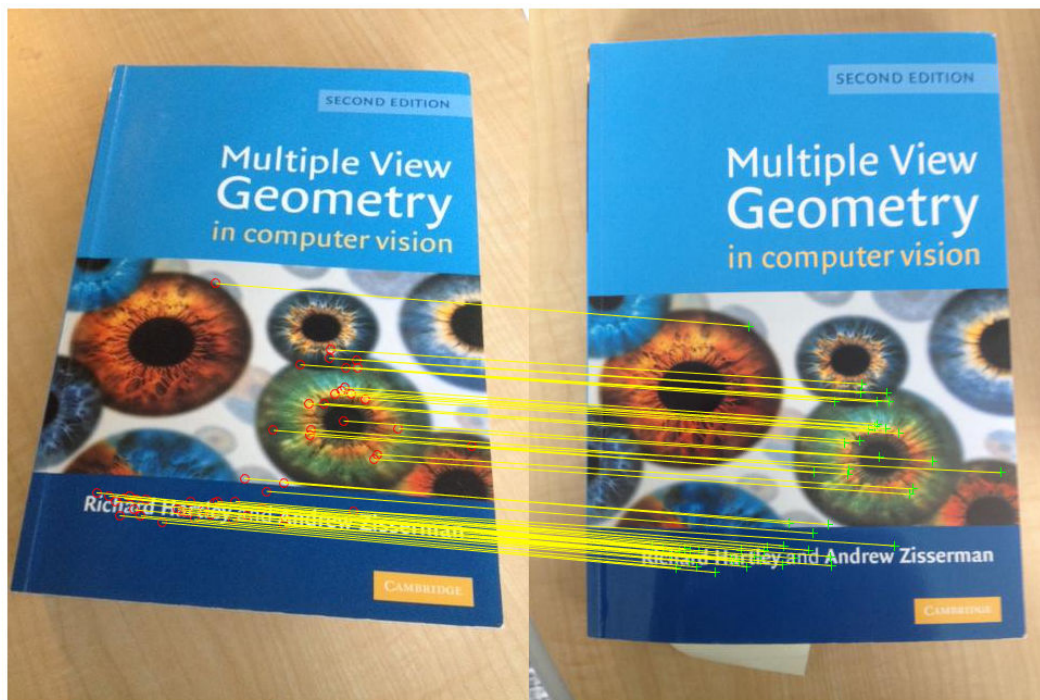
Apply the estimated transform.

```
outputView = imref2d(size(bestImage));
Ir = imwarp(queryImage, tform, 'OutputView', outputView);

figure
imshowpair(Ir,bestImage,'montage')
```
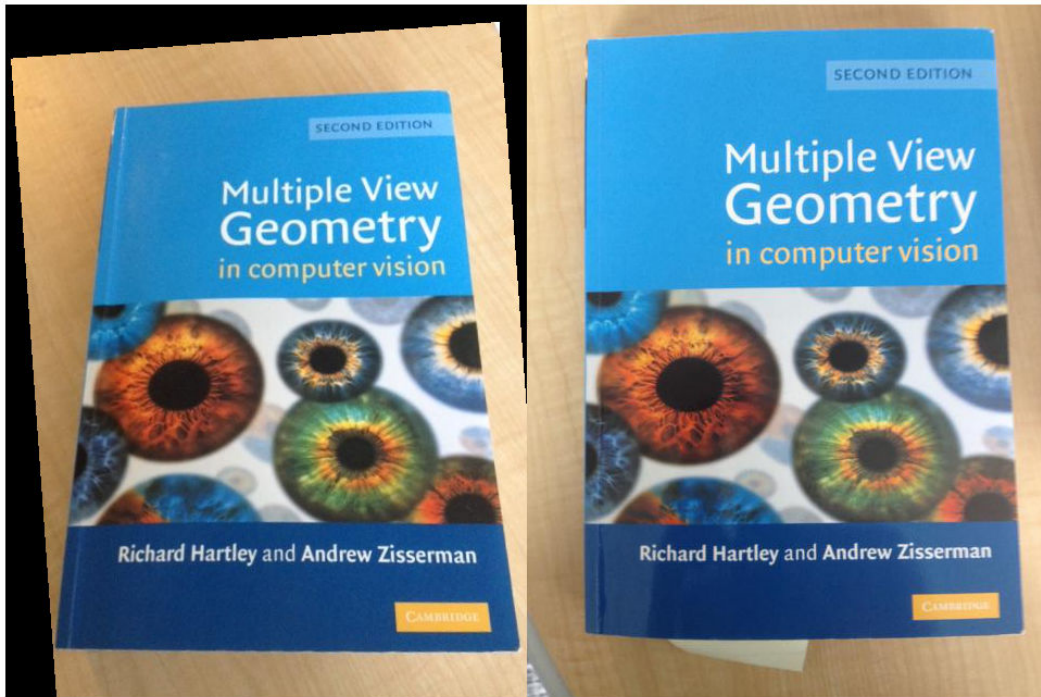
Modify Search Parameters For Image Search

Use the `evaluateImageRetrieval` function to help select proper search parameters.

Create an image set.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets','cups');
imds = imageDatastore(setDir, 'IncludeSubfolders', true, 'LabelSource', 'foldernames');
```

Index the image set.

```
 imageIndex = indexImages(imds,'Verbose',false);
```

Tune image search parameters.

```
imageIndex.MatchThreshold = 0.2;
imageIndex.WordFrequencyRange = [0 1]

imageIndex =
  invertedImageIndex with properties:

          ImageLocation: {6x1 cell}
             ImageWords: [6x1 vision.internal.visualWords]
          WordFrequency: [1x1366 double]
          BagOfFeatures: [1x1 bagOfFeatures]
         MatchThreshold: 0.2000
    WordFrequencyRange: [0 1]


queryImage = readimage(imds, 1);
indices = retrieveImages(queryImage,imageIndex);
```

- "Image Retrieval Using Customized Bag of Features"

Input Arguments

queryImage — Input query image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input query image, specified as either an *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-D grayscale image.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

imageIndex — Image search index
`invertedImageIndex` object

Image search index, specified as an `invertedImageIndex` object. The `indexImages` function creates the `invertedImageIndex` object, which stores the data used for the image search.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single

quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NumResults',25` sets the `'NumResults'` property to 25

NumResults — Maximum number of results
20 (default) | numeric value

Maximum number of results to return, specified as the comma-separated pair consisting of `'NumResults'` and a numeric value. Set this value to `Inf` to return as many matching images as possible.

ROI — Query image search region
`[1 1 size(queryImage,2) size(queryImage,1)]` (default) | [*x y width height*] vector

Query image search region, specified as the comma-separated pair consisting of `'ROI'` and an [*x y width height*] vector.

Output Arguments

imageIDs — Ranked index of retrieved images
M-by-1 vector

Ranked index of retrieved images, returned as an *M*-by-1 vector. The image IDs are returned in ranked order, from the most to least similar matched image.

scores — Similarity metric
N-by-1 vector

Similarity metric, returned as an *N*-by-1 vector. This output contains the scores that correspond to the retrieved images in the `imageIDs` output. The scores are computed using the cosine similarity and range from 0 to 1.

imageWords — Object for storing visual word assignments
`visualWords` object

Object for storing visual word assignments, returned as a `visualWords` object. The object stores the visual word assignments of `queryImage` and their locations within that image.

References

[1] Sivic, J. and A. Zisserman. *Video Google: A text retrieval approach to object matching in videos*. ICCV (2003) pg 1470-1477.

[2] Philbin, J., O. Chum, M. Isard, J. Sivic, and A. Zisserman. *Object retrieval with large vocabularies and fast spatial matching*. CVPR (2007).

See Also

bagOfFeatures | evaluateImageRetrieval | imageDatastore | imageSet | invertedImageIndex

Topics

"Image Retrieval Using Customized Bag of Features"
"Image Retrieval with Bag of Visual Words"

Introduced in R2015a

rotationMatrixToVector

Convert 3-D rotation matrix to rotation vector

Syntax

```
rotationVector = rotationMatrixToVector(rotationMatrix)
```

Description

`rotationVector = rotationMatrixToVector(rotationMatrix)` returns an axis-angle rotation vector that corresponds to the input 3-D rotation matrix. The function uses the Rodrigues formula for the conversion.

Examples

Convert Rotation Matrix to Rotation Vector

Create a matrix representing a 90-degree rotation about the Z-axis.

```
rotationMatrix = [0, -1, 0; 1, 0, 0; 0, 0, 1];
```

Find the equivalent rotation vector.

```
rotationVector = rotationMatrixToVector(rotationMatrix)
```

rotationVector = *1×3*

      0   0   -1.5708

- "Evaluating the Accuracy of Single Camera Calibration"
- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Input Arguments

`rotationMatrix` — Rotation of camera
3-by-3 matrix

Rotation of camera, specified as a 3-by-3 matrix. You can obtain this matrix by using the `extrinsics` function.

Output Arguments

`rotationVector` — Rotation vector
three-element vector

Rotation vector, returned as a three-element vector. The vector represents the axis of rotation in 3-D, where the magnitude corresponds to the rotation angle in radians.

Data Types: `single` | `double`

References

[1] Trucco, E., and A. Verri. *Introductory Techniques for 3-D Computer Vision.*" Prentice Hall, 1998.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`extrinsics` | `relativeCameraPose` | `rotationVectorToMatrix` | `triangulate`

Topics
"Evaluating the Accuracy of Single Camera Calibration"

"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

Introduced in R2016a

rotationVectorToMatrix

Convert 3-D rotation vector to rotation matrix

Syntax

```
rotationMatrix = rotationVectorToMatrix(rotationVector)
```

Description

`rotationMatrix = rotationVectorToMatrix(rotationVector)` returns a 3-D rotation matrix that corresponds to the input axis-angle rotation vector. The function uses the Rodrigues formula for the computation.

Examples

Convert Rotation Vector to Rotation Matrix

Create a vector representing a 90-degree rotation about the Z-axis.

```
rotationVector = pi/2 * [0, 0, 1];
```

Find the equivalent rotation matrix.

```
rotationMatrix = rotationVectorToMatrix(rotationVector)
```

rotationMatrix = *3×3*

```
    0.0000    1.0000         0
   -1.0000    0.0000         0
         0         0    1.0000
```

- "Evaluating the Accuracy of Single Camera Calibration"

- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Input Arguments

`rotationVector` — Rotation vector
three-element vector

Rotation vector, specified as a three-element vector. The vector represents the axis of rotation in 3-D, where the magnitude corresponds to the rotation angle in radians.

Data Types: `single` | `double`

Output Arguments

`rotationMatrix` — Rotation of camera
3-by-3 matrix

Rotation of camera, returned as a 3-by-3 matrix that corresponds to the input axis-angle rotation vector.

References

[1] Trucco, E., and A. Verri. *Introductory Techniques for 3-D Computer Vision.*" Prentice Hall, 1998.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
extrinsics | relativeCameraPose | rotationMatrixToVector | triangulate

Topics
"Evaluating the Accuracy of Single Camera Calibration"
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

Introduced in R2016a

selectStrongestBbox

Select strongest bounding boxes from overlapping clusters

Syntax

```
[selectedBbox,selectedScore] = selectStrongestBbox(bbox,score)
[selectedBbox,selectedScore,index] = selectStrongestBbox(bbox,score)
[ ___ ] = selectStrongestBbox( ___ ,Name,Value)
```

Description

`[selectedBbox,selectedScore] = selectStrongestBbox(bbox,score)` returns selected bounding boxes that have a high confidence score. The function uses nonmaximal suppression to eliminate overlapping bounding boxes from the `bbox` input.

`[selectedBbox,selectedScore,index] = selectStrongestBbox(bbox,score)` additionally returns the `index` vector associated with `selectedBbox`. This vector contains the indices of the selected boxes in the `bbox` input.

`[ ___ ] = selectStrongestBbox( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Run Nonmaximal Suppression on Bounding Boxes Using People Detector

Load the pretrained people detector and disable bounding box merging.

```
peopleDetector = vision.PeopleDetector('ClassificationThreshold',...
        0,'MergeDetections',false);
```

Read an image, run the people detector, and then insert bounding boxes with confidence scores.

```
I = imread('visionteam1.jpg');
[bbox,score] = step(peopleDetector,I);
I1 = insertObjectAnnotation(I,'rectangle',bbox,...
        cellstr(num2str(score)),'Color','r');
```

Run nonmaximal suppression on the bounding boxes.

```
[selectedBbox,selectedScore] = selectStrongestBbox(bbox,score);
I2 = insertObjectAnnotation(I,'rectangle',selectedBbox,...
        cellstr(num2str(selectedScore)),'Color','r');
```

Display detection before and after suppression.

```
figure, imshow(I1); ...
title('Detected people and detection scores before suppression');
```

Detected people and detection scores before suppression


```
figure, imshow(I2); ...
title('Detected people and detection scores after suppression');
```

Detected people and detection scores after suppression
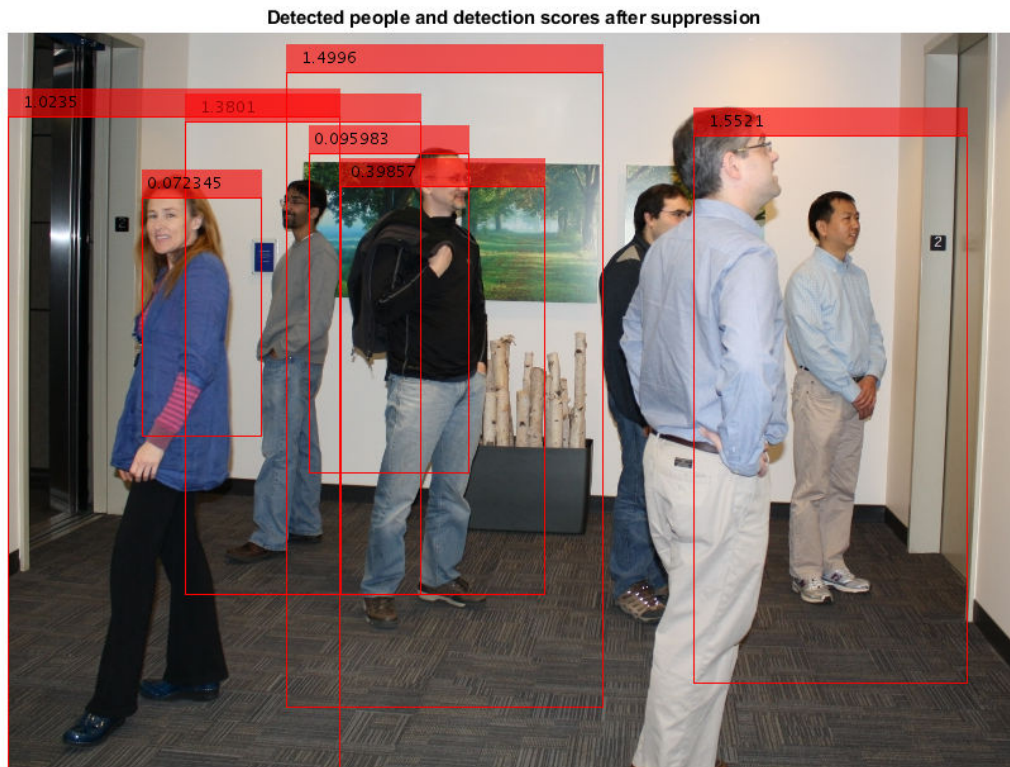
Input Arguments

bbox — Bounding boxes
M-by-4 matrix

Bounding boxes, specified as an *M*-by-4 matrix defining *M* bounding boxes. Each row is specified in the format [*x y width height*], where *x* and *y* correspond to the upper left corner of the bounding box. The `bbox` input must be real, finite, and nonsparse.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32`

score — Confidence score
M-by-1 vector

Confidence score, specified as an *M*-by-1 vector. The *M*th score corresponds to the *M*th bounding box in the `bbox` input. The `selectStrongestBbox` function uses nonmaximal suppression to eliminate overlapping bounding boxes and associate the confidence score with the boxes. A higher score represents a higher confidence in keeping the bounding box. The `score` input must be real, finite, and nonsparse.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'RatioType','Union'` sets the `'RatioType'` property to `'Union'`.

RatioType — Bounding box overlap ratio denominator
`'Union'` (default) | `'Min'`

Ratio type, specified as the character vector `'Union'` or `'Min'`.

- Set the ratio type to `'Union'` to compute the ratio as the area of intersection between `bboxA` and `bboxB`, divided by the area of the union of the two.

- Set the ratio type to `'Min'` to compute the ratio as the area of intersection between `bboxA` and `bboxB`, divided by the minimum area of the two bounding boxes.

$$\text{Union:} \quad \frac{\text{area}(A \cap B)}{\text{area}(A \cup B)}$$

$$\text{Min:} \quad \frac{\text{area}(A \cap B)}{\min(\text{area}(A), \text{area}(B))}$$

Data Types: `char`

OverlapThreshold — Overlap ratio threshold
`0.5` (default) | scalar in the range [0 1]

Overlap ratio threshold, specified as the comma-separated pair consisting of `'OverlapThreshold'` and a scalar in the range [0 1]. When the overlap ratio is above the threshold you set, the function removes bounding boxes around the reference box. Decrease this value to reduce the number of selected bounding boxes. However, if you decrease the overlap ratio too much, you might eliminate boxes that represent objects close to each other in the image.

Data Types: `single` | `double`

Output Arguments

`selectedBbox` — Selected bounding boxes
M-by-4 matrix

Selected bounding boxes, returned as an *M*-by-4 matrix. The `selectedBbox` output returns the selected bounding boxes from the `bbox` input that have the highest confidence score. The function uses nonmaximal suppression to eliminate overlapping bounding boxes.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32`

`selectedScore` — Scores of selected bounding boxes
M-by-1 vector

Scores of selected bounding boxes, returned as an *M*-by-1 vector. The *M*th score in the `selectedScore` output corresponds to the *M*th bounding box in the `selectedBbox` output.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32`

`index` — Index of selected bounding boxes
M-by-1 vector

Index of selected bounding boxes, returned as an *M*-by-1 vector. The `index` vector contains the indices to the selected boxes in the `bbox` input.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

See Also
bboxOverlapRatio | selectStrongestBboxMulticlass

Introduced in R2014b

selectStrongestBboxMulticlass

Select strongest multiclass bounding boxes from overlapping clusters

Syntax

```
selectedBboxes = selectStrongestBboxMulticlass(bboxes,scores,labels)
[selectedBboxes,selectedScores,selectedLabels,index] =
selectStrongestBboxMulticlass(bboxes,scores,labels)
[ ___ ] = selectStrongestBboxMulticlass( ___ ,Name,Value)
```

Description

`selectedBboxes = selectStrongestBboxMulticlass(bboxes,scores,labels)` returns selected bounding boxes that have high confidence scores. The function uses greedy nonmaximal suppression (NMS) to eliminate overlapping bounding boxes from the `bboxes` input, only if they have the same class label.

`[selectedBboxes,selectedScores,selectedLabels,index] = selectStrongestBboxMulticlass(bboxes,scores,labels)` additionally returns the scores, labels, and index associated with the selected bounding boxes.

`[ ___ ] = selectStrongestBboxMulticlass( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

Examples

Run Multiclass Nonmaximal Suppression on Bounding Boxes Using People Detector

Create detectors using two different models. These will be used to generate multiclass detection results.

```
detectorInria = peopleDetectorACF('inria-100x41');
detectorCaltech = peopleDetectorACF('caltech-50x21');
```

Apply the detectors.

```
I = imread('visionteam1.jpg');
[bboxesInria,scoresInria] = detect(detectorInria,I);
[bboxesCaltech,scoresCaltech] = detect(detectorCaltech,I);
```

Create categorical labels for each the result of each detector.

```
labelsInria = repelem("inria",numel(scoresInria),1);
labelsInria = categorical(labelsInria,{'inria','caltech'});
labelsCaltech = repelem("caltech",numel(scoresCaltech),1);
labelsCaltech = categorical(labelsCaltech,{'inria','caltech'});
```

Combine results from all detectors to for multiclass detection results.

```
allBBoxes = [bboxesInria;bboxesCaltech];
allScores = [scoresInria;scoresCaltech];
allLabels = [labelsInria;labelsCaltech];
```

Run multiclass non-maximal suppression.

```
[bboxes,scores,labels] = selectStrongestBboxMulticlass(allBBoxes,allScores,allLabels);
```

Annotate detected people.

```
annotations = string(labels) + ": " + string(scores);
I = insertObjectAnnotation(I,'rectangle',bboxes,cellstr(annotations));
imshow(I)
title('Detected People, Scores, and Labels')
```

Detected People, Scores, and Labels

Input Arguments

bboxes — Bounding boxes
M-by-4 matrix

Bounding boxes, specified as an *M*-by-4 matrix defining *M* bounding boxes. Each row is specified in the format [*x y width height*], where *x* and *y* correspond to the upper left corner of the bounding box. The `bboxes` input must be real, finite, and nonsparse.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32`

scores — Confidence scores
M-by-1 vector

Confidence scores corresponding to the input bounding boxes, specified as an *M*-by-1 vector. The `selectStrongestBboxMulticlass` function uses greedy NMS to eliminate overlapping bounding boxes and associate the confidence score with the boxes. A higher score represents a higher confidence in keeping the bounding box. The `scores` input must be real, finite, and nonsparse.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32`

labels — Labels
M-by-1 categorical vector | *M*-by-1 numeric vector

Labels corresponding to the input bounding boxes, specified as an *M*-by-1 categorical or numeric vector.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8` | `uint16` | `uint32` | `categorical`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'RatioType','Union'` sets the `'RatioType'` property to `'Union'`.

RatioType — Bounding box overlap ratio denominator
`'Union'` (default) | `'Min'`

Ratio type, specified as the character vector `'Union'` or `'Min'`.

- Set the ratio type to `'Union'` to compute the ratio as the area of intersection between `bboxA` and `bboxB`, divided by the area of the union of the two.

- Set the ratio type to `'Min'` to compute the ratio as the area of intersection between `bboxA` and `bboxB`, divided by the minimum area of the two bounding boxes.

$$\text{Union:} \quad \frac{\text{area}(A \cap B)}{\text{area}(A \cup B)}$$

$$\text{Min:} \quad \frac{\text{area}(A \cap B)}{\min(\text{area}(A), \text{area}(B))}$$

Data Types: `char`

`OverlapThreshold` — Overlap ratio threshold
`0.5` (default) | scalar in the range [0 1]

Overlap ratio threshold, specified as the comma-separated pair consisting of
`'OverlapThreshold'` and a scalar in the range [0 1]. When the overlap ratio is above the
threshold, the function removes bounding boxes around the reference box. Decrease the
threshold to reduce the number of selected bounding boxes. However, if you decrease the
threshold too much, you might eliminate boxes that represent objects close to each other
in the image.

Data Types: `single` | `double`

Output Arguments

`selectedBboxes` — Selected bounding boxes
M-by-4 matrix

Selected bounding boxes, returned as an *M*-by-4 matrix. The `selectedBboxes` output
returns the selected bounding boxes from the `bboxes` input that have the highest
confidence score. The function uses NMS to eliminate overlapping bounding boxes. The
data type of `selectedBboxes` matches the data type of `bboxes`.

`selectedScores` — Scores of selected bounding boxes
M-by-1 vector

Scores of selected bounding boxes, returned as an *M*-by-1 vector. The *M*th score in the
`selectedScores` output corresponds to the *M*th bounding box in the `selectedBboxes`
output. The data type of `selectedScores` matches the data type of `scores`.

`selectedLabels` — Labels of selected bounding boxes
M-by-1 categorical vector | *M*-by-1 numeric vector

Labels of selected bounding boxes, returned as an *M*-by-1 categorical or numeric vector. The *M*th label in the `selectedLabels` output corresponds to the *M*th bounding box in the `selectedBboxes` output. The data type of `selectedLabels` matches the data type of `labels`.

`index` — Index of selected bounding boxes
M-by-1 vector

Index of selected bounding boxes, returned as an *M*-by-1 vector. The `index` vector contains the indices to the selected boxes in the `bboxes` input.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Code generation is only supported for numeric `labels`.

See Also
bboxOverlapRatio | selectStrongestBbox

Introduced in R2018a

showExtrinsics

Visualize extrinsic camera parameters

Syntax

```
showExtrinsics(cameraParams)
showExtrinsics(cameraParams,view)
showExtrinsics( ___ ,Name,Value)

ax = showExtrinsics( ___ )
```

Description

`showExtrinsics(cameraParams)` renders a 3-D visualization of extrinsic parameters of a single calibrated camera or a calibrated stereo pair. The function plots a 3-D view of the calibration patterns with respect to the camera. The `cameraParams` input contains either a `cameraParameters`, `fisheyeParameters`, or a `stereoParameters` object, which the `estimateCameraParameters` or `estimateFisheyeParameters` function returns.

`showExtrinsics(cameraParams,view)` displays visualization of the camera extrinsic parameters using the style specified by the `view` input.

`showExtrinsics( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

`ax = showExtrinsics( ___ )` returns the plot axis, using any of the preceding syntaxes.

Examples

Visualize Single Camera Extrinsic Parameters

Create a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
  'calibration','webcam'));
imageFileNames = images.Files(1:5);
```

Detect calibration pattern.

```
[imagePoints,boardSize] = detectCheckerboardPoints(imageFileNames);
```

Generate world coordinates of the corners of the squares. The square size is in millimeters.

```
squareSide = 25;
worldPoints = generateCheckerboardPoints(boardSize,squareSide);
```

Calibrate the camera.

```
I = readimage(images,1);
imageSize = [size(I, 1), size(I, 2)];
cameraParams = estimateCameraParameters(imagePoints,worldPoints, ...
                                'ImageSize',imageSize);
```

Visualize pattern locations.

```
figure
showExtrinsics(cameraParams);
```
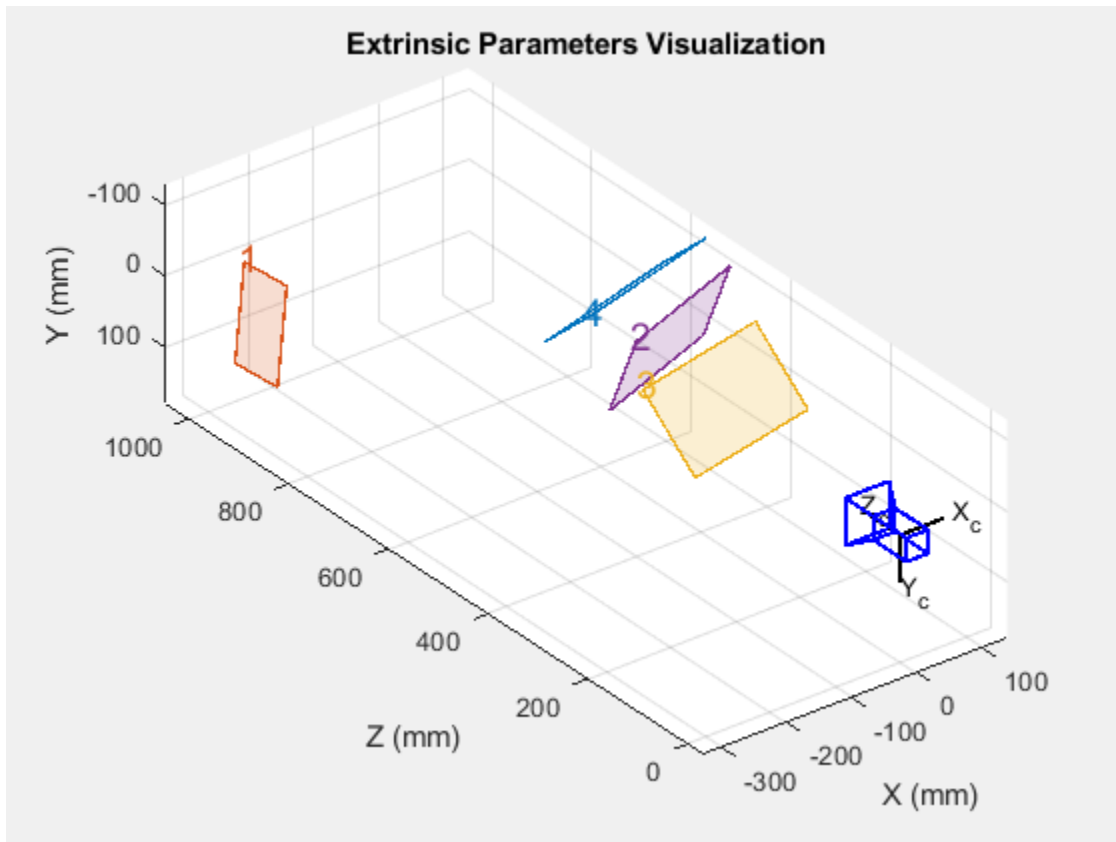
Visualize camera locations.

```
figure
showExtrinsics(cameraParams,'patternCentric');
```
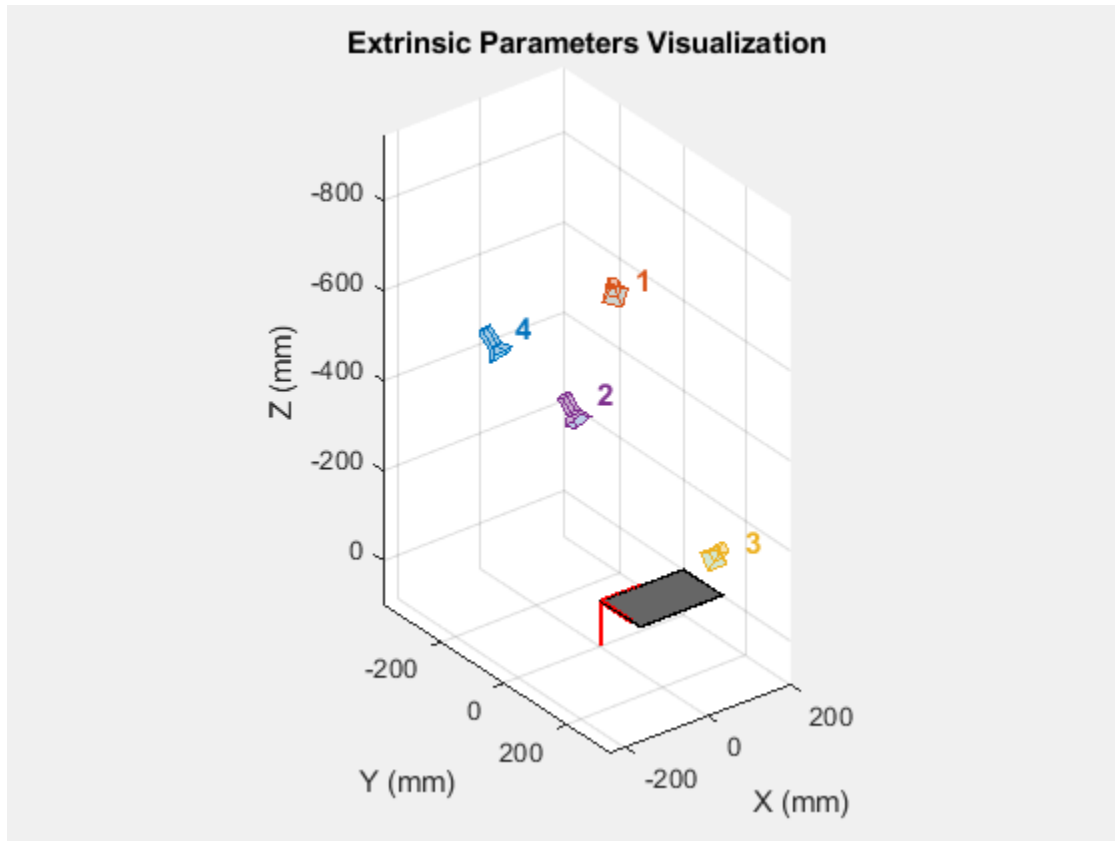
Visualize Stereo Pair of Camera Extrinsic Parameters

Specify calibration images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','stereo');
leftImages = imageDatastore(fullfile(imageDir,'left'));
rightImages = imageDatastore(fullfile(imageDir,'right'));
```

Detect the checkerboards.

```
[imagePoints,boardSize] = detectCheckerboardPoints(...
     leftImages.Files,rightImages.Files);
```

Specify world coordinates of checkerboard keypoints. Square size is in millimeters.

```
squareSize = 108;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the stereo camera system. Both cameras have the same resolution.

```
I = readimage(leftImages,1);
imageSize = [size(I, 1), size(I, 2)];
cameraParams = estimateCameraParameters(imagePoints,worldPoints, ...
                               'ImageSize',imageSize);
```

Visualize pattern locations.

```
figure;
showExtrinsics(cameraParams);
```

Visualize camera locations.

```
figure;
showExtrinsics(cameraParams,'patternCentric');
```

Extrinsic Parameters Visualization

Input Arguments

cameraParams — Object containing parameters of single camera or stereo pair
cameraParameters object | fisheyeParameters object | stereoParameters object

Object containing parameters of single camera or stereo pair, specified as either a
cameraParameters, fisheyeParameters, or stereoParameters object. You can
create the single camera or stereo pair input object using the
estimateCameraParameters function. The fisheye parameters input object is created
using estimateFisheyeParameters.

You can also use the **Camera Calibrator** app to create the `cameraParameters` input object, or use **Stereo Camera Calibrator** app to create the `stereoParameters` input object. See "Single Camera Calibrator App" and "Stereo Camera Calibrator App".

view — Camera- or pattern-centric view
`'CameraCentric'` | `'PatternCentric'`

Camera or pattern-centric view, specified as the character vector `'CameraCentric'` or `'PatternCentric'`. The `view` input sets the visualization for the camera extrinsic parameters. If you keep your camera stationary while moving the calibration pattern, set `view` to `'CameraCentric'`. If the pattern is stationary while you move your camera, set it to `'PatternCentric'`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'HighlightIndex',[1, 4]` sets the `'HighlightIndex'` to patterns 1 and 4.

HighlightIndex — Highlight selection index
`[]` (default) | vector | scalar

Highlight selection index, specified as a scalar or a vector of integers. For example, if you want to highlight patterns 1 and 4, use `[1, 4]`. Doing so increases the opacity of patterns 1 and 4 in contrast to the rest of the patterns.

Parent — Output axes
current axes (default) | scalar value

Output axes, specified as the comma-separated pair consisting of `'Parent'` and a scalar value. Specify an output axes for displaying the visualization. You can obtain the current axes handle by returning the function to an output variable:
`ax = showExtrinsics(cameraParams)`
You can also use the `gca` function to get the current axes handle.

Example: `showExtrinsics(cameraParams,'Parent',ax)`

Output Arguments

ax — Current axes handle
scalar value

Current axes handle, returned as a scalar value. The function returns the handle to the current axes for the current figure.

Example: `ax = showExtrinsics(cameraParams)`

See Also

Camera Calibrator | **Stereo Camera Calibrator** | cameraParameters |
detectCheckerboardPoints | estimateCameraParameters | fisheyeParameters
| generateCheckerboardPoints | plotCamera | showReprojectionErrors |
stereoParameters | undistortImage

Topics
"Single Camera Calibrator App"

Introduced in R2014a

showMatchedFeatures

Display corresponding feature points

Syntax

```
showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2)
showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2,method)

showMatchedFeatures( ___ ,PlotOptions, {MarkerStyle1, MarkerStyle2,
LineStyle})

H = showMatchedFeatures( ___ )
```

Description

showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2) displays a falsecolor overlay of images I1 and I2 with a color-coded plot of corresponding points connected by a line. matchedPoints1 and matchedPoints2 contain the coordinates of corresponding points in I1 and I2. The input points can be *M*-by-2 matrices of *M* number of [x y] coordinates, or SURFPoints, MSERRegions, or cornerPoints object.

showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2,method) displays images I1 and I2 using the visualization style specified by the method parameter.

showMatchedFeatures(___ ,PlotOptions, {MarkerStyle1, MarkerStyle2, LineStyle}) lets you specify custom plot options in a cell array containing three character vector values. The MarkerStyle1, MarkerStyle2, and LineStyle character vector values correspond to the marker specification in I1, marker specification in I2, and line style and color. The LineSpec syntax of the plot function defines each of the specifiers.

H = showMatchedFeatures(___) returns the handle to the image object returned by showMatchedFeatures.

Examples

Find Corresponding Points Between Two Images Using Harris Features

Read Images.

```
I1 = rgb2gray(imread('parkinglot_left.png'));
I2 = rgb2gray(imread('parkinglot_right.png'));
```

Detect SURF features

```
points1 = detectHarrisFeatures(I1);
points2 = detectHarrisFeatures(I2);
```

Extract features

```
[f1, vpts1] = extractFeatures(I1, points1);
[f2, vpts2] = extractFeatures(I2, points2);
```

Match features.

```
indexPairs = matchFeatures(f1, f2) ;
matchedPoints1 = vpts1(indexPairs(1:20, 1));
matchedPoints2 = vpts2(indexPairs(1:20, 2));
```

Visualize candidate matches.

```
figure; ax = axes;
showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2,'montage','Parent',ax);
title(ax, 'Candidate point matches');
legend(ax, 'Matched points 1','Matched points 2');
```

Candidate point matches
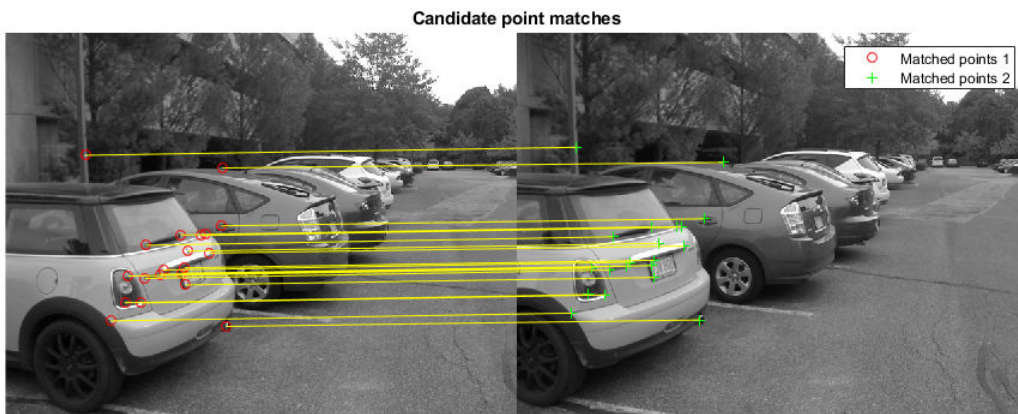
Display Corresponding Points Between Two Rotated and Scaled Images

Use SURF features to find corresponding points between two images rotated and scaled with respect to each other.

Read images.

```
I1 = imread('cameraman.tif');
I2 = imresize(imrotate(I1,-20), 1.2);
```

Detect SURF features.

```
points1 = detectSURFFeatures(I1);
points2 = detectSURFFeatures(I2);
```

Extract features.

```
[f1, vpts1] = extractFeatures(I1, points1);
[f2, vpts2] = extractFeatures(I2, points2);
```

Match features.

```
indexPairs = matchFeatures(f1, f2) ;
matchedPoints1 = vpts1(indexPairs(:, 1));
matchedPoints2 = vpts2(indexPairs(:, 2));
```

Visualize candidate matches.

```
figure; ax = axes;
showMatchedFeatures(I1,I2,matchedPoints1,matchedPoints2,'Parent',ax);
title(ax, 'Putative point matches');
legend(ax,'Matched points 1','Matched points 2');
```

Putative point matches
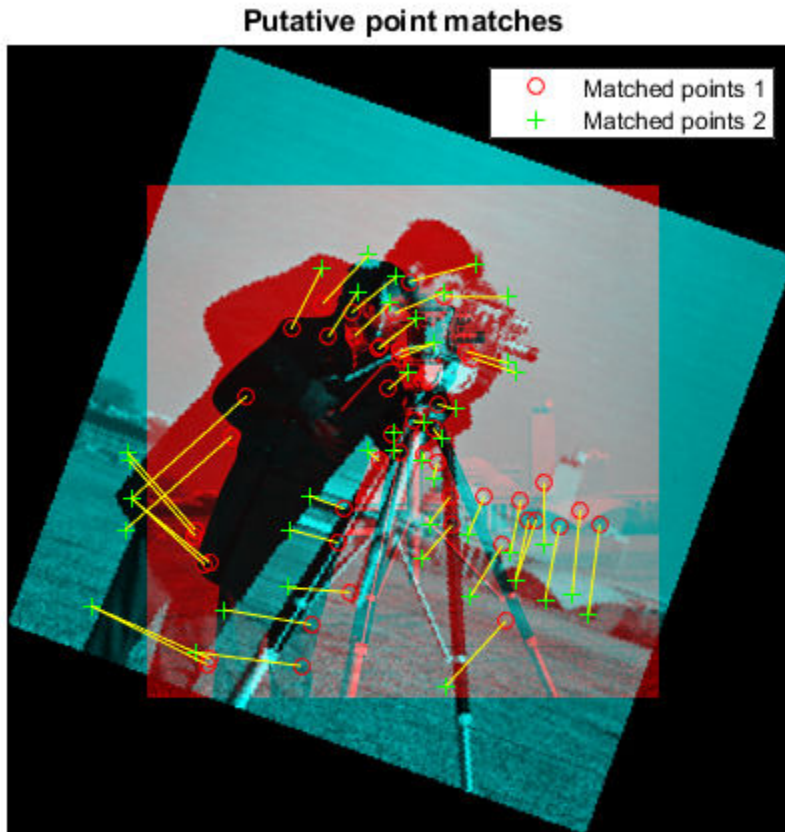
Input Arguments

I1 — Input image
numeric array

Input image one, specified as a numeric array.

I2 — Input image
numeric array

Input image two, specified as a numeric array.

matchedPoints1 — Coordinates of points
M-by-2 matrix | SURFPoints object | MSERRegions object | cornerPoints object | BRISKPoints object

Coordinates of points in image one, specified as an *M*-by-2 matrix of *M* number of [x y] coordinates, or as a SURFPoints, MSERRegions, cornerPoints, or BRISKPoints object.

matchedPoints2 — Coordinates of points
M-by-2 matrix | SURFPoints object | MSERRegions object | cornerPoints object | BRISKPoints object

Coordinates of points in image two, specified as an *M*-by-2 matrix of *M* number of [x y] coordinates, or as a SURFPoints, MSERRegions, cornerPoints, or BRISKPoints object.

method — Display method
falsecolor (default) | blend | montage

Display style method, specified as one of the following:

falsecolor:	Overlay the images by creating a composite red-cyan image showing I1 as red and I2 as cyan.
blend:	Overlay I1 and I2 using alpha blending.
montage:	Place I1 and I2 next to each other in the same image.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example:

`PlotOptions` — Line style and color
{'ro','g+','y-'} (default) | cell array

Line style and color options, specified as a cell array containing three character vector values, {*MarkerStyle1*, *MarkerStyle2*, *LineStyle*}, corresponding to a marker specification in `I1`, marker specification in `I2`, and line style and color. The `LineSpec` syntax of the `plot` function defines each of the specifiers.

`Parent` — Output axes
`axes` graphics object

Output axes for displaying visualization, specified as an `axes` graphics object.

Output Arguments

`H` — Handle to image object
handle

Handle to image object, returned as the handle to the image object returned by `showMatchedFeatures`.

See Also
MSERRegions | SURFPoints | cornerPoints | estimateGeometricTransform | imshowpair | legend | matchFeatures

Introduced in R2012b

showPointCloud

Plot 3-D point cloud

Syntax

showPointCloud

Description

showPointCloud was renamed to pcshow. Please use pcshow in place of showPointCloud.

Introduced in R2014b

pcshow

Plot 3-D point cloud

Syntax

```
pcshow(ptCloud)

pcshow(xyzPoints)
pcshow(xyzPoints,C)
pcshow(filename)

pcshow( ___ ,Name,Value)

ax = pcshow( ___ )
```

Description

pcshow(`ptCloud`) displays points using the locations and colors stored in the point cloud object.

pcshow(`xyzPoints`) displays points specified by the `xyzPoints` matrix.

pcshow(`xyzPoints,C`) displays points contained in the `xyzPoints` matrix, with colors specified by `C`.

pcshow(`filename`) displays the point cloud stored in the file specified by `filename`.

pcshow(___ ,`Name,Value`) uses additional options specified by one or more `Name,Value` pair arguments, using any of the preceding syntaxes.

`ax` = pcshow(___) returns the plot axes.

Examples

Plot Spherical Point Cloud with Texture Mapping

Generate a sphere consisting of 600-by-600 faces.

```
numFaces = 600;
[x,y,z] = sphere(numFaces);
```

Plot the sphere using the default color map.

```
figure;
pcshow([x(:),y(:),z(:)]);
title('Sphere with Default Color Map');
xlabel('X');
ylabel('Y');
zlabel('Z');
```
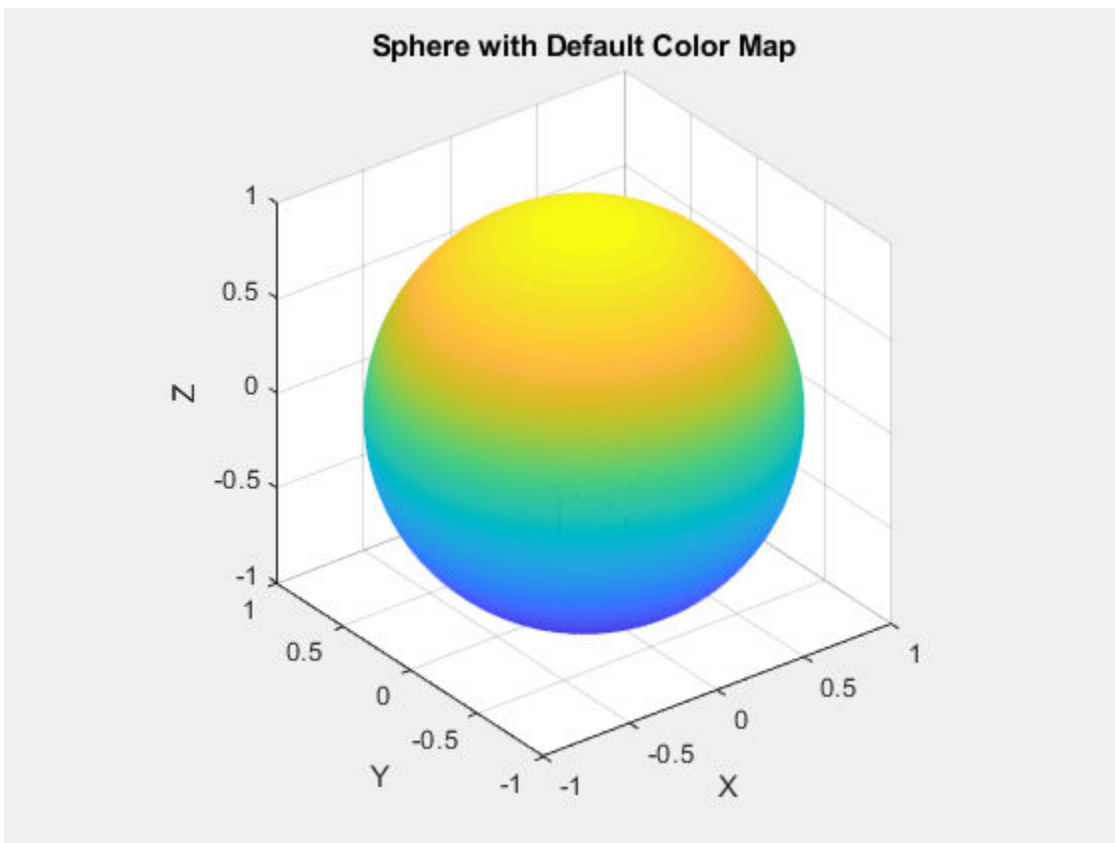
Load and display an image for texture mapping.

```
I = im2double(imread('visionteam1.jpg'));
imshow(I);
```


Resize and flip the image for mapping the coordinates.

```
J = flipud(imresize(I,size(x)));
```

Plot the sphere with the color texture.

```
pcshow([x(:),y(:),z(:)],reshape(J,[],3));
title('Sphere with Color Texture');
xlabel('X');
```

```
ylabel('Y');
zlabel('Z');
```


Sphere with Color Texture

- "Structure From Motion From Two Views"
- "Depth Estimation From Stereo Video"

Input Arguments

ptCloud — Point cloud
pointCloud object

Point cloud, specified as a `pointCloud` object. The object contains the locations, intensities, and RGB colors to render the point cloud.

Point Cloud Property	Color Rendering Result
`Location` only	Maps the z-value to a color value in the current color map.
`Location` and `Intensity`	Maps the intensity to a color value in the current color map.
`Location` and `Color`	Use provided color.
`Location`, `Intensity`, and `Color`	Use provided color.

`filename` — Point cloud filename
character vector

Point cloud filename, specified as a character vector. The file must be supported by `pcread`. `pcshow` calls `pcread` to read the point cloud from the file, but does not store the data in the MATLAB workspace.

`xyzPoints` — Point cloud *x*, *y*, and *z* locations
M-by-3 matrix | *M*-by-*N*-by-3 matrix

Point cloud *x*, *y*, and *z* locations, specified as either an *M*-by-3 or an *M*-by-*N*-by-3 numeric matrix. The `xyzPoints` numeric matrix contains *M* or *M*-by-*N* [*x*,*y*,*z*] points. The *z* values in the matrix, which generally corresponds to depth or elevation, determine the color of each point. When you do not specify the `C` input color, the function maps the *z* value to a color in the current colormap.

`C` — Point cloud color
ColorSpec (Color Specification) color character vector | 1-by-3 RGB vector | *M*-by-1 vector | *M*-by-*N* matrix | *M*-by-3 matrix | *M*-by-*N*-by-3 matrix

Point cloud color of points, specified as one of:

- `ColorSpec (Color Specification)` color character vector, a 1-by-3 RGB vector
- *M*-by-1 vector
- *M*-by-*N* matrix
- *M*-by-3 matrix
- *M*-by-*N*-by-3 matrix

You can specify the same color for all points or a different color for each point. When you set C to single or double, the RGB values range between [0, 1]. When you set C to uint8, the values range between [0, 255].

Points Input	Color Selection	Valid Values of C	
xyzPoints	Same color for all points	ColorSpec (Color Specification) color character vector or a 1-by-3 RGB vector	r g b 1-by-3
	Different color for each point	Vector or *M*-by-*N* matrix. The matrix must contain values that are linearly mapped to a color in the current colormap.	
		M-by-3 matrix or *M*-by-*N*-by-3 matrix containing RGB values for each point.	

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'VerticalAxisDir','Up' sets the vertical axis direction to up.

MarkerSize — Diameter of marker
6 (default) | positive scalar

Diameter of marker, specified as the comma-separated pair consisting of 'MarkerSize' and a positive scalar. The value specifies the approximate diameter of the point marker. MATLAB graphics define the unit as points. A marker size larger than six can reduce the rendering performance.

VerticalAxis — Vertical axis
'Z' (default) | 'X' | 'Y'

Vertical axis, specified as the comma-separated pair consisting of `'VerticalAxis'` and a character vector specifying the vertical axis: `'X'`, `'Y'`, or `'Z'`.

VerticalAxisDir — Vertical axis direction
`'Up'` (default) | `'Down'`

Vertical axis direction, specified as the comma-separated pair consisting of `'VerticalAxisDir'` and a character vector specifying the direction of the vertical axis: `'Up'` or `'Down'`.

Parent — Output axes
`axes` graphics object

Output axes, specified as the comma-separated pair consisting of `'Parent'` and an `axes` graphics object that displays the point cloud visualization.

Output Arguments

ax — Plot axes
`axes` graphics object

Plot axes, returned as an `axes` graphics object.

You can set the default center of rotation for the point cloud viewer to rotate around the axes center or around a point. Set the default behavior from the "Computer Vision System Toolbox Preferences".

Tips

To improve performance, `pcshow` automatically downsamples the rendered point cloud during interaction with the figure. The downsampling occurs only for rendering the point cloud and does not affect the saved points.

Algorithms

The `pcshow` function supports the `'opengl'` option for the `Renderer figure` property only.

See Also

pcdenoise | pcdownsample | pcfitplane | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pcwrite | planeModel | plot3 | pointCloud | reconstructScene | scatter3 | triangulate

Topics

"Structure From Motion From Two Views"
"Depth Estimation From Stereo Video"
"Coordinate Systems"

Introduced in R2015b

pcshowpair

Visualize difference between two point clouds

Syntax

```
pcshowpair(ptCloudA,ptCloudB)
```

```
pcshowpair(ptCloudA,ptCloudB,Name,Value)
```

```
ax = pcshowpair( ___ )
```

Description

pcshowpair(ptCloudA,ptCloudB) creates a visualization depicting the differences between the two input point clouds. The differences are displayed using a blending of magenta for point cloud A and green for point cloud B.

pcshowpair(ptCloudA,ptCloudB,Name,Value) visualizes the differences using additional options specified by one or more Name,Value pair arguments.

ax = pcshowpair(___) returns the plot axes to the visualization of the differences, using any of the preceding syntaxes.

Examples

Visualize the Difference Between Two Point Clouds

Load two point clouds that were captured using a Kinect device in a home setting.

```
load('livingRoom');

pc1 = livingRoomData{1};
pc2 = livingRoomData{2};
```

Plot and set the viewpoint of point clouds.

```
figure
pcshowpair(pc1,pc2,'VerticalAxis','Y','VerticalAxisDir','Down')
title('Difference Between Two Point Clouds')
xlabel('X(m)')
ylabel('Y(m)')
zlabel('Z(m)')
```
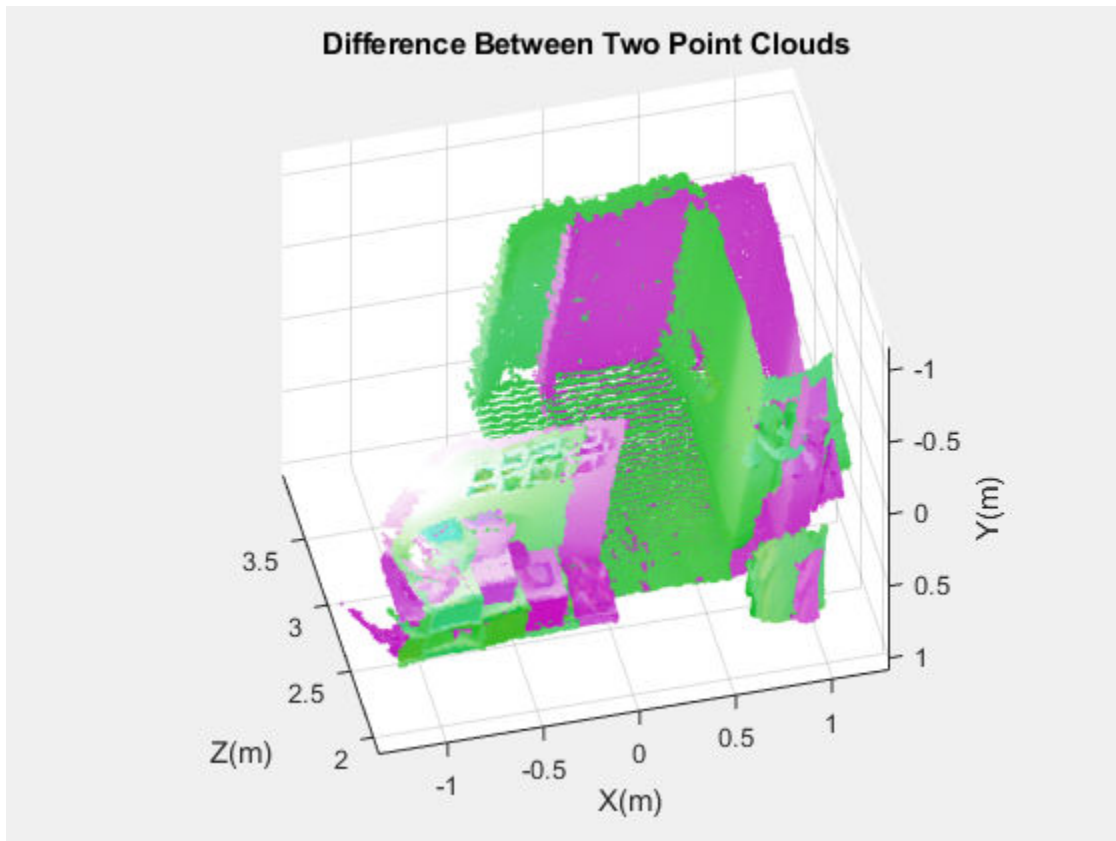

Difference Between Two Point Clouds

- "Structure From Motion From Two Views"
- "Depth Estimation From Stereo Video"

Input Arguments

ptCloudA — Point cloud
pointCloud object

Point cloud A, specified as a pointCloud object. The function uses levels of magenta to represent ptCloudA and a pure magenta when the point cloud contains no color information.

ptCloudB — Point cloud
pointCloud object

Point cloud B, specified as a pointCloud object. The function uses levels of green to represent ptCloudB and a pure green when the point cloud contains no color information.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name, Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1, Value1, ..., NameN, ValueN.

Example: 'VerticalAxisDir', 'Up' sets the vertical axis direction to up.

MarkerSize — Diameter of marker
6 (default) | positive scalar

Approximate diameter of the point marker, specified as the comma-separated pair consisting of 'MarkerSize' and a positive scalar. The units are in points. A marker size larger than six can reduce the rendering performance.

VerticalAxis — Vertical axis
'Z' (default) | 'X' | 'Y'

Vertical axis, specified as the comma-separated pair consisting of 'VerticalAxis' and a character vector specifying the vertical axis: 'X', 'Y', or 'Z'.

VerticalAxisDir — Vertical axis direction
'Up' (default) | 'Down'

Vertical axis direction, specified as the comma-separated pair consisting of 'VerticalAxisDir' and a character vector specifying the direction of the vertical axis: 'Up' or 'Down'.

Parent — Output axes
axes graphics object

Output axes, specified as the comma-separated pair consisting of 'Parent' and an axes graphics object that displays the point cloud visualization.

Output Arguments

ax — Plot axes
axes graphics object

Plot axes, returned as an axes graphics object. Points with NaN or Inf coordinates are not displayed.

You can set the default center of rotation for the point cloud viewer to rotate around the axes center or around a point. Set the default behavior from the "Computer Vision System Toolbox Preferences".

Tips

To improve performance, pcshowpair automatically downsamples the rendered point cloud during interaction with the figure. The downsampling occurs only for rendering the point cloud and does not affect the saved points.

See Also

pcdenoise | pcdownsample | pcfitplane | pcmerge | pcplayer | pcread | pcregistericp | pcshow | pcwrite | planeModel | plot3 | pointCloud | reconstructScene | scatter3 | triangulate

Topics
"Structure From Motion From Two Views"
"Depth Estimation From Stereo Video"

"Coordinate Systems"

Introduced in R2015b

showReprojectionErrors

Visualize calibration errors

Syntax

```
showReprojectionErrors(cameraParams)
showReprojectionErrors(cameraParams,view)
showReprojectionErrors( ___ ,Name,Value)

ax = showReprojectionErrors( ___ )
```

Description

showReprojectionErrors(cameraParams) displays a bar graph that represents the calibration accuracy for a single camera or for a stereo pair. The bar graph displays the mean reprojection error per image. The cameraParams input contains either a cameraParameters, fisheyeParameters, or a stereoParameters object, which the estimateCameraParameters or estimateFisheyeParameters function returns.

showReprojectionErrors(cameraParams,view) displays the reprojection errors using the visualization style specified by the view input.

showReprojectionErrors(___ ,Name,Value) uses additional options specified by one or more Name,Value pair arguments, using any of the preceding syntaxes.

ax = showReprojectionErrors(___) returns the plot axis, using any of the preceding syntaxes.

Examples

Visualize Reprojection Errors for a Single Camera

Create a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
  'calibration','webcam'));
imageFileNames = images.Files(1:5);
```

Detect calibration pattern.

```
[imagePoints, boardSize] = detectCheckerboardPoints(imageFileNames);
```

Generate world coordinates of the corners of the squares. The square size is in millimeters.

```
squareSize = 25;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the camera.

```
I = readimage(images,1);
imageSize = [size(I, 1), size(I, 2)];
params = estimateCameraParameters(imagePoints,worldPoints, ...
                                  'ImageSize',imageSize);
```

Visualize the errors as a bar graph.

```
subplot(1,2,1);
showReprojectionErrors(params);
```
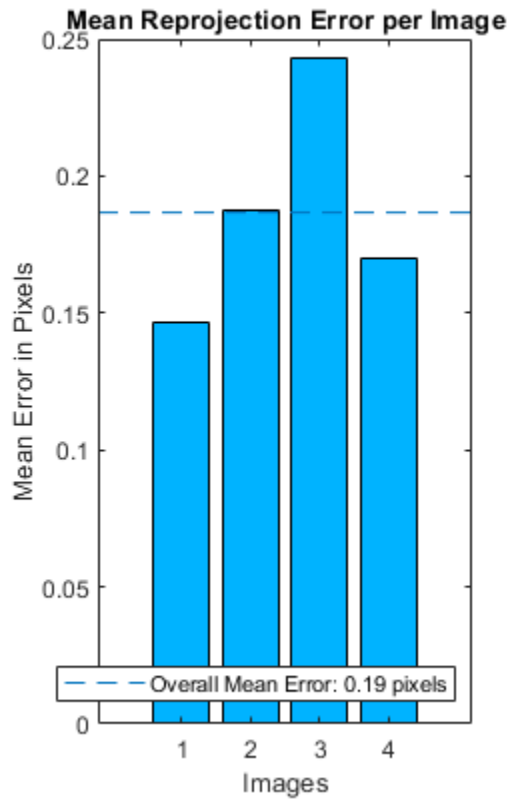
Visualize the errors as a scatter plot.

```
subplot(1,2,2);
showReprojectionErrors(params,'ScatterPlot');
```
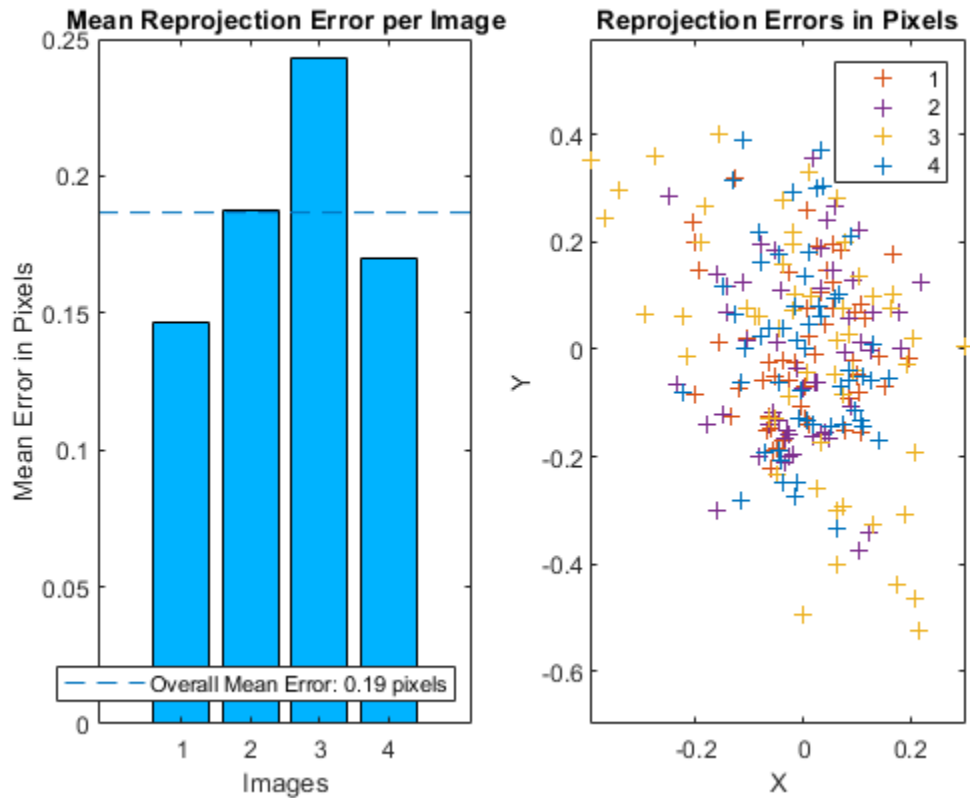
Visualize Reprojection Errors for a Stereo Pair of Cameras

Specify calibration images

```
imageDir = fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','stereo');
leftImages = imageDatastore(fullfile(imageDir,'left'));
rightImages = imageDatastore(fullfile(imageDir,'right'));
```

Detect the checkerboards.

```
[imagePoints, boardSize] = detectCheckerboardPoints(...
    leftImages.Files,rightImages.Files);
```

Specify world coordinates of checkerboard keypoints. The square size is in millimeters.

```
squareSize = 108;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the stereo camera system. Here both cameras have the same resolution.

```
I = readimage(leftImages,1);
imageSize = [size(I, 1), size(I, 2)];
params = estimateCameraParameters(imagePoints,worldPoints, ...
                                  'ImageSize',imageSize);
```

Visualize calibration accuracy.

```
showReprojectionErrors(params);
```

Input Arguments

cameraParams — Object containing parameters of single camera or stereo pair
cameraParameters object | fisheyeParameters object | stereoParameters object

Object containing parameters of single camera or stereo pair, specified as either a cameraParameters, fisheyeParameters, or stereoParameters object. You can create the single camera or stereo pair input object using the estimateCameraParameters function. The fisheye parameters input object is created using estimateFisheyeParameters.

You can also use the **Camera Calibrator** app to create the `cameraParameters` input object, or use **Stereo Camera Calibrator** app to create the `stereoParameters` input object. See "Single Camera Calibrator App" and "Stereo Camera Calibrator App".

view — Bar graph or scatter plot view
`'BarGraph'` | `'ScatterPlot'`

Bar graph or scatter plot view, specified as the character vector `'BarGraph'` or `'ScatterPlot'`. The `view` input sets the visualization for the camera extrinsic parameters. Set `view` to `'BarGraph'` to display the mean error per image as a bar graph. Set `view` to `'ScatterPlot'` to display the error for each point as a scatter plot. The `'ScatterPlot'` option applies only to the single camera case.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'view','BarGraph'` displays the mean error per image as a bar graph.

HighlightIndex — Highlight selection index
`[ ]` (default) | vector | scalar

Highlight selection index, specified as a scalar or a vector of integers. When you set the `view` to `'BarGraph'`, the function highlights the bars corresponding to the selected images. When you set the `view` to `'ScatterPlot'`, the function highlights the points corresponding to the selected images with circle markers.

Parent — Output axes
current axes (default) | scalar value

Output axes, specified as the comma-separated pair consisting of `'Parent'` and a scalar value. Specify output axes to display the visualization. You can obtain the current axes handle by returning the function to an output variable:
`ax = showReprojectionErrors(cameraParams)`
You can also use the `gca` function to get the current axes handle.

Example: `showReprojectionErrors(cameraParams,'Parent',ax)`

Output Arguments

ax — Current axes handle
scalar value

Current axes handle, returned as a scalar value. The function returns the handle to the current axes for the current figure.

Example: `ax = showReprojectionErrors(cameraParams)`

See Also
Camera Calibrator | **Stereo Camera Calibrator** | cameraParameters | detectCheckerboardPoints | estimateCameraParameters | fisheyeParameters | generateCheckerboardPoints | showExtrinsics | stereoParameters | undistortImage

Topics
"Single Camera Calibrator App"

Introduced in R2014a

stereoAnaglyph

Create red-cyan anaglyph from stereo pair of images

Syntax

```
J = stereoAnaglyph(I1,I2)
```

Description

`J = stereoAnaglyph(I1,I2)` combines images `I1` and `I2` into a red-cyan anaglyph. When the inputs are rectified stereo images, you can view the output image with red-blue stereo glasses to see the stereo effect.

Examples

Create 3-D Stereo Display

Load parameters for a calibrated stereo pair of cameras.

```
load('webcamsSceneReconstruction.mat')
```

Load a stereo pair of images.

```
I1 = imread('sceneReconstructionLeft.jpg');
I2 = imread('sceneReconstructionRight.jpg');
```

Rectify the stereo images.

```
[J1, J2] = rectifyStereoImages(I1, I2, stereoParams);
```

Create the anaglyph.

```
A = stereoAnaglyph(J1, J2);
```

Display the anaglyph. Use red-blue stereo glasses to see the stereo effect.

```
figure; imshow(A);
```


- "Structure From Motion From Two Views"
- "Structure From Motion From Multiple Views"

Input Arguments

I1 — Input image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-*D* grayscale image

Input image I1, specified as an *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-*D* grayscale image. I1 and I2 must be real, finite, and nonsparse, and the images must be the same size. If the images are not the same size, use `imfuse` to pad the smaller image dimension with zeros before creating the anaglyph.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

I2 — Input image
M-by-*N* 2-*D* grayscale image | *M*-by-*N*-by-3 truecolor image

Input image I2, specified as an *M*-by-*N*-by-3 truecolor image or an *M*-by-*N* 2-*D* grayscale image. I1 and I2 must be real, finite, and nonsparse, and the images must be the same size. If the images are not the same size, use `imfuse` to pad the smaller image dimension with zeros before creating the anaglyph.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

Output Arguments

J — Stereo anaglyph output image
M-by-*N*-by-3 truecolor image

Stereo anaglyph output image, returned as an *M*-by-*N*-by-3 truecolor image. Output image J is the same size as input images I1 and I2.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`estimateUncalibratedRectification` | `imfuse` | `imshowpair` | `reconstructScene` | `rectifyStereoImages`

Topics
"Structure From Motion From Two Views"
"Structure From Motion From Multiple Views"

Introduced in R2014b

trainCascadeObjectDetector

Train cascade object detector model

Syntax

```
trainCascadeObjectDetector(outputXMLFilename,positiveInstances,
negativeImages)
trainCascadeObjectDetector(outputXMLFilename,'resume')

trainCascadeObjectDetector( ___ ,Name,Value)
```

Description

`trainCascadeObjectDetector(outputXMLFilename,positiveInstances,
negativeImages)` writes a trained cascade detector XML file named,
`outputXMLFilename`. The file name must include an XML extension. For a more detailed
explanation on how this function works, refer to "Train a Cascade Object Detector".

`trainCascadeObjectDetector(outputXMLFilename,'resume')` resumes an
interrupted training session. The `outputXMLFilename` input must match the output file
name from the interrupted session. All arguments saved from the earlier session are
reused automatically.

`trainCascadeObjectDetector( ___ ,Name,Value)` uses additional options specified
by one or more `Name,Value` pair arguments.

Examples

Train Stop Sign Detector

Load the positive samples data from a MAT file. The file contains a table specifying
bounding boxes for several object categories. The table was exported from the `Training
Image Labeler` app.

Load positive samples.

```
load('stopSignsAndCars.mat');
```

Select the bounding boxes for stop signs from the table.

```
positiveInstances = stopSignsAndCars(:,1:2);
```

Add the image folder to the MATLAB path.

```
imDir = fullfile(matlabroot,'toolbox','vision','visiondata',...
    'stopSignImages');
addpath(imDir);
```

Specify the folder for negative images.

```
negativeFolder = fullfile(matlabroot,'toolbox','vision','visiondata',...
    'nonStopSigns');
```

Create an `imageDatastore` object containing negative images.

```
negativeImages = imageDatastore(negativeFolder);
```

Train a cascade object detector called 'stopSignDetector.xml' using HOG features. NOTE: The command can take several minutes to run.

```
trainCascadeObjectDetector('stopSignDetector.xml',positiveInstances, ...
    negativeFolder,'FalseAlarmRate',0.1,'NumCascadeStages',5);
```

```
Automatically setting ObjectTrainingSize to [35, 32]
Using at most 42 of 42 positive samples per stage
Using at most 84 negative samples per stage

--cascadeParams--
Training stage 1 of 5
[....................................................................]
Used 42 positive and 84 negative samples
Time to train stage 1: 1 seconds

Training stage 2 of 5
[....................................................................]
Used 42 positive and 84 negative samples
Time to train stage 2: 0 seconds

Training stage 3 of 5
```

```
[.............................................................................]
Used 42 positive and 84 negative samples
Time to train stage 3: 3 seconds

Training stage 4 of 5
[.............................................................................]
Used 42 positive and 84 negative samples
Time to train stage 4: 9 seconds

Training stage 5 of 5
[.............................................................................]
Used 42 positive and 17 negative samples
Time to train stage 5: 14 seconds

Training complete
```

Use the newly trained classifier to detect a stop sign in an image.

```
detector = vision.CascadeObjectDetector('stopSignDetector.xml');
```

Read the test image.

```
img = imread('stopSignTest.jpg');
```

Detect a stop sign.

```
bbox = step(detector,img);
```

Insert bounding box rectangles and return the marked image.

```
 detectedImg = insertObjectAnnotation(img,'rectangle',bbox,'stop sign');
```

Display the detected stop sign.

```
figure; imshow(detectedImg);
```

Remove the image directory from the path.

```
rmpath(imDir);
```

- "Image Category Classification Using Bag of Features"

Input Arguments

positiveInstances — Positive samples
table | struct

Positive samples, specified as a two-column table or two-field structure.

The first table column or structure field contains image file names, specified as character vectors. Each image can be true color, grayscale, or indexed, in any of the formats supported by imread.

The second table column or structure field contains an *M*-by-4 matrix of *M* bounding boxes. Each bounding box is in the format [*x y width height*] and specifies an object location in the corresponding image.

You can use the **Image Labeler** app to label objects of interest with bounding boxes. The app outputs a table or a struct to use as `positiveInstances`. The function automatically determines the number of positive samples to use at each of the cascade stages. This value is based on the number of stages and the true positive rate. The true positive rate specifies how many positive samples can be misclassified.

Data Types: `table` | `struct`

negativeImages — Negative images
`ImageDatastore` object | cell array | character vector

Negative images, specified as an `ImageDatastore` object, a path to a folder containing images, or as a cell array of image file names. Because the images are used to generate negative samples, they must not contain any objects of interest. Instead, they should contain backgrounds associated with the object.

outputXMLFilename — Trained cascade detector file name
character vector

Trained cascade detector file name, specified as a character vector with an XML extension. For example, `'stopSignDetector.xml'`.

Data Types: `char`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'FeatureType','Haar'` specifies Haar for the type of features to use.

ObjectTrainingSize — Object size for training
`'Auto'` (default) | two-element vector

Training object size, specified as the comma-separated pair. This pair contains `'ObjectTrainingSize'` and either a two-element [*height, width*] vector, or as `'Auto'`.

Before training, the function resizes the positive and negative samples to `ObjectTrainingSize` in pixels. If you select `'Auto'`, the function determines the size automatically based on the median width-to-height ratio of the positive instances. For optimal detection accuracy, specify an object training size close to the expected size of the object in the image. However, for faster training and detection, set the object training size to be smaller than the expected size of the object in the image.

Data Types: `char` | `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

NegativeSamplesFactor — Negative sample factor
`2` (default) | real-valued scalar

Negative sample factor, specified as the comma-separated pair consisting of `'NegativeSamplesFactor'` and a real-valued scalar. The number of negative samples to use at each stage is equal to

NegativeSamplesFactor × [*the number of positive samples used at each stage*].

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

NumCascadeStages — Number of cascade stages
`20` (default) | positive integer

Number of cascade stages to train, specified as the comma-separated pair consisting of `'NumCascadeStages'` and a positive integer. Increasing the number of stages may result in a more accurate detector but also increases training time. More stages can require more training images, because at each stage, some number of positive and negative samples are eliminated. This value depends on the values of `FalseAlarmRate` and `TruePositiveRate`. More stages can also enables you to increase the `FalseAlarmRate`. See the "Train a Cascade Object Detector" tutorial for more details.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

FalseAlarmRate — Acceptable false alarm rate
`0.5` (default) | value in the range (0 1)

Acceptable false alarm rate at each stage, specified as the comma-separated pair consisting of `'FalseAlarmRate'` and a value in the range (0 1]. The false alarm rate is the fraction of negative training samples incorrectly classified as positive samples.

The overall false alarm rate is calculated using the `FalseAlarmRate` per stage and the number of cascade stages, `NumCascadeStages`:

FalseAlarmRate^{*NumCascadeStages*}

Lower values for `FalseAlarmRate` increase complexity of each stage. Increased complexity can achieve fewer false detections but can result in longer training and detection times. Higher values for `FalseAlarmRate` can require a greater number of cascade stages to achieve reasonable detection accuracy.

Data Types: `single` | `double`

TruePositiveRate — Minimum true positive rate
`0.995` (default) | value in the range (0,1]

Minimum true positive rate required at each stage, specified as the comma-separated pair consisting of '`TruePositiveRate`' and a value in the range (0 1]. The true positive rate is the fraction of correctly classified positive training samples.

The overall resulting target positive rate is calculated using the `TruePositiveRate` per stage and the number of cascade stages, `NumCascadeStages`:

TruePositiveRate^{*NumCascadeStages*}

Higher values for `TruePositiveRate` increase complexity of each stage. Increased complexity can achieve a greater number of correct detections but can result in longer training and detection times.

Data Types: `single` | `double`

FeatureType — Feature type
'`HOG`' (default) | '`LBP`' | '`Haar`'

Feature type, specified as the comma-separated pair consisting of '`FeatureType`' and one of the following:
'`Haar`'[1] — Haar-like features
'`LBP`'[2] — Local binary patterns
'`HOG`'[3] — Histogram of oriented gradients

The function allocates a large amount of memory, especially the Haar features. To avoid running out of memory, use this function on a 64-bit operating system with a sufficient amount of RAM.

Data Types: `char`

Tips

Training a good detector requires thousands of training samples. Processing time for a large amount of data varies, but it is likely to take hours or even days. During training, the function displays the time it took to train each stage in the MATLAB command window.

References

[1] Viola, P., and M. J. Jones. "Rapid Object Detection using a Boosted Cascade of Simple Features." *Proceedings of the 2001 IEEE Computer Society Conference*. Volume 1, 15 April 2001, pp. I-511–I-518.

[2] Ojala, T., M. Pietikainen, and T. Maenpaa. "Multiresolution Gray-scale and Rotation Invariant Texture Classification With Local Binary Patterns." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Volume 24, No. 7 July 2002, pp. 971–987.

[3] Dalal, N., and B. Triggs. "Histograms of Oriented Gradients for Human Detection." *IEEE Computer Society Conference on Computer Vision and Pattern Recognition*. Volume 1, 2005, pp. 886–893.

See Also

Apps
Image Labeler

Functions
`imrect` | `insertObjectAnnotation` | `vision.CascadeObjectDetector`

Topics
"Image Category Classification Using Bag of Features"
"Define Ground Truth for Image Collections"
"Train a Cascade Object Detector"
"Multiple Object Tracking"

External Websites

Cascade Training GUI

Introduced in R2013a

trainImageCategoryClassifier

Train an image category classifier

Syntax

```
classifier = trainImageCategoryClassifier(imds,bag)
classifier = trainImageCategoryClassifier(imds,bag,Name,Value)
```

Description

`classifier = trainImageCategoryClassifier(imds,bag)` returns an image category classifier. The classifier contains the number of categories and the category labels for the input `imds` images. The function trains a support vector machine (SVM) multiclass classifier using the input `bag`, a `bagOfFeatures` object.

You must have a Statistics and Machine Learning Toolbox license to use this function.

This function supports parallel computing using multiple MATLAB workers. Enable parallel computing using the "Computer Vision System Toolbox Preferences" dialog. To open Computer Vision System Toolbox preferences, on the **Home** tab, in the **Environment** section, click **Preferences**. Select **Computer Vision System Toolbox**.

`classifier = trainImageCategoryClassifier(imds,bag,Name,Value)` returns a `classifier` object with optional input properties specified by one or more `Name,Value` pair arguments.

Examples

Train, Evaluate, and Apply Image Category Classifier

Load two image categories.

```
setDir  = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imds = imageDatastore(setDir,'IncludeSubfolders',true,'LabelSource',...
    'foldernames');
```

Split the data set into a training and test data. Pick 30% of images from each set for the training data and the remainder 70% for the test data.

```
[trainingSet,testSet] = splitEachLabel(imds,0.3,'randomize');
```

Create bag of visual words.

```
bag = bagOfFeatures(trainingSet);
```

```
Creating Bag-Of-Features.
-------------------------
* Image category 1: books
* Image category 2: cups
* Selecting feature point locations using the Grid method.
* Extracting SURF features from the selected feature point locations.
** The GridStep is [8 8] and the BlockWidth is [32 64 96 128].

* Extracting features from 4 images...done. Extracted 76800 features.

* Keeping 80 percent of the strongest features from each category.

* Using K-Means clustering to create a 500 word visual vocabulary.
* Number of features       : 61440
* Number of clusters (K)    : 500

* Initializing cluster centers...100.00%.
* Clustering...completed 20/100 iterations (~0.24 seconds/iteration)...converged in 20

* Finished creating Bag-Of-Features
```

Train a classifier with the training sets.

```
categoryClassifier = trainImageCategoryClassifier(trainingSet,bag);
```

```
Training an image category classifier for 2 categories.
-------------------------------------------------------
* Category 1: books
* Category 2: cups

* Encoding features for 4 images...done.

* Finished training the category classifier. Use evaluate to test the classifier on a t
```

Evaluate the classifier using test images. Display the confusion matrix.

```
confMatrix = evaluate(categoryClassifier,testSet)
```

```
Evaluating image category classifier for 2 categories.
-------------------------------------------------------

* Category 1: books
* Category 2: cups

* Evaluating 8 images...done.

* Finished evaluating all the test sets.

* The confusion matrix for this test set is:


            PREDICTED
KNOWN    | books    cups
-------------------------
books    | 0.75     0.25
cups     | 0.25     0.75

* Average Accuracy is 0.75.

confMatrix = 2×2

    0.7500    0.2500
    0.2500    0.7500
```

Find the average accuracy of the classification.

```
mean(diag(confMatrix))
```

```
ans = 0.7500
```

Apply the newly trained classifier to categorize new images.

```
img = imread(fullfile(setDir,'cups','bigMug.jpg'));
[labelIdx, score] = predict(categoryClassifier,img);
```

Display the classification label.

```
categoryClassifier.Labels(labelIdx)
```

3-707

```
ans = 1x1 cell array
    {'cups'}
```

• "Image Category Classification Using Bag of Features"

Input Arguments

`imds` — Images
`imageDatastore` object

Images specified as an `imageDatastore` object.

`bag` — Bag of features
`bagOfFeatures` object

Bag of features, specified as a `bagOfFeatures` object. The object contains a visual vocabulary of extracted feature descriptors from representative images of each image category.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Verbose',true` sets `'Verbose'` to the logical `true`.

Verbose — Enable progress display to screen
`true` (default) | false

Enable progress display to screen, specified as the comma-separated pair consisting of `'Verbose'` and the logical `true` or `false`.

`LearnerOptions` — Classifier options
default values of `templateSVM` function

Classifier options, specified as the comma-separated pair consisting of `'LearnerOptions'` and the learner options output returned by the `templateSVM` function.

Example 3.2. Example

To adjust the regularization parameter of `templateSVM` and to set a custom kernel function, use the following syntax:

```
opts = templateSVM('BoxConstraint',1.1,'KernelFunction','gaussian');
classifier = trainImageCategoryClassifier(imds,bag,'LearnerOptions',opts);
```

Output Arguments

`classifier` — Image category classifier
imageCategoryClassifier object

Image category classifier, returned as an `imageCategoryClassifier` object. The function trains a support vector machine (SVM) multiclass classifier using the error correcting output codes (ECOC) framework.

References

[1] Csurka, G., C. R. Dance, L. Fan, J. Willamowski, and C. Bray *Visual Categorization with Bag of Keypoints*, Workshop on Statistical Learning in Computer Vision, ECCV 1 (1-22), 1-2.

See Also

bagOfFeatures | fitcecoc | imageCategoryClassifier | imageSet | templateSVM

Topics
"Image Category Classification Using Bag of Features"
"Image Classification with Bag of Visual Words"

Introduced in R2014b

Image Labeler

Label ground truth in a collection of images

Description

The **Image Labeler** app enables you to label ground truth data in a sequence of images. Use the app to interactively label rectangular regions of interest (ROIs) for object detection and pixels for semantic segmentation. The ROI labels define locations of objects in an image frame. The scene labels define and describe the labels pertaining to the entire image frame. You can use ROIs and pixel segmentation labels to mark objects, such as cars, pedestrians, and lane markers. Scene labels can be used to mark scene conditions, such as sunny or cloudy, or to mark events such as intersections. Use ROIs for object detection, pixel labels for semantic segmentation, and scene labels for image classification.

The app exports data as a `groundTruth` object. You can use the `groundTruth` object to "Train an Object Detector from Ground Truth Data". You can also "Create Automation Algorithm for Image Labeling".

You can define and execute custom label automation algorithms with the Image Labeler by creating an `AutomationAlgorithm`.

Open the Image Labeler App

- MATLAB Toolstrip: On the **Apps** tab, under **Image Processing and Computer Vision**, click the app icon.
- MATLAB command prompt: Enter `imageLabeler`.

Programmatic Use

`imageLabeler` opens the app, enabling you to label ground truth data in images.

`imageLabeler(imageFolder)` opens the app and loads all the images from the `imageFolder`.

imageLabeler(imgDatastore) opens the app and reads all of the images from an imageDatastore object.

imageLabeler(sessionFile) opens the app and loads a saved **Image Labeler** session, sessionFile. The sessionFile input contains the path and file name. The MAT-file that sessionFile points to contains the saved session.

See Also

groundTruth | groundTruthDataSource | objectDetectorTrainingData

Topics

"Define Ground Truth for Image Collections"
"Label Pixels for Semantic Segmentation"
"Create Automation Algorithm for Image Labeling"
"Train an Object Detector from Ground Truth Data"

Training Image Labeler

Label images for training a classifier

Description

The **Image Labeler** app replaces the **Training Image Labeler** app. Use the Image Labeler instead.

Open the Training Image Labeler App

- MATLAB command prompt: Enter `trainingImageLabeler`.

Note The `trainingImageLabeler` function opens the **Image Labeler** app.

Examples

Open Training Image Labeler App

Type `trainingImageLabeler` on the MATLAB command line or select it from the MATLAB desktop **Apps** tab.

Note The `trainingImageLabeler` function opens the **Image Labeler** app.

Programmatic Use

`trainingImageLabeler` invokes an app for labeling ground truth data in images. This app allows you to interactively specify rectangular Regions of Interest (ROIs). The ROIs define locations of objects, which are used to train a classifier. It outputs training data in a format supported by the `trainCascadeObjectDetector` function. The function trains a model to use with the `vision.CascadeObjectDetector` detector.

Note The `trainingImageLabeler` function opens the **Image Labeler** app.

See Also
Image Labeler | `imageDatastore` | `imrect` | `insertObjectAnnotation` | `trainCascadeObjectDetector` | `vision.CascadeObjectDetector`

Topics
"Define Ground Truth for Image Collections"
"Train a Cascade Object Detector"

Introduced in R2014a

triangulate

3-D locations of undistorted matching points in stereo images

Syntax

```
worldPoints = triangulate(matchedPoints1,matchedPoints2,
stereoParams)
worldPoints = triangulate(matchedPoints1,matchedPoints2,
cameraMatrix1,cameraMatrix2)
[worldPoints,reprojectionErrors] = triangulate( ___ )
```

Description

`worldPoints = triangulate(matchedPoints1,matchedPoints2,
stereoParams)` returns 3-D locations of matching pairs of undistorted image points from
two stereo images.

`worldPoints = triangulate(matchedPoints1,matchedPoints2,
cameraMatrix1,cameraMatrix2)` returns the 3-D locations of the matching pairs in a
world coordinate system. These locations are defined by camera projection matrices.

`[worldPoints,reprojectionErrors] = triangulate( ___ )` additionally returns
reprojection errors for the world points using any of the input arguments from previous
syntaxes.

Examples

Measure Distance from Stereo Camera to a Face

Load stereo parameters.

```
load('webcamsSceneReconstruction.mat');
```

Read in the stereo pair of images.

```
I1 = imread('sceneReconstructionLeft.jpg');
I2 = imread('sceneReconstructionRight.jpg');
```

Undistort the images.

```
I1 = undistortImage(I1,stereoParams.CameraParameters1);
I2 = undistortImage(I2,stereoParams.CameraParameters2);
```

Detect a face in both images.

```
faceDetector = vision.CascadeObjectDetector;
face1 = faceDetector(I1);
face2 = faceDetector(I2);
```

Find the center of the face.

```
center1 = face1(1:2) + face1(3:4)/2;
center2 = face2(1:2) + face2(3:4)/2;
```

Compute the distance from camera 1 to the face.

```
point3d = triangulate(center1, center2, stereoParams);
distanceInMeters = norm(point3d)/1000;
```

Display the detected face and distance.

```
distanceAsString = sprintf('%0.2f meters', distanceInMeters);
I1 = insertObjectAnnotation(I1,'rectangle',face1,distanceAsString,'FontSize',18);
I2 = insertObjectAnnotation(I2,'rectangle',face2, distanceAsString,'FontSize',18);
I1 = insertShape(I1,'FilledRectangle',face1);
I2 = insertShape(I2,'FilledRectangle',face2);

imshowpair(I1, I2, 'montage');
```

- "Structure From Motion From Two Views"
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

matchedPoints1 — Coordinates of points in image 1
M-by-2 matrix | SURFPoints object | MSERRegions object | cornerPoints object | BRISKPoints object

Coordinates of points in image 1, specified as an *M*-by-2 matrix of *M* number of [*x y*] coordinates, or as a SURFPoints, MSERRegions, cornerPoints, or BRISKPoints object. The matchedPoints1 and matchedPoints2 inputs must contain points that are matched using a function such as matchFeatures.

matchedPoints2 — Coordinates of points
M-by-2 matrix | SURFPoints object | MSERRegions object | cornerPoints object | BRISKPoints object

Coordinates of points in image 2, specified as an *M*-by-2 matrix of *M* number of [*x y*] coordinates, or as a SURFPoints, MSERRegions, cornerPoints, or BRISKPoints object. The matchedPoints1 and matchedPoints2 inputs must contain points that are matched using a function such as matchFeatures.

stereoParams — Camera parameters for stereo system
stereoParameters object

Camera parameters for stereo system, specified as a `stereoParameters` object. The object contains the intrinsic, extrinsic, and lens distortion parameters of the stereo camera system. You can use the `estimateCameraParameters` function to estimate camera parameters and return a `stereoParameters` object.

When you pass a `stereoParameters` object to the function, the origin of the world coordinate system is located at the optical center of camera 1. The *x*-axis points to the right, the *y*-axis points down, and the *z*-axis points away from the camera.
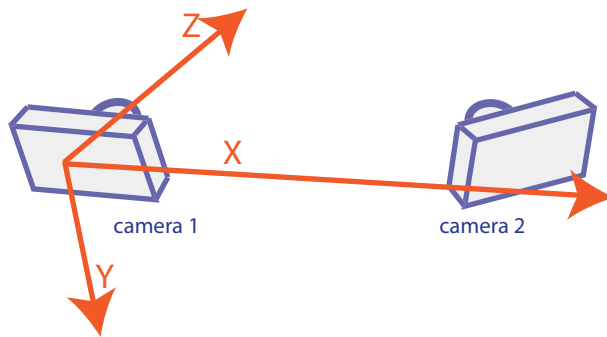
`cameraMatrix1` — Projection matrix
4-by-3 matrix

Projection matrix for camera 1, specified as a 4-by-3 matrix. The matrix maps a 3-D point in homogeneous coordinates onto the corresponding point in the camera's image. This input describes the location and orientation of camera 1 in the world coordinate system. `cameraMatrix1` must be a real and nonsparse numeric matrix. You can obtain the camera matrix using the `cameraMatrix` function.
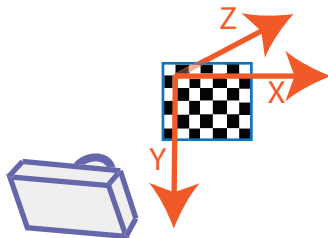
Camera matrices passed to the function, define the world coordinate system.

`cameraMatrix2` — Projection matrix
4-by-3 projection matrix

Projection matrix for camera 1, specified as a 4-by-3 matrix. The matrix maps a 3-D point in homogeneous coordinates onto the corresponding point in the camera's image. This input describes the location and orientation of camera 1 in the world coordinate system. `cameraMatrix1` must be a real and nonsparse numeric matrix. You can obtain the camera matrix using the `cameraMatrix` function.

Camera matrices passed to the function, define the world coordinate system.

Output Arguments

`worldPoints` — 3-D locations of matching pairs of undistorted image points
M-by-3 matrix

3-D locations of matching pairs of undistorted image points, specified as an *M*-by-3 matrix. The matrix contains *M* number of [*x*,*y*, *z*] locations of matching pairs of undistorted image points from two stereo images.

When you specify the camera geometry using `stereoParams`, the world point coordinates are relative to the optical center of camera 1.

When you specify the camera geometry using `cameraMatrix1` and `cameraMatrix2`, the world point coordinates are defined by the camera matrices.

The function returns `worldPoints` as `double`, if `matchedPoints1` and `matchedPoints2` are `double`. Otherwise the function returns `worldPoints` as `single`.

Data Types: `single` | `double`

`reprojectionErrors` — Reprojection errors
M-by-1 vector

Reprojection errors, returned as an *M*-by-1 vector. The function projects each world point back into both images. Then in each image, the function calculates the reprojection error

as the distance between the detected and the reprojected point. The `reprojectionErrors` vector contains the average reprojection error for each world point.
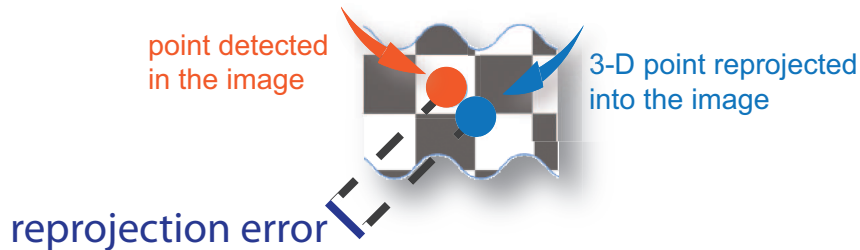
Tips

The `triangulate` function does not account for lens distortion. You can undistort the images using the `undistortImage` function before detecting the points. Alternatively, you can undistort the points themselves using the `undistortPoints` function.

References

[1] Hartley, R. and A. Zisserman. "Multiple View Geometry in Computer Vision." *Cambridge University Press*, p. 312, 2003.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

See Also

Camera Calibrator | **Stereo Camera Calibrator** | cameraMatrix | cameraParameters | estimateCameraParameters | reconstructScene | relativeCameraPose | stereoParameters | undistortImage | undistortPoints

Topics
"Structure From Motion From Two Views"
"Code Generation for Depth Estimation From Stereo Video"
"Coordinate Systems"

Introduced in R2014b

triangulateMultiview

3-D locations of undistorted points matched across multiple images

Syntax

```
xyzPoints = triangulateMultiview(pointTracks,cameraPoses,
cameraParams)
[xyzPoints,reprojectionErrors] = triangulateMultiview(pointTracks,
cameraPoses,cameraParams)
```

Description

`xyzPoints = triangulateMultiview(pointTracks,cameraPoses, cameraParams)` returns locations of 3-D world points that correspond to points matched across multiple images taken with a calibrated camera.

`[xyzPoints,reprojectionErrors] = triangulateMultiview(pointTracks, cameraPoses,cameraParams)` also returns reprojection errors for the world points.

Code Generation Support:
Supports Code Generation: No
Supports MATLAB Function block: No
"Code Generation Support, Usage Notes, and Limitations"

Examples

Find 3-D World Points Across Multiple Images Using Triangulation

Load images.

```
imageDir = fullfile(toolboxdir('vision'),'visiondata',...
    'structureFromMotion');
images = imageSet(imageDir);
```

Load precomputed camera parameters.

```
load(fullfile(imageDir,'cameraParams.mat'));
```

Compute features for the first image.

```
I = rgb2gray(read(images,1));
I = undistortImage(I,cameraParams);
pointsPrev = detectSURFFeatures(I);
[featuresPrev,pointsPrev] = extractFeatures(I,pointsPrev);
```

Load camera locations and orientations.

```
load(fullfile(imageDir,'cameraPoses.mat'));
```

Create a viewSet object.

```
vSet = viewSet;
vSet = addView(vSet, 1,'Points',pointsPrev,'Orientation',...
    orientations(:,:,1),'Location',locations(1,:));
```

Compute features and matches for the rest of the images.

```
for i = 2:images.Count
  I = rgb2gray(read(images, i));
  I = undistortImage(I, cameraParams);
  points = detectSURFFeatures(I);
  [features, points] = extractFeatures(I, points);
  vSet = addView(vSet,i,'Points',points,'Orientation',...
      orientations(:,:,i),'Location',locations(i,:));
  pairsIdx = matchFeatures(featuresPrev,features,'MatchThreshold',5);
  vSet = addConnection(vSet,i-1,i,'Matches',pairsIdx);
  featuresPrev = features;
end
```

Find point tracks.

```
tracks = findTracks(vSet);
```

Get camera poses.

```
cameraPoses = poses(vSet);
```

Find 3-D world points.

```
[xyzPoints,errors] = triangulateMultiview(tracks,cameraPoses,cameraParams);
z = xyzPoints(:,3);
```

```
idx = errors < 5 & z > 0 & z < 20;
pcshow(xyzPoints(idx, :),'VerticalAxis','y','VerticalAxisDir','down','MarkerSize',30);
hold on
plotCamera(cameraPoses, 'Size', 0.1);
hold off
```
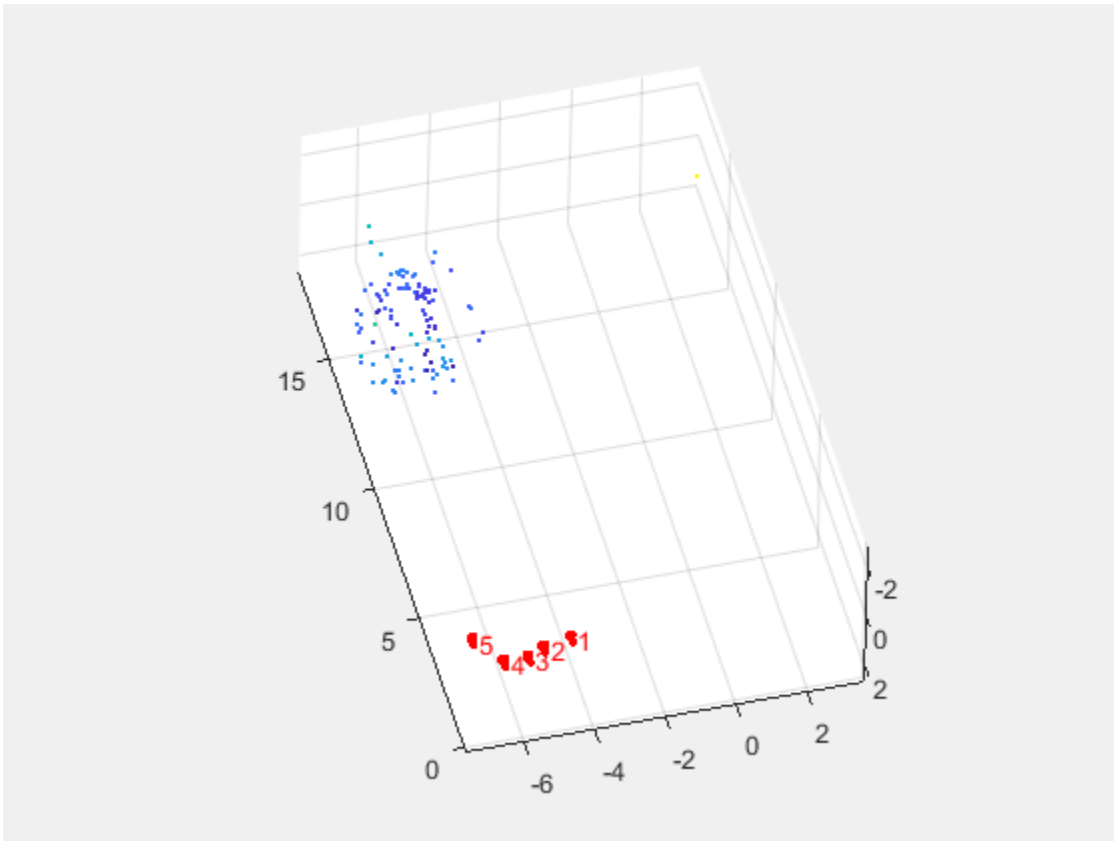

- "Structure From Motion From Two Views"
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

pointTracks — Matching points across multiple images
N-element array of `pointTrack` objects

Matching points across multiple images, specified as an *N*-element array of `pointTrack` objects. Each element contains two or more points that match across multiple images.

cameraPoses — Camera pose information
three-column table

Camera pose information, specified as a three-column table. The table contains columns for `ViewId`, `Orientation`, and `Location`. The view IDs correspond to the IDs in the `pointTracks` object. Specify the orientations as 3-by-3 rotation matrices and the locations as three-element vectors. You can obtain `cameraPoses` from a `viewSet` object by using its `poses` method.

cameraParams — Object for storing camera parameters
`cameraParameters` object | `cameraIntrinsics` object

Camera parameters, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

Output Arguments

xyzPoints — 3-D world points
N-by-3 array

3-D world points, specified as an *N*-by-3 array of [*x,y,z*] coordinates.

Data Types: `single` | `double`

reprojectionErrors — Reprojection errors
N-by-1 vector

Reprojection errors, returned as an *N*-by-1 vector. The function projects each world point back into both images. Then in each image, the function calculates the reprojection error as the distance between the detected and the reprojected point. The

`reprojectionErrors` vector contains the average reprojection error for each world point.
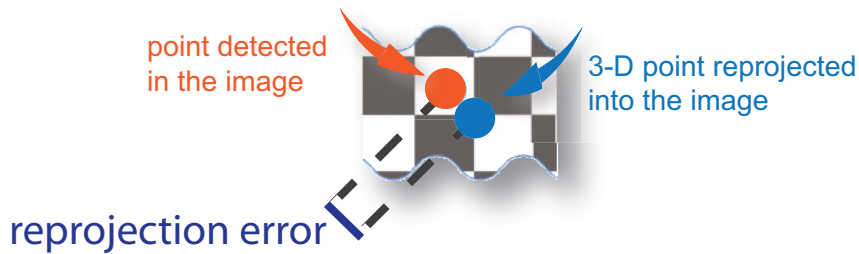
Tips

Because `triangulateMultiview` does not account for lens distortion, you can undistort the images before detecting the points by using `undistortImage`. Alternatively, you can undistort the points directly using `undistortPoints`.

References

[1] Hartley, R. and A. Zisserman. "Multiple View Geometry in Computer Vision." *Cambridge University Press*, p. 312, 2003.

See Also

Camera Calibrator | bundleAdjustment | cameraParameters | estimateCameraParameters | pointTrack | relativeCameraPose | undistortImage | undistortPoints | viewSet

Topics

"Structure From Motion From Two Views"
"Code Generation for Depth Estimation From Stereo Video"
"Structure from Motion"
"Coordinate Systems"

Introduced in R2016a

undistortImage

Correct image for lens distortion

Syntax

```
[J,newOrigin] = undistortImage(I,cameraParams)
[J,newOrigin] = undistortImage(I,cameraParams,interp)
[J,newOrigin] = undistortImage( ___ ,Name,Value)
```

Description

`[J,newOrigin] = undistortImage(I,cameraParams)` returns an image, `J`, containing the input image, `I`, with lens distortion removed. The function also returns the [*x*,*y*] location of the output image origin. The location is set in terms of the input intrinsic coordinates specified in `cameraParams`.

`[J,newOrigin] = undistortImage(I,cameraParams,interp)` specifies the interpolation method for the function to use on the input image.

`[J,newOrigin] = undistortImage( ___ ,Name,Value)` specifies one or more `Name,Value` pair arguments, using any of the preceding syntaxes. Unspecified properties have their default values.

Examples

Correct Image for Lens Distortion

Create a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','mono'));
```

Detect calibration pattern.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate world coordinates of the corners of the squares. The square size is in millimeters.

```
squareSize = 29;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the camera.

```
I = readimage(images,1);
imageSize = [size(I,1),size(I,2)];
cameraParams = estimateCameraParameters(imagePoints,worldPoints, ...
                                'ImageSize',imageSize);
```

Remove lens distortion and display results.

```
I = images.readimage(1);
J1 = undistortImage(I,cameraParams);

figure; imshowpair(I,J1,'montage');
title('Original Image (left) vs. Corrected Image (right)');
```

Original Image (left) vs. Corrected Image (right)


```
J2 = undistortImage(I,cameraParams,'OutputView','full');
figure;
imshow(J2);
title('Full Output View');
```

Full Output View
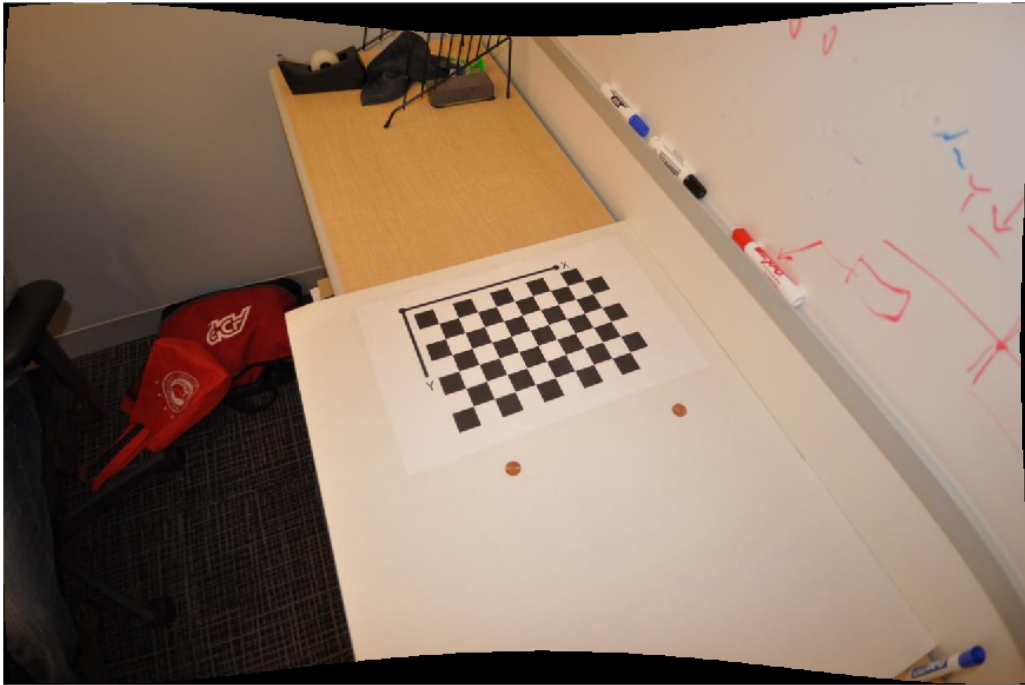
- "Code Generation for Depth Estimation From Stereo Video"

Input Arguments

I — Input image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input image, specified in either *M*-by-*N*-by-3 truecolor or *M*-by-*N* 2-D grayscale. The input image must be real and nonsparse.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

cameraParams — Object for storing camera parameters
`cameraParameters` object | `cameraIntrinsics` object

Camera parameters, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

`interp` — Interpolation method

'linear' (default) | 'nearest' | 'cubic'

Interpolation method to use on the input image, specified as the character vector 'linear', 'nearest', or 'cubic'.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: 'FillValues',0 sets the sets the output pixel fill values to 0.

`FillValues` — Output pixel fill values

0 (default) | scalar | 3-element vector

Output pixel fill values, specified as the comma-separated pair consisting of 'FillValues' and an array containing one or more fill values. When the corresponding inverse transformed location in the input image lies completely outside the input image boundaries, you use the fill values for output pixels. When you use a 2-D grayscale input image, you must set the `FillValues` to scalar. When you use a truecolor, `FillValues` can be a scalar or a 3-element vector of RGB values.

`OutputView` — Size of output image

'same' (default) | 'full' | 'valid'
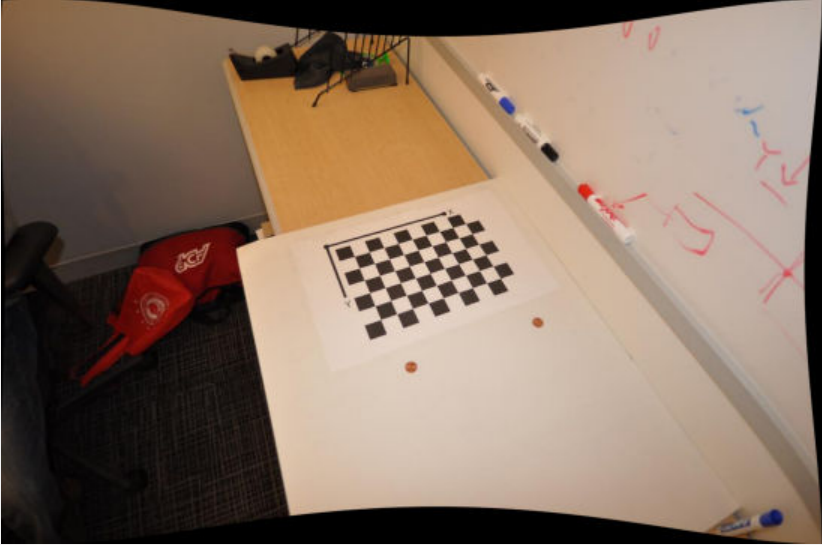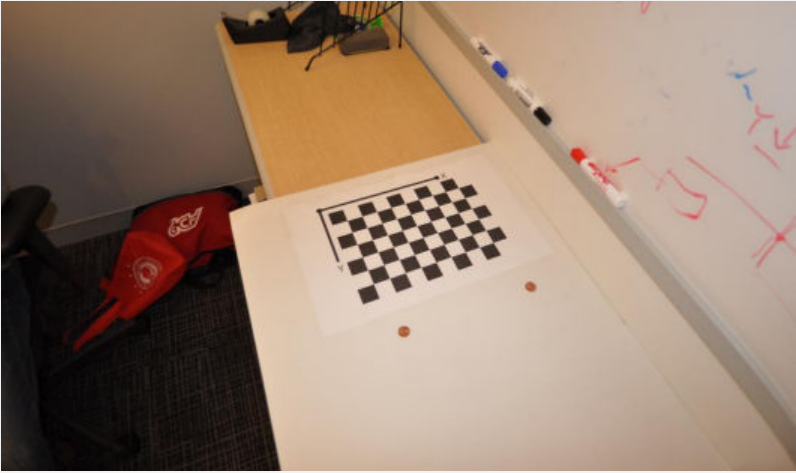
Size of output image, specified as the comma-separated pair consisting of 'OutputView' and the character vector 'same', 'full', or 'valid'. When you set the property to 'same', the function sets the output image to match the size of the input image. When you set the property to 'full', the output includes all pixels from the input image. When you set the property to 'valid', the function crops the output image to contain only valid pixels.

For the input image:

OutputView	Output Image
`'same'`	Match the size of the input image.

OutputView	Output Image
`'full'`	All pixels from the input image.
`'valid'`	Only valid pixels from the input image.

Output Arguments

J — Undistorted image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Undistorted image, returned in either *M*-by-*N*-by-3 truecolor or *M*-by-*N* 2-D grayscale.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

newOrigin — Output image origin
2-element vector

Output image origin, returned as a 2-element [*x*,*y*] vector. The function sets the output origin location in terms of the input intrinsic coordinates. When you set `OutputView` to `'same'`, which means the output image is the same size as the input image, the function sets the `newOrigin` to `[0,0]`.

The `newOrigin` output represents the translation from the intrinsic coordinates of the output image `J` into the intrinsic coordinates of the input image `I`.
Let P_I represent a point in the intrinsic coordinates of input image I.
Let P_J represent the same point in the intrinsic coordinates of the output image J.

$P_I = P_J + $ `newOrigin`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Use in a MATLAB Function block is not supported.

- `'interp'` and `'OutputView'` must be compile-time constants.

See Also

Camera Calibrator | **Stereo Camera Calibrator** | cameraIntrinsics | cameraParameters | estimateCameraParameters | extrinsics | stereoParameters | triangulate | undistortPoints

Topics

"Code Generation for Depth Estimation From Stereo Video"

Introduced in R2014a

undistortPoints

Correct point coordinates for lens distortion

Syntax

```
undistortedPoints = undistortPoints(points,cameraParams)
[undistortedPoints,reprojectionErrors] = undistortPoints(points,
cameraParams)
```

Description

`undistortedPoints = undistortPoints(points,cameraParams)` returns point coordinates corrected for lens distortion. This function uses numeric nonlinear least-squares optimization.

`[undistortedPoints,reprojectionErrors] = undistortPoints(points, cameraParams)` additionally returns the errors used to evaluate the accuracy of undistorted points.

Examples

Undistort Checkerboard Points

Create an imageDatastore object containing calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','mono'));
imageFileNames = images.Files;
```

Detect the calibration pattern.

```
[imagePoints,boardSize] = detectCheckerboardPoints(imageFileNames);
```

Generate world coordinates of the corners of the squares. The square size is in millimeters.

```
squareSize = 29;
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Calibrate the camera.

```
I = readimage(images,10);
imageSize = [size(I, 1), size(I, 2)];
params = estimateCameraParameters(imagePoints,worldPoints, ...
                                   'ImageSize',imageSize);
```

Load an image and detect the checkerboard points.

```
points = detectCheckerboardPoints(I);
```

Undistort the points

```
undistortedPoints = undistortPoints(points,params);
```

Undistort the image.

```
[J, newOrigin] = undistortImage(I,params,'OutputView','full');
```

Translate undistorted points

```
undistortedPoints = [undistortedPoints(:,1) - newOrigin(1), ...
                     undistortedPoints(:,2) - newOrigin(2)];
```

Display the results

```
figure;
imshow(I);
hold on;
plot(points(:,1),points(:,2),'r*-');
title('Detected Points');
hold off;
```

Detected Points
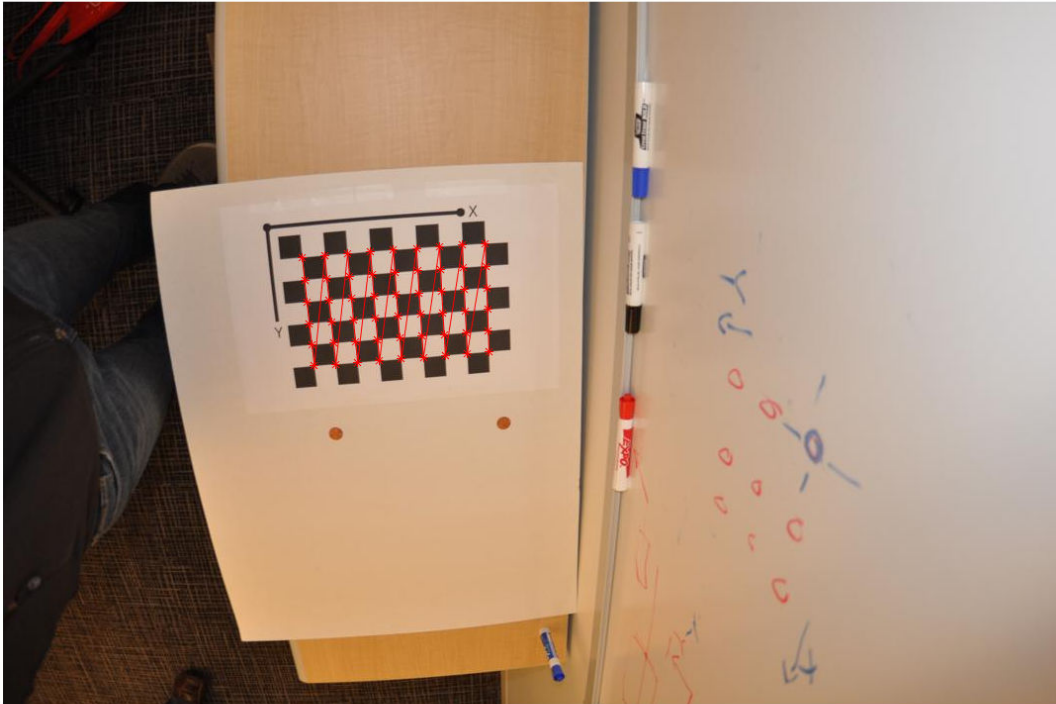
```
figure;
imshow(J);
hold on;
plot(undistortedPoints(:,1),undistortedPoints(:,2),'g*-');
title('Undistorted Points');
hold off;
```

Undistorted Points
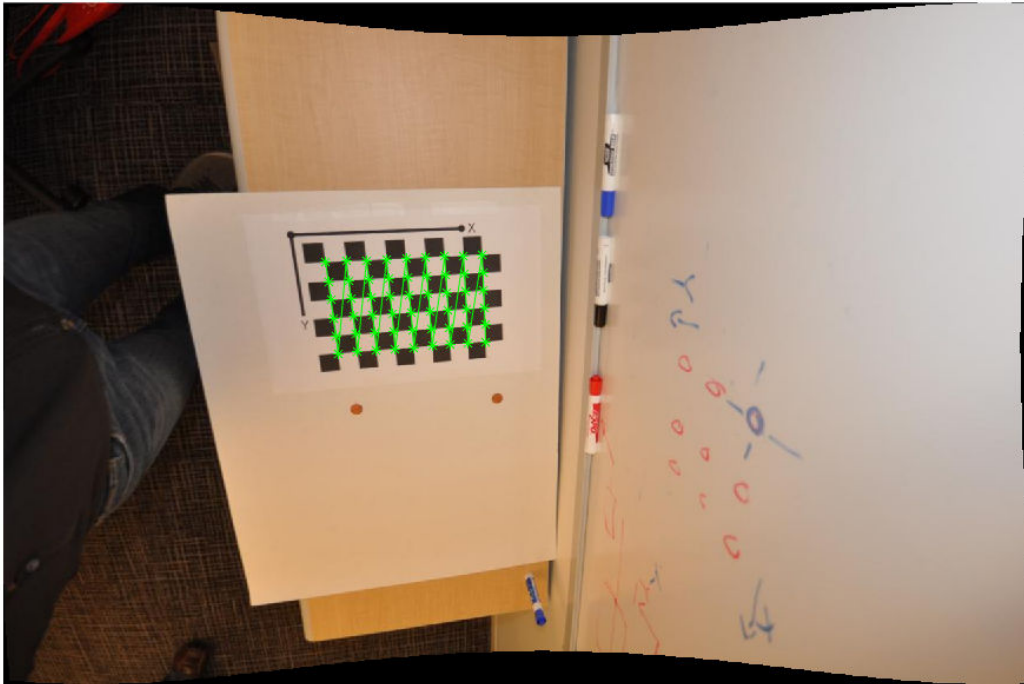
Input Arguments

points — Input points
cornerPoints object | SURFPoints object | MSERRegions object | BRISKPoints object | *M*-by-2 matrix

Input points, specified as either a BRISKPoints, SURFPoints, MSERRegions, or cornerPoints object, or an *M*-by-2 matrix of *M* number of [x y] coordinates.

cameraParams — Object for storing camera parameters
cameraParameters object | cameraIntrinsics object

Camera parameters, specified as a `cameraParameters` or `cameraIntrinsics` object. You can return the `cameraParameters` object using the `estimateCameraParameters` function. The `cameraParameters` object contains the intrinsic, extrinsic, and lens distortion parameters of a camera.

Output Arguments

undistortedPoints — Undistorted points
M-by-2 matrix

Undistorted points, returned as an *M*-by-2 matrix. The `undistortedPoints` output contains *M* [*x,y*] point coordinates corrected for lens distortion. When you input points as `double`, the function outputs `undistortedPoints` as `double`. Otherwise, it outputs `undistortedPoints` as single.

Data Types: `single` | `double`

reprojectionErrors — Reprojection errors
M-by-1 vector

Reprojection errors, returned as an *M*-by-1 vector. You can use the errors to evaluate the accuracy of undistorted points. The function computes the errors by applying distortion to the undistorted points, and then taking the distances between the result and the corresponding input points. The `reprojectionErrors` output is in pixels.

See Also
Camera Calibrator | **Stereo Camera Calibrator** | `cameraIntrinsics` | `cameraParameters` | `estimateCameraParameters` | `extrinsics` | `stereoParameters` | `triangulate`

Introduced in R2014b

visionlib

Open top-level Computer Vision System Toolbox Simulink library

Syntax

```
visionlib
```

Description

`visionlib` opens the top-level Computer Vision System Toolbox block library model.

Examples

View and gain access to the Computer Vision System Toolbox blocks:

```
visionlib
```

Alternatives

To view and gain access to the Computer Vision System Toolbox blocks using the Simulink library browser:

- Type `simulink` at the MATLAB command line, and then expand the Computer Vision System Toolbox node in the library browser.

- Click the Simulink icon from the MATLAB desktop or from a model.

Introduced in R2011a

visionSupportPackages

Start installer to download, install, or uninstall Computer Vision System Toolbox data

Syntax

```
visionSupportPackages
```

Description

`visionSupportPackages` launches the Support Package Installer, which you can use to download, install, or uninstall support packages for Computer Vision System Toolbox.

Computer Vision System Toolbox Support Packages
"Install OCR Language Data Files"
"Install and Use Computer Vision System Toolbox OpenCV Interface"

Examples

Start Computer Vision System Toolbox installer

```
visionSupportPackages
```

See Also

Topics
"Install Computer Vision System Toolbox Add-on Support Files"

Introduced in R2014b

ocvStructToKeyPoints

Convert MATLAB feature points struct to OpenCV `KeyPoint` vector

C++ Syntax

```
#include "opencvmex.hpp"
void ocvStructToKeyPoints(const mxArray *
in,cv::vector<cv::KeyPoint> &keypoints);
```

Arguments

`in`

Pointer to a MATLAB structure, `mxArray`, that represents a point feature. Format:

Field Name	Field Requirement	Field Data Type
`Location`	Required	Single
`Scale`	Required	Single
`Metric`	Required	Single
`Orientation`	Optional	Single
`Octave`	Optional	int32
`Misc`	Optional	int32

Description

The `ocvStructToKeyPoints` function converts a point feature data structure from a MATLAB struct to an OpenCV's KeyPoint vector.

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See Also

mxArray, ocvKeyPointsToStruct, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxGpuArrayToGpuMat_{DataType}

Create `cv::gpu::GpuMat` from `mxArray` containing GPU data

C++ Syntax

```
#include "opencvgpumex.hpp"
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_double(const mxArray
* in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_single(const mxArray
* in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_uint8(const mxArray *
in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_uint16(const mxArray
* in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_uint32(const mxArray
* in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_int8(const mxArray *
in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_int16(const mxArray *
in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_int32(const mxArray *
in);
cv::Ptr<cv::gpu::GpuMat> ocvMxGpuArrayToGpuMat_bool(const mxArray *
in);
```

Arguments

`in`

Pointer to a MATLAB struct, `mxArray`, containing GPU data. Supported data types:

real_T (double)	real32_T (single)	uint8_T (uint8)
uint16_T (uint16)	uint32_T (uint32)	int8_T (int8)
int16_T (int16)	int32_T (int32)	boolean_T (bool)

Returns

OpenCV smart pointer (`cv::Ptr`) to a `cv::gpu::GpuMat` object.

Description

The `ocvMxGpuArrayToGpuMat_{DataType}` function creates a `cv::gpu::GpuMat` object from an `mxArray` containing GPU data. This function requires the Parallel Computing Toolbox software.

See Also

`mxArray`, `ocvMxGpuArrayFromGpuMat_{DataType}`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxGpuArrayFromGpuMat_{DataType}

Create an `mxArray` from `cv::gpu::GpuMat` object

C++ Syntax

```
#include "opencvgpumex.hpp"
mxArray * ocvMxGpuArrayFromGpuMat_double(const cv::gpu::GpuMat &
in);
mxArray * ocvMxGpuArrayFromGpuMat_single(const cv::gpu::GpuMat &
in);
mxArray * ocvMxGpuArrayFromGpuMat_uint8(const cv::gpu::GpuMat & in);
mxArray * ocvMxGpuArrayFromGpuMat_uint16(const cv::gpu::GpuMat &
in);
mxArray * ocvMxGpuArrayFromGpuMat_uint32(const cv::gpu::GpuMat &
in);
mxArray * ocvMxGpuArrayFromGpuMat_int8(const cv::gpu::GpuMat & in);
mxArray * ocvMxGpuArrayFromGpuMat_int16(const cv::gpu::GpuMat & in);
mxArray * ocvMxGpuArrayFromGpuMat_int32(const cv::gpu::GpuMat & in);
mxArray * ocvMxGpuArrayFromGpuMat_bool(const cv::gpu::GpuMat & in)
```

Arguments

`in`

> Reference to OpenCV `cv::gpu::GpuMat` object.

Returns

Pointer to a MATLAB struct, `mxArray`, containing GPU data. Supported data types:

real_T (double)	real32_T (single)	uint8_T (uint8)
uint16_T (uint16)	uint32_T (uint32)	int8_T (int8)
int16_T (int16)	int32_T (int32)	boolean_T (bool)

Description

The `ocvMxGpuArrayFromGpuMat` function creates an `mxArray` from a `cv::gpu::GpuMat` object. `GpuMat` supports 2-D arrays only. This function requires the Parallel Computing Toolbox software.

See Also

`mxArray`, `ocvMxGpuArrayToGpuMat_{DataType}`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayToSize_{DataType}

Convert 2-element `mxArray` to `cv::Size`.

C++ Syntax

```
#include "opencvmex.hpp"
cv::Size ocvMxArrayToSize_single(const mxArray * in, bool rcInput =
true);
cv::Size ocvMxArrayToSize_int32(const mxArray * in, bool rcInput =
true);
```

Arguments

`in`

Pointer to a MATLAB `mxArray` having 2 elements. Supported data types:

single
int32

`rcInput`

Boolean flag that indicates if input `mxArray` is of the format [$r\,c$] or [$x\,y$].

rcInput	in
`true` (default)	[$r\,c$] (*height*, *width*)
`false`	[$x\,y$] (*width*, *height*)

Returns

OpenCV `cv::Size`

Description

The `ocvMxArrayToSize_{DataType}` function converts a 2-element `mxArray` to `cv::Size`. Empty input (`[]`) returns `cv::Size(0,0)`;

See Also

`mxArray`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayToMat_{DataType}

Convert column major `mxArray` to row major `cv::Mat` for generic matrix

C++ Syntax

```
#include "opencvmex.hpp"
void ocvMxArrayToMat_double(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_single(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_uint8(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_uint16(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_uint32(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_int8(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_int16(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_int32(const mxArray *in, cv::Mat &out);
void ocvMxArrayToMat_bool(const mxArray *in, cv::Mat &out);
cv::Ptr<cv::Mat> ocvMxArrayToMat_double(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_single(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_uint8(const mxArray *in, const bool
copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_uint16(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_uint32(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_int8(const mxArray *in, const bool
copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_int16(const mxArray *in, const bool
copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_int32(const mxArray *in, const bool
copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToMat_uint8(const mxArray *in, const bool
copyData = true);
```

Arguments

in

Pointer to a MATLAB struct, `mxArray`, having column major data. The data can be *n*-channel matrices. Supported data types:

real_T (double)	uint8_T (uint8)	uint32_T (uint32)	int16_T (int16)
real32_T (single)	uint16_T (uint16)	int8_T (int8)	int32_T (int32)

copyData

Boolean flag to copy data from `mxArray` to the `Mat` object.

- `true` (default) — The function transposes and interleaves (for RGB images) column major `mxArray` data into a row major `cv::Mat` object.

- `false` — No data copies from the `mxArray` to the `Mat` object. The function creates a new `Mat` wrapper and uses it to point to the `mxArray` data. Because OpenCV is row-based and MATLAB is column-based, the columns of the `mxArray` become the rows of the `Mat` object. If the image is 2-D, then `copyData` is `false`.

out

Reference to OpenCV `cv::Mat` with row major data.

Returns

The functions that set `copyData` return an OpenCV smart pointer (`cv::Ptr`) to a `cv::Mat` object.

Description

The `ocvMxArrayToMat_{DataType}` function applies to two C++ implementations. One set returns `void` and the other set returns an OpenCV smart pointer. The functions that return `void` reallocate memory for the `cv::Mat` if needed.

The `ocvMxArrayToMat_{DataType}` transposes and interleaves column major `mxArray` data into row major `cv::Mat`. This matrix conversion is a generic routine for any number of channels.

See Also

`mxArray`, `ocvMxArrayToImage_{DataType}`, `ocvMxArrayFromMat_{DataType}`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayToImage_{DataType}

Convert column major `mxArray` to row major `cv::Mat` for image

C++ Syntax

```
#include "opencvmex.hpp"
void ocvMxArrayToImage_double(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_single(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_uint8(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_uint16(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_uint32(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_int8(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_int16(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_int32(const mxArray *in, cv::Mat &out);
void ocvMxArrayToImage_bool(const mxArray *in, cv::Mat &out);
cv::Ptr<cv::Mat> ocvMxArrayToImage_double(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_single(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_uint8(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_uint16(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_uint32(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_int8(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_int16(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_int32(const mxArray *in, const
bool copyData = true);
cv::Ptr<cv::Mat> ocvMxArrayToImage_bool(const mxArray *in, const
bool copyData = true);
```

Arguments

`in`

Pointer to a MATLAB struct, `mxArray`, having column major data that represents a 2-D or 3-D image. Supported data types:

real_T (double)	uint8_T (uint8)	uint32_T (uint32)	int16_T (int16)
real32_T (single)	uint16_T (uint16)	int8_T (int8)	int32_T (int32)

`copyData`

Boolean flag to copy data from `mxArray` to the `Mat` object.

- `true` (default) — The function transposes and interleaves (for RGB images) column major `mxArray` data into a row major `cv::Mat` object.

- `false` — No data copies from the `mxArray` to the `Mat` object. The function creates a new `Mat` wrapper and uses it to point to the `mxArray` data. Because OpenCV is row-based and MATLAB is column-based, the columns of the `mxArray` become the rows of the `Mat` object. If the image is 2-D, then `copyData` is `false`.

`out`

Reference to OpenCV `cv::Mat` with row major data.

Returns

The functions that set `copyData` return an OpenCV smart pointer (`cv::Ptr`) to a `cv::Mat` object.

Description

The `ocvMxArrayToImage_{DataType}` function applies to two C++ implementations. One set returns `void` and the other set returns an OpenCV smart pointer. The functions that return `void` reallocate memory for the `cv::Mat` if needed.

The `ocvMxArrayToImage_{DataType}` transposes and interleaves column major `mxArray` data into row major `cv::Mat`. The `ocvMxArrayToImage_{DataType}` function supports 2-D and 3-D images.

These functions are not a generic matrix conversion routine. For 3-D images, they take into account that the OpenCV format uses BGR ordering and manipulate the data to comply with that formatting.

See Also

`mxArray`, `ocvMxArrayToMat_{DataType}`, `ocvMxArrayFromImage_{DataType}`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayToCvRect

Convert a MATLAB struct representing a rectangle to an OpenCV `CvRect`

C++ Syntax

```
#include "opencvmex.hpp"
CvRect ocvMxArrayToCvRect(const mxArray *in);
```

Arguments

`in`

> Pointer to a MATLAB structure, `mxArray`, that represents a rectangle. The structure must have four scalar-valued fields: `x`, `y`, `width`, and `height`. The (`x`, `y`) fields represent the upper-left corner of the rectangle.

Returns

OpenCV `CvRect`.

Description

The `ocvMxArrayToCvRect` function converts a rectangle data structure from a MATLAB struct to an OpenCV KeyPoint vector.

See Also

`mxArray`, `ocvCvRectToMxArray`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayFromVector

Convert numeric `vectorT` to `mxArray`

C++ Syntax

```
#include "opencvmex.hpp"
mxArray *ocvMxArrayFromVector(const std::vector<real_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<real32_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<uint8_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<uint16_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<uint32_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<int8_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<int16_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<int32_T> &v);
mxArray *ocvMxArrayFromVector(const std::vector<boolean_T> &v);
```

Arguments

v

Reference to `vector<DataType>`. Supported data types:

real_T	real32_T	uint8_T
uint16_T	uint32_T	int8_T
int16_T	int32_T	boolean_T

Returns

Pointer to a MATLAB struct `mxArray`.

Description

The `ocvMxArrayFromVector` function converts numeric `std::vector<DataType>` to an `mxArray`.

See Also

`mxArray`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayFromPoints2f

Converts `vector<cv::Point2f>` to `mxArray`

C++ Syntax

```
#include "opencvmex.hpp"
mxArray *ocvMxArrayFromPoints2f(const std::vector<cv::Point2f>
&points);
```

Arguments

points

   Reference to OpenCV `vector<cv::Point2f>`.

Returns

Pointer to a MATLAB `mxArray`.

Description

The `ocvMxArrayFromPoints2f` function converts `std::vector<cv::Point2f>` to an `mxArray`.

See Also

"C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayFromMat_{DataType}

Convert row major `cv::Mat` to column major `mxArray` for generic matrix

C++ Syntax

```
#include "opencvmex.hpp"
mxArray *ocvMxArrayFromMat_double(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_single(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_uint8(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_uint16(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_uint32(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_int8(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_int16(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_int32(const cv::Mat &in);
mxArray *ocvMxArrayFromMat_bool(const cv::Mat &in);
```

Arguments

in

>   Reference to OpenCV `cv::Mat` with row major data.

Returns

Pointer to a MATLAB struct, `mxArray`, having column major data. Supported data types:

real_T (double)	uint8_T (uint8)	uint32_T (uint32)	int16_T (int16)
real32_T (single)	uint16_T (uint16)	int8_T (int8)	int32_T (int32)

Description

The `ocvMxArrayFromMat_{DataType}` function creates an `mxArray` from a `cv::Mat` object. The `mxArray` contains column major data and `cv::Mat` contains row major data. This matrix conversion is a generic routine for any number of channels.

See Also

`mxArray`, `ocvMxArrayToImage_{DataType}`, `ocvMxArrayFromImage_{DataType}`, `ocvMxArrayToMat_{DataType}`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvMxArrayFromImage_{DataType}

Convert row major `cv::Mat` to column major `mxArray` for image

C++ Syntax

```
#include "opencvmex.hpp"
mxArray *ocvMxArrayFromImage_double(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_single(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_uint8(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_uint16(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_uint32(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_int8(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_int16(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_int32(const cv::Mat &in);
mxArray *ocvMxArrayFromImage_bool(const cv::Mat &in);
```

Arguments

`in`

Reference to OpenCV `cv::Mat` with row major data.

Returns

Pointer to a MATLAB struct, `mxArray`, with column major data. Supported data types:

real_T (double)	uint8_T (uint8)	uint32_T (uint32)	int16_T (int16)
real32_T (single)	uint16_T (uint16)	int8_T (int8)	int32_T (int32)

Description

The `ocvMxArrayFromImage_{DataType}` function creates an `mxArray` from a `cv::Mat` object. The `mxArray` contains column major data and the `cv::Mat` contains row major data.

This function is not a generic matrix conversion routine. For 3-D images, it takes into account that the OpenCV format uses BGR ordering and manipulates the data to comply with that formatting.

See Also

`mxArray`, `ocvMxArrayToImage_{DataType}`, `ocvMxArrayFromMat_{DataType}`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvKeyPointsToStruct

Convert OpenCV `KeyPoint` vector to MATLAB struct

C++ Syntax

```
#include "opencvmex.hpp"
mxArray *ocvKeyPointsToStruct(cv::vector<cv::KeyPoint> &in);
```

Arguments

`in`

   Reference to an OpenCV's KeyPoint vector.

Returns

Pointer to a MATLAB structure `mxArray` that represents a point feature.

Format:

Field Name	Field Requirement	Field Data Type
Location	Required	Single
Scale	Required	Single
Metric	Required	Single
Orientation	Optional	Single
Octave	Optional	int32
Misc	Optional	int32

Description

The `ocvKeyPointsToStruct` function converts a point feature data structure from an OpenCV KeyPoint vector to a MATLAB struct.

See Also

`mxArray`, `ocvStructToKeyPoints`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvCvRectToMxArray

Convert OpenCV `CvRect` to a MATLAB struct

C++ Syntax

```
#include "opencvmex.hpp"
mxArray *ocvCvRectToMxArray(const CvRect *in);
```

Arguments

`in`

> Pointer to OpenCV `CvRect`.

Returns

Pointer to a MATLAB structure, `mxArray`, that represents a rectangle. The structure must have four scalar-valued fields, `x`, `y`, `width`, and `height`. The (`x`, `y`) fields represent the upper-left corner of the rectangle.

Description

The `ocvCvRectToMxArray` function converts a rectangle data structure from an OpenCV KeyPoint vector to a MATLAB struct.

See Also

`mxArray`, `ocvMxArrayToCvRect`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvCvRectToBoundingBox_{DataType}

Convert `vector<cv::Rect>` to *M*-by-4 `mxArray` of bounding boxes

C++ Syntax

```
#include "opencvmex.hpp"
mxArray * ocvCvRectToBoundingBox_double(const std::vector<cv::Rect>
& rects);
mxArray * ocvCvRectToBoundingBox_single(const std::vector<cv::Rect>
& rects);
mxArray * ocvCvRectToBoundingBox_uint8(const std::vector<cv::Rect> &
rects);
mxArray * ocvCvRectToBoundingBox_uint16(const std::vector<cv::Rect>
& rects);
mxArray * ocvCvRectToBoundingBox_uint32(const std::vector<cv::Rect>
& rects);
mxArray * ocvCvRectToBoundingBox_int8(const std::vector<cv::Rect> &
rects);
mxArray * ocvCvRectToBoundingBox_int16(const std::vector<cv::Rect> &
rects);
mxArray * ocvCvRectToBoundingBox_int32(const std::vector<cv::Rect> &
rects);
```

Arguments

`rects`

> Reference to OpenCV `vector<cv::Rect>`.

Returns

Pointer to a MATLAB `mxArray` having *M*-by-4 elements. Supported data types:

real_T (double)	uint8_T (uint8)	uint32_T (uint32)	int16_T (int16)

`real32_T` (single)	`uint16_T` (uint16)	`int8_T` (int8)	`int32_T` (int32)

Description

The `ocvCvRectToBoundingBox_{DataType}` function converts `vector<cv::Rect>` to an *M*-by-4 `mxArray` of bounding boxes.

See Also

`mxArray`, `ocvCvBox2DToMxArray`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvCvBox2DToMxArray

Convert OpenCV `CvBox2D` to a MATLAB struct

C++ Syntax

```
#include "opencvmex.hpp"
mxArray *ocvCvBox2DToMxArray(const CvBox2D *in);
```

Arguments

`in`

> Pointer to OpenCV `CvBox2D`.

Returns

Pointer to a MATLAB structure, `mxArray`, that represents a rectangle. The structure must have five scalar-valued fields: `x_center`, `y_center`, `width`, `height`, and `angle`. The (`x_center`, `y_center`) fields represent the center of the rectangle.

Description

The `ocvCvBox2DToMxArray` function converts a rectangle data structure from an OpenCV `CvBox2D` to a MATLAB struct.

See Also

`mxArray`, `ocvCvRectToBoundingBox_{DataType}`, "C Matrix API" (MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

ocvCheckFeaturePointsStruct

Check that MATLAB struct represents feature points

C++ Syntax

```
#include "opencvmex.hpp"
void ocvCheckFeaturePointsStruct(const mxArray *in);
```

Arguments

`in`

Pointer to a MATLAB structure, `mxArray`, that represents point feature. Format:

Field Name	Field Requirement	Field Data Type
Location	Required	Single
Scale	Required	Single
Metric	Required	Single
Orientation	Optional	Single
Octave	Optional	int32
Misc	Optional	int32

Description

The `ocvCheckFeaturePointsStruct` function performs the key point struct checker.

See Also

`mxArrayocvStructToKeyPoints`, `ocvKeyPointsToStruct`, "C Matrix API"
(MATLAB), "C MEX File Applications" (MATLAB)

Introduced in R2015a

trainFasterRCNNObjectDetector

Train a Faster R-CNN deep learning object detector

Syntax

```
trainedDetector = trainFasterRCNNObjectDetector(trainingData,
network,options)
trainedDetector = trainFasterRCNNObjectDetector(trainingData,
checkpoint,options)
trainedDetector = trainFasterRCNNObjectDetector(trainingData,
detector,options)
trainedDetector = trainFasterRCNNObjectDetector( ___ ,Name,Value)
[trainedDetector,info] = trainFasterRCNNObjectDetector( ___ )
```

Description

`trainedDetector = trainFasterRCNNObjectDetector(trainingData, network,options)` trains a Faster R-CNN (regions with convolution neural networks) object detector in four training stages using deep learning [1]. You can train a Faster R-CNN detector to detect multiple object classes. Specify your ground truth training data, your network, and training options. The network can be a pretrained series network such as `alexnet` or `vgg16` for training using transfer learning, or you can train a network from scratch using an array of `Layer` objects with uninitialized weights.

This function requires that you have Neural Network Toolbox. It is recommended that you also have Parallel Computing Toolbox to use with a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher.

`trainedDetector = trainFasterRCNNObjectDetector(trainingData, checkpoint,options)` resumes training from a detector checkpoint.

`trainedDetector = trainFasterRCNNObjectDetector(trainingData, detector,options)` continues training a detector with additional training data or performs more training iterations to improve detector accuracy.

`trainedDetector = trainFasterRCNNObjectDetector( ___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments and any of the previous inputs.

`[trainedDetector,info] = trainFasterRCNNObjectDetector( ___ )` additionally returns information on the training progress, such as training loss and accuracy, for each iteration.

Examples

Train Faster R-CNN Vehicle Detector

Load training data.

```
data = load('fasterRCNNVehicleTrainingData.mat');
```

```
trainingData = data.vehicleTrainingData;
```

```
trainingData.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    trainingData.imageFilename);
```

Setup network layers.

```
layers = data.layers
```

```
layers =

  11x1 Layer array with layers:

      1   ''    Image Input            32x32x3 images with 'zerocenter' normalization
      2   ''    Convolution            32 3x3 convolutions with stride [1  1] and paddir
      3   ''    ReLU                   ReLU
      4   ''    Convolution            32 3x3 convolutions with stride [1  1] and paddir
      5   ''    ReLU                   ReLU
      6   ''    Max Pooling            3x3 max pooling with stride [2  2] and padding [C
      7   ''    Fully Connected        64 fully connected layer
      8   ''    ReLU                   ReLU
      9   ''    Fully Connected        2 fully connected layer
     10   ''    Softmax                softmax
     11   ''    Classification Output  crossentropyex
```

Configure training options.

- Lower the InitialLearningRate to reduce the rate at which network parameters are changed.
- Set the CheckpointPath to save detector checkpoints to a temporary directory. Change this to another location if required.
- Set MaxEpochs to 1 to reduce example training time. Increase this to 10 for proper training.

```
options = trainingOptions('sgdm', ...
     'InitialLearnRate', 1e-3, ...
     'MaxEpochs', 5, ...
     'VerboseFrequency', 200, ...
     'CheckpointPath', tempdir);
```

Train detector. Training will take a few minutes.

```
detector = trainFasterRCNNObjectDetector(trainingData, layers, options)
```

```
**************************************************************************
Training a Faster R-CNN Object Detector for the following object classes:

* vehicle

Step 1 of 4: Training a Region Proposal Network (RPN).
Training on single GPU.
|=========================================================================================
| Epoch   | Iteration   | Time Elapsed  | Mini-batch  | Mini-batch  | Base Learning
|         |             | (hh:mm:ss)    | Accuracy    | RMSE        | Rate
|=========================================================================================
|       1 |           1 |    00:00:00   |     50.00%  |     0.90    |       0.001
|       1 |         200 |    00:00:08   |    100.00%  |     0.67    |       0.001
|       2 |         400 |    00:00:16   |    100.00%  |     0.82    |       0.001
|       3 |         600 |    00:00:27   |     50.00%  |     0.87    |       0.001
|       3 |         800 |    00:00:37   |    100.00%  |     1.43    |       0.001
|       4 |        1000 |    00:00:47   |    100.00%  |     1.32    |       0.001
|       5 |        1200 |    00:00:57   |     50.00%  |     0.90    |       0.001
|       5 |        1400 |    00:01:09   |     50.00%  |     0.85    |       0.001
|       5 |        1475 |    00:01:13   |    100.00%  |     0.71    |       0.001
|=========================================================================================

Step 2 of 4: Training a Fast R-CNN Network using the RPN from step 1.
**********************************************************************
Training a Fast R-CNN Object Detector for the following object classes:
```

```
* vehicle

--> Extracting region proposals from 295 training images...done.

Training on single GPU.
|========================================================================================
|  Epoch  |  Iteration  |  Time Elapsed  |  Mini-batch  |  Mini-batch  |  Base Learning
|         |             |  (hh:mm:ss)    |   Accuracy   |     RMSE     |      Rate
|========================================================================================
|      1  |          1  |   00:00:00     |    87.60%    |     1.07     |      0.001
|      1  |        200  |   00:00:06     |    87.50%    |     1.10     |      0.001
|      2  |        400  |   00:00:14     |    95.31%    |     0.76     |      0.001
|      3  |        600  |   00:00:21     |    93.60%    |     0.76     |      0.001
|      3  |        800  |   00:00:29     |    92.19%    |     0.79     |      0.001
|      4  |       1000  |   00:00:37     |    97.66%    |     0.44     |      0.001
|      5  |       1200  |   00:00:45     |    95.37%    |     0.46     |      0.001
|      5  |       1400  |   00:00:53     |    90.00%    |     1.05     |      0.001
|      5  |       1435  |   00:00:54     |    92.97%    |     1.24     |      0.001
|========================================================================================

Step 3 of 4: Re-training RPN using weight sharing with Fast R-CNN.
Training on single GPU.
|========================================================================================
|  Epoch  |  Iteration  |  Time Elapsed  |  Mini-batch  |  Mini-batch  |  Base Learning
|         |             |  (hh:mm:ss)    |   Accuracy   |     RMSE     |      Rate
|========================================================================================
|      1  |          1  |   00:00:00     |   100.00%    |     0.73     |      0.001
|      1  |        200  |   00:00:08     |    50.00%    |     0.96     |      0.001
|      2  |        400  |   00:00:17     |   100.00%    |     0.75     |      0.001
|      3  |        600  |   00:00:27     |   100.00%    |     0.62     |      0.001
|      3  |        800  |   00:00:36     |    25.00%    |     0.89     |      0.001
|      4  |       1000  |   00:00:45     |    49.22%    |     0.75     |      0.001
|      5  |       1200  |   00:00:54     |   100.00%    |     1.18     |      0.001
|      5  |       1400  |   00:01:02     |    81.25%    |     0.75     |      0.001
|      5  |       1475  |   00:01:06     |    66.41%    |     0.67     |      0.001
|========================================================================================

Step 4 of 4: Re-training Fast R-CNN using updated RPN.
********************************************************************
Training a Fast R-CNN Object Detector for the following object classes:

* vehicle
```

```
--> Extracting region proposals from 295 training images...done.

Training on single GPU.
|========================================================================================
|  Epoch  |  Iteration  |  Time Elapsed  |  Mini-batch  |  Mini-batch  |  Base Learning
|         |             |   (hh:mm:ss)   |   Accuracy   |     RMSE     |      Rate
|========================================================================================
|      1  |          1  |    00:00:00    |    95.31%    |     0.76     |       0.001
|      1  |        200  |    00:00:06    |    96.09%    |     0.90     |       0.001
|      2  |        400  |    00:00:13    |    96.88%    |     0.59     |       0.001
|      3  |        600  |    00:00:20    |    97.96%    |     0.42     |       0.001
|      3  |        800  |    00:00:27    |    96.88%    |     0.34     |       0.001
|      4  |       1000  |    00:00:33    |   100.00%    |     0.77     |       0.001
|      5  |       1200  |    00:00:41    |    96.09%    |     0.38     |       0.001
|      5  |       1400  |    00:00:47    |    99.22%    |     0.39     |       0.001
|      5  |       1470  |    00:00:49    |    96.88%    |     0.63     |       0.001
|========================================================================================

Finished training Faster R-CNN object detector.


detector =

  fasterRCNNObjectDetector with properties:

                 ModelName: 'vehicle'
                   Network: [1×1 vision.cnn.FastRCNN]
    RegionProposalNetwork: [1×1 vision.cnn.RegionProposalNetwork]
               MinBoxSizes: [16 21]
           BoxPyramidScale: 2
      NumBoxPyramidLevels: 5
                ClassNames: {2×1 cell}
              MinObjectSize: [1 1]
```

Test the Fast R-CNN detector on a test image.

```
img = imread('highway.png');
```

Run detector.

```
[bbox, score, label] = detect(detector, img);
```

Display detection results.

```
detectedImg = insertShape(img, 'Rectangle', bbox);
figure
imshow(detectedImg)
```


- "Object Detection Using Faster R-CNN Deep Learning"

Input Arguments

`trainingData` — Labeled ground truth images
table

Labeled ground truth images, specified as a table with two or more columns. The first column must contain paths and file names to grayscale or truecolor (RGB) images. The remaining columns must contain bounding boxes related to the corresponding image. Each column represents a single object class, such as a car, dog, flower, or stop sign.

	1 imageFilename	2 stopSign
1	'stopSignImages/image005.jpg'	[980,393,31,56]
2	'stopSignImages/image006.jpg'	[1.0408e+03,354.7500,73,72]
3	'stopSignImages/image009.jpg'	[635,254,65,63]
4	'stopSignImages/image013.jpg'	[398.2050,261.2996,349.6806,385.6992]
5	'stopSignImages/image014.jpg'	[365.1880,306.3229,357.1845,421.7178]
6	'stopSignImages/image020.jpg'	[653.7500,307.7500,73.0000,76]
7	'stopSignImages/image021.jpg'	[589.7500,239.7500,181,196.0000]
8	'stopSignImages/image022.jpg'	[509.7500,470.7500,43,73]
9		

stopSigns ✕

27x2 table

Each bounding box must be in the format [*x y width height*]. The format specifies the upper-left corner location and size of the object in the corresponding image. The table variable name defines the object class name. To create the ground truth table, use the **Training Image Labeler** app.

network — Network
SeriesNetwork object | array of Layer objects

Network, specified as one of the following. The network is trained to classify the object classes defined in the trainingData table.

- A SeriesNetwork object, including pretrained networks such as alexnet or vgg16. When the network is a SeriesNetwork, the network layers are automatically adjusted to support the number of object classes defined within the specified trainingData. The background is added as an additional class.

- An array of Layer objects. For example,

```
layers = [imageInputLayer([28 28 3])
        convolution2dLayer([5 5],10)
        reluLayer()
        fullyConnectedLayer(10)
        softmaxLayer()
        classificationLayer()];
```

When the network is an array of `Layer` objects, the network must have a classification layer that supports the number of object classes, plus a background class. Use this input type to customize the learning rates of each layer.

The function replaces the last `averagePooling2dLayer` or `maxPooling2dLayer` with an ROI pooling layer.

Note `trainFasterRCNNObjectDetector` does not support DAG networks, such as ResNet-50, Inception-v3, or GoogLeNet. Additionally, you cannot pass a Layers array from a DAG network to the training function, because the Layers property from a DAG network does not contain the connection information.

---

options — Training options of neural network
`trainingOptionsSGDM` object | four-element array of `trainingOptionsSGDM` objects

Training options of the neural network, specified as one of the following, which you can obtain by using the `trainingOptions` function with the `'sgdm'` solver name.

- A scalar `TrainingOptionsSGDM` object. All four training stages use the same set of training options.
- A four-element array of `trainingOptionsSGDM` objects. Each of the four training stages uses its own set of training options. To create a four-element array of training options, assign the output of the `trainingOptions` function to each element.

```
options(1) = trainingOptions('sgdm')
options(2) = trainingOptions('sgdm')
options(3) = trainingOptions('sgdm')
options(4) = trainingOptions('sgdm')
```

To fine-tune a pretrained network for detection, lower the initial learning rate to avoid changing the model parameters too rapidly. For example:

```
options = trainingOptions('sgdm', ...
                          'InitialLearningRate',1e-6, ...
                          'CheckpointPath',tempdir);

detector = trainFasterRCNNObjectDetector(trainingData,network,options);
```

The number of iterations per epoch always equals the number of training images because the faster r-cnn uses the "image-centric" training scheme. The `trainingOptions`

`MinibatchSize` controls the number or ROI (or regions) that are sampled from each image.

To save the detector after every epoch, set the `'CheckpointPath'` property when using the `trainingOptions` function. Saving a checkpoint after every epoch is recommended because network training can take a few hours.

Note `trainFasterRCNNObjectDetector` does not support these training options:

- The `ExecutionEnvironment` values: `'multi-gpu'` or `'parallel'`
- The `Plots` value: `'training-progress'`
- The `ValidationData`, `ValidationFrequency`, or `ValidationPatience` options
- ADAM and RMSProp solvers

---

checkpoint — Saved detector checkpoint
`fasterRCNNObjectDetector` object

Saved detector checkpoint, specified as a `fasterRCNNObjectDetector` object. To save the detector after every epoch, set the `'CheckpointPath'` property when using the `trainingOptions` function. Saving a checkpoint after every epoch is recommended because network training can take a few hours.

To load a checkpoint for a previously trained detector, load the MAT-file from the checkpoint path. For example, if the `'CheckpointPath'` property of `options` is `'/tmp'`, load a checkpoint MAT-file using:

```
data = load('/tmp/faster_rcnn_checkpoint__105__2016_11_18__14_25_08.mat');
```

The name of the MAT-file includes the iteration number and timestamp of when the detector checkpoint was saved. The detector is saved in the `detector` variable of the file. Pass this file back into the `trainFasterRCNNObjectDetector` function:

```
frcnn = trainFasterRCNNObjectDetector(stopSigns,...
                         data.detector,options);
```

detector — Previously trained Faster R-CNN object detector
`fasterRCNNObjectDetector` object

Previously trained Faster R-CNN object detector, specified as a `fasterRCNNObjectDetector` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'PositiveOverlapRange',[0.75 1]`

PositiveOverlapRange — Bounding box overlap ratios for positive training samples
`[0.5 1]` (default) | two-element vector | 4-by-2 matrix

Bounding box overlap ratios for positive training samples, specified as the comma-separated pair consisting of `'PositiveOverlapRange'` and one of the following:

- A two-element vector that specifies an identical overlap ratio for all four training stages.
- A 4-by-2 matrix, where each row specifies the overlap ratio for each of the four training stages.

Values are in the range [0,1]. Region proposals that overlap with ground truth bounding boxes within the specified range are used as positive training samples.

The overlap ratio used for both the `PositiveOverlapRange` and `NegativeOverlapRange` is defined as:

$$\frac{area(A \sqcap B)}{area(A \sqcup B)}$$

A and *B* are bounding boxes.

NegativeOverlapRange — Bounding box overlap ratios for negative training samples
`[0.1 0.5]` (default) | two-element vector | 4-by-2 matrix

Bounding box overlap ratios for negative training samples, specified as the comma-separated pair consisting of `NegativeOverlapRange` and one of the following.

- A two-element vector that specifies an identical overlap ratio for all four training stages.

- A 4-by-2 matrix, where each row specifies the overlap ratio for each of the four training stages.

Values are the range [0,1]. Region proposals that overlap with the ground truth bounding boxes within the specified range are used as negative training samples.

The overlap ratio used for both the `PositiveOverlapRange` and `NegativeOverlapRange` is defined as:

$$\frac{area(A \cap B)}{area(A \cup B)}$$

A and *B* are bounding boxes.

NumStrongestRegions — Maximum number of strongest region proposals
2000 (default) | positive integer

Maximum number of strongest region proposals to use for generating training samples, specified as the comma-separated pair consisting of `'NumStrongestRegions'` and a positive integer. Reduce this value to speed up processing time at the cost of training accuracy. To use all region proposals, set this value to `Inf`.

SmallestImageDimension — Length of smallest image dimension
[ ] (default) | positive integer

Length of smallest image dimension, either width or height, specified as the comma-separated pair consisting of `'SmallestImageDimension'` and a positive integer. Training images are resized such that the length of the shortest dimension is equal to the specified integer. By default, training images are not resized. Resizing training images helps reduce computational costs and memory used when training images are large. Typical values range from 400–600 pixels.

MinBoxSizes — Minimum anchor box sizes
`'auto'` (default) | *m*-by-2 matrix

Minimum anchor box sizes used to build the anchor box pyramid of the region proposal network (RPN), specified as the comma-separated pair consisting of `'MinBoxSizes'` and an *m*-by-2 matrix. Each row defines the [*height width*] of an anchor box.

The default `'auto'` setting uses the minimum size and the median aspect ratio from the bounding boxes for each class in the ground truth data. To remove redundant box sizes, the function keeps boxes that have an intersection-over-union that is less than or equal to

0.5. This behavior ensures that the minimum number of anchor boxes are used to cover all the object sizes and aspect ratios.

BoxPyramidScale — Anchor box pyramid scale
2 (default) | scalar

Anchor box pyramid scale factor used to successively upscale anchor box sizes, specified as the comma-separated pair consisting of `'BoxPyramidScale'` and a scalar. Recommended values are from 1 through 2.

NumBoxPyramidLevels — Number of anchor box pyramid levels
`'auto'` (default) | scalar

Number of levels in an anchor box pyramid, specified as the comma-separated pair consisting of `'NumBoxPyramidLevels'` and a scalar. Select a value that ensures that the multiscale anchor boxes are comparable in size to the size of objects in the ground truth data.

The default setting, `'auto'`, selects the number of levels based on the size of objects within the ground truth data. The number of levels is selected such that it covers the range of object sizes.

Output Arguments

trainedDetector — Trained Faster R-CNN object detector
fasterRCNNObjectDetector object

Trained Faster R-CNN object detector, returned as a `fasterRCNNObjectDetector` object.

info — Training information
structure array

Training information, returned as a structure array with four elements. Each element corresponds to a stage of training Faster R-CNN, and has following fields. Each field is a numeric vector with one element per training iteration. Values that have not been calculated at a specific iteration are represented by NaN.

*   `TrainingLoss` — Training loss at each iteration. This is the combination of the classification and regression loss used to train the Faster R-CNN network.

- `TrainingAccuracy` — Training set accuracy at each iteration
- `TrainingRMSE` — Training root mean square error (RMSE) for the box regression layer
- `BaseLearnRate` — Learning rate at each iteration

Tips

- To accelerate data preprocessing for training, `trainFasterRCNNObjectDetector` automatically creates and uses a parallel pool based on your parallel preference settings. This requires Parallel Computing Toolbox.

- If you have a large network (such as VGG-16) or large images, you may encounter an "Out of Memory" error. To avoid this error for large images, set the `'SmallestImageDimension'` parameter to `600` or smaller, which will automatically resize the images during training. Alternatively, manually resize the images along with the bounding box ground truth data before calling `trainFasterRCNNObjectDetector`.

- Transfer learning is supported for series networks such as AlexNet and VGG-16. Passing a network or an array of Layers to the training function preserves the weights of the pretrained network. You can perform transfer learning using code such as this.

```
net = alexnet;
detector = trainFasterRCNNObjectDetector(trainingData,net,options);
```

For more information, see "Get Started with Transfer Learning" (Neural Network Toolbox) and "Transfer Learning Using AlexNet" (Neural Network Toolbox).

- Use the `trainingOptions` function to enable or disable verbose printing.

Algorithms

The `trainFasterRCNNObjectDetector` function trains the Faster R-CNN object detector in four stages with alternating optimization [1].

References

[1] Ren, Shaoqing, Kaiming He, Ross Girshick, and Jian Sun. "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks." *Advances in Neural Information Processing Systems* . Vol. 28, 2015.

See Also

Apps
Image Labeler

Functions
Layer | SeriesNetwork | averagePooling2dLayer | fasterRCNNObjectDetector |
maxPooling2dLayer | trainFastRCNNObjectDetector |
trainRCNNObjectDetector | trainingOptions

Topics
"Object Detection Using Faster R-CNN Deep Learning"
"Choose Among R-CNN, Fast R-CNN, or Faster R-CNN Object Detectors"

Introduced in R2017a

trainFastRCNNObjectDetector

Train a Fast R-CNN deep learning object detector

Syntax

```
trainedDetector = trainFastRCNNObjectDetector(trainingData,network,
options)
trainedDetector = trainFastRCNNObjectDetector(trainingData,
checkpoint,options)
trainedDetector = trainFastRCNNObjectDetector(trainingData,detector,
options)
trainedDetector = trainFastRCNNObjectDetector(___
,'RegionProposalFcn',proposalFcn)
trainedDetector = trainFastRCNNObjectDetector(___ ,Name,Value)
[trainedDetector,info] = trainFastRCNNObjectDetector(___ )
```

Description

`trainedDetector = trainFastRCNNObjectDetector(trainingData,network, options)` trains a Fast R-CNN (regions with convolution neural networks) object detector using deep learning. You can train a Fast R-CNN detector to detect multiple object classes. Specify your ground truth training data, your network, and training options. The network can be a pretrained series network such as `alexnet` or `vgg16` for training using transfer learning, or you can train a network from scratch using an array of `Layer` objects with uninitialized weights.

This function requires that you have Neural Network Toolbox. It is recommended that you also have Parallel Computing Toolbox to use with a CUDA-enabled NVIDIA GPU with compute capability 3.0 or higher.

`trainedDetector = trainFastRCNNObjectDetector(trainingData, checkpoint,options)` resumes training from a detector checkpoint.

`trainedDetector = trainFastRCNNObjectDetector(trainingData,detector, options)` continues training a detector with additional training data or performs more training iterations to improve detector accuracy.

`trainedDetector = trainFastRCNNObjectDetector(___`
`,'RegionProposalFcn',proposalFcn)` optionally trains a custom region proposal function, `proposalFcn`, using any of the previous inputs. If you do not specify a proposal function, then the function uses a variation of the Edge Boxes algorithm.

`trainedDetector = trainFastRCNNObjectDetector(___ ,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

`[trainedDetector,info] = trainFastRCNNObjectDetector(___ )` additionally returns information on the training progress, such as training loss and accuracy, for each iteration.

Examples

Train Fast R-CNN Stop Sign Detector

Load training data.

```
data = load('rcnnStopSigns.mat', 'stopSigns', 'fastRCNNLayers');
stopSigns = data.stopSigns;
fastRCNNLayers = data.fastRCNNLayers;
```

Add fullpath to image files.

```
stopSigns.imageFilename = fullfile(toolboxdir('vision'),'visiondata', ...
    stopSigns.imageFilename);
```

Set network training options:

- Set the CheckpointPath to save detector checkpoints to a temporary directory. Change this to another location if required.

```
options = trainingOptions('sgdm', ...
    'InitialLearnRate', 1e-3, ...
    'MaxEpochs', 10, ...
    'CheckpointPath', tempdir);
```

Train the Fast R-CNN detector. Training can take a few minutes to complete.

```
frcnn = trainFastRCNNObjectDetector(stopSigns, fastRCNNLayers , options, ...
    'NegativeOverlapRange', [0 0.1], ...
```

```
      'PositiveOverlapRange', [0.7 1], ...
      'SmallestImageDimension', 600);

*********************************************************************
Training a Fast R-CNN Object Detector for the following object classes:

* stopSign

--> Extracting region proposals from 27 training images...done.

Training on single GPU.
|========================================================================================
| Epoch  |  Iteration  |  Time Elapsed  |  Mini-batch  |  Mini-batch  |  Base Learning
|        |             |   (hh:mm:ss)   |   Accuracy   |     RMSE     |      Rate
|========================================================================================
|     1  |          1  |    00:00:00    |     98.44%   |      1.11    |      0.001
|     3  |         50  |    00:00:05    |    100.00%   |      0.79    |      0.001
|     5  |        100  |    00:00:10    |    100.00%   |      0.97    |      0.001
|     8  |        150  |    00:00:15    |    100.00%   |      0.52    |      0.001
|    10  |        200  |    00:00:21    |    100.00%   |      0.74    |      0.001
|    10  |        210  |    00:00:22    |    100.00%   |      1.03    |      0.001
|========================================================================================
```

Test the Fast R-CNN detector on a test image.

```
img = imread('stopSignTest.jpg');
```

Run the detector.

```
[bbox, score, label] = detect(frcnn, img);
```

Display detection results.

```
detectedImg = insertShape(img, 'Rectangle', bbox);
figure
imshow(detectedImg)
```

Input Arguments

`trainingData` — Labeled ground truth images
table

Labeled ground truth images, specified as a table with two or more columns. The first column must contain paths and file names to grayscale or truecolor (RGB) images. The remaining columns must contain bounding boxes related to the corresponding image. Each column represents a single object class, such as a car, dog, flower, or stop sign.

	1 imageFilename	2 stopSign
1	'stopSignImages/image005.jpg'	[980,393,31,56]
2	'stopSignImages/image006.jpg'	[1.0408e+03,354.7500,73,72]
3	'stopSignImages/image009.jpg'	[635,254,65,63]
4	'stopSignImages/image013.jpg'	[398.2050,261.2996,349.6806,385.6992]
5	'stopSignImages/image014.jpg'	[365.1880,306.3229,357.1845,421.7178]
6	'stopSignImages/image020.jpg'	[653.7500,307.7500,73.0000,76]
7	'stopSignImages/image021.jpg'	[589.7500,239.7500,181,196.0000]
8	'stopSignImages/image022.jpg'	[509.7500,470.7500,43,73]
9		

Each bounding box must be in the format [*x y width height*]. The format specifies the upper-left corner location and size of the object in the corresponding image. The table variable name defines the object class name. To create the ground truth table, use the **Image Labeler** app. Boxes smaller than 32-by-32 are not used for training.

network — Network
SeriesNetwork object | array of Layer objects

Network, specified as one of the following. The network is trained to classify the object classes defined in the trainingData table.

- A SeriesNetwork object, including pretrained networks such as alexnet or vgg16. When the network is a SeriesNetwork, the network layers are automatically adjusted to support the number of object classes defined within the specified trainingData. The background is added as an additional class.

- An array of Layer objects. For example,

```
layers = [imageInputLayer([28 28 3])
        convolution2dLayer([5 5],10)
        reluLayer()
        fullyConnectedLayer(10)
        softmaxLayer()
        classificationLayer()];
```

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When the network is an array of `Layer` objects, the network must have a classification layer that supports the number of object classes, plus a background class. Use this input type to customize the learning rates of each layer.

The function replaces the last `averagePooling2dLayer` or `maxPooling2dLayer` with an ROI pooling layer.

Note `trainFastRCNNObjectDetector` does not support DAG networks, such as ResNet-50, Inception-v3, or GoogLeNet. Additionally, you cannot pass a Layers array from a DAG network to the training function, because the Layers property from a DAG network does not contain the connection information.

---

options — Training options of neural network
`trainingOptionsSGDM` object

Training options of the neural network, specified as an `TrainingOptionsSGDM` object. You can obtain this object by using the `trainingOptions` function with the `'sgdm'` solver name.

To fine-tune a pretrained network for detection, lower the initial learning rate to avoid changing the model parameters too rapidly. For example:

```
options = trainingOptions('sgdm', ...
                          'InitialLearningRate',1e-6, ...
                          'CheckpointPath',tempdir);

detector = trainFastRCNNObjectDetector(trainingData,network,options);
```

The number of iterations per epoch always equals the number of training images because the fast r-cnn uses the "image-centric" training scheme. The `trainingOptions` `MinibatchSize` controls the number or ROI (or regions) that are sampled from each image.

To save the detector after every epoch, set the `'CheckpointPath'` property when using the `trainingOptions` function. Saving a checkpoint after every epoch is recommended because network training can take a few hours.

Note `trainFastRCNNObjectDetector` does not support these training options:

- The ExecutionEnvironment values: `'multi-gpu'` or `'parallel'`
- The Plots value: `'training-progress'`
- The ValidationData, ValidationFrequency, or ValidationPatience options
- ADAM and RMSProp solvers

---

checkpoint — Saved detector checkpoint
fastRCNNObjectDetector object

Saved detector checkpoint, specified as a fastRCNNObjectDetector object. To save the detector after every epoch, set the `'CheckpointPath'` property when using the trainingOptions function. Saving a checkpoint after every epoch is recommended because network training can take a few hours.

To load a checkpoint for a previously trained detector, load the MAT-file from the checkpoint path. For example, if the `'CheckpointPath'` property of options is `'/tmp'`, load a checkpoint MAT-file using:

```
data = load('/tmp/faster_rcnn_checkpoint__105__2016_11_18__14_25_08.mat');
```

The name of the MAT-file includes the iteration number and timestamp of when the detector checkpoint was saved. The detector is saved in the detector variable of the file. Pass this file back into the trainFastRCNNObjectDetector function:

```
frcnn = trainFastRCNNObjectDetector(stopSigns,...
                        data.detector,options);
```

detector — Previously trained Fast R-CNN object detector
fastRCNNObjectDetector object

Previously trained Fast R-CNN object detector, specified as a fastRCNNObjectDetector object.

proposalFcn — Region proposal method
function handle

Region proposal method, specified as a function handle. The function must have the form:

```
[bboxes,scores] = proposalFcn(I)
```

The input, I, is an image defined in the trainingData table. The function must return rectangular bound boxes, bboxes, in an *m*-by-4 array. Each row of bboxes contains a

four-element vector, `[x y width height]`. This vector specifies the upper-left corner and size of a bounding box in pixels. The function must also return a score for each bounding box in an *m*-by-1 vector. Higher score values indicate that the bounding box is more likely to contain an object. The scores are used to select the strongest *n* regions, where *n* is defined by the value of `NumStrongestRegions`.

If you do not specify a custom proposal function, the function uses a variation of the Edge Boxes algorithm.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'PositiveOverlapRange',[0.75 1]`

PositiveOverlapRange — Bounding box overlap ratios for positive training samples
`[0.5 1]` (default) | two-element vector

Bounding box overlap ratios for positive training samples, specified as the comma-separated pair consisting of `'PositiveOverlapRange'` and a two-element vector. The vector contains values in the range [0,1]. Region proposals that overlap with ground truth bounding boxes within the specified range are used as positive training samples.

The overlap ratio used for both the `PositiveOverlapRange` and `NegativeOverlapRange` is defined as:

$$\frac{area(A \text{ Ⅰ } B)}{area(A \text{ ∪ } B)}$$

A and *B* are bounding boxes.

NegativeOverlapRange — Bounding box overlap ratios for negative training samples
`[0.1 0.5]` (default) | two-element vector

Bounding box overlap ratios for negative training samples, specified as the comma-separated pair consisting of `NegativeOverlapRange` and a two-element vector. The

vector contains values in the range [0,1]. Region proposals that overlap with the ground truth bounding boxes within the specified range are used as negative training samples.

The overlap ratio used for both the `PositiveOverlapRange` and `NegativeOverlapRange` is defined as:

$$\frac{area(A \mathrm{I} B)}{area(A \mathrm{U} B)}$$

A and *B* are bounding boxes.

NumStrongestRegions — Maximum number of strongest region proposals
2000 (default) | positive integer

Maximum number of strongest region proposals to use for generating training samples, specified as the comma-separated pair consisting of `'NumStrongestRegions'` and a positive integer. Reduce this value to speed up processing time at the cost of training accuracy. To use all region proposals, set this value to `Inf`.

SmallestImageDimension — Length of smallest image dimension
[] (default) | positive integer

Length of smallest image dimension, either width or height, specified as the comma-separated pair consisting of `'SmallestImageDimension'` and a positive integer. Training images are resized such that the length of the shortest dimension is equal to the specified integer. By default, training images are not resized. Resizing training images helps reduce computational costs and memory used when training images are large. Typical values range from 400–600 pixels.

Output Arguments

trainedDetector — Trained Fast R-CNN object detector
`fastRCNNObjectDetector` object

Trained Fast R-CNN object detector, returned as a `fastRCNNObjectDetector` object.

info — Training information
structure

Training information, returned as a structure with the following fields. Each field is a numeric vector with one element per training iteration. Values that have not been calculated at a specific iteration are represented by `NaN`.

- `TrainingLoss` — Training loss at each iteration. This is the combination of the classification and regression loss used to train the Fast R-CNN network.
- `TrainingAccuracy` — Training set accuracy at each iteration
- `TrainingRMSE` — Training root mean square error (RMSE) for the box regression layer
- `BaseLearnRate` — Learning rate at each iteration

Tips

- To accelerate data preprocessing for training, `trainFastRCNNObjectDetector` automatically creates and uses a parallel pool based on your parallel preference settings. This requires Parallel Computing Toolbox.

- If you have a large network (such as VGG-16) or large images, you may encounter an "Out of Memory" error. To avoid this error for large images, set the `'SmallestImageDimension'` parameter to `600` or smaller, which will automatically resize the images during training. Alternatively, manually resize the images along with the bounding box ground truth data before calling `trainFastRCNNObjectDetector`.

- Transfer learning is supported for series networks such as AlexNet and VGG-16. Passing a network or an array of Layers to the training function preserves the weights of the pretrained network. You can perform transfer learning using code such as this.

```
net = alexnet;
detector = trainFastRCNNObjectDetector(trainingData,net,options);
```

For more information, see "Get Started with Transfer Learning" (Neural Network Toolbox) and "Transfer Learning Using AlexNet" (Neural Network Toolbox).

- Use the `trainingOptions` function to enable or disable verbose printing.

References

[1] Girshick, Ross. "Fast R-CNN." *Proceedings of the IEEE International Conference on Computer Vision*. 2015.

[2] Zitnick, C. Lawrence, and Piotr Dollar. "Edge Boxes: Locating Object Proposals From Edges." *Computer Vision-ECCV 2014*. Springer International Publishing, 2014, pp. 391–405.

See Also

Apps
Image Labeler

Functions
Layer | SeriesNetwork | fastRCNNObjectDetector | trainFasterRCNNObjectDetector | trainRCNNObjectDetector | trainingOptions

Topics
"Choose Among R-CNN, Fast R-CNN, or Faster R-CNN Object Detectors"

Introduced in R2017a

peopleDetectorACF

Detect people using aggregate channel features

Syntax

```
detector = peopleDetectorACF
detector = peopleDetectorACF(name)
```

Description

`detector = peopleDetectorACF` returns a pretrained upright people detector using aggregate channel features (ACF). The detector is an `acfObjectDetector` object, and is trained using the INRIA person data set.

`detector = peopleDetectorACF(name)` returns a pretrained upright people detector based on the specified model `name`.

Examples

Detect People Using Aggregated Channel Features

Load the upright people detector.
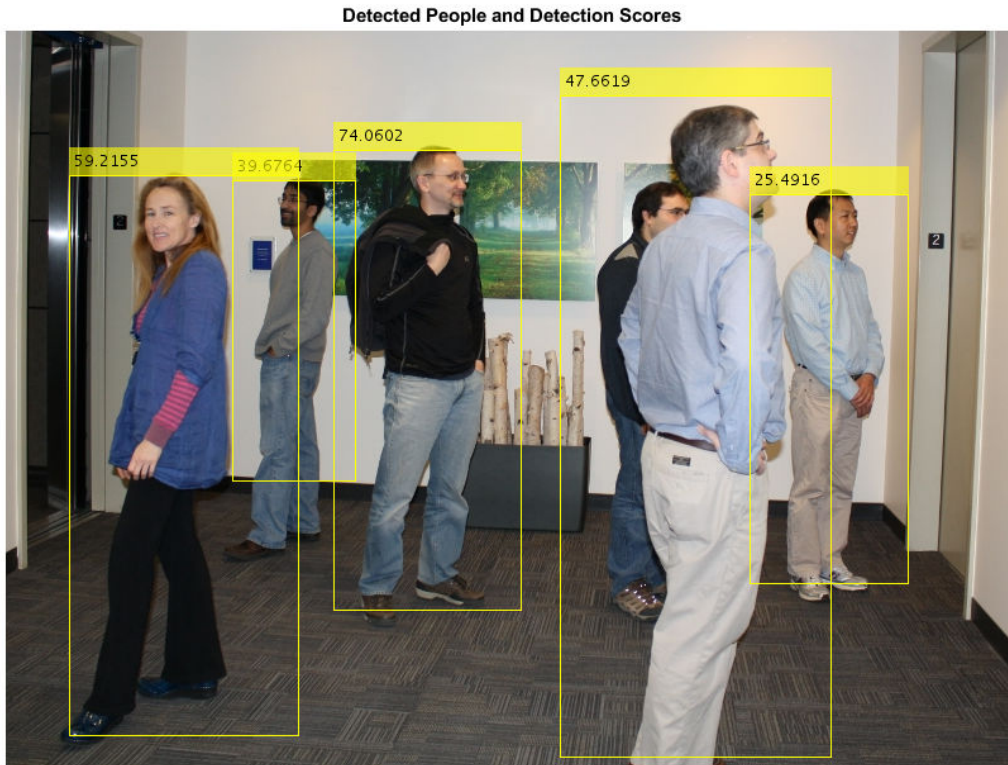
```
detector = peopleDetectorACF;
```

Read an image. Detect people in the image.

```
I = imread('visionteam1.jpg');
[bboxes,scores] = detect(detector,I);
```

Annotate detected people with bounding boxes and their detection scores.

```
I = insertObjectAnnotation(I,'rectangle',bboxes,scores);
figure
```

```
imshow(I)
title('Detected People and Detection Scores')
```


Detected People and Detection Scores

- "Tracking Pedestrians from a Moving Car"

Input Arguments

name — ACF classification model
'inria-100x41' (default) | 'caltech-50x21'

ACF classification model, specified as `'inria-100x41'` or `'caltech-50x21'`. The `'inria-100x41'` model was trained using the INRIA Person data set. The `'caltech-50x21'` model was trained using the Caltech Pedestrian data set.

Output Arguments

`detector` — Trained ACF-based object detector
`acfObjectDetector` object

Trained ACF-based object detector, returned as an `acfObjectDetector` object. The detector is trained to detect upright people in an image.

References

[1] Dollar, P., R. Appel, S. Belongie, and P. Perona. "Fast Feature Pyramids for Object Detection." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 36, Issue 8, 2014, pp. 1532–1545.

[2] Dollar P., C. Wojek, B. Shiele, and P. Perona. "Pedestrian Detection: An Evaluation of the State of the Art." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 34, Issue 4, 2012, pp. 743–761.

[3] Dollar, P., C., Wojek, B. Shiele, and P. Perona. "Pedestrian Detection: A Benchmark." *IEEE Conference on Computer Vision and Pattern Recognition*. 2009.

See Also

`acfObjectDetector` | `detect` | `selectStrongestBbox` | `trainACFObjectDetector` | `vision.CascadeObjectDetector` | `vision.PeopleDetector`

Topics
"Tracking Pedestrians from a Moving Car"
"Point Feature Types"

Introduced in R2017a

objectDetectorTrainingData

Create training data for an object detector

Syntax

```
trainingData = objectDetectorTrainingData(gTruth)
trainingData = objectDetectorTrainingData(gTruth,Name,Value)
```

Description

`trainingData = objectDetectorTrainingData(gTruth)` returns a table of training data from the specified ground truth. The table can be used to train an object detector using training functions such as `trainACFObjectDetector`, `trainRCNNObjectDetector`, `trainFastRCNNObjectDetector`, and `trainFasterRCNNObjectDetector`.

This function supports parallel computing using multiple MATLAB workers. Enable parallel computing using the "Computer Vision System Toolbox Preferences" dialog.

`trainingData = objectDetectorTrainingData(gTruth,Name,Value)` returns a training data table with additional options specified by one or more name-value pair arguments. If the `groundTruth` objects in `gTruth` were created using a video file or a custom data source, then you can specify any combination of name-value pair arguments. If the `groundTruth` objects were created from an image collection or image sequence data source, then you can specify only the `SamplingFactor` name-value pair argument.

Examples

Train an ACF Stop Sign Detector

Use training data to train an ACF-based detector.

Add the folder containing images to the MATLAB path.

```
imageDir = fullfile(matlabroot, 'toolbox', 'vision', 'visiondata', 'stopSignImages');
addpath(imageDir);
```

Load groundTruth data. Ground truth contains data for stops signs and cars.

```
load('stopSignsAndCarsGroundTruth.mat','stopSignsAndCarsGroundTruth')
```

View label definitions to see label types in the ground truth.

```
stopSignsAndCarsGroundTruth.LabelDefinitions
```

```
ans=3×2 table
      Name          Type
    _____    _____

    'stopSign'    Rectangle
    'carRear'     Rectangle
    'carFront'    Rectangle
```

Select the stop sign data for training.

```
stopSignGroundTruth = selectLabels(stopSignsAndCarsGroundTruth,'stopSign');
```

Create training data for a vehicle object detector.

```
trainingData = objectDetectorTrainingData(stopSignGroundTruth);
summary(trainingData)
```

```
Variables:

    imageFilename: 41x1 cell array of character vectors

    stopSign: 41x1 cell
```

Train an ACF object detector for vehicles.

```
acfDetector = trainACFObjectDetector(trainingData,'NegativeSamplesFactor',2);
```

```
ACF Object Detector Training
The training will take 4 stages. The model size is 34x31.
Sample positive examples(~100% Completed)
Compute approximation coefficients...Completed.
Compute aggregated channel features...Completed.
--------------------------------------------
Stage 1:
```

```
Sample negative examples(~100% Completed)
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 19 weak learners.
--------------------------------------------
Stage 2:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 20 weak learners.
--------------------------------------------
Stage 3:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 54 weak learners.
--------------------------------------------
Stage 4:
Sample negative examples(~100% Completed)
Found 84 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 42 positive examples and 84 negative examples...Completed.
The trained classifier has 61 weak learners.
--------------------------------------------
ACF object detector training is completed. Elapsed time is 42.079 seconds.
```

Test the ACF detector on a sample image.

```
I = imread('stopSignTest.jpg');
bboxes = detect(acfDetector,I);
```

Display the detected object.

```
annotation = acfDetector.ModelName;
I = insertObjectAnnotation(I,'rectangle',bboxes,annotation);

figure
imshow(I)
```

Remove the image folder from the path.

```
rmpath(imageDir);
```

Train an ACF-Based Vehicle Detector

Add the image folder to the MATLAB path.

```
imageDir = fullfile(matlabroot,'toolbox','driving','drivingdata','vehiclesSequence');
addpath(imageDir);
```

Load `groundTruth` data.

```
load vehicleGroundTruth.mat
```

Create training data for a vehicle object detector.

```
trainingData = objectDetectorTrainingData(gTruth,'SamplingFactor',2);
```

Train an ACF object detector for vehicles.

```
acfDetector = trainACFObjectDetector(trainingData,'ObjectTrainingSize',[20 20]);
```

```
ACF Object Detector Training
The training will take 4 stages. The model size is 20x20.
Sample positive examples(~100% Completed)
Compute approximation coefficients...Completed.
Compute aggregated channel features...Completed.
--------------------------------------------
Stage 1:
Sample negative examples(~100% Completed)
Compute aggregated channel features...Completed.
Train classifier with 71 positive examples and 355 negative examples...Completed.
The trained classifier has 68 weak learners.
--------------------------------------------
Stage 2:
Sample negative examples(~100% Completed)
Found 76 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 71 positive examples and 355 negative examples...Completed.
The trained classifier has 120 weak learners.
--------------------------------------------
Stage 3:
Sample negative examples(~100% Completed)
Found 54 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 71 positive examples and 355 negative examples...Completed.
The trained classifier has 170 weak learners.
--------------------------------------------
Stage 4:
Sample negative examples(~100% Completed)
Found 63 new negative examples for training.
Compute aggregated channel features...Completed.
Train classifier with 71 positive examples and 355 negative examples...Completed.
The trained classifier has 215 weak learners.
--------------------------------------------
ACF object detector training is completed. Elapsed time is 10.1224 seconds.
```

Test the ACF detector on a test image.

```
I = imread('highway.png');
[bboxes, scores] = detect(acfDetector,I,'Threshold',1);
```
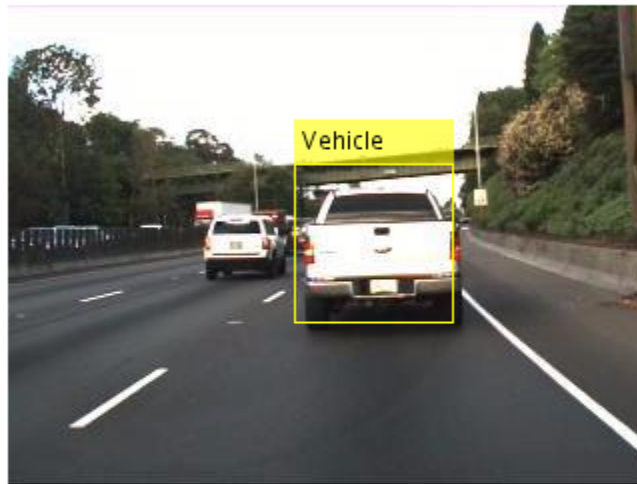
Select strongest detection.

```
[~,idx] = max(scores);
```

Display the detected object.

```
annotation = acfDetector.ModelName;
I = insertObjectAnnotation(I,'rectangle',bboxes(idx,:),annotation);

figure
imshow(I)
```


Remove the image folder from the path.

```
rmpath(imageDir);
```

Input Arguments

gTruth — Ground truth data
array of groundTruth objects

Ground truth data, specified as an array of `groundTruth` objects. You can create ground truth objects from existing ground truth data by using the `groundTruth` object.

If you use custom data sources in `groundTruth` with parallel computing enabled, then the reader function is expected to work with a pool of MATLAB workers to read images from the data source in parallel.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'SamplingFactor',5`

SamplingFactor — Factor at which to subsample images
`'auto'` (default) | integer | vector of integers

Factor at which to subsample images in the ground truth data source, specified as `'auto'`, an integer, or a vector of integers. For a sampling factor of N, the returned training data includes every Nth image in the ground truth data source, ignoring ground truth images with empty label data.

SamplingFactor	Sampling Factor Applied
`'auto'`	The sampling factor N is 5 for data sources with timestamps, and 1 for a collection of images.
Integer	All ground truth data sources in `gTruth` are sampled with the same sampling factor, N.
Vector of integers	The kth ground truth data source in `gTruth` is sampled with a sampling factor of $N(k)$.

WriteLocation — Folder name
pwd (current working folder) (default) | string scalar | character vector

Folder name to write extracted images to, specified as a string scalar or character vector. The specified folder must exist and have write permissions. This property applies only for `groundTruth` objects created using a video file or a custom data source.

ImageFormat — Image file format
PNG (default) | string scalar | character vector

Image file format, specified as a string scalar or character vector. File formats must be supported by `imwrite`. This argument applies only for `groundTruth` objects created using a video file or a custom data source.

NamePrefix — Prefix applied to output image file names
string scalar | character vector

Prefix applied to output image file names, specified as a string scalar or character vector. The image files are named as:

`<name_prefix><image_number>.<image_format>`

The default value uses the name of the data source are the images where extracted from, `strcat(sourceName,'_')`. This property applies only for `groundTruth` objects created using a video file or a custom data source.

Verbose — Display training progress
`true` (default) | `false`

Display training progress on the MATLAB command line, specified as either `true` or `false`. This property applies only for `groundTruth` objects created using a video file or a custom data source.

Output Arguments

trainingData — Training data
table

Training data, returned as a table with two or more columns. The first column of the table contains image file names. The remaining columns contain object positions for rectangular ROI labels found in the ground truth object input, `gTruth`. The rectangular ROI labels must be [*x*,*y*,*width*,*height*] bounding boxes that specify object positions within each image. Only labels corresponding to rectangle ROI labels are returned in

`trainingData`. Other labels are ignored. The output table ignores any sublabel and/or attribute data present in the input `gTruth` object.

See Also

Apps
Ground Truth Labeler | **Image Labeler**

Functions
`trainACFObjectDetector` | `trainFastRCNNObjectDetector` | `trainFasterRCNNObjectDetector` | `trainRCNNObjectDetector`

Objects
`acfObjectDetector` | `groundTruth`

Introduced in R2017a

estimateFisheyeParameters

Calibrate fisheye camera

Syntax

```
[fisheyeParams,imagesUsed,estimationErrors] =
estimateFisheyeParameters(imagePoints,worldPoints,imageSize)
[ ___ ] = estimateFisheyeParameters( ___ ,Name,Value)
```

Description

`[fisheyeParams,imagesUsed,estimationErrors] = estimateFisheyeParameters(imagePoints,worldPoints,imageSize)` returns a `fisheyeParameters` object containing estimates for the intrinsic and extrinsic parameters of a fisheye camera. The function also returns the images you used to estimate the fisheye parameters and the standard estimation errors for the single camera calibration.

`[ ___ ] = estimateFisheyeParameters( ___ ,Name,Value)` configures the `fisheyeParams` object properties specified by one or more `Name,Value` pair arguments, using the previous syntax. Unspecified properties have their default values.

Examples

Fisheye Camera Calibration

Use calibration images to detect a checkerboard calibration pattern. Then calibrate the camera using corneres extracted from the pattern and visualize the results.

Gather a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata',...
        'calibration','gopro'));
imageFileNames = images.Files;
```

Detect the calibration pattern from the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(imageFileNames);
```

Generate world coordinates for the corners of the checkerboard squares.

```
squareSize = 29; % millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the fisheye camera calibration parameters based on the image and world points.

```
I = readimage(images,1);
imageSize = [size(I,1) size(I,2)];
params = estimateFisheyeParameters(imagePoints,worldPoints,imageSize);
```
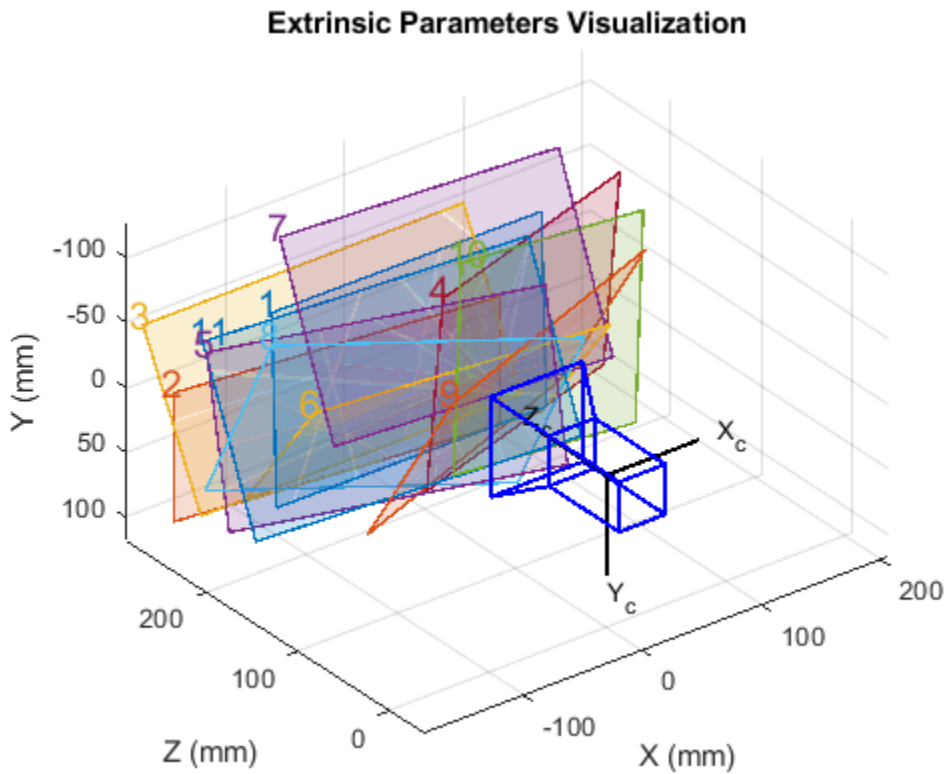
Visualize the calibration accuracy.

```
figure
showReprojectionErrors(params);
```
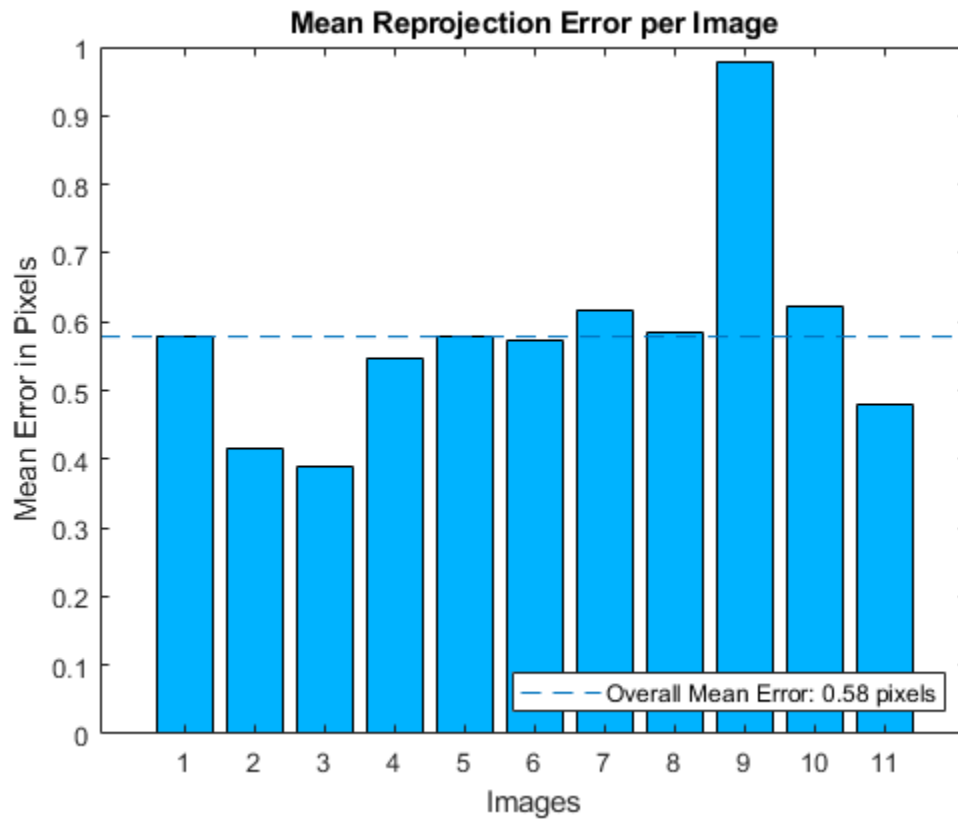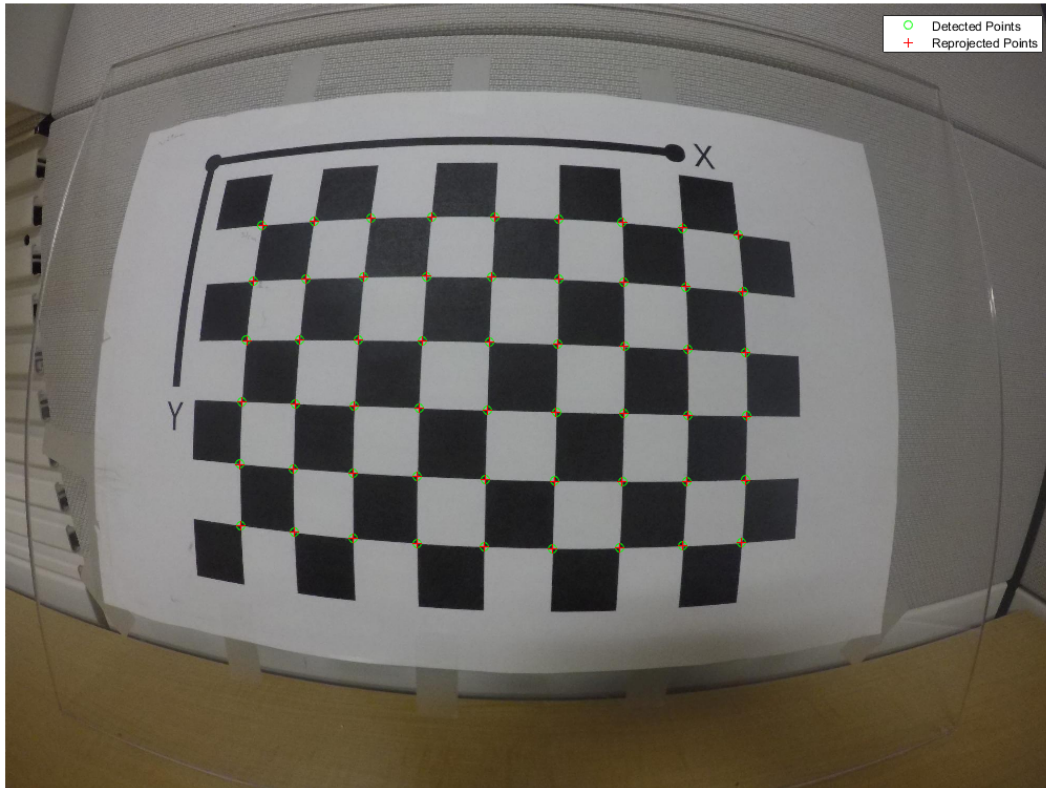
Visualize the camera extrinsics.

```
figure
showExtrinsics(params);
drawnow
```

Extrinsic Parameters Visualization

Plot the detected and reprojected points.

```
figure
imshow(I);
hold on
plot(imagePoints(:,1,1),imagePoints(:,2,1),'go');
plot(params.ReprojectedPoints(:,1,1),params.ReprojectedPoints(:,2,1),'r+');
legend('Detected Points','Reprojected Points');
hold off
```

Input Arguments

imagePoints — Key points of calibration pattern
M-by-2-by-*numImages* array

Key points of calibration pattern, specified as an *M*-by-2-by-*numImages* array of [*x,y*] intrinsic image coordinates. The number of images, *numImages*, must be greater than 2. The number of keypoint coordinates in each pattern, *M*, must be greater than 3.

Data Types: `single` | `double`

worldPoints — Key points of calibration pattern in world coordinates
M-by-2 matrix

Key points of calibration pattern in world coordinates, specified as an *M*-by-2 matrix of *M* [*x*,*y*] world coordinates. Because the pattern must be planar, the *z*-coordinates are zero.

Data Types: `single` | `double`

imageSize — Image size
`[mrows ncols]` vector

Image size, specified as an `[mrows ncols]` vector.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'WorldUnits','mm'` sets the world point units to millimeters.

EstimateAlignment — Estimate axes alignment
`false` (default) | `true`

Estimate the axes alignment, specified as the comma-separated pair consisting of `'EstimateAlignment'` and `false` or `true`. Set to `true` if the optical axis of the fisheye lens is not perpendicular to the image plane.

WorldUnits — World point units
`'mm'` (default) | character vector

World point units, specified as the comma-separated pair consisting of `'WorldUnits'` and a character vector representing units. This argument is used simply to store the unit type and does not affect any calculations. Any character vector is valid.

Output Arguments

fisheyeParams — Fisheye camera parameters
`fisheyeParameters` object

Fisheye camera parameters, returned as a `fisheyeParameters` object.

`imagesUsed` — Images used to estimate camera parameters
P-by-1 logical array

Images used to the estimate camera parameters, returned as a *P*-by-1 logical array. *P* corresponds to the number of images. A logical `true` value indicates the index of an image used to estimate the camera parameters.

`estimationErrors` — Standard errors of estimated parameters
`fisheyeCalibrationErrors` object

Standard errors of estimated parameters, returned as a `fisheyeCalibrationErrors` object.

References

[1] Scaramuzza, D., A. Martinelli, and R. Siegwart. "A Toolbox for Easy Calibrating Omindirectional Cameras." *Proceedings to IEEE International Conference on Intelligent Robots and Systems (IROS 2006)*. Beijing, China, October 7–15, 2006.

[2] Urban, S., J. Leitloff, and S. Hinz. "Improved Wide-Angle, Fisheye and Omnidirecitonal Camera Calibration." *ISPRS Journal of Photogrammetry and Remove Sensing*. Vol. 108, 2015, pp.72–79.

See Also
detectCheckerboardPoints | fisheyeCalibrationErrors | fisheyeIntrinsics | fisheyeParameters | generateCheckerboardPoints | showExtrinsics | showReprojectionErrors | undistortFisheyeImage

Topics
"Fisheye Calibration Basics"

Introduced in R2017b

undistortFisheyeImage

Correct fisheye image for lens distortion

Syntax

```
J = undistortFisheyeImage(I,intrinsics)
[J,camIntrinsics] = undistortFisheyeImage(I,intrinsics)
[ ___ ] = undistortFisheyeImage( ___ ,interp)
[ ___ ] = undistortFisheyeImage( ___ ,Name,Value)
```

Description

`J = undistortFisheyeImage(I,intrinsics)` removes lens distortion for image `I` and returns the result as image `J`.

`[J,camIntrinsics] = undistortFisheyeImage(I,intrinsics)` also returns a `cameraIntrinsics` object, which corresponds to a virtual perspective camera that produces image `J`.

`[ ___ ] = undistortFisheyeImage( ___ ,interp)` specifies the interpolation method, `interp`, using the preceding syntaxes.

`[ ___ ] = undistortFisheyeImage( ___ ,Name,Value)` specifies one or more `Name,Value` pair arguments. Unspecified properties have their default values.

Examples

Correct Fisheye Image for Lens Distortion

Remove lens distortion from a fisheye image by detecting a checkboard calibration pattern and calibrating the camera. Then, display the results.

Gather a set of checkerboard calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
    'calibration','gopro'));
```

Detect the calibration pattern from the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate world coordinates for the corners of the checkerboard squares.

```
squareSize = 29; % millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the fisheye camera calibration parameters based on the image and world points. Use the first image to get the image size.

```
I = readimage(images,1);
imageSize = [size(I,1) size(I,2)];
params = estimateFisheyeParameters(imagePoints,worldPoints,imageSize);
```

Remove lens distortion from the first image I and display the results.

```
J1 = undistortFisheyeImage(I,params.Intrinsics);
figure
imshowpair(I,J1,'montage')
title('Original Image (left) vs. Corrected Image (right)')

J2 = undistortFisheyeImage(I,params.Intrinsics,'OutputView','full');
figure
imshow(J2)
title('Full Output View')
```

Original Image (left) vs. Corrected Image (right)
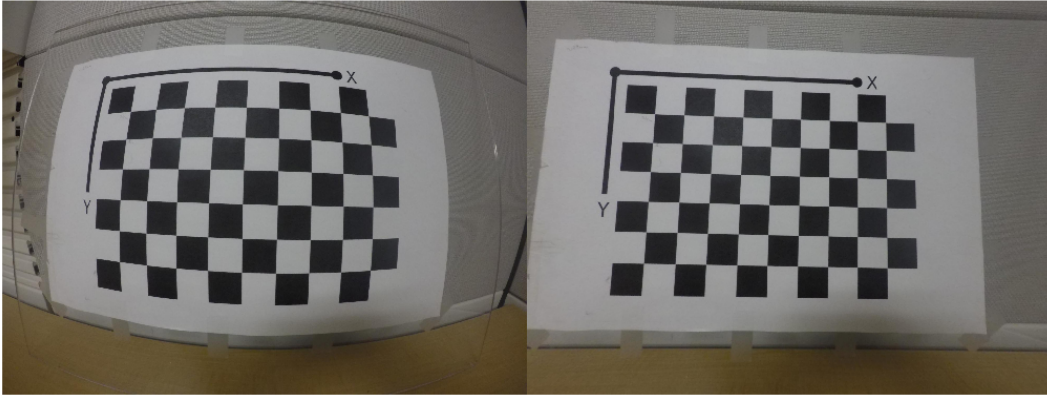
Full Output View
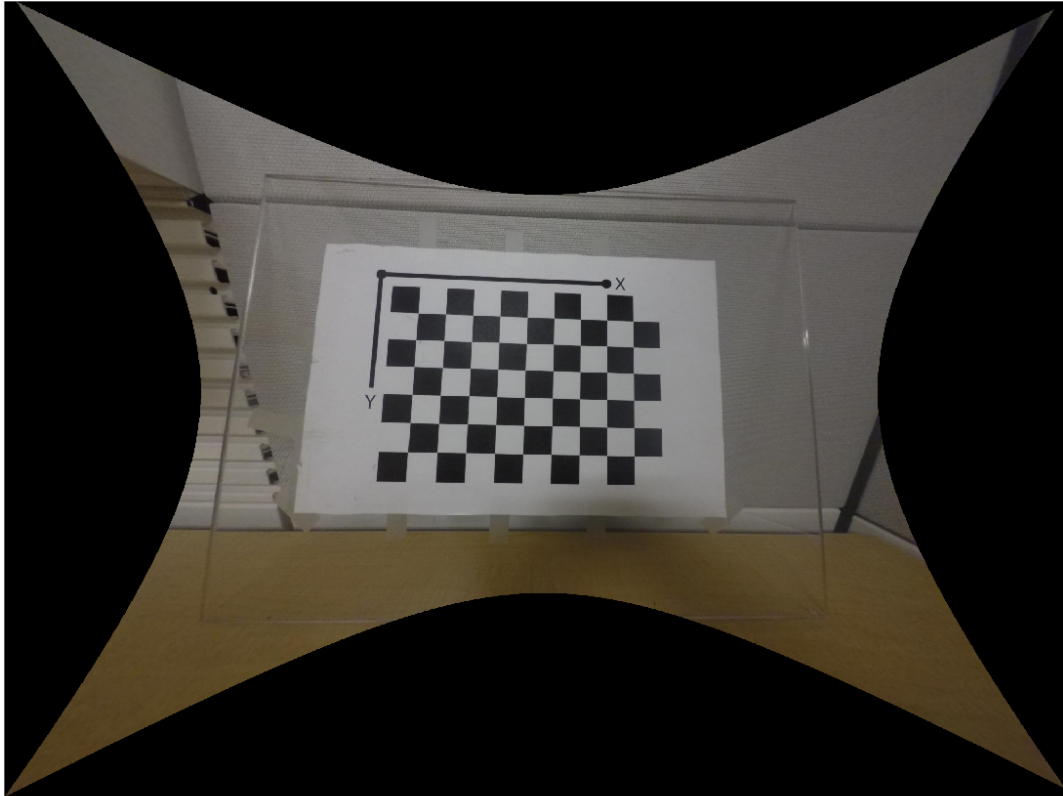
Input Arguments

I — Input image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Input image, specified as an *M*-by-*N*-by-3 truecolor or *M*-by-*N* 2-D grayscale image. The input image must be real and nonsparse.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

intrinsics — Fisheye intrinsic camera parameters
fisheyeIntrinsics object

Fisheye intrinsic camera parameters, specified as a `fisheyeIntrinsics` object.

interp — Interpolation method
'bilinear' (default) | 'nearest' | 'cubic'

Interpolation method to use on the input image, specified as `'bilinear'`, `'nearest'`, or `'cubic'`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'ScaleFactor',2` sets the scale factor to increase the zoom in the camera view.

OutputView — Size of the output image
'same' (default) | 'full' | 'valid'

Size of the output image, specified as either `'same'`, `'full'`, or `'valid'`.

ScaleFactor — Scale factor for focal length
1 (default) | scalar | [sx sy] vector

Scale factor for the focal length of a virtual camera perspective, in pixels, specified as a scalar or an [sx sy] vector. Specify a vector to scale the *x* and *y* axes individually. Increase the scale to zoom in the perspective of the camera view.

FillValues — Output pixel fill values
0 (default) | scalar | 3-element vector

Output pixel fill values, specified as the comma-separated pair consisting of 'FillValues' and scalar or 3-element vector. When the corresponding inverse-transformed location in the input image lies completely outside the input image boundaries, you use the fill values for output pixels. When you use a 2-D grayscale input image, `FillValues` must be a scalar. When you use a truecolor image, `FillValues` can be a scalar or a 3-element vector of RGB values.

Output Arguments

J — Undistorted image
M-by-*N*-by-3 truecolor image | *M*-by-*N* 2-D grayscale image

Undistorted image, returned as an *M*-by-*N*-by-3 truecolor or *M*-by-*N* 2-D grayscale image.

Data Types: `single` | `double` | `int16` | `uint8` | `uint16` | `logical`

`camIntrinsics` — Undistorted intrinsics of virtual camera
`cameraIntrinsics` object

Undistorted intrinsics of a virtual camera, returned as a `cameraIntrinsics` object. These intrinsics are for a camera that has a perspective that produces the undistorted image.

See Also

`cameraIntrinsics` | `estimateFisheyeParameters` | `fisheyeIntrinsics` | `undistortFisheyePoints`

Topics
"Fisheye Calibration Basics"

Introduced in R2017b

undistortFisheyePoints

Correct point coordinates for fisheye lens distortion

Syntax

```
undistortedPoints = undistortFisheyePoints(points,intrinsics)
undistortedPoints = undistortFisheyePoints( ___ ,scaleFactor)
[ ___ ,camIntrinsics] = undistortFisheyePoints( ___ )
[ ___ ,reprojectionErrors] = undistortFisheyePoints( ___ )
```

Description

`undistortedPoints = undistortFisheyePoints(points,intrinsics)` returns point coordinates corrected for fisheye lens distortion.

`undistortedPoints = undistortFisheyePoints( ___ ,scaleFactor)` returns corrected point coordinates using the `scaleFactor` and the previous inputs.

`[ ___ ,camIntrinsics] = undistortFisheyePoints( ___ )` also returns a `cameraIntrinsics` object, which corresponds to a virtual perspective camera that produces undistorted points.

`[ ___ ,reprojectionErrors] = undistortFisheyePoints( ___ )` also returns `reprojectionErrors` used to evaluate the accuracy of undistorted points. The function computes the reprojection errors by applying distortion to the points, and taking the distances between the result and the corresponding input points.

Examples

Undistort Checkerboard Points from Fisheye Image

Undistort and translate checkerboard points detected in a calibration image, and then display the results.

Create an `imageDatastore` object containing checkerboard calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata',...
    'calibration','gopro'));
imageFileNames = images.Files;
```

Detect the calibration pattern from the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(imageFileNames);
```

Generate world coordinates for the corners of the checkerboard squares.

```
squareSize = 29; % millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the fisheye parameters from the image and world points. Get the image size from the first image.

```
I = readimage(images,10);
imageSize = [size(I,1) size(I,2)];
params = estimateFisheyeParameters(imagePoints,worldPoints,imageSize);
```

In the first image, detect the checkerboard points.

```
points = detectCheckerboardPoints(I);
```

Undistort the points and image.

```
[undistortedPoints,intrinsics1] = undistortFisheyePoints(points,params.Intrinsics);
[J, intrinsics2] = undistortFisheyeImage(I,params.Intrinsics,'OutputView','full');
```

Translate the undistorted points.

```
newOrigin = intrinsics2.PrincipalPoint - intrinsics1.PrincipalPoint;
undistortedPoints = [undistortedPoints(:,1) + newOrigin(1), ...
                     undistortedPoints(:,2) + newOrigin(2)];
```

Display the results.

```
figure
imshow(I)
hold on
plot(points(:,1),points(:,2),'r*-')
title('Detected Points')
hold off
```

```
figure
imshow(J)
hold on
plot(undistortedPoints(:, 1),undistortedPoints(:, 2),'g*-')
title('Undistorted Points')
hold off
```

Detected Points

Undisted Points
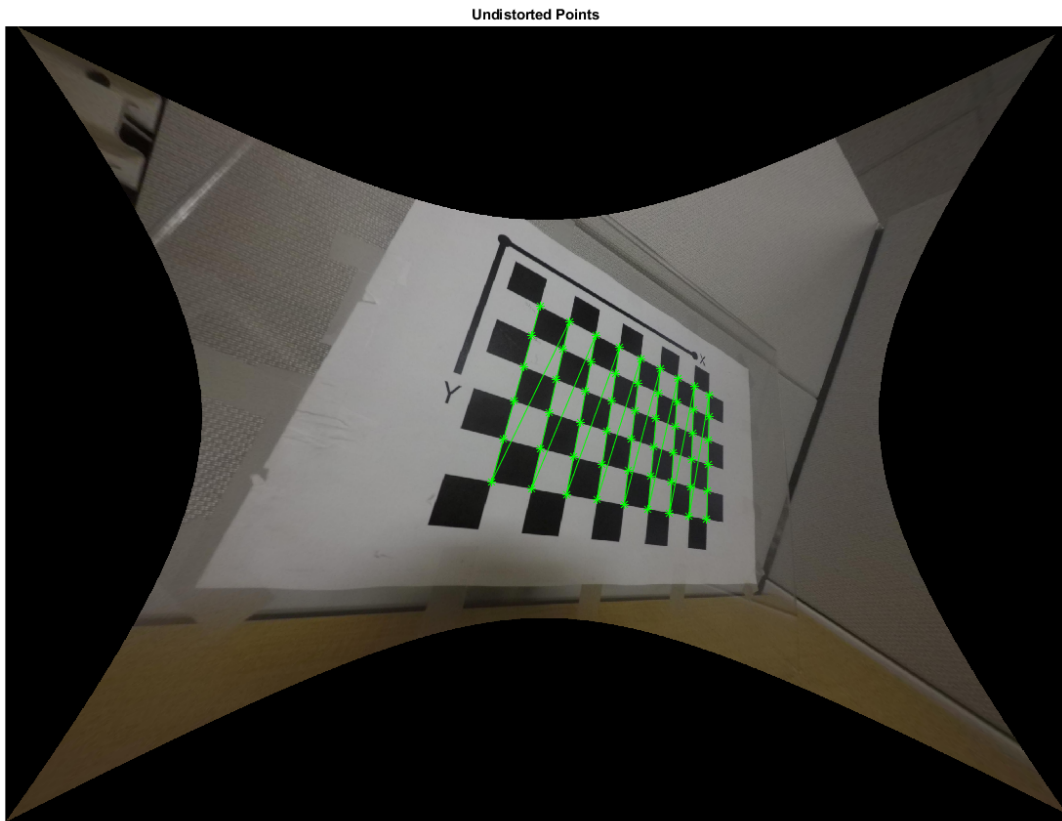
Input Arguments

`points` — Input points
M-by-2 matrix

Input points, specified as an *M*-by-2 matrix of *M* [x y] coordinates.

`intrinsics` — Fisheye intrinsic camera parameters
`fisheyeIntrinsics` object

Fisheye intrinsic camera parameters, specified as a `fisheyeIntrinsics` object.

scaleFactor — Scale factor for points
1 (default) | scalar | [sx sy] vector

Scale factor for points, specified as a scalar or an [sx sy] vector. Specify a vector to scale the *x* and *y* axes individually. Increase the scale to zoom in the perspective of the camera view.

Output Arguments

undistortedPoints — Undistorted points
M-by-2 matrix

Undistorted points, returned as an *M*-by-2 matrix of *M* number of [x y] coordinates. If points is double, then undistortedPoints is double. Otherwise, undistortedPoints is single.

Data Types: single | double

camIntrinsics — Undistorted intrinsics of virtual camera
cameraIntrinsics object

Undistorted intrinsics of a virtual camera, returned as a cameraIntrinsics object. These intrinsics are for a camera that has a perspective that produces the undistorted image.

reprojectionErrors — Reprojection errors
M-by-1 vector

Reprojection errors, returned as an *M*-by-1 vector. The function computes the reprojection errors by applying distortion to the undistorted points and taking the distances between the results and the corresponding input points. Errors are expressed in pixels.

See Also

fisheyeIntrinsics | undistortFisheyeImage

Topics
"Fisheye Calibration Basics"

Introduced in R2017b

pointsToWorld

Determine world coordinates of image points

Syntax

```
worldPoints = pointsToWorld(cameraParams,rotationMatrix,
translationVector,imagePoints)
```

Description

`worldPoints = pointsToWorld(cameraParams,rotationMatrix,
translationVector,imagePoints)` returns world points on the *X-Y* plane, which correspond to the input image points. Points are converted using the input rotation matrix, translation vector, and camera parameters.

Examples

Map Image Points of Fisheye Image to World Coordinates

Map the points of a fisheye image to world coordinates and compare these points to the ground truth points. A series of checkerboard pattern images are used to estimate the fisheye parameters and calibrate the camera.

Create a set of checkerboard calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata' ,...
    'calibration','gopro'));
```

Detect the checkerboard corners in the images. Leave the last image for testing.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files(1:end-1));
```

Generate the world coordinates of the checkerboard corners in the pattern-centric coordinate system, with the upper-left corner at (0,0).

```
squareSize = 29; % millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the fisheye camera parameters from the image and world points. Use the first image to get image size.

```
I = imread(images.Files{end});
imageSize = [size(I,1) size(I,2)];
fisheyeParams = estimateFisheyeParameters(imagePoints,worldPoints,imageSize);
intrinsics = fisheyeParams.Intrinsics;
```

Find the reference object in the new image.

```
imagePoints = detectCheckerboardPoints(I);
```
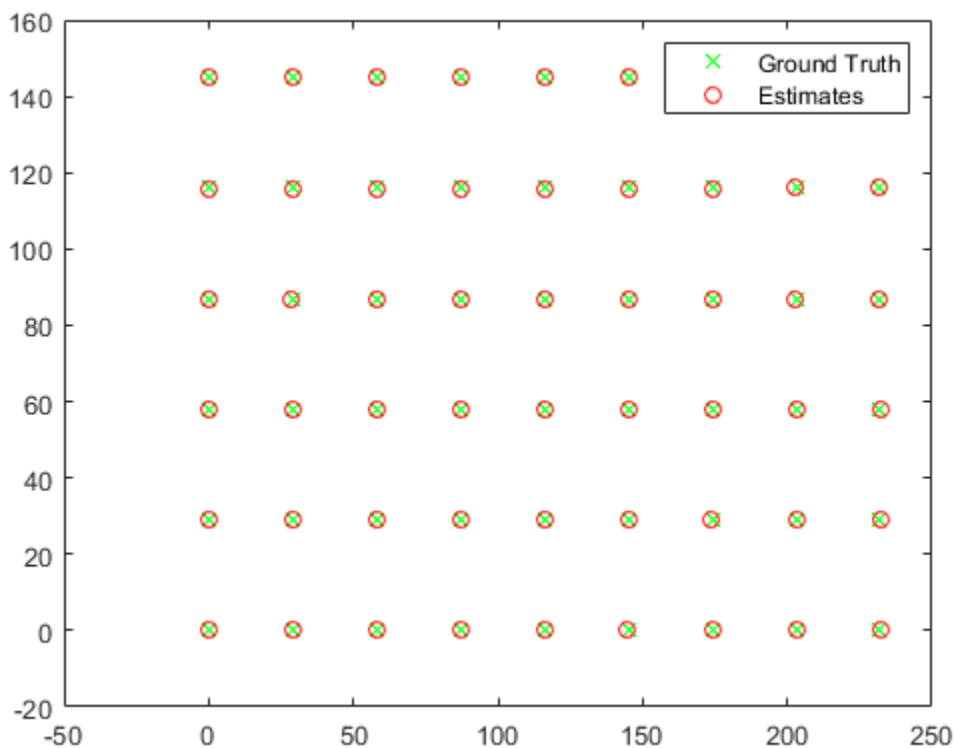
Compute new extrinsics.

```
[R,t] = extrinsics(imagePoints,worldPoints,intrinsics);
```

Map image points to world coordinates in the X-Y plane.

```
newWorldPoints = pointsToWorld(intrinsics,R,t,imagePoints);
```

Compare estimated world points to the ground truth points.

```
plot(worldPoints(:,1),worldPoints(:,2),'gx');
hold on
plot(newWorldPoints(:,1),newWorldPoints(:,2),'ro');
legend('Ground Truth','Estimates');
hold off
```

Input Arguments

cameraParams — Camera parameters
cameraParameters object | fisheyeParameters object

Camera parameters, specified as a cameraParameters or fisheyeParameters object. These objects contain the intrinsic, extrinsic, and lens distortion parameters of a camera.

- To create a cameraParameters, use the estimateCameraParameters function or the **Camera Calibrator** app.

- To create a `fisheyeParameters`, use the `estimateFisheyeParameters` function.

`rotationMatrix` — 3-D rotation
3-by-3 matrix

3-D rotation of the world coordinates relative to the image coordinates, specified as a 3-by-3 matrix. The rotation matrix, together with the translation vector, enable you to transform points from the world coordinate system to the camera coordinate system. The `rotationMatrix` and `translationVector` inputs must be the same data type.

$$[x\ y\ z]\ =\ [X\ Y\ Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

Data Types: `double` | `single`

`translationVector` — 3-D translation
1-by-3 vector

3-D translation of the world coordinates relative to the image coordinates, specified as a 1-by-3 vector. The translation vector, together with the rotation matrix, enable you to transform points from the world coordinate system to the camera coordinate system. The `rotationMatrix` and `translationVector` inputs must be the same data type.

$$[x\ y\ z]\ =\ [X\ Y\ Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

Data Types: `double` | `single`

`imagePoints` — Image points
M-by-2 matrix

Image points, specified as an M-by-2 matrix containing M $[x, y]$ coordinates of image points.

When using the `cameraParameters` object as the `cameraParams` input, `pointsToWorld` does not account for lens distortion. Therefore, the `imagePoints` input must contain image points detected in the undistorted image, or they must be undistorted

using the `undistortPoints` function. For a `fisheyeIntrinsics` object, the image points are distorted.

Output Arguments

worldPoints — World coordinates
M-by-2 matrix

World coordinates, returned as an *M*-by-2 matrix. *M* represents the number of undistorted points in [*x*, *y*] world coordinates.

See Also

Functions
estimateCameraParameters | estimateFisheyeParameters | extrinsics | undistortImage | undistortPoints

Objects
cameraParameters | fisheyeIntrinsics | fisheyeParameters

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Introduced in R2016a

worldToImage

Project world points into image

Syntax

```
imagePoints = worldToImage(cameraParams,rotationMatrix,
translationVector,worldPoints)
imagePoints = worldToImage(cameraParams,'ApplyDistortion',distort)
```

Description

`imagePoints = worldToImage(cameraParams,rotationMatrix,
translationVector,worldPoints)` returns the projection of 3-D world points into an
image given camera parameters, the rotation matrix, and the translation vector.

`imagePoints = worldToImage(cameraParams,'ApplyDistortion',distort)`
returns the projection with the option of applying distortion. This syntax is supported for
nonfisheye camera parameters.

Examples

Project World Points into Image

Create a set of calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata', ...
     'calibration','slr'));
```

Detect the checkerboard corners in the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate the world coordinates of the checkerboard corners in the pattern-centric
coordinate system, with the upper-left corner at (0,0).

```
squareSize = 29; % in millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```
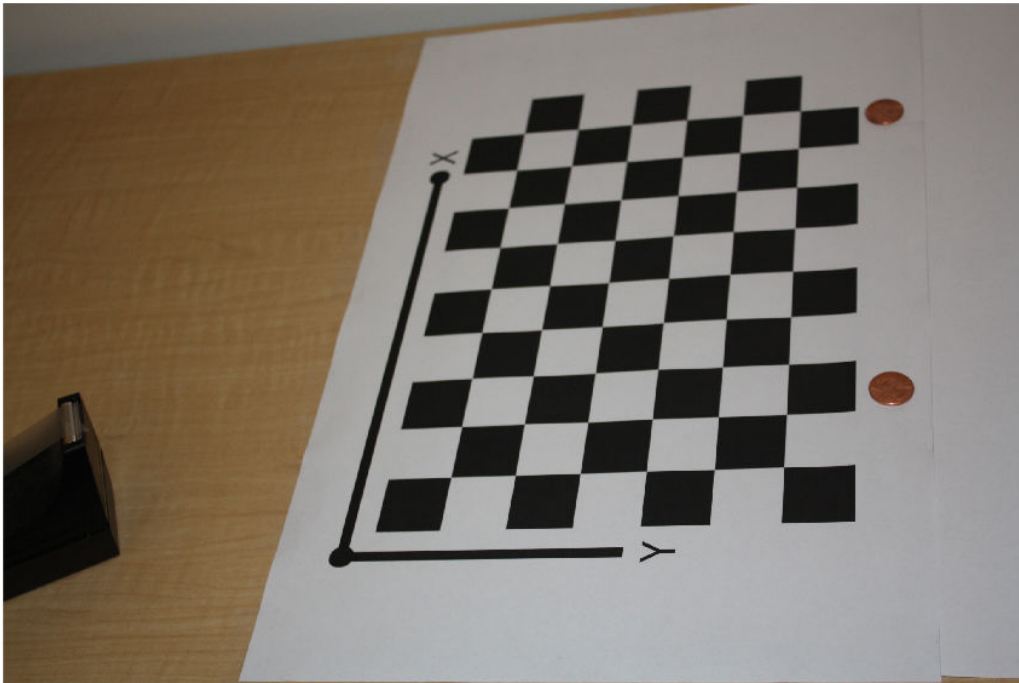
Calibrate the camera.

```
cameraParams = estimateCameraParameters(imagePoints,worldPoints);
```

Load the image at a new location.

```
imOrig = imread(fullfile(matlabroot,'toolbox','vision','visiondata', ...
        'calibration','slr','image9.jpg'));

imshow(imOrig,'InitialMagnification',30);
```


Undistort the image.

```
imUndistorted = undistortImage(imOrig,cameraParams);
```

Find a reference object in the new image.

```
[imagePoints,boardSize] = detectCheckerboardPoints(imUndistorted);
```

Compute new extrinsics.

```
[R,t] = extrinsics(imagePoints,worldPoints,cameraParams);
```
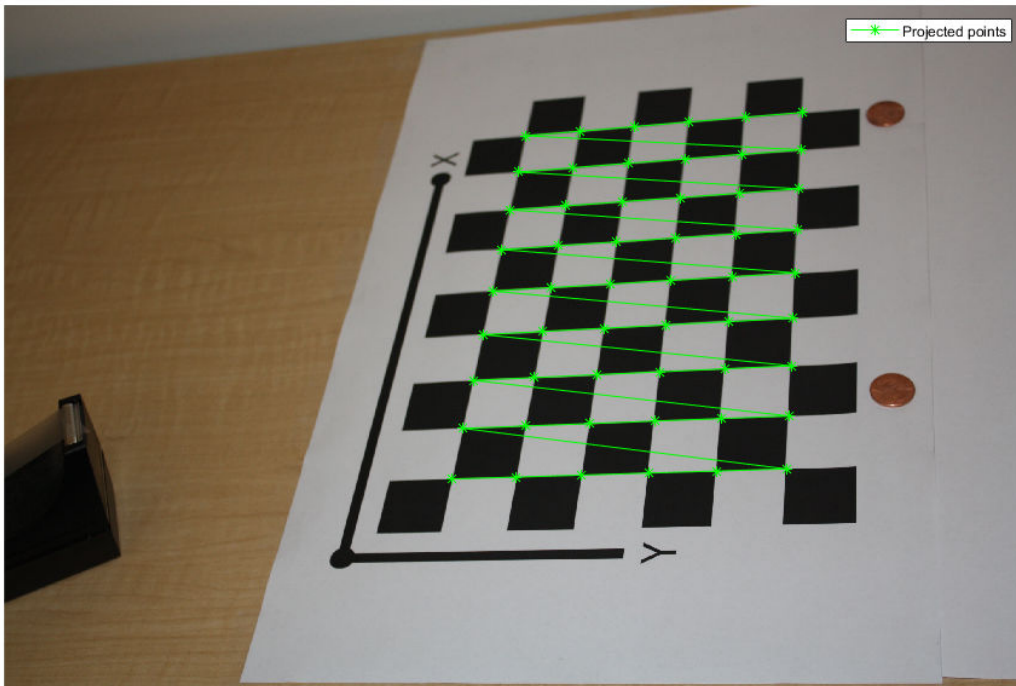
Add a *z*-coordinate to the world points.

```
zCoord = zeros(size(worldPoints,1),1);
worldPoints = [worldPoints zCoord];
```

Project the world points back into the original image.

```
projectedPoints = worldToImage(cameraParams,R,t,worldPoints);
hold on
plot(projectedPoints(:,1),projectedPoints(:,2),'g*-');
legend('Projected points');
hold off
```

Input Arguments

cameraParams — Camera parameters
cameraParameters object | fisheyeParameters object

Camera parameters, specified as a cameraParameters or fisheyeParameters object. These objects contain the intrinsic, extrinsic, and lens distortion parameters of a camera.

- To create a cameraParameters, use the estimateCameraParameters function or the **Camera Calibrator** app.

- To create a fisheyeParameters, use the estimateFisheyeParameters function.

rotationMatrix — 3-D rotation
3-by-3 matrix

3-D rotation of the world coordinates relative to the image coordinates, specified as a 3-by-3 matrix. The rotation matrix, together with the translation vector, enable you to transform points from the world coordinate system to the camera coordinate system. The `rotationMatrix` and `translationVector` inputs must be the same data type.

$$[x \; y \; z] \; = \; [X \; Y \; Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

Data Types: `double` | `single`

translationVector — 3-D translation
1-by-3 vector

3-D translation of the world coordinates relative to the image coordinates, specified as a 1-by-3 vector. The translation vector, together with the rotation matrix, enable you to transform points from the world coordinate system to the camera coordinate system. The `rotationMatrix` and `translationVector` inputs must be the same data type.

$$[x \; y \; z] \; = \; [X \; Y \; Z]R + t$$

camera coordinates   world coordinates   rotation matrix   translation vector

Data Types: `double` | `single`

worldPoints — 3-D world points
M-by-3 matrix

3-D world points, specified as an *M*-by-3 matrix containing *M* [*x*,*y*,*z*] coordinates of 3-D world points.

distort — Apply lens distortion
`false` (default) | `true`

Option to apply lens distortion, specified as `false` or `true`. When you set this argument to `true`, the function applies lens distortion to the output `imagePoints`.

This argument is valid only when using a `cameraParameters` object as the `cameraParams` input.

Output Arguments

`imagePoints` — Image points
M-by-2 matrix

Image points, returned as an *M*-by-2 matrix of *M* [*x*,*y*] point coordinates.

See Also

Apps
Camera Calibrator | **Stereo Camera Calibrator**

Functions
cameraParameters | estimateCameraParameters | extrinsics | fisheyeIntrinsics | undistortImage | undistortPoints

Introduced in R2016b

toStruct

Convert a camera parameters object into a struct

Syntax

```
paramStruct = toStruct(cameraParams)
```

Description

`paramStruct = toStruct(cameraParams)` returns a struct containing the camera parameters in the `cameraParams` input object. You can use the struct to create an identical `cameraParameters` object. Use the struct for C code generation. You can call `toStruct`, and then pass the resulting structure into the generated code, which re-creates the `cameraParameters` object.

Input Arguments

cameraParams — Camera parameters
cameraParameters object

Camera parameters, specified as a `cameraParameters` object. The object contains the parameters for the camera.

Output Arguments

paramStruct — Camera parameters
struct

Camera parameters, returned as a struct.

See Also
cameraParameters

Topics

"Code Generation for Depth Estimation From Stereo Video"

Introduced in R2015a

displayErrors

Display standard errors of camera parameter estimates

Syntax

```
displayErrors(estimationErrors,cameraParams)
```

Description

`displayErrors(estimationErrors,cameraParams)` displays the camera parameters and corresponding standard errors.

Examples

Display Fisheye Camera Calibration Errors

Gather a set of checkerboard calibration images.

```
images = imageDatastore(fullfile(toolboxdir('vision'),'visiondata',...
 'calibration','gopro'));
```

Detect the calibration pattern from the images.

```
[imagePoints,boardSize] = detectCheckerboardPoints(images.Files);
```

Generate world coordinates for the corners of the checkerboard squares.

```
squareSize = 29; % millimeters
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the fisheye parameters using image and world points. Use the first image to get the image size. Also, store the errors from the calibration.

```
I = readimage(images,1);
imageSize = [size(I,1) size(I,2)];
```

```
[params,~,errors] = estimateFisheyeParameters(imagePoints, ...
                          worldPoints,imageSize);
```

Display the standard errors of the estimated camera parameters.

```
displayErrors(errors,params);
```

```
            Standard Errors of Estimated Camera Parameters
            ----------------------------------------------

Intrinsics
----------
Mapping coefficients:    [  875.0782 +/- 0.9451      -0.0003 +/- -0.0000      -0.0000
Distortion center (pixels):[ 1005.8165 +/- 0.6871     743.0346 +/- 0.5578  ]
Stretch matrix parameters:[    1.0000 +/- 0.0000       0.0000 +/- 0.0000        0.0000

Extrinsics
----------
Rotation vectors:
                          [   -0.0699 +/- 0.0010      -0.0267 +/- 0.0009       0.0258
                          [    0.3628 +/- 0.0010       0.2950 +/- 0.0009      -0.1967
                          [   -0.2159 +/- 0.0009       0.3442 +/- 0.0009      -0.1941
                          [    0.0282 +/- 0.0009      -0.3784 +/- 0.0009       0.0829
                          [    0.0146 +/- 0.0008       0.4575 +/- 0.0009      -0.1215
                          [    0.6775 +/- 0.0008       0.1089 +/- 0.0008      -0.0386
                          [   -0.4936 +/- 0.0008       0.0063 +/- 0.0008       0.0486
                          [    0.3823 +/- 0.0008       0.2797 +/- 0.0008       0.1509
                          [    0.5171 +/- 0.0008      -0.3295 +/- 0.0008       0.0541
                          [   -0.1896 +/- 0.0008      -0.3543 +/- 0.0009       0.2637
                          [   -0.2911 +/- 0.0008       0.3680 +/- 0.0008      -0.1329

Translation vectors (mm):
                          [ -132.9182 +/- 0.1609     -82.6066 +/- 0.1356     195.1106
                          [ -178.9931 +/- 0.1905     -15.7750 +/- 0.1712     241.7126
                          [ -183.7957 +/- 0.2168     -56.7378 +/- 0.1884     269.9739
                          [  -17.6295 +/- 0.1315     -70.2875 +/- 0.1041     157.0826
                          [ -161.9824 +/- 0.1808     -46.9681 +/- 0.1569     228.4060
                          [ -122.4240 +/- 0.1309     -16.0260 +/- 0.1153     162.6247
                          [ -112.4268 +/- 0.1745    -125.5877 +/- 0.1428     212.8055
                          [ -148.7137 +/- 0.1387     -72.5409 +/- 0.1260     173.7615
                          [  -49.5392 +/- 0.0919     -24.8329 +/- 0.0745     104.3541
                          [   -3.4045 +/- 0.1274     -93.4074 +/- 0.1010     155.8247
                          [ -160.7344 +/- 0.1855     -51.9152 +/- 0.1600     234.4075
```

Input Arguments

`estimationErrors` — Standard errors of estimated parameters
`cameraCalibrationErrors` object | `fisheyeCalibrationErrors` object

Standard errors of estimated parameters, specified as a `cameraCalibrationErrors` or `fisheyeCalibrationErrors` object.

`cameraParams` — Camera parameters
`cameraParameters` object | `fisheyeParameters` object

Camera parameters, specified as a `cameraParameters` or `fisheyeParameters` object. These objects contain the intrinsic, extrinsic, and lens distortion parameters of a camera.

- To create a `cameraParameters`, use the `estimateCameraParameters` function or the **Camera Calibrator** app.
- To create a `fisheyeParameters`, use the `estimateFisheyeParameters` function.

See Also

Functions
`estimateCameraParameters` | `estimateFisheyeParameters`

Objects
`cameraParameters` | `fisheyeParameters`

Apps
Camera Calibrator

Introduced in R2017b

info

Information about specified video file

Syntax

```
S = info(videoFReader)
```

Description

`S = info(videoFReader)` returns a MATLAB structure, `S`, with information about the video file specified in the `Filename` property.

Input Arguments

videoFReader — Video file reader object
object (default)

Video file reader, specified as a `vision.VideoFileReader` System object.

Output Arguments

S — Information about input file
structure

Information about input file, returned as a structure. The fields and possible values for the structure `S` are described below:

Audio	Logical value indicating if the file has audio content.
Video	Logical value indicating if the file has video content.

VideoFrameRate	Frame rate of the video stream in frames per second. The value may vary from the actual frame rate of the recorded video, and takes into consideration any synchronization issues between audio and video streams when the file contains both audio and video content. This implies that video frames may be dropped if the audio stream leads the video stream by more than 1/(actual video frames per second).
VideoSize	Video size as a two-element numeric vector of the form: `[VideoWidthInPixels, VideoHeightInPixels]`
VideoFormat	Video signal format.

Introduced in R2012a

isDone

End-of-file status (logical)

Syntax

```
status = isDone(videoFReader)
```

Description

`status = isDone(videoFReader)` returns a logical value indicating that the `VideoFileReader` System object `videoFReader`, has reached the end of the multimedia file after playing it `PlayCount` number of times. After the object plays the file the number of times set by the `PlayCount` property, it sets the status to `true`.

Examples

Read and Play a Video File

Load the video using a video reader object.

```
videoFReader = vision.VideoFileReader('ecolicells.avi');
```

Create a video player object to play the video file.

```
videoPlayer = vision.VideoPlayer;
```
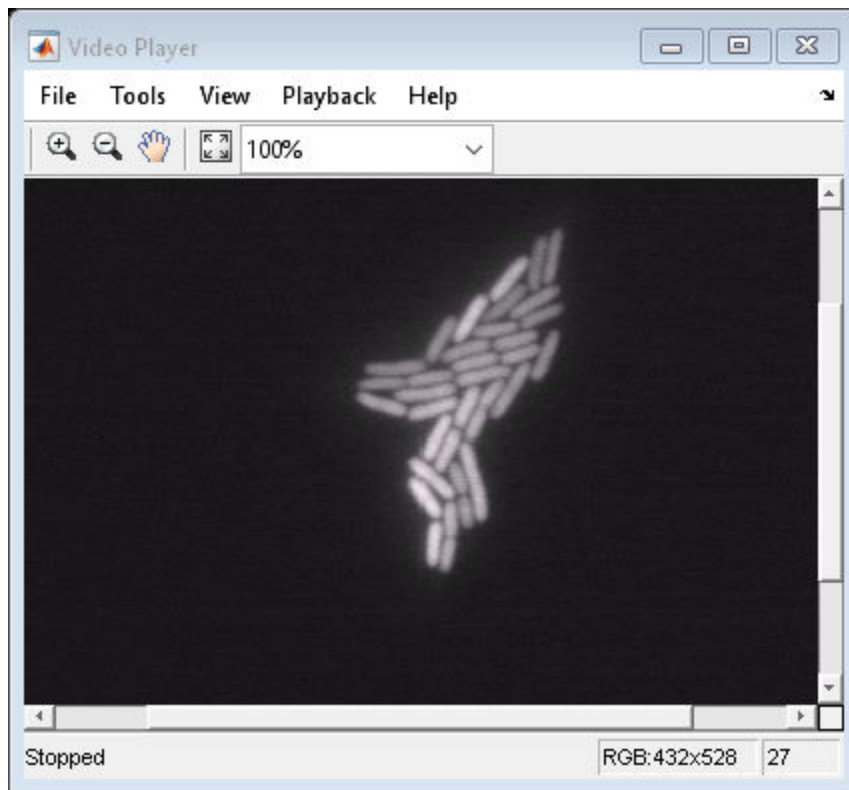
Use a while loop to read and play the video frames. Pause for 0.1 seconds after displaying each frame.

```
while ~isDone(videoFReader)
  videoFrame = videoFReader();
  videoPlayer(videoFrame);
  pause(0.1)
end
```

Release the objects.

```
release(videoPlayer);
```
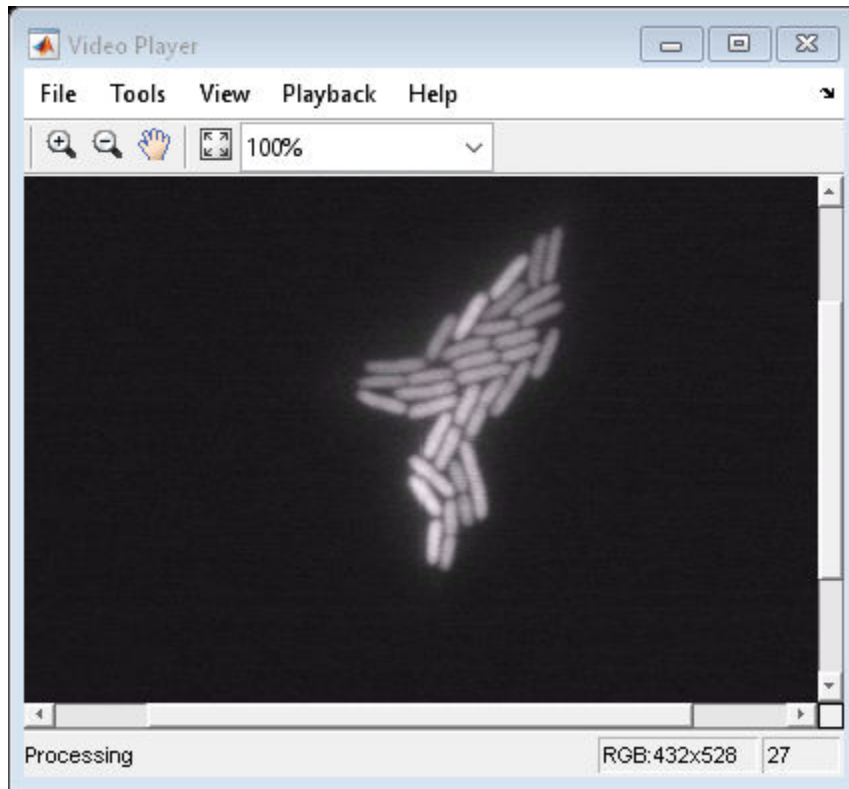
```
release(videoFReader);
```

Input Arguments

videoFReader — Video file reader object
object (default)

Video file reader, specified as a `vision.VideoFileReader` System object.

Output Arguments

status — Status of reader file
true | false

Status of reader file, returned as true or false.

Introduced in R2012a