Sensor Fusion and Tracking Toolbox™

Reference
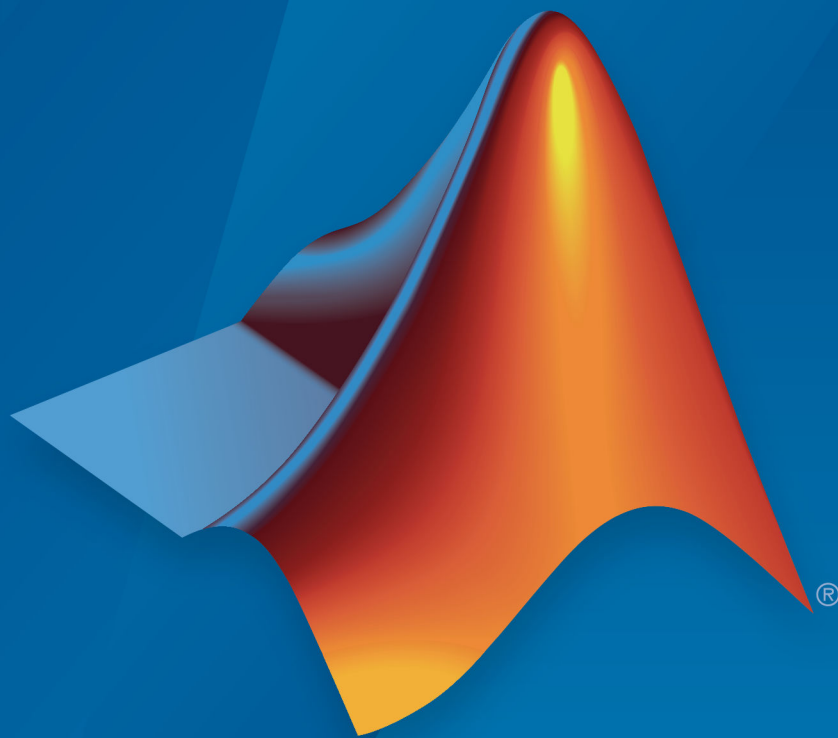
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Contents

Functions in Sensor Fusion and Tracking Toolbox

insfilter

Create inertial navigation filter

Syntax

```
filt = insfilter
filt = insfilter(Name,Value)
```

Description

`filt = insfilter` returns an inertial navigation filter object that estimates pose based on accelerometer, gyroscope, GPS, and magnetometer measurements.

`filt = insfilter(Name,Value)` returns an inertial navigation filter configured by the name-value pair arguments. The filter object can be a `MARGGPSFuser`, or an `NHConstrainedIMUGPSFuser`.

Examples

Creating Inertial Navigation Filters

Create a MARGGPSFuser

Create a `MARGGPSFuser` filter object with default properties.

```
filter = insfilter

filter =
  MARGGPSFuser with properties:

        IMUSampleRate: 100                  Hz
    ReferenceLocation: [0 0 0]              [deg deg m]
                State: [22x1 double]
       StateCovariance: [22x22 double]
```

```
Multiplicative Process Noise Variances
        GyroscopeNoise: [1e-09 1e-09 1e-09]        (rad/s)²
    AccelerometerNoise: [0.0001 0.0001 0.0001]    (m/s²)²
    GyroscopeBiasNoise: [1e-10 1e-10 1e-10]        (rad/s)²
AccelerometerBiasNoise: [0.0001 0.0001 0.0001]    (m/s²)²

Additive Process Noise Variances
 GeomagneticVectorNoise: [1e-06 1e-06 1e-06]     uT²
  MagnetometerBiasNoise: [0.1 0.1 0.1]            uT²
```

Create an NHConstrainedIMUGPSFuser

Create an `NHConstrainedIMUFuser` filter object with default properties.

```
filter = insfilter('NonholonomicHeading',true,'Magnetometer',false)
```

```
filter =
  NHConstrainedIMUGPSFuser with properties:

      IMUSampleRate: 100        Hz
  ReferenceLocation: [0 0 0]    [deg deg m]
   DecimationFactor: 2

  Extended Kalman Filter Values
            State: [16x1 double]
   StateCovariance: [16x16 double]

  Process Noise Variances
                GyroscopeNoise: [4.8e-06 4.8e-06 4.8e-06]    (rad/s)²
            AccelerometerNoise: [0.048 0.048 0.048]          (m/s²)²
            GyroscopeBiasNoise: [4e-14 4e-14 4e-14]          (rad/s)²
       GyroscopeBiasDecayFactor: 0.999
         AccelerometerBiasNoise: [4e-14 4e-14 4e-14]         (m/s²)²
  AccelerometerBiasDecayFactor: 0.9999

  Measurement Noise Variances
```

```
     ZeroVelocityConstraintNoise: 0.01    (m/s)²
```

Input Arguments

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 quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'NonholonomicHeading',true`

NonholonomicHeading — Create filter with nonholonomic heading constraints
`false` (default) | `true`

Create a filter with nonholonomic heading constraints, specified as the comma-separated pair of `'NonholonomicHeading'`, and `'true'` or `'false'`.

Data Types: `logical`

Magnetometer — Create filter with magnetometer input
`true` (default) | `false`

Create a filter that uses magnetometer readings, specified as the comma-separated pair of `'Magnetometer'`, and `'true'` or `'false'`.

Data Types: `logical`

Note `NonholonomicHeading` and `Magnetometer` parameters are mutually exclusive. If you set one parameter to `true`, you have to set the other parameter to `false`.

Output Arguments

`filt` — Inertial navigation filter
`MARGGPSFuser` (default) | `NHConstrainedIMUGPSFuser`

Inertial navigation filter, returned as a `MARGGPSFuser` or an `NHConstrainedIMUGPSFuser` object.

Output Filter Objects for Supported Configurations

NonholonomicHeading	Magnetometer	Filter Object	Filter Description
false	true	MARGGPSFuser	Pose estimation using an extended Kalman filter based on accelerometer, gyroscope, GPS, and magnetometer input.
true	false	NHConstrainedIMUGPSFuser	Pose estimation using an extended Kalman filter based on accelerometer, gyroscope, and GPS input with constraints on the velocity in the literal and vertical body axes.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
MARGGPSFuser | NHConstrainedIMUGPSFuser | ahrsfilter | imufilter

Topics
"Estimate Position and Orientation of a Ground Vehicle"

Introduced in R2018b

ecompass

Orientation from magnetometer and accelerometer readings

Syntax

```
orientation = ecompass(accelerometerReading,magnetometerReading)
orientation = ecompass(accelerometerReading,magnetometerReading,
orientationFormat)
```

Description

`orientation = ecompass(accelerometerReading,magnetometerReading)`
returns a `quaternion` that can rotate quantities from a parent (NED) frame to a child
(sensor) frame.

`orientation = ecompass(accelerometerReading,magnetometerReading,
orientationFormat)` specifies the orientation format as `quaternion` or rotation
matrix.

Examples

Determine Declination of Boston

Use the known magnetic field strength and proper acceleration of a device pointed true
north in Boston to determine the magnetic declination of Boston.

Define the known acceleration and magnetic field strength in Boston.

```
magneticFieldStrength = [19.535 -5.109 47.930];
properAcceleration = [0 0 9.8];
```

Pass the magnetic field strength and acceleration to the `ecompass` function. The
`ecompass` function returns a quaternion rotation operator. Convert the quaternion to
Euler angles in degrees.

```
q = ecompass(properAcceleration,magneticFieldStrength);
e = eulerd(q,'ZYX','frame');
```

The angle, `e`, represents the angle between true north and magnetic north in Boston. By convention, magnetic declination is negative when magnetic north is west of true north. Negate the angle to determine the magnetic declination.

```
magneticDeclinationOfBoston = -e(1)
```

```
magneticDeclinationOfBoston =

  -14.6563
```

Return Rotation Matrix

The `ecompass` function fuses magnetometer and accelerometer data to return a quaternion that, when used within a quaternion rotation operator, can rotate quantities from a parent (NED) frame to a child frame. The `ecompass` function can also return rotation matrices that perform equivalent rotations as the quaternion operator.

Define a rotation that can take a parent frame pointing to magnetic north to a child frame pointing to geographic north. Define the rotation as both a quaternion and a rotation matrix. Then, convert the quaternion and rotation matrix to Euler angles in degrees for comparison.

Define the magnetic field strength in microteslas in Boston, MA, when pointed true north.

```
m = [19.535 -5.109 47.930];
a = [0 0 9.8];
```

Determine the quaternion and rotation matrix that is capable of rotating a frame from magnetic north to true north. Display the results for comparison.

```
q = ecompass(a,m);
quaterionEulerAngles = eulerd(q,'ZYX','frame')

r = ecompass(a,m,'rotmat');
theta = -asin(r(1,3));
psi = atan2(r(2,3)/cos(theta),r(3,3)/cos(theta));
rho = atan2(r(1,2)/cos(theta),r(1,1)/cos(theta));
rotmatEulerAngles = rad2deg([rho,theta,psi])
```

```
quaterionEulerAngles =

   14.6563         0         0


rotmatEulerAngles =

   14.6563         0         0
```

Determine Gravity Vector

Use `ecompass` to determine the gravity vector based on data from a rotating IMU.

Load the inertial measurement unit (IMU) data.

```
load 'rpy_9axis.mat' sensorData Fs
```

Determine the orientation of the sensor body relative to the local NED frame over time.

```
orientation = ecompass(sensorData.Acceleration,sensorData.MagneticField);
```

To estimate the gravity vector, first rotate the accelerometer readings from the sensor body frame to the NED frame using the `orientation` quaternion vector.

```
gravityVectors = rotatepoint(orientation,sensorData.Acceleration);
```

Determine the gravity vector as an average of the recovered gravity vectors over time.

```
gravityVectorEstimate = mean(gravityVectors,1)
```

gravityVectorEstimate = *1×3*

```
   0.0000   -0.0000   10.2102
```

Track Spinning Platform

Fuse modeled accelerometer and gyroscope data to track a spinning platform using both idealized and realistic data.

Generate Ground-Truth Trajectory

Describe the ground-truth orientation of the platform over time. Use the `kinematicTrajectory` System object™ to create a trajectory for a platform that has no translation and spins about its *z*-axis.

```
duration = 12;
fs = 100;
numSamples = fs*duration;

accelerationBody = zeros(numSamples,3);

angularVelocityBody = zeros(numSamples,3);
zAxisAngularVelocity = [linspace(0,4*pi,4*fs),4*pi*ones(1,4*fs),linspace(4*pi,0,4*fs)]
angularVelocityBody(:,3) = zAxisAngularVelocity;

trajectory = kinematicTrajectory('SampleRate',fs);

[~,orientationNED,~,accelerationNED,angularVelocityNED] = trajectory(accelerationBody,
```

Model Receiving IMU Data

Use an `imuSensor` System object to mimic data received from an IMU that contains an ideal magnetometer and an ideal accelerometer.

```
IMU = imuSensor('accel-mag','SampleRate',fs);
[accelerometerData,magnetometerData] = IMU(accelerationNED, ...
                                           angularVelocityNED, ...
                                           orientationNED);
```

Fuse IMU Data to Estimate Orientation

Pass the accelerometer data and magnetometer data to the `ecompass` function to estimate orientation over time. Convert the orientation to Euler angles in degrees and plot the result.

```
orientation = ecompass(accelerometerData,magnetometerData);
orientationEuler = eulerd(orientation,'ZYX','frame');

timeVector = (0:numSamples-1).'/fs;

figure(1)
plot(timeVector,orientationEuler)
legend('z-axis','y-axis','x-axis')
xlabel('Time (s)')
```

```
ylabel('Rotation (degrees)')
title('Orientation from Ideal IMU')
```
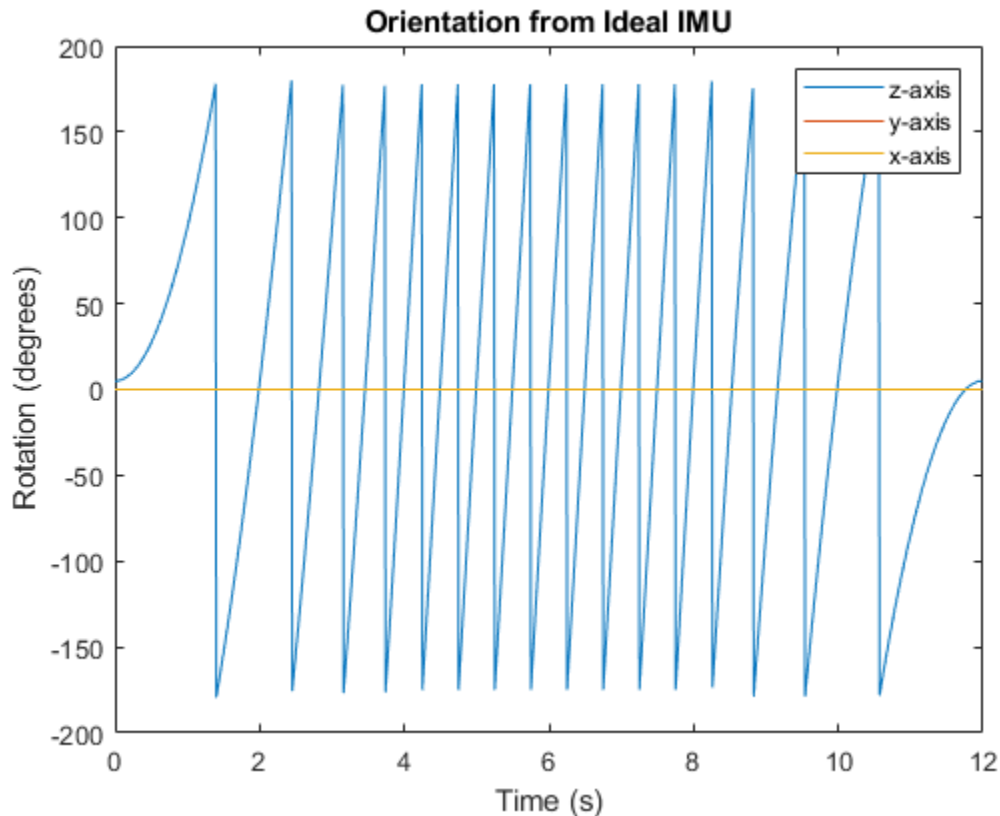

Repeat Experiment with Realistic IMU Sensor Model

Modify parameters of the IMU System object to approximate realistic IMU sensor data. Reset the IMU and then call it with the same ground-truth acceleration, angular velocity, and orientation. Use ecompass to fuse the IMU data and plot the results.

```
IMU.Accelerometer = accelparams( ...
    'MeasurementRange',20, ...
    'Resolution',0.0006, ...
    'ConstantBias',0.5, ...
    'AxesMisalignment',2, ...
```

```
    'NoiseDensity',0.004, ...
    'BiasInstability',0.5);
IMU.Magnetometer = magparams( ...
    'MeasurementRange',200, ...
    'Resolution',0.01);
reset(IMU)

[accelerometerData,magnetometerData] = IMU(accelerationNED,angularVelocityNED,orientat:

orientation = ecompass(accelerometerData,magnetometerData);
orientationEuler = eulerd(orientation,'ZYX','frame');

figure(2)
plot(timeVector,orientationEuler)
legend('z-axis','y-axis','x-axis')
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation from Realistic IMU')
```

Orientation from Realistic IMU
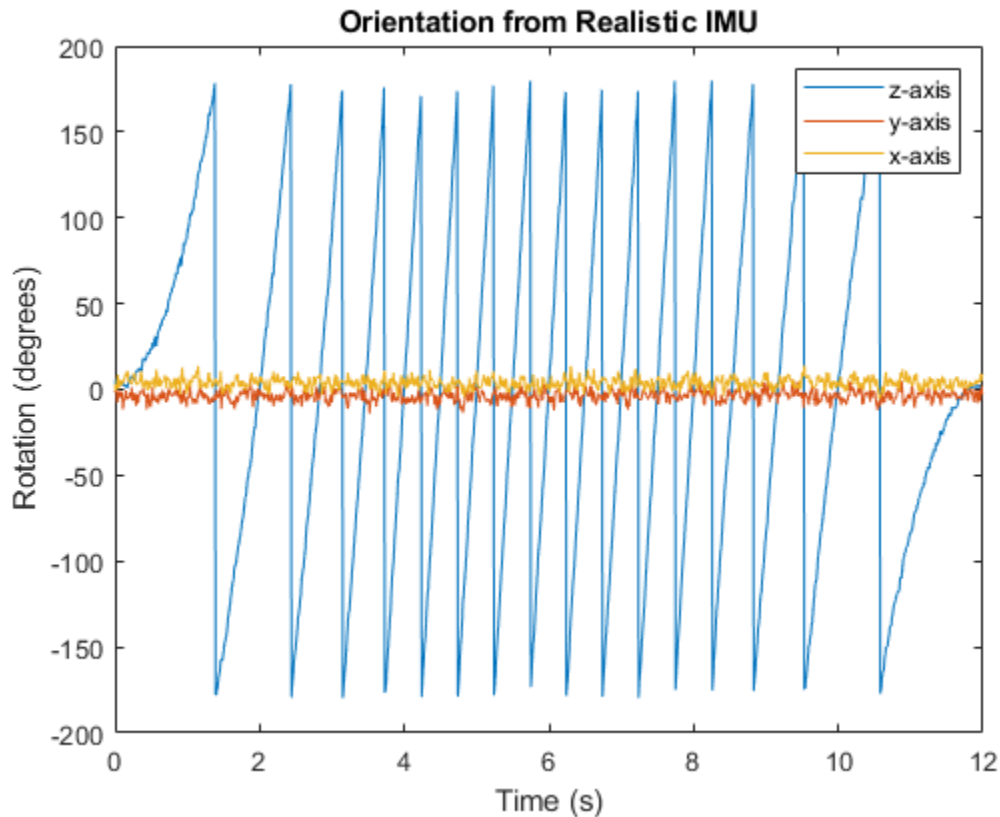
Input Arguments

accelerometerReading — Accelerometer readings in sensor body coordinate system (m/s²)
N-by-3 matrix

Accelerometer readings in sensor body coordinate system in m/s², specified as an *N*-by-3 matrix. The columns of the matrix correspond to the *x*-, *y*-, and *z*-axes of the sensor body. The rows in the matrix, *N*, correspond to individual samples. The accelerometer readings are normalized before use in the function.

Data Types: `single` | `double`

magnetometerReading — Magnetometer readings in sensor body coordinate system (µT)
N-by-3 matrix

Magnetometer readings in sensor body coordinate system in µT, specified as an *N*-by-3 matrix. The columns of the matrix correspond to the *x*-, *y*-, and *z*-axes of the sensor body. The rows in the matrix, *N*, correspond to individual samples. The magnetometer readings are normalized before use in the function.

Data Types: `single` | `double`

orientationFormat — Format used to describe orientation
`'quaternion'` (default) | `'rotmat'`

Format used to describe orientation, specified as `'quaternion'` or `'rotmat'`.

Data Types: `char` | `string`

Output Arguments

orientation — Orientation that rotates quantities from global coordinate system to sensor body coordinate system
N-by-1 vector of quaternions (default) | 3-by-3-by-*N* array

Orientation that can rotate quantities from a global coordinate system to a body coordinate system, returned as a vector of quaternions or an array. The size and type of the `orientation` depends on the format used to describe orientation:

- `'quaternion'` –– *N*-by-1 vector of quaternions with the same underlying data type as the input
- `'rotmat'` –– 3-by-3-by-*N* array the same data type as the input

Data Types: `quaternion` | `single` | `double`

Algorithms

The `ecompass` function returns a quaternion or rotation matrix that can rotate quantities from a parent (NED) frame to a child (sensor) frame. For both output orientation formats, the rotation operator is determined by computing the rotation matrix.

The rotation matrix is first calculated with an intermediary:

$$R = \begin{bmatrix} (a \times m) \times a & a \times m & a \end{bmatrix}$$

and then normalized column-wise. a and m are the `accelerometerReading` input and the `magnetometerReading` input, respectively.

To understand the rotation matrix calculation, consider an arbitrary point on the Earth and its corresponding local NED frame. Assume a sensor body frame, [x,y,z], with the same origin.
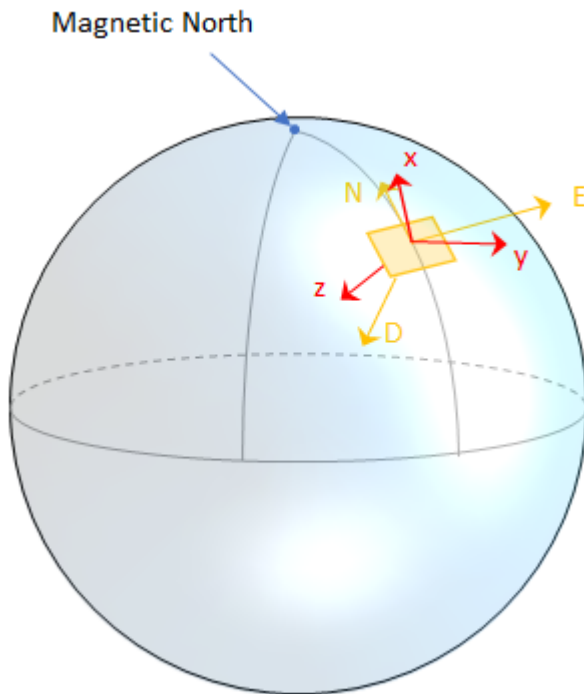
Recall that orientation of a sensor body is defined as the rotation operator (rotation matrix or quaternion) required to rotate a quantity from a parent (NED) frame to a child (sensor body) frame:

$$
\begin{bmatrix} & & \\ & R & \\ & & \end{bmatrix}
\begin{bmatrix} \\ p_{\text{parent}} \\ \end{bmatrix}
=
\begin{bmatrix} \\ p_{\text{child}} \\ \end{bmatrix}
$$

where

- R is a 3-by-3 rotation matrix, which can be interpreted as the orientation of the child frame.
- p_{parent} is a 3-by-1 vector in the parent frame.
- p_{child} is a 3-by-1 vector in the child frame.

For a stable sensor body, an accelerometer returns the acceleration due to gravity. If the sensor body is perfectly aligned with the NED coordinate system, all acceleration due to gravity is along the z-axis, and the accelerometer reads [0 0 1]. Consider the rotation matrix required to rotate a quantity from the NED coordinate system to a quantity indicated by the accelerometer.
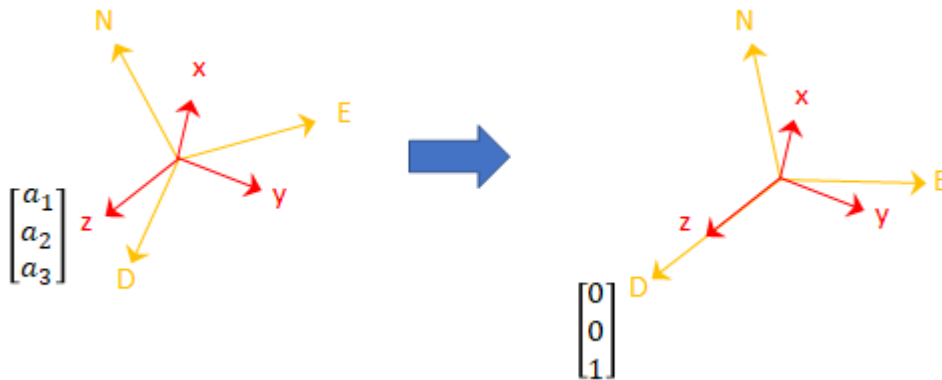
$$
\begin{bmatrix} r_{11} & r_{21} & r_{31} \\ r_{12} & r_{22} & r_{32} \\ r_{13} & r_{23} & r_{33} \end{bmatrix}
\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}
=
\begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}
$$

The third column of the rotation matrix corresponds to the accelerometer reading:

$$
\begin{bmatrix} r_{31} \\ r_{32} \\ r_{33} \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}
$$

A magnetometer reading points toward magnetic north and is in the *N-D* plane. Again, consider a sensor body frame aligned with the NED coordinate system.
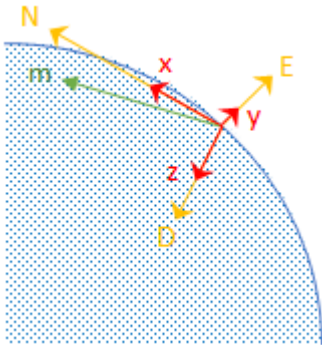
By definition, the *E*-axis is perpendicular to the *N-D* plane, therefore $N \times D = E$, within some amplitude scaling. If the sensor body frame is aligned with NED, both the acceleration vector from the accelerometer and the magnetic field vector from the magnetometer lie in the *N-D* plane. Therefore $m \times a = y$, again with some amplitude scaling.

Consider the rotation matrix required to rotate NED to the child frame, [*x y z*].
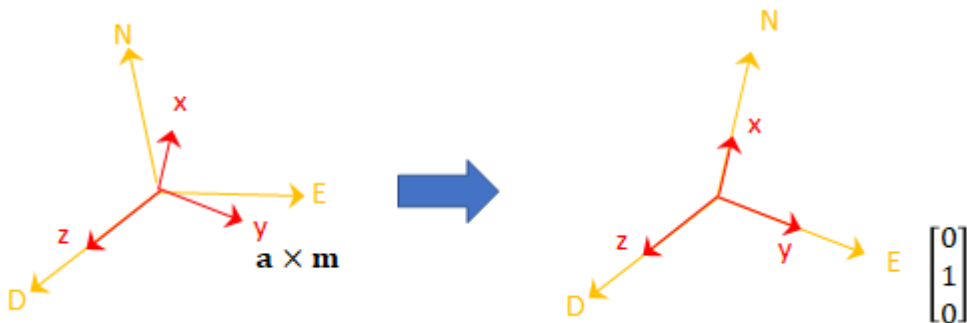
$$\begin{bmatrix} r_{11} & r_{21} & r_{31} \\ r_{12} & r_{22} & r_{32} \\ r_{13} & r_{23} & r_{33} \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \times \begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix}$$

The second column of the rotation matrix corresponds to the cross product of the accelerometer reading and the magnetometer reading:

$$\begin{bmatrix} r_{21} \\ r_{22} \\ r_{23} \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \times \begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix}$$

By definition of a rotation matrix, column 1 is the cross product of columns 2 and 3:

$$\begin{bmatrix} r_{11} \\ r_{12} \\ r_{13} \end{bmatrix} = \begin{bmatrix} r_{21} \\ r_{22} \\ r_{23} \end{bmatrix} \times \begin{bmatrix} r_{31} \\ r_{32} \\ r_{33} \end{bmatrix}$$
$$= (a \times m) \times a$$

Finally, the rotation matrix is normalized column-wise:

$$R_{ij} = \frac{R_{ij}}{\sqrt{\sum_{i=1}^{3} R_{ij}^2}} \quad , \ \forall j$$

Note The `ecompass` algorithm uses magnetic north, not true north, for the NED coordinate system.

References

[1] Open Source Sensor Fusion. https://github.com/memsindustrygroup/Open-Source-Sensor-Fusion/tree/master/docs

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
ahrsfilter | imufilter | quaternion

Topics
"Determine Orientation Using Inertial Sensors"

Introduced in R2018b

rotvecd

Convert quaternion to rotation vector (degrees)

Syntax

```
rotationVector = rotvecd(quat)
```

Description

`rotationVector = rotvecd(quat)` converts the quaternion array, `quat`, to an *N*-by-3 matrix of equivalent rotation vectors in degrees. The elements of `quat` are normalized before conversion.

Examples

Convert Quaternion to Rotation Vector in Degrees

Convert a random quaternion scalar to a rotation vector in degrees.

```
quat = quaternion(randn(1,4));
rotvecd(quat)
```

ans = *1×3*

   96.6345 -119.0274   45.4312

Input Arguments

quat — Quaternion to convert
scalar | vector | matrix | multidimensional array

Quaternion to convert, specified as scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

Output Arguments

`rotationVector` — Rotation vector (degrees)
N-by-3 matrix

Rotation vector representation, returned as an *N*-by-3 matrix of rotation vectors, where each row represents the [*x y z*] angles of the rotation vectors in degrees. The *i*th row of `rotationVector` corresponds to the element `quat(i)`.

The data type of the rotation vector is the same as the underlying data type of `quat`.

Data Types: `single` | `double`

Algorithms

All rotations in 3-D can be represented by four elements: a three-element axis of rotation and a rotation angle. If the rotation axis is constrained to be unit length, the rotation angle can be distributed over the vector elements to reduce the representation to three elements.

Recall that a quaternion can be represented in axis-angle form

$$q = \cos\left(\frac{\theta}{2}\right) + \sin\left(\frac{\theta}{2}\right)(x\mathrm{i} + y\mathrm{j} + z\mathrm{k}),$$

where θ is the angle of rotation in degrees, and [*x,y,z*] represent the axis of rotation.

Given a quaternion of the form

$$q = a + bi + cj + dk\,,$$

you can solve for the rotation angle using the axis-angle form of quaternions:

$$\theta = 2\cos^{-1}\left(a\right).$$

Assuming a normalized axis, you can rewrite the quaternion as a rotation vector without loss of information by distributing θ over the parts b, c, and d. The rotation vector representation of q is

$$q_{rv} = \frac{\theta}{\sin\left(\theta/2\right)} \, [b, \ c, \ d] \, .$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
euler | eulerd | rotvec

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

eulerd

Convert quaternion to Euler angles (degrees)

Syntax

```
eulerAngles = eulerd(quat,rotationSequence,rotationType)
```

Description

`eulerAngles = eulerd(quat,rotationSequence,rotationType)` converts the quaternion, `quat`, to an *N*-by-3 matrix of Euler angles in degrees.

Examples

Convert Quaternion to Euler Angles in Degrees

Convert a quaternion frame rotation to Euler angles in degrees using the 'ZYX' rotation sequence.

```
quat = quaternion([0.7071 0.7071 0 0]);
eulerAnglesDegrees = eulerd(quat,'ZYX','frame')
```

eulerAnglesDegrees = *1×3*

```
     0        0   90.0000
```

Input Arguments

quat — Quaternion to convert to Euler angles
scalar | vector | matrix | multidimensional array

Quaternion to convert to Euler angles, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

rotationSequence — Rotation sequence
`'ZYX'` | `'ZYZ'` | `'ZXY'` | `'ZXZ'` | `'YXZ'` | `'YXY'` | `'YZX'` | `'XYZ'` | `'XYX'` | `'XZY'` | `'XZX'`

Rotation sequence of Euler angle representation, specified as a character vector or string.

The rotation sequence defines the order of rotations about the axes. For example, if you specify a rotation sequence of `'YZX'`:

1   The first rotation is about the *y*-axis.
2   The second rotation is about the new *z*-axis.
3   The third rotation is about the new *x*-axis.

Data Types: `char` | `string`

rotationType — Type of rotation
`'point'` | `'frame'`

Type of rotation, specified as `'point'` or `'frame'`.

In a point rotation, the frame is static and the point moves. In a frame rotation, the point is static and the frame moves. Point rotation and frame rotation define equivalent angular displacements but in opposite directions.

Data Types: char | string

Output Arguments

eulerAngles — Euler angle representation (degrees)
N-by-3 matrix

Euler angle representation in degrees, returned as a *N*-by-3 matrix. *N* is the number of quaternions in the `quat` argument.

For each row of `eulerAngles`, the first column corresponds to the first axis in the rotation sequence, the second column corresponds to the second axis in the rotation sequence, and the third column corresponds to the third axis in the rotation sequence.

The data type of the Euler angles representation is the same as the underlying data type of `quat`.

Data Types: single | double

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
euler | rotateframe | rotatepoint

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

meanrot

Quaternion mean rotation

Syntax

```
quatAverage = meanrot(quat)
quatAverage = meanrot(quat,dim)
quatAverage = meanrot( ___ ,nanflag)
```

Description

quatAverage = meanrot(quat) returns the average rotation of the elements of quat along the first array dimension whose size not does equal 1.

- If quat is a vector, meanrot(quat) returns the average rotation of the elements.

- If quat is a matrix, meanrot(quat) returns a row vector containing the average rotation of each column.

- If quat is a multidimensional array, then mearot(quat) operates along the first array dimension whose size does not equal 1, treating the elements as vectors. This dimension becomes 1 while the sizes of all other dimensions remain the same.

The meanrot function normalizes the input quaternions, quat, before calculating the mean.

quatAverage = meanrot(quat,dim) return the average rotation along dimension dim. For example, if quat is a matrix, then meanrot(quat,2) is a column vector containing the mean of each row.

quatAverage = meanrot(___ ,nanflag) specifies whether to include or omit NaN values from the calculation for any of the previous syntaxes.
meanrot(quat,'includenan') includes all NaN values in the calculation while mean(quat,'omitnan') ignores them.

Examples

Quaternion Mean Rotation

Create a matrix of quaternions corresponding to three sets of Euler angles.

```
eulerAngles = [40 20 10; ...
               50 10 5; ...
               45 70 1];

quat = quaternion(eulerAngles,'eulerd','ZYX','frame');
```

Determine the average rotation represented by the quaternions. Convert the average rotation to Euler angles in degrees for readability.

```
quatAverage = meanrot(quat)
eulerAverage = eulerd(quatAverage,'ZYX','frame')


quatAverage =

  quaternion


     0.88863 - 0.062598i +  0.27822j +  0.35918k


eulerAverage =

   45.7876   32.6452    6.0407
```

Average Out Rotational Noise

Use `meanrot` over a sequence of quaternions to average out additive noise.

Create a vector of 1e6 quaternions whose distance, as defind by the `dist` fucntion, from quaternion(1,0,0,0) is normally distributed. Plot the Euler angles corresponding to the noisy quaternion vector.

```
nrows = 1e6;
ax = 2*rand(nrows,3) - 1;
```

```
ax = ax./sqrt(sum(ax.^2,2));
ang = 0.5*randn(size(ax,1),1);
q = quaternion(ax.*ang ,'rotvec');

noisyEulerAngles = eulerd(q,'ZYX','frame');

figure(1)

subplot(3,1,1)
plot(noisyEulerAngles(:,1))
title('Z-Axis')
ylabel('Rotation (degrees)')
hold on

subplot(3,1,2)
plot(noisyEulerAngles(:,2))
title('Y-Axis')
ylabel('Rotation (degrees)')
hold on

subplot(3,1,3)
plot(noisyEulerAngles(:,3))
title('X-Axis')
ylabel('Rotation (degrees)')
hold on
```
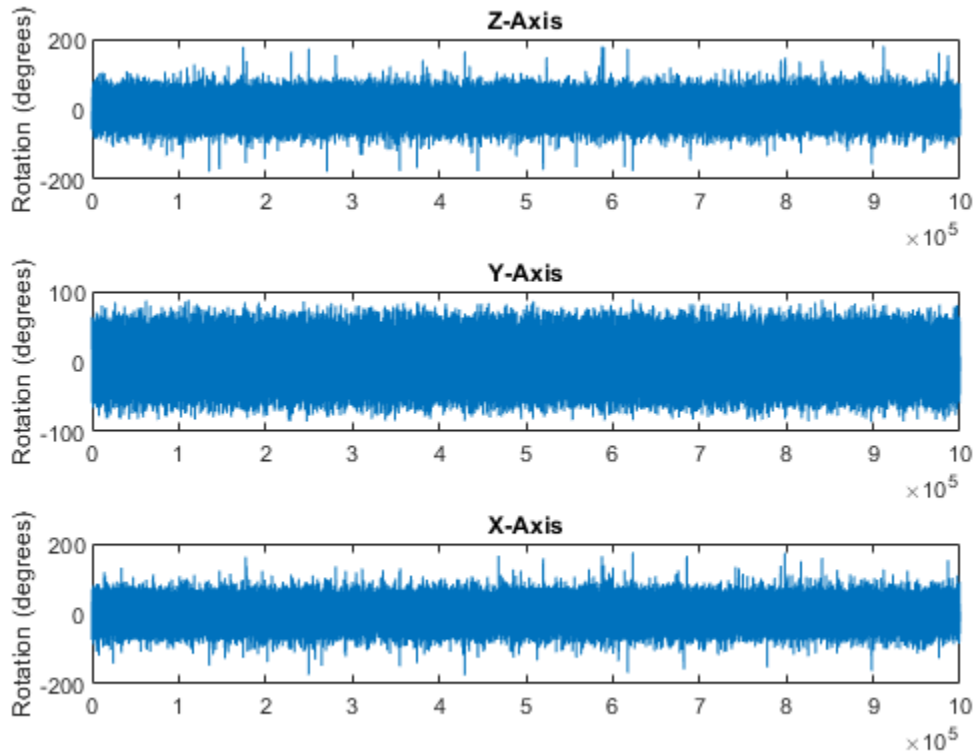
Use `meanrot` to determine the average quaternion given the vector of quaternions. Convert to Euler angles and plot the results.

```
qAverage = meanrot(q);

qAverageInEulerAngles = eulerd(qAverage,'ZYX','frame');

figure(1)

subplot(3,1,1)
plot(ones(nrows,1)*qAverageInEulerAngles(:,1))
title('Z-Axis')

subplot(3,1,2)
```

```
plot(ones(nrows,1)*qAverageInEulerAngles(:,2))
title('Y-Axis')

subplot(3,1,3)
plot(ones(nrows,1)*qAverageInEulerAngles(:,3))
title('X-Axis')
```
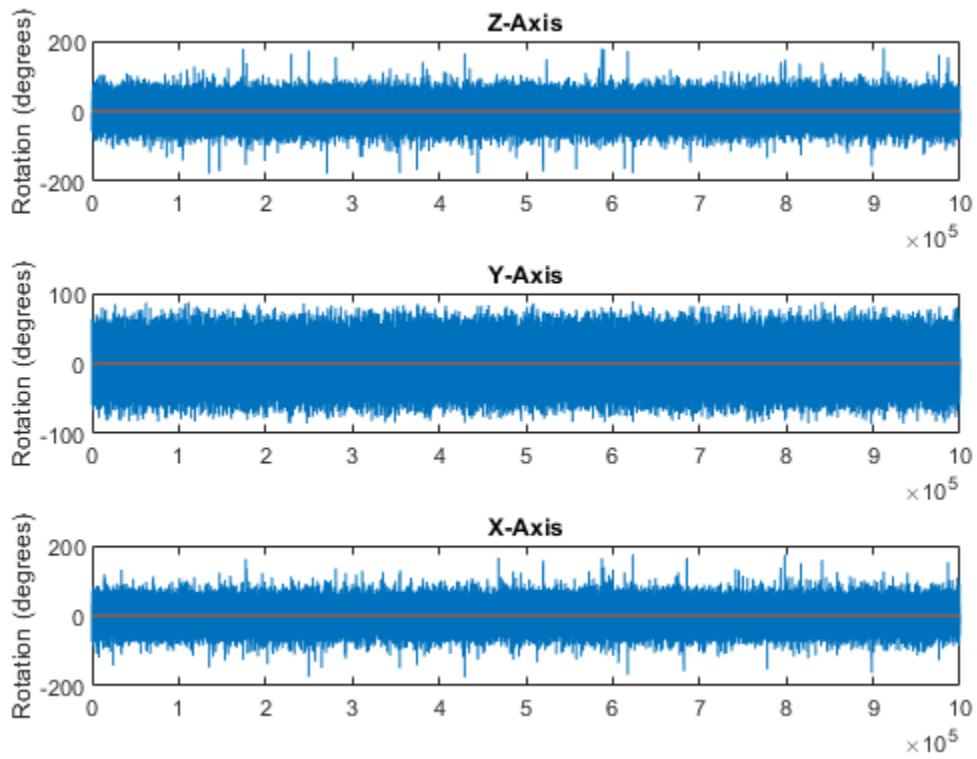
The `meanrot` Algorithm and Limitations

The `meanrot` Algorithm

The `meanrot` function outputs a quaternion that minimizes the squared Frobenius norm of the difference between rotation matrices. Consider two quaternions:

- `q0` represents no rotation.
- `q90` represents a 90 degree rotation about the *x*-axis.

```
q0 = quaternion([0 0 0],'eulerd','ZYX','frame');
q90 = quaternion([0 0 90],'eulerd','ZYX','frame');
```

Create a quaternion sweep, `qSweep`, that represents rotations from 0 to 180 degrees about the *x*-axis.

```
eulerSweep = (0:1:180)';
qSweep = quaternion([zeros(numel(eulerSweep),2),eulerSweep], ...
    'eulerd','ZYX','frame');
```

Convert `q0`, `q90`, and `qSweep` to rotation matrices. In a loop, calculate the metric to minimize for each member of the quaternion sweep. Plot the results and return the value of the Euler sweep that corresponds to the minimum of the metric.

```
r0    = rotmat(q0,'frame');
r90   = rotmat(q90,'frame');
rSweep = rotmat(qSweep,'frame');

metricToMinimize = zeros(size(rSweep,3),1);
for i = 1:numel(qSweep)
    metricToMinimize(i) = norm((rSweep(:,:,i) - r0),'fro').^2 + ...
                          norm((rSweep(:,:,i) - r90),'fro').^2;
end

plot(eulerSweep,metricToMinimize)
xlabel('Euler Sweep (degrees)')
ylabel('Metric to Minimize')

[~,eulerIndex] = min(metricToMinimize);
eulerSweep(eulerIndex)
```

```
ans =
```

45
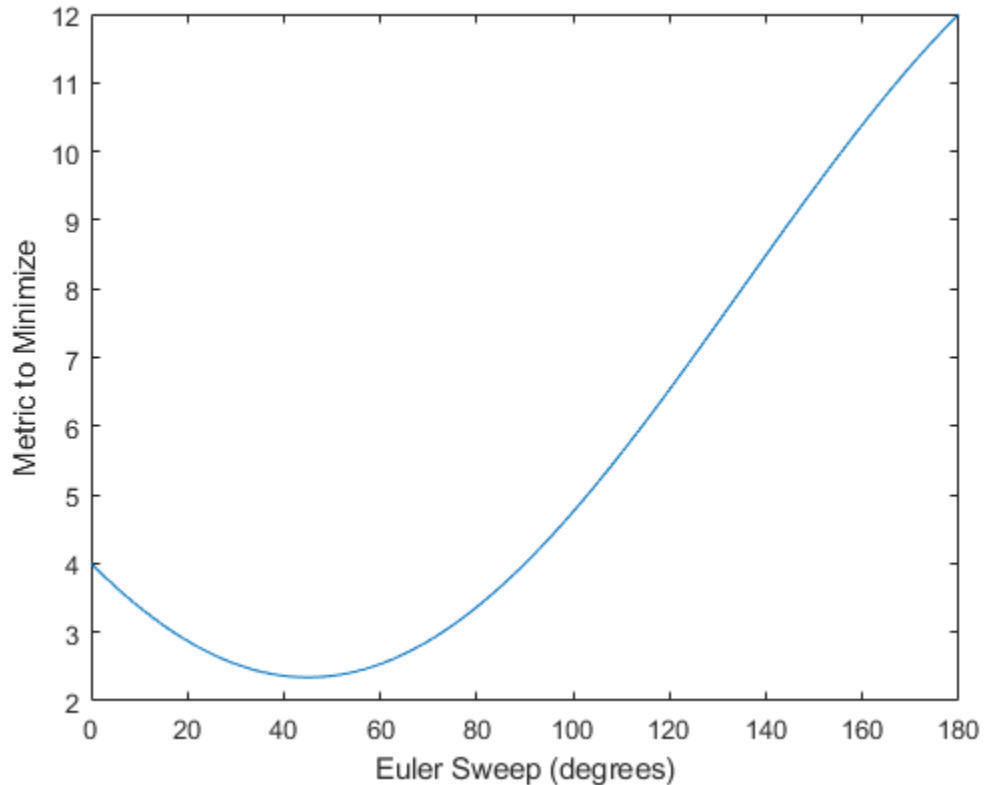
The minimum of the metric corresponds to the Euler angle sweep at 45 degrees. That is, `meanrot` defines the average between `quaterion([0 0 0],'ZYX','frame')` and `quaternion([0 0 90],'ZYX','frame')` as `quaternion([0 0 45],'ZYX','frame')`. Call `meanrot` with `q0` and `q90` to verify the same result.

```
eulerd(meanrot([q0,q90]),'ZYX','frame')
```

ans =

```
         0         0   45.0000
```

Limitations

The metric that `meanrot` uses to determine the mean rotation is not unique for quaternions significantly far apart. Repeat the experiment above for quaternions that are separated by 180 degrees.

```
q180 = quaternion([0 0 180],'eulerd','ZYX','frame');
r180 = rotmat(q180,'frame');

for i = 1:numel(qSweep)
    metricToMinimize(i) = norm((rSweep(:,:,i) - r0),'fro').^2 + ...
                          norm((rSweep(:,:,i) - r180),'fro').^2;
end

plot(eulerSweep,metricToMinimize)
xlabel('Euler Sweep (degrees)')
ylabel('Metric to Minimize')

[~,eulerIndex] = min(metricToMinimize);
eulerSweep(eulerIndex)
```

```
ans =

   159
```
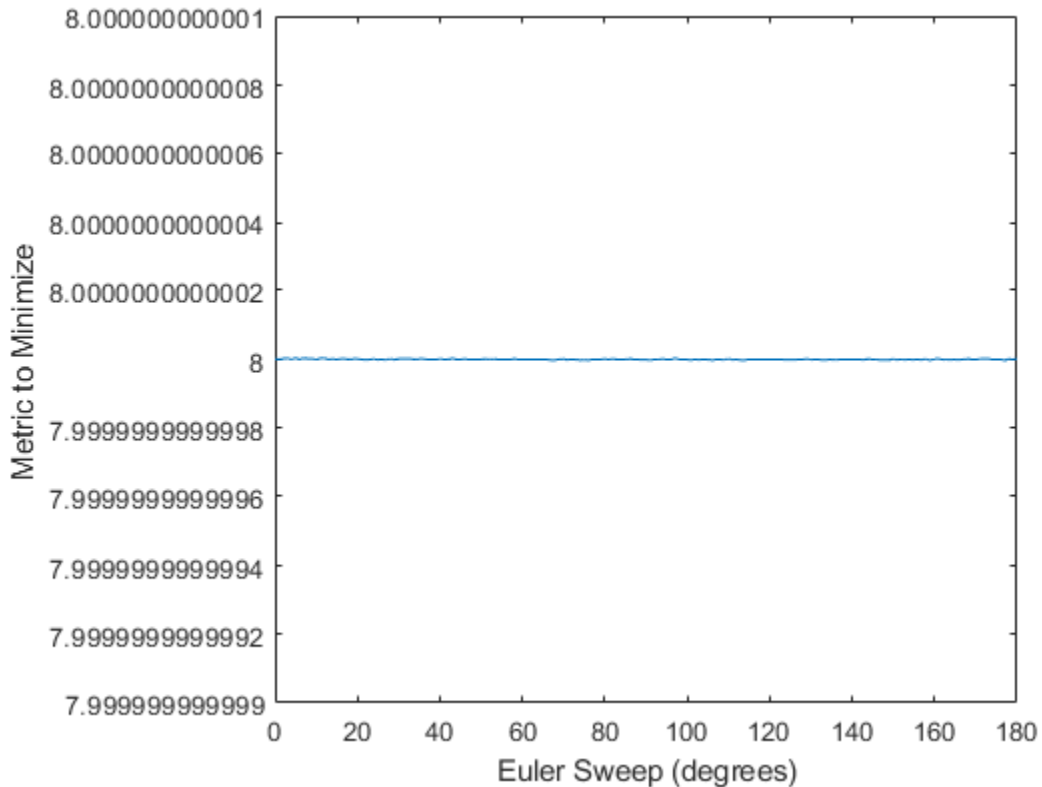
Quaternion means are usually calculated for rotations that are close to each other, which makes the edge case shown in this example unlikely in real-world applications. To average two quaternions that are significantly far apart, use the `slerp` function. Repeat the experiment using `slerp` and verify that the quaternion mean returned is more intuitive for large distances.

```
qMean = slerp(q0,q180,0.5);
q0_q180 = eulerd(qMean,'ZYX','frame')
```

```
q0_q180 =
```

```
           0           0    90.0000
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion for which to calculate the mean, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

dim — Dimension to operate along
positive integer scalar

Dimension to operate along, specified as a positive integer scalar. If no value is specified, then the default is the first array dimension whose size does not equal 1.

Dimension `dim` indicates the dimension whose length reduces to 1. The `size(quatAverage,dim)` is `1`, while the sizes of all other dimensions remain the same.

Data Types: `double` | `single`

nanflag — NaN condition
`'includenan'` (default) | `'omitnan'`

NaN condition, specified as one of these values:

- `'includenan'` -- Include NaN values when computing the mean rotation, resulting in NaN.
- `'omitnan'` -- Ignore all NaN values in the input.

Data Types: `char` | `string`

Output Arguments

quatAverage — Quaternion average rotation
scalar | vector | matrix | multidimensional array

Quaternion average rotation, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `single` | `double`

Algorithms

`meanrot` determines a quaternion mean, $\overline{q}$, according to [1]. $\overline{q}$ is the quaternion that minimizes the squared Frobenius norm of the difference between rotation matrices:

$$\overline{q} = \arg \min_{q \in S^3} \sum_{i=1}^{n} \left\| A\left(q\right) - A\left(q_i\right) \right\|_F^2$$

References

[1] Markley, F. Landis, Yang Chen, John Lucas Crassidis, and Yaakov Oshman. "Average Quaternions." *Journal of Guidance, Control, and Dynamics*. Vol. 30, Issue 4, 2007, pp. 1193-1197.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`dist` | `slerp`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018b

slerp

Spherical linear interpolation

Syntax

```
q0 = slerp(q1,q2,T)
```

Description

`q0 = slerp(q1,q2,T)` spherically interpolates between `q1` and `q2` by the interpolation coefficient `T`.

Examples

Interpolate Between Two Quaternions

Create two quaternions with the following interpretation:

1 `a` = 45 degree rotation around the *z*-axis
2 `c` = -45 degree rotation around the *z*-axis

```
a = quaternion([45,0,0],'eulerd','ZYX','frame');
c = quaternion([-45,0,0],'eulerd','ZYX','frame');
```

Call `slerp` with the the quaternions `a` and `c` and specify an interpolation coefficient of 0.5.

```
interpolationCoefficient = 0.5;
```

```
b = slerp(a,c,interpolationCoefficient);
```

The output of `slerp`, `b`, represents an average rotation of `a` and `c`. To verify, convert `b` to Euler angles in degrees.

```
averageRotation = eulerd(b,'ZYX','frame')
```

```
averageRotation =

     0     0     0
```

The interpolation coefficient is specified as a normalized value between 0 and 1, inclusive. An interpolation coefficient of 0 corresponds to the a quaternion, and an interpolation coefficient of 1 corresponds to the c quaternion. Call slerp with coefficients 0 and 1 to confirm.

```
b = slerp(a,c,[0,1]);
eulerd(b,'ZYX','frame')
```

```
ans =

   45.0000        0        0
  -45.0000        0        0
```

You can create smooth paths between quaternions by specifying arrays of equally spaced interpolation coefficients.

```
path = 0:0.1:1;
```

```
interpolatedQuaternions = slerp(a,c,path);
```

For quaternions that represent rotation only about a single axis, specifying interpolation coefficients as equally spaced results in quaternions equally spaced in Euler angles. Convert interpolatedQuaternions to Euler angles and verify that the difference between the angles in the path is constant.

```
k = eulerd(interpolatedQuaternions,'ZYX','frame');
abc = abs(diff(k))
```

```
abc =

    9.0000        0        0
    9.0000        0        0
    9.0000        0        0
    9.0000        0        0
    9.0000        0        0
    9.0000        0        0
```

```
    9.0000          0          0
    9.0000          0          0
    9.0000          0          0
    9.0000          0          0
```

Alternatively, you can use the `dist` function to verify that the distance between the interpolated quaternions is consistent. The `dist` function returns angular distance in radians; convert to degrees for easy comparison.

```
def = rad2deg(dist(interpolatedQuaternions(2:end),interpolatedQuaternions(1:end-1)))
```

```
def =

  Columns 1 through 7

    9.0000    9.0000    9.0000    9.0000    9.0000    9.0000    9.0000

  Columns 8 through 10

    9.0000    9.0000    9.0000
```

SLERP Minimizes Great Circle Path

The SLERP algorithm interpolates along a great circle path connecting two quaternions. This example shows how the SLERP algorithm minimizes the great circle path.

Define three quaternions:

1 q0 - quaternion indicating no rotation from the global frame
2 q179 - quaternion indicating a 179 degree rotation about the *z*-axis
3 q180 - quaternion indicating a 180 degree rotation about the *z*-axis
4 q181 - quaternion indicating a 181 degree rotation about the *z*-axis

```
q0 = ones(1,'quaternion');

q179 = quaternion([179,0,0],'eulerd','ZYX','frame');

q180 = quaternion([180,0,0],'eulerd','ZYX','frame');
```

1-41

```
q181 = quaternion([181,0,0],'eulerd','ZYX','frame');
```

Use `slerp` to interpolate between `q0` and the three quaternion rotations. Specify that the paths are traveled in 10 steps.

```
T = linspace(0,1,10);

q179path = slerp(q0,q179,T);
q180path = slerp(q0,q180,T);
q181path = slerp(q0,q181,T);
```

Plot each path in terms of Euler angles in degrees.

```
q179pathEuler = eulerd(q179path,'ZYX','frame');
q180pathEuler = eulerd(q180path,'ZYX','frame');
q181pathEuler = eulerd(q181path,'ZYX','frame');

plot(T,q179pathEuler(:,1),'bo', ...
     T,q180pathEuler(:,1),'r*', ...
     T,q181pathEuler(:,1),'gd');
legend('Path to 179 degrees', ...
       'Path to 180 degrees', ...
       'Path to 181 degrees')
xlabel('Interpolation Coefficient')
ylabel('Z-Axis Rotation (Degrees)')
```
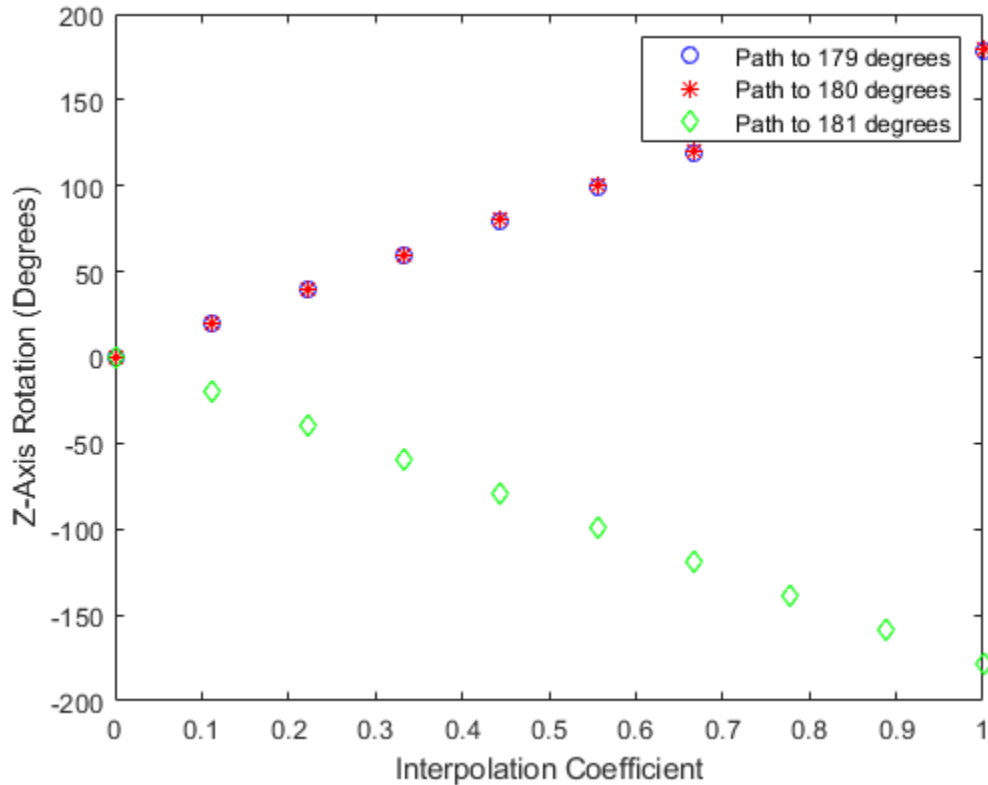
The path between `q0` and `q179` is clockwise to minimize the great circle distance. The path between `q0` and `q181` is counterclockwise to minimize the great circle distance. The path between `q0` and `q180` can be either clockwise or counterclockwise, depending on numerical rounding.

Input Arguments

q1 — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion to interpolate, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

q1, q2, and T must have compatible sizes. In the simplest cases, they can be the same size or any one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are either the same or one of them is 1.

Data Types: `quaternion`

q2 — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion to interpolate, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

q1, q2, and T must have compatible sizes. In the simplest cases, they can be the same size or any one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are either the same or one of the dimension sizes is 1.

Data Types: `quaternion`

T — Interpolation coefficient
scalar | vector | matrix | multidimensional array

Interpolation coefficient, specified as a scalar, vector, matrix, or multidimensional array of numbers with each element in the range [0,1].

q1, q2, and T must have compatible sizes. In the simplest cases, they can be the same size or any one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are either the same or one of the dimension sizes is 1.

Data Types: `single` | `double`

Output Arguments

q0 — Interpolated quaternion
scalar | vector | matrix | multidimensional array

Interpolated quaternion, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Quaternion **s**pherical **l**inear int**erp**olation (SLERP) is an extension of linear interpolation along a plane to spherical interpolation in three dimensions. The algorithm was first proposed in [1]. Given two quaternions, q_1 and q_2, SLERP interpolates a new quaternion, q_0, along the great circle that connects q_1 and q_2. The interpolation coefficient, T, determines how close the output quaternion is to either q_1 and q_2.

The SLERP algorithm can be described in terms of sinusoids:

$$q_0 = \frac{\sin\left((1 - T)\theta\right)}{\sin\left(\theta\right)} q_1 + \frac{\sin\left(T\theta\right)}{\sin\left(\theta\right)} q_2$$

where q_1 and q_2 are normalized quaternions, and θ is half the angular distance between q_1 and q_2.

References

[1] Shoemake, Ken. "Animating Rotation with Quaternion Curves." *ACM SIGGRAPH Computer Graphics* Vol. 19, Issue 3, 1985, pp. 345–354.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
dist | meanrot

Objects
quaternion

Topics
"Lowpass Filter Orientation Using Quaternion SLERP"
"Rotations, Orientation and Quaternions"

Introduced in R2018b

classUnderlying

Class of parts within quaternion

Syntax

```
underlyingClass = classUnderlying(quat)
```

Description

`underlyingClass = classUnderlying(quat)` returns the name of the class of the parts of the quaternion `quat`.

Examples

Get Underlying Class of Quaternion

A quaternion is a four-part hyper-complex number used in three-dimensional representations. The four parts of the quaternion are of data type `single` or `double`.

Create two quaternions, one with an underlying data type of `single`, and one with an underlying data type of `double`. Verify the underlying data types by calling `classUnderlying` on the quaternions.

```
qSingle = quaternion(single([1,2,3,4]))

qSingle = quaternion
    1 + 2i + 3j + 4k


classUnderlying(qSingle)

ans =
'single'

qDouble = quaternion([1,2,3,4])
```

```
qDouble = quaternion
     1 + 2i + 3j + 4k
```

```
classUnderlying(qDouble)
```

```
ans =
'double'
```

You can separate quaternions into their parts using the `parts` function. Verify the parts of each quaternion are the correct data type. Recall that `double` is the default MATLAB® type.

```
[aS,bS,cS,dS] = parts(qSingle)
```

```
aS = single
    1
```

```
bS = single
    2
```

```
cS = single
    3
```

```
dS = single
    4
```

```
[aD,bD,cD,dD] = parts(qDouble)
```

```
aD = 1
```

```
bD = 2
```

```
cD = 3
```

```
dD = 4
```

Quaternions follow the same implicit casting rules as other data types in MATLAB. That is, a quaternion with underlying data type `single` that is combined with a quaternion with underlying data type `double` results in a quaternion with underlying data type `single`. Multiply `qDouble` and `qSingle` and verify the resulting underlying data type is `single`.

```
q = qDouble*qSingle;
classUnderlying(q)
```

```
ans =
'single'
```

Input Arguments

quat — Quaternion to investigate
scalar | vector | matrix | multi-dimensional array

Quaternion to investigate, specified as a quaternion or array of quaternions.

Data Types: `quaternion`

Output Arguments

underlyingClass — Underlying class of quaternion object
`'single'` | `'double'`

Underlying class of quaternion, returned as the character vector `'single'` or `'double'`.

Data Types: `char`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
compact | parts

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

compact

Convert quaternion array to *N*-by-4 matrix

Syntax

```
matrix = compact(quat)
```

Description

`matrix = compact(quat)` converts the quaternion array, `quat`, to an *N*-by-4 matrix. The columns are made from the four quaternion parts. The ith row of the matrix corresponds to `quat(i)`.

Examples

Convert Quaternion Array to Compact Representation of Parts

Create a scalar quaternion with random parts. Convert the parts to a 1-by-4 vector using `compact`.

```
randomParts = randn(1,4)
```

randomParts = *1×4*

```
    0.5377    1.8339   -2.2588    0.8622
```

```
quat = quaternion(randomParts)
```

quat = *quaternion*
```
    0.53767 +  1.8339i -  2.2588j + 0.86217k
```

```
quatParts = compact(quat)
```

1-51

```
quatParts = 1×4

   0.5377    1.8339   -2.2588    0.8622
```

Create a 2-by-2 array of quaternions, then convert the representation to a matrix of quaternion parts. The output rows correspond to the linear indices of the quaternion array.

```
quatArray = [quaternion([1:4;5:8]),quaternion([9:12;13:16])]

quatArray = 2x2 quaternion array
     1 +  2i +  3j +  4k       9 + 10i + 11j + 12k
     5 +  6i +  7j +  8k      13 + 14i + 15j + 16k
```

```
quatArrayParts = compact(quatArray)

quatArrayParts = 4×4

    1     2     3     4
    5     6     7     8
    9    10    11    12
   13    14    15    16
```

Input Arguments

quat — Quaternion to convert
scalar | vector | matrix | multidimensional array

Quaternion to convert, specified as scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: quaternion

Output Arguments

matrix — Quaternion in matrix form
N-by-4 matrix

Quaternion in matrix form, returned as an *N*-by-4 matrix, where N = `numel(quat)`.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`classUnderlying` | `parts`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

conj

Complex conjugate of quaternion

Syntax

```
quatConjugate = conj(quat)
```

Description

`quatConjugate = conj(quat)` returns the complex conjugate of the quaternion, `quat`.

If $q = a + bi + cj + dk$, the complex conjugate of q is

$q^* = a - bi - cj - dk$. Considered as a rotation operator, the conjugate performs the opposite rotation. For example,

```
q = quaternion(deg2rad([16 45 30]),'rotvec');
a = q*conj(q);
rotatepoint(a,[0,1,0])
```

```
ans =

     0     1     0
```

Examples

Complex Conjugate of Quaternion

Create a quaternion scalar and get the complex conjugate.

```
q = normalize(quaternion([0.9 0.3 0.3 0.25]))
```

```
q = quaternion
      0.87727 + 0.29242i + 0.29242j + 0.24369k
```

```
qConj = conj(q)
```

```
qConj = quaternion
      0.87727 - 0.29242i - 0.29242j - 0.24369k
```

Verify that a quaternion multiplied by its conjugate returns a quaternion one.

```
q*qConj
```

```
ans = quaternion
      1 + 0i + 0j + 0k
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion to conjugate, specified as a scalar, vector, matrix, or array of quaternions.

Data Types: quaternion

Output Arguments

quatConjugate — Quaternion conjugate
scalar | vector | matrix | multidimensional array

Quaternion conjugate, returned as a quaternion or array of quaternions the same size as quat.

Data Types: quaternion

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
norm | times, .*

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

ctranspose, '

Complex conjugate transpose of quaternion array

Syntax

```
quatTransposed = quat'
```

Description

`quatTransposed = quat'` returns the complex conjugate transpose of the quaternion, `quat`.

Examples

Vector Complex Conjugate Transpose

Create a vector of quaternions and compute its complex conjugate transpose.

```
quat = quaternion(randn(4,4))

quat = 4x1 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k
       1.8339 -   1.3077i +   2.7694j - 0.063055k
      -2.2588 -  0.43359i -   1.3499j +  0.71474k
      0.86217 +  0.34262i +   3.0349j -  0.20497k
```

```
quatTransposed = quat'

quatTransposed = 1x4 quaternion array
      0.53767 -  0.31877i -   3.5784j -   0.7254k        1.8339 +   1.3077i -   2.7694j
```

Matrix Complex Conjugate Transpose

Create a matrix of quaternions and compute its complex conjugate transpose.

```
quat = [quaternion(randn(2,4)),quaternion(randn(2,4))]

quat = 2x2 quaternion array
      0.53767 -   2.2588i +  0.31877j -  0.43359k        3.5784 -   1.3499i +   0.7254j
       1.8339 +  0.86217i -   1.3077j +  0.34262k        2.7694 +   3.0349i - 0.063055j
```

```
quatTransposed = quat'

quatTransposed = 2x2 quaternion array
      0.53767 +   2.2588i -  0.31877j +  0.43359k        1.8339 -  0.86217i +   1.3077j
       3.5784 +   1.3499i -   0.7254j -  0.71474k        2.7694 -   3.0349i + 0.063055j
```

Input Arguments

quat — Quaternion to transpose
scalar | vector | matrix

Quaternion to transpose, specified as a vector or matrix or quaternions. The complex conjugate transpose is defined for 1-D and 2-D arrays.

Data Types: quaternion

Output Arguments

quatTransposed — Conjugate transposed quaternion
scalar | vector | matrix

Conjugate transposed quaternion, returned as an N-by-M array, where quat was specified as an M-by-N array.

Data Types: quaternion

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`transpose, .'`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

dist

Angular distance in radians

Syntax

```
distance = dist(quatA,quatB)
```

Description

`distance = dist(quatA,quatB)` returns the angular distance in radians between the quaternion rotation operators for `quatA` and `quatB`.

Examples

Calculate Quaternion Distance

Calculate the quaternion distance between a single quaternion and each element of a vector of quaternions. Define the quaternions using Euler angles.

```
q = quaternion([0,0,0],'eulerd','zyx','frame')

q = quaternion
     1 + 0i + 0j + 0k
```

```
qArray = quaternion([0,45,0;0,90,0;0,180,0;0,-90,0;0,-45,0],'eulerd','zyx','frame')

qArray = 5×1 quaternion array
      0.92388 +        0i +   0.38268j +          0k
      0.70711 +        0i +   0.70711j +          0k
   6.1232e-17 +        0i +         1j +          0k
      0.70711 +        0i -   0.70711j +          0k
      0.92388 +        0i -   0.38268j +          0k
```

```
quaternionDistance = rad2deg(dist(q,qArray))
```

```
quaternionDistance = 5×1
```

```
    45.0000
    90.0000
   180.0000
    90.0000
    45.0000
```

If both arguments to `dist` are vectors, the quaternion distance is calculated between corresponding elements. Calculate the quaternion distance between two quaternion vectors.

```
angles1 = [30,0,15; ...
           30,5,15; ...
           30,10,15; ...
           30,15,15];
angles2 = [30,6,15; ...
           31,11,15; ...
           30,16,14; ...
           30.5,21,15.5];
```

```
qVector1 = quaternion(angles1,'eulerd','zyx','frame');
qVector2 = quaternion(angles2,'eulerd','zyx','frame');
```

```
rad2deg(dist(qVector1,qVector2))
```

```
ans = 4×1
```

```
    6.0000
    6.0827
    6.0827
    6.0287
```

Note that a quaternion represents the same rotation as its negative. Calculate a quaternion and its negative.

```
qPositive = quaternion([30,45,-60],'eulerd','zyx','frame')
```

```
qPositive = quaternion
     0.72332 - 0.53198i + 0.20056j +  0.3919k
```

```
qNegative = -qPositive
```

```
qNegative = quaternion
     -0.72332 + 0.53198i - 0.20056j -  0.3919k
```

Find the distance between the quaternion and its negative.

```
dist(qPositive,qNegative)
```

```
ans = 0
```

The components of a quaternion may look different from the components of its negative, but both expressions represent the same rotation.

Input Arguments

quatA,quatB — Quaternions to calculate distance between
scalar | vector | matrix | multidimensional array

Quaternions to calculate distance between, specified as comma-separated quaternions or arrays of quaternions. `quatA` and `quatB` must have compatible sizes:

- `size(quatA) == size(quatB)`, or
- `numel(quatA) == 1`, or
- `numel(quatB) == 1`, or
- if `[Adim1,…,AdimN] = size(quatA)` and `[Bdim1,…,BdimN] = size(quatB)`, then for `i = 1:N`, either `Adimi==Bdimi` or `Adim==1` or `Bdim==1`.

  If one of the quaternion arguments contains only one quaternion, then this function returns the distances between that quaternion and every quaternion in the other argument.

Data Types: `quaternion`

Output Arguments

distance — Angular distance (radians)
scalar | vector | matrix | multidimensional array

Angular distance in radians, returned as an array. The dimensions are the maximum of the union of `size(quatA)` and `size(quatB)`.

Data Types: `single` | `double`

Algorithms

The `dist` function returns the angular distance between two quaternion rotation operators.

A quaternion may be defined by an axis (u_b, u_c, u_d) and angle of rotation θ_q:

$$q = \cos\left(\frac{\theta_q}{2}\right) + \sin\left(\frac{\theta_q}{2}\right)(u_b \mathrm{i} + u_c \mathrm{j} + u_d \mathrm{k})$$

.
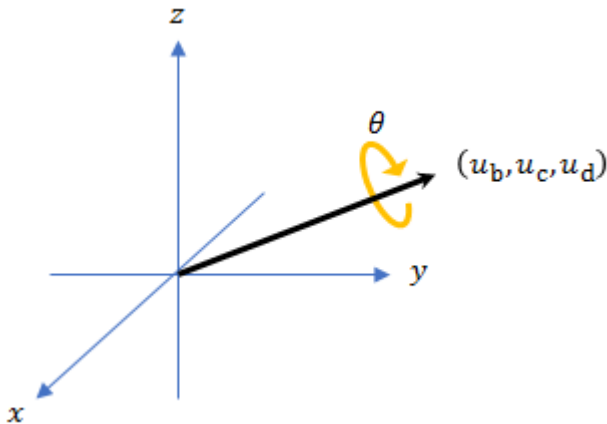
Given a quaternion in the form, $q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, where a is the real part, you can solve for θ_q: $\theta_q = 2\cos^{-1}(a)$.

Consider two quaternions, p and q, and the product $z = p \,{*}\, \mathrm{conjugate}(q)$. In a rotation operator, z rotates by p and derotates by q. As p approaches q, the angle of z goes to 0, and the product approaches the unit quaternion.

The angular distance between two quaternions can be expressed as

$$\theta_z = 2\cos^{-1}\left(\texttt{real}\left(z\right)\right)$$
.

Using the `quaternion` data type syntax, angular distance is calculated as:

```
angularDistance = 2*acos(parts(p*conj(q)));
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
conj | parts

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

euler

Convert quaternion to Euler angles (radians)

Syntax

```
eulerAngles = euler(quat,rotationSequence,rotationType)
```

Description

`eulerAngles = euler(quat,rotationSequence,rotationType)` converts the quaternion, `quat`, to an *N*-by-3 matrix of Euler angles.

Examples

Convert Quaternion to Euler Angles in Radians

Convert a quaternion frame rotation to Euler angles in radians using the 'ZYX' rotation sequence.

```
quat = quaternion([0.7071 0.7071 0 0]);
eulerAnglesRandians = euler(quat,'ZYX','frame')
```

eulerAnglesRandians = *1×3*

```
         0        0    1.5708
```

Input Arguments

quat — Quaternion to convert to Euler angles
scalar | vector | matrix | multidimensional array

Quaternion to convert to Euler angles, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

rotationSequence — Rotation sequence
`'ZYX'` | `'ZYZ'` | `'ZXY'` | `'ZXZ'` | `'YXZ'` | `'YXY'` | `'YZX'` | `'XYZ'` | `'XYX'` | `'XZY'` | `'XZX'`

Rotation sequence of Euler representation, specified as a character vector or string.

The rotation sequence defines the order of rotations about the axes. For example, if you specify a rotation sequence of `'YZX'`:

1   The first rotation is about the y-axis.

2   The second rotation is about the new z-axis.

3   The third rotation is about the new x-axis.

Data Types: `char` | `string`

rotationType — Type of rotation
`'point'` | `'frame'`

Type of rotation, specified as `'point'` or `'frame'`.

In a point rotation, the frame is static and the point moves. In a frame rotation, the point is static and the frame moves. Point rotation and frame rotation define equivalent angular displacements but in opposite directions.

Data Types: char | string

Output Arguments

eulerAngles — Euler angle representation (radians)
N-by-3 matrix

Euler angle representation in radians, returned as a *N*-by-3 matrix. *N* is the number of quaternions in the quat argument.

For each row of eulerAngles, the first element corresponds to the first axis in the rotation sequence, the second element corresponds to the second axis in the rotation sequence, and the third element corresponds to the third axis in the rotation sequence.

The data type of the Euler angles representation is the same as the underlying data type of quat.

Data Types: single | double

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
eulerd | rotateframe | rotatepoint

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

exp

Exponential of quaternion array

Syntax

```
B = exp(A)
```

Description

`B = exp(A)` computes the exponential of the elements of the quaternion array A.

Examples

Exponential of Quaternion Array

Create a 4-by-1 quaternion array A.

```
A = quaternion(magic(4))

A = 4×1 quaternion array
    16 +  2i +  3j + 13k
     5 + 11i + 10j +  8k
     9 +  7i +  6j + 12k
     4 + 14i + 15j +  1k
```

Compute the exponential of A.

```
B = exp(A)

B = 4×1 quaternion array
    5.3525e+06 + 1.0516e+06i + 1.5774e+06j + 6.8352e+06k
       -57.359 -     89.189i -     81.081j -     64.865k
       -6799.1 +     2039.1i +     1747.8j +     3495.6k
```

```
           -6.66 +     36.931i +     39.569j +      2.6379k
```

Input Arguments

A — Input quaternion
scalar | vector | matrix | multidimensional array

Input quaternion, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Output Arguments

B — Result
scalar | vector | matrix | multidimensional array

Result of quaternion exponential, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Given a quaternion $A = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k} = a + \bar{v}$, the exponential is computed by

$$\exp(A) = e^a \left(\cos\|\bar{v}\| + \frac{\bar{v}}{\|\bar{v}\|} \sin\|\bar{v}\| \right)$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
log | power, .^

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018b

ldivide, .\

Element-wise quaternion left division

Syntax

```
C = A.\B
```

Description

`C = A.\B` performs quaternion element-wise division by dividing each element of quaternion B by the corresponding element of quaternion A.

Examples

Divide a Quaternion Array by a Real Scalar

Create a 2-by-1 quaternion array, and divide it element-by-element by a real scalar.

```
A = quaternion([1:4;5:8])

A = 2×1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k


B = 2;
C = A.\B

C = 2×1 quaternion array
    0.066667 -  0.13333i -      0.2j -  0.26667k
    0.057471 - 0.068966i -  0.08046j - 0.091954k
```

Divide a Quaternion Array by Another Quaternion Array

Create a 2-by-2 quaternion array, and divide it element-by-element by another 2-by-2 quaternion array.

```
q1 = quaternion([1:4;2:5;4:7;5:8]);
A = reshape(q1,2,2)

A = 2×2 quaternion array
    1 + 2i + 3j + 4k      4 + 5i + 6j + 7k
    2 + 3i + 4j + 5k      5 + 6i + 7j + 8k
```

```
q2 = quaternion(magic(4));
B = reshape(q2,2,2)

B = 2×2 quaternion array
   16 +  2i +  3j + 13k      9 +  7i +  6j + 12k
    5 + 11i + 10j +  8k      4 + 14i + 15j +  1k
```

```
C = A.\B

C = 2×2 quaternion array
        2.7 -       1.9i -      0.9j -      1.7k       1.5159 -  0.37302i -  0.15079j
      2.2778 +  0.46296i -  0.57407j + 0.092593k       1.2471 +  0.91379i -  0.33908j
```

Input Arguments

A — Divisor
scalar | vector | matrix | multidimensional array

Divisor, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of the dimensions is 1.

Data Types: quaternion | single | double

B — Dividend
scalar | vector | matrix | multidimensional array

Dividend, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of the dimensions is 1.

Data Types: `quaternion` | `single` | `double`

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

Result of quaternion division, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Quaternion Division

Given a quaternion $A = a_1 + a_2 \mathrm{i} + a_3 \mathrm{j} + a_4 \mathrm{k}$ and a real scalar p,

$$C = p.\backslash A = \frac{a_1}{p} + \frac{a_2}{p}\mathrm{i} + \frac{a_3}{p}\mathrm{j} + \frac{a_4}{p}\mathrm{k}$$

Note For a real scalar p, $A./p = A.\backslash p$.

Quaternion Division by a Quaternion Scalar

Given two quaternions A and B of compatible sizes, then

$$C = A.\backslash B = A^{-1}.*B = \left(\frac{conj(A)}{norm(A)^2} \right).*B$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`conj` | `norm` | `rdivide, ./` | `times, .*`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018b

log

Natural logarithm of quaternion array

Syntax

```
B = log(A)
```

Description

`B = log(A)` computes the natural logarithm of the elements of the quaternion array A.

Examples

Logarithmic Values of Quaternion Array

Create a 3-by-1 quaternion array A.

```
A = quaternion(randn(3,4))
```

```
A = 3×1 quaternion array
     0.53767 + 0.86217i - 0.43359j +  2.7694k
      1.8339 + 0.31877i + 0.34262j -  1.3499k
     -2.2588 -  1.3077i +  3.5784j +  3.0349k
```

Compute the logarithmic values of A.

```
B = log(A)
```

```
B = 3×1 quaternion array
     1.0925 + 0.40848i - 0.20543j +  1.3121k
     0.8436 + 0.14767i + 0.15872j - 0.62533k
```

```
1.6807 - 0.53829i +  1.473j +  1.2493k
```

Input Arguments

A — Input array
scalar | vector | matrix | multidimensional array

Input array, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Output Arguments

B — Logarithm values
scalar | vector | matrix | multidimensional array

Quaternion natural logarithm values, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Given a quaternion $A = a + \bar{v} = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, the logarithm is computed by

$$\log(A) = \log\|A\| + \frac{\bar{v}}{\|\bar{v}\|}\arccos\frac{a}{\|A\|}$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
exp | power, .^

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018b

minus, -

Quaternion subtraction

Syntax

C = A - B

Description

C = A - B subtracts quaternion B from quaternion A using quaternion subtraction. Either A or B may be a real number, in which case subtraction is performed with the real part of the quaternion argument.

Examples

Subtract a Quaternion from a Quaternion

Quaternion subtraction is defined as the subtraction of the corresponding parts of each quaternion. Create two quaternions and perform subtraction.

```
Q1 = quaternion([1,0,-2,7]);
Q2 = quaternion([1,2,3,4]);

Q1minusQ2 = Q1 - Q2

Q1minusQ2 = quaternion
     0 - 2i - 5j + 3k
```

Subtract a Real Number from a Quaternion

Addition and subtraction of real numbers is defined for quaternions as acting on the real part of the quaternion. Create a quaternion and then subtract 1 from the real part.

```
Q = quaternion([1,1,1,1])

Q = quaternion
     1 + 1i + 1j + 1k
```

```
Qminus1 = Q - 1

Qminus1 = quaternion
     0 + 1i + 1j + 1k
```

Input Arguments

A — Input
scalar | vector | matrix | multidimensional array

Input, specified as a quaternion, array of quaternions, real number, or array of real numbers.

Data Types: quaternion | single | double

B — Input
scalar | vector | matrix | multidimensional array

Input, specified as a quaternion, array of quaternions, real number, or array of real numbers.

Data Types: quaternion | single | double

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

Result of quaternion subtraction, returned as a scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
mtimes, * | times, .* | uminus, -

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

mtimes, *

Quaternion multiplication

Syntax

```
quatC = A*B
```

Description

`quatC = A*B` implements quaternion multiplication if either A or B is a quaternion. Either A or B must be a scalar.

You can use quaternion multiplication to compose rotation operators:

- To compose a sequence of frame rotations, multiply the quaternions in the order of the desired sequence of rotations. For example, to apply a p quaternion followed by a q quaternion, multiply in the order pq. The rotation operator becomes $(pq)^* v (pq)$, where v represents the object to rotate specified in quaternion form. * represents conjugation.

- To compose a sequence of point rotations, multiply the quaternions in the reverse order of the desired sequence of rotations. For example, to apply a p quaternion followed by a q quaternion, multiply in the reverse order, qp. The rotation operator becomes $(qp) v (qp)^*$.

Examples

Multiply Quaternion Scalar and Quaternion Vector

Create a 4-by-1 column vector, A, and a scalar, b. Multiply A times b.

```
A = quaternion(randn(4,4))
```

```
A = 4x1 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k
       1.8339 -   1.3077i +   2.7694j - 0.063055k
      -2.2588 -  0.43359i -   1.3499j +  0.71474k
      0.86217 +  0.34262i +   3.0349j -  0.20497k


b = quaternion(randn(1,4))

b = quaternion
    -0.12414 +  1.4897i +   1.409j +  1.4172k


C = A*b

C = 4x1 quaternion array
      -6.6117 +   4.8105i +  0.94224j -   4.2097k
      -2.0925 +   6.9079i +   3.9995j -   3.3614k
       1.8155 -   6.2313i -    1.336j -     1.89k
      -4.6033 +   5.8317i + 0.047161j -    2.791k
```

Input Arguments

A — Input
scalar | vector | matrix | multidimensional array

Input to multiply, specified as a quaternion, array of quaternions, real scalar, or array of real scalars.

If B is nonscalar, then A must be scalar.

Data Types: quaternion | single | double

B — Input
scalar | vector | matrix | multidimensional array

Input to multiply, specified as a quaternion, array of quaternions, real scalar, or array of real scalars.

If A is nonscalar, then B must be scalar.

Data Types: quaternion | single | double

Output Arguments

quatC — Quaternion product
scalar | vector | matrix | multidimensional array

Quaternion product, returned as a quaternion or array of quaternions.

Data Types: quaternion

Algorithms

Quaternion Multiplication by a Real Scalar

Given a quaternion

$$q = a_q + b_q i + c_q j + d_q k,$$

the product of q and a real scalar β is

$$\beta q = \beta a_q + \beta b_q i + \beta c_q j + \beta d_q k$$

Quaternion Multiplication by a Quaternion Scalar

The definition of the basis elements for quaternions,

$$i^2 = j^2 = k^2 = ijk = -1,$$

can be expanded to populate a table summarizing quaternion basis element multiplication:

	1	i	j	k
1	1	i	j	k
i	i	−1	k	−j
j	j	−k	−1	i

k	k	j	−i	−1

When reading the table, the rows are read first, for example: ij = k and ji = −k.

Given two quaternions, $q = a_q + b_q i + c_q j + d_q k$, and
$p = a_p + b_p i + c_p j + d_p k$, the multiplication can be expanded as:

$$z = pq = \left(a_p + b_p i + c_p j + d_p k\right)\left(a_q + b_q i + c_q j + d_q k\right)$$
$$= a_p a_q + a_p b_q i + a_p c_q j + a_p d_q k$$
$$+ b_p a_q i + b_p b_q i^2 + b_p c_q ij + b_p d_q ik$$
$$+ c_p a_q j + c_p b_q ji + c_p c_q j^2 + c_p d_q jk$$
$$+ d_p a_q k + d_p b_q ki + d_p c_q kj + d_p d_q k^2$$

You can simplify the equation using the quaternion multiplication table:

$$z = pq = a_p a_q + a_p b_q i + a_p c_q j + a_p d_q k$$
$$+ b_p a_q i - b_p b_q + b_p c_q k - b_p d_q j$$
$$+ c_p a_q j - c_p b_q k - c_p c_q + c_p d_q i$$
$$+ d_p a_q k + d_p b_q j - d_p c_q i - d_p d_q$$

References

[1] Kuipers, Jack B. *Quaternions and Rotation Sequences: A Primer with Applications to Orbits, Aerospace, and Virtual Reality*. Princeton, NJ: Princeton University Press, 2007.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
times, .*

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

norm

Quaternion norm

Syntax

```
N = norm(quat)
```

Description

`N = norm(quat)` returns the norm of the quaternion, `quat`.

Given a quaternion of the form $Q = a + bi + cj + dk$, the norm of the quaternion is defined as $norm(Q) = \sqrt{a^2 + b^2 + c^2 + d^2}$.

Examples

Calculate Quaternion Norm

Create a scalar quaternion and calculate its norm.

```
quat = quaternion(1,2,3,4);
norm(quat)
```

```
ans = 5.4772
```

The quaternion norm is defined as the square root of the sum of the quaternion parts squared. Calculate the quaternion norm explicitly to verify the result of the `norm` function.

```
[a,b,c,d] = parts(quat);
sqrt(a^2+b^2+c^2+d^2)
```

```
ans = 5.4772
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion for which to calculate the norm, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

Output Arguments

N — Quaternion norm
scalar | vector | matrix | multidimensional array

Quaternion norm. If the input `quat` is an array, the output is returned as an array the same size as `quat`. Elements of the array are real numbers with the same data type as the underlying data type of the quaternion, `quat`.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`conj` | `normalize` | `parts`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

normalize

Quaternion normalization

Syntax

```
quatNormalized = normalize(quat)
```

Description

`quatNormalized = normalize(quat)` normalizes the quaternion.

Given a quaternion of the form $Q = a + bi + cj + dk$, the normalized quaternion is defined as $Q \big/ \sqrt{a^2 + b^2 + c^2 + d^2}$.

Examples

Normalize Elements of Quaternion Vector

Quaternions can represent rotations when normalized. You can use `normalize` to normalize a scalar, elements of a matrix, or elements of a multi-dimensional array of quaternions. Create a column vector of quaternions, then normalize them.

```
quatArray = quaternion([1,2,3,4; ...
                        2,3,4,1; ...
                        3,4,1,2]);
quatArrayNormalized = normalize(quatArray)

quatArrayNormalized = 3x1 quaternion array
     0.18257 + 0.36515i + 0.54772j +  0.7303k
     0.36515 + 0.54772i +  0.7303j + 0.18257k
     0.54772 +  0.7303i + 0.18257j + 0.36515k
```

Input Arguments

quat — Quaternion to normalize
scalar | vector | matrix | multidimensional array

Quaternion to normalize, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: quaternion

Output Arguments

quatNormalized — Normalized quaternion
scalar | vector | matrix | multidimensional array

Normalized quaternion, returned as a quaternion or array of quaternions the same size as quat.

Data Types: quaternion

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
conj | norm | times, .*

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

ones

Create quaternion array with real parts set to one and imaginary parts set to zero

Syntax

```
quatOnes = ones('quaternion')
quatOnes = ones(n,'quaternion')
quatOnes = ones(sz,'quaternion')
quatOnes = ones(sz1,...,szN,'quaternion')

quatOnes = ones( ___ ,'like',prototype,'quaternion')
```

Description

`quatOnes = ones('quaternion')` returns a scalar quaternion with the real part set to 1 and the imaginary parts set to 0.

Given a quaternion of the form $Q = a + bi + cj + dk$, a quaternion one is defined as $Q = 1 + 0i + 0j + 0k$.

`quatOnes = ones(n,'quaternion')` returns an n-by-n quaternion matrix with the real parts set to 1 and the imaginary parts set to 0.

`quatOnes = ones(sz,'quaternion')` returns an array of quaternion ones where the size vector, `sz`, defines `size(qOnes)`.

Example: `ones([1,4,2],'quaternion')` returns a 1-by-4-by-2 array of quaternions with the real parts set to 1 and the imaginary parts set to 0.

`quatOnes = ones(sz1,...,szN,'quaternion')` returns a `sz1`-by-...-by-`szN` array of ones where `sz1,…,szN` indicates the size of each dimension.

`quatOnes = ones( ___ ,'like',prototype,'quaternion')` specifies the underlying class of the returned quaternion array to be the same as the underlying class of the quaternion prototype.

Examples

Quaternion Scalar One

Create a quaternion scalar one.

```
quatOnes = ones('quaternion')
```

```
quatOnes = quaternion
     1 + 0i + 0j + 0k
```

Square Matrix of Quaternion Ones

Create an n-by-n matrix of quaternion ones.

```
n = 3;
quatOnes = ones(n,'quaternion')
```

```
quatOnes = 3x3 quaternion array
     1 + 0i + 0j + 0k     1 + 0i + 0j + 0k     1 + 0i + 0j + 0k
     1 + 0i + 0j + 0k     1 + 0i + 0j + 0k     1 + 0i + 0j + 0k
     1 + 0i + 0j + 0k     1 + 0i + 0j + 0k     1 + 0i + 0j + 0k
```

Multidimensional Array of Quaternion Ones

Create a multidimensional array of quaternion ones by defining array dimensions in order. In this example, you create a 3-by-1-by-2 array. You can specify dimensions using a row vector or comma-separated integers. Specify the dimensions using a row vector and display the results:

```
dims = [3,1,2];
quatOnesSyntax1 = ones(dims,'quaternion')
```

```
quatOnesSyntax1 = 3x1x2 quaternion array
quatOnesSyntax1(:,:,1) =
```

```
      1 + 0i + 0j + 0k
      1 + 0i + 0j + 0k
      1 + 0i + 0j + 0k


quatOnesSyntax1(:,:,2) =

      1 + 0i + 0j + 0k
      1 + 0i + 0j + 0k
      1 + 0i + 0j + 0k
```

Specify the dimensions using comma-separated integers, and then verify the equivalency of the two syntaxes:

```
quatOnesSyntax2 = ones(3,1,2,'quaternion');
isequal(quatOnesSyntax1,quatOnesSyntax2)

ans = logical
   1
```

Underlying Class of Quaternion Ones

A quaternion is a four-part hyper-complex number used in three-dimensional rotations and orientations. You can specify the underlying data type of the parts as `single` or `double`. The default is `double`.

Create a quaternion array of ones with the underlying data type set to `single`.

```
quatOnes = ones(2,'like',single(1),'quaternion')

quatOnes = 2x2 quaternion array
      1 + 0i + 0j + 0k     1 + 0i + 0j + 0k
      1 + 0i + 0j + 0k     1 + 0i + 0j + 0k
```

Verify the underlying class using the `classUnderlying` function.

```
classUnderlying(quatOnes)

ans =
'single'
```

Input Arguments

n — Size of square quaternion matrix
integer value

Size of square quaternion matrix, specified as an integer value.

If n is zero or negative, then quatOnes is returned as an empty matrix.

Example: `ones(4,'quaternion')` returns a 4-by-4 matrix of quaternions with the real parts set to 1 and the imaginary parts set to 0.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

sz — Output size
row vector of integer values

Output size, specified as a row vector of integer values. Each element of sz indicates the size of the corresponding dimension in quatOnes. If the size of any dimension is 0 or negative, then quatOnes is returned as an empty array.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

prototype — Quaternion prototype
variable

Quaternion prototype, specified as a variable.

Example: `ones(2,'like',quat,'quaternion')` returns a 2-by-2 matrix of quaternions with the same underlying class as the prototype quaternion, `quat`.

Data Types: `quaternion`

sz1,...,szN — Size of each dimension
two or more integer values

Size of each dimension, specified as two or more integers. If the size of any dimension is 0 or negative, then quatOnes is returned as an empty array.

Example: `ones(2,3,'quaternion')` returns a 2-by-3 matrix of quaternions with the real parts set to 1 and the imaginary parts set to 0.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

quatOnes — Quaternion ones
scalar | vector | matrix | multidimensional array

Quaternion ones, returned as a scalar, vector, matrix, or multidimensional array of quaternions.

Given a quaternion of the form $Q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, a quaternion one is defined as $Q = 1 + 0\mathrm{i} + 0\mathrm{j} + 0\mathrm{k}$.

Data Types: `quaternion`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`zeros`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

parts

Extract quaternion parts

Syntax

```
[a,b,c,d] = parts(quat)
```

Description

`[a,b,c,d] = parts(quat)` returns the parts of the quaternion array as arrays, each the same size as `quat`.

Examples

Convert Quaternion to Matrix of Quaternion Parts

Convert a quaternion representation to parts using the `parts` function.

Create a two-element column vector of quaternions by specifying the parts.

```
quat = quaternion([1:4;5:8])
```

```
quat = 2×1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k
```

Recover the parts from the quaternion matrix using the `parts` function. The parts are returned as separate output arguments, each the same size as the input 2-by-1 column vector of quaternions.

```
[qA,qB,qC,qD] = parts(quat)
```

```
qA = 2×1
```

```
       1
       5


qB = 2×1

       2
       6


qC = 2×1

       3
       7


qD = 2×1

       4
       8
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion, specified as a quaternion or array of quaternions.

Data Types: `quaternion`

Output Arguments

[a,b,c,d] — Quaternion parts
scalar | vector | matrix | multidimensional array

Quaternion parts, returned as four arrays: a, b, d, and d. Each part is the same size as `quat`.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
classUnderlying

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

power, .^

Element-wise quaternion power

Syntax

```
C = A.^b
```

Description

`C = A.^b` raises each element of A to the corresponding power in b.

Examples

Raise a Quaternion to a Real Scalar Power

Create a quaternion and raise it to a real scalar power.

```
A = quaternion(1,2,3,4)

A = quaternion
    1 + 2i + 3j + 4k
```

```
b = 3;
C = A.^b

C = quaternion
   -86 -  52i -  78j - 104k
```

Raise a Quaternion Array to Powers from a Multidimensional Array

Create a 2-by-1 quaternion array and raise it to powers from a 2-D array.

```
A = quaternion([1:4;5:8])

A = 2×1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k
```

```
b = [1 0 2; 3 2 1]

b = 2×3

     1     0     2
     3     2     1
```

```
C = A.^b

C = 2×3 quaternion array
        1 +    2i +    3j +    4k       1 +   0i +   0j +   0k     -28 +    4i +
    -2110 -  444i -  518j -  592k    -124 +  60i +  70j +  80k       5 +    6i +
```

Input Arguments

A — Base
scalar | vector | matrix | multidimensional array

Base, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion` | `single` | `double`

b — Exponent
scalar | vector | matrix | multidimensional array

Exponent, specified as a real scalar, vector, matrix, or multidimensional array.

Data Types: `single` | `double`

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

Each element of quaternion A raised to the corresponding power in b, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

The polar representation of a quaternion $A = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$ is given by

$$A = \|A\| \left(\cos\theta + \hat{u}\sin\theta \right)$$

where θ is the angle of rotation, and $\hat{u}$ is the unit quaternion.

Quaternion A raised by a real exponent b is given by

$$P = A.^{\wedge}b = \|A\|^{b} \left(\cos(b\theta) + \hat{u}\sin(b\theta) \right)$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`exp` | `log`

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018b

prod

Product of a quaternion array

Syntax

```
quatProd = prod(quat)
quatProd = prod(quat,dim)
```

Description

`quatProd = prod(quat)` returns the quaternion product of the elements of the array.

`quatProd = prod(quat,dim)` calculates the quaternion product along dimension `dim`.

Examples

Product of Quaternions in Each Column

Create a 3-by-3 array whose elements correspond to their linear indices.

```
A = reshape(quaternion(randn(9,4)),3,3)
```

```
A = 3x3 quaternion array
      0.53767 +   2.7694i +    1.409j - 0.30344k      0.86217 +   0.7254i -   1.2075j
       1.8339 -   1.3499i +   1.4172j + 0.29387k      0.31877 - 0.063055i +  0.71724j
      -2.2588 +   3.0349i +   0.6715j - 0.78728k       -1.3077 +  0.71474i +   1.6302j
```

Find the product of the quaternions in each column. The length of the first dimension is 1, and the length of the second dimension matches `size(A,2)`.

```
B = prod(A)
```

```
B = 1x3 quaternion array
      -19.837 -  9.1521i +  15.813j -  19.918k      -5.4708 - 0.28535i +   3.077j -  1.2
```

Product of Specified Dimension of Quaternion Array

You can specify which dimension of a quaternion array to take the product of.

Create a 2-by-2-by-2 quaternion array.

```
A = reshape(quaternion(randn(8,4)),2,2,2);
```

Find the product of the elements in each page of the array. The length of the first dimension matches `size(A,1)`, the length of the second dimension matches `size(A,2)`, and the length of the third dimension is `1`.

```
dim = 3;
B = prod(A,dim)

B = 2x2 quaternion array
    -2.4847 +  1.1659i - 0.37547j +  2.8068k      0.28786 - 0.29876i - 0.51231j -  4.29
    0.38986 -  3.6606i -  2.0474j -   6.047k      -1.741 - 0.26782i + 5.4346j + 4.14
```

Input Arguments

`quat` — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion, specified as scalar, vector, matrix, or multidimensional array of quaternions.

Example: `qProd = prod(quat)` calculates the quaternion product along the first non-singleton dimension of `quat`.

Data Types: `quaternion`

`dim` — Dimension
first non-singleton dimension (default) | positive integer

Dimension along which to calculate the quaternion product, specified as a positive integer. If `dim` is not specified, `prod` operates along the first non-singleton dimension of `quat`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

quatProd — Quaternion product
positive integer

Quaternion product, returned as quaternion array with one less non-singleton dimension than `quat`.

For example, if `quat` is a 2-by-2-by-5 array,

- `prod(quat,1)` returns a 1-by-2-by-5 array.
- `prod(quat,2)` returns a 2-by-1-by-5 array.
- `prod(quat,3)` returns a 2-by-2 array.

Data Types: `quaternion`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`mtimes, *` | `times, .*`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

rdivide, ./

Element-wise quaternion right division

Syntax

```
C = A./B
```

Description

`C = A./B` performs quaternion element-wise division by dividing each element of quaternion A by the corresponding element of quaternion B.

Examples

Divide a Quaternion Array by a Real Scalar

Create a 2-by-1 quaternion array, and divide it element-by-element by a real scalar.

```
A = quaternion([1:4;5:8])

A = 2×1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k


B = 2;
C = A./B

C = 2×1 quaternion array
     0.5 +   1i + 1.5j +   2k
     2.5 +   3i + 3.5j +   4k
```

Divide a Quaternion Array by Another Quaternion Array

Create a 2-by-2 quaternion array, and divide it element-by-element by another 2-by-2 quaternion array.

```
q1 = quaternion(magic(4));
A = reshape(q1,2,2)

A = 2×2 quaternion array
    16 +  2i +  3j + 13k     9 +  7i +  6j + 12k
     5 + 11i + 10j +  8k     4 + 14i + 15j +  1k
```

```
q2 = quaternion([1:4;3:6;2:5;4:7]);
B = reshape(q2,2,2)

B = 2×2 quaternion array
    1 + 2i + 3j + 4k     2 + 3i + 4j + 5k
    3 + 4i + 5j + 6k     4 + 5i + 6j + 7k
```

```
C = A./B

C = 2×2 quaternion array
        2.7 -       0.1i -      2.1j -      1.7k      2.2778 + 0.092593i -  0.46296j
     1.8256 - 0.081395i +  0.45349j -  0.24419k      1.4524 -       0.5i +   1.0238j
```

Input Arguments

A — Dividend
scalar | vector | matrix | multidimensional array

Dividend, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of the dimensions is 1.

Data Types: quaternion | single | double

B — Divisor
scalar | vector | matrix | multidimensional array

Divisor, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of the dimensions is 1.

Data Types: `quaternion` | `single` | `double`

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

Result of quaternion division, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Quaternion Division

Given a quaternion $A = a_1 + a_2\mathrm{i} + a_3\mathrm{j} + a_4\mathrm{k}$ and a real scalar p,

$$C = A./p = \frac{a_1}{p} + \frac{a_2}{p}\mathrm{i} + \frac{a_3}{p}\mathrm{j} + \frac{a_4}{p}\mathrm{k}$$

Note For a real scalar p, $A./p = A.\backslash p$.

Quaternion Division by a Quaternion Scalar

Given two quaternions A and B of compatible sizes,

$$C = A./B = A.*B^{-1} = A.*\left(\frac{conj(B)}{norm(B)^2} \right)$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
conj | ldivide, .\ | norm | times, .*

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018b

rotateframe

Quaternion frame rotation

Syntax

```
rotationResult = rotateframe(quat,cartesianPoints)
```

Description

`rotationResult = rotateframe(quat,cartesianPoints)` rotates the frame of reference for the Cartesian points using the quaternion, `quat`. The elements of the quaternion are normalized before use in the rotation.
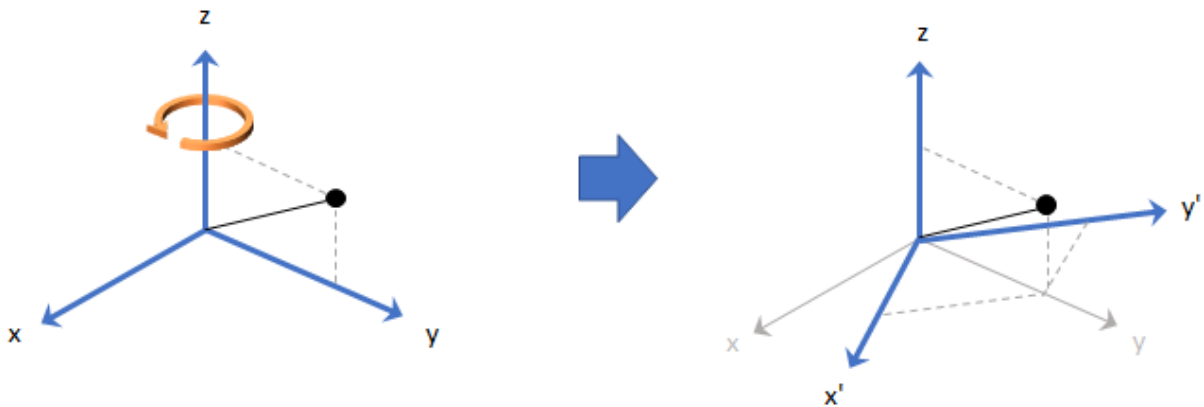
Examples

Rotate Frame Using Quaternion Vector

Define a point in three dimensions. The coordinates of a point are always specified in the order x, y, and z. For convenient visualization, define the point on the x-y plane.

```
x = 0.5;
y = 0.5;
z = 0;
plot(x,y,'ko')
hold on
axis([-1 1 -1 1])
```
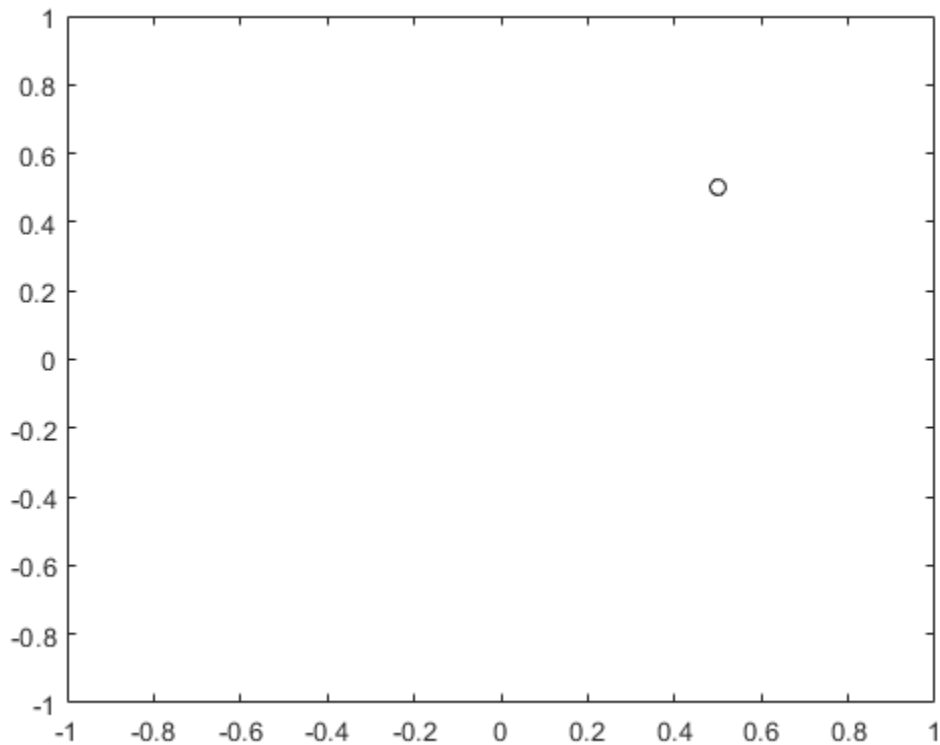
Create a quaternion vector specifying two separate rotations, one to rotate the frame 45 degrees and another to rotate the point -90 degrees about the *z*-axis. Use `rotateframe` to perform the rotations.

```
quat = quaternion([0,0,pi/4; ...
                   0,0,-pi/2],'euler','XYZ','frame');
```

```
rereferencedPoint = rotateframe(quat,[x,y,z])
```

rereferencedPoint = *2×3*

```
    0.7071   -0.0000        0
   -0.5000    0.5000        0
```

Plot the rereferenced points.

```
plot(rereferencedPoint(1,1),rereferencedPoint(1,2),'bo')
plot(rereferencedPoint(2,1),rereferencedPoint(2,2),'go')
```
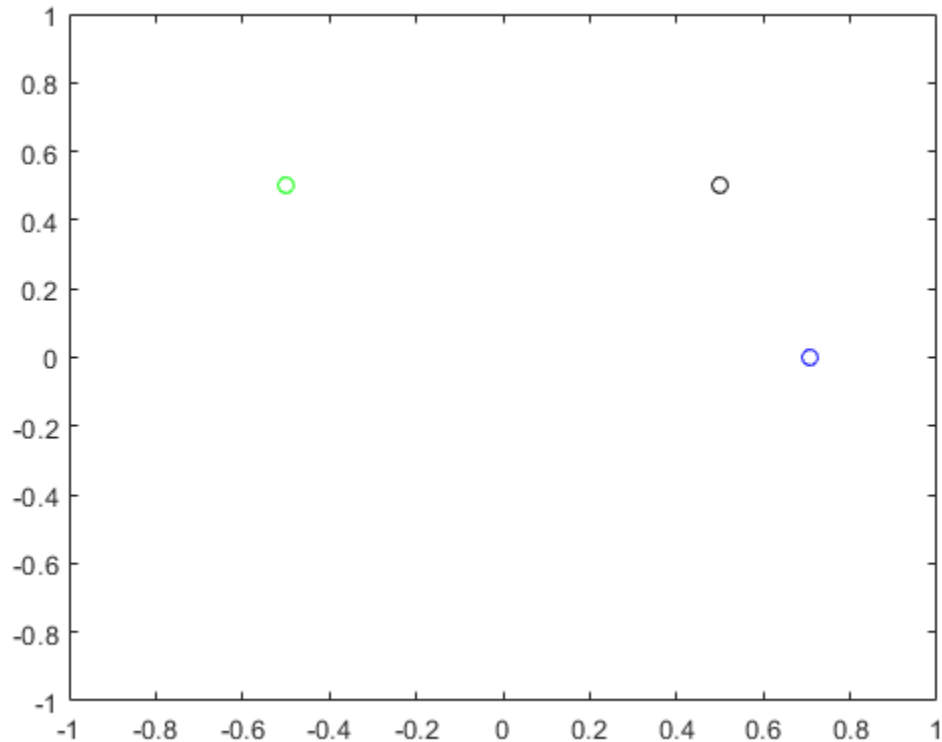
Rereference Group of Points using Quaternion

Define two points in three-dimensional space. Define a quaternion to rereference the points by first rotating the reference frame about the *z*-axis 30 degrees and then about the new *y*-axis 45 degrees.

```
a = [1,0,0];
b = [0,1,0];
quat = quaternion([30,45,0],'eulerd','ZYX','point');
```

Use `rotateframe` to reference both points using the quaternion rotation operator. Display the result.

```
rP = rotateframe(quat,[a;b])
```

rP = *2×3*

```
    0.6124   -0.3536    0.7071
    0.5000    0.8660   -0.0000
```

Visualize the original orientation and the rotated orientation of the points. Draw lines from the origin to each of the points for visualization purposes.

```
plot3(a(1),a(2),a(3),'bo');

hold on
grid on
axis([-1 1 -1 1 -1 1])
xlabel('x')
ylabel('y')
zlabel('z')

plot3(b(1),b(2),b(3),'ro');
plot3(rP(1,1),rP(1,2),rP(1,3),'bd')
plot3(rP(2,1),rP(2,2),rP(2,3),'rd')

plot3([0;rP(1,1)],[0;rP(1,2)],[0;rP(1,3)],'k')
plot3([0;rP(2,1)],[0;rP(2,2)],[0;rP(2,3)],'k')
plot3([0;a(1)],[0;a(2)],[0;a(3)],'k')
plot3([0;b(1)],[0;b(2)],[0;b(3)],'k')
```
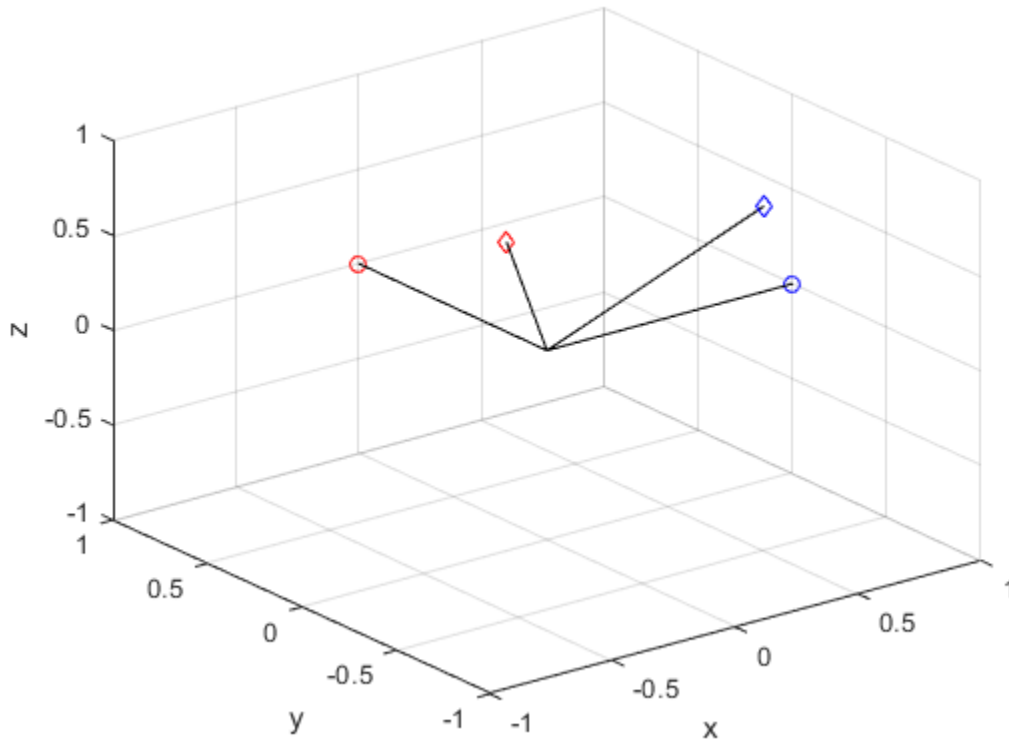
Input Arguments

`quat` — Quaternion that defines rotation
scalar | vector

Quaternion that defines rotation, specified as a scalar quaternion or vector of quaternions.

Data Types: `quaternion`

`cartesianPoints` — Three-dimensional Cartesian points
1-by-3 vector | *N*-by-3 matrix

Three-dimensional Cartesian points, specified as a 1-by-3 vector or *N*-by-3 matrix.

Data Types: `single` | `double`

Output Arguments

`rotationResult` — Re-referenced Cartesian points
vector | matrix

Cartesian points defined in reference to rotated reference frame, returned as a vector or matrix the same size as `cartesianPoints`.

The data type of the re-referenced Cartesian points is the same as the underlying data type of `quat`.

Data Types: `single` | `double`

Algorithms

Quaternion frame rotation re-references a point specified in $\mathbf{R}^3$ by rotating the original frame of reference according to a specified quaternion:

$$L_q\left(u\right) \; = \; q^* u q$$

where *q* is the quaternion, * represents conjugation, and *u* is the point to rotate, specified as a quaternion.

For convenience, the `rotateframe` function takes a point in $\mathbf{R}^3$ and returns a point in $\mathbf{R}^3$. Given a function call with some arbitrary quaternion, $q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, and arbitrary coordinate, [*x*,*y*,*z*],

```
point = [x,y,z];
rereferencedPoint = rotateframe(q,point)
```

the `rotateframe` function performs the following operations:

1 Converts point [*x*,*y*,*z*] to a quaternion:

$$u_q \; = \; 0 \; + \; xi \; + \; yj \; + \; zk$$

2   Normalizes the quaternion, q:

$$q_n \; = \; \frac{q}{\sqrt{a^2 \; + \; b^2 \; + \; c^2 \; + \; d^2}}$$

3   Applies the rotation:

$$v_q \; = \; q^* u_q q$$

4   Converts the quaternion output, v_q, back to $\mathbf{R}^3$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
rotatepoint

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

rotatepoint

Quaternion point rotation

Syntax

```
rotationResult = rotatepoint(quat,cartesianPoints)
```

Description

`rotationResult = rotatepoint(quat,cartesianPoints)` rotates the Cartesian points using the quaternion, `quat`. The elements of the quaternion are normalized before use in the rotation.
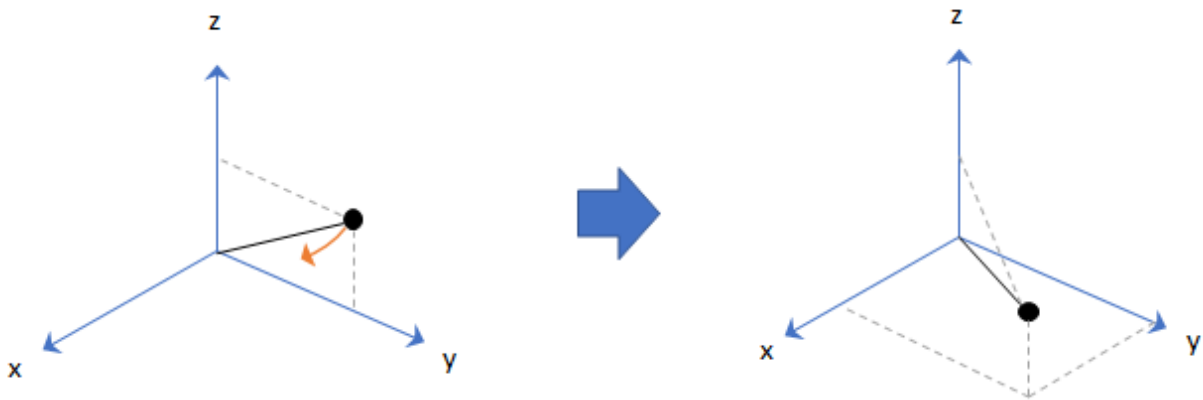
Examples

Rotate Point Using Quaternion Vector

Define a point in three dimensions. The coordinates of a point are always specified in order x, y, z. For convenient visualization, define the point on the x-y plane.

```
x = 0.5;
y = 0.5;
z = 0;

plot(x,y,'ko')
hold on
axis([-1 1 -1 1])
```
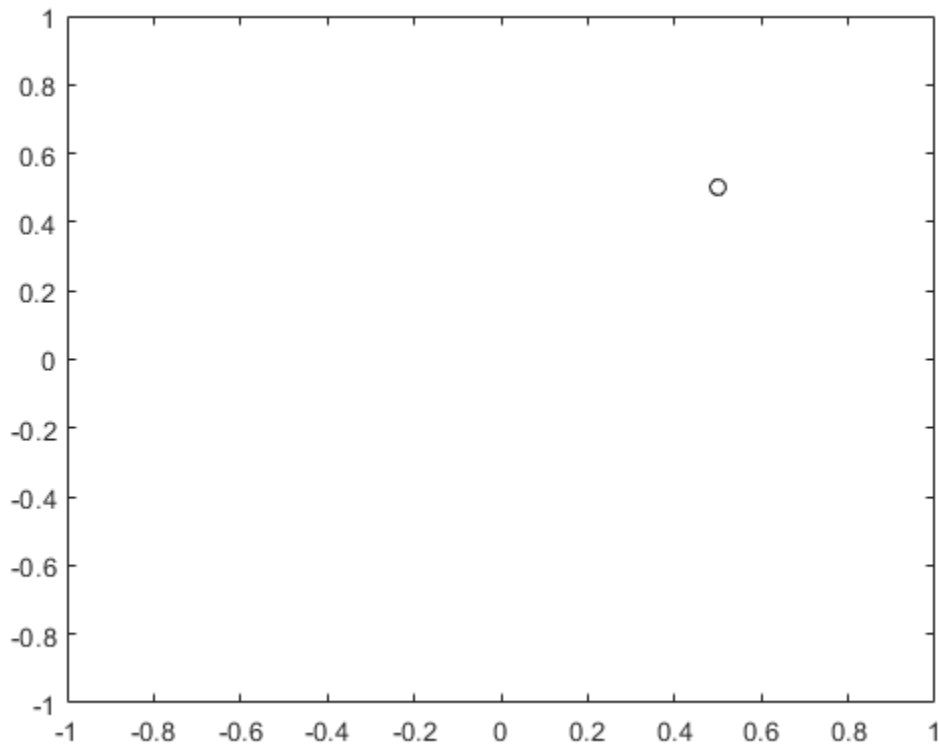

Create a quaternion vector specifying two separate rotations, one to rotate the point 45 and another to rotate the point -90 degrees about the *z*-axis. Use `rotatepoint` to perform the rotation.

```
quat = quaternion([0,0,pi/4; ...
                   0,0,-pi/2],'euler','XYZ','point');
```

1-123

```
rotatedPoint = rotatepoint(quat,[x,y,z])

rotatedPoint = 2×3

   -0.0000      0.7071            0
    0.5000     -0.5000            0
```

Plot the rotated points.

```
plot(rotatedPoint(1,1),rotatedPoint(1,2),'bo')
plot(rotatedPoint(2,1),rotatedPoint(2,2),'go')
```
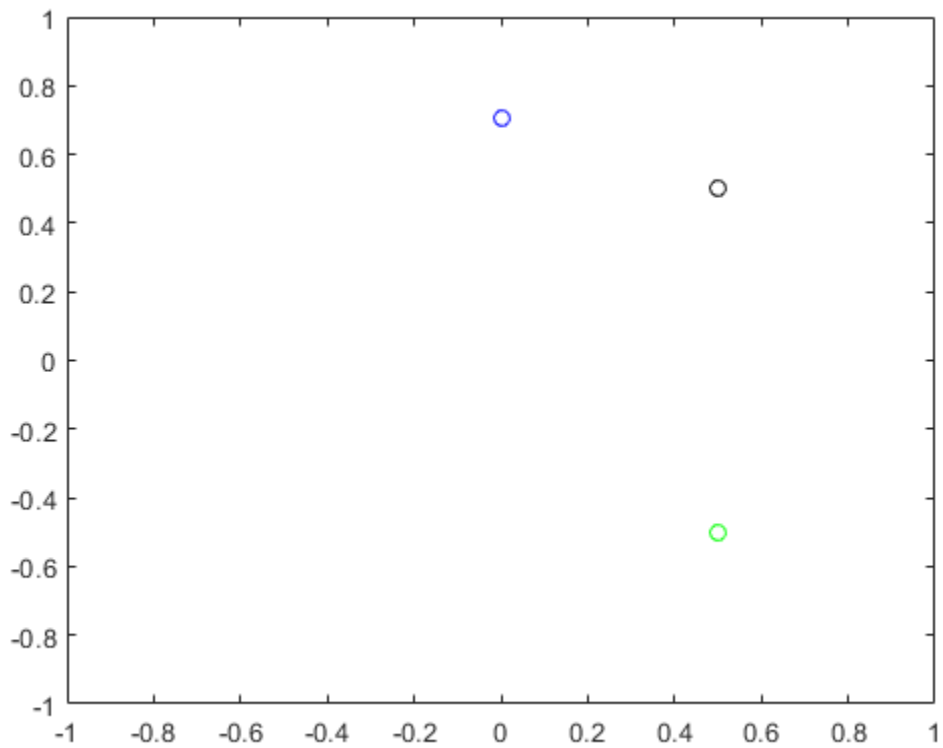
Rotate Group of Points Using Quaternion

Define two points in three-dimensional space. Define a quaternion to rotate the point by first rotating about the *z*-axis 30 degrees and then about the new *y*-axis 45 degrees.

```
a = [1,0,0];
b = [0,1,0];
quat = quaternion([30,45,0],'eulerd','ZYX','point');
```

Use `rotatepoint` to rotate both points using the quaternion rotation operator. Display the result.

```
rP = rotatepoint(quat,[a;b])
```

rP = *2×3*

```
    0.6124    0.5000   -0.6124
   -0.3536    0.8660    0.3536
```

Visualize the original orientation and the rotated orientation of the points. Draw lines from the origin to each of the points for visualization purposes.

```
plot3(a(1),a(2),a(3),'bo');

hold on
grid on
axis([-1 1 -1 1 -1 1])
xlabel('x')
ylabel('y')
zlabel('z')

plot3(b(1),b(2),b(3),'ro');
plot3(rP(1,1),rP(1,2),rP(1,3),'bd')
plot3(rP(2,1),rP(2,2),rP(2,3),'rd')

plot3([0;rP(1,1)],[0;rP(1,2)],[0;rP(1,3)],'k')
plot3([0;rP(2,1)],[0;rP(2,2)],[0;rP(2,3)],'k')
plot3([0;a(1)],[0;a(2)],[0;a(3)],'k')
plot3([0;b(1)],[0;b(2)],[0;b(3)],'k')
```
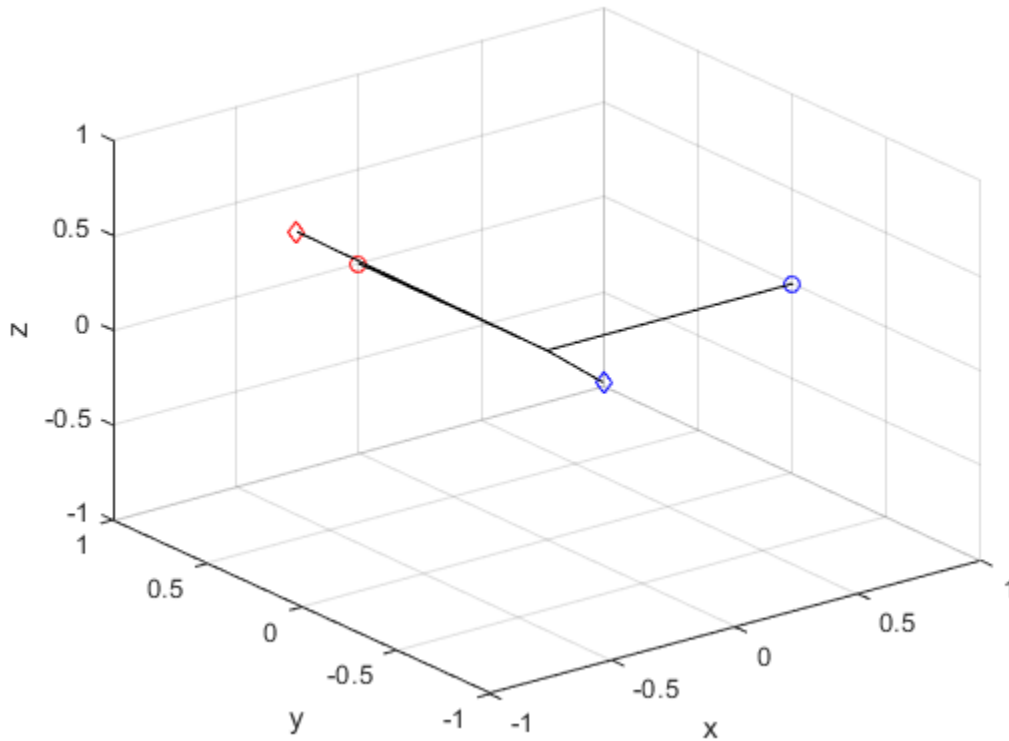
Input Arguments

quat — Quaternion that defines rotation
scalar | vector

Quaternion that defines rotation, specified as a scalar quaternion, row vector of quaternions, or column vector of quaternions.

Data Types: `quaternion`

cartesianPoints — Three-dimensional Cartesian points
1-by-3 vector | *N*-by-3 matrix

Three-dimensional Cartesian points, specified as a 1-by-3 vector or *N*-by-3 matrix.

Data Types: `single` | `double`

Output Arguments

`rotationResult` — Repositioned Cartesian points
vector | matrix

Rotated Cartesian points defined using the quaternion rotation, returned as a vector or matrix the same size as `cartesianPoints`.

Data Types: `single` | `double`

Algorithms

Quaternion point rotation rotates a point specified in $\mathbf{R}^3$ according to a specified quaternion:

$$L_q(u) = quq^*$$

where *q* is the quaternion, * represents conjugation, and *u* is the point to rotate, specified as a quaternion.

For convenience, the `rotatepoint` function takes in a point in $\mathbf{R}^3$ and returns a point in $\mathbf{R}^3$. Given a function call with some arbitrary quaternion, $q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, and arbitrary coordinate, [*x*,*y*,*z*], for example,

`rereferencedPoint = rotatepoint(q,[x,y,z])`

the `rotatepoint` function performs the following operations:

1 Converts point [*x*,*y*,*z*] to a quaternion:

$$u_q = 0 + xi + yj + zk$$

2 Normalizes the quaternion, *q*:

$$q_n = \frac{q}{\sqrt{a^2 + b^2 + c^2 + d^2}}$$

3 Applies the rotation:

$$v_q \;=\; q u_q q^*$$

4 Converts the quaternion output, v_q, back to $\mathbf{R}^3$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
rotateframe

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

rotmat

Convert quaternion to rotation matrix

Syntax

```
rotationMatrix = rotmat(quat,rotationType)
```

Description

`rotationMatrix = rotmat(quat,rotationType)` converts the quaternion, `quat`, to an equivalent rotation matrix representation.

Examples

Convert Quaternion to Rotation Matrix for Point Rotation

Define a quaternion for use in point rotation.

```
theta = 45;
gamma = 30;
quat = quaternion([0,theta,gamma],'eulerd','ZYX','point')
```

```
quat = quaternion
      0.8924 +  0.23912i +  0.36964j + 0.099046k
```

Convert the quaternion to a rotation matrix.

```
rotationMatrix = rotmat(quat,'point')
```

```
rotationMatrix = 3×3

    0.7071   -0.0000    0.7071
    0.3536    0.8660   -0.3536
   -0.6124    0.5000    0.6124
```

To verify the rotation matrix, directly create two rotation matrices corresponding to the rotations about the *y*- and *x*-axes. Multiply the rotation matrices and compare to the output of `rotmat`.

```
theta = 45;
gamma = 30;

ry = [cosd(theta)    0           sind(theta) ; ...
      0              1           0           ; ...
      -sind(theta)   0           cosd(theta)];

rx = [1              0           0           ;    ...
      0              cosd(gamma) -sind(gamma) ;   ...
      0              sind(gamma) cosd(gamma)];

rotationMatrixVerification = rx*ry

rotationMatrixVerification = 3×3

    0.7071         0    0.7071
    0.3536    0.8660   -0.3536
   -0.6124    0.5000    0.6124
```

Convert Quaternion to Rotation Matrix for Frame Rotation

Define a quaternion for use in frame rotation.

```
theta = 45;
gamma = 30;
quat = quaternion([0,theta,gamma],'eulerd','ZYX','frame')

quat = quaternion
      0.8924 +  0.23912i +  0.36964j - 0.099046k
```

Convert the quaternion to a rotation matrix.

```
rotationMatrix = rotmat(quat,'frame')

rotationMatrix = 3×3
```

```
    0.7071   -0.0000   -0.7071
    0.3536    0.8660    0.3536
    0.6124   -0.5000    0.6124
```

To verify the rotation matrix, directly create two rotation matrices corresponding to the rotations about the *y*- and *x*-axes. Multiply the rotation matrices and compare to the output of `rotmat`.

```
theta = 45;
gamma = 30;

ry = [cosd(theta)   0              -sind(theta) ; ...
      0             1               0            ; ...
      sind(theta)   0               cosd(theta)];

rx = [1               0             0            ;     ...
      0               cosd(gamma) sind(gamma) ;     ...
      0              -sind(gamma) cosd(gamma)];

rotationMatrixVerification = rx*ry
```

```
rotationMatrixVerification = 3×3
```

```
    0.7071         0   -0.7071
    0.3536    0.8660    0.3536
    0.6124   -0.5000    0.6124
```

Convert Quaternion Vector to Rotation Matrices

Create a 3-by-1 normalized quaternion vector.

```
qVec = normalize(quaternion(randn(3,4)));
```

Convert the quaternion array to rotation matrices. The pages of `rotmatArray` correspond to the linear index of `qVec`.

```
rotmatArray = rotmat(qVec,'frame');
```

Assume `qVec` and `rotmatArray` correspond to a sequence of rotations. Combine the quaternion rotations into a single representation, then apply the quaternion rotation to arbitrarily initialized Cartesian points.

```
loc = normalize(randn(1,3));
quat = prod(qVec);
rotateframe(quat,loc)
```

ans = *1×3*

```
    0.9524    0.5297    0.9013
```

Combine the rotation matrices into a single representation, then apply the rotation matrix to the same initial Cartesian points. Verify the quaternion rotation and rotation matrix result in the same orientation.

```
totalRotMat = eye(3);
for i = 1:size(rotmatArray,3)
    totalRotMat = rotmatArray(:,:,i)*totalRotMat;
end
totalRotMat*loc'
```

ans = *3×1*

```
    0.9524
    0.5297
    0.9013
```

Input Arguments

quat — Quaternion to convert
scalar | vector | matrix | multidimensional array

Quaternion to convert, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

rotationType — Type or rotation
`'frame'` | `'point'`

Type of rotation represented by the `rotationMatrix` output, specified as `'frame'` or `'point'`.

Data Types: `char` | `string`

Output Arguments

`rotationMatrix` — Rotation matrix representation
3-by-3 matrix | 3-by-3-by-*N* multidimensional array

Rotation matrix representation, returned as a 3-by-3 matrix or 3-by-3-by-*N* multidimensional array.

- If `quat` is a scalar, `rotationMatrix` is returned as a 3-by-3 matrix.
- If `quat` is non-scalar, `rotationMatrix` is returned as a 3-by-3-by-*N* multidimensional array, where `rotationMatrix(:,:,i)` is the rotation matrix corresponding to `quat(i)`.

The data type of the rotation matrix is the same as the underlying data type of `quat`.

Data Types: `single` | `double`

Algorithms

Given a quaternion of the form

$$q = a + bi + cj + dk \,,$$

the equivalent rotation matrix for frame rotation is defined as

$$\begin{bmatrix} 2a^2 - 1 + 2b^2 & 2bc + 2ad & 2bd - 2ac \\ 2bc - 2ad & 2a^2 - 1 + 2c^2 & 2cd + 2ab \\ 2bd + 2ac & 2cd - 2ab & 2a^2 - 1 + 2d^2 \end{bmatrix} \,.$$

The equivalent rotation matrix for point rotation is the transpose of the frame rotation matrix:

$$\begin{bmatrix} 2a^2 - 1 + 2b^2 & 2bc - 2ad & 2bd + 2ac \\ 2bc + 2ad & 2a^2 - 1 + 2c^2 & 2cd - 2ab \\ 2bd - 2ac & 2cd + 2ab & 2a^2 - 1 + 2d^2 \end{bmatrix}.$$

References

[1] Kuipers, Jack B. *Quaternions and Rotation Sequences: A Primer with Applications to Orbits, Aerospace, and Virtual Reality.* Princeton, NJ: Princeton University Press, 2007.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
euler | eulerd | rotvec | rotvecd

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

rotvec

Convert quaternion to rotation vector (radians)

Syntax

```
rotationVector = rotvec(quat)
```

Description

`rotationVector = rotvec(quat)` converts the quaternion array, `quat`, to an *N*-by-3 matrix of equivalent rotation vectors in radians. The elements of `quat` are normalized before conversion.

Examples

Convert Quaternion to Rotation Vector in Radians

Convert a random quaternion scalar to a rotation vector in radians

```
quat = quaternion(randn(1,4));
rotvec(quat)
```

ans = *1×3*

```
    1.6866   -2.0774    0.7929
```

Input Arguments

quat — Quaternion to convert
scalar | vector | matrix | multidimensional array

1-135

Quaternion to convert, specified as scalar quaternion, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

Output Arguments

`rotationVector` — Rotation vector (radians)
N-by-3 matrix

Rotation vector representation, returned as an *N*-by-3 matrix of rotations vectors, where each row represents the [X Y Z] angles of the rotation vectors in radians. The *i*th row of `rotationVector` corresponds to the element `quat(i)`.

The data type of the rotation vector is the same as the underlying data type of `quat`.

Data Types: `single` | `double`

Algorithms

All rotations in 3-D can be represented by a three-element axis of rotation and a rotation angle, for a total of four elements. If the rotation axis is constrained to be unit length, the rotation angle can be distributed over the vector elements to reduce the representation to three elements.

Recall that a quaternion can be represented in axis-angle form

$$q = \cos\left(\frac{\theta}{2}\right) + \sin\left(\frac{\theta}{2}\right)(x\mathtt{i} + y\mathtt{j} + z\mathtt{k}),$$

where θ is the angle of rotation and [*x,y,z*] represent the axis of rotation.

Given a quaternion of the form

$$q = a + bi + cj + dk,$$

you can solve for the rotation angle using the axis-angle form of quaternions:

$$\theta = 2\cos^{-1}(a).$$

Assuming a normalized axis, you can rewrite the quaternion as a rotation vector without loss of information by distributing θ over the parts b, c, and d. The rotation vector representation of q is

$$q_{\mathrm{rv}} = \frac{\theta}{\sin\left(\theta/2\right)} \, [b, \, c, \, d] \, .$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
euler | eulerd | rotvecd

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

times, .*

Element-wise quaternion multiplication

Syntax

```
quatC = A.*B
```

Description

`quatC = A.*B` returns the element-by-element quaternion multiplication of quaternion arrays.

You can use quaternion multiplication to compose rotation operators:

- To compose a sequence of frame rotations, multiply the quaternions in the same order as the desired sequence of rotations. For example, to apply a *p* quaternion followed by a *q* quaternion, multiply in the order *pq*. The rotation operator becomes

  $(pq)^* \, v \, (pq)$, where *v* represents the object to rotate in quaternion form. * represents conjugation.

- To compose a sequence of point rotations, multiply the quaternions in the reverse order of the desired sequence of rotations. For example, to apply a *p* quaternion followed by a *q* quaternion, multiply in the reverse order, *qp*. The rotation operator

  becomes $(qp) \, v \, (qp)^*$.

Examples

Multiply Two Quaternion Vectors

Create two vectors, A and B, and multiply them element by element.

```
A = quaternion([1:4;5:8]);
B = A;
C = A.*B
```

```
C = 2x1 quaternion array
     -28 +   4i +   6j +   8k
    -124 +  60i +  70j +  80k
```

Multiply Two Quaternion Arrays

Create two 3-by-3 arrays, A and B, and multiply them element by element.

```
A = reshape(quaternion(randn(9,4)),3,3);
B = reshape(quaternion(randn(9,4)),3,3);
C = A.*B
```

```
C = 3x3 quaternion array
     0.60169 +  2.4332i -  2.5844j + 0.51646k    -0.49513 +  1.1722i +  4.4401j -   1.2
    -4.2329  +  2.4547i +  3.7768j + 0.77484k    -0.65232 - 0.43112i -  1.4645j - 0.900
    -4.4159  +  2.1926i +  1.9037j -  4.0303k     -2.0232 +  0.4205i - 0.17288j +  3.85
```

Note that quaternion multiplication is not commutative:

```
isequal(C,B.*A)
```

```
ans = logical
   0
```

Multiply Quaternion Row and Column Vectors

Create a row vector a and a column vector b, then multiply them. The 1-by-3 row vector and 4-by-1 column vector combine to produce a 4-by-3 matrix with all combinations of elements multiplied.

```
a = [zeros('quaternion'),ones('quaternion'),quaternion(randn(1,4))]
```

```
a = 1x3 quaternion array
         0 +        0i +        0j +        0k            1 +        0i +        0j +

b = quaternion(randn(4,4))

b = 4x1 quaternion array
     0.31877 +    3.5784i +   0.7254j -   0.12414k
     -1.3077 +    2.7694i - 0.063055j +    1.4897k
    -0.43359 -    1.3499i +   0.71474j +     1.409k
     0.34262 +    3.0349i -   0.20497j +    1.4172k

a.*b

ans = 4x3 quaternion array
             0 +         0i +         0j +         0k       0.31877 +    3.5784i +    0.7254j
             0 +         0i +         0j +         0k       -1.3077 +    2.7694i - 0.063055j
             0 +         0i +         0j +         0k      -0.43359 -    1.3499i +   0.71474j
             0 +         0i +         0j +         0k       0.34262 +    3.0349i -   0.20497j
```

Input Arguments

A — Array to multiply
scalar | vector | matrix | multidimensional array

Array to multiply, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of them is 1.

Data Types: quaternion | single | double

B — Array to multiply
scalar | vector | matrix | multidimensional array

Array to multiply, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of them is 1.

Data Types: `quaternion` | `single` | `double`

Output Arguments

quatC — Quaternion product
scalar | vector | matrix | multidimensional array

Quaternion product, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Quaternion Multiplication by a Real Scalar

Given a quaternion,

$$q = a_q + b_q\mathtt{i} + c_q\mathtt{j} + d_q\mathtt{k},$$

the product of q and a real scalar β is

$$\beta q = \beta a_q + \beta b_q\mathtt{i} + \beta c_q\mathtt{j} + \beta d_q\mathtt{k}$$

Quaternion Multiplication by a Quaternion Scalar

The definition of the basis elements for quaternions,

$$\mathtt{i}^2 = \mathtt{j}^2 = \mathtt{k}^2 = \mathtt{i}\mathtt{j}\mathtt{k} = -1,$$

can be expanded to populate a table summarizing quaternion basis element multiplication:

	1	**i**	**j**	**k**
1	1	i	j	k
i	i	−1	k	−j
j	j	−k	−1	i
k	k	j	−i	−1

When reading the table, the rows are read first, for example: ij = k and ji = −k.

Given two quaternions, $q = a_q + b_q i + c_q j + d_q k$, and $p = a_p + b_p i + c_p j + d_p k$, the multiplication can be expanded as:

$$z = pq = \left(a_p + b_p i + c_p j + d_p k \right) \left(a_q + b_q i + c_q j + d_q k \right)$$
$$= a_p a_q + a_p b_q i + a_p c_q j + a_p d_q k$$
$$+ b_p a_q i + b_p b_q i^2 + b_p c_q ij + b_p d_q ik$$
$$+ c_p a_q j + c_p b_q ji + c_p c_q j^2 + c_p d_q jk$$
$$+ d_p a_q k + d_p b_q ki + d_p c_q kj + d_p d_q k^2$$

You can simplify the equation using the quaternion multiplication table.

$$z = pq = a_p a_q + a_p b_q i + a_p c_q j + a_p d_q k$$
$$+ b_p a_q i - b_p b_q + b_p c_q k - b_p d_q j$$
$$+ c_p a_q j - c_p b_q k - c_p c_q + c_p d_q i$$
$$+ d_p a_q k + d_p b_q j - d_p c_q i - d_p d_q$$

References

[1] Kuipers, Jack B. *Quaternions and Rotation Sequences: A Primer with Applications to Orbits, Aerospace, and Virtual Reality.* Princeton, NJ: Princeton University Press, 2007.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
mtimes, * | prod

Objects
quaternion

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

transpose, .'

Transpose a quaternion array

Syntax

```
Y = quat.'
```

Description

`Y = quat.'` returns the non-conjugate transpose of the quaternion array, `quat`.

Examples

Vector Transpose

Create a vector of quaternions and compute its nonconjugate transpose.

```
quat = quaternion(randn(4,4))

quat = 4x1 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k
       1.8339 -   1.3077i +   2.7694j - 0.063055k
      -2.2588 -  0.43359i -   1.3499j +  0.71474k
      0.86217 +  0.34262i +   3.0349j -  0.20497k


quatTransposed = quat.'

quatTransposed = 1x4 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k       1.8339 -   1.3077i +   2.7694j
```

Matrix Transpose

Create a matrix of quaternions and compute its nonconjugate transpose.

```
quat = [quaternion(randn(2,4)),quaternion(randn(2,4))]
```

```
quat = 2x2 quaternion array
     0.53767 -   2.2588i +  0.31877j -  0.43359k       3.5784 -   1.3499i +   0.7254j
      1.8339 +  0.86217i -   1.3077j +  0.34262k       2.7694 +   3.0349i - 0.063055j
```

```
quatTransposed = quat.'
```

```
quatTransposed = 2x2 quaternion array
     0.53767 -   2.2588i +  0.31877j -  0.43359k       1.8339 +  0.86217i -   1.3077j
      3.5784 -   1.3499i +   0.7254j +  0.71474k       2.7694 +   3.0349i - 0.063055j
```

Input Arguments

quat — Quaternion array to transpose
vector | matrix

Quaternion array to transpose, specified as a vector or matrix of quaternions. `transpose` is defined for 1-D and 2-D arrays. For higher-order arrays, use `permute`.

Data Types: `quaternion`

Output Arguments

Y — Transposed quaternion array
vector | matrix

Transposed quaternion array, returned as an *N*-by-*M* array, where `quat` was specified as an *M*-by-*N* array.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`ctranspose`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

uminus, -

Quaternion unary minus

Syntax

```
mQuat = -quat
```

Description

`mQuat = -quat` negates the elements of `quat` and stores the result in `mQuat`.

Examples

Negate Elements of Quaternion Matrix

Unary minus negates each part of a the quaternion. Create a 2-by-2 matrix, `Q`.

```
Q = quaternion(randn(2),randn(2),randn(2),randn(2))

Q = 2x2 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k      -2.2588 -  0.43359i -   1.3499j
       1.8339 -   1.3077i +   2.7694j - 0.063055k       0.86217 +  0.34262i +   3.0349j
```

Negate the parts of each quaternion in `Q`.

```
R = -Q

R = 2x2 quaternion array
     -0.53767 -  0.31877i -   3.5784j -   0.7254k       2.2588 +  0.43359i +   1.3499j
      -1.8339 +   1.3077i -   2.7694j + 0.063055k      -0.86217 -  0.34262i -   3.0349j
```

1-147

Input Arguments

quat — Quaternion array
scalar | vector | matrix | multidimensional array

Quaternion array, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Output Arguments

mQuat — Negated quaternion array
scalar | vector | matrix | multidimensional array

Negated quaternion array, returned as the same size as `quat`.

Data Types: `quaternion`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`minus, -`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

zeros

Create quaternion array with all parts set to zero

Syntax

```
quatZeros = zeros('quaternion')
quatZeros = zeros(n,'quaternion')
quatZeros = zeros(sz,'quaternion')
quatZeros = zeros(sz1,...,szN,'quaternion')

quatZeros = zeros( ___ ,'like',prototype,'quaternion')
```

Description

`quatZeros = zeros('quaternion')` returns a scalar quaternion with all parts set to zero.

`quatZeros = zeros(n,'quaternion')` returns an n-by-n matrix of quaternions.

`quatZeros = zeros(sz,'quaternion')` returns an array of quaternions where the size vector, `sz`, defines `size(quatZeros)`.

`quatZeros = zeros(sz1,...,szN,'quaternion')` returns a `sz1`-by-...-by-`szN` array of quaternions where `sz1,…,szN` indicates the size of each dimension.

`quatZeros = zeros( ___ ,'like',prototype,'quaternion')` specifies the underlying class of the returned quaternion array to be the same as the underlying class of the quaternion prototype.

Examples

Quaternion Scalar Zero

Create a quaternion scalar zero.

```
quatZeros = zeros('quaternion')

quatZeros = quaternion
     0 + 0i + 0j + 0k
```

Square Matrix of Quaternions

Create an n-by-n array of quaternion zeros.

```
n = 3;
quatZeros = zeros(n,'quaternion')

quatZeros = 3x3 quaternion array
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
```

Multidimensional Array of Quaternion Zeros

Create a multidimensional array of quaternion zeros by defining array dimensions in order. In this example, you create a 3-by-1-by-2 array. You can specify dimensions using a row vector or comma-separated integers.

Specify the dimensions using a row vector and display the results:

```
dims = [3,1,2];
quatZerosSyntax1 = zeros(dims,'quaternion')

quatZerosSyntax1 = 3x1x2 quaternion array
quatZerosSyntax1(:,:,1) =

     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k


quatZerosSyntax1(:,:,2) =
```

```
     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k
```

Specify the dimensions using comma-separated integers, and then verify the equivalence of the two syntaxes:

```
quatZerosSyntax2 = zeros(3,1,2,'quaternion');
isequal(quatZerosSyntax1,quatZerosSyntax2)
```

```
ans = logical
   1
```

Underlying Class of Quaternion Zeros

A quaternion is a four-part hyper-complex number used in three-dimensional representations. You can specify the underlying data type of the parts as `single` or `double`. The default is `double`.

Create a quaternion array of zeros with the underlying data type set to `single`.

```
quatZeros = zeros(2,'like',single(1),'quaternion')
```

```
quatZeros = 2x2 quaternion array
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
```

Verify the underlying class using the `classUnderlying` function.

```
classUnderlying(quatZeros)
```

```
ans =
'single'
```

Input Arguments

n — Size of square quaternion matrix
integer value

Size of square quaternion matrix, specified as an integer value. If `n` is `0` or negative, then `quatZeros` is returned as an empty matrix.

Example: `zeros(4,'quaternion')` returns a 4-by-4 matrix of quaternion zeros.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

sz — Output size
row vector of integer values

Output size, specified as a row vector of integer values. Each element of `sz` indicates the size of the corresponding dimension in `quatZeros`. If the size of any dimension is `0` or negative, then `quatZeros` is returned as an empty array.

Example: `zeros([1,4,2],'quaternion')` returns a 1-by-4-by-2 array of quaternion zeros.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

prototype — Quaternion prototype
variable

Quaternion prototype, specified as a variable.

Example: `zeros(2,'like',quat,'quaternion')` returns a 2-by-2 matrix of quaternions with the same underlying class as the prototype quaternion, `quat`.

Data Types: `quaternion`

sz1,...,szN — Size of each dimension
two or more integer values

Size of each dimension, specified as two or more integers.

- If the size of any dimension is `0`, then `quatZeros` is returned as an empty array.
- If the size of any dimension is negative, then it is treated as `0`.

Example: `zeros(2,3,'quaternion')` returns a 2-by-3 matrix of quaternion zeros.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

quatZeros — Quaternion zeros
scalar | vector | matrix | multidimensional array

Quaternion zeros, returned as a quaternion or array of quaternions.

Given a quaternion of the form $Q = a + bi + cj + dk$, a quaternion zero is defined as $Q = 0 + 0i + 0j + 0k$.

Data Types: `quaternion`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`ones`

Objects
`quaternion`

Topics
"Rotations, Orientation and Quaternions"

Introduced in R2018a

constvel

Constant velocity state update

Syntax

```
updatedstate = constvel(state)
updatedstate = constvel(state,dt)
```

Description

`updatedstate = constvel(state)` returns the updated state, `state`, of a constant-velocity Kalman filter motion model after a one-second time step.

`updatedstate = constvel(state,dt)` specifies the time step, `dt`.

Examples

Update State for Constant-Velocity Motion

Update the state of two-dimensional constant-velocity motion for a time interval of one second.

```
state = [1;1;2;1];
state = constvel(state)

state = 4×1

    2
    1
    3
    1
```

Update State for Constant-Velocity Motion with Specified Time Step

Update the state of two-dimensional constant-velocity motion for a time interval of 1.5 seconds.

```
state = [1;1;2;1];
state = constvel(state,1.5)
```

```
state = 4×1

    2.5000
    1.0000
    3.5000
    1.0000
```

Input Arguments

`state` — Kalman filter state vector
real-valued *2N*-element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued *2N*-element column vector where *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	`[x;vx]`
2-D	`[x;vx;y;vy]`
3-D	`[x;vx;y;vy;z;vz]`

For example, x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. If the motion model is 1-D, values along the *y* and *z* axes are assumed to be zero. If the motion model is 2-D, values along the *z* axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: `[5;.1;0;-.2;-3;.05]`

Data Types: `single` | `double`

`dt` — Time step interval of filter
`1.0` (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: `0.5`

Data Types: `single` | `double`

Output Arguments

updatedstate — Updated state vector
real-valued column or row vector | real-valued matrix

Updated state vector, returned as a real-valued vector or real-valued matrix with same number of elements and dimensions as the input state vector.

Algorithms

For a two-dimensional constant-velocity process, the state transition matrix after a time step, T, is block diagonal as shown here.

$$\begin{bmatrix} x_{k+1} \\ v_{x,k+1} \\ y_{k+1} \\ v_{y,k+1} \end{bmatrix} = \begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_k \\ vx_k \\ y_k \\ vy_k \end{bmatrix}$$

The block for each spatial dimension is:

$$\begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

constveljac

Jacobian for constant-velocity motion

Syntax

```
jacobian = constveljac(state)
jacobian = constveljac(state,dt)
```

Description

`jacobian = constveljac(state)` returns the updated Jacobian , `jacobian`, for a constant-velocity Kalman filter motion model for a step time of one second. The `state` argument specifies the current state of the filter.

`jacobian = constveljac(state,dt)` specifies the time step, `dt`.

Examples

Compute State Jacobian for Constant-Velocity Motion

Compute the state Jacobian for a two-dimensional constant-velocity motion model for a one second update time.

```
state = [1,1,2,1].';
jacobian = constveljac(state)

jacobian = 4×4

    1    1    0    0
    0    1    0    0
    0    0    1    1
    0    0    0    1
```

Compute State Jacobian for Constant-Velocity Motion with Specified Time Step

Compute the state Jacobian for a two-dimensional constant-velocity motion model for a half-second update time.

```
state = [1;1;2;1];
```

Compute the state update Jacobian for 0.5 second.

```
jacobian = constveljac(state,0.5)

jacobian = 4×4

    1.0000    0.5000         0         0
         0    1.0000         0         0
         0         0    1.0000    0.5000
         0         0         0    1.0000
```

Input Arguments

state — Kalman filter state vector
real-valued *2N*-element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued *2N*-element column vector where *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx]
2-D	[x;vx;y;vy]
3-D	[x;vx;y;vy;z;vz]

For example, x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. If the motion model is 1-D, values along the *y* and *z* axes are assumed to be zero. If the motion model is 2-D, values along the *z* axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: `[5;.1;0;-.2;-3;.05]`

Data Types: `single` | `double`

`dt` — Time step interval of filter
`1.0` (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: `0.5`

Data Types: `single` | `double`

Output Arguments

`jacobian` — Constant-velocity motion Jacobian
real-valued *2N*-by-*2N* matrix

Constant-velocity motion Jacobian, returned as a real-valued *2N*-by-*2N* matrix. *N* is the number of spatial degrees of motion.

Algorithms

For a two-dimensional constant-velocity motion, the Jacobian matrix for a time step, *T*, is block diagonal:

$$\begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The block for each spatial dimension has this form:

$$\begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

cvmeas

Measurement function for constant velocity motion

Syntax

```
measurement = cvmeas(state)
measurement = cvmeas(state,frame)
measurement = cvmeas(state,frame,sensorpos)
measurement = cvmeas(state,frame,sensorpos,sensorvel)
measurement = cvmeas(state,frame,sensorpos,sensorvel,laxes)
measurement = cvmeas(state,measurementParameters)
```

Description

`measurement = cvmeas(state)` returns the measurement for a constant-velocity Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the tracking filter.

`measurement = cvmeas(state,frame)` also specifies the measurement coordinate system, `frame`.

`measurement = cvmeas(state,frame,sensorpos)` also specifies the sensor position, `sensorpos`.

`measurement = cvmeas(state,frame,sensorpos,sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurement = cvmeas(state,frame,sensorpos,sensorvel,laxes)` specifies the local sensor axes orientation, `laxes`.

`measurement = cvmeas(state,measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Create Measurement from Constant-Velocity Object in Rectangular Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in both dimensions. The measurements are in rectangular coordinates.

```
state = [1;10;2;20];
measurement = cvmeas(state)
```

measurement = *3×1*

```
     1
     2
     0
```

The *z*-component of the measurement is zero.

Create Measurement from Constant Velocity Object in Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each spatial dimension. The measurements are in spherical coordinates.

```
state = [1;10;2;20];
measurement = cvmeas(state,'spherical')
```

measurement = *4×1*

```
   63.4349
         0
    2.2361
   22.3607
```

The elevation of the measurement is zero and the range rate is positive. These results indicate that the object is moving away from the sensor.

1-165

Create Measurement from Constant-Velocity Object in Translated Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state consists of position and velocity in each spatial dimension. The measurements are in spherical coordinates with respect to a frame located at *(20;40;0)* meters.

```
state = [1;10;2;20];
measurement = cvmeas(state,'spherical',[20;40;0])
```

```
measurement = 4×1

 -116.5651
        0
   42.4853
  -22.3607
```

The elevation of the measurement is zero and the range rate is negative. These results indicate that the object is moving toward the sensor.

Create Measurement from Constant-Velocity Object Using Measurement Parameters

Define the state of an object in 2-D constant-velocity motion. The state consists of position and velocity in each spatial dimension. The measurements are in spherical coordinates with respect to a frame located at *(20;40;0)* meters.

```
state2d = [1;10;2;20];
frame = 'spherical';
sensorpos = [20;40;0];
sensorvel = [0;5;0];
laxes = eye(3);
measurement = cvmeas(state2d,frame,sensorpos,sensorvel,laxes)
```

```
measurement = 4×1

 -116.5651
        0
   42.4853
  -17.8885
```

The elevation of the measurement is zero and the range rate is negative. These results indicate that the object is moving toward the sensor.

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurement = cvmeas(state2d,measparm)

measurement = 4×1

 -116.5651
         0
   42.4853
  -17.8885
```

Input Arguments

state — Kalman filter state vector
real-valued *2N*-element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued *2N*-element column vector where *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx]
2-D	[x;vx;y;vy]
3-D	[x;vx;y;vy;z;vz]

For example, x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. If the motion model is 1-D, values along the *y* and *z* axes are assumed to be zero. If the motion model is 2-D, values along the *z* axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: [5;.1;0;-.2;-3;.05]

Data Types: single | double

frame — Measurement frame
'rectangular' (default) | 'spherical'

Measurement frame, specified as 'rectangular' or 'spherical'. When the frame is 'rectangular', a measurement consists of the x, y, and z Cartesian coordinates of the tracked object. When specified as 'spherical', a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: char

sensorpos — Sensor position
[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: double

sensorvel — Sensor velocity
[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: double

laxes — Local sensor coordinate axes
[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x-, y-, and z-axes, respectively, with respect to the global coordinate system.

Data Types: double

measurementParameters — Measurement parameters
structure

Measurement parameters, specified as a structure. The fields of the structure are:

measurementParameters struct

Parameter	Definition	Default
OriginPosition	Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.	[0;0;0]
OriginVelocity	Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in m/s.	[0;0;0]
Orientation	Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.	eye(3)
HasVelocity	Indicates whether measurements contain velocity or range rate components, specified as true or false.	false when frame argument is 'rectangular' and true when frame argument is 'spherical'
HasElevation	Indicates whether measurements contain elevation components, specified as true or false.	true

Data Types: struct

Output Arguments

measurement — Measurement vector
N-by-1 column vector

Measurement vector, returned as an *N*-by-1 column vector. The form of the measurement depends upon which syntax you use.

- When the syntax does not use the `measurementParameters` argument, the measurement vector is `[x,y,z]` when the `frame` input argument is set to `'rectangular'` and `[az;el;r;rr]` when the `frame` is set to `'spherical'`.

- When the syntax uses the `measurementParameters` argument, the size of the measurement vector depends on the values of the `frame`, `HasVelocity`, and `HasElevation` fields in the `measurementParameters` structure.

frame	measurement
`'spherical'`	Specifies the azimuth angle, *az*, elevation angle, *el*, range, *r*, and range rate, *rr*, of the object with respect to the local ego coordinate system. Positive values for range rate indicate that an object is moving away from the sensor. **Spherical measurements** <table><tr><td></td><td></td><td colspan="2">**HasElevation**</td></tr><tr><td></td><td></td><td>false</td><td>true</td></tr><tr><td>**HasVelocity**</td><td>false</td><td>`[az;r]`</td><td>`[az;el;r]`</td></tr><tr><td></td><td>true</td><td>`[az;r;rr]`</td><td>`[az;el;r;rr]`</td></tr></table> Angle units are in degrees, range units are in meters, and range rate units are in m/s.

frame	measurement
`'rectangular`	Specifies the Cartesian position and velocity coordinates of the tracked object with respect to the ego coordinate system. **Rectangular measurements** <table><tr><td rowspan="2">**HasVelocity**</td><td>false</td><td>`[x;y;y]`</td></tr><tr><td>true</td><td>`[x;vx;y,vy;z;vz]`</td></tr></table> Position units are in meters and velocity units are in m/s.

Data Types: `double`

Definitions

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Sensor Fusion and Tracking Toolbox.

The azimuth angle of a vector is the angle between the *x*-axis and its orthogonal projection onto the *xy* plane. The angle is positive in going from the *x* axis toward the *y* axis. Azimuth angles lie between –180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the *xy*-plane. The angle is positive when going toward the positive *z*-axis from the *xy* plane.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

cvmeasjac

Jacobian of measurement function for constant velocity motion

Syntax

```
measurementjac = cvmeasjac(state)
measurementjac = cvmeasjac(state,frame)
measurementjac = cvmeasjac(state,frame,sensorpos)
measurementjac = cvmeasjac(state,frame,sensorpos,sensorvel)
measurementjac = cvmeasjac(state,frame,sensorpos,sensorvel,laxes)
measurementjac = cvmeasjac(state,measurementParameters)
```

Description

measurementjac = cvmeasjac(state) returns the measurement Jacobian for constant-velocity Kalman filter motion model in rectangular coordinates. state specifies the current state of the tracking filter.

measurementjac = cvmeasjac(state,frame) also specifies the measurement coordinate system, frame.

measurementjac = cvmeasjac(state,frame,sensorpos) also specifies the sensor position, sensorpos.

measurementjac = cvmeasjac(state,frame,sensorpos,sensorvel) also specifies the sensor velocity, sensorvel.

measurementjac = cvmeasjac(state,frame,sensorpos,sensorvel,laxes) also specifies the local sensor axes orientation, laxes.

measurementjac = cvmeasjac(state,measurementParameters) specifies the measurement parameters, measurementParameters.

Examples

Measurement Jacobian of Constant-Velocity Object in Rectangular Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each spatial dimension. Construct the measurement Jacobian in rectangular coordinates.

```
state = [1;10;2;20];
jacobian = cvmeasjac(state)
```

```
jacobian = 3×4

     1     0     0     0
     0     0     1     0
     0     0     0     0
```

Measurement Jacobian of Constant-Velocity Motion in Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each dimension. Compute the measurement Jacobian with respect to spherical coordinates.

```
state = [1;10;2;20];
measurementjac = cvmeasjac(state,'spherical')
```

```
measurementjac = 4×4

  -22.9183         0   11.4592         0
         0         0         0         0
    0.4472         0    0.8944         0
    0.0000    0.4472    0.0000    0.8944
```

Measurement Jacobian of Constant-Velocity Object in Translated Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each spatial dimension. Compute the measurement Jacobian with respect to spherical coordinates centered at *(5;-20;0)* meters.

1-175

```
state = [1;10;2;20];
sensorpos = [5;-20;0];
measurementjac = cvmeasjac(state,'spherical',sensorpos)

measurementjac = 4×4

   -2.5210         0   -0.4584         0
         0         0         0         0
   -0.1789         0    0.9839         0
    0.5903   -0.1789    0.1073    0.9839
```

Create Measurement Jacobian for Constant-Velocity Object Using Measurement Parameters

Define the state of an object in 2-D constant-velocity motion. The state consists of position and velocity in each spatial dimension. The measurements are in spherical coordinates with respect to a frame located at *(20;40;0)* meters.

```
state2d = [1;10;2;20];
frame = 'spherical';
sensorpos = [20;40;0];
sensorvel = [0;5;0];
laxes = eye(3);
measurementjac = cvmeasjac(state2d,frame,sensorpos,sensorvel,laxes)

measurementjac = 4×4

    1.2062         0   -0.6031         0
         0         0         0         0
   -0.4472         0   -0.8944         0
    0.0471   -0.4472   -0.0235   -0.8944
```

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurementjac = cvmeasjac(state2d,measparm)

measurementjac = 4×4
```

```
    1.2062          0   -0.6031          0
         0          0         0          0
   -0.4472          0   -0.8944          0
    0.0471    -0.4472   -0.0235    -0.8944
```

Input Arguments

`state` — Kalman filter state vector
real-valued *2N*-element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued *2N*-element column vector where *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	`[x;vx]`
2-D	`[x;vx;y;vy]`
3-D	`[x;vx;y;vy;z;vz]`

For example, `x` represents the *x*-coordinate and `vx` represents the velocity in the *x*-direction. If the motion model is 1-D, values along the *y* and *z* axes are assumed to be zero. If the motion model is 2-D, values along the *z* axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: `[5;.1;0;-.2;-3;.05]`

Data Types: `single` | `double`

`frame` — Measurement frame
`'rectangular'` (default) | `'spherical'`

Measurement frame, specified as `'rectangular'` or `'spherical'`. When the frame is `'rectangular'`, a measurement consists of the *x*, *y*, and *z* Cartesian coordinates of the tracked object. When specified as `'spherical'`, a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: `char`

`sensorpos` — Sensor position
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: `double`

`sensorvel` — Sensor velocity
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: `double`

`laxes` — Local sensor coordinate axes
`[1,0,0;0,1,0;0,0,1]` (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x-, y-, and z-axes, respectively, with respect to the global coordinate system.

Data Types: `double`

`measurementParameters` — Measurement parameters
structure

Measurement parameters, specified as a structure. The fields of the structure are:

measurementParameters struct

Parameter	Definition	Default
OriginPosition	Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.	[0;0;0]
OriginVelocity	Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in m/s.	[0;0;0]
Orientation	Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x-, y-, and z-axes, respectively, with respect to the global coordinate system.	eye(3)
HasVelocity	Indicates whether measurements contain velocity or range rate components, specified as true or false.	false when frame argument is 'rectangular' and true when frame argument is 'spherical'
HasElevation	Indicates whether measurements contain elevation components, specified as true or false.	true

Data Types: struct

Output Arguments

measurementjac — Measurement Jacobian
real-valued 3-by-N matrix | real-valued 4-by-N matrix

Measurement Jacobian, specified as a real-valued 3-by-*N* or 4-by-*N* matrix. *N* is the dimension of the state vector. The first dimension and meaning depend on value of the `frame` argument.

Frame	Measurement Jacobian
`'rectangular'`	Jacobian of the measurements `[x;y;z]` with respect to the state vector. The measurement vector is with respect to the local coordinate system. Coordinates are in meters.
`'spherical'`	Jacobian of the measurement vector `[az;el;r;rr]` with respect to the state vector. Measurement vector components specify the azimuth angle, elevation angle, range, and range rate of the object with respect to the local sensor coordinate system. Angle units are in degrees. Range units are in meters and range rate units are in meters/second.

Definitions

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Sensor Fusion and Tracking Toolbox.

The azimuth angle of a vector is the angle between the *x*-axis and its orthogonal projection onto the *xy* plane. The angle is positive in going from the *x* axis toward the *y* axis. Azimuth angles lie between –180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the *xy*-plane. The angle is positive when going toward the positive *z*-axis from the *xy* plane.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

constacc

Constant-acceleration motion model

Syntax

```
updatedstate = constacc(state)
updatedstate = constacc(state,dt)
```

Description

updatedstate = constacc(state) returns the updated state, state, of a constant velocity Kalman filter motion model for a step time of one second.

updatedstate = constacc(state,dt) specifies the time step, dt.

Examples

Predict State for Constant-Acceleration Motion

Define an initial state for 2-D constant-acceleration motion.

```
state = [1;1;1;2;1;0];
```

Predict the state 1 second later.

```
state = constacc(state)
```

state = 6×1

```
    2.5000
    2.0000
    1.0000
    3.0000
    1.0000
```

```
            0
```

Predict State for Constant-Acceleration Motion With Specified Time Step

Define an initial state for 2-D constant-acceleration motion.

```
state = [1;1;1;2;1;0];
```

Predict the state 0.5 s later.

```
state = constacc(state,0.5)

state = 6×1

    1.6250
    1.5000
    1.0000
    2.5000
    1.0000
         0
```

Input Arguments

`state` — Kalman filter state vector
real-valued *3N*-element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued *3N*-element vector. *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	`[x;vx;ax]`
2-D	`[x;vx;ax;y;vy;ay]`
3-D	`[x;vx;ax;y;vy;ay;z;vz;az]`

For example, `x` represents the *x*-coordinate, `vx` represents the velocity in the *x*-direction, and `ax` represents the acceleration in the *x*-direction. If the motion model is in one-dimensional space, the *y*- and *z*-axes are assumed to be zero. If the motion model is in two-dimensional space, values along the *z*-axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second^2.

Example: `[5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]`

Data Types: `double`

dt — Time step interval of filter
`1.0` (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: `0.5`

Data Types: `single` | `double`

Output Arguments

updatedstate — Updated state vector
real-valued column or row vector | real-valued matrix

Updated state vector, returned as a real-valued vector or real-valued matrix with same number of elements and dimensions as the input state vector.

Algorithms

For a two-dimensional constant-acceleration process, the state transition matrix after a time step, *T*, is block diagonal:

$$\begin{bmatrix} x_{k+1} \\ vx_{k+1} \\ ax_{k+1} \\ y_{k+1} \\ vy_{k+1} \\ ay_{k+1} \end{bmatrix} = \begin{bmatrix} 1 & T & \frac{1}{2}T^2 & 0 & 0 & 0 \\ 0 & 1 & T & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & T & \frac{1}{2}T^2 \\ 0 & 0 & 0 & 0 & 1 & T \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_k \\ vx_k \\ ax_k \\ y_k \\ vy_k \\ ay_k \end{bmatrix}$$

The block for each spatial dimension has this form:

$$\begin{bmatrix} 1 & T & \frac{1}{2}T^2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constaccjac | constturn | constturnjac | constvel |
constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF |
trackingUKF

Introduced in R2017a

constaccjac

Jacobian for constant-acceleration motion

Syntax

```
jacobian = constaccjac(state)
jacobian = constaccjac(state,dt)
```

Description

`jacobian = constaccjac(state)` returns the updated Jacobian , `jacobian`, for a constant-acceleration Kalman filter motion model. The step time is one second. The `state` argument specifies the current state of the filter.

`jacobian = constaccjac(state,dt)` also specifies the time step, `dt`.

Examples

Compute State Jacobian for Constant-Acceleration Motion

Compute the state Jacobian for two-dimensional constant-acceleration motion.

Define an initial state and compute the state Jacobian for a one second update time.

```
state = [1,1,1,2,1,0];
jacobian = constaccjac(state)

jacobian = 6×6

    1.0000    1.0000    0.5000         0         0         0
         0    1.0000    1.0000         0         0         0
         0         0    1.0000         0         0         0
         0         0         0    1.0000    1.0000    0.5000
         0         0         0         0    1.0000    1.0000
```

```
       0        0        0        0        0    1.0000
```

Compute State Jacobian for Constant-Acceleration Motion with Specified Time Step

Compute the state Jacobian for two-dimensional constant-acceleration motion. Set the step time to 0.5 seconds.

```
state = [1,1,1,2,1,0].';
jacobian = constaccjac(state,0.5)
```

jacobian = *6×6*

```
   1.0000    0.5000    0.1250         0         0         0
        0    1.0000    0.5000         0         0         0
        0         0    1.0000         0         0         0
        0         0         0    1.0000    0.5000    0.1250
        0         0         0         0    1.0000    0.5000
        0         0         0         0         0    1.0000
```

Input Arguments

state — Kalman filter state vector
real-valued *3N*-element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued *3N*-element vector. *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx;ax]
2-D	[x;vx;ax;y;vy;ay]
3-D	[x;vx;ax;y;vy;ay;z;vz;az]

For example, x represents the *x*-coordinate, vx represents the velocity in the *x*-direction, and ax represents the acceleration in the *x*-direction. If the motion model is in one-

dimensional space, the *y*- and *z*-axes are assumed to be zero. If the motion model is in two-dimensional space, values along the *z*-axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second^2.

Example: `[5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]`

Data Types: `double`

dt — Time step interval of filter
`1.0` (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: `0.5`

Data Types: `single` | `double`

Output Arguments

`jacobian` — Constant-acceleration motion Jacobian
real-valued *3N*-by-*3N* matrix

Constant-acceleration motion Jacobian, returned as a real-valued *3N*-by-*3N* matrix.

Algorithms

For a two-dimensional constant-acceleration process, the Jacobian matrix after a time step, *T*, is block diagonal:

$$\begin{bmatrix} 1 & T & \frac{1}{2}T^2 & 0 & 0 & 0 \\ 0 & 1 & T & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & T & \frac{1}{2}T^2 \\ 0 & 0 & 0 & 0 & 1 & T \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The block for each spatial dimension has this form:

$$\begin{bmatrix} 1 & T & \frac{1}{2}T^2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

constvelmsc

Constant velocity (CV) motion model in MSC frame

Syntax

```
state = constvelmsc(state,vNoise)
state = constvelmsc(state,vNoise,dt)
state = constvelmsc(state,vNoise,dt,u)
```

Description

`state = constvelmsc(state,vNoise)` calculates the state at the next time-step based on current state and target acceleration noise, `vNoise`, in the scenario. The function assumes a time interval, `dt`, of one second, and zero observer acceleration in all dimensions.

`state = constvelmsc(state,vNoise,dt)` specifies the time interval, `dt`. The function assumes zero observer acceleration in all dimensions.

`state = constvelmsc(state,vNoise,dt,u)` specifies the observer input, `u`, during the time interval, `dt`.

Examples

Predict Constant Velocity MSC State with Different Inputs

Define a state vector for a 3-D MSC state.

```
mscState = [0.1;0.01;0.1;0.01;0.001;1];
dt = 0.1;
```

Predict the state with zero observer acceleration.

```
mscState = constvelmsc(mscState,zeros(3,1),dt)
```

```
mscState = 6×1

    0.1009
    0.0083
    0.1009
    0.0083
    0.0009
    0.9091
```

Predict the state with [5;3;1] observer acceleration in scenario.

```
mscState = constvelmsc(mscState,zeros(3,1),dt,[5;3;1])
```

```
mscState = 6×1

    0.1017
    0.0067
    0.1017
    0.0069
    0.0008
    0.8329
```

Predict the state with observer maneuver and unit standard deviation random noise in target acceleration. Let observer acceleration in the time interval be $\begin{bmatrix} \sin(t) & \cos(t) \end{bmatrix}$.

```
velManeuver = [1 - cos(dt);sin(dt);0];
posManeuver = [-sin(dt);cos(dt) - 1;0];
u = zeros(6,1);
u(1:2:end) = posManeuver;
u(2:2:end) = velManeuver;
mscState = constvelmsc(mscState,randn(3,1),dt,u)
```

```
mscState = 6×1

    0.1023
    0.0058
    0.1023
    0.0057
    0.0008
    0.7689
```

Predict and Measure State of Constant Velocity Target in Modified Spherical Coordinates

Define a state vector for a motion model in 2-D. The time interval is 2 seconds.

```
mscState = [0.5;0.02;1/1000;-10/1000];
dt = 2;
```

As modified spherical coordinates (MSC) state is relative, let the observer state be defined by a constant acceleration model in 2-D.

```
observerState = [100;10;0.5;20;-5;0.1];
```

Pre-allocate memory. `rPlot` is the range for plotting bearing measurements.

```
observerPositions = zeros(2,10);
targetPositions = zeros(2,10);
azimuthMeasurement = zeros(1,10);
bearingHistory = zeros(2,30);
rPlot = 2000;
```

Use a loop to predict the state multiple times. Use `constvelmsc` to create a trajectory with constant velocity target and measure the angles using the measurement function, `cvmeasmsc`.

```
for i = 1:10
    obsAcceleration = observerState(3:3:end);
    % Use zeros(2,1) as process noise to get true predictions
    mscState = constvelmsc(mscState,zeros(2,1),dt,obsAcceleration);

    % Update observer state using constant acceleration model
    observerState = constacc(observerState,dt);
    observerPositions(:,i) = observerState(1:3:end);

    % Update bearing history with current measurement.
    az = cvmeasmsc(mscState);
    bearingHistory(:,3*i-2) = observerState(1:3:end);
    bearingHistory(:,3*i-1) = observerState(1:3:end) + [rPlot*cosd(az);rPlot*sind(az)];
    bearingHistory(:,3*i) = [NaN;NaN];

    % Use the 'rectangular' frame to get relative positions of the
    % target using cvmeasmsc function.
```

```
    relativePosition = cvmeasmsc(mscState,'rectangular');
    relativePosition2D = relativePosition(1:2);
    targetPositions(:,i) = relativePosition2D + observerPositions(:,i);
end

plot(observerPositions(1,:),observerPositions(2,:)); hold on;
plot(targetPositions(1,:),targetPositions(2,:));
plot(bearingHistory(1,:),bearingHistory(2,:),'-.');
title('Constant velocity model in modified spherical coordinates');xlabel('X[m]'); ylab
legend('Observer Positions', 'Target Positions', 'Bearings Measurements'); hold off;
```
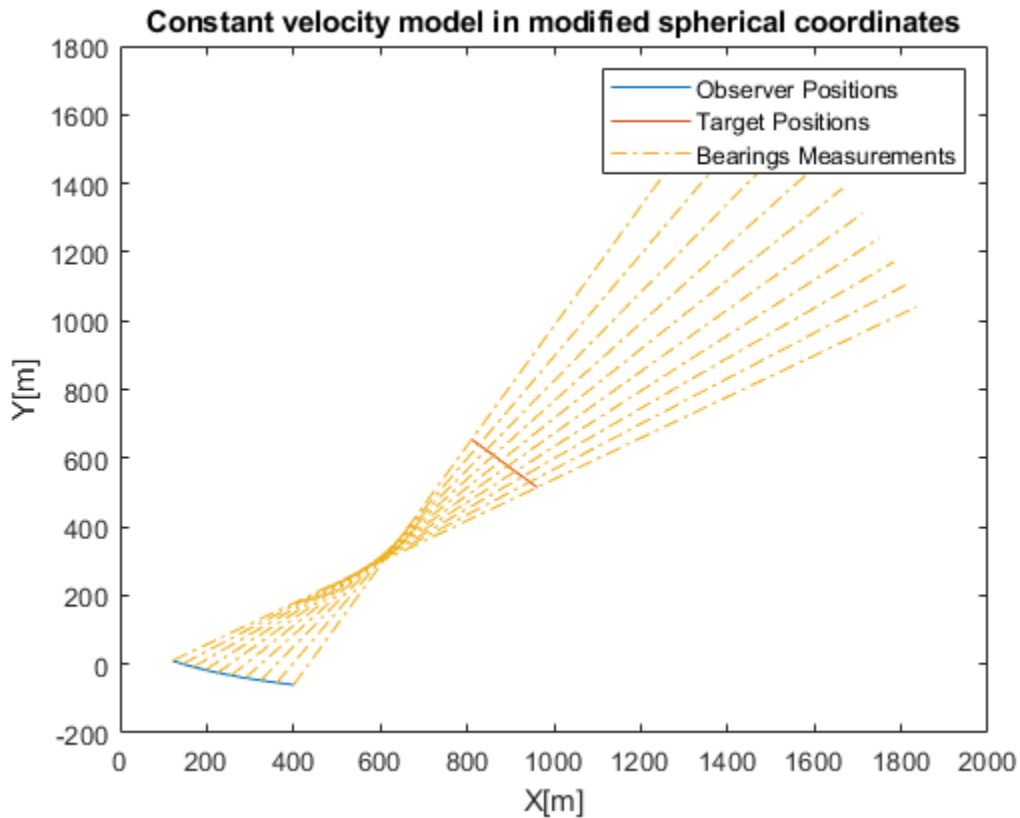
Input Arguments

`state` — Relative state
vector | 2-D matrix

State that is defined relative to an observer in modified spherical coordinates, specified as a vector or a 2-D matrix. For example, if there is a constant velocity target state, *xT*, and a constant velocity observer state, *xO*, then the `state` is defined as *xT - xO* transformed in modified spherical coordinates.

The two-dimensional version of modified spherical coordinates (MSC) is also referred to as the modified polar coordinates (MPC). In the case of:

- 2-D space –– State is equal to [*az azRate* 1/*r vr/r*]
- 3-D space –– State is equal to [*az omega el elRate* 1/*r vr/r*]

If specified as a matrix, states must be concatenated along columns, where each column represents a state following the convention specified above.

The variables used in the convention are:

- *az* –– Azimuth angle (rad)
- *el* –– Elevation angle (rad)
- *azRate* –– Azimuth rate (rad/s)
- *elRate* –– Elevation rate (rad/s)
- *omega* –– *azRate* × cos(*el*) (rad/s)
- 1/*r* –– 1/range (1/m)
- *vr/r* –– range-rate/range or inverse time-to-go (1/s)

Data Types: `single` | `double`

`vNoise` — Target acceleration noise
vector | matrix

Target acceleration noise in the scenario, specified as a vector of 2 or 3 elements or a matrix with dimensions corresponding to `state`. That is, if the dimensions of the `state` matrix is 6-by-10, then the acceptable dimensions for `vNoise` is 3-by-10. If the dimensions of the `state` matrix is 4-by-10, then the acceptable dimensions for `vNoise` is 2-by-10. For more details, see "Orientation, Position, and Coordinate Systems".

Data Types: `double`

`dt` — Time difference
scalar

Time difference between current state and the time at which the state is to be calculated, specified as a real finite numeric scalar.

Data Types: `single` | `double`

`u` — Observer input
vector

Observer input, specified as a vector. The observer input can have the following impact on state-prediction based on its dimensions:

- When the number of elements in `u` equals the number of elements in `state`, the input `u` is assumed to be the maneuver performed by the observer during the time interval, `dt`. A maneuver is defined as motion of the observer higher than first order (or constant velocity).

- When the number of elements in `u` equals half the number of elements in `state`, the input `u` is assumed to be constant acceleration of the observer, specified in the scenario frame during the time interval, `dt`.

Data Types: `double`

Output Arguments

`state` — State at next time step
vector | 2-D matrix | 3-D matrix

State at the next time step, returned as a vector and a matrix of two or three dimensions. The state at the next time step is calculated based on the current state and the target acceleration noise, `vNoise`.

Data Types: `double`

Algorithms

The function provides a constant velocity transition function in modified spherical coordinates (MSC) using a non-additive noise structure. The MSC frame assumes a single observer and the state is defined relative to it.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Objects
trackingMSCEKF

Classes
trackingEKF

Functions
constvelmscjac

Introduced in R2018b

constvelmscjac

Jacobian of constant velocity (CV) motion model in MSC frame

Syntax

```
[jacobianState,jacobianNoise] = constvelmscjac(state,vNoise)
[jacobianState,jacobianNoise] = constvelmscjac(state,vNoise,dt)
[jacobianState,jacobianNoise] = constvelmscjac(state,vNoise,dt,u)
```

Description

`[jacobianState,jacobianNoise] = constvelmscjac(state,vNoise)` calculates the Jacobian matrix of the motion model with respect to the state vector and the noise. The input `state` defines the current state, and `vNoise` defines the target acceleration noise in the observer's Cartesian frame. The functon assumes a time interval, `dt`, of one second, and zero observer acceleration in all dimensions.

The `trackingEKF` object allows you to specify the `StateTransitionJacobianFcn` property. The function can be used as a `StateTransitionJacobianFcn` when the `HasAdditiveProcessNoise` is set to `false`.

`[jacobianState,jacobianNoise] = constvelmscjac(state,vNoise,dt)` specifies the time interval, `dt`. The function assumes zero observer acceleration in all dimensions.

`[jacobianState,jacobianNoise] = constvelmscjac(state,vNoise,dt,u)` specifies the observer input, `u`, during the time interval, `dt`.

Examples

Compute Jacobian of State Transition Function

Define a state vector for 2-D MSC.

```
state = [0.5;0.01;0.001;0.01];
```

Calculate the Jacobian matrix assuming dt = 1 second, no observer maneuver, and zero target acceleration noise.

```
[jacobianState,jacobianNoise] = constvelmscjac(state,zeros(2,1)) %#ok
```

jacobianState = *4×4*

```
    1.0000     0.9900    -0.0000    -0.0098
   -0.0000     0.9800    -0.0000    -0.0194
    0.0000    -0.0000     0.9901    -0.0010
   -0.0000     0.0194    -0.0000     0.9800
```

jacobianNoise = *4×2*
10^{-3} ×

```
   -0.2416     0.4321
   -0.4851     0.8574
   -0.0004    -0.0002
    0.8574     0.4851
```

Calculate the Jacobian matrix, given dt = 0.1 seconds, no observer maneuver, and a unit standard deviation target acceleration noise.

```
[jacobianState,jacobianNoise] = constvelmscjac(state,randn(2,1),0.1) %#ok
```

jacobianState = *4×4*

```
    1.0000     0.0999     0.0067    -0.0001
   -0.0001     0.9980     0.1348    -0.0020
   -0.0000    -0.0000     0.9990    -0.0001
    0.0001     0.0020     0.1351     0.9980
```

jacobianNoise = *4×2*
10^{-4} ×

```
   -0.0240     0.0438
   -0.4800     0.8755
   -0.0000    -0.0000
    0.8755     0.4800
```

Calculate the Jacobian matrix, given dt = 0.1 seconds and observer acceleration = [0.1 0.3] in the 2-D observer's Cartesian coordinates.

```
[jacobianState,jacobianNoise] = constvelmscjac(state,randn(2,1),0.1,[0.1;0.3])
```

jacobianState = *4×4*

```
    1.0000     0.0999     0.0081    -0.0001
    0.0002     0.9980     0.1625    -0.0020
   -0.0000    -0.0000     0.9990    -0.0001
    0.0002     0.0020    -0.1795     0.9980
```

jacobianNoise = *4×2*
10^{-4} ×

```
   -0.0240     0.0438
   -0.4800     0.8756
   -0.0000    -0.0000
    0.8756     0.4800
```

Input Arguments

state — Relative state
vector

State that is defined relative to an observer in modified spherical coordinates, specified as a vector. For example, if there is a constant velocity target state, *xT*, and a constant velocity observer state, *xO*, then the state is defined as *xT* - *xO* transformed in modified spherical coordinates.

The two-dimensional version of modified spherical coordinates (MSC) is also referred to as the modified polar coordinates (MPC).

In case the motion is in:

- 2-D space –– State is equal to [*az azRate* 1/*r vr*/*r*]
- 3-D space –– State is equal to [*az omega el elRate* 1/*r vr*/*r*]

The variables used in the convention are:

- *az* –– Azimuth angle (rad)
- *el* –– Elevation angle (rad)
- *azRate* –– Azimuth rate (rad/s)
- *elRate* –– Elevation rate (rad/s)
- *omega* –– *azRate* × cos(*el*) (rad/s)
- $1/r$ –– 1/range (1/m)
- *vr/r* –– range-rate/range or inverse time-to-go (1/s)

Data Types: `single` | `double`

`vNoise` — Target acceleration noise
vector

Target acceleration noise in scenario, specified as a vector of 2 or 3 elements.

Data Types: `double`

`dt` — Time difference
scalar

Time difference between the current state and the time at which the state is to be calculated, specified as a real finite numeric scalar.

Data Types: `single` | `double`

`u` — Observer input
vector | 2-D matrix | 3-D matrix

Observer input, specified as a vector or a matrix. The observer input can have the following impact on state-prediction based on its dimensions:

- When the number of elements in u equals the number of elements in `state`, the input u is assumed to be the maneuver performed by the observer during the time interval, `dt`. A maneuver is defined as motion of the observer higher than first order (or constant velocity).
- When the number of elements in u equals half the number of elements in `state`, the input u is assumed to be constant acceleration of the observer, specified in the scenario frame during the time interval, `dt`.

Data Types: `double`

Output Arguments

`jacobianState` — Jacobian of predicted state
matrix

Jacobian of the predicted state with respect to the previous state, returned as an *n*-by-*n* matrix, where *n* is the number of states in the state vector.

Data Types: `double`

`jacobianNoise` — Jacobian of predicted state
matrix

Jacobian of the predicted state with respect to the noise elements, returned as an *n*-by-*m* matrix. The variable *n* is the number of states in the state vector, and the variable *m* is the number of process noise terms. That is, *m* = 2 for state in 2-D space, and *m* = 3 for state in 3-D space.

For example, if the state vector is a 4-by-1 vector in a 2-D space, `vNoise` must be a 2-by-1 vector, and `jacobianNoise` is a 4-by-2 matrix.

If the state vector is a 6-by-1 vector in 3-D space, `vNoise` must be a 3-by-1 vector, and `jacobianNoise` is a 6-by-3 matrix.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
trackingEKF

Functions
constvelmsc

Introduced in R2018b

cvmeasmsc

Measurement based on constant velocity (CV) model in MSC frame

Syntax

```
measurement = cvmeasmsc(state)
measurement = cvmeasmsc(state,frame)
measurement = cvmeasmsc(state,frame,laxes)
measurement = cvmeasmsc(state,measurementParameters)
```

Description

measurement = cvmeasmsc(state) provides the angular measurement (azimuth and elevation) of the state in the sensor frame described by the state.

Tracking filters require a definition of the MeasurementFcn property. The cvmeasmsc function can be used as the MeasurementFcn. To use this MeasurementFcn with trackerGNN and trackerTOMHT, you can use the trackingMSCEKF filter.

measurement = cvmeasmsc(state,frame) provides the measurement in the frame specified. The allowed values for frame are 'rectangular' and 'spherical'.

measurement = cvmeasmsc(state,frame,laxes) specifies the axes of the sensor's coordinate system. The laxes input is a 3-by-3 matrix with each column specifying the direction of local *x, y* and *z* axes in the observer's Cartesian frame. The default for laxes is [1 0 0;0 1 0;0 0 1].

measurement = cvmeasmsc(state,measurementParameters) specifies the measurement parameters as a scalar struct or an array of struct.

Examples

Obtain Measurements in MSC Frame

Using the `cvmeasmsc` function, you can obtain measurements of the state in the spherical and the rectangular frames.

Spherical Frame

Obtain the azimuth and elevation measurements from an MSC state.

```
mscState = [0.5;0;0.3;0;1e-3;1e-2];
cvmeasmsc(mscState)
```

ans = *2×1*

```
   28.6479
   17.1887
```

Rectangular Frame

Obtain the position measurement from an MSC state. Specify the frame as a second input.

```
cvmeasmsc(mscState,'rectangular')
```

ans = *3×1*

```
  838.3866
  458.0127
  295.5202
```

Alternatively, you can specify the frame using `measurementParameters`.

```
cvmeasmsc(mscState,struct('Frame','rectangular'))
```

ans = *3×1*

```
  838.3866
  458.0127
  295.5202
```

Input Arguments

`state` — Relative state
vector | matrix

State that is defined relative to an observer in modified spherical coordinates, specified as a vector or a 2-D matrix. For example, if there is a constant velocity target state, *xT*, and a constant velocity observer state, *xO*, then the `state` is defined as *xT* - *xO* transformed in modified spherical coordinates.

The two-dimensional version of modified spherical coordinates (MSC) is also referred to as the modified polar coordinates (MPC). In the case of:

- 2-D space –– State is equal to [*az azRate* 1/*r vr/r*].
- 3-D space –– State is equal to [*az omega el elRate* 1/*r vr/r*].

The variables used in the convention are:

- *az* –– Azimuth angle (rad)
- *el* –– Elevation angle (rad)
- *azRate* –– Azimuth rate (rad/s)
- *elRate* –– Elevation rate (rad/s)
- *omega* –– *azRate* × cos(*el*) (rad/s)
- 1/*r* –– 1/range (1/m)
- *vr/r* –– range-rate/range or inverse time-to-go (1/s)

If the input state is specified as a matrix, states must be concatenated along columns, where each column represents a state following the convention specified above. The output is a matrix with the same number of columns as the input, where each column represents the measurement from the corresponding state.

If the motion model is in 2-D space, values corresponding to elevation are assumed to be zero if elevation is requested as an output.

Data Types: `single` | `double`

frame — Measurement frame
`'spherical'` (default) | `'rectangular'`

Measurement frame, specified as `'spherical'` or `'rectangular'`. If using the `'rectangular'` frame, the three elements present in the measurement represent *x*, *y*, and *z* position of the target in the observer's Cartesian frame. If using the `'spherical'` frame, the two elements present in the measurement represent azimuth and elevation measurement of the target. If not specified, the function provides the measurements in `'spherical'` frame.

laxes — Direction of local axes
`[1 0 0;0 1 0;0 0 1]` (default) | 3-by-3 matrix

Direction of local *x*, *y*, and *z* axes in the scenario, specified as a 3-by-3 matrix. If not specified, `laxes` is equal to `[1 0 0;0 1 0;0 0 1]`.

Data Types: `double`

measurementParameters — Measurement parameters
scalar struct | array of struct

Measurement parameters, specified as a scalar struct or an array of struct. The structures must have the following fields (or a subset of them):

- `Frame` –– Either `'rectangular'` or `'spherical'` or an enumeration with the same values. Default: `'spherical'`.
- `Orientation` –– A 3-by-3 `laxes` matrix.
- `HasElevation` –– A logical scalar, `true` if elevation is measured. Default: `true` if `state` is in 3-D space, `false` if `state` is in 2-D space.
- `IsParentToChild` –– A logical scalar, `true` if the orientation is given as a parent to child frame rotation.

Data Types: `struct`

Output Arguments

measurement — Measurement from MSC state
vector

Target measurement in MSC frame, returned as a:

- One-element vector –– When `HasElevation` is set to `false`, the vector contains azimuth as the only measurement.
- Two-element vector –– When the `frame` is set to `'spherical'`, the function measures the azimuth and elevation measurements from an MSC state.
- Three-element vector –– When the `frame` is set to `'rectangular'`, the function measures the position measurement from an MSC state.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Objects
trackingMSCEKF

Functions
constvelmsc | cvmeasmscjac | initcvmscekf

Introduced in R2018b

cvmeasmscjac

Jacobian of measurement using constant velocity (CV) model in MSC frame

Syntax

```
jacobian = cvmeasmscjac(state)
jacobian = cvmeasmscjac(state,frame)
jacobian = cvmeasmscjac(state,frame,laxes)
jacobian = cvmeasmscjac(state,measurementParameters)
```

Description

`jacobian = cvmeasmscjac(state)` calculates the Jacobian with respect to angular measurement (azimuth and elevation) of the state in the sensor frame. The motion can be either in 2-D or 3-D space. If motion model is in 2-D space, values corresponding to elevation are assumed to be zero.

The `trackingEKF` and `trackingMSCEKF` filters require a definition of the `MeasurementJacobianFcn` property. The `cvmeasmscjac` function can be used as the `MeasurementJacobianFcn`. To use this `MeasurementFcn` with `trackerGNN` and `trackerTOMHT`, you can use the `trackingMSCEKF` filter.

`jacobian = cvmeasmscjac(state,frame)` provides the Jacobian measurement in the frame specified. The allowed values for frame are `'rectangular'` and `'spherical'`.

`jacobian = cvmeasmscjac(state,frame,laxes)` specifies the axes of the sensor's coordinate system. The `laxes` input is a 3-by-3 matrix with each column specifying the direction of local x, y, and z axes in the sensor coordinate system. The default for `laxes` is [1 0 0;0 1 0;0 0 1].

`jacobian = cvmeasmscjac(state,measurementParameters)` specifies the measurement parameters as a struct.

Examples

Obtain Jacobian of State Measurements in MSC Frame

Using the `cvmeasmscjac` function, you can obtain the jacobian of the state measurements in the spherical and the rectangular frames.

Spherical Frame

Obtain the Jacobian of the azimuth and elevation measurements from an MSC state.

```
mscState = [0.5;0;0.3;0;1e-3;1e-2];
cvmeasmscjac(mscState)
```

ans = *2×6*

```
  57.2958         0         0         0         0         0
        0         0   57.2958         0         0         0
```

Rectangular Frame

Obtain the Jacobian of the position measurement from an MSC state. Specify the frame as a second input.

```
cvmeasmscjac(mscState,'rectangular')
```

ans = *3×6*
$10^5 \times$

```
  -0.0046         0   -0.0026         0   -8.3839         0
   0.0084         0   -0.0014         0   -4.5801         0
        0         0    0.0096         0   -2.9552         0
```

Alternatively, you can specify the frame using `measurementParameters`.

```
cvmeasmscjac(mscState,struct('Frame','rectangular'))
```

ans = *3×6*
$10^5 \times$

```
  -0.0046         0   -0.0026         0   -8.3839         0
   0.0084         0   -0.0014         0   -4.5801         0
        0         0    0.0096         0   -2.9552         0
```

1-211

Input Arguments

state — Relative state
vector

State that is defined relative to an observer in modified spherical coordinates, as a vector. For example, if there is a target state, *xT*, and an observer state, *xO*, the `state` used by the function is *xT* - *xO*.

The 2-D version of modified spherical coordinates (MSC) is also referred to as the modified polar coordinates (MPC). In the case of:

- 2-D space –– State equals [*az azRate* 1/*r vr/r*].
- 3-D space –– State equals [*az omega el elRate* 1/*r vr/r*].

The variables used in the convention are:

- *az* –– Azimuth angle (rad)
- *el* –– Elevation angle (rad)
- *azRate* –– Azimuth rate (rad/s)
- *elRate* –– Elevation rate (rad/s)
- *omega* –– *azRate* × cos(*el*) (rad/s)
- 1/*r* –– 1/range (1/m)
- *vr/r* –– range-rate/range or inverse time-to-go (1/s)

If the motion model is in 2-D space, values corresponding to elevation are assumed to be zero if elevation is requested as an output.

Data Types: `single` | `double`

frame — Measurement frame
`'spherical'` (default) | `'rectangular'`

Measurement frame, specified as `'spherical'` or `'rectangular'`. If using the `'rectangular'` frame, the three rows present in `jacobian` represent the Jacobian of the measurements with respect to *x*, *y*, and *z* position of the target in the sensor's Cartesian frame. If using the `'spherical'` frame, the two rows present in `jacobian`

represent the Jacobian of the azimuth and elevation measurements of the target. If not specified, the function provides the Jacobian of the measurements in the `'spherical'` frame.

laxes — Direction of local axes
[1 0 0;0 1 0;0 0 1] (default) | 3-by-3 matrix

Direction of local *x*, *y*, and *z* axes in the scenario, specified as a 3-by-3 matrix. Each column of the matrix specifies the direction of the local *x*, *y*, and *z* axes in the sensor coordinate system. If not specified, the `laxes` is equal to `[1 0 0;0 1 0;0 0 1]`.

Data Types: `double`

measurementParameters — Measurement parameters
struct

Measurement parameters, specified as a struct. The structure must have the following fields (or a subset of them):

- `Frame` –– Either `'rectangular'` or `'spherical'` or an enum with the same values. Default: `'spherical'`.

- `Orientation` –– A 3-by-3 `laxes` matrix.

- `HasElevation` –– A logical scalar, `true` if elevation is measured. Default: `true` if `state` is in 3-D space, `false` if `state` is in 2-D space.

- `IsParentToChild` –– A logical scalar, `true` if the orientation is given as a parent to child frame rotation.

Data Types: `struct`

Output Arguments

jacobian — Measurement from MSC state
matrix

Target measurement in MSC frame, returned as a:

- One-row matrix –– When `HasElevation` is set to `false`.

- Two-row matrix –– When the `frame` is set to `'spherical'`, the function measures the azimuth and elevation measurements from a MSC state.

1-213

- Three-row matrix –– When the `frame` is set to `'rectangular'`, the function measures the position measurement from a MSC state.

Extended Capabilities

C/C++ Code Generation
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See Also

Objects
trackingMSCEKF

Functions
constvelmsc | cvmeasmsc | initcvmscekf

Introduced in R2018b

cameas

Measurement function for constant-acceleration motion

Syntax

```
measurement = cameas(state)
measurement = cameas(state,frame)
measurement = cameas(state,frame,sensorpos)
measurement = cameas(state,frame,sensorpos,sensorvel)
measurement = cameas(state,frame,sensorpos,sensorvel,laxes)
measurement = cameas(state,measurementParameters)
```

Description

`measurement = cameas(state)` returns the measurement, for the constant-acceleration Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the filter.

`measurement = cameas(state,frame)` also specifies the measurement coordinate system, `frame`.

`measurement = cameas(state,frame,sensorpos)` also specifies the sensor position, `sensorpos`.

`measurement = cameas(state,frame,sensorpos,sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurement = cameas(state,frame,sensorpos,sensorvel,laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurement = cameas(state,measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Create Measurement from Accelerating Object in Rectangular Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. The measurements are in rectangular coordinates.

```
state = [1,10,3,2,20,0.5].';
measurement = cameas(state)
```

```
measurement = 3×1

     1
     2
     0
```

The measurement is returned in three-dimensions with the *z*-component set to zero.

Create Measurement from Accelerating Object in Spherical Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. The measurements are in spherical coordinates.

```
state = [1,10,3,2,20,5].';
measurement = cameas(state,'spherical')
```

```
measurement = 4×1

   63.4349
         0
    2.2361
   22.3607
```

The elevation of the measurement is zero and the range rate is positive. These results indicate that the object is moving away from the sensor.

Create Measurement from Accelerating Object in Translated Spherical Frame

Define the state of an object moving in 2-D constant-acceleration motion. The state consists of position, velocity, and acceleration in each dimension. The measurements are in spherical coordinates with respect to a frame located at *(20;40;0)* meters from the origin.

```
state = [1,10,3,2,20,5].';
measurement = cameas(state,'spherical',[20;40;0])
```

measurement = *4×1*

```
 -116.5651
         0
   42.4853
  -22.3607
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

Create Measurement from Constant-Accelerating Object Using Measurement Parameters

Define the state of an object moving in 2-D constant-acceleration motion. The state consists of position, velocity, and acceleration in each dimension. The measurements are in spherical coordinates with respect to a frame located at *(20;40;0)* meters from the origin.

```
state2d = [1,10,3,2,20,5].';
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

```
frame = 'spherical';
sensorpos = [20;40;0];
sensorvel = [0;5;0];
laxes = eye(3);
measurement = cameas(state2d,'spherical',sensorpos,sensorvel,laxes)
```

measurement = *4×1*

```
  -116.5651
          0
    42.4853
  -17.8885
```

The elevation of the measurement is zero and the range rate is negative. These results indicate that the object is moving toward the sensor.

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurement = cameas(state2d,measparm)
```

measurement = *4×1*

```
  -116.5651
          0
    42.4853
  -17.8885
```

Input Arguments

`state` — Kalman filter state vector
real-valued *3N*-element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued *3N*-element vector. *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	`[x;vx;ax]`
2-D	`[x;vx;ax;y;vy;ay]`
3-D	`[x;vx;ax;y;vy;ay;z;vz;az]`

For example, x represents the *x*-coordinate, vx represents the velocity in the *x*-direction, and ax represents the acceleration in the *x*-direction. If the motion model is in one-dimensional space, the *y*- and *z*-axes are assumed to be zero. If the motion model is in

two-dimensional space, values along the *z*-axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second^2.

Example: `[5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]`

Data Types: `double`

`frame` — Measurement frame
`'rectangular'` (default) | `'spherical'`

Measurement frame, specified as `'rectangular'` or `'spherical'`. When the frame is `'rectangular'`, a measurement consists of the *x*, *y*, and *z* Cartesian coordinates of the tracked object. When specified as `'spherical'`, a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: `char`

`sensorpos` — Sensor position
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: `double`

`sensorvel` — Sensor velocity
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: `double`

`laxes` — Local sensor coordinate axes
`[1,0,0;0,1,0;0,0,1]` (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.

Data Types: `double`

`measurementParameters` — Measurement parameters
structure

Measurement parameters, specified as a structure. The fields of the structure are:

measurementParameters struct

Parameter	Definition	Default
OriginPosition	Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.	[0;0;0]
OriginVelocity	Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in m/s.	[0;0;0]
Orientation	Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.	eye(3)
HasVelocity	Indicates whether measurements contain velocity or range rate components, specified as true or false.	false when frame argument is 'rectangular' and true when frame argument is 'spherical'
HasElevation	Indicates whether measurements contain elevation components, specified as true or false.	true

Data Types: struct

Output Arguments

measurement — Measurement vector
N-by-1 column vector

Measurement vector, returned as an *N*-by-1 column vector. The form of the measurement depends upon which syntax you use.

- When the syntax does not use the `measurementParameters` argument, the measurement vector is `[x,y,z]` when the `frame` input argument is set to `'rectangular'` and `[az;el;r;rr]` when the `frame` is set to `'spherical'`.

- When the syntax uses the `measurementParameters` argument, the size of the measurement vector depends on the values of the `frame`, `HasVelocity`, and `HasElevation` fields in the `measurementParameters` structure.

frame	measurement
`'spherical'`	Specifies the azimuth angle, *az*, elevation angle, *el*, range, *r*, and range rate, *rr*, of the object with respect to the local ego coordinate system. Positive values for range rate indicate that an object is moving away from the sensor. **Spherical measurements** <table><tr><td></td><td></td><td colspan="2">**HasElevation**</td></tr><tr><td></td><td></td><td>false</td><td>true</td></tr><tr><td>**HasVelocity**</td><td>false</td><td>`[az;r]`</td><td>`[az;el;r]`</td></tr><tr><td></td><td>true</td><td>`[az;r;rr]`</td><td>`[az;el;r;rr]`</td></tr></table> Angle units are in degrees, range units are in meters, and range rate units are in m/s.

frame	measurement
`'rectangular`	Specifies the Cartesian position and velocity coordinates of the tracked object with respect to the ego coordinate system. **Rectangular measurements** |		
---	---	---
HasVelocity	false	`[x;y;y]`
	true	`[x;vx;y,vy;z;vz]`	 Position units are in meters and velocity units are in m/s.

Data Types: `double`

Definitions

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Sensor Fusion and Tracking Toolbox.

The azimuth angle of a vector is the angle between the *x*-axis and its orthogonal projection onto the *xy* plane. The angle is positive in going from the *x* axis toward the *y* axis. Azimuth angles lie between –180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the *xy*-plane. The angle is positive when going toward the positive *z*-axis from the *xy* plane.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

cameasjac

Jacobian of measurement function for constant-acceleration motion

Syntax

```
measurementjac = cameasjac(state)
measurementjac = cameasjac(state,frame)
measurementjac = cameasjac(state,frame,sensorpos)
measurementjac = cameasjac(state,frame,sensorpos,sensorvel)
measurementjac = cameasjac(state,frame,sensorpos,sensorvel,laxes)
measurementjac = cameasjac(state,measurementParameters)
```

Description

`measurementjac = cameasjac(state)` returns the measurement Jacobian, for constant-acceleration Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the filter.

`measurementjac = cameasjac(state,frame)` also specifies the measurement coordinate system, `frame`.

`measurementjac = cameasjac(state,frame,sensorpos)` also specifies the sensor position, `sensorpos`.

`measurementjac = cameasjac(state,frame,sensorpos,sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurementjac = cameasjac(state,frame,sensorpos,sensorvel,laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurementjac = cameasjac(state,measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Measurement Jacobian of Accelerating Object in Rectangular Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Construct the measurement Jacobian in rectangular coordinates.

```
state = [1,10,3,2,20,5].';
jacobian = cameasjac(state)
```

```
jacobian = 3×6

    1    0    0    0    0    0
    0    0    0    1    0    0
    0    0    0    0    0    0
```

Measurement Jacobian of Accelerating Object in Spherical Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Compute the measurement Jacobian in spherical coordinates.

```
state = [1;10;3;2;20;5];
measurementjac = cameasjac(state,'spherical')
```

```
measurementjac = 4×6

  -22.9183         0         0   11.4592         0         0
         0         0         0         0         0         0
    0.4472         0         0    0.8944         0         0
    0.0000    0.4472         0    0.0000    0.8944         0
```

Measurement Jacobian of Accelerating Object in Translated Spherical Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Compute the measurement Jacobian in spherical coordinates with respect to an origin at *(5;-20;0)* meters.

```
state = [1,10,3,2,20,5].';
sensorpos = [5,-20,0].';
measurementjac = cameasjac(state,'spherical',sensorpos)
```

```
measurementjac = 4×6

   -2.5210         0         0   -0.4584         0         0
         0         0         0         0         0         0
   -0.1789         0         0    0.9839         0         0
    0.5903   -0.1789         0    0.1073    0.9839         0
```

Create Measurement Jacobian of Accelerating Object Using Measurement Parameters

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Compute the measurement Jacobian in spherical coordinates with respect to an origin at *(5;-20;0)* meters.

```
state2d = [1,10,3,2,20,5].';
sensorpos = [5,-20,0].';
frame = 'spherical';
sensorvel = [0;8;0];
laxes = eye(3);
measurementjac = cameasjac(state2d,frame,sensorpos,sensorvel,laxes)
```

```
measurementjac = 4×6

   -2.5210         0         0   -0.4584         0         0
         0         0         0         0         0         0
   -0.1789         0         0    0.9839         0         0
    0.5274   -0.1789         0    0.0959    0.9839         0
```

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurementjac = cameasjac(state2d,measparm)
```

```
measurementjac = 4×6
```

```
  -2.5210          0          0    -0.4584          0          0
        0          0          0          0          0          0
  -0.1789          0          0     0.9839          0          0
   0.5274    -0.1789          0     0.0959     0.9839          0
```

Input Arguments

`state` — Kalman filter state vector
real-valued *3N*-element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued *3N*-element vector. *N* is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	`[x;vx;ax]`
2-D	`[x;vx;ax;y;vy;ay]`
3-D	`[x;vx;ax;y;vy;ay;z;vz;az]`

For example, `x` represents the *x*-coordinate, `vx` represents the velocity in the *x*-direction, and `ax` represents the acceleration in the *x*-direction. If the motion model is in one-dimensional space, the *y*- and *z*-axes are assumed to be zero. If the motion model is in two-dimensional space, values along the *z*-axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second^2.

Example: `[5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]`

Data Types: `double`

`frame` — Measurement frame
`'rectangular'` (default) | `'spherical'`

Measurement frame, specified as `'rectangular'` or `'spherical'`. When the frame is `'rectangular'`, a measurement consists of the *x*, *y*, and *z* Cartesian coordinates of the tracked object. When specified as `'spherical'`, a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: `char`

`sensorpos` — Sensor position
[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: `double`

`sensorvel` — Sensor velocity
[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: `double`

`laxes` — Local sensor coordinate axes
[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x-, y-, and z-axes, respectively, with respect to the global coordinate system.

Data Types: `double`

`measurementParameters` — Measurement parameters
structure

Measurement parameters, specified as a structure. The fields of the structure are:

measurementParameters struct

Parameter	Definition	Default
OriginPosition	Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.	[0;0;0]
OriginVelocity	Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in m/s.	[0;0;0]
Orientation	Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.	eye(3)
HasVelocity	Indicates whether measurements contain velocity or range rate components, specified as true or false.	false when frame argument is 'rectangular' and true when frame argument is 'spherical'
HasElevation	Indicates whether measurements contain elevation components, specified as true or false.	true

Data Types: struct

Output Arguments

measurementjac — Measurement Jacobian
real-valued 3-by-*N* matrix | real-valued 4-by-*N* matrix

Measurement Jacobian, specified as a real-valued 3-by-*N* or 4-by-*N* matrix. *N* is the dimension of the state vector. The interpretation of the rows and columns depends on the `frame` argument, as described in this table.

Frame	Measurement Jacobian
`'rectangular'`	Jacobian of the measurements `[x;y;z]` with respect to the state vector. The measurement vector is with respect to the local coordinate system. Coordinates are in meters.
`'spherical'`	Jacobian of the measurement vector `[az;el;r;rr]` with respect to the state vector. Measurement vector components specify the azimuth angle, elevation angle, range, and range rate of the object with respect to the local sensor coordinate system. Angle units are in degrees. Range units are in meters and range rate units are in meters/second.

Definitions

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Sensor Fusion and Tracking Toolbox.

The azimuth angle of a vector is the angle between the *x*-axis and its orthogonal projection onto the *xy* plane. The angle is positive in going from the *x* axis toward the *y* axis. Azimuth angles lie between –180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the *xy*-plane. The angle is positive when going toward the positive *z*-axis from the *xy* plane.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

constturn

Constant turn-rate motion model

Syntax

```
updatedstate = constturn(state)
updatedstate = constturn(state,dt)
updatedstate = constturn(state,dt,w)
```

Description

`updatedstate = constturn(state)` returns the updated state, `updatedstate`, obtained from the previous state, `state`, after a one-second step time for motion modelled as constant turn rate. Constant turn rate means that motion in the *x-y* plane follows a constant angular velocity and motion in the vertical *z* directions follows a constant velocity model.

`updatedstate = constturn(state,dt)` also specifies the time step, `dt`.

`updatedstate = constturn(state,dt,w)` also specifies noise, `w`.

Examples

Update State for Constant Turn-Rate Motion

Define an initial state for 2-D constant turn-rate motion. The turn rate is 12 degrees per second. Update the state to one second later.

```
state = [500,0,0,100,12].';
state = constturn(state)
```

state = *5×1*

```
489.5662
```

```
 -20.7912
  99.2705
  97.8148
  12.0000
```

Update State for Constant Turn-Rate Motion with Specified Time Step

Define an initial state for 2-D constant turn-rate motion. The turn rate is 12 degrees per second. Update the state to 0.1 seconds later.

```
state = [500,0,0,100,12].';
state = constturn(state,0.1)
```

state = *5×1*

```
 499.8953
  -2.0942
   9.9993
  99.9781
  12.0000
```

Input Arguments

state — State vector
real-valued 5-element vector | real-valued 7-element vector | 5-by-*N* real-valued matrix | 7-by-*N* real-valued matrix

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector or matrix.

- When specified as a 5-element vector, the state vector describes 2-D motion in the *x-y* plane. You can specify the state vector as a row or column vector. The components of the state vector are [x;vx;y;vy;omega] where x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. y represents the *y*-coordinate and vy represents the velocity in the *y*-direction. omega represents the turn rate.

When specified as a 5-by-*N* matrix, each column represents a different state vector *N* represents the number of states.

- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector are [x;vx;y;vy;omega;z;vz] where x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. y represents the *y*-coordinate and vy represents the velocity in the *y*-direction. omega represents the turn rate. z represents the *z*-coordinate and vz represents the velocity in the *z*-direction.

When specified as a 7-by-*N* matrix, each column represents a different state vector. *N* represents the number of states.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: [5;0.1;4;-0.2;0.01]

Data Types: double

dt — Time step interval of filter
1.0 (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: 0.5

Data Types: single | double

w — State noise
scalar | real-valued (*D*+1)-by-*N* matrix

State noise, specified as a scalar or real-valued (*D*+1)-length -by-*N* matrix. *D* is the number of motion dimensions and *N* is the number of state vectors. The components are each columns are [ax;ay;alpha] for 2-D motion or [ax;ay;alpha;az] for 3-D motion. ax, ay, and az are the linear acceleration noise values in the *x*-, *y*-, and *z*-axes, respectively, and alpha is the angular acceleration noise value. If specified as a scalar, the value expands to a (*D*+1)-by-*N* matrix.

Data Types: single | double

Output Arguments

updatedstate — Updated state vector
real-valued column or row vector | real-valued matrix

Updated state vector, returned as a real-valued vector or real-valued matrix with same number of elements and dimensions as the input state vector.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initctekf | initctukf

Classes
trackingEKF | trackingUKF

Introduced in R2017a

constturnjac

Jacobian for constant turn-rate motion

Syntax

```
jacobian = constturnjac(state)
jacobian = constturnjac(state,dt)
[jacobian,noisejacobian] = constturnjac(state,dt,w)
```

Description

`jacobian = constturnjac(state)` returns the updated Jacobian, `jacobian`, for constant turn-rate Kalman filter motion model for a one-second step time. The `state` argument specifies the current state of the filter. Constant turn rate means that motion in the *x-y* plane follows a constant angular velocity and motion in the vertical *z* directions follows a constant velocity model.

`jacobian = constturnjac(state,dt)` specifies the time step, `dt`.

`[jacobian,noisejacobian] = constturnjac(state,dt,w)` also specifies noise, `w`, and returns the Jacobian, `noisejacobian`, of the state with respect to the noise.

Examples

Compute State Jacobian for Constant Turn-Rate Motion

Compute the Jacobian for a constant turn-rate motion state. Assume the turn rate is 12 degrees/second. The time step is one second.

```
state = [500,0,0,100,12];
jacobian = constturnjac(state)

jacobian = 5×5
```

```
1.0000    0.9927         0   -0.1043   -0.8631
     0    0.9781         0   -0.2079   -1.7072
     0    0.1043    1.0000    0.9927   -0.1213
     0    0.2079         0    0.9781   -0.3629
     0         0         0         0    1.0000
```

Compute State Jacobian for Constant Turn-Rate Motion with Specified Time Step

Compute the Jacobian for a constant turn-rate motion state. Assume the turn rate is 12 degrees/second. The time step is 0.1 second.

```
state = [500,0,0,100,12];
jacobian = constturnjac(state,0.1)
```

jacobian = *5×5*

```
1.0000    0.1000         0   -0.0010   -0.0087
     0    0.9998         0   -0.0209   -0.1745
     0    0.0010    1.0000    0.1000   -0.0001
     0    0.0209         0    0.9998   -0.0037
     0         0         0         0    1.0000
```

Input Arguments

state — State vector
real-valued 5-element vector | real-valued 7-element vector

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector.

- When specified as a 5-element vector, the state vector describes 2-D motion in the *x-y* plane. You can specify the state vector as a row or column vector. The components of the state vector are [x;vx;y;vy;omega] where x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. y represents the *y*-coordinate and vy represents the velocity in the *y*-direction. omega represents the turn rate.

- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector

are `[x;vx;y;vy;omega;z;vz]` where `x` represents the *x*-coordinate and `vx` represents the velocity in the *x*-direction. `y` represents the *y*-coordinate and `vy` represents the velocity in the *y*-direction. `omega` represents the turn rate. `z` represents the *z*-coordinate and `vz` represents the velocity in the *z*-direction.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: `[5;0.1;4;-0.2;0.01]`

Data Types: `double`

dt — Time step interval of filter
`1.0` (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: `0.5`

Data Types: `single` | `double`

w — State noise
scalar | real-valued (*D*+1) vector

State noise, specified as a scalar or real-valued M-by-(*D*+1)-length vector. *D* is the number of motion dimensions. *D* is two for 2-D motion and *D* is three for 3-D motion. The vector components are `[ax;ay;alpha]` for 2-D motion or `[ax;ay;alpha;az]` for 3-D motion. `ax`, `ay`, and `az` are the linear acceleration noise values in the *x*-, *y*-, and *z*-axes, respectively, and `alpha` is the angular acceleration noise value. If specified as a scalar, the value expands to a (*D*+1) vector.

Data Types: `single` | `double`

Output Arguments

jacobian — Constant turn-rate motion Jacobian
real-valued 5-by-5 matrix | real-valued 7-by-7 matrix

Constant turn-rate motion Jacobian, returned as a real-valued 5-by-5 matrix or 7-by-7 matrix depending on the size of the `state` vector. The Jacobian is constructed from the partial derivatives of the state at the updated time step with respect to the state at the previous time step.

noisejacobian — Constant turn-rate motion noise Jacobian
real-valued 5-by-5 matrix | real-valued 7-by-7 matrix

Constant turn-rate motion noise Jacobian, returned as a real-valued 5-by-(D+1) matrix where D is two for 2-D motion or a real-valued 7-by-(D+1) matrix where D is three for 3-D motion. The Jacobian is constructed from the partial derivatives of the state at the updated time step with respect to the noise components.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initctekf

Classes
trackingEKF

Introduced in R2017a

ctmeas

Measurement function for constant turn-rate motion

Syntax

```
measurement = ctmeas(state)
measurement = ctmeas(state,frame)
measurement = ctmeas(state,frame,sensorpos)
measurement = ctmeas(state,frame,sensorpos,sensorvel)
measurement = ctmeas(state,frame,sensorpos,sensorvel,laxes)
measurement = ctmeas(state,measurementParameters)
```

Description

`measurement = ctmeas(state)` returns the measurement for a constant turn-rate Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the filter.

`measurement = ctmeas(state,frame)` also specifies the measurement coordinate system, `frame`.

`measurement = ctmeas(state,frame,sensorpos)` also specifies the sensor position, `sensorpos`.

`measurement = ctmeas(state,frame,sensorpos,sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurement = ctmeas(state,frame,sensorpos,sensorvel,laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurement = ctmeas(state,measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Create Measurement from Constant Turn-Rate Motion in Rectangular Frame

Create a measurement from an object undergoing constant turn-rate motion. The state is the position and velocity in each dimension and the turn-rate. The measurements are in rectangular coordinates.

```
state = [1;10;2;20;5];
measurement = ctmeas(state)
```

measurement = *3×1*

```
    1
    2
    0
```

The *z*-component of the measurement is zero.

Create Measurement from Constant Turn-Rate Motion in Spherical Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. The measurements are in spherical coordinates.

```
state = [1;10;2;20;5];
measurement = ctmeas(state,'spherical')
```

measurement = *4×1*

```
   63.4349
         0
    2.2361
   22.3607
```

The elevation of the measurement is zero and the range rate is positive indicating that the object is moving away from the sensor.

1-243

Create Measurement from Constant Turn-Rate Motion in Translated Spherical Frame

Define the state of an object moving in 2-D constant turn-rate motion. The state consists of position and velocity, and the turn rate. The measurements are in spherical coordinates with respect to a frame located at `[20;40;0]`.

```
state = [1;10;2;20;5];
measurement = ctmeas(state,'spherical',[20;40;0])
```

```
measurement = 4×1

 -116.5651
         0
   42.4853
  -22.3607
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

Create Measurement from Constant Turn-Rate Motion using Measurement Parameters

Define the state of an object moving in 2-D constant turn-rate motion. The state consists of position and velocity, and the turn rate. The measurements are in spherical coordinates with respect to a frame located at `[20;40;0]`.

```
state2d = [1;10;2;20;5];
frame = 'spherical';
sensorpos = [20;40;0];
sensorvel = [0;5;0];
laxes = eye(3);
measurement = ctmeas(state2d,frame,sensorpos,sensorvel,laxes)
```

```
measurement = 4×1

 -116.5651
         0
   42.4853
  -17.8885
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes);
measurement = ctmeas(state2d,measparm)
```

measurement = *4×1*

```
 -116.5651
        0
   42.4853
  -17.8885
```

Input Arguments

`state` — State vector
real-valued 5-element vector | real-valued 7-element vector | 5-by-*N* real-valued matrix | 7-by-*N* real-valued matrix

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector or matrix.

- When specified as a 5-element vector, the state vector describes 2-D motion in the *x-y* plane. You can specify the state vector as a row or column vector. The components of the state vector are `[x;vx;y;vy;omega]` where x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. y represents the *y*-coordinate and vy represents the velocity in the *y*-direction. omega represents the turn rate.

  When specified as a 5-by-*N* matrix, each column represents a different state vector *N* represents the number of states.

- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector are `[x;vx;y;vy;omega;z;vz]` where x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. y represents the *y*-coordinate and vy represents the velocity in the *y*-direction. omega represents the turn rate. z represents the *z*-coordinate and vz represents the velocity in the *z*-direction.

When specified as a 7-by-*N* matrix, each column represents a different state vector. *N* represents the number of states.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: `[5;0.1;4;-0.2;0.01]`

Data Types: `double`

`frame` — Measurement frame
`'rectangular'` (default) | `'spherical'`

Measurement frame, specified as `'rectangular'` or `'spherical'`. When the frame is `'rectangular'`, a measurement consists of the *x*, *y*, and *z* Cartesian coordinates of the tracked object. When specified as `'spherical'`, a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: `char`

`sensorpos` — Sensor position
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: `double`

`sensorvel` — Sensor velocity
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: `double`

`laxes` — Local sensor coordinate axes
`[1,0,0;0,1,0;0,0,1]` (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.

Data Types: `double`

measurementParameters — Measurement parameters
structure

Measurement parameters, specified as a structure. The fields of the structure are:

measurementParameters struct

Parameter	Definition	Default
OriginPosition	Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.	[0;0;0]
OriginVelocity	Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in m/s.	[0;0;0]
Orientation	Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.	eye(3)
HasVelocity	Indicates whether measurements contain velocity or range rate components, specified as true or false.	false when frame argument is 'rectangular' and true when frame argument is 'spherical'
HasElevation	Indicates whether measurements contain elevation components, specified as true or false.	true

Data Types: struct

Output Arguments

`measurement` — Measurement vector
N-by-1 column vector

Measurement vector, returned as an *N*-by-1 column vector. The form of the measurement depends upon which syntax you use.

- When the syntax does not use the `measurementParameters` argument, the measurement vector is `[x,y,z]` when the `frame` input argument is set to `'rectangular'` and `[az;el;r;rr]` when the `frame` is set to `'spherical'`.

- When the syntax uses the `measurementParameters` argument, the size of the measurement vector depends on the values of the `frame`, `HasVelocity`, and `HasElevation` fields in the `measurementParameters` structure.

frame	measurement
`'spherical'`	Specifies the azimuth angle, *az*, elevation angle, *el*, range, *r*, and range rate, *rr*, of the object with respect to the local ego coordinate system. Positive values for range rate indicate that an object is moving away from the sensor. **Spherical measurements** |		**HasElevation**	
---	---	---	---
		false	true
HasVelocity	false	`[az;r]`	`[az;el;r]`
	true	`[az;r;rr]`	`[az;el;r;rr]`	 Angle units are in degrees, range units are in meters, and range rate units are in m/s.

frame	measurement
`'rectangular`	Specifies the Cartesian position and velocity coordinates of the tracked object with respect to the ego coordinate system. **Rectangular measurements** table below Position units are in meters and velocity units are in m/s.

HasVelocity	false	`[x;y;y]`
	true	`[x;vx;y,vy;z;vz]`

Data Types: `double`

Definitions

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Sensor Fusion and Tracking Toolbox.

The azimuth angle of a vector is the angle between the *x*-axis and its orthogonal projection onto the *xy* plane. The angle is positive in going from the *x* axis toward the *y* axis. Azimuth angles lie between –180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the *xy*-plane. The angle is positive when going toward the positive *z*-axis from the *xy* plane.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeasjac | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

ctmeasjac

Jacobian of measurement function for constant turn-rate motion

Syntax

```
measurementjac = ctmeasjac(state)
measurementjac = ctmeasjac(state,frame)
measurementjac = ctmeasjac(state,frame,sensorpos)
measurementjac = ctmeasjac(state,frame,sensorpos,sensorvel)
measurementjac = ctmeasjac(state,frame,sensorpos,sensorvel,laxes)
measurementjac = ctmeasjac(state,measurementParameters)
```

Description

`measurementjac = ctmeasjac(state)` returns the measurement Jacobian, `measurementjac`, for a constant turn-rate Kalman filter motion model in rectangular coordinates. `state` specifies the current state of the track.

`measurementjac = ctmeasjac(state,frame)` also specifies the measurement coordinate system, `frame`.

`measurementjac = ctmeasjac(state,frame,sensorpos)` also specifies the sensor position, `sensorpos`.

`measurementjac = ctmeasjac(state,frame,sensorpos,sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurementjac = ctmeasjac(state,frame,sensorpos,sensorvel,laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurementjac = ctmeasjac(state,measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Measurement Jacobian of Constant Turn-Rate Motion in Rectangular Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Construct the measurement Jacobian in rectangular coordinates.

```
state = [1;10;2;20;5];
jacobian = ctmeasjac(state)
```

jacobian = *3×5*

```
    1     0     0     0     0
    0     0     1     0     0
    0     0     0     0     0
```

Measurement Jacobian of Constant Turn-Rate Motion in Spherical Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Compute the measurement Jacobian with respect to spherical coordinates.

```
state = [1;10;2;20;5];
measurementjac = ctmeasjac(state,'spherical')
```

measurementjac = *4×5*

```
  -22.9183        0   11.4592        0        0
        0         0         0        0        0
    0.4472        0    0.8944        0        0
    0.0000   0.4472    0.0000   0.8944        0
```

Measurement Jacobian of Constant Turn-Rate Object in Translated Spherical Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Compute the measurement Jacobian with respect to spherical coordinates centered at [5;-20;0].

```
state = [1;10;2;20;5];
sensorpos = [5;-20;0];
measurementjac = ctmeasjac(state,'spherical',sensorpos)
```

measurementjac = *4×5*

```
  -2.5210          0   -0.4584          0          0
        0          0          0          0          0
  -0.1789          0     0.9839          0          0
   0.5903    -0.1789     0.1073     0.9839          0
```

Measurement Jacobian of Constant Turn-Rate Object Using Measurement Parameters

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Compute the measurement Jacobian with respect to spherical coordinates centered at [25;-40;0].

```
state2d = [1;10;2;20;5];
sensorpos = [25,-40,0].';
frame = 'spherical';
sensorvel = [0;5;0];
laxes = eye(3);
measurementjac = ctmeasjac(state2d,frame,sensorpos,sensorvel,laxes)
```

measurementjac = *4×5*

```
  -1.0284          0   -0.5876          0          0
        0          0          0          0          0
  -0.4961          0     0.8682          0          0
   0.2894    -0.4961     0.1654     0.8682          0
```

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurementjac = ctmeasjac(state2d,measparm)
```

measurementjac = *4×5*

```
-1.0284         0   -0.5876         0         0
      0         0         0         0         0
-0.4961         0    0.8682         0         0
 0.2894   -0.4961    0.1654    0.8682         0
```

Input Arguments

state — State vector
real-valued 5-element vector | real-valued 7-element vector | 5-by-*N* real-valued matrix | 7-by-*N* real-valued matrix

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector or matrix.

- When specified as a 5-element vector, the state vector describes 2-D motion in the *x-y* plane. You can specify the state vector as a row or column vector. The components of the state vector are `[x;vx;y;vy;omega]` where x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. y represents the *y*-coordinate and vy represents the velocity in the *y*-direction. omega represents the turn rate.

  When specified as a 5-by-*N* matrix, each column represents a different state vector *N* represents the number of states.

- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector are `[x;vx;y;vy;omega;z;vz]` where x represents the *x*-coordinate and vx represents the velocity in the *x*-direction. y represents the *y*-coordinate and vy represents the velocity in the *y*-direction. omega represents the turn rate. z represents the *z*-coordinate and vz represents the velocity in the *z*-direction.

  When specified as a 7-by-*N* matrix, each column represents a different state vector. *N* represents the number of states.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: `[5;0.1;4;-0.2;0.01]`

Data Types: `double`

`frame` — Measurement frame
`'rectangular'` (default) | `'spherical'`

Measurement frame, specified as `'rectangular'` or `'spherical'`. When the frame is `'rectangular'`, a measurement consists of the *x*, *y*, and *z* Cartesian coordinates of the tracked object. When specified as `'spherical'`, a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: `char`

`sensorpos` — Sensor position
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: `double`

`sensorvel` — Sensor velocity
`[0;0;0]` (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: `double`

`laxes` — Local sensor coordinate axes
`[1,0,0;0,1,0;0,0,1]` (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.

Data Types: `double`

`measurementParameters` — Measurement parameters
structure

Measurement parameters, specified as a structure. The fields of the structure are:

measurementParameters struct

Parameter	Definition	Default
OriginPosition	Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.	[0;0;0]
OriginVelocity	Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in m/s.	[0;0;0]
Orientation	Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local *x*-, *y*-, and *z*-axes, respectively, with respect to the global coordinate system.	eye(3)
HasVelocity	Indicates whether measurements contain velocity or range rate components, specified as true or false.	false when frame argument is 'rectangular' and true when frame argument is 'spherical'
HasElevation	Indicates whether measurements contain elevation components, specified as true or false.	true

Data Types: struct

Output Arguments

measurementjac — Measurement Jacobian
real-valued 3-by-5 matrix | real-valued 4-by-5 matrix

Measurement Jacobian, returned as a real-valued 3-by-5 or 4-by-5 matrix. The row dimension and interpretation depend on value of the `frame` argument.

Frame	Measurement Jacobian
`'rectangular'`	Jacobian of the measurements `[x;y;z]` with respect to the state vector. The measurement vector is with respect to the local coordinate system. Coordinates are in meters.
`'spherical'`	Jacobian of the measurement vector `[az;el;r;rr]` with respect to the state vector. Measurement vector components specify the azimuth angle, elevation angle, range, and range rate of the object with respect to the local sensor coordinate system. Angle units are in degrees. Range units are in meters and range rate units are in meters/second.

Definitions

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Sensor Fusion and Tracking Toolbox.

The azimuth angle of a vector is the angle between the *x*-axis and its orthogonal projection onto the *xy* plane. The angle is positive in going from the *x* axis toward the *y* axis. Azimuth angles lie between –180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the *xy*-plane. The angle is positive when going toward the positive *z*-axis from the *xy* plane.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | cvmeas | cvmeasjac

Classes
trackingCKF | trackingEKF | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

getTrackPositions

Returns updated track positions and position covariance matrix

Syntax

```
position = getTrackPositions(tracks,positionSelector)
[position,positionCovariances] = getTrackPositions(tracks,
positionSelector)
```

Description

`position = getTrackPositions(tracks,positionSelector)` returns a matrix of track positions. Each row contains the position of a tracked object.

`[position,positionCovariances] = getTrackPositions(tracks, positionSelector)` returns a matrix of track positions.

Examples

Find Position and Covariance of 3-D Constant-Velocity Object

Create an extended Kalman filter tracker for 3-D constant-velocity motion.

```
tracker = trackerTOMHT('FilterInitializationFcn',@initcvekf);
```

Update the tracker with a single detection and get the tracks output.

```
detection = objectDetection(0,[10;3;-7],'ObjectClassID',3);
tracks = step(tracker,detection,0)

tracks = struct with fields:
            TrackID: 1
           BranchID: 1
         UpdateTime: 0
                Age: 1
```

```
            State: [6x1 double]
  StateCovariance: [6x6 double]
        TrackLogic: 'Score'
   TrackLogicState: [13.7102 13.7102]
        IsConfirmed: 1
          IsCoasted: 0
       ObjectClassID: 3
     ObjectAttributes: {}
```

Obtain the position vector and position covariance for that track

```
positionSelector = [1 0 0 0 0 0; 0 0 1 0 0 0; 0 0 0 0 1 0];
[position,positionCovariance] = getTrackPositions(tracks,positionSelector)
```

position = *1×3*

```
   10.0000     3.0000    -7.0000
```

positionCovariance = *3×3*

```
    1.0000    -0.0000          0
   -0.0000     1.0000    -0.0000
         0    -0.0000     1.0000
```

Find Position of 3-D Constant-Acceleration Object

Create an extended Kalman filter tracker for 3-D constant-acceleration motion.

```
tracker = trackerTOMHT('FilterInitializationFcn',@initcaekf);
```

Update the tracker with a single detection and get the tracks output.

```
detection = objectDetection(0,[10;-20;4],'ObjectClassID',3);
tracks = step(tracker,detection,0)
```

tracks = *struct with fields:*
```
         TrackID: 1
        BranchID: 1
      UpdateTime: 0
             Age: 1
```

```
           State: [9x1 double]
  StateCovariance: [9x9 double]
       TrackLogic: 'Score'
  TrackLogicState: [13.7102 13.7102]
      IsConfirmed: 1
        IsCoasted: 0
    ObjectClassID: 3
 ObjectAttributes: {}
```

Obtain the position vector from the track state.

```
positionSelector = [1 0 0 0 0 0 0 0 0; 0 0 0 1 0 0 0 0 0; 0 0 0 0 0 0 1 0 0];
position = getTrackPositions(tracks, positionSelector)
```

position = *1×3*

```
  10.0000  -20.0000    4.0000
```

Input Arguments

tracks — Track data structure
struct array

Tracked object, specified as a `struct` array. A track `struct` array is an array of MATLAB® `struct` types containing sufficient information to obtain the track position vector and, optionally, the position covariance matrix. At a minimum, the `struct` must contain a `State` column vector field and a positive-definite `StateCovariance` matrix field. For an example of a track `struct` used by Sensor Fusion and Tracking Toolbox, examine the output argument, `tracks`, returned by the `step` object function of `trackerGNN`.

positionSelector — Position selection matrix
D-by-*N* real-valued matrix.

Position selector, specified as a *D*-by-*N* real-valued matrix of ones and zeros. *D* is the number of dimensions of the tracker. *N* is the size of the state vector. Using this matrix, the function extracts track positions from the state vector. Multiply the state vector by position selector matrix returns positions. The same selector is applied to all object tracks.

Output Arguments

`position` — Positions of tracked objects
real-valued M-by-D matrix

Positions of tracked objects at last update time, returned as a real-valued M-by-D matrix. D represents the number of position elements. M represents the number of tracks.

`positionCovariances` — Position covariance matrices of tracked objects
real-valued D-by-D-M array

Position covariance matrices of tracked objects, returned as a real-valued D-by-D-M array. D represents the number of position elements. M represents the number of tracks. Each D-by-D submatrix is a position covariance matrix for a track.

Definitions

Position Selector for 2-Dimensional Motion

Show the position selection matrix for two-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Position Selector for 3-Dimensional Motion

Show the position selection matrix for three-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Position Selector for 3-Dimensional Motion with Acceleration

Show the position selection matrix for three-dimensional motion when the state consists of the position, velocity, and acceleration.

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
getTrackVelocities | initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvkf | initcvukf

Classes
objectDetection

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

getTrackVelocities

Obtain updated track velocities and velocity covariance matrix

Syntax

```
velocity = getTrackVelocities(tracks,velocitySelector)
[velocity,velocityCovariances] = getTrackVelocities(tracks,
velocitySelector)
```

Description

`velocity = getTrackVelocities(tracks,velocitySelector)` returns velocities of tracked objects.

`[velocity,velocityCovariances] = getTrackVelocities(tracks, velocitySelector)` also returns the track velocity covariance matrices.

Examples

Find Velocity of 3-D Constant-Acceleration Object

Create an extended Kalman filter tracker for 3-D constant-acceleration motion.

```
tracker = trackerGNN('FilterInitializationFcn',@initcaekf);
```

Initialize the tracker with one detection.

```
detection = objectDetection(0,[10;-20;4],'ObjectClassID',3);
tracks = step(tracker,detection,0);
```

Add a second detection at a later time and at a different position.

```
detection = objectDetection(0.1,[10.3;-20.2;4],'ObjectClassID',3);
tracks = step(tracker,detection,0.2);
```

Obtain the velocity vector from the track state.

```
velocitySelector = [0 1 0 0 0 0 0 0 0; 0 0 0 0 1 0 0 0 0; 0 0 0 0 0 0 0 1 0];
velocity = getTrackVelocities(tracks,velocitySelector)
```

velocity = *1×3*

    1.0093   -0.6728   0

Velocity and Covariance of 3-D Constant-Acceleration Object

Create an extended Kalman filter tracker for 3-D constant-acceleration motion.

```
tracker = trackerGNN('FilterInitializationFcn',@initcaekf);
```

Initialize the tracker with one detection.

```
detection = objectDetection(0,[10;-20;4],'ObjectClassID',3);
tracks = step(tracker,detection,0);
```

Add a second detection at a later time and at a different position.

```
detection = objectDetection(0.1,[10.3;-20.2;4.3],'ObjectClassID',3);
tracks = step(tracker,detection,0.2);
```

Obtain the velocity vector from the track state.

```
velocitySelector = [0 1 0 0 0 0 0 0 0; 0 0 0 0 1 0 0 0 0; 0 0 0 0 0 0 0 1 0];
[velocity,velocityCovariance] = getTrackVelocities(tracks,velocitySelector)
```

velocity = *1×3*

    1.0093   -0.6728   1.0093

velocityCovariance = *3×3*

   70.0685   0   0
        0   70.0685   0
        0   0   70.0685

Input Arguments

`tracks` — Track data structure
struct array

Tracked object, specified as a `struct` array. A track `struct` array is an array of MATLAB `struct` types containing sufficient information to obtain the track position vector and, optionally, the position covariance matrix. At a minimum, the `struct` must contain a `State` column vector field and a positive-definite `StateCovariance` matrix field. For an example of a track `struct` used by Sensor Fusion and Tracking Toolbox, examine the output argument, `tracks`, returned by the `step` object function of `trackerGNN`.

`velocitySelector` — Velocity selection matrix
D-by-*N* real-valued matrix.

Velocity selector, specified as a *D*-by-*N* real-valued matrix of ones and zeros. *D* is the number of dimensions of the tracker. *N* is the size of the state vector. Using this matrix, the function extracts track velocities from the state vector. Multiply the state vector by velocity selector matrix returns velocities. The same selector is applied to all object tracks.

Output Arguments

`velocity` — Velocities of tracked objects
real-valued *1*-by-*D* vector | real-valued *M*-by-*D* matrix

Velocities of tracked objects at last update time, returned as a *1*-by-*D* vector or a real-valued *M*-by-*D* matrix. *D* represents the number of velocity elements. *M* represents the number of tracks.

`velocityCovariances` — Velocity covariance matrices of tracked objects
real-valued *D*-by-*D*-matrix | real-valued *D*-by-*D*-by-*M* array

Velocity covariance matrices of tracked objects, returned as a real-valued *D*-by-*D*-matrix or a real-valued *D*-by-*D*-by-*M* array. *D* represents the number of velocity elements. *M* represents the number of tracks. Each *D*-by-*D* submatrix is a velocity covariance matrix for a track.

Definitions

Velocity Selector for 2-Dimensional Motion

Show the velocity selection matrix for two-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Velocity Selector for 3-Dimensional Motion

Show the velocity selection matrix for three-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Velocity Selector for 3-Dimensional Motion with Acceleration

Show the velocity selection matrix for three-dimensional motion when the state consists of the position, velocity, and acceleration.

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
getTrackPositions | initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvkf | initcvukf

Classes
objectDetection

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

initcaabf

Create constant acceleration alpha-beta tracking filter from detection report

Syntax

```
abf = initcaabf(detection)
```

Description

`abf = initcaabf(detection)` initializes a constant acceleration alpha-beta tracking filter for object tracking based on information provided in `detection`.

Examples

Creating Constant Acceleration trackingABF Object from Detection

Create an objectDetection with a position measurement at x=1, y=3 and a measurement noise of [1 0.2; 0.2 2];

```
detection = objectDetection(0,[1;3],'MeasurementNoise',[1 0.2;0.2 2]);
```

Use `initccabf` to create a `trackingABF` filter initialized at the provided position and using the measurement noise defined above.

```
ABF = initcaabf(detection);
```

Check the values of the state and measurement noise. Verify that the filter state, `ABF.State`, has the same position components as the `Detection.Measurement`. Verify that the filter measurement noise, `ABF.MeasurementNoise`, is the same as the `Detection.MeasurementNoise` values.

```
ABF.State
ABF.MeasurementNoise
```

```
ans =
```

```
        1
        0
        0
        3
        0
        0


ans =

    1.0000    0.2000
    0.2000    2.0000
```

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

abf — Constant velocity alpha-beta filter
trackingABF object

Constant acceleration alpha-beta tracking filter for object tracking, returned as a trackingABF object.

Algorithms

• The function computes the process noise matrix assuming a unit standard deviation for the acceleration change rate.
• You can use this function as the FilterInitializationFcn property of trackerTOMHT and trackerGNN System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | constacc | initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingCKF | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

initcvabf

Create constant velocity tracking alpha-beta filter from detection report

Syntax

```
abf = initcvabf(detection)
```

Description

`abf = initcvabf(detection)` initializes a constant velocity alpha-beta filter for object tracking based on information provided in `detection`.

Examples

Creating trackingABF Object from Detection

Create an objectDetection with a position measurement at x=1, y=3 and a measurement noise of [1 0.2; 0.2 2];

```
detection = objectDetection(0,[1;3],'MeasurementNoise',[1 0.2;0.2 2]);
```

Use `initcvabf` to create a `trackingABF` filter initialized at the provided position and using the measurement noise defined above.

```
ABF = initcvabf(detection);
```

Check the values of the state and measurement noise. Verify that the filter state, `ABF.State`, has the same position components as the `Detection.Measurement`. Verify that the filter measurement noise, `ABF.MeasurementNoise`, is the same as the `Detection.MeasurementNoise` values.

```
ABF.State
ABF.MeasurementNoise
```

```
ans =
```

```
     1
     0
     3
     0


ans =

    1.0000    0.2000
    0.2000    2.0000
```

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

abf — Constant velocity alpha-beta filter
trackingABF object

Constant velocity alpha-beta tracking filter for object tracking, returned as a trackingABF object.

Algorithms

- The function computes the process noise matrix assuming a unit acceleration standard deviation.
- You can use this function as the FilterInitializationFcn property of trackerTOMHT and trackerGNN System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
constvel | cvmeas | cvmeasjac | initcaabf | initcackf | initcaekf | initcakf |
initcaukf | initctckf | initctekf | initctukf | initcvckf | initcvekf |
initcvkf | initcvukf

Classes
objectDetection | trackingCKF | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

initcackf

Create constant acceleration tracking cubature Kalman filter from detection report

Syntax

```
ckf = initcackf(detection)
```

Description

`ckf = initcackf(detection)` initializes a constant acceleration cubature Kalman filter for object tracking based on information provided in an `objectDetection` class object, `detection`.

Examples

Create Constant Acceleration Tracking CKF Object from Rectangular Measurements

Create a constant acceleration tracking cubature Kalman filter object, `trackingCKF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the Kalman filter state in rectangular coordinates. You can obtain the 3-D position measurement using the constant acceleration measurement function, `cameas`.

This example uses the coordinates, $x = 1$, $y = 3$, $z = 0$ and a 3-D position measurement noise of [1 0.2 0; 0.2 2 0; 0 0 1].

```
detection = objectDetection(0, [1;3;0], 'MeasurementNoise', [1 0.2 0; 0.2 2 0; 0 0 1]);
```

Use `initcackf` to create a `trackingCKF` filter initialized at the provided position and using the measurement noise defined above.

```
ckf = initcackf(detection)

ckf =
  trackingCKF with properties:
```

```
                        State: [9x1 double]
              StateCovariance: [9x9 double]

            StateTransitionFcn: @constacc
                  ProcessNoise: [3x3 double]
         HasAdditiveProcessNoise: 0

                MeasurementFcn: @cameas
              MeasurementNoise: [3x3 double]
      HasAdditiveMeasurementNoise: 1
```

Check the values of the state and the measurement noise. Verify that the filter state, `ckf.State`, has the same position components as the detection measurement, `detection.Measurement`.

`ckf.State`

ans = *9×1*

```
     1
     0
     0
     3
     0
     0
     0
     0
     0
```

Verify that the filter measurement noise, `ckf.MeasurementNoise`, is the same as the `detection.MeasurementNoise` values.

`ckf.MeasurementNoise`

ans = *3×3*

```
    1.0000    0.2000         0
    0.2000    2.0000         0
         0         0    1.0000
```

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Create Constant Acceleration Tracking CKF Object from Spherical Measurements

Create a constant acceleration tracking cubature Kalman filter object, `trackingCKF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the Kalman filter state in spherical coordinates. You can obtain the 3-D position measurement using the constant acceleration measurement function, `cameas`.

This example uses the coordinates, az = 30, el = 5, r = 100, rr = 4 and a measurement noise of `diag([2.5, 2.5, 0.5, 1].^2)`.

```
meas = [30;5;100;4];
measNoise = diag([2.5, 2.5, 0.5, 1].^2);
```

Use the `MeasurementParameters` property of the `detection` object to define the frame. When not defined, the fields of the `MeasurementParameters` struct use default values. In this example, sensor position, sensor velocity, orientation, elevation, and range rate flags are default.

```
measParams = struct('Frame','spherical');
detection = objectDetection(0,meas,'MeasurementNoise',measNoise,...
    'MeasurementParameters',measParams)

detection =
  objectDetection with properties:

                     Time: 0
              Measurement: [4x1 double]
         MeasurementNoise: [4x4 double]
              SensorIndex: 1
            ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
         ObjectAttributes: {}
```

Use `initcackf` to create a `trackingCKF` filter initialized at the provided position and using the measurement noise defined above.

```
ckf = initcackf(detection)

ckf =
  trackingCKF with properties:
```

```
                 State: [9x1 double]
       StateCovariance: [9x9 double]

     StateTransitionFcn: @constacc
           ProcessNoise: [3x3 double]
   HasAdditiveProcessNoise: 0

         MeasurementFcn: @cameas
       MeasurementNoise: [4x4 double]
 HasAdditiveMeasurementNoise: 1
```

Verify that the filter state produces the same measurement as above.

```
meas2 = cameas(ckf.State, measParams)
```

meas2 = 4×1

```
   30.0000
    5.0000
  100.0000
    4.0000
```

Input Arguments

`detection` — Detection report
`objectDetection` class object

Detection report, specified as an "Object Detections" object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

`ckf` — Constant acceleration cubature Kalman filter
`trackingCKF` object

Constant acceleration cubature Kalman filter for object tracking, returned as a `trackingCKF` object.

Algorithms

- The function computes the process noise matrix assuming a unit standard deviation for the acceleration change rate.
- You can use this function as the `FilterInitializationFcn` property of `trackerTOMHT` and `trackerGNN` System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | constacc | initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingCKF | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

initcapf

Create constant acceleration tracking particle filter from detection report

Syntax

```
pf = initcapf(detection)
```

Description

`pf = initcapf(detection)` initializes a constant acceleration particle filter for object tracking based on information provided in an `objectDetection` class object, `detection`.

Examples

Create Constant Acceleration Tracking PF Object from Rectangular Measurements

Create a constant acceleration tracking particle filter object, `trackingPF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the particle filter state in rectangular coordinates. You can obtain the 3-D position measurement using the constant acceleration measurement function, `cameas`.

This example uses the coordinates, `x = 1`, `y = 3`, `z = 0` and a 3-D position measurement noise of `[1 0.2 0; 0.2 2 0; 0 0 1]`.

```
detection = objectDetection(0, [1;3;0], 'MeasurementNoise', [1 0.2 0; 0.2 2 0; 0 0 1]);
```

Use `initcapf` to create a `trackingPF` filter initialized at the provided position and using the measurement noise defined above.

```
pf = initcapf(detection)

pf =
  trackingPF with properties:
```

```
                    State: [9×1 double]
          StateCovariance: [9×9 double]
   IsStateVariableCircular: [0 0 0 0 0 0 0 0 0]

        StateTransitionFcn: @constacc
    ProcessNoiseSamplingFcn: []
              ProcessNoise: [3x3 double]
      HasAdditiveProcessNoise: 0

            MeasurementFcn: @cameas
   MeasurementLikelihoodFcn: []
        MeasurementNoise: [3x3 double]

                Particles: [9x1000 double]
                  Weights: [1x1000 double]
         ResamplingPolicy: [1x1 trackingResamplingPolicy]
         ResamplingMethod: 'multinomial'
```

Check the values of the state and the measurement noise. Verify that the filter state, `pf.State`, has approximately the same position components as the detection measurement, `detection.Measurement`.

`pf.State`

ans = *9×1*

```
    0.9857
   -0.2361
   -0.0030
    3.0097
    0.4079
    0.0214
    0.0460
   -0.2209
   -0.5646
```

Verify that the filter measurement noise, `pf.MeasurementNoise`, is the same as the `detection.MeasurementNoise` values.

`pf.MeasurementNoise`

1-283

```
ans = 3×3

    1.0000    0.2000         0
    0.2000    2.0000         0
         0         0    1.0000
```

Create Constant Acceleration Tracking PF Object from Spherical Measurements

Create a constant acceleration tracking particle filter object, `trackingPF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the particle filter state in spherical coordinates. You can obtain the 3-D position measurement using the constant acceleration measurement function, `cameas`.

This example uses the coordinates, `az = 30, el = 5, r = 100, rr = 4` and a measurement noise of `diag([2.5, 2.5, 0.5, 1].^2)`.

```
meas = [30;5;100;4];
measNoise = diag([2.5, 2.5, 0.5, 1].^2);
```

Use the `MeasurementParameters` property of the `detection` object to define the frame. When not defined, the fields of the `MeasurementParameters` struct use default values. In this example, sensor position, sensor velocity, orientation, elevation, and range rate flags are default.

```
measParams = struct('Frame','spherical');
detection = objectDetection(0,meas,'MeasurementNoise',measNoise,...
    'MeasurementParameters',measParams)

detection =
  objectDetection with properties:

                     Time: 0
              Measurement: [4x1 double]
         MeasurementNoise: [4x4 double]
              SensorIndex: 1
            ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
         ObjectAttributes: {}
```

Use `initcapf` to create a `trackingPF` filter initialized at the provided position and using the measurement noise defined above.

```
pf = initcapf(detection)
```

```
pf =
  trackingPF with properties:

                        State: [9×1 double]
              StateCovariance: [9×9 double]
      IsStateVariableCircular: [0 0 0 0 0 0 0 0 0]

            StateTransitionFcn: @constacc
        ProcessNoiseSamplingFcn: []
                  ProcessNoise: [3x3 double]
        HasAdditiveProcessNoise: 0

                MeasurementFcn: @cameas
      MeasurementLikelihoodFcn: []
             MeasurementNoise: [4x4 double]

                     Particles: [9x1000 double]
                       Weights: [1x1000 double]
              ResamplingPolicy: [1x1 trackingResamplingPolicy]
              ResamplingMethod: 'multinomial'
```

Verify that the filter state produces approximately the same measurement as `detection.Measurement`.

```
meas2 = cameas(pf.State, detection.MeasurementParameters)
```

meas2 = *4×1*

```
   29.9188
    5.0976
   99.8303
    4.0255
```

Input Arguments

`detection` — Detection report
`objectDetection` class object

Detection report, specified as an "Object Detections" object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

`pf` — Constant acceleration particle filter
`trackingPF` object

Constant acceleration particle filter for object tracking, returned as a `trackingPF` object.

Algorithms

- The function configures the filter with 1000 particles. In creating the filter, the function computes the process noise matrix assuming a unit standard deviation for the acceleration change rate.

- You can use this function as the `FilterInitializationFcn` property of `trackerTOMHT` and `trackerGNN` System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | constacc | initcackf | initcaekf | initcakf | initcaukf | initctpf |
initcvpf

Classes
objectDetection | trackingEKF | trackingKF | trackingPF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

initcvckf

Create constant velocity tracking cubature Kalman filter from detection report

Syntax

```
ckf = initcvckf(detection)
```

Description

`ckf = initcvckf(detection)` initializes a constant velocity cubature Kalman filter for object tracking based on information provided in an `objectDetection` class object, `detection`.

Examples

Create Constant Velocity Tracking CKF Object from Rectangular Measurements

Create a constant velocity tracking cubature Kalman filter object, `trackingCKF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the Kalman filter state in rectangular coordinates. You can obtain the 3-D position measurement using the constant velocity measurement function, `cvmeas`.

This example uses the coordinates, `x = 1`, `y = 3`, `z = 0` and a 3-D position measurement noise of `[1 0.2 0; 0.2 2 0; 0 0 1]`.

```
detection = objectDetection(0, [1;3;0], 'MeasurementNoise', [1 0.2 0; 0.2 2 0; 0 0 1]);
```

Use `initcvckf` to create a `trackingCKF` filter initialized at the provided position and using the measurement noise defined above.

```
ckf = initcvckf(detection)

ckf =
  trackingCKF with properties:
```

```
                        State: [6x1 double]
              StateCovariance: [6x6 double]

           StateTransitionFcn: @constvel
                 ProcessNoise: [3x3 double]
       HasAdditiveProcessNoise: 0

                MeasurementFcn: @cvmeas
             MeasurementNoise: [3x3 double]
   HasAdditiveMeasurementNoise: 1
```

Check the values of the state and the measurement noise. Verify that the filter state, `ckf.State`, has the same position components as the detection measurement, `detection.Measurement`.

`ckf.State`

ans = *6×1*

```
    1
    0
    3
    0
    0
    0
```

Verify that the filter measurement noise, `ckf.MeasurementNoise`, is the same as the `detection.MeasurementNoise` values.

`ckf.MeasurementNoise`

ans = *3×3*

```
    1.0000    0.2000         0
    0.2000    2.0000         0
         0         0    1.0000
```

Create Constant Velocity Tracking CKF Object from Spherical Measurements

Create a constant velocity tracking cubature Kalman filter object, `trackingCKF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the Kalman filter state in spherical coordinates. You can obtain the 3D position measurement using the constant velocity measurement function, `cvmeas`.

This example uses the coordinates, az = 30, el = 5, r = 100, rr = 4 and a measurement noise of `diag([2.5, 2.5, 0.5, 1].^2)`.

```
meas = [30;5;100;4];
measNoise = diag([2.5, 2.5, 0.5, 1].^2);
```

Use the `MeasurementParameters` property of the `detection` object to define the frame. When not defined, the fields of the `MeasurementParameters` struct use default values. In this example, sensor position, sensor velocity, orientation, elevation, and range rate flags are default.

```
measParams = struct('Frame','spherical');
detection = objectDetection(0,meas,'MeasurementNoise',measNoise,...
    'MeasurementParameters',measParams)
```

```
detection =
  objectDetection with properties:

                    Time: 0
             Measurement: [4x1 double]
        MeasurementNoise: [4x4 double]
             SensorIndex: 1
           ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

Use `initcvckf` to create a `trackingCKF` filter initialized at the provided position and using the measurement noise defined above.

```
ckf = initcvckf(detection)
```

```
ckf =
  trackingCKF with properties:

                    State: [6x1 double]
          StateCovariance: [6x6 double]
```

```
         StateTransitionFcn: @constvel
                ProcessNoise: [3x3 double]
      HasAdditiveProcessNoise: 0

             MeasurementFcn: @cvmeas
           MeasurementNoise: [4x4 double]
  HasAdditiveMeasurementNoise: 1
```

Verify that the filter state produces the same measurement as above.

```
meas2 = cvmeas(ckf.State, measParams)
```

```
meas2 = 4×1

   30.0000
    5.0000
  100.0000
    4.0000
```

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

ckf — Constant velocity cubature Kalman filter for object tracking
trackingCKF object

Constant velocity cubature Kalman filter for object tracking, returned as a trackingCKF
object.

Algorithms

- The function computes the process noise matrix assuming a unit acceleration standard deviation.
- You can use this function as the `FilterInitializationFcn` property of `trackerTOMHT` and `trackerGNN` System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
constvel | cvmeas | cvmeasjac | initcackf | initcaekf | initcakf | initcaukf | initctckf | initctekf | initctukf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingCKF | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

initcvpf

Create constant velocity tracking particle filter from detection report

Syntax

```
pf = initcvpf(detection)
```

Description

`pf = initcvpf(detection)` initializes a constant velocity particle filter for object tracking based on information provided in an `objectDetection` class object, `detection`.

Examples

Create Constant Velocity Tracking PF Object from Rectangular Measurements

Create a constant velocity tracking particle filter object, `trackingPF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the particle filter state in rectangular coordinates. You can obtain the 3-D position measurement using the constant velocity measurement function, `cvmeas`.

This example uses the coordinates, $x = 1$, $y = 3$, $z = 0$ and a 3-D position measurement noise of `[1 0.2 0; 0.2 2 0; 0 0 1]`.

```
detection = objectDetection(0, [1;3;0], 'MeasurementNoise', [1 0.2 0; 0.2 2 0; 0 0 1]);
```

Use `initcvpf` to create a `trackingPF` filter initialized at the provided position and using the measurement noise defined above.

```
pf = initcvpf(detection)

pf =
  trackingPF with properties:
```

```
                        State: [6×1 double]
                StateCovariance: [6×6 double]
        IsStateVariableCircular: [0 0 0 0 0 0]

              StateTransitionFcn: @constvel
         ProcessNoiseSamplingFcn: []
                    ProcessNoise: [3x3 double]
          HasAdditiveProcessNoise: 0

                   MeasurementFcn: @cvmeas
         MeasurementLikelihoodFcn: []
                MeasurementNoise: [3x3 double]

                       Particles: [6x1000 double]
                         Weights: [1x1000 double]
                ResamplingPolicy: [1x1 trackingResamplingPolicy]
                ResamplingMethod: 'multinomial'
```

Check the values of the state and the measurement noise. Verify that the filter state, `pf.State`, has approximately the same position components as the detection measurement, `detection.Measurement`.

`pf.State`

ans = *6×1*

```
    1.0208
    0.2489
    2.9758
    0.1525
    0.0186
   -0.1791
```

Verify that the filter measurement noise, `pf.MeasurementNoise`, is the same as the `detection.MeasurementNoise` values.

`pf.MeasurementNoise`

ans = *3×3*

```
    1.0000    0.2000         0
    0.2000    2.0000         0
```

```
            0         0    1.0000
```

Create Constant Velocity Tracking PF Object from Spherical Measurements

Create a constant velocity tracking particle filter object, `trackingPF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the particle filter state in spherical coordinates. You can obtain the 3-D position measurement using the constant velocity measurement function, `cvmeas`.

This example uses the coordinates, az = 30, el = 5, r = 100, rr = 4 and a measurement noise of `diag([2.5, 2.5, 0.5, 1].^2)`.

```
meas = [30;5;100;4];
measNoise = diag([2.5, 2.5, 0.5, 1].^2);
```

Use the `MeasurementParameters` property of the `detection` object to define the frame. When not defined, the fields of the `MeasurementParameters` struct use default values. In this example, sensor position, sensor velocity, orientation, elevation, and range rate flags are default.

```
measParams = struct('Frame','spherical');
detection = objectDetection(0,meas,'MeasurementNoise',measNoise,...
    'MeasurementParameters',measParams)

detection =
  objectDetection with properties:

                     Time: 0
              Measurement: [4x1 double]
         MeasurementNoise: [4x4 double]
              SensorIndex: 1
            ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
         ObjectAttributes: {}
```

Use `initcvpf` to create a `trackingPF` filter initialized at the provided position and using the measurement noise defined above.

```
pf = initcvpf(detection)
```

```
pf =
  trackingPF with properties:

                        State: [6×1 double]
              StateCovariance: [6×6 double]
       IsStateVariableCircular: [0 0 0 0 0 0]

            StateTransitionFcn: @constvel
       ProcessNoiseSamplingFcn: []
                  ProcessNoise: [3x3 double]
        HasAdditiveProcessNoise: 0

                MeasurementFcn: @cvmeas
      MeasurementLikelihoodFcn: []
             MeasurementNoise: [4x4 double]

                     Particles: [6x1000 double]
                       Weights: [1x1000 double]
             ResamplingPolicy: [1x1 trackingResamplingPolicy]
             ResamplingMethod: 'multinomial'
```

Verify that the filter state produces approximately the same measurement as
`detection.Measurement`.

```
meas2 = cvmeas(pf.State, detection.MeasurementParameters)
```

meas2 = 4×1

```
    29.9188
     5.0976
    99.8303
     4.0255
```

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

pf — Constant velocity particle filter
`trackingPF` object

Constant velocity particle filter for object tracking, returned as a `trackingPF` object.

Algorithms

- The function configures the filter with 1000 particles. In creating the filter, the function computes the process noise matrix assuming a unit acceleration standard deviation.

- You can use this function as the `FilterInitializationFcn` property of `trackerTOMHT` and `trackerGNN` System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`constvel` | `cvmeas` | `initcapf` | `initctpf` | `initcvckf` | `initcvekf` | `initcvkf` | `initcvukf`

Classes
`objectDetection` | `trackingEKF` | `trackingKF` | `trackingPF` | `trackingUKF`

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

initctckf

Create constant turn rate tracking cubature Kalman filter from detection report

Syntax

```
ckf = initctckf(detection)
```

Description

`ckf = initctckf(detection)` initializes a constant turn rate cubature Kalman filter for object tracking based on information provided in an `objectDetection` class object, `detection`.

Examples

Create Constant Turn Rate Tracking CKF Object from Rectangular Measurements

Create a turn rate tracking cubature Kalman filter object, `trackingCKF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the Kalman filter state in rectangular coordinates. You can obtain the 3-D position measurement using the constant turn rate measurement function, `ctmeas`.

This example uses the coordinates, $x = 1$, $y = 3$, $z = 0$ and a 3-D position measurement noise of `[1 0.2 0; 0.2 2 0; 0 0 1]`.

```
detection = objectDetection(0, [1;3;0], 'MeasurementNoise', [1 0.2 0; 0.2 2 0; 0 0 1]);
```

Use `initctckf` to create a `trackingCKF` filter initialized at the provided position and using the measurement noise defined above.

```
ckf = initctckf(detection)

ckf =
  trackingCKF with properties:
```

```
                         State: [7x1 double]
               StateCovariance: [7x7 double]

             StateTransitionFcn: @constturn
                   ProcessNoise: [4x4 double]
        HasAdditiveProcessNoise: 0

                 MeasurementFcn: @ctmeas
              MeasurementNoise: [3x3 double]
    HasAdditiveMeasurementNoise: 1
```

Check the values of the state and the measurement noise. Verify that the filter state, `ckf.State`, has the same position components as the detection measurement, `detection.Measurement`.

`ckf.State`

ans = *7×1*

```
     1
     0
     3
     0
     0
     0
```

Verify that the filter measurement noise, `ckf.MeasurementNoise`, is the same as the `detection.MeasurementNoise` values.

`ckf.MeasurementNoise`

ans = *3×3*

```
    1.0000    0.2000         0
    0.2000    2.0000         0
         0         0    1.0000
```

Create Constant Turn Rate Tracking CKF Object from Spherical Measurements

Create a constant turn rate tracking cubature Kalman filter object, `trackingCKF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the Kalman filter state in spherical coordinates. You can obtain the 3-D position measurement using the constant turn rate measurement function, `ctmeas`.

This example uses the coordinates, az = 30, el = 5, r = 100, rr = 4 and a measurement noise of `diag([2.5, 2.5, 0.5, 1].^2)`.

```
meas = [30;5;100;4];
measNoise = diag([2.5, 2.5, 0.5, 1].^2);
```

Use the `MeasurementParameters` property of the `detection` object to define the frame. When not defined, the fields of the `MeasurementParameters` struct use default values. In this example, sensor position, sensor velocity, orientation, elevation, and range rate flags are default.

```
measParams = struct('Frame','spherical');
detection = objectDetection(0,meas,'MeasurementNoise',measNoise,...
    'MeasurementParameters',measParams)

detection =
  objectDetection with properties:

                    Time: 0
             Measurement: [4x1 double]
        MeasurementNoise: [4x4 double]
             SensorIndex: 1
            ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
         ObjectAttributes: {}
```

Use `initctckf` to create a `trackingCKF` filter initialized at the provided position and using the measurement noise defined above.

```
ckf = initctckf(detection)

ckf =
  trackingCKF with properties:

                         State: [7x1 double]
               StateCovariance: [7x7 double]
```

```
          StateTransitionFcn: @constturn
                ProcessNoise: [4x4 double]
      HasAdditiveProcessNoise: 0

               MeasurementFcn: @ctmeas
            MeasurementNoise: [4x4 double]
   HasAdditiveMeasurementNoise: 1
```

Verify that the filter state produces the same measurement as above.

```
meas2 = ctmeas(ckf.State, measParams)
```

meas2 = *4×1*

```
   30.0000
    5.0000
  100.0000
    4.0000
```

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

ckf — Constant turn rate cubature Kalman filter for object tracking
trackingCKF object

Constant turn rate cubature Kalman filter for object tracking, returned as a
trackingCKF object.

Algorithms

- The function computes the process noise matrix assuming a unit acceleration standard deviation and a unit angular acceleration standard deviation.

- You can use this function as the `FilterInitializationFcn` property of `trackerTOMHT` and `trackerGNN` System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
constturn | ctmeas | initcackf | initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvckf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingCKF | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

initctpf

Create constant turn rate tracking particle filter from detection report

Syntax

```
pf = initctpf(detection)
```

Description

`pf = initctpf(detection)` initializes a constant turn rate particle filter for object tracking based on information provided in an `objectDetection` class object, `detection`.

Examples

Create Constant Turn Rate Tracking PF Object from Rectangular Measurements

Create a constant turn rate tracking particle filter object, `trackingPF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the particle filter state in rectangular coordinates. You can obtain the 3-D position measurement using the constant turn rate measurement function, `ctmeas`.

This example uses the coordinates, `x = 1`, `y = 3`, `z = 0` and a 3-D position measurement noise of `[1 0.2 0; 0.2 2 0; 0 0 1]`.

```
detection = objectDetection(0, [1;3;0], 'MeasurementNoise', [1 0.2 0; 0.2 2 0; 0 0 1]);
```

Use `initctpf` to create a `trackingPF` filter initialized at the provided position and using the measurement noise defined above.

```
pf = initctpf(detection)

pf =
  trackingPF with properties:
```

```
                         State: [7×1 double]
               StateCovariance: [7×7 double]
        IsStateVariableCircular: [0 0 0 0 0 0 0]

             StateTransitionFcn: @constturn
         ProcessNoiseSamplingFcn: []
                   ProcessNoise: [4x4 double]
         HasAdditiveProcessNoise: 0

                 MeasurementFcn: @ctmeas
       MeasurementLikelihoodFcn: []
              MeasurementNoise: [3x3 double]

                     Particles: [7x1000 double]
                       Weights: [1x1000 double]
              ResamplingPolicy: [1x1 trackingResamplingPolicy]
              ResamplingMethod: 'multinomial'
```

Check the values of the state and the measurement noise. Verify that the filter state, `pf.State`, has approximately the same position components as the detection measurement, `detection.Measurement`.

`pf.State`

ans = *7×1*

```
    1.0043
    0.5556
    3.0166
   -0.1605
   -0.0213
   -0.0163
    0.0866
```

Verify that the filter measurement noise, `pf.MeasurementNoise`, is the same as the `detection.MeasurementNoise` values.

`pf.MeasurementNoise`

ans = *3×3*

```
    1.0000    0.2000         0
```

```
    0.2000    2.0000         0
         0         0    1.0000
```

Create Constant Turn Rate Tracking PF Object from Spherical Measurements

Create a constant turn rate tracking particle filter object, `trackingPF`, from an initial detection report. The detection report is made from an initial 3-D position measurement of the particle filter state in spherical coordinates. You can obtain the 3D position measurement using the constant turn rate measurement function, `ctmeas`.

This example uses the coordinates, `az = 30, el = 5, r = 100, rr = 4` and a measurement noise of `diag([2.5, 2.5, 0.5, 1].^2)`.

```
meas = [30;5;100;4];
measNoise = diag([2.5, 2.5, 0.5, 1].^2);
```

Use the `MeasurementParameters` property of the `detection` object to define the frame. When not defined, the fields of the `MeasurementParameters` struct use default values. In this example, sensor position, sensor velocity, orientation, elevation, and range rate flags are default.

```
measParams = struct('Frame','spherical');
detection = objectDetection(0,meas,'MeasurementNoise',measNoise,...
    'MeasurementParameters',measParams)
```

```
detection =
  objectDetection with properties:

                    Time: 0
             Measurement: [4x1 double]
        MeasurementNoise: [4x4 double]
             SensorIndex: 1
            ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

Use `initctpf` to create a `trackingPF` filter initialized at the provided position and using the measurement noise defined above.

```
pf = initctpf(detection)
```

```
pf =
  trackingPF with properties:

                         State: [7×1 double]
               StateCovariance: [7×7 double]
        IsStateVariableCircular: [0 0 0 0 0 0 0]

            StateTransitionFcn: @constturn
        ProcessNoiseSamplingFcn: []
                   ProcessNoise: [4x4 double]
         HasAdditiveProcessNoise: 0

                 MeasurementFcn: @ctmeas
       MeasurementLikelihoodFcn: []
              MeasurementNoise: [4x4 double]

                      Particles: [7x1000 double]
                        Weights: [1x1000 double]
              ResamplingPolicy: [1x1 trackingResamplingPolicy]
              ResamplingMethod: 'multinomial'
```

Verify that the filter state produces approximately the same measurement as `detection.Measurement`.

```
meas2 = ctmeas(pf.State, detection.MeasurementParameters)
```

meas2 = *4×1*

```
   29.9188
    5.0976
   99.8303
    4.0255
```

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

`pf` — Constant turn rate particle filter
`trackingPF` object

Constant turn rate particle filter for object tracking, returned as a `trackingPF` object.

Algorithms

- The function configures the filter with 1000 particles. In creating the filter, the function computes the process noise matrix assuming a unit acceleration standard deviation and a unit angular acceleration standard deviation.

- You can use this function as the `FilterInitializationFcn` property of `trackerTOMHT` and `trackerGNN` System objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`constturn` | `ctmeas` | `initcapf` | `initctckf` | `initctekf` | `initctukf` | `initcvpf`

Classes
`objectDetection` | `trackingEKF` | `trackingKF` | `trackingPF` | `trackingUKF`

System Objects
`trackerGNN` | `trackerTOMHT`

Introduced in R2018b

switchimm

Model conversion function for `trackingIMM` object

Syntax

```
x = switchimm(modelType1,x1,modelType2)
x = switchimm( ___ ,x2)
```

Description

`x = switchimm(modelType1,x1,modelType2)` converts the `State` or `StateCovariance` properties of the `trackingIMM` object from `modelType1` state definition to `modelType2` state definition.

- `modelType1` –– Specifies the string name of the current motion model.
- `x1` –– Specifies `State` or `StateCovariance` corresponding to `modelType1`.
- `modelType2` –– Specifies the string name of the motion model to which `x1` needs to be converted.

`x = switchimm( ___ ,x2)` additionally lets you specify the size and type of the output. When not specified, `x` has the same data type and dimensionality as `x1`.

`x2` specifies `State` or `StateCovariance` corresponding to `modelType2`.

Examples

Convert State from Constant Acceleration to Constant Velocity

Convert state from constant acceleration model to constant velocity model using the `switchimm` function.

Initialization

Set the current model to `'constacc'` and the destination model to `'constvel'`. The variable x1 defines the state in the current model.

```
modelType1 = 'constacc';
modelType2 = 'constvel';
x1 = single([1;2;3;4;5;6]);
```

Conversion

The switchimm function converts the 2-D constant acceleration state input to a 2-D constant velocity state output. The output has the same dimensionality and data type as the input x1.

```
x = switchimm(modelType1,x1,modelType2)
```

```
x = 4x1 single column vector

    1
    2
    4
    5
```

Convert State from Constant Acceleration to Constant Turn

Convert state from constant acceleration model to constant turn model using the switchimm function. Specify x2 as an input parameter.

Initialization

Set the current model to `'constacc'` and the destination model to `'constturn'`. The variable x1 defines the state in the current model. The size and data type of the output is determined by the optional input x2.

```
modelType1 = 'constacc';
modelType2 = 'constturn';
x1 = [1;2;3;4;5;6];
x2 = [0;0;0;0;0;0;0];
```

Conversion

The `switchimm` function converts the 2-D constant acceleration state input to a 3-D constant turn model state output. The output has the same size and data type as the input `x2`.

```
x = switchimm(modelType1,x1,modelType2,x2)
```

x = *7×1*

```
    1
    2
    4
    5
    0
    0
    0
```

Input Arguments

`modelType1` — Current motion model
`'constvel'` | `'constacc'` | `'constturn'`

Current motion model, specified as:

- `'constvel'` –– Constant velocity motion model.
- `'constacc'` –– Constant-acceleration motion model.
- `'constturn'` –– Constant turn-rate motion model.

`x1` — State or state covariance of current model
vector | matrix

State vector or state covariance matrix corresponding to the current model in `modelType1`, specified as an L-by-1 real vector or an L-by-L real matrix.

The size of the state vector must fit the motion model. For example, if the `modelType` is `'constvel'`, the state vector must be of size 2, 4, or 6. Similarly, if the `modelType` is `'constacc'`, the state vector must be of size 3, 6, or 9. If the `modelType` is

`'constturn'`, the state vector must be of size 5, 7, 10, 15, 14, or 21. The relationship between model type, state size, and the space dimension is given by the following table:

modelType1	Supported Space Dimension	State size
`'constvel'`	1-D, 2-D, 3-D	$2 \times$ Space dimension
`'constacc'`	1-D, 2-D, 3-D	$3 \times$ Space dimension
`'constturn'`	2-D and 3-D	5 for 2-D space and 7 for 3-D space

The `'constturn'` model type supports only 2-D and 3-D spaces, since a turn cannot be made in 1-D space. If the space dimension is computed to be 1-D, that is, the state size equals 5 or 7, the function treats the output dimension as 2 and the values corresponding to the second dimension are set to 0. For example, run the following in the MATLAB command prompt:

```
switchimm('constvel',rand(2,1),'constturn')
```

Data Types: `single` | `double`

modelType2 — Motion model to which x1 needs to be converted
`'constvel'` | `'constacc'` | `'constturn'`

Motion model to which `x1` needs to be converted, specified as:

- `'constvel'` –– Constant velocity motion model.
- `'constacc'` –– Constant-acceleration motion model.
- `'constturn'` –– Constant turn-rate motion model.

x2 — Specify size and type of output state or state covariance
vector | matrix

The optional input `x2` has the same size and data type as the output state vector or the state covariance matrix, `x`. The variable `x2` does not contain the actual output state information, but only holds the size and the data type of the output state. For example, when `x2` is set to [0;0;0;0;0;0;0], the function determines the output state vector to be a vector of size 7 with a data type of double.

The size of the state vector must fit the motion model. For example, if the `modelType` is `'constvel'`, the state vector must be of size 2, 4, or 6. Similarly, if the `modelType` is

'constacc', the state vector must be of size 3, 6, or 9. The relationship between model type, state size, and the space dimension is given by the following table:

modelType1	Supported Space Dimension	State size
'constvel'	1-D, 2-D, 3-D	2 × Space dimension
'constacc'	1-D, 2-D, 3-D	3 × Space dimension
'constturn'	2-D and 3-D	5 for 2-D space and 7 for 3-D space

Example: [0;0;0;0;0;0;0]

Data Types: single | double

Output Arguments

x — State or state covariance corresponding to modelType2
vector | matrix

State vector or state covariance matrix, corresponding to the motion model specified in modelType2.

The relationship between model type, state size, and the space dimension is given by the following table:

modelType1	Supported Space Dimension	State size
'constvel'	1-D, 2-D, 3-D	2 × Space dimension
'constacc'	1-D, 2-D, 3-D	3 × Space dimension
'constturn'	2-D and 3-D	5 for 2-D space and 7 for 3-D space

If x2 is not specified:

Given modelType1 and x1, the function determines the input state dimension based on the relationship specified in the table. For example, if modelType1 is 'constvel', and x1 is a 4-by-1 vector, the input state dimension is given by 4/2, which equals 2.

If `modelType1` is `'constacc'` and `x1` is a 6-by-1 vector, the input state dimension is given by 6/3, which equals 2.

In this case when `x2` is not specified, the output `x` has the same data type as `x1` and the dimension is calculated using `modelType1` and `x1`.

If `x2` is specified:

The function calculates the output space dimnension using `modelType2` and `x2`. For example, if `modelType2` is `'constacc'` and `x2` is a 6-by-1 vector, the output state dimension is given by 6/3, which equals 2.

The output `x` has the same data type and dimensionality as `x2`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Objects
`trackingIMM`

Functions
`constacc` | `constturn` | `constvel` | `initcvmscekf`

Introduced in R2018b

initcvmscekf

Constant velocity `trackingMSCEKF` initialization

Syntax

```
mscekf = initcvmscekf(detection)
mscekf = initcvmscekf(detection,rangeEstimation)
```

Description

`mscekf = initcvmscekf(detection)` initializes a `trackingMSCEKF` class (extended Kalman filter for tracking in modified spherical coordinates) based on information provided in an `objectDetection` class object, `detection`. The function assumes a target range of $3e^4$ units and a range-covariance of $1e^{10}$ units^2.

The `trackingMSCEKF` object can be used with trackers for tracking targets with angle-only measurements from a single observer.

`mscekf = initcvmscekf(detection,rangeEstimation)` allows specifying the range information to the filter. The `rangeEstimation` variable is a two-element vector, where the first element specifies the range of the target, and the second element specifies the standard deviation in range.

Examples

Initialize a `trackingMSCEKF` Object Using Angle-Only Detection

Create an angle-only detection.

```
detection = objectDetection(0,[30;20],'MeasurementParameters',...
    struct('Frame','Spherical','HasRange',false));
```

Use `initcvmscekf` to create a `trackingMSCEKF` filter initialized using the angle-only detection.

```
filter = initcvmscekf(detection)

filter =
  trackingMSCEKF with properties:

                            State: [6×1 double]
                  StateCovariance: [6×6 double]

                StateTransitionFcn: @constvelmsc
        StateTransitionJacobianFcn: @constvelmscjac
                      ProcessNoise: [3×3 double]
            HasAdditiveProcessNoise: 0
                     ObserverInput: [3×1 double]

                    MeasurementFcn: @cvmeasmsc
           MeasurementJacobianFcn: @cvmeasmscjac
                  MeasurementNoise: [2×2 double]
       HasAdditiveMeasurementNoise: 1
```

Initialize `trackingMSCEKF` Object with Detection from Rotating Sensor

Create measurement parameters for subsequent rotation.

```
measParamSensorToPlat = struct('Frame','Spherical','HasRange',false,...
'Orientation',rotmat(quaternion([0 0 30],'rotvecd'),'frame'))

measParamSensorToPlat = struct with fields:
        Frame: 'Spherical'
     HasRange: 0
  Orientation: [3×3 double]


measParamPlatToScenario = struct('Frame','Rectangular','HasRange',false,...
'Orientation',rotmat(quaternion([30 0 0],'rotvecd'),'frame'))

measParamPlatToScenario = struct with fields:
        Frame: 'Rectangular'
     HasRange: 0
  Orientation: [3×3 double]
```

```
measParam = [measParamSensorToPlat;measParamPlatToScenario];
detection = objectDetection(0,[30;20],'MeasurementParameters',measParam);
```

Initialize a filter.

```
filter = initcvmscekf(detection);
```

Check that filter's measurement is same as detection.

```
cvmeasmsc(filter.State,measParam)
```

```
ans = 2×1

    30.0000
    20.0000
```

Track a Constant Velocity Target Using `trackerGNN`

Consider a scenario when the target is moving at a constant velocity along and the observer is moving at a constant acceleration. Define target's initial state using a constant velocity model.

```
tgtState = [2000;-3;500;-5;0;0];
```

Define observer's initial state using a constant acceleration model.

```
observerState = [0;2;0;490;-10;0.2;0;0;0];
```

Create a `trackerGNN` object to use with `initcvmscekf` with some prior information about range and range-covariance.

```
range = 1000;
rangeStdDev = 1e3;
rangeEstimate = [range rangeStdDev];
tracker = trackerGNN('FilterInitializationFcn',@(det)initcvmscekf(det,rangeEstimate));
```

Simulate synthetic data by using measurement models. Get `az` and `el` information using the `cvmeas` function.

```
syntheticParams = struct('Frame','Spherical','HasRange',false,...
    'OriginPosition',observerState(1:3:end));
meas = cvmeas(tgtState,syntheticParams);
```

Create an angle-only objectDetection to simulate synthetic detection.

```
detection = objectDetection(0,meas,'MeasurementParameters',...
    struct('Frame','Spherical','HasRange',false),'MeasurementNoise',0.033*eye(2));
```

Create trackPlotter and platformPlotter to visualize the scenario.

```
tp = theaterPlot('XLimits',[0 2500],'YLimits',[0 1000]);
targetPlotter = platformPlotter(tp,'DisplayName','Target','MarkerFaceColor','k');
observerPlotter = platformPlotter(tp,'DisplayName', 'Observer','MarkerFaceColor','r');
trkPlotter = trackPlotter(tp,'DisplayName','Track','MarkerFaceColor','g','HistoryDepth
tgtTrajPlotter = trajectoryPlotter(tp,'DisplayName','Target Trajectory','Color','k');
obsTrajPlotter = trajectoryPlotter(tp,'DisplayName','Observer Trajectory','Color','r');
```
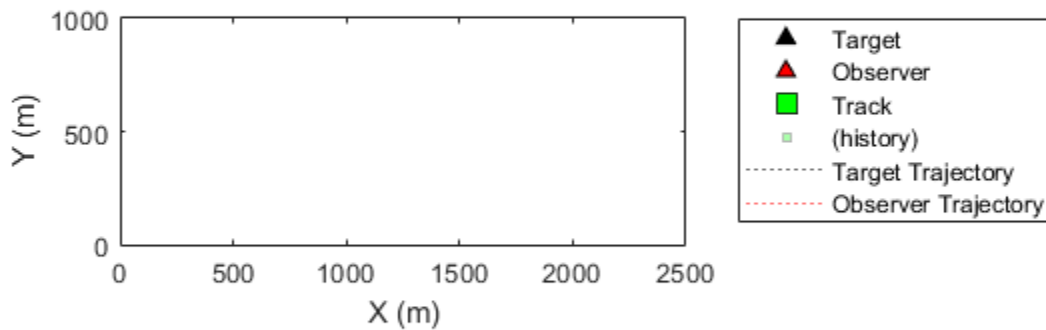

Run the tracker.

```matlab
time = 0; dT = 0.1;
tgtPoses = [];
obsPoses = [];
while time < 50
    [confTracks,tentTracks,allTracks] = tracker(detection,time);
    for i = 1:numel(allTracks)
        setTrackFilterProperties(tracker,allTracks(i).TrackID,'ObserverInput',observerS
    end

    % Update synthetic detection.
    observerState = constacc(observerState,dT);
    tgtState = constvel(tgtState,dT);
    syntheticParams.OriginPosition = observerState(1:3:end);
    detection.Measurement = cvmeas(tgtState,syntheticParams);
    time = time + dT;
    detection.Time = time;

    % Update plots
    tgtPoses = [tgtPoses;tgtState(1:2:end)']; %#ok
    obsPoses = [obsPoses;observerState(1:3:end)']; %#ok
    targetPlotter.plotPlatform(tgtState(1:2:end)');
    observerPlotter.plotPlatform(observerState(1:3:end)');
    tgtTrajPlotter.plotTrajectory({tgtPoses});
    obsTrajPlotter.plotTrajectory({obsPoses});
    % Plot the first track as there are no false alarms, this should be
    % the target.
    % Get positions from the MSC state of the track.
    cartState = cvmeasmsc(allTracks(i).State,'rectangular') + observerState(1:3:end);
    trkPlotter.plotTrack(cartState');
end
```
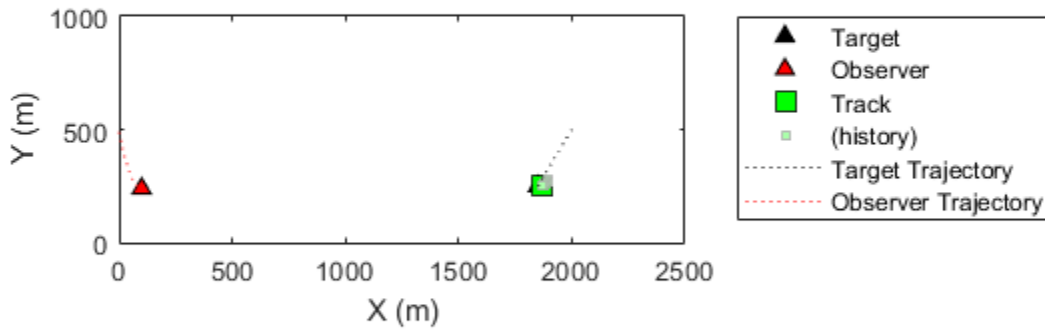
Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

rangeEstimation — Range information
two-element vector

Range information, specified as a two-element vector, where the first element specifies the range of the target, and the second element specifies the standard deviation in range.

Data Types: `single` | `double`

Output Arguments

`mscekf` — Constant velocity tracking extended Kalman filter in MSC frame
`trackingMSCEKF` object

Constant velocity tracking extended Kalman filter in an MSC frame, returned as a `trackingMSCEKF` class object.

Algorithms

- The function configures the filter with process noise assuming a unit target acceleration standard deviation.

- The function configures the covariance of the state in an MSC frame by using a linear transformation of covariance in a Cartesian frame.

- You can use this function as the `FilterInitializationFcn` property of `trackerTOMHT` and `trackGNN` System objects.

- The function initializes the `ObserverInput` of the `trackingMSCEKF` class with zero observer acceleration in all directions. You must use the `setTrackFilterProperties` function of the trackers to update the `ObserverInput`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
constvelmsc | constvelmscjac | cvmeasmsc | cvmeasmscjac

Classes
objectDetection | trackingMSCEKF

Introduced in R2018b

initapekf

Constant velocity angle-parameterized EKF initialization

Syntax

```
filter = initapekf(detection)
filter = initapekf(detection,numFilters)
filter = initapekf(detection,numFilters,angleLimits)
```

Description

`filter = initapekf(detection)` configures the filter with 10 extended Kalman filters (EKFs). The function configures the process noise with unit standard deviation in acceleration.

The angle-parameterized extended Kalman filter (APEKF) is a Gaussian-sum filter (`trackingGSF`) with multiple EKFs, each initialized at an estimated angular position of the target. Angle-parametrization is a commonly used technique to initialize a filter from a range-only detection.

`filter = initapekf(detection,numFilters)` specifies the number of EKFs in the filter.

`filter = initapekf(detection,numFilters,angleLimits)` specifies the limits on angular position of the target.

Examples

Initialize APEKF from Range Only Detection and Visualize Filter

The APEKF is a special type of filter that can be initialized using range-only measurements. When the `'Frame'` is set to `'spherical'`, the detection has [azimuth elevation range range-rate] measurements. Specify the measurement parameters appropriately to define a range-only measurement.

```
measParam = struct('Frame','Spherical','HasAzimuth',false,'HasElevation',false,'HasVelo
```

The `objectDetection` class defines an interface to the range-only detection measured by the sensor. The `MeasurementParameters` field of `objectDetection` carries information about what the sensor is measuring.

```
detection = objectDetection(0,100,'MeasurementNoise',100,'MeasurementParameters',measPa

detection =
  objectDetection with properties:

                    Time: 0
             Measurement: 100
        MeasurementNoise: 100
             SensorIndex: 1
           ObjectClassID: 0
   MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

The `initapekf` function uses the range-only detection to initialize the APEKF.

```
apekf = initapekf(detection) %#ok

apekf =
  trackingGSF with properties:

                 State: [6x1 double]
       StateCovariance: [6x6 double]

       TrackingFilters: {10x1 cell}
     ModelProbabilities: [10x1 double]

      MeasurementNoise: 100
```

You can also initialize the APEKF with 10 filters and to operate within the angular limits of [-30 30] degrees.

```
angleLimits = [-30 30];
numFilters = 10;
apekf = initapekf(detection, numFilters, angleLimits)

apekf =
  trackingGSF with properties:
```

1-325

```
                 State: [6x1 double]
        StateCovariance: [6x6 double]

        TrackingFilters: {10x1 cell}
     ModelProbabilities: [10x1 double]

       MeasurementNoise: 100
```

You can also specify the `initapekf` function as a `FilterInitializationFcn` to the `trackerGNN` object.

```
funcHandle = @(detection)initapekf(detection,numFilters,angleLimits)

funcHandle = function_handle with value:
    @(detection)initapekf(detection,numFilters,angleLimits)


tracker = trackerGNN('FilterInitializationFcn',funcHandle);
```

Visualize the filter.

```
tp = theaterPlot;
componentPlot = trackPlotter(tp,'DisplayName','Individual sums','MarkerFaceColor','r');
sumPlot = trackPlotter(tp,'DisplayName','Mixed State','MarkerFaceColor','g');

indFilters = apekf.TrackingFilters;
pos = zeros(numFilters,3);
cov = zeros(3,3,numFilters);
for i = 1:numFilters
    pos(i,:) = indFilters{i}.State(1:2:end);
    cov(1:3,1:3,i) = indFilters{i}.StateCovariance(1:2:end,1:2:end);
end
componentPlot.plotTrack(pos,cov);

mixedPos = apekf.State(1:2:end)';
mixedPosCov = apekf.StateCovariance(1:2:end,1:2:end);
sumPlot.plotTrack(mixedPos,mixedPosCov);
```

Initialize APEKF from Azimuth and Range Detection and Visualize Filter

Create an angle-parameterized EKF from an [az r] detection.

```
measParam = struct('Frame','Spherical','HasAzimuth',true,'HasElevation',false,'HasVeloc
```

The `objectDetection` class defines an interface to the range-only detection measured by the sensor. The `MeasurementParameters` field of `objectDetection` carries information about what the sensor is measuring.

```
det = objectDetection(0,[30;100],'MeasurementParameters',measParam,'MeasurementNoise',1
```

1-327

The `initapekf` function parameterizes the `apekf` filter on the elevation measurement.

```
numFilters = 10;
apekf = initapekf(det,numFilters,[-30 30]);
indFilters = apekf.TrackingFilters;
pos = zeros(numFilters,3);
cov = zeros(3,3,numFilters);
for i = 1:numFilters
    pos(i,:) = indFilters{i}.State(1:2:end);
    cov(1:3,1:3,i) = indFilters{i}.StateCovariance(1:2:end,1:2:end);
end
```
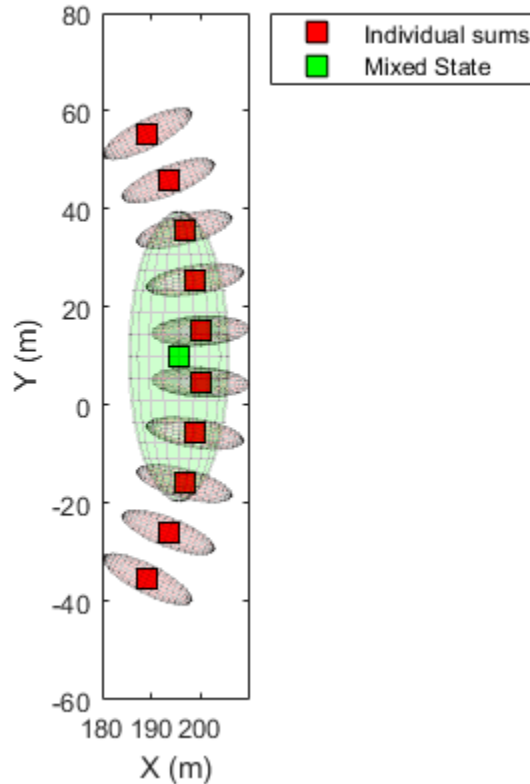
Visualize the filter.

```
tp = theaterPlot;
componentPlot = trackPlotter(tp,'DisplayName','Individual sums','MarkerFaceColor','r');
sumPlot = trackPlotter(tp,'DisplayName','Mixed State','MarkerFaceColor','g');
componentPlot.plotTrack(pos,cov);
mixedPos = apekf.State(1:2:end)';
mixedPosCov = apekf.StateCovariance(1:2:end,1:2:end);
sumPlot.plotTrack(mixedPos,mixedPosCov);
view(3);
```
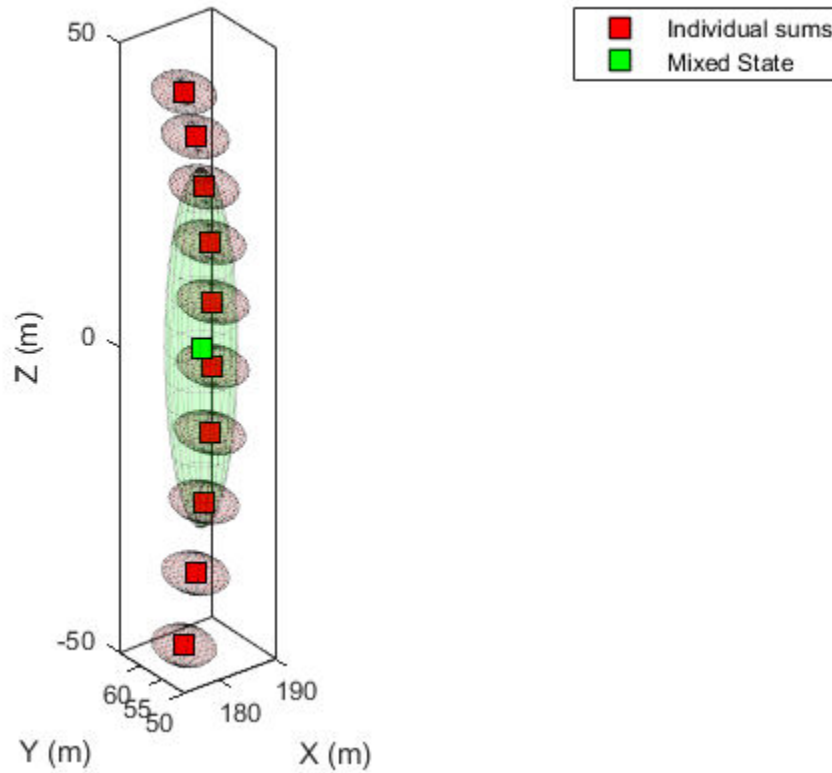
Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

numFilters — Number of EKFs
10 (default) | positive integer

Number of EKFs each initialized at an estimated angular position of the target, specified as a positive integer. When not specified, the default number of EKFs is 10.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

angleLimits — Angular limits of target
two-element vector

Angular limits of the target, specified as a two-element vector. The two elements in the vector represent the lower and upper limits of the target angular position.

When the function detects:

- Range measurements –– Default angular limits are [–180 180].

- Azimuth and range measurements –– Default angular limits are [–90 90].

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

filter — Constant velocity angle-parameterized EKF
`trackingGSF` object

Constant velocity angle-parameterized extended Kalman filter (EKF), returned as a `trackingGSF` object.

Algorithms

The function can support the following types of measurements in the detection.

- Range measurements –– Parameterization is done on the azimuth of the target, and the angular limits are [–180 180] by default.

- Azimuth and range measurements –– Parameterization is done on the elevation of the target, and the angular limits are [–90 90] by default.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcvekf

Classes
objectDetection | trackingEKF

Objects
trackingGSF

Introduced in R2018b

initrpekf

Constant velocity range-parameterized EKF initialization

Syntax

```
filter = initrpekf(detection)
filter = initrpekf(detection,numFilters)
filter = initrpekf(detection,numFilters,rangeLimits)
```

Description

`filter = initrpekf(detection)` configures the filter with 6 extended Kalman filters (EKFs), and the target range is assumed to be within 1e3 and 1e5 scenario units. The function configures the process noise with unit standard deviation in acceleration.

The range-parameterized extended Kalman filter (RPEKF) is a Gaussian-sum filter (`trackingGSF`) with multiple EKFs, each initialized at an estimated range of the target. Range-parameterization is a commonly used technique to initialize a filter from an angle-only detection.

`filter = initrpekf(detection,numFilters)` specifies the number of EKFs in the filter.

`filter = initrpekf(detection,numFilters,rangeLimits)` specifies the range limits of the target.

Examples

Initialize RPEKF from Angle-only Detection and Visualize Filter

The RPEKF is a special type of filter that can be initialized using angle-only measurements, that is, azimuth and/or elevation. When the `'Frame'` is set to `'spherical'` and `'HasRange'` is set to `'false'`, the detection has [azimuth elevation]

measurements. Specify the measurement parameters appropriately to define an angle-only measurement with no range information.

```
measParam = struct('Frame','spherical','HasRange',false,'OriginPosition',[100;10;0]);
```

The `objectDetection` class defines an interface to the angle-only detection measured by the sensor. The `MeasurementParameters` field of `objectDetection` carries information about what the sensor is measuring.

```
detection = objectDetection(0,[30;30],'MeasurementParameters',measParam,'MeasurementNo
```

The `initrpekf` function uses the angle-only detection to initialize the RPEKF.

```
rpekf = initrpekf(detection) %#ok

rpekf =
  trackingGSF with properties:

                State: [6x1 double]
      StateCovariance: [6x6 double]

       TrackingFilters: {6x1 cell}
    ModelProbabilities: [6x1 double]

      MeasurementNoise: [2x2 double]
```

You can also initialize the RPEKF with 10 filters and to operate within the range limits of [1000, 10,000] scenario units.

```
rangeLimits = [1000 10000];
numFilters = 10;
rpekf = initrpekf(detection, numFilters, rangeLimits)

rpekf =
  trackingGSF with properties:

                State: [6x1 double]
      StateCovariance: [6x6 double]

       TrackingFilters: {10x1 cell}
    ModelProbabilities: [10x1 double]

      MeasurementNoise: [2x2 double]
```

You can also specify the `initrpekf` function as a `FilterInitializationFcn` to the `trackerGNN` object.

```
funcHandle = @(detection)initrpekf(detection,numFilters,rangeLimits)

funcHandle = function_handle with value:
    @(detection)initrpekf(detection,numFilters,rangeLimits)
```

```
tracker = trackerGNN('FilterInitializationFcn',funcHandle)

tracker =
  trackerGNN with properties:

        FilterInitializationFcn: [function_handle]
                     Assignment: 'Munkres'
            AssignmentThreshold: 30
                   MaxNumTracks: 100
                  MaxNumSensors: 20

                      TrackLogic: 'History'
           ConfirmationThreshold: [2 3]
               DeletionThreshold: [5 5]

              HasCostMatrixInput: false
      HasDetectableTrackIDsInput: false

                       NumTracks: 0
              NumConfirmedTracks: 0
```

Visualize the filter.

```
tp = theaterPlot;
componentPlot = trackPlotter(tp,'DisplayName','Individual sums','MarkerFaceColor','r');
sumPlot = trackPlotter(tp,'DisplayName','Mixed State','MarkerFaceColor','g');

indFilters = rpekf.TrackingFilters;
pos = zeros(numFilters,3);
cov = zeros(3,3,numFilters);
for i = 1:numFilters
    pos(i,:) = indFilters{i}.State(1:2:end);
    cov(1:3,1:3,i) = indFilters{i}.StateCovariance(1:2:end,1:2:end);
end
componentPlot.plotTrack(pos,cov);
```

```
mixedPos = rpekf.State(1:2:end)';
mixedPosCov = rpekf.StateCovariance(1:2:end,1:2:end);
sumPlot.plotTrack(mixedPos,mixedPosCov);
```
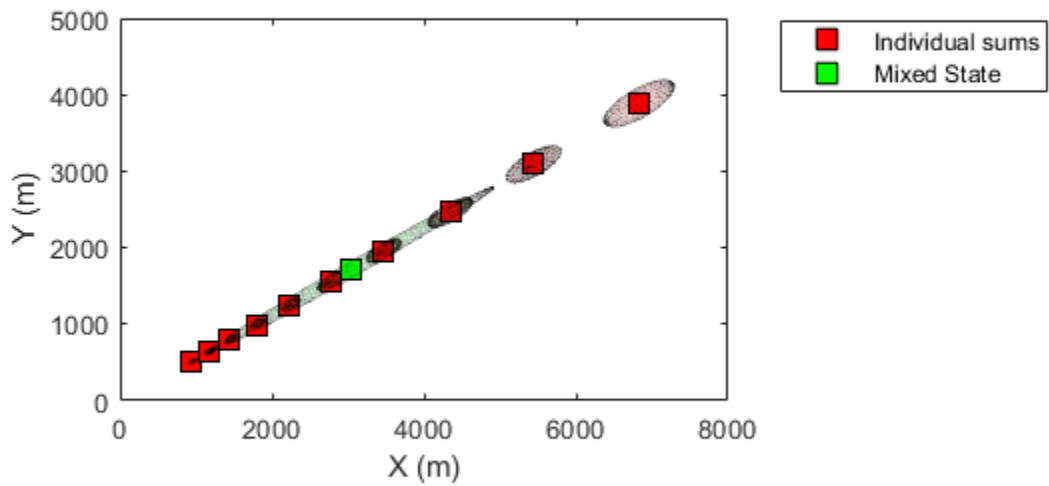

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])`

`numFilters` — Number of EKFs
6 (default) | positive integer

Number of EKFs each initialized at an estimated range of the target, specified as a positive integer. When not specified, the default number of EKFs is 6.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`rangeLimits` — Range limits of target
[1e3 1e5] (default) | two-element vector

Range limits of the target, specified as a two-element vector. The two elements in the vector represent the lower and upper limits of the target range. When not specified, the default range limits are [1e3 1e5] scenario units.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

`filter` — Constant velocity range-parameterized EKF
`trackingGSF` object

Constant velocity range-parameterized extended Kalman filter (EKF), returned as a `trackingGSF` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initapekf | initcvekf | initcvmscekf

Classes
objectDetection | trackingEKF

Objects
trackingGSF

Introduced in R2018b

initekfimm

Initialize `trackingIMM` object

Syntax

```
imm = initekfimm(detection)
```

Description

`imm = initekfimm(detection)` initializes a constant velocity (CV), constant acceleration (CA), and a constant turn (CT) `trackingIMM` (imm) object based on information provided in an `objectDetection` class object, `detection`.

Examples

Detection with Position Measurement in Rectangular Frame

A 3-D position measurement in rectangular frame is provided. For example, $x = 1$, $y = 3$, and $z = 0$. Use a 3-D position measurement noise [1 0.4 0; 0.4 4 0; 0 0 1].

```
detection = objectDetection(0, [1;3;0], 'MeasurementNoise', [1 0.4 0; 0.4 4 0; 0 0 1]);
```

Use `initekfimm` to create a `trackingIMM` filter initialized at the provided position and using the measurement noise defined above.

```
imm = initekfimm(detection);
```

Check the values of the state and measurement noise. Verify that the filter state, `imm.State`, has the same position components as detection measurement, `detection.Measurement`.

```
imm.State
```

ans = 6×1

```
                1
                0
                3
                0
                0
                0
```

Verify that the filter measurement noise, `imm.MeasurementNoise`, is the same as the `detection.MeasurementNoise` values.

`imm.MeasurementNoise`

ans = *3×3*

```
    1.0000    0.4000         0
    0.4000    4.0000         0
         0         0    1.0000
```

Detection with Position Measurement in Spherical Frame

A 3-D position measurement in spherical frame is provided. For example: `az = 40`, `el = 6`, `r = 100`, `rr = 5`. Measurement noise is `diag([2.5, 2.5, 0.5, 1].^2)`.

```
meas = [40;6;100;5];
measNoise = diag([2.5,2.5,0.5,1].^2);
```

Use the `MeasurementParameters` to define the frame. You can leave out other fields of the `MeasurementParameters` struct, and they will be completed by default values. In this example, sensor position, sensor velocity, orientation, elevation, and range rate flags are default.

```
measParams = struct('Frame','spherical');
detection = objectDetection(0,meas,'MeasurementNoise',measNoise,...
    'MeasurementParameters', measParams);
```

Use `initekfimm` to create a `trackingIMM` filter initialized at the provided position and using the measurement noise defined above.

```
imm = initekfimm(detection)
```

```
imm =
  trackingIMM with properties:

                    State: [6x1 double]
          StateCovariance: [6x6 double]

          TrackingFilters: {3x1 cell}
        ModelConversionFcn: @switchimm
   TransitionProbabilities: [3x3 double]

          MeasurementNoise: [4x4 double]
         ModelProbabilities: [3x1 double]
```

Input Arguments

detection — Detection report
objectDetection class object

Detection report, specified as an "Object Detections" object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

imm — trackingIMM object
trackingIMM object

Constant velocity (CV), constant acceleration (CA), and a constant turn (CT)
trackingIMM (imm) object based on information provided in detection, returned as a
trackingIMM object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
objectDetection

Objects
trackingIMM

Functions
initcaekf | initctekf | initcvekf

Introduced in R2018b

initcaekf

Create constant-acceleration extended Kalman filter from detection report

Syntax

```
filter = initcaekf(detection)
```

Description

`filter = initcaekf(detection)` creates and initializes a constant-acceleration extended Kalman `filter` from information contained in a `detection` report. For more information about the extended Kalman filter, see `trackingEKF`.

Examples

Initialize 3-D Constant-Acceleration Extended Kalman Filter

Create and initialize a 3-D constant-acceleration extended Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, *(-200;30;0)* , of the object position. Assume uncorrelated measurement noise.

```
detection = objectDetection(0,[-200;-30;0],'MeasurementNoise',2.1*eye(3), ...
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Car',2});
```

Create the new filter from the detection report and display its properties.

```
filter = initcaekf(detection)

filter =
  trackingEKF with properties:

                        State: [9x1 double]
              StateCovariance: [9x9 double]
```

```
           StateTransitionFcn: @constacc
   StateTransitionJacobianFcn: @constaccjac
                 ProcessNoise: [3x3 double]
     HasAdditiveProcessNoise: 0

              MeasurementFcn: @cameas
      MeasurementJacobianFcn: @cameasjac
            MeasurementNoise: [3x3 double]
  HasAdditiveMeasurementNoise: 1
```

Show the filter state.

`filter.State`

ans = *9×1*

```
  -200
     0
     0
   -30
     0
     0
     0
     0
     0
```

Show the state covariance matrix.

`filter.StateCovariance`

ans = *9×9*

```
    2.1000         0         0         0         0         0         0         0
         0  100.0000         0         0         0         0         0         0
         0         0  100.0000         0         0         0         0         0
         0         0         0    2.1000         0         0         0         0
         0         0         0         0  100.0000         0         0         0
         0         0         0         0         0  100.0000         0         0
         0         0         0         0         0         0    2.1000         0
         0         0         0         0         0         0         0  100.0000
         0         0         0         0         0         0         0         0  100.0
```

???

Input Arguments

`detection` — Detection report
`objectDetection` object

Detection report, specified as an `objectDetection` object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

`filter` — Extended Kalman filter
`trackingEKF` object

Extended Kalman filter, returned as a `trackingEKF` object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration-rate standard deviation of 1 m/s^3.
- You can use this function as the `FilterInitializationFcn` property of a `trackerGNN` or `trackerTOMHT` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcakf | initcaukf | initctekf | initctukf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

initcakf

Create constant-acceleration linear Kalman filter from detection report

Syntax

```
filter = initcakf(detection)
```

Description

`filter = initcakf(detection)` creates and initializes a constant-acceleration linear Kalman `filter` from information contained in a `detection` report. For more information about the linear Kalman filter, see `trackingKF`.

Examples

Initialize 2-D Constant-Acceleration Linear Kalman Filter

Create and initialize a 2-D constant-acceleration linear Kalman filter object from an initial detection report.

Create the detection report from an initial 2-D measurement, $(10, -5)$, of the object position. Assume uncorrelated measurement noise.

```
detection = objectDetection(0,[10;-5],'MeasurementNoise',eye(2), ...
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Car',5});
```

Create the new filter from the detection report.

```
filter = initcakf(detection);
```

Show the filter state.

```
filter.State
```

```
ans = 6×1
```

```
    10
     0
     0
    -5
     0
     0
```

Show the state transition model.

```
filter.StateTransitionModel
```

ans = *6×6*

```
    1.0000    1.0000    0.5000         0         0         0
         0    1.0000    1.0000         0         0         0
         0         0    1.0000         0         0         0
         0         0         0    1.0000    1.0000    0.5000
         0         0         0         0    1.0000    1.0000
         0         0         0         0         0    1.0000
```

Input Arguments

detection — Detection report
objectDetection object

Detection report, specified as an objectDetection object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

filter — Linear Kalman filter
trackingKF object

Linear Kalman filter, returned as a trackingKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration rate standard deviation of 1 m/s^3.

- You can use this function as the `FilterInitializationFcn` property of a `trackerGNN` or `trackerTOMHT` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcaekf | initcaukf | initctekf | initctukf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

initcaukf

Create constant-acceleration unscented Kalman filter from detection report

Syntax

```
filter = initcaukf(detection)
```

Description

`filter = initcaukf(detection)` creates and initializes a constant-acceleration unscented Kalman `filter` from information contained in a `detection` report. For more information about the unscented Kalman filter, see `trackingUKF`.

Examples

Initialize 3-D Constant-Acceleration Unscented Kalman Filter

Create and initialize a 3-D constant-acceleration unscented Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (-200,-30,5), of the object position. Assume uncorrelated measurement noise.

```
detection = objectDetection(0,[-200;-30;5],'MeasurementNoise',2.0*eye(3), ...
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Car',2});
```

Create the new filter from the detection report and display the filter properties.

```
filter = initcaukf(detection)
```

```
filter =
  trackingUKF with properties:

                        State: [9x1 double]
              StateCovariance: [9x9 double]
```

```
            StateTransitionFcn: @constacc
                  ProcessNoise: [3x3 double]
         HasAdditiveProcessNoise: 0

                 MeasurementFcn: @cameas
              MeasurementNoise: [3x3 double]
    HasAdditiveMeasurementNoise: 1

                          Alpha: 1.0000e-03
                           Beta: 2
                          Kappa: 0
```

Show the state.

```
filter.State
```

ans = *9×1*

```
  -200
     0
     0
   -30
     0
     0
     5
     0
     0
```

Show the state covariance matrix.

```
filter.StateCovariance
```

ans = *9×9*

```
        2      0      0      0      0      0      0      0      0
        0    100      0      0      0      0      0      0      0
        0      0    100      0      0      0      0      0      0
        0      0      0      2      0      0      0      0      0
        0      0      0      0    100      0      0      0      0
        0      0      0      0      0    100      0      0      0
        0      0      0      0      0      0      2      0      0
        0      0      0      0      0      0      0    100      0
```

```
    0     0     0     0     0     0     0     0   100
```

Create 3D Constant Acceleration UKF from Spherical Measurement

Initialize a 3D constant-acceleration unscented Kalman filter from an initial detection report made from a measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the Frame field set to 'spherical'. Set the azimuth angle of the target to $45°$, and the range to 1000 meters.

```matlab
frame = 'spherical';
sensorpos = [25,-40,-10].';
sensorvel = [0;5;0];
laxes = eye(3);
```

Create the measurement structure. Set 'HasVelocity' and 'HasElevation' to false. Then, the measurement vector consists of azimuth angle and range.

```matlab
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',false, ...
    'HasElevation',false);
meas = [45;1000];
measnoise = diag([3.0,2.0].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
  objectDetection with properties:

                   Time: 0
            Measurement: [2x1 double]
       MeasurementNoise: [2x2 double]
            SensorIndex: 1
           ObjectClassID: 0
   MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

```matlab
filter = initcaukf(detection);
```

Display the state vector.

```
disp(filter.State)
```

```
   732.1068
          0
          0
   667.1068
          0
          0
   -10.0000
          0
          0
```

Input Arguments

`detection` — Detection report
`objectDetection` object

Detection report, specified as an `objectDetection` object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

`filter` — Unscented Kalman filter
`trackingUKF` object

Unscented Kalman filter, returned as a `trackingUKF` object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration rate standard deviation of 1 m/s^3.
- You can use this function as the `FilterInitializationFcn` property of a `trackerGNN` or `trackerTOMHT` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcaekf | initcakf | initctekf | initctukf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

initctekf

Create constant turn-rate extended Kalman filter from detection report

Syntax

```
filter = initcaekf(detection)
```

Description

`filter = initcaekf(detection)` creates and initializes a constant-turn-rate extended Kalman `filter` from information contained in a `detection` report. For more information about the extended Kalman filter, see `trackingEKF`.

Examples

Initialize 2-D Constant Turn-Rate Extended Kalman Filter

Create and initialize a 2-D constant turn-rate extended Kalman filter object from an initial detection report.

Create the detection report from an initial 2-D measurement, (-250,-40), of the object position. Assume uncorrelated measurement noise.

Extend the measurement to three dimensions by adding a *z*-component of zero.

```
detection = objectDetection(0,[-250;-40;0],'MeasurementNoise',2.0*eye(3), ...
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Car',2});
```

Create the new filter from the detection report and display the filter properties.

```
filter = initctekf(detection)
```

```
filter =
  trackingEKF with properties:
```

```
                      State: [7x1 double]
             StateCovariance: [7x7 double]

           StateTransitionFcn: @constturn
   StateTransitionJacobianFcn: @constturnjac
                 ProcessNoise: [4x4 double]
      HasAdditiveProcessNoise: 0

               MeasurementFcn: @ctmeas
       MeasurementJacobianFcn: @ctmeasjac
             MeasurementNoise: [3x3 double]
   HasAdditiveMeasurementNoise: 1
```

Show the state.

```
filter.State
```

ans = *7×1*

```
  -250
     0
   -40
     0
     0
     0
     0
```

Show the state covariance matrix.

```
filter.StateCovariance
```

ans = *7×7*

```
    2     0     0     0     0     0     0
    0   100     0     0     0     0     0
    0     0     2     0     0     0     0
    0     0     0   100     0     0     0
    0     0     0     0   100     0     0
    0     0     0     0     0     2     0
    0     0     0     0     0     0   100
```

Create 2-D Constant Turnrate EKF from Spherical Measurement

Initialize a 2-D constant-turnrate extended Kalman filter from an initial detection report made from an initial measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the Frame field set to 'spherical'. Set the azimuth angle of the target to 45 degrees, the range to 1000 meters, and the range rate to -4.0 m/s.

```
frame = 'spherical';
sensorpos = [25,-40,-10].';
sensorvel = [0;5;0];
laxes = eye(3);
```

Create the measurement parameters structure. Set 'HasElevation' to false. Then, the measurement consists of azimuth, range, and range rate.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',true, ...
    'HasElevation',false);
meas = [45;1000;-4];
measnoise = diag([3.0,2,1.0].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
  objectDetection with properties:

                    Time: 0
             Measurement: [3x1 double]
        MeasurementNoise: [3x3 double]
             SensorIndex: 1
           ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

```
filter = initctekf(detection);
```

Filter state vector.

```
disp(filter.State)
```

```
  732.1068
   -2.8284
  667.1068
```

```
    2.1716
         0
  -10.0000
         0
```

Input Arguments

detection — Detection report
objectDetection object

Detection report, specified as an objectDetection object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

filter — Extended Kalman filter
trackingEKF object

Extended Kalman filter, returned as a trackingEKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step. The function assumes an acceleration standard deviation of 1 m/s^2, and a turn-rate acceleration standard deviation of 1°/s^2.

- You can use this function as the FilterInitializationFcn property of a trackerGNN or trackerTOMHT object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcaekf | initcakf | initcaukf | initctukf | initcvekf | initcvkf | initcvukf

Classes
objectDetection | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

initctukf

Create constant turn-rate unscented Kalman filter from detection report

Syntax

```
filter = initcaukf(detection)
```

Description

`filter = initcaukf(detection)` creates and initializes a constant-turn-rate unscented Kalman `filter` from information contained in a `detection` report. For more information about the unscented Kalman filter, see `trackingUKF`.

Examples

???

Create 2-D Constant Turnrate UKF from Spherical Measurement

Initialize a 2-D constant-turnrate extended Kalman filter from an initial detection report made from an initial measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45 degrees and the range to 1000 meters.

```
frame = 'spherical';
sensorpos = [25,-40,-10].';
sensorvel = [0;5;0];
laxes = eye(3);
```

Create the measurement parameters structure. Set `'HasVelocity'` and `'HasElevation'` to `false`. Then, the measurement consists of azimuth and range.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',false, ...
    'HasElevation',false);
meas = [45;1000];
measnoise = diag([3.0,2].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)

detection =
  objectDetection with properties:

                     Time: 0
              Measurement: [2x1 double]
         MeasurementNoise: [2x2 double]
              SensorIndex: 1
            ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
         ObjectAttributes: {}
```

```
filter = initctekf(detection);
```

Filter state vector.

```
disp(filter.State)
```

```
  732.1068
         0
  667.1068
         0
         0
  -10.0000
         0
```

Input Arguments

detection — Detection report
objectDetection object

Detection report, specified as an objectDetection object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

`filter` — Unscented Kalman filter
`trackingUKF` object

Unscented Kalman filter, returned as a `trackingUKF` object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step. The function assumes an acceleration standard deviation of 1 m/s^2, and a turn-rate acceleration standard deviation of 1°/s^2.
- You can use this function as the `FilterInitializationFcn` property of a `trackerGNN` or `trackerTOMHT` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`initcaekf` | `initcakf` | `initcaukf` | `initctekf` | `initcvekf` | `initcvkf` | `initcvukf`

Classes
`objectDetection` | `trackingEKF` | `trackingKF` | `trackingUKF`

System Objects
`trackerGNN` | `trackerTOMHT`

Introduced in R2017a

initcvekf

Create constant-velocity extended Kalman filter from detection report

Syntax

```
filter = initcvekf(detection)
```

Description

`filter = initcvekf(detection)` creates and initializes a constant-velocity extended Kalman `filter` from information contained in a `detection` report. For more information about the extended Kalman filter, see `trackingEKF`.

Examples

Initialize 3-D Constant-Velocity Extended Kalman Filter

Create and initialize a 3-D constant-velocity extended Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (10,20,−5), of the object position.

```
detection = objectDetection(0,[10;20;-5],'MeasurementNoise',1.5*eye(3), ...
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Sports Car',5});
```

Create the new filter from the detection report.

```
filter = initcvekf(detection)
```

```
filter =
  trackingEKF with properties:

                        State: [6x1 double]
              StateCovariance: [6x6 double]
```

```
          StateTransitionFcn: @constvel
  StateTransitionJacobianFcn: @constveljac
                ProcessNoise: [3x3 double]
     HasAdditiveProcessNoise: 0

              MeasurementFcn: @cvmeas
      MeasurementJacobianFcn: @cvmeasjac
            MeasurementNoise: [3x3 double]
  HasAdditiveMeasurementNoise: 1
```

Show the filter state.

```
filter.State
```

ans = *6×1*

```
    10
     0
    20
     0
    -5
     0
```

Show the state covariance.

```
filter.StateCovariance
```

ans = *6×6*

```
    1.5000         0         0         0         0         0
         0  100.0000         0         0         0         0
         0         0    1.5000         0         0         0
         0         0         0  100.0000         0         0
         0         0         0         0    1.5000         0
         0         0         0         0         0  100.0000
```

Create 3-D Constant Velocity EKF from Spherical Measurement

Initialize a 3-D constant-velocity extended Kalman filter from an initial detection report made from a 3-D measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the Frame field set to `'spherical'`. Set the azimuth angle of the target to 45 degrees, the elevation to -10 degrees, the range to 1000 meters, and the range rate to -4.0 m/s.

```matlab
frame = 'spherical';
sensorpos = [25,-40,0].';
sensorvel = [0;5;0];
laxes = eye(3);
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',true, ...
    'HasElevation',true);
meas = [45;-10;1000;-4];
measnoise = diag([3.0,2.5,2,1.0].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
  objectDetection with properties:

                   Time: 0
            Measurement: [4x1 double]
       MeasurementNoise: [4x4 double]
            SensorIndex: 1
           ObjectClassID: 0
   MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

```matlab
filter = initcvekf(detection);
```

Filter state vector.

```matlab
disp(filter.State)
```

```
  721.3642
   -2.7855
  656.3642
    2.2145
 -173.6482
    0.6946
```

Input Arguments

detection — Detection report
objectDetection object

Detection report, specified as an objectDetection object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

filter — Extended Kalman filter
trackingEKF object

Extended Kalman filter, returned as a trackingEKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration standard deviation of 1 m/s^2.

- You can use this function as the FilterInitializationFcn property of a trackerGNN or trackerTOMHT object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvkf |
initcvukf

Classes
objectDetection | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

initcvkf

Create constant-velocity linear Kalman filter from detection report

Syntax

```
filter = initcakf(detection)
```

Description

`filter = initcakf(detection)` creates and initializes a constant-velocity linear Kalman `filter` from information contained in a `detection` report. For more information about the linear Kalman filter, see `trackingKF`.

Examples

Initialize 2-D Constant-Velocity Linear Kalman Filter

Create and initialize a 2-D linear Kalman filter object from an initial detection report.

Create the detection report from an initial 2-D measurement, (10,20), of the object position.

```
detection = objectDetection(0,[10;20],'MeasurementNoise',[1 0.2; 0.2 2], ...
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Yellow Car',5});
```

Create the new track from the detection report.

```
filter = initcvkf(detection)

filter =
  trackingKF with properties:

              State: [4x1 double]
     StateCovariance: [4x4 double]
```

```
       MotionModel: '2D Constant Velocity'
      ControlModel: []
      ProcessNoise: [4x4 double]

 MeasurementModel: [2x4 double]
 MeasurementNoise: [2x2 double]
```

Show the state.

```
filter.State
```

ans = *4×1*

```
    10
     0
    20
     0
```

Show the state transition model.

```
filter.StateTransitionModel
```

ans = *4×4*

```
     1     1     0     0
     0     1     0     0
     0     0     1     1
     0     0     0     1
```

Initialize 3-D Constant-Velocity Linear Kalman Filter

Create and initialize a 3-D linear Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (10,20,−5), of the object position.

```
detection = objectDetection(0,[10;20;-5],'MeasurementNoise',eye(3), ...
    'SensorIndex', 1,'ObjectClassID',1,'ObjectAttributes',{'Green Car', 5});
```

Create the new filter from the detection report and display its properties.

```
filter = initcvkf(detection)

filter =
  trackingKF with properties:

               State: [6x1 double]
     StateCovariance: [6x6 double]

          MotionModel: '3D Constant Velocity'
         ControlModel: []
         ProcessNoise: [6x6 double]

     MeasurementModel: [3x6 double]
     MeasurementNoise: [3x3 double]
```

Show the state.

```
filter.State
```

```
ans = 6×1

    10
     0
    20
     0
    -5
     0
```

Show the state transition model.

```
filter.StateTransitionModel
```

```
ans = 6×6

     1     1     0     0     0     0
     0     1     0     0     0     0
     0     0     1     1     0     0
     0     0     0     1     0     0
     0     0     0     0     1     1
     0     0     0     0     0     1
```

Input Arguments

detection — Detection report
objectDetection object

Detection report, specified as an objectDetection object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

filter — Linear Kalman filter
trackingKF object

Linear Kalman filter, returned as a trackingKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration standard deviation of 1 m/s^2.
- You can use this function as the FilterInitializationFcn property of a trackerGNN or trackerTOMHT object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvekf |
initcvukf

Classes
trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

initcvukf

Create constant-velocity unscented Kalman filter from detection report

Syntax

```
filter = initcaukf(detection)
```

Description

`filter = initcaukf(detection)` creates and initializes a constant-velocity unscented Kalman `filter` from information contained in a `detection` report. For more information about the unscented Kalman filter, see `trackingUKF`.

Examples

Initialize 3-D Constant-Velocity Unscented Kalman Filter

Create and initialize a 3-D constant-velocity unscented Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (10,200,−5), of the object position.

```
detection = objectDetection(0,[10;200;-5],'MeasurementNoise',1.5*eye(3), ...
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Sports Car',5});
```

Create the new filter from the detection report and display the filter properties.

```
filter = initcvukf(detection)

filter =
  trackingUKF with properties:

                        State: [6x1 double]
              StateCovariance: [6x6 double]
```

```
          StateTransitionFcn: @constvel
                ProcessNoise: [3x3 double]
      HasAdditiveProcessNoise: 0

              MeasurementFcn: @cvmeas
            MeasurementNoise: [3x3 double]
  HasAdditiveMeasurementNoise: 1

                       Alpha: 1.0000e-03
                        Beta: 2
                       Kappa: 0
```

Display the state.

```
filter.State
```

ans = *6×1*

```
    10
     0
   200
     0
    -5
     0
```

Show the state covariance.

```
filter.StateCovariance
```

ans = *6×6*

```
    1.5000        0        0        0        0        0
         0 100.0000        0        0        0        0
         0        0   1.5000        0        0        0
         0        0        0 100.0000        0        0
         0        0        0        0   1.5000        0
         0        0        0        0        0 100.0000
```

Create Constant Velocity UKF from Spherical Measurement

Initialize a constant-velocity unscented Kalman filter from an initial detection report made from an initial measurement in spherical coordinates. Because the object lies in the *x-y* plane, no elevation measurement is made. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45 degrees, the range to 1000 meters, and the range rate to -4.0 m/s.

```
frame = 'spherical';
sensorpos = [25,-40,0].';
sensorvel = [0;5;0];
laxes = eye(3);
```

Create the measurement parameters structure. Set `'HasElevation'` to `false`. Then, the measurement consists of azimuth, range, and range rate.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',true, ...
    'HasElevation',false);
meas = [45;1000;-4];
measnoise = diag([3.0,2,1.0].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
  objectDetection with properties:

                    Time: 0
             Measurement: [3x1 double]
        MeasurementNoise: [3x3 double]
             SensorIndex: 1
           ObjectClassID: 0
    MeasurementParameters: [1x1 struct]
         ObjectAttributes: {}
```

```
filter = initcvukf(detection);
```

Display filter state vector.

```
disp(filter.State)
```

```
  732.1068
   -2.8284
```

```
   667.1068
     2.1716
          0
          0
```

Input Arguments

detection — Detection report
objectDetection object

Detection report, specified as an objectDetection object.

Example: detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',
[1.0 0 0; 0 2.0 0; 0 0 1.5])

Output Arguments

filter — Unscented Kalman filter
trackingUKF object

Unscented Kalman filter, returned as a trackingUKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration standard deviation of 1 m/s^2.

- You can use this function as the FilterInitializationFcn property of a trackerGNN or trackerTOMHT object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
initcaekf | initcakf | initcaukf | initctekf | initctukf | initcvekf | initcvkf

Classes
objectDetection | trackingEKF | trackingKF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

clone

Copy filter for object tracking

Syntax

```
copiedObj = clone(filterObj)
```

Description

copiedObj = clone(filterObj) creates a copy of the given filter object with the same property values.

Input Arguments

filterObj — Filter for object tracking
object

Filter for object tracking, specified as an object.

Output Arguments

copiedObj — Copy of filter
object

Copy of filter, returned as an object.

See Also

Functions
constvel | correct | cvmeas | distance | likelihood | predict | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF |
trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

correct

Correct state and state estimation error covariance

Syntax

```
[xCorr,pCorr] = correct(filterObj,zMeas)
[xCorr,pCorr] = correct(filterObj,zMeas,vargin)

xCorr = correct(filterObj,zMeas)
[xCorr,pCorr,zCorr] = correct(filterObj,zMeas)
```

Description

`[xCorr,pCorr] = correct(filterObj,zMeas)` corrects the state and measurement of the tracking filter object based on the current measurement, `zMeas`. The internal state and covariance of the filter are overwritten by the corrected values.

`[xCorr,pCorr] = correct(filterObj,zMeas,vargin)` specifies additional parameters used by the state transition function defined in the `MeasurementFcn` property of the tracking object.

`xCorr = correct(filterObj,zMeas)` corrects the state of the tracking filter object based on the current measurement, `zMeas`. This syntax is only supported for the `trackingABF` object.

`[xCorr,pCorr,zCorr] = correct(filterObj,zMeas)` also returns the corrected measurement. This syntax is only supported for the `trackingABF` object.

Input Arguments

`filterObj` — Filter for object tracking
object

Filter for object tracking, specified as an object. Calling the `predict` overwrites the internal states of the object.

zMeas — Measurement of filter
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

Output Arguments

xCorr — Corrected state of filter
vector | matrix

Corrected state of the filter, specified as a vector or matrix. The `State` property of the input `filterObj` is overwritten with this value.

pCorr — Corrected state covariance of filter
vector | matrix

Corrected state covariance of the filter, specified as a vector or matrix. The `StateCovariance` property of the input `filterObj` is overwritten with this value.

zCorr — Corrected measurement of filter
vector | matrix

Corrected measurement of the filter, specified as a vector or matrix. This output is only supported for the `trackingABF` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
clone | constvel | cvmeas | distance | likelihood | predict | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF |
trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

distance

Distances between measurements and predicted measurements

Syntax

```
dist = distance(filterObj,zMatrix)
dist = distance(filterObj,zMatrix,measurementParams)
```

Description

`dist = distance(filterObj,zMatrix)` computes the distance between one or more predicted measurements given in `zMatrix` and the current measurement in the `filterObj`.

`dist = distance(filterObj,zMatrix,measurementParams)` specifies additional parameters that are used by the `MeasurementFcn` of the `filterObj`.

Input Arguments

`filterObj` — Filter for object tracking
object

Filter for object tracking, specified as an object.

`zMatrix` — Measurements of tracked objects
matrix

Measurements of tracked objects, specified as a matrix. Each row of the matrix contains a measurement vector.

`measurementParams` — Parameters for measurement function
cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function defined in the `MeasurementFcn` property of the `filterObj`

Output Arguments

`dist` — Distances between measurements
row vector

Distances between measurements, returned as a row vector. Each element corresponds to a distance between the predicted measurement in the `filterObj` and a row of the `zMatrix`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
clone | constvel | correct | cvmeas | likelihood | predict | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

initialize

Initialize state and covariance of filter

Syntax

```
initialize(filterObj,state,stateCovariance)
initialize(filterObj,state,stateCovariance,Name,Value)
```

Description

`initialize(filterObj,state,stateCovariance)` initializes the filter by setting the `State` and `StateCovariance` properties of the `filterObj` with the given values.

`initialize(filterObj,state,stateCovariance,Name,Value)` also sets additional property names and their values as `Name,Value` pairs in the `filterObj`.

Input Arguments

`filterObj` — Filter for object tracking
object

Filter for object tracking, specified as an object.

`state` — Filter state
real-valued *M*-element vector

Filter state, specified as a real-valued *M*-element vector.

Example: `[200;0.2]`

Data Types: `double`

`stateCovariance` — State estimation error covariance
positive-definite real-valued *M*-by-*M* matrix

State estimation error covariance, specified as a positive-definite real-valued M-by-M matrix where M is the size of the filter state. The covariance matrix represents the uncertainty in the filter state.

Example: [20 0.1; 0.1 1]

See Also

Functions
clone | constvel | correct | cvmeas | distance | predict | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2018b

predict

Predict state and state estimation error covariance

Syntax

```
[xPred,pPred] = predict(filterObj)
[xPred,pPred] = predict(filterObj,tStep)
[xPred,pPred] = predict(filterObj,vargin)

xPred = predict(filterObj)
[xPred,pPred,zPred] = predict(filterObj,tStep)
```

Description

`[xPred,pPred] = predict(filterObj)` returns the predicted state and state estimation error covariance at the next time step.

`[xPred,pPred] = predict(filterObj,tStep)` specifies the time step as a positive scalar in seconds.

`[xPred,pPred] = predict(filterObj,vargin)` specifies additional parameters used by the state transition function defined in the `StateTransitionFcn` property of the tracking object.

`xPred = predict(filterObj)` returns the predicted state at the next time step. The internal state of the input filter object is overwritten by the prediction results. This syntax is only supported for the `trackingABF` object.

`[xPred,pPred,zPred] = predict(filterObj,tStep)` also returns the predicted measurement, `zPred`. This syntax is only supported for the `trackingABF` object.

Input Arguments

`filterObj` — Filter for object tracking
object

Filter for object tracking, specified as an object. Calling the `predict` overwrites the internal states of the object.

tStep — Time step
positive scalar

Time step for next prediction, specified as a positive scalar in seconds.

Output Arguments

xPred — Predicted state of filter
vector | matrix

Predicted state of the filter, specified as a vector or matrix. The `State` property of the input `filterObj` is overwritten with this value.

pPred — Predicted state covariance of filter
vector | matrix

Predicted state covariance of the filter, specified as a vector or matrix. The `StateCovariance` property of the input `filterObj` is overwritten with this value.

zPred — Predicted measurement
vector | matrix

Predicted measurement, specified as a vector or matrix. This output is only supported for the `trackingABF` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
clone | constvel | correct | cvmeas | distance | likelihood | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

residual

Measurement residual and residual noise

Syntax

```
[zRes,resCovariance] = residual(filterObj,zMeas)
[zRes,resCovariance] = residual(filterObj,zMeas,measurementParams)
```

Description

`[zRes,resCovariance] = residual(filterObj,zMeas)` computes the residual and residual covariance of the current given measurement, `zMeas`, with the predicted measurement in the filter, `filterObj`.

`[zRes,resCovariance] = residual(filterObj,zMeas,measurementParams)` specifies additional parameters that are used by the `MeasurementFcn` of the `filterObj` filter.

Input Arguments

`filterObj` — Filter for object tracking
object

Filter for object tracking, specified as an object. Calling the `predict` overwrites the internal states of the object.

`zMeas` — Measurement of filter
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

`measurementParams` — Parameters for measurement function
cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function defined in the `MeasurementFcn` property of the `filterObj`

Output Arguments

zRes — Residual between current and predicted measurement
matrix

Residual between current and predicted measurement, returned as a matrix.

resCovariance — Residual covariance
matrix

Residual covariance, returned as a matrix.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
clone | constvel | correct | cvmeas | distance | likelihood | predict

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2017a

likelihood

Likelihood of measurement

Syntax

```
measLikelihood = likelihood(filterObj,zMeas)
[measLikelihood = likelihood(filterObj,zMeas,measurementParams)
```

Description

`measLikelihood = likelihood(filterObj,zMeas)` returns the likelihood of a measurement given by the specified filter, `filterObj`.

`[measLikelihood = likelihood(filterObj,zMeas,measurementParams)` specifies additional parameters that are used by the `MeasurementFcn` of the `filterObj`.

Input Arguments

`filterObj` — Filter for object tracking
object

Filter for object tracking, specified as an object. Calling the `predict`overwrites the internal states of the object.

`zMeas` — Measurement of the filter
vector | matrix

Measurement of the tracked object, specified a vector, or matrix.

`measurementParams` — Parameters for measurement function
cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function defined in the `MeasurementFcn` of the `filterObj`

Output Arguments

measLikelihood — Likelihood of measurement
scalar

Likelihood of measurement, returned as a scalar.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
clone | constvel | correct | cvmeas | distance | predict | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2018b

assignauction

Assignment using auction global nearest neighbor

Syntax

```
[assignments,unassignedrows,unassignedcolumns] = assignauction(
costmatrix,costofnonassignment)
```

Description

`[assignments,unassignedrows,unassignedcolumns] = assignauction(`
`costmatrix,costofnonassignment)` returns a table of `assignments` of detections to
tracks derived based on the forward/reverse auction algorithm. The auction algorithm
finds a suboptimal solution to the global nearest neighbor (GNN) assignment problem by
minimizing the total cost of assignment. While suboptimal, the auction algorithm is faster
than the Munkres algorithm for large GNN assignment problems, for example, when
there are more than 50 rows and columns in the cost matrix.

The cost of each potential assignment is contained in the cost matrix, `costmatrix`. Each
matrix entry represents the cost of a possible assignments. Matrix rows represent tracks
and columns represent detections. All possible assignments are represented in the cost
matrix. The lower the cost, the more likely the assignment is to be made. Each track can
be assigned to at most one detection and each detection can be assigned to at most one
track. If the number of rows is greater than the number of columns, some tracks are
unassigned. If the number of columns is greater than the number of rows, some
detections are unassigned. You can set an entry of `costmatrix` to `Inf` to prohibit an
assignment.

`costofnonassignment` represents the cost of leaving tracks or detections unassigned.
Higher values increase the likelihood that every existing object is assigned.

The function returns a list of unassigned tracks, `unassignedrows`, and a list of
unassigned detections, `unassignedcolumns`.

Examples

Assign Detections to Tracks Using Auction Algorithm

Use `assignAuction` to assign three detections to two tracks.

Start with two predicted track locations in x-y coordinates.

```
tracks = [1,1; 2,2];
```

Assume three detections are received. At least one detection will not be assigned.

```
dets = [1.1, 1.1; 2.1, 2.1; 1.5, 3];
```

Construct a cost matrix by defining the cost of assigning a detection to a track as the Euclidean distance between them. Set the cost of non-assignment to 0.2.

```
for i = size(tracks, 1):-1:1
    delta = dets - tracks(i, :);
    costMatrix(i, :) = sqrt(sum(delta .^ 2, 2));
end
costofnonassignment = 0.2;
```

Use the Auction algorithm to assign detections to tracks.

```
[assignments, unassignedTracks, unassignedDetections] = ...
    assignauction(costMatrix,costofnonassignment);
```

Display the assignments.

```
disp(assignments)
```

```
    1    1
    2    2
```

Show that there are no unassigned tracks.
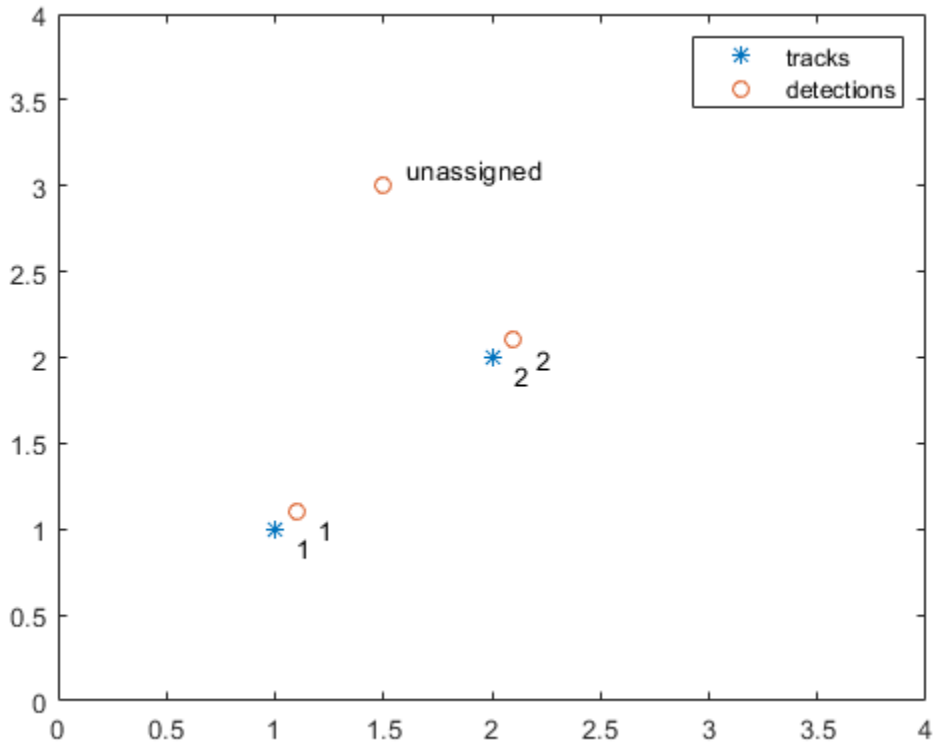
```
disp(unassignedTracks)
```

Display the unassigned detections.

```
disp(unassignedDetections)
```

3

Plot detection to track assignments.

```
plot(tracks(:, 1), tracks(:, 2), '*', dets(:, 1), dets(:, 2), 'o')
hold on
xlim([0, 4])
ylim([0, 4])
legend('tracks', 'detections')
assignStr = strsplit(num2str(1:size(assignments,1)));
text(tracks(assignments(:, 1),1) + 0.1, ...
    tracks(assignments(:, 1),2) - 0.1, assignStr);
text(dets(assignments(:, 2),1) + 0.1, ...
    dets(assignments(:, 2),2) - 0.1, assignStr);
text(dets(unassignedDetections(:),1) + 0.1, ...
    dets(unassignedDetections(:),2) + 0.1, 'unassigned');
```

The track to detection assignments are:

1 Detection 1 is assigned to track 1.

2 Detection 2 is assigned to track 2.

3 Detection 3 is not assigned.

Input Arguments

`costmatrix` — Cost matrix
real-valued *M*-by-*N*

Cost matrix, specified as an *M*-by-*N* matrix. *M* is the number of tracks to be assigned and *N* is the number of detections to be assigned. Each entry in the cost matrix contains the cost of a track and detection assignment. The matrix may contain `Inf` entries to indicate that an assignment is prohibited. The cost matrix cannot be a sparse matrix.

Data Types: `single` | `double`

costofnonassignment — cost of non-assignment of tracks and detections
scalar

Cost of non-assignment, specified as a scalar. The cost of non-assignment represents the cost of leaving tracks or detections unassigned. Higher values increase the likelihood that every object is assigned. The value cannot be set to `Inf`.

Data Types: `single` | `double`

Output Arguments

assignments — Assignment of tracks to detections
integer-valued *L*-by-2 matrix

Assignment of detections to track, returned as an integer-valued *L*-by-2 matrix where *L* is the number of assignments. The first column of the matrix contains the assigned track indices and the second column contains the assigned detection indices.

Data Types: `uint32`

unassignedrows — Indices of unassigned tracks
integer-valued *P*-by-1 column vector

Indices of unassigned tracks, returned as an integer-valued *P*-by-1 column vector.

Data Types: `uint32`

unassignedcolumns — Indices of unassigned detections
integer-valued *Q*-by-1 column vector

Indices of unassigned detections, returned as an integer-valued *Q*-by-1 column vector.

Data Types: `uint32`

References

[1] Samuel S. Blackman and Popoli, R. *Design and Analysis of Modern Tracking Systems*. Artech House: Norwood, MA. 1999.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
assignTOMHT | assignjv | assignkbest | assignkbestsd | assignmunkres | assignsd | trackerGNN | trackerTOMHT

Introduced in R2018b

assignjv

Jonker-Volgenant global nearest neighbor assignment algorithm

Syntax

```
[assignments,unassignedrows,unassignedcolumns] = assignjv(
costmatrix,costofnonassignment)
```

Description

`[assignments,unassignedrows,unassignedcolumns] = assignjv(`
`costmatrix,costofnonassignment)` returns a table of `assignments` of detections to tracks using the Jonker-Volgenant algorithm. The JV algorithm finds an optimal solution to the global nearest neighbor (GNN) assignment problem by finding the set of assignments that minimize the total cost of the assignments. The Jonker-Volgenant algorithm solves the GNN assignment in two phases: begin with the auction algorithm and end with the Dijkstra shortest path algorithm.

The cost of each potential assignment is contained in the cost matrix, `costmatrix`. Each matrix entry represents the cost of a possible assignments. Matrix rows represent tracks and columns represent detections. All possible assignments are represented in the cost matrix. The lower the cost, the more likely the assignment is to be made. Each track can be assigned to at most one detection and each detection can be assigned to at most one track. If the number of rows is greater than the number of columns, some tracks are unassigned. If the number of columns is greater than the number of rows, some detections are unassigned. You can set an entry of `costmatrix` to `Inf` to prohibit an assignment.

`costofnonassignment` represents the cost of leaving tracks or detections unassigned. Higher values increase the likelihood that every existing object is assigned.

The function returns a list of unassigned tracks, `unassignedrows`, and a list of unassigned detections, `unassignedcolumns`.

Examples

Assign Detections to Tracks Using Jonker-Volgenant Algorithm

Use assignjv to assign three detections to two tracks.

Start with two predicted track locations in x-y coordinates.

```
tracks = [1,1; 2,2];
```

Assume three detections are received. At least one detection will not be assigned.

```
dets = [1.1, 1.1; 2.1, 2.1; 1.5, 3];
```

Construct a cost matrix by defining the cost of assigning a detection to a track as the Euclidean distance between them. Set the cost of non-assignment to 0.2.

```
for i = size(tracks,1):-1:1
    delta = dets - tracks(i,:);
    costMatrix(i,:) = sqrt(sum(delta .^ 2,2));
end
costofnonassignment = 0.2;
```

Use the Auction algorithm to assign detections to tracks.

```
[assignments, unassignedTracks, unassignedDetections] = ...
    assignjv(costMatrix,costofnonassignment);
```

Display the assignments.

```
disp(assignments)
```

```
     1    1
     2    2
```

Show that there are no unassigned tracks.
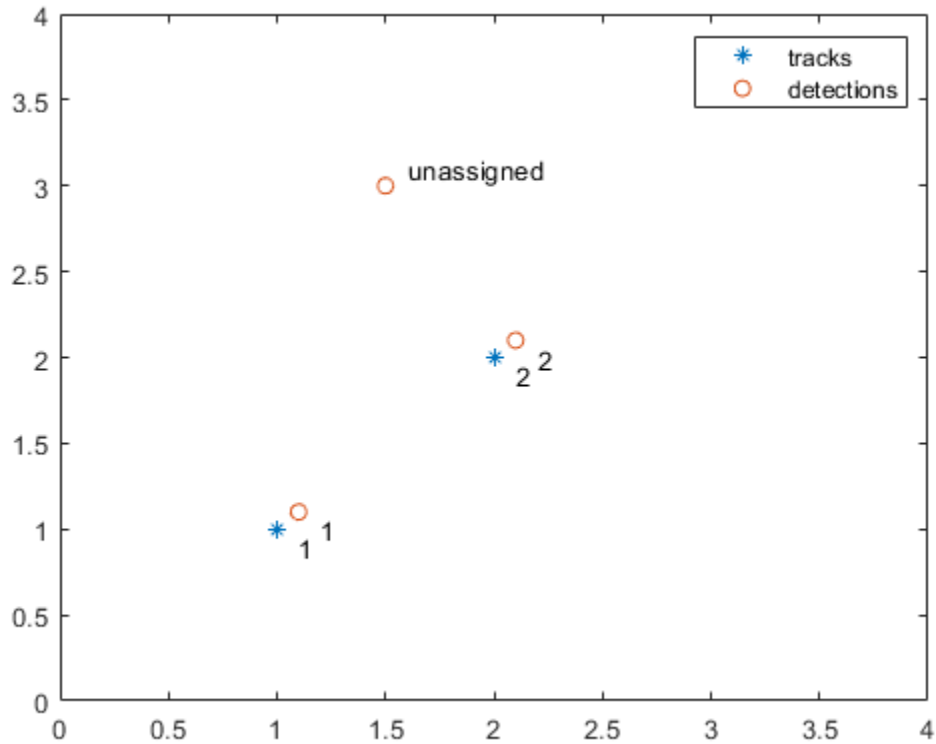
```
disp(unassignedTracks)
```

Display the unassigned detections.

```
disp(unassignedDetections)
```

3

Plot the detection to track assignments.

```
plot(tracks(:, 1), tracks(:, 2), '*', dets(:, 1), dets(:, 2), 'o')
hold on
xlim([0,4])
ylim([0,4])
legend('tracks', 'detections')
assignStr = strsplit(num2str(1:size(assignments,1)));
text(tracks(assignments(:,1),1) + 0.1, ...
    tracks(assignments(:,1),2) - 0.1, assignStr);
text(dets(assignments(:,2),1) + 0.1, ...
    dets(assignments(:,2),2) - 0.1, assignStr);
text(dets(unassignedDetections(:),1) + 0.1, ...
    dets(unassignedDetections(:),2) + 0.1, 'unassigned');
```

The track to detection assignments are:

1   Detection 1 is assigned to track 1.

2   Detection 2 is assigned to track 2.

3   Detection 3 is not assigned.

Input Arguments

`costmatrix` — Cost matrix
real-valued *M*-by-*N*

Cost matrix, specified as an *M*-by-*N* matrix. *M* is the number of tracks to be assigned and *N* is the number of detections to be assigned. Each entry in the cost matrix contains the cost of a track and detection assignment. The matrix may contain `Inf` entries to indicate that an assignment is prohibited. The cost matrix cannot be a sparse matrix.

Data Types: `single` | `double`

costofnonassignment — cost of non-assignment of tracks and detections
scalar

Cost of non-assignment, specified as a scalar. The cost of non-assignment represents the cost of leaving tracks or detections unassigned. Higher values increase the likelihood that every object is assigned. The value cannot be set to `Inf`.

Data Types: `single` | `double`

Output Arguments

assignments — Assignment of tracks to detections
integer-valued *L*-by-2 matrix

Assignment of detections to track, returned as an integer-valued *L*-by-2 matrix where *L* is the number of assignments. The first column of the matrix contains the assigned track indices and the second column contains the assigned detection indices.

Data Types: `uint32`

unassignedrows — Indices of unassigned tracks
integer-valued *P*-by-1 column vector

Indices of unassigned tracks, returned as an integer-valued *P*-by-1 column vector.

Data Types: `uint32`

unassignedcolumns — Indices of unassigned detections
integer-valued *Q*-by-1 column vector

Indices of unassigned detections, returned as an integer-valued *Q*-by-1 column vector.

Data Types: `uint32`

References

[1] Samuel S. Blackman and Popoli, R. *Design and Analysis of Modern Tracking Systems*. Artech House: Norwood, MA. 1999.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
assignTOMHT | assignauction | assignkbest | assignkbestsd | assignmunkres | assignsd | trackerGNN | trackerTOMHT

Introduced in R2018b

assignkbest

Assignment using k-best global nearest neighbor

Syntax

```
[assignments,unassignedrows,unassignedcolumns,cost] = assignkbest(
costmatrix,costofnonassignment)
[assignments,unassignedrows,unassignedcolumns,cost] = assignkbest(
costmatrix,costofnonassignment,k)
[assignments,unassignedrows,unassignedcolumns,cost] = assignkbest(
costmatrix,costofnonassignment,k,algorithm)
```

Description

[assignments,unassignedrows,unassignedcolumns,cost] = assignkbest(
costmatrix,costofnonassignment) returns a table of assignments, assignments,
of detections to tracks using the Munkres algorithm. The algorithm finds the global
nearest neighbor (GNN) solution that minimizes the total cost of the assignments.

The cost of each potential assignment is contained in the cost matrix, costmatrix. Each
matrix entry represents the cost of a possible assignments. Matrix rows represent tracks
and columns represent detections. All possible assignments are represented in the cost
matrix. The lower the cost, the more likely the assignment is to be made. Each track can
be assigned to at most one detection and each detection can be assigned to at most one
track. If the number of rows is greater than the number of columns, some tracks are
unassigned. If the number of columns is greater than the number of rows, some
detections are unassigned. You can set an entry of costmatrix to Inf to prohibit an
assignment.

costofnonassignment represents the cost of leaving tracks or detections unassigned.
Higher values increase the likelihood that every existing object is assigned.

All inputs must all be single precision or all be double precision.

The function returns a list of unassigned tracks, unassignedrows, a list of unassigned
detections, unassignedcolumns, and the cost of assignment, cost.

```
[assignments,unassignedrows,unassignedcolumns,cost] = assignkbest(
costmatrix,costofnonassignment,k)
```
also specifies the number, k, of *k*-best global nearest neighbor solutions that minimize the total cost of assignments. In addition to the best solution, the function uses the Murty algorithm to find the remaining *k*-1 solutions.

```
[assignments,unassignedrows,unassignedcolumns,cost] = assignkbest(
costmatrix,costofnonassignment,k,algorithm)
```
also specifies the algorithm, `algorithm`, for finding the assignments.

Examples

Find Five Best Solutions Using Assignkbest

Create a cost matrix containing prohibited assignments. Then, use the `assignkbest` function to find the 5 best solutions.

Set up the cost matrix to contain some prohibited or invalid assignments by inserting `Inf` into the matrix.

```
costMatrix = [10 5 8 9; 7 Inf 20 Inf; Inf 21 Inf Inf; Inf 15 17 Inf; Inf inf 16 22];
costOfNonAssignment = 100;
```

Find the 5 best assignments.

```
[assignments,unassignedrows,unassignedcols,cost] = ...
    assignkbest(costMatrix,costOfNonAssignment,5)
```

```
assignments =

  5×1 cell array

    {4×2 uint32}
    {4×2 uint32}
    {4×2 uint32}
    {4×2 uint32}
    {4×2 uint32}


unassignedrows =
```

```
  5×1 cell array

    {[3]}
    {[3]}
    {[3]}
    {[4]}
    {[5]}


unassignedcols =

  5×1 cell array

    {0×1 uint32}
    {0×1 uint32}
    {0×1 uint32}
    {0×1 uint32}
    {0×1 uint32}


cost =

   147
   151
   152
   153
   154
```

Input Arguments

`costmatrix` — Cost matrix
real-valued *M*-by-*N*

Cost matrix, specified as an *M*-by-*N* matrix. *M* is the number of tracks to be assigned and *N* is the number of detections to be assigned. Each entry in the cost matrix contains the cost of a track and detection assignment. The matrix may contain `Inf` entries to indicate that an assignment is prohibited. The cost matrix cannot be a sparse matrix.

Data Types: `single` | `double`

`costofnonassignment` — cost of non-assignment of tracks and detections
scalar

Cost of non-assignment, specified as a scalar. The cost of non-assignment represents the cost of leaving tracks or detections unassigned. Higher values increase the likelihood that every object is assigned. The value cannot be set to `Inf`.

Data Types: `single` | `double`

k — Number of best solutions
positive integer

Number of best solutions, specified as a positive integer.

Data Types: `single` | `double`

algorithm — Assignment algorithm
`'munkres'` (default) | `'jv'` | `'auction'`

Assignment algorithm, specified as `'munkres'` for the Munkres algorithm, `'jv'` for the Jonker-Volgenant algorithm, or `'auction'` for the Auction algorithm.

Example: `'jv'`

Data Types: `char` | `string`

Output Arguments

assignments — Assignment of tracks to detections
k-element cell array

Assignment of tracks to detections, returned as a *k*-element cell array. *k* is the number of best solutions. Each cell contains an L_i-by-2 matrix of pairs of track indices and assigned detection indices. L_i is the number of assignment pairs in the ith solution cell. The first column of each matrix contains the track indices and the second column contains the assigned detection indices.

unassignedrows — Indices of unassigned tracks
k-element cell array

Indices of unassigned tracks, returned as a *k*-element cell array. Each cell is a P_i vector where $P_i = M - L_i$ is the number of unassigned rows in the ith cell. Each element is the index of a row to which no columns are assigned. *k* is the number of best solutions.

Data Types: `uint32`

unassignedcolumns — Indices of unassigned detections
k-element cell array

Indices of unassigned detections, returned as a *k*-element cell array. Each cell is a Q_i vector where $Q_i = M - L_i$ is the number of unassigned detections in the ith cell. Each element is the index of a column to which no rows are assigned. *k* is the number of best solutions.

Data Types: `uint32`

cost — Total cost of solutions
k-element vector (default)

Total cost of solutions, returned as a *k*-element vector. Each element is a scalar value summarizing the total cost of the solution to the assignment problem.

Data Types: `single` | `double`

References

[1] Samuel Blackman and Robert Popoli. *Design and Analysis of Modern Tracking Systems*, Artech House, 1999.

Extended Capabilities

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See Also

Functions
`assignTOMHT` | `assignauction` | `assignjv` | `assignkbestsd` | `assignmunkres` | `assignsd` | `trackerGNN` | `trackerTOMHT`

Introduced in R2018b

assignkbestsd

K-best S-D solution that minimizes total cost of assignment

Syntax

```
[assignments,cost,solutionGap] = assignkbestsd(costmatrix)
[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k)
[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k,
desiredGap)
[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k,
desiredGap,maxIterations)
[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k,
desiredGap,maxIterations,algorithm)
```

Description

[assignments,cost,solutionGap] = assignkbestsd(costmatrix) returns a table of assignments of detections to tracks by finding the best S-D solution that minimizes the total cost of the assignments. The algorithm uses Lagrangian relaxation to convert the S-D assignment problem to a corresponding 2-D assignment problem and then solves the 2-D problem. The cost of each potential assignment is contained in the cost matrix, costmatrix.

costmatrix is an n-dimensional cost matrix where costmatrix(i,j,k ...) defines the cost of the n-tuple (i,j,k, ...) in assignment. The index '1' on all dimensions in costmatrix represents dummy measurement or a false track and is used to complete the assignment problem. The index 1, being a dummy, can be a part of multiple n-tuples. The index can be assigned more than once. A typical cost value for costmatrix(1,1,1,1, ...) is 0.

The function also returns the solution gap, solutionGap, and the cost of assignments, cost.

[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k) also specifies the number, k of *K*-best S-D solutions. The function finds *K* optimal solutions that

minimize the total cost. First, the function finds the best solution. Then, the function uses the Murty algorithm to generate partitioned cost matrices. Finally, the function obtains the remaining K - 1 minimum cost solutions for each partitioned matrix.

`[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k, desiredGap)` also specifies the desired maximum gap, `desiredGap`, between the dual solution and the feasible solution. The gap controls the quality of the solution. Values usually range from 0 to 1. A value of 0 means the dual and feasible solutions are the same.

`[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k, desiredGap,maxIterations)` also specifies the maximum number of iterations allowed. The `desiredGap` and `maxIterations` arguments define the terminating conditions for the S-D algorithm.

`[assignments,cost,solutionGap] = assignkbestsd(costmatrix,k, desiredGap,maxIterations,algorithm)` also specifies the `algorithm` for finding the assignments.

Examples

Assign Detections to Tracks Using K-Best SD

Find the first 5 best assignments of the S-D assignment problem. Set the desired gap to 0.01 and the maximum number of iterations to 100.

Load the cost matrix.

```
load passiveAssociationCostMatrix.mat
```

Find the 5 best solutions.

```
[assignments,cost,solutionGap] = assignkbestsd(costMatrix,5,0.01,100)
```

```
assignments =

  5×1 cell array

    {2×3 uint32}
    {3×3 uint32}
```

```
     {3×3 uint32}
     {3×3 uint32}
     {3×3 uint32}


cost =

  -34.7000
  -31.7000
  -29.1000
  -28.6000
  -28.0000


solutionGap =

         0
    0.0552
    0.0884
    0.1075
    0.1964
```

Input Arguments

costmatrix — Cost matrix
real-valued *M*-by-*N*

Cost matrix, specified as an n-dimensional array where `costmatrix(i,j,k ...)` defines the cost of the n-tuple `(i,j,k, ...)` in an assignment. The index '1' on all dimensions in `costmatrix` represents a dummy measurement or a false track and is used to complete the assignment problem. The index 1, being a dummy, can be a part of multiple n-tuples. The index can be assigned more than once. A typical cost value for `costmatrix(1,1,1,1, ...)` is 0.

Data Types: `single` | `double`

k — Number of best solutions
1 (default) | positive integer

Number of best solutions, specified as a positive integer.

Data Types: `single` | `double`

desiredGap — Desired maximal gap
`0.01` (default) | nonnegative scalar

Desired maximum gap between the dual and feasible solutions, specified as a nonnegative scalar.

Example: `0.05`

Data Types: `single` | `double`

maxIterations — Maximum number of iterations
`100` (default) | positive integer

Maximum number of iterations, specified as a positive integer.

Example: `50`

Data Types: `single` | `double`

algorithm — Assignment algorithm
`'auction'` (default) | `'munkres'` | `'jv'`

Assignment algorithm for solving the 2-D assignment problem, specified as `'munkres'` for the Munkres algorithm, `'jv'` for the Jonker-Volgenant algorithm, or `'auction'` for the Auction algorithm.

Example: `'jv'`

Output Arguments

assignments — Assignment of tracks to detections
K-element cell array

Assignments of tracks to detections, returned as a *K*-element cell array. Each cell is an *P*-by-*N* list of assignments. Assignments of the type `[1 1 Q 1]` from a four-dimensional cost matrix can be seen as a `Q-1` entity from dimension 3 that was left unassigned. The cost value at `(1,1,Q,1)` defines the cost of not assigning the $(Q\text{-}1)^{\text{th}}$ entity from dimension 3.

cost — Total cost of solutions
K-element array

Total cost of solutions, returned as a *K*-element vector where *K* is the number of best solutions. Each element is a scalar value summarizing the total cost of the solution to the assignment problem.

Data Types: `single` | `double`

solutionGap — Solution gap
real-valued *K*-element array

Solution gap, returned as a positive-valued *K*-element array where *K* is the number of best solutions. Each element is the duality gap achieved between the feasible and dual solution. A gap value near zero indicates the quality of solution.

Data Types: `single` | `double`

Algorithms

All numeric inputs can be single or double precision, but they all must have the same precision.

References

[1] Popp, R.L., Pattipati, K., and Bar Shalom, Y. "*M-best S=D Assignment Algorithm with Application to Multitarget Tracking*". IEEE Transactions on Aerospace and Electronic Systems, 37(1), 22-39. 2001.

[2] Deb, S., Yeddanapudi, M., Pattipati, K., & Bar-Shalom, Y. (1997). "*A generalized SD assignment algorithm for multisensor-multitarget state estimation*". IEEE Transactions on Aerospace and Electronic Systems, 33(2), 523-538.

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See Also

Functions
assignTOMHT | assignauction | assignjv | assignkbest | assignmunkres |
assignsd

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

assignmunkres

Munkres global nearest neighbor assignment algorithm

Syntax

```
[assignments,unassignedrows,unassignedcolumns] = assignmunkres(
costmatrix,costofnonassignment)
```

Description

`[assignments,unassignedrows,unassignedcolumns] = assignmunkres(costmatrix,costofnonassignment)` returns a table of `assignments` of detections to tracks using the Munkres algorithm. The Munkres algorithm obtains an optimal solution to the global nearest neighbor (GNN) assignment problem. An optimal solution minimizes the total cost of the assignments.

The cost of each potential assignment is contained in the cost matrix, `costmatrix`. Each matrix entry represents the cost of a possible assignments. Matrix rows represent tracks and columns represent detections. All possible assignments are represented in the cost matrix. The lower the cost, the more likely the assignment is to be made. Each track can be assigned to at most one detection and each detection can be assigned to at most one track. If the number of rows is greater than the number of columns, some tracks are unassigned. If the number of columns is greater than the number of rows, some detections are unassigned. You can set an entry of `costmatrix` to `Inf` to prohibit an assignment.

`costofnonassignment` represents the cost of leaving tracks or detections unassigned. Higher values increase the likelihood that every existing object is assigned.

The function returns a list of unassigned tracks, `unassignedrows`, and a list of unassigned detections, `unassignedcolumns`

Examples

Assign Detections to Tracks Using Munkres Algorithm

Use `assignMunkres` to assign three detections to two tracks.

Start with two predicted track locations in x-y coordinates.

```
tracks = [1,1; 2,2];
```

Assume three detections are received. At least one detection will not be assigned.

```
dets = [1.1, 1.1; 2.1, 2.1; 1.5, 3];
```

Construct a cost matrix by defining the cost of assigning a detection to a track as the Euclidean distance between them. Set the cost of non-assignment to 0.2.

```
for i = size(tracks, 1):-1:1
    delta = dets - tracks(i, :);
    costMatrix(i, :) = sqrt(sum(delta .^ 2, 2));
end
costofnonassignment = 0.2;
```

Use the Auction algorithm to assign detections to tracks.

```
[assignments, unassignedTracks, unassignedDetections] = ...
    assignmunkres(costMatrix,costofnonassignment);
```

Display the assignments.

```
disp(assignments)
```

```
    1    1
    2    2
```

Show that there are no unassigned tracks.
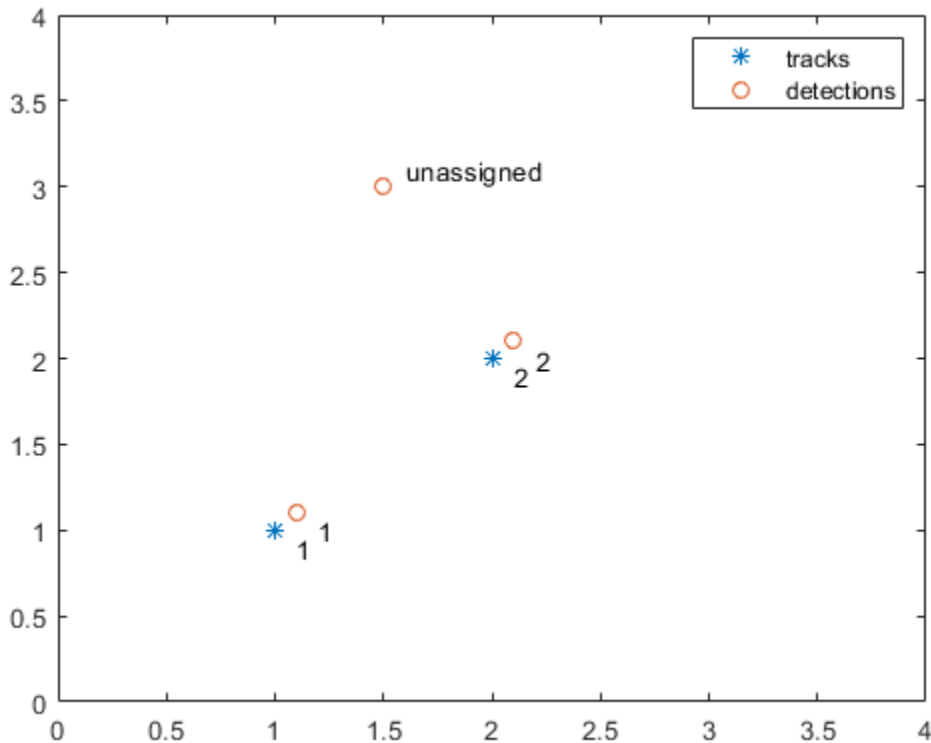
```
disp(unassignedTracks)
```

Display the unassigned detections.

```
disp(unassignedDetections)
```

```
    3
```

Plot detection to track assignments.

```matlab
plot(tracks(:, 1), tracks(:, 2), '*', dets(:, 1), dets(:, 2), 'o')
hold on
xlim([0, 4])
ylim([0, 4])
legend('tracks', 'detections')
assignStr = strsplit(num2str(1:size(assignments,1)));
text(tracks(assignments(:, 1),1) + 0.1, ...
    tracks(assignments(:, 1),2) - 0.1, assignStr);
text(dets(assignments(:, 2),1) + 0.1, ...
    dets(assignments(:, 2),2) - 0.1, assignStr);
text(dets(unassignedDetections(:),1) + 0.1, ...
    dets(unassignedDetections(:),2) + 0.1, 'unassigned');
```


The track to detection assignments are:

1   Detection 1 is assigned to track 1.

2   Detection 2 is assigned to track 2.

3   Detection 3 is not assigned.

Input Arguments

costmatrix — Cost matrix
real-valued *M*-by-*N*

Cost matrix, specified as an *M*-by-*N* matrix. *M* is the number of tracks to be assigned and *N* is the number of detections to be assigned. Each entry in the cost matrix contains the cost of a track and detection assignment. The matrix may contain `Inf` entries to indicate that an assignment is prohibited. The cost matrix cannot be a sparse matrix.

Data Types: `single` | `double`

costofnonassignment — cost of non-assignment of tracks and detections
scalar

Cost of non-assignment, specified as a scalar. The cost of non-assignment represents the cost of leaving tracks or detections unassigned. Higher values increase the likelihood that every object is assigned. The value cannot be set to `Inf`.

Data Types: `single` | `double`

Output Arguments

assignments — Assignment of tracks to detections
integer-valued *L*-by-2 matrix

Assignment of detections to track, returned as an integer-valued *L*-by-2 matrix where *L* is the number of assignments. The first column of the matrix contains the assigned track indices and the second column contains the assigned detection indices.

Data Types: `uint32`

unassignedrows — Indices of unassigned tracks
integer-valued *P*-by-1 column vector

Indices of unassigned tracks, returned as an integer-valued *P*-by-1 column vector.

Data Types: `uint32`

unassignedcolumns — Indices of unassigned detections
integer-valued *Q*-by-1 column vector

Indices of unassigned detections, returned as an integer-valued *Q*-by-1 column vector.

Data Types: `uint32`

References

[1] Samuel S. Blackman and Popoli, R. *Design and Analysis of Modern Tracking Systems*. Artech House: Norwood, MA. 1999.

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See Also

Functions
`assignTOMHT` | `assignauction` | `assignjv` | `assignkbest` | `assignkbestsd` | `assignsd` | `trackerGNN` | `trackerTOMHT`

Introduced in R2018b

assignsd

S-D assignment using Lagrangian relaxation

Syntax

```
[assignments,cost,solutionGap] = assignsd(costmatrix)
[assignments,cost,solutionGap] = assignsd(costmatrix,desiredGap)
[assignments,cost,solutionGap] = assignsd(costmatrix,desiredGap,
maxIterations)
[assignments,cost,solutionGap] = assignsd(costmatrix,desiredGap,
maxIterations,algorithm)
```

Description

`[assignments,cost,solutionGap] = assignsd(costmatrix)` returns a table of assignments, `assignments`, of detections to tracks by finding a suboptimal solution to the S-D assignment problem using Lagrangian relaxation. The cost of each potential assignment is contained in the cost matrix, `costmatrix`. The algorithm terminates when the gap reaches below 0.01 (1 percent) or if the number of iterations reaches 100.

`costmatrix` is an n-dimensional cost matrix where `costmatrix(i,j,k ...)` defines the cost of the n-tuple `(i,j,k, ...)` in assignment. The index '1' on all dimensions in `costmatrix` represents dummy measurement or a false track and is used to complete the assignment problem. The index 1, being a dummy, can be a part of multiple n-tuples. The index can be assigned more than once. A typical cost value for `costmatrix(1,1,1,1, ...)` is 0.

All inputs can be single or double precision, but they all must be of the same precision.

The function also returns the solution gap, `solutionGap`, and the total cost of assignments, `cost`.

`[assignments,cost,solutionGap] = assignsd(costmatrix,desiredGap)` also specifies the desired maximum gap, `desiredGap`, between the dual and the feasible solutions as a scalar. The gap controls the quality of the solution. Values usually range from 0 to 1. A value of 0 means the dual and feasible solutions are the same.

```
[assignments,cost,solutionGap] = assignsd(costmatrix,desiredGap,
maxIterations)
```
also specifies the maximum number of iterations, `maxIterations`.

```
[assignments,cost,solutionGap] = assignsd(costmatrix,desiredGap,
maxIterations,algorithm)
```
also specifies the assignment algorithm, `algorithm`.

Examples

Assign Detections to Tracks Using assignsd Algorithm

Use `assignsd` to perform strict assignment without index 1.

Not having dummy index means that no entity is left unassigned. Therefore, define the cost matrix to be equi-dimensional.

```
costMatrix = rand(6,6,6);
```

Initialize the `fullmatrix` to all `Inf`. The `fullmatix` is one size larger than the cost matrix in all dimensions.

```
fullMatrix = inf(7,7,7);
```

Set the inner matrix to costMatrix to force the assignments involving index 1 to have infinite cost.

```
fullMatrix(2:end,2:end,2:end) = costMatrix;
fullMatrix(1,1,1) = 0;
[assignments,cost,gapAchieved] = assignsd(fullMatrix,0.01,100);
```

Restore the actual indices.

```
assignments = assignments - 1


assignments =

  6×3 uint32 matrix

    1   6   6
    2   4   3
    3   3   4
    4   1   2
```

```
     5     2     1
     6     5     5
```

Input Arguments

costmatrix — Cost matrix
real-valued *M*-by-*N*

Cost matrix, specified as an n-dimensional array where `costmatrix(i,j,k ...)` defines the cost of the n-tuple (`i,j,k, ...`) in an assignment. The index '1' on all dimensions in `costmatrix` represents a dummy measurement or a false track and is used to complete the assignment problem. The index 1, being a dummy, can be a part of multiple n-tuples. The index can be assigned more than once. A typical cost value for `costmatrix(1,1,1,1, ...)` is 0.

Data Types: `single` | `double`

desiredGap — Desired maximal gap
`0.01` (default) | nonnegative scalar

Desired maximum gap between the dual and feasible solutions, specified as a nonnegative scalar.

Example: `0.05`

Data Types: `single` | `double`

maxIterations — Maximum number of iterations
`100` (default) | positive integer

Maximum number of iterations, specified as a positive integer.

Example: `50`

Data Types: `single` | `double`

algorithm — Assignment algorithm
`'auction'` (default) | `'munkres'` | `'jv'`

Assignment algorithm for solving the 2-D assignment problem, specified as `'munkres'` for the Munkres algorithm, `'jv'` for the Jonker-Volgenant algorithm, or `'auction'` for the Auction algorithm.

Example: `'jv'`

Output Arguments

`assignments` — Assignment of tracks to detections
P-by-*N* matrix

Assignments of tracks to detections, returned as a *P*-by-*N* list of assignments. Assignments of the type `[1 1 Q 1]` from a four-dimensional cost matrix can be seen as a `Q-1` entity from dimension 3 that was left unassigned. The cost value at `(1,1,Q,1)` defines the cost of not assigning the (*Q*-1)[th] entity from dimension 3.

`cost` — Total cost of assignment solution
positive scalar

Total cost of solutions, returned as a *K*-element vector where *K* is the number of best solutions. Each element is a scalar value summarizing the total cost of the solution to the assignment problem.

Data Types: `single` | `double`

`solutionGap` — Solution gap
positive scalar (default)

Solution gap, returned as a positive scalar. The solution gap is the duality gap achieved between the feasible and dual solution. A gap value near zero indicates the quality of solution.

Data Types: `single` | `double`

Algorithms

- The Lagrangian relaxation method computes a suboptimal solution to the S-D assignment problem. The method relaxes the S-D assignment problem to a 2-D assignment problem using a set of Lagrangian multipliers. The relaxed 2-D assignment problem is commonly known as the dual problem, which can be solved optimally using algorithms like the Munkres algorithm. Constraints are then enforced on the dual solution by solving multiple 2-D assignment problems to obtain a feasible solution to the original problem. The cost of the dual solution and the feasible solution serves as

lower and upper bounds on the optimal cost, respectively. The algorithm iteratively tries to minimize the gap between the dual and feasible solutions, commonly known as the dual gap. The iteration stops when the dual gap is below a desired gap or the maximum number of iterations have reached.

- When using the auction algorithm, the `assignsd` function uses the Heuristic Price Update algorithm to update the Lagrangian multipliers. When using the Munkres and jv algorithms, the function uses the Accelerated Subgradient Update algorithm.

- For cost matrices with well-defined solutions, such as passive association with high-precision sensors, the solution gap converges to within 0.05 (5 percent) in approximately 100 iterations.

- As the optimal solution is unknown, the solution gap can be non-zero even when the returned solution is optimal.

References

[1] Deb, S., Yeddanapudi, M., Pattipati, K., and Bar-Shalom, Y. (1997). *A generalized SD assignment algorithm for multisensor-multitarget state estimation.* IEEE Transactions on Aerospace and Electronic Systems, 33(2), 523-538.

[2] Blackman, Samuel, and Robert Popoli. *Design and analysis of modern tracking systems*. Norwood, MA: Artech House, 1999. (1999)

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See Also

Functions
assignTOMHT | assignauction | assignjv | assignkbest | assignkbestsd | assignmunkres | trackerGNN | trackerTOMHT

Introduced in R2018b

assignTOMHT

Track-oriented multi-hypotheses tracking assignment

Syntax

```
[assignments,unassignedrows,unassignedcolumns] = assignTOMHT(
costmatrix,costThreshold)
```

Description

[assignments,unassignedrows,unassignedcolumns] = assignTOMHT(
costmatrix,costThreshold) returns a table of assignments, assignments, of
detections to tracks using a track-oriented multi-hypothesis algorithm (TOMHT).

The cost of each potential assignment is contained in the cost matrix, costmatrix. Each
matrix entry represents the cost of a possible assignments. Matrix rows represent tracks
and columns represent detections. All possible assignments are represented in the cost
matrix. The lower the cost, the more likely the assignment is to be made. Each track can
be assigned to at most one detection and each detection can be assigned to at most one
track. If the number of rows is greater than the number of columns, some tracks are
unassigned. If the number of columns is greater than the number of rows, some
detections are unassigned. You can set an entry of costmatrix to Inf to prohibit an
assignment.

costThreshold represents the set of three gates used for assigning detections to tracks.

The function returns a list of unassigned tracks, unassignedrows, and a list of
unassigned detections, unassignedcolumns.

Examples

Assignment Using AssignTOMHT

Find the assignments from a cost matrix using `assignTOMHT` with a nonzero C1 gate and a nonzero C2 gate.

Create a cost matrix that assigns:

- Track 1 to detection 1 within the C1 gate and detection 2 within the C2 gate.
- Track 2 to detection 2 within the C2 gate and detection 3 within the C3 gate.
- Track 3 is unassigned.
- Detection 4 is unassigned.

```
costMatrix = [4 9 200 Inf; 300 12 28 Inf; 32 100 210 1000];
costThresh = [5 10 30];
```

Calculate the assignments.

```
[assignments, unassignedTracks, unassignedDets] = assignTOMHT(costMatrix,costThresh)
```

```
assignments =

  4×2 uint32 matrix

   1   1
   1   2
   2   2
   2   3


unassignedTracks =

  2×1 uint32 column vector

   2
   3


unassignedDets =

  2×1 uint32 column vector

   3
```

4

Tracks that are assigned detections within the C1 gate are not considered as unassigned. For example, track 1. Detections that are assigned to tracks within the C2 gate are not considered as unassigned. For example, detections 1 and 2.

Input Arguments

costmatrix — Cost matrix
real-valued *M*-by-*N*

Cost matrix, specified as an *M*-by-*N* matrix. *M* is the number of tracks to be assigned and *N* is the number of detections to be assigned. Each entry in the cost matrix contains the cost of a track and detection assignment. The matrix may contain `Inf` entries to indicate that an assignment is prohibited. The cost matrix cannot be a sparse matrix.

Data Types: `single` | `double`

costThreshold — Assignment gates
positive, real-valued 3-element vector

Assignment gates, specified as a positive, real-valued three-element vector `[c1gate,c2gate,c3gate]` where `c1gate <= c2gate <= c3gate`.

Example: `[0.1,0.3,0.5]`

Data Types: `single` | `double`

Output Arguments

assignments — Assignment of tracks to detections
integer-valued *L*-by-2 matrix

Assignment of detections to track, returned as an integer-valued *L*-by-2 matrix where *L* is the number of assignments. The first column of the matrix contains the assigned track indices and the second column contains the assigned detection indices.

Data Types: `uint32`

unassignedrows — Indices of unassigned tracks
integer-valued *P*-by-1 column vector

Indices of unassigned tracks, returned as an integer-valued *P*-by-1 column vector.

Data Types: `uint32`

unassignedcolumns — Indices of unassigned detections
integer-valued *Q*-by-1 column vector

Indices of unassigned detections, returned as an integer-valued *Q*-by-1 column vector.
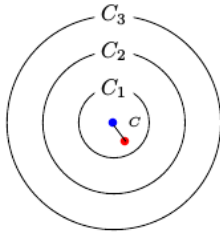
Data Types: `uint32`

Algorithms

Assignment Thresholds for Multi-Hypothesis Tracker

Three assignment thresholds, C_1, C_2, and C_3, control (1) the assignment of a detection to a track, (2) the creation of a new branch from a detection, and (3) the creation of a new branch from an unassigned track. The threshold values must satisfy: C_1 <= C_2 <= C_3.

If the cost of an assignment is `C = costmatrix(i,j)`, the following hypotheses are created based on comparing the cost to the values of the assignment thresholds. Below each comparison, there is a list of the possible hypotheses.
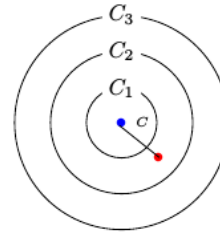
- **Track**
- **Detection**
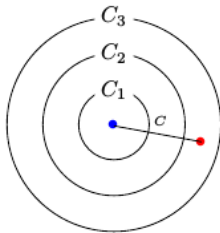
$C \leq C_1$

Single Hypothesis

(1) Detection is assigned to track. A branch is created updating the track with this detection.

$C_1 < C \leq C_2$

Two Hypotheses

(1) Detection is assigned to track. A branch is created updating the track with this detection.
(2) Track is not assigned to detection and is coasted.
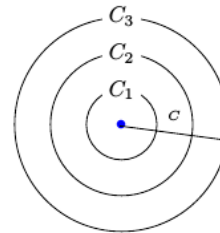
$C_2 < C \leq C_3$

Three Hypotheses

(1) Detection is assigned to track. A branch is created updating the track with this detection.
(2) Track is not assigned to detection and is coasted.
(3) Detection is not assigned and creates a new track (branch).

$C_3 < C$

Single Hypothesis

(1) Detection is not assigned and creates a new track (branch).

Tips:

- Increase the value of C_3 if there are detections that should be assigned to tracks but are not. Decrease the value if there are detections that are assigned to tracks they should not be assigned to (too far away).

- Increasing the values C_1 and C_2 helps control the number of track branches that are created. However, doing so reduces the number of branches (hypotheses) each track has.
- To allow each track to be unassigned, set $C_1 = 0$.
- To allow each detection to be unassigned, set $C_2 = 0$.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
assignauction | assignjv | assignkbest | assignkbestsd | assignmunkres | assignsd | trackerGNN | trackerTOMHT

Introduced in R2018b

fusecovint

Covariance fusion using covariance intersection

Syntax

```
[fusedState,fusedCov] = fusecovint(trackState,trackCov)
[fusedState,fusedCov] = fusecovint(trackState,trackCov,minProp)
```

Description

`[fusedState,fusedCov] = fusecovint(trackState,trackCov)` fuses the track states in `trackState` and their corresponding covariance matrices `trackCov`. The function computes the fused state and covariance as an intersection of the individual covariances. It creates a convex combination of the covariances and finds weights that minimize the determinant of the fused covariance matrix.

`[fusedState,fusedCov] = fusecovint(trackState,trackCov,minProp)` estimates the fused covariance by minimizing `minProp`, which can be either the determinant or the trace of the fused covariance matrix.

Examples

Covariance Intersection Fusion Using Default Values

Define a state vector of tracks.

```
x(:,1) = [1;2;0];
x(:,2) = [2;2;0];
x(:,3) = [2;3;0];
```

Define the covariance matrices of the tracks.

```
p(:,:,1) = [10 5 0; 5 10 0; 0 0 1];
p(:,:,2) = [10 -5 0; -5 10 0; 0 0 1];
p(:,:,3) = [12 9 0; 9 12 0; 0 0 1];
```

Estimate the fused state vector and its covariance.

```
[fusedState,fusedCov] = fusecovint(x,p);
```

Use `trackPlotter` to plot the results.

```
tPlotter = theaterPlot('XLim',[-10 10],'YLim',[-10 10],'ZLim',[-10 10]);
tPlotter1 = trackPlotter(tPlotter, ...
    'DisplayName','Input Tracks','MarkerEdgeColor',[0.000 0.447 0.741]);
tPlotter2 = trackPlotter(tPlotter,'DisplayName', ...
    'Fused Track','MarkerEdgeColor',[0.850 0.325 0.098]);
plotTrack(tPlotter1,x',p)
plotTrack(tPlotter2,fusedState',fusedCov)
title('Covariance Intersection Fusion')
```

Covariance Intersection Fusion Using Trace Minimization

Define a state vector of tracks.

```
x(:,1) = [1;2;0];
x(:,2) = [2;2;0];
x(:,3) = [2;3;0];
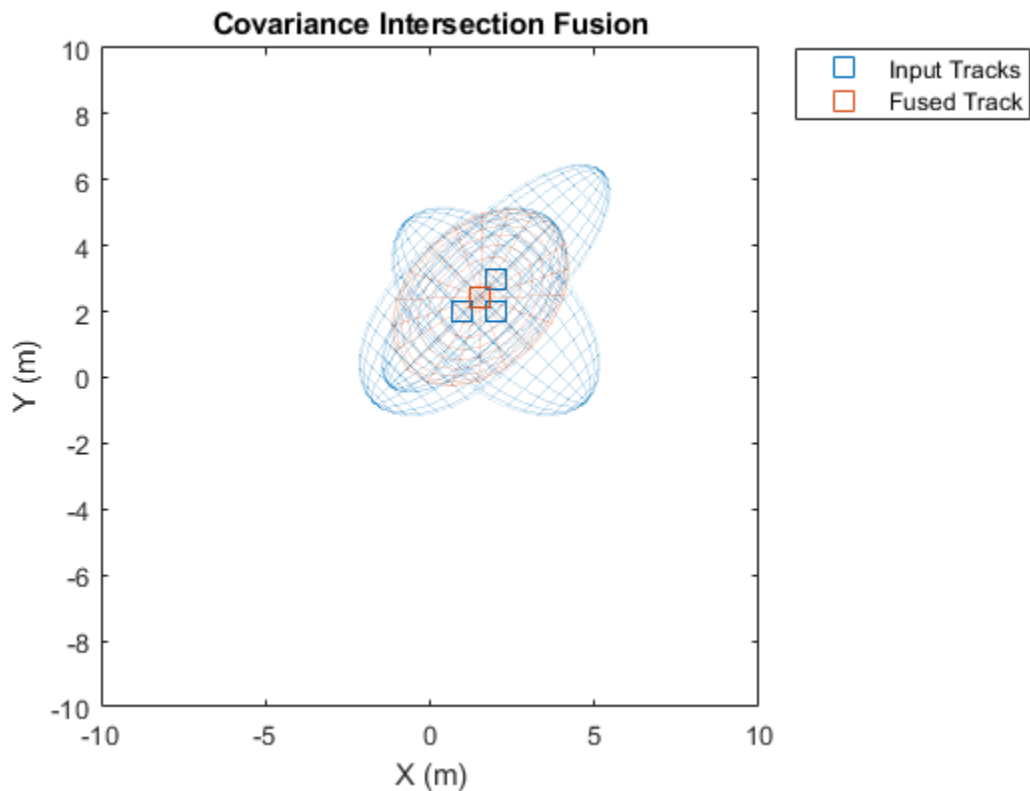```

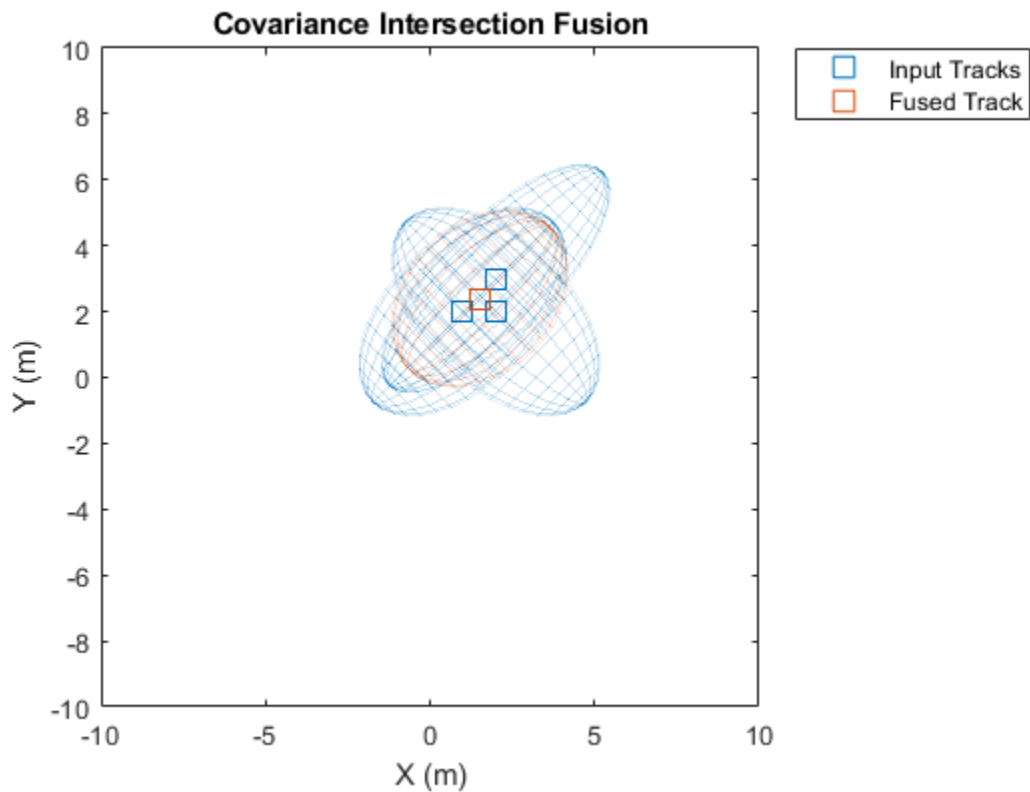Define the covariance matrices of the tracks.

```
p(:,:,1) = [10 5 0; 5 10 0; 0 0 1];
p(:,:,2) = [10 -5 0; -5 10 0; 0 0 1];
p(:,:,3) = [12 9 0; 9 12 0; 0 0 1];
```

Estimate the fused state vector and its covariance. Combine the original covariances so that the trace of the fused covariance matrix is minimized.

```
[fusedState,fusedCov] = fusecovint(x,p,'trace');
```

Use `trackPlotter` to plot the results.

```
tPlotter = theaterPlot('XLim',[-10 10],'YLim',[-10 10],'ZLim',[-10 10]);
tPlotter1 = trackPlotter(tPlotter, ...
    'DisplayName','Input Tracks','MarkerEdgeColor',[0.000 0.447 0.741]);
tPlotter2 = trackPlotter(tPlotter, ...
    'DisplayName','Fused Track','MarkerEdgeColor',[0.850 0.325 0.098]);
plotTrack(tPlotter1,x',p)
plotTrack(tPlotter2,fusedState',fusedCov)
title('Covariance Intersection Fusion')
```

Input Arguments

`trackState` — Track states
N-by-*M* matrix

Track states, specified as an *N*-by-*M* matrix, where *N* is the dimension of the state and *M* is the number of tracks.

Data Types: `single` | `double`

`trackCov` — Track covariance matrices
N-by-*N*-by-*M* array

Track covariance matrices, specified as an *N*-by-*N*-by-*M* array, where *N* is the dimension of the state and *M* is the number of tracks.

Data Types: `single` | `double`

`minProp` — Property to minimize
`'det'` (default) | `'trace'`

Property to minimize when estimating the fused covariance, specified as `'det'` or `'trace'`.

.

Data Types: `char` | `string`

Output Arguments

`fusedState` — Fused state
N-by-1 vector

Fused state, returned as an *N*-by-1 vector, where *N* is the dimension of the state.

`fusedCov` — Fused covariance matrix
N-by-*N* matrix

Fused covariance matrix, returned as an *N*-by-*N* matrix, where *N* is the dimension of the state.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
fusecovunion | fusexcov

Introduced in R2018b

fusecovunion

Covariance fusion using covariance union

Syntax

```
[fusedState,fusedCov] = fusecovunion(trackState,trackCov)
```

Description

`[fusedState,fusedCov] = fusecovunion(trackState,trackCov)` fuses the track states in `trackState` and their corresponding covariance matrices `trackCov`. The function estimates the fused state and covariance in a way that maintains consistency. For more details, see "Consistent Estimator" on page 1-441.

Examples

Covariance Union Fusion

Define a state vector of tracks.

```
x(:,1) = [1;2;0];
x(:,2) = [2;2;0];
x(:,3) = [2;3;0];
```

Define the covariance matrices of the tracks.

```
p(:,:,1) = [10 5 0; 5 10 0;0 0 1];
p(:,:,2) = [10 -5 0; -5 10 0;0 0 1];
p(:,:,3) = [12 9 0; 9 12 0;0 0 1];
```

Estimate the fused state vector and its covariance.

```
[fusedState,fusedCov] = fusecovunion(x,p);
```

Use `trackPlotter` to plot the results.

```matlab
tPlotter = theaterPlot('XLim',[-10 10],'YLim',[-10 10],'ZLim',[-10 10]);
tPlotter1 = trackPlotter(tPlotter, ...
    'DisplayName','Input Tracks','MarkerEdgeColor',[0.000 0.447 0.741]);
tPlotter2 = trackPlotter(tPlotter, ...
    'DisplayName','Fused Track','MarkerEdgeColor',[0.850 0.325 0.098]);
plotTrack(tPlotter1,x',p)
plotTrack(tPlotter2, fusedState', fusedCov)
title('Covariance Union Fusion')
```

Input Arguments

`trackState` — Track states
N-by-*M* matrix

Track states, specified as an *N*-by-*M* matrix, where *N* is the dimension of the state and *M* is the number of tracks.

Data Types: `single` | `double`

`trackCov` — Track covariance matrices
N-by-*N*-by-*M* array

Track covariance matrices, specified as an *N*-by-*N*-by-*M* array, where *N* is the dimension of the state and *M* is the number of tracks.

Data Types: `single` | `double`

Output Arguments

`fusedState` — Fused state
N-by-1 vector

Fused state, returned as an *N*-by-1 vector, where *N* is the dimension of the state.

`fusedCov` — Fused covariance matrix
N-by-*N* matrix

Fused covariance matrix, returned as an *N*-by-*N* matrix, where *N* is the dimension of the state.

Definitions

Consistent Estimator

A *consistent estimator* is an estimator that converges in probability to the quantity being estimated as the sample size grows. In the case of tracking, a position estimate is consistent if its covariance (error) matrix is not smaller than the covariance of the actual distribution of the true state about the estimate. The covariance union method guarantees

consistency by ensuring that all the individual means and covariances are bounded by the fused mean and covariance.

References

[1] Reece, Steven, and Stephen Rogers. "Generalised Covariance Union: A Unified Approach to Hypothesis Merging in Tracking." *IEEE® Transactions on Aerospace and Electronic Systems*. Vol. 46, No. 1, Jan. 2010, pp. 207–221.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
fusecovint | fusexcov

Introduced in R2018b

fusexcov

Covariance fusion using cross-covariance

Syntax

```
[fusedState,fusedCov] = fusexcov(trackState,trackCov)
[fusedState,fusedCov] = fusexcov(trackState,trackCov,crossCovFactor)
```

Description

[fusedState,fusedCov] = fusexcov(trackState,trackCov) fuses the track states in trackState and their corresponding covariance matrices trackCov. The function estimates the fused state and covariance within a Bayesian framework in which the cross-correlation between tracks is unknown.

[fusedState,fusedCov] = fusexcov(trackState,trackCov,crossCovFactor) specifies a cross-covariance factor for the effective correlation coefficient when computing the cross-covariance.

Examples

Cross-Covariance Fusion Using Default Values

Define a state vector of tracks.

```
x(:,1) = [1;2;0];
x(:,2) = [2;2;0];
x(:,3) = [2;3;0];
```

Define the covariance matrices of the tracks.

```
p(:,:,1) = [10 5 0; 5 10 0;0 0 1];
p(:,:,2) = [10 -5 0; -5 10 0;0 0 1];
p(:,:,3) = [12 9 0; 9 12 0;0 0 1];
```

Estimate the fused state vector and its covariance.

```
[fusedState,fusedCov] = fusexcov(x,p);
```

Use `trackPlotter` to plot the results.

```
tPlotter = theaterPlot('XLim',[-10 10],'YLim',[-10 10],'ZLim',[-10 10]);
tPlotter1 = trackPlotter(tPlotter, ...
    'DisplayName','Input Tracks','MarkerEdgeColor',[0.000 0.447 0.741]);
tPlotter2 = trackPlotter(tPlotter, ...
    'DisplayName','Fused Track','MarkerEdgeColor',[0.850 0.325 0.098]);
plotTrack(tPlotter1,x',p)
plotTrack(tPlotter2, fusedState', fusedCov)
title('Cross-Covariance Fusion')
```

Cross-Covariance Fusion Using Cross-Covariance Factor

Define a state vector of tracks.

```
x(:,1) = [1;2;0];
x(:,2) = [2;2;0];
x(:,3) = [2;3;0];
```
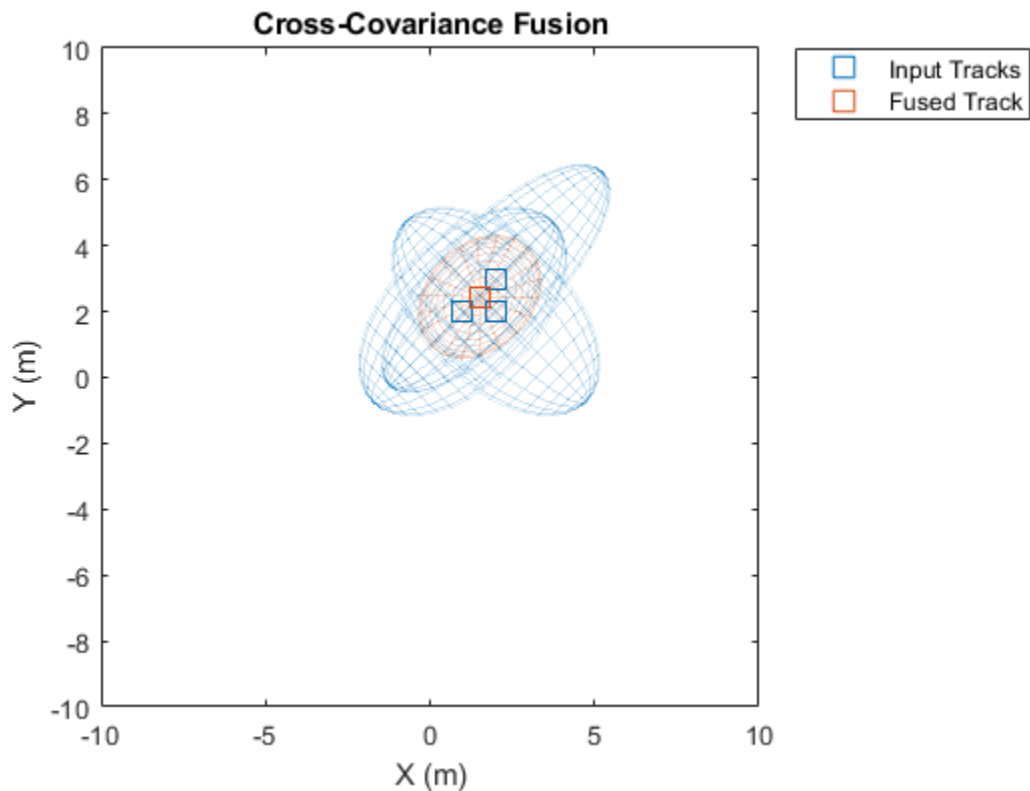
Define the covariance matrices of the tracks.

```
p(:,:,1) = [10 5 0; 5 10 0;0 0 1];
p(:,:,2) = [10 -5 0; -5 10 0;0 0 1];
p(:,:,3) = [12 9 0; 9 12 0;0 0 1];
```

Estimate the fused state vector and its covariance. Specify a cross-covariance factor of `0.5`.

```
[fusedState,fusedCov] = fusexcov(x,p,0.5);
```

Use `trackPlotter` to plot the results.

```
tPlotter = theaterPlot('XLim',[-10 10],'YLim',[-10 10],'ZLim',[-10 10]);
tPlotter1 = trackPlotter(tPlotter, ...
    'DisplayName','Input Tracks','MarkerEdgeColor',[0.000 0.447 0.741]);
tPlotter2 = trackPlotter(tPlotter, ...
    'DisplayName','Fused Track','MarkerEdgeColor',[0.850 0.325 0.098]);
plotTrack(tPlotter1,x',p)
plotTrack(tPlotter2, fusedState', fusedCov)
title('Cross-Covariance Fusion')
```

Input Arguments

`trackState` — Track states
N-by-*M* matrix

Track states, specified as an *N*-by-*M* matrix, where *N* is the dimension of the state and *M* is the number of tracks.

Data Types: `single` | `double`

`trackCov` — Track covariance matrices
N-by-*N*-by-*M* array

Track covariance matrices, specified as an *N*-by-*N*-by-*M* array, where *N* is the dimension of the state and *M* is the number of tracks.

Data Types: `single` | `double`

crossCovFactor — Cross-covariance factor
`0.4` (default) | scalar

Cross-covariance factor, specified as a scalar.

Data Types: `single` | `double`

Output Arguments

fusedState — Fused state
N-by-1 vector

Fused state, returned as an *N*-by-1 vector, where *N* is the dimension of the state.

fusedCov — Fused covariance matrix
N-by-*N* matrix

Fused covariance matrix, returned as an *N*-by-*N* matrix, where *N* is the dimension of the state.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`fusecovint` | `fusecovunion`

Introduced in R2018b

clusterTrackBranches

Cluster track-oriented multi-hypothesis history

Syntax

```
[clusters,incompatibleBranches] = clusterTrackBranches(
branchHistory)
[clusters,incompatibleBranches] = clusterTrackBranches(
branchHistory,'OutputForm',out)
```

Description

[clusters,incompatibleBranches] = clusterTrackBranches(
branchHistory) computes the clusters and incompatibility matrix for a set of branches.

Branches *i*, *j*, and *k* belong to the same cluster if branches *i* and *j* are pairwise-incompatible and branches *j* and *k* are pairwise-incompatible. Two branches are pairwise-incompatible if they share a track ID (the first column of `branchHistory`) or if they share detections that fall in their gates during the number of recent scans as specified by the history depth.

[clusters,incompatibleBranches] = clusterTrackBranches(
branchHistory,'OutputForm',out) returns the clusters in the format specified by
out.

Examples

Compute Clusters of Branches

Create a branch history matrix for 12 branches. For this example, the branch history matrix has 11 columns that represent the history of 2 sensors with a history depth of 4.

```
branchHistory = uint32([
    4     9     9     0     0     1     0     0     0     0     0
```

```
   5    10    10     0     0     0     2     0     0     0     0
   6    11    11     0     0     3     0     0     0     0     0
   1    12    12     0     0     1     0     1     0     0     0
   1    13    13     0     0     0     2     1     0     0     0
   1    14    14     0     0     1     2     1     0     0     0
   2    15    15     0     0     3     0     3     0     0     0
   3    16    16     0     0     0     4     0     4     0     0
   7     0    17     1     0     0     0     0     0     0     0
   1     5    18     1     0     0     0     0     2     0     0
   1     5    19     0     2     0     0     0     2     0     0
   1     5    20     1     2     0     0     0     2     0     0]);
```

Get the list of clusters and the list of incompatible branches. The `clusters` matrix has three columns, therefore there are three clusters.

```
[clusters,incompBranches] = clusterTrackBranches(branchHistory);
size(clusters)
```

ans = *1×2*

```
    12     3
```

Show the incompatible branches as a graph. The numeric branch IDs are in the third column of `branchHistory`. To display the IDs of the branches on the graph, convert the IDs to character vectors. You can see the three distinct clusters.

```
branchIDs = cellstr(num2str(branchHistory(:,3)));
g = graph(incompBranches,branchIDs,'omitselfloops');
plot(g)
```
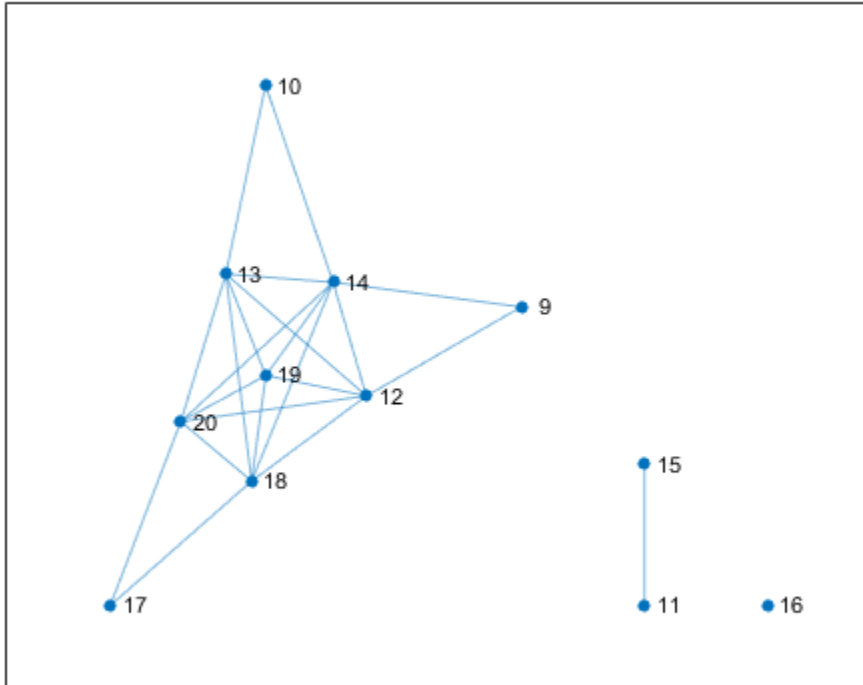
Input Arguments

branchHistory — Branch history
matrix of integers

Branch history, specified as a matrix of integers. Each row of `branchHistory` represents a unique track branch. `branchHistory` must have 3+(D×S) columns, where D is the number of maintained scans (the history depth) and S is the maximum number of maintained sensors. For more information, see the `history` output of the `trackBranchHistory` system object.

out — Output form
'logical' (default) | 'vector' | 'cell'

Output form of the returned clusters, specified as 'logical', 'vector', or 'cell'.

Output Arguments

clusters — Clusters
M-by-*P* logical matrix | *M*-element numeric vector | cell array

Clusters, returned as one of the following. The format of clusters is specified by out.

- An *M*-by-*P* logical matrix. *M* is the number of branches (rows) in branchHistory and *P* is the number of clusters. The (*i,j*) element is true if branch *j* is contained in cluster *i*. The value of *P* is less than or equal to *M*.
- A vector of length *M*, where the *i*-th element gives the index of the cluster that contains branch *i*.
- A cell array c, where c{*j*} contains the IDs of all the branches in cluster *j*.

Data Types: logical

incompatibleBranches — Incompatible branches
M-by-*M* symmetric logical matrix

Incompatible branches, returned as an *M*-by-*M* symmetric logical matrix. The (*i,j*) element is true if branches *i* and *j* are pairwise-incompatible.

Data Types: logical

References

[1] Werthmann, John R. "A Step-by-Step Description of a Computationally Efficient Version of Multiple Hypothesis Tracking." In *Proceedings of SPIE Vol. 1698, Signal and Processing of Small Targets*. 1992, pp. 288–300. doi: 10.1117/12.139379.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Code generation only supports the `'logical'` value of output form `out`.

See Also
`compatibleTrackBranches` | `pruneTrackBranches` | `trackBranchHistory` | `trackerTOMHT`

Introduced in R2018b

compatibleTrackBranches

Formulate global hypotheses from clusters

Syntax

```
[hypotheses,hypScores] = compatibleTrackBranches(clusters,
incompatibleBranches,scores,maxNumHypotheses)
```

Description

[hypotheses,hypScores] = compatibleTrackBranches(clusters,
incompatibleBranches,scores,maxNumHypotheses) returns the list of hypotheses
hypotheses and their scores hypScores from information about clusters of branches
and incompatibility of branches.

Hypotheses are sets of compatible track branches, which are branches that do not belong
to the same track or share a detection in their history. The score of each hypothesis is the
sum of scores of all branches included in the hypothesis.

Examples

Get Hypotheses of Branches

Create a branch history matrix for 12 branches. For this example, the branch history
matrix has 11 columns that represent the history of 2 sensors with a history depth of 4.

```
branchHistory = uint32([
    4    9    9    0    0    1    0    0    0    0    0
    5   10   10    0    0    0    2    0    0    0    0
    6   11   11    0    0    3    0    0    0    0    0
    1   12   12    0    0    1    0    1    0    0    0
    1   13   13    0    0    0    2    1    0    0    0
    1   14   14    0    0    1    2    1    0    0    0
    2   15   15    0    0    3    0    3    0    0    0
```

```
    3    16    16     0     0     0     4     0     4     0     0
    7     0    17     1     0     0     0     0     0     0     0
    1     5    18     1     0     0     0     0     2     0     0
    1     5    19     0     2     0     0     0     2     0     0
    1     5    20     1     2     0     0     0     2     0     0]);
```

Get the list of clusters and the list of incompatible branches. The `clusters` matrix has three columns, therefore there are three clusters.

```
[clusters,incompBranches] = clusterTrackBranches(branchHistory);
```

Specify a 12-by-1 column vector containing the branch scores.

```
scores = [81.4; 90.5; 12.7; 91.3; 63.2; 9.7; 27.8; 54.6; 95.7; 96.4; 15.7; 97.1];
```

Specify the number of global hypotheses.

```
numHypotheses = 6;
```

Get a matrix of hypotheses and the score of each hypothesis.

```
[hyps,hypScores] = compatibleTrackBranches(clusters,incompBranches,scores,numHypotheses
```

```
hyps = 12x6 logical array

    1    0    1    1    1    0
    1    1    1    1    1    1
    0    0    0    0    1    1
    0    1    0    0    0    1
    0    0    0    0    0    0
    0    0    0    0    0    0
    1    1    1    1    0    0
    1    1    1    1    1    1
    1    1    0    0    1    1
    0    0    0    1    0    0
     ⋮

hypScores = 1×6

  365.7000  359.9000  351.4000  350.7000  350.6000  344.8000
```

Input Arguments

`clusters` — Clusters
M-by-*P* logical matrix | *M*-element numeric vector | cell array

Clusters, specified as one of the following.

- An *M*-by-*P* logical matrix. *M* is the number of branches and *P* is the number of clusters. The (i,j) element is `true` if branch j is contained in cluster i. The value of *P* is less than or equal to *M*.
- A vector of length *M*, where the *i*-th element gives the index of the cluster that contains branch *i*.
- A cell array `c`, where `c{j}` contains the IDs of all the branches in cluster j.

You can use `clusterTrackBranches` to compute the clusters from a branch history matrix.

Data Types: `logical`

`incompatibleBranches` — Incompatible branches
M-by-*M* symmetric logical matrix

Incompatible branches, specified as an *M*-by-*M* symmetric logical matrix. The (i,j) element is `true` if branches *i* and *j* are pairwise-incompatible.

You can use `clusterTrackBranches` to compute incompatible branches from a branch history matrix.

Data Types: `logical`

`scores` — Branch scores
M-by-*1* numeric vector | *M*-by-*2* numeric matrix

Branch scores, specified as an *M*-by-*1* numeric vector or an *M*-by-*2* numeric matrix.

Note If you specify `scores` as an *M*-by-*2* numeric matrix, then the first column specifies the current score of each branch and the second column specifies the maximum score. `compatibleTrackBranches` ignores the second column.

Data Types: `single` | `double`

`maxNumHypotheses` — Maximum number of hypotheses
positive integer

Maximum number of hypotheses, specified as a positive integer.

Output Arguments

`hypotheses` — Hypotheses
M-by-H logical matrix

Hypotheses, returned as an M-by-H logical matrix, where M is the number of branches and H is the value of `maxNumHypotheses`.

`hypScores` — Hypotheses score
1-by-H numeric vector

Hypotheses score, returned as a 1-by-H numeric vector.

References

[1] Werthmann, John R. "A Step-by-Step Description of a Computationally Efficient Version of Multiple Hypothesis Tracking." In *Proceedings of SPIE Vol. 1698, Signal and Processing of Small Targets*. 1992, pp. 288–300. doi: 10.1117/12.139379.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Code generation only supports `clusters` specified as an M-by-P logical matrix.

See Also

clusterTrackBranches | pruneTrackBranches | trackBranchHistory | trackerTOMHT

Introduced in R2018b

pruneTrackBranches

Prune track branches with low likelihood

Syntax

```
[toPrune,globalProbability] = pruneTrackBranches(branchHistory,
scores,hypotheses)
[toPrune,globalProbability] = pruneTrackBranches(branchHistory,
scores,hypotheses,Name,Value)
[toPrune,globalProbability,info] = pruneTrackBranches( ___ )
```

Description

`[toPrune,globalProbability] = pruneTrackBranches(branchHistory, scores,hypotheses)` returns a logical flag, `toPrune`, that indicates which branches should be pruned based on the branch history, branch scores, and hypotheses. `pruneTrackBranches` also returns the global branch probabilities, `globalProbability`.

`[toPrune,globalProbability] = pruneTrackBranches(branchHistory, scores,hypotheses,Name,Value)` uses name-value pairs to modify how branches are pruned.

`[toPrune,globalProbability,info] = pruneTrackBranches( ___ )` returns additional information, `info`, about the pruned branches.

Examples

Prune Branches For Single Sensor Using N-Scan Pruning

Create a branch history matrix for a single sensor with 20 branches. For this example, the history depth is 4 therefore the matrix has 7 columns.

```
history = [
    8    14    14     0     0     2     0
    1    23    23     0     0     2     1
    2    24    24     0     0     1     2
    9    25    25     0     1     0     0
   10    26    26     0     2     0     0
    1    28    28     0     1     0     1
    4    33    33     0     1     2     1
    1    34    34     0     1     2     1
    2    35    35     0     2     1     2
   11     0    36     1     0     0     0
   12     0    37     2     0     0     0
    8    14    38     2     0     2     0
    1    23    39     2     0     2     1
    2    24    40     1     0     1     2
    9    25    41     2     1     0     0
   10    26    42     1     2     0     0
    1    28    43     2     1     0     1
    4    33    44     2     1     2     1
    1    34    45     2     1     2     1
    2    35    46     1     2     1     2];
```

Get the list of clusters and the list of incompatible branches. The `clusters` matrix has two columns, therefore there are two clusters.

```
[clusters,incompBranches] = clusterTrackBranches(history);
```

Specify a 20-by-1 column vector containing branch scores.

```
scores = [4.5 44.9 47.4 6.8 6.8 43.5 50.5 61.9 64.7 9.1 9.1 19 61.7 ...
    63.5 21.2 20.5 60.7 67.3 79.2 81.5]';
```

Get a matrix of hypothesis.

```
hypotheses = compatibleTrackBranches(clusters,incompBranches,scores,10);
```

Prune the track branches, using name-value pair arguments to specify a single sensor and the `'Hypothesis'` method of N-scan pruning. Return the pruning flag, global probability, and pruning information about each branch. To make the information easier to compare, convert the information from a struct to a table.

The *i*-th value of `toPrune` is `true` if any of `'PrunedByProbability'`, `'PrunedByNScan'`, or `'PrunedByNumBranches'` are `true` in the *i*-th row of the information table.

```
[toPrune,probs,info] = pruneTrackBranches(history,scores,hypotheses, ...
    'NumSensors',1,'NScanPruning','Hypothesis');
infoTable = struct2table(info)
```

infoTable=*20×6 table*

BranchID	PriorProbability	GlobalProbability	PrunedByProbability	PrunedE
14	0.98901	0.098901	false	fal
23	1	0.1	false	fal
24	1	0.1	false	fal
25	0.99889	0.099889	false	fal
26	0.99889	0.099889	false	fal
28	1	0	true	tru
33	1	0	true	fal
34	1	0.2	false	fal
35	1	0.2	false	fal
36	0.99989	0.19998	false	fal
37	0.99989	0.19998	false	fal
38	1	0	true	fal
39	1	0.1	false	fal
40	1	0.1	false	fal
41	1	0.1	false	fal
42	1	0.1	false	fal
⋮				

Input Arguments

branchHistory — Branch history
matrix of integers

Branch history, specified as a matrix of integers. Each row of `branchHistory` represents a unique track branch. `branchHistory` must have $3+(D×S)$ columns, where D is the number of maintained scans (the history depth) and S is the maximum number of maintained sensors. For more information, see the `history` output of the `trackBranchHistory` system object.

scores — Branch scores
M-by-*1* numeric vector | *M*-by-*2* numeric matrix

Branch scores, specified as an *M*-by-*1* numeric vector or an *M*-by-*2* numeric matrix.

Note If you specify `scores` as an *M*-by-*2* numeric matrix, then the first column specifies the current score of each branch and the second column specifies the maximum score. `pruneTrackBranches` ignores the second column.

Data Types: `single` | `double`

hypotheses — Hypotheses
M-by-*H* logical matrix

Hypotheses, returned as an *M*-by-*H* logical matrix, where *M* is the number of branches and *H* is the number of global hypotheses. You can use `clusterTrackBranches` to compute the clusters from a branch history matrix, then use `compatibleTrackBranches` to compute the hypotheses from the clusters.

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 quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `[toPrune,probs] = pruneTrackBranches(branchHistory,scores,hypotheses,'MinBranchProbability',2e-3);`

MinBranchProbability — Minimum branch probability
`1e-3` (default) | number in the range [0,1)

Minimum branch probability threshold, specified as the comma-separated pair consisting of `'MinBranchProbability'` and a number in the range [0,1). Typical values are between 1e-3 and 5e-3. The `pruneTrackBranches` function prunes branches with global probability less than the threshold.

MaxNumTrackBranches — Maximum number of branches
`3` (default) | positive integer

Maximum number of branches to keep per track, specified as the comma-separated pair consisting of `'MaxNumTrackBranches'` and a positive integer. Typical values are between 2 and 6. If a track has more than this number of branches, then `pruneTrackBrances` prunes branches with the lowest initial score.

NScanPruning — N-scan pruning method
'None' (default) | 'Hypothesis'

N-scan pruning method, specified as the comma-separated pair consisting of 'NScanPruning' and 'None' or 'Hypothesis'. If you specify 'Hypothesis', then pruneTrackBrances prunes branches that are incompatible with the current most likely branch in the most recent *N* scans. By default, pruneTrackBrances does not use N-scan pruning.

NumSensors — Number of sensors
20 (default) | positive integer

Number of sensors in history, specified as the comma-separated pair consisting of 'NumSensors' and a positive integer.

Output Arguments

toPrune — Branches to prune
M-by-*1* logical vector

Branches to prune, returned as an *M*-by-*1* logical vector. A value of true indicates that the branch should be pruned.

Data Types: logical

globalProbability — Global branch probabilities
M-by-*1* numeric vector

Global branch probabilities, returned as an *M*-by-*1* numeric vector.

info — Pruning information
struct

Pruning information about each branch, returned as a struct with the following fields.

- BranchID — An *M*-by-*1* numeric vector. Each value specifies the ID of a track branch. The IDs come from the third column of branchHistory.

- PriorProbability — An *M*-by-*1* numeric vector. Each value specifies the branch prior probability from the branch score.

- GlobalProbability — An *M*-by-*1* numeric vector. Each value specifies the branch global probability, which considers the hypotheses that contain the branch and their scores.

- PrunedByProbability — An *M*-by-*1* logical vector. A value of `true` indicates that the branch is pruned by `MinBranchProbability`.

- PrunedByNScan — An *M*-by-*1* logical vector. A value of `true` indicates that the branch is pruned by `NScanPruning`.

- PrunedByNumBranches — An *M*-by-*1* logical vector. A value of `true` indicates that the branch is pruned by `MaxNumTrackBranches`.

References

[1] Werthmann, John R. "A Step-by-Step Description of a Computationally Efficient Version of Multiple Hypothesis Tracking." In *Proceedings of SPIE Vol. 1698, Signal and Processing of Small Targets*. 1992, pp. 288–300. doi: 10.1117/12.139379.

[2] Blackman, Samuel, and Robert Popoli. "Design and Analysis of Modern Tracking Systems." Artech House, 1999.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
clusterTrackBranches | compatibleTrackBranches | trackBranchHistory | trackerTOMHT

Introduced in R2018b

triangulateLOS

Triangulate multiple line-of-sight detections

Syntax

```
estPos = triangulateLOS(detections)
[estPos,estCov] = triangulateLOS(detections)
```

Description

`estPos = triangulateLOS(detections)` estimates the position of a target in a global Cartesian coordinate frame by triangulating a set of angle-only `detections`. Angle-only detections are also known as line-of-sight (LOS) detections. For more details, see "Algorithms" on page 1-468.

`[estPos,estCov] = triangulateLOS(detections)` also returns `estCov`, the covariance of the error in target position. The function uses a Taylor-series approximation to estimate the error covariance.

Examples

Triangulate Line-of-Sight Measurements from Three Sensors

Load a MAT-file containing a set of line-of-sight detections stored in the variable `detectionSet`.

```
load angleOnlyDetectionFusion.mat
```

Plot the angle-only detections and the sensor positions. Specify a range of 5 km for plotting the direction vector. To specify the position of the origin, use the second measurement parameter because the sensor is located at the center of the platform. Convert the azimuth and elevation readings to Cartesian coordinates.

```
rPlot = 5000;
```

```
for i = 1:numel(detectionSet)
    originPos = detectionSet{i}.MeasurementParameters(2).OriginPosition;

    az = detectionSet{i}.Measurement(1);
    el = detectionSet{i}.Measurement(2);
    [xt,yt,zt] = sph2cart(deg2rad(az),deg2rad(el),rPlot);

    positionData(:,i) = originPos;
    plotData(:,3*i+(-2:0)) = [xt yt zt]'.*[1 0 NaN]+originPos;
end

plot3(positionData(1,:),positionData(2,:),positionData(3,:),'*')
hold on
plot3(plotData(1,:),plotData(2,:),plotData(3,:))
```

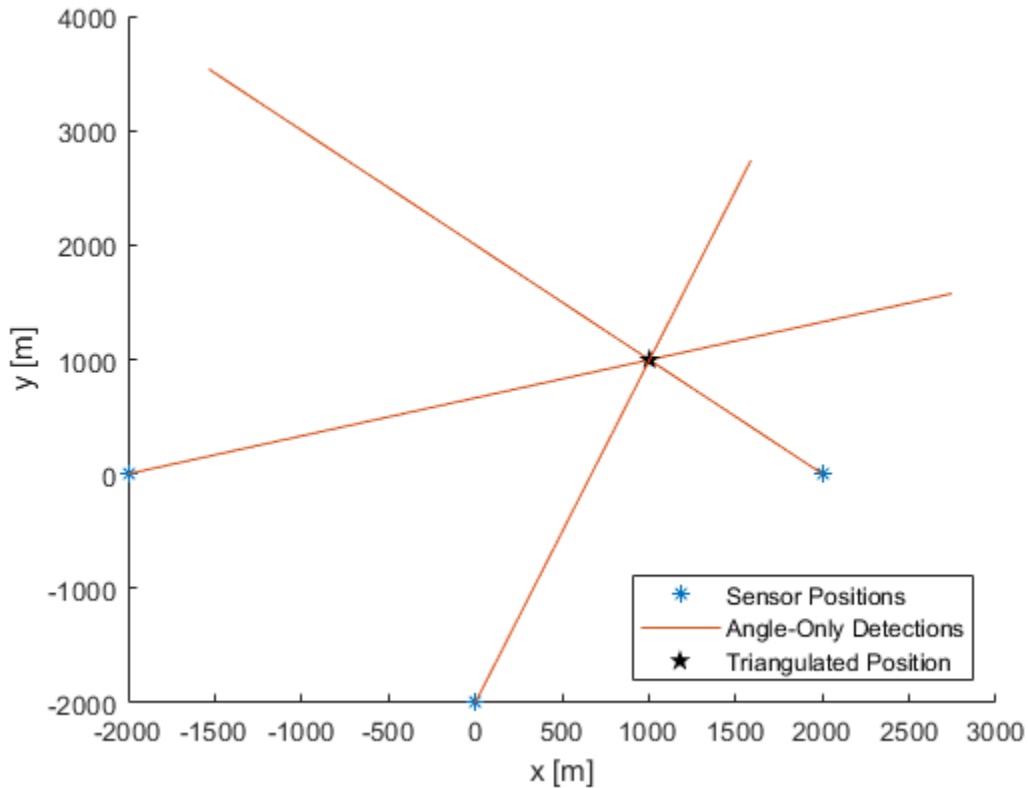Triangulate the detections by using `triangulateLOS`. Plot the triangulated position.

```
[estPos,estCov] = triangulateLOS(detectionSet);

plot3(estPos(1),estPos(2),estPos(3),'pk','MarkerFaceColor','k')
hold off

legend('Sensor Positions','Angle-Only Detections','Triangulated Position', ...
    'location','southeast')
xlabel('x [m]')
ylabel('y [m]')
view(2)
```

Input Arguments

detections — Line-of-sight measurements
cell array of `objectDetection` objects

Line-of-sight measurements, specified as a cell array of `objectDetection` objects. Each object has the properties listed in the table.

Property	Definition
`Time`	Measurement time

Property	Definition
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor
ObjectClassID	Object classification
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

Each detection must specify the MeasurementParameters property as a structure with the fields described in the table.

Parameter	Definition
Frame	Frame used to report measurements. Specify Frame as 'spherical' for the first structure.
OriginPosition	Position offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 real vector.
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 real vector.
Orientation	A 3-by-3 real-valued orthonormal frame orientation matrix.
IsParentToChild	A logical scalar that indicates if Orientation is given as a frame rotation from the parent coordinate frame to the child coordinate frame. If false, then Orientation is given as a frame rotation from the child coordinate frame to the parent coordinate frame.
HasElevation	A logical scalar that indicates if elevation is included in the measurements. This parameter is true by default.

Parameter	Definition
HasAzimuth	A logical scalar that indicates if azimuth is included in the measurements. This parameter is `true` by default. If specified as a field, it must be set to `true`.
HasRange	A logical scalar that indicates if range is included in the measurements. This parameter must be specified as a field and set to `false`.
HasVelocity	A logical scalar that indicates if velocity is included in the measurements. This parameter is `false` by default. If specified as a field, it must be set to `false`.

The function provides default values for fields left unspecified.

Output Arguments

estPos — Estimated position
3-by-1 vector

Estimated position of the target, returned as a 3-by-1 vector.

estCov — Estimated error covariance
3-by-3 matrix

Estimated error covariance of the target position, returned as a 3-by-3 matrix.

Algorithms

Multiple angle-only or line-of-sight measurements result in lines in space. These lines might or might not intersect because of measurement noise. `triangulateLOS` uses a suboptimal linear least-squares method to minimize the distance of miss between multiple detections. The formulation makes these assumptions:

- All detections report measurements with approximately the same accuracy in azimuth and elevation (if measured).

- The distances from the different sensors to the triangulated target are all of the same order.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
objectDetection

System Objects
staticDetectionFuser

Introduced in R2018b

radarChannel

Free space propagation and reflection of radar signals

Syntax

```
radarsigout = radarChannel(radarsigin,platforms)
```

Description

`radarsigout = radarChannel(radarsigin,platforms)` returns radar signals,`radarsigout`, as combinations of the signals, `radarsigin`, that are reflected from the platforms, `platforms`.

Examples

Reflect Radar Emission From Platform

Create a radar emission and a platform and reflect the emission from the platform.

Create a radar emission object.

```
radarSig = radarEmission('PlatformID',1,'EmitterIndex',1,'OriginPosition',[0 0 0]);
```

Create a platform structure.

```
platfm = struct('PlatformID',2,'Position',[10 0 0],'Signatures',rcsSignature());
```

Reflect the emission from the platform.

```
sigs = radarChannel(radarSig,platfm)
```

```
sigs =

  radarEmission with properties:
```

```
                  EIRP: 0
                   RCS: 0
            PlatformID: 1
          EmitterIndex: 1
        OriginPosition: [0 0 0]
        OriginVelocity: [0 0 0]
           Orientation: [1x1 quaternion]
           FieldOfView: [180 180]
       CenterFrequency: 300000000
             Bandwidth: 3000000
          WaveformType: 0
        ProcessingGain: 0
     PropagationRange: 0
 PropagationRangeRate: 0
```

Reflect Radar Emission From Platform within Tracking Scenario

Reflect a radar emission from a platform defined within a trackingScenario.

Create a tracking scenario object.

```
scenario = trackingScenario;
```

Create a radarEmitter object.

```
emitter = radarEmitter(1);
```

Mount the emitter on a platform within the scenario.

```
plat = platform(scenario,'Emitters',emitter);
```

Add another platform to reflect the emitted signal.

```
target = platform(scenario);
target.Trajectory.Position = [30 0 0];
```

Emit the signal using the emit object function of a platform.

```
txsigs = emit(plat,scenario.SimulationTime)
```

```
txsigs =
```

```
radarEmission with properties:

                   EIRP: 100
                    RCS: 0
             PlatformID: 1
           EmitterIndex: 1
         OriginPosition: [0 0 0]
         OriginVelocity: [0 0 0]
            Orientation: [1×1 quaternion]
             FieldOfView: [1 5]
        CenterFrequency: 300000000
              Bandwidth: 3000000
           WaveformType: 0
          ProcessingGain: 0
       PropagationRange: 0
   PropagationRangeRate: 0
```

Reflect the signal from the platforms in the scenario.

```
sigs = radarChannel(txsigs,scenario.Platforms)
```

```
sigs =

  2×1 radarEmission array with properties:

    EIRP
    RCS
    PlatformID
    EmitterIndex
    OriginPosition
    OriginVelocity
    Orientation
    FieldOfView
    CenterFrequency
    Bandwidth
    WaveformType
    ProcessingGain
    PropagationRange
```

PropagationRangeRate

Input Arguments

radarsigin — Input radar signals
array of radarEmission objects

Input radar signals, specified as an array of radarEmission objects.

platforms — Reflector platforms
cell array of Platform objects | array of Platform structures

Reflector platforms, specified as a cell array of Platform objects, Platform, or an array of Platform structures:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field which has no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in scenario coordinates, specified as a real-valued 1-by-3 vector. This is a required field. There is no default value. Units are in meters.
Velocity	Velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default is [0 0 0].

Field	Description
Speed	Speed of the platform in the scenario frame specified as a real scalar. When speed is specified, the platform velocity is aligned with its orientation. Specify either the platform speed or velocity, but not both. Units are in meters per second The default is `0`.
Acceleration	Acceleration of the platform in scenario coordinates specified as a 1-by-3 row vector in meters per second-squared. The default is `[0 0 0]`.
Orientation	Orientation of the platform with respect to the local scenario NED coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the local NED coordinate system to the current platform body coordinate system. Units are dimensionless. The default is `quaternion(1,0,0,0)`.
AngularVelocity	Angular velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is `[0 0 0]`.
Signatures	Cell array of signatures defining the visibility of the platform to emitters and sensors in the scenario. The default is the cell array `{rcsSignature,irSignature, tsSignature}`

If you specify an array of platform structures, set a unique `PlatformID` for each platform and set the `Position` field for each platform. Any other fields not specified are assigned default values.

Output Arguments

radarsigout — Reflected radar signals
array of `radarEmission` objects

Reflected radar signals, specified as an array of `radarEmission` objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
radarEmission | radarEmitter | radarSensor

Introduced in R2018b

underwaterChannel

Propagated and reflected sonar signals

Syntax

```
sonarsigout = underwaterChannel(sonarsigin,platforms)
```

Description

`sonarsigout = underwaterChannel(sonarsigin,platforms)` returns sonar signals, `sonarsigout`, as combinations of signals, `sonarsigin`, reflected from platforms, `platforms`.

Examples

Reflect Sonar Emission From Platform

Create a sonar emission and a platform and reflect the emission from the platform.

Create a sonar emission object.

```
sonarSig = sonarEmission('PlatformID',1,'EmitterIndex',1,'OriginPosition',[0 0 0]);
```

Create a platform structure.

```
platfm = struct('PlatformID',2,'Position',[10 0 0],'Signatures',tsSignature());
```

Reflect the emission from the platform.

```
sigs = underwaterChannel(sonarSig,platfm)
```

```
sigs =

  2x1 sonarEmission array with properties:
```

```
        SourceLevel
        TargetStrength
        PlatformID
        EmitterIndex
        OriginPosition
        OriginVelocity
        Orientation
        FieldOfView
        CenterFrequency
        Bandwidth
        WaveformType
        ProcessingGain
        PropagationRange
        PropagationRangeRate
```

Reflect Sonar Emission from Platform within Tracking Scenario

Reflect a sonar emission from a platform defined within a trackingScenario.

Create a tracking scenario object.

```
scenario = trackingScenario;
```

Create an sonarEmitter.

```
emitter = sonarEmitter(1);
```

Mount the emitter on a platform within the scenario.

```
plat = platform(scenario,'Emitters',emitter);
```

Add another platform to reflect the emitted signal.

```
tgt = platform(scenario);
tgt.Trajectory.Position = [30 0 0];
```

Emit the signal using the emit object function of a platform.

```
txSigs = emit(plat, scenario.SimulationTime)
```

```
txSigs =
```

```
    sonarEmission with properties:

              SourceLevel: 140
           TargetStrength: 0
               PlatformID: 1
             EmitterIndex: 1
           OriginPosition: [0 0 0]
           OriginVelocity: [0 0 0]
              Orientation: [1×1 quaternion]
              FieldOfView: [1 5]
          CenterFrequency: 20000
                Bandwidth: 2000
             WaveformType: 0
            ProcessingGain: 0
        PropagationRange: 0
    PropagationRangeRate: 0
```

Reflect the signal from the platforms in the scenario.

```
sigs = underwaterChannel(txSigs, scenario.Platforms)
```

```
sigs =

  sonarEmission with properties:

              SourceLevel: 140
           TargetStrength: 0
               PlatformID: 1
             EmitterIndex: 1
           OriginPosition: [0 0 0]
           OriginVelocity: [0 0 0]
              Orientation: [1×1 quaternion]
              FieldOfView: [1 5]
          CenterFrequency: 20000
                Bandwidth: 2000
             WaveformType: 0
            ProcessingGain: 0
        PropagationRange: 0
```

```
    PropagationRangeRate: 0
```

Input Arguments

sonarsigin — Input sonar signals
array of `sonarEmission` objects

Input sonar signals, specified as an array of `sonarEmission` objects.

platforms — Reflector platform
cell array of `Platform` objects | array of `Platform` structures

Reflector platforms, specified as a cell array of `Platform` objects, `Platform`, or an array of `Platform` structures:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field which has no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in scenario coordinates, specified as a real-valued 1-by-3 vector. This is a required field. There is no default value. Units are in meters.
Velocity	Velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default is [0 0 0].

Field	Description
Speed	Speed of the platform in the scenario frame specified as a real scalar. When speed is specified, the platform velocity is aligned with its orientation. Specify either the platform speed or velocity, but not both. Units are in meters per second The default is 0.
Acceleration	Acceleration of the platform in scenario coordinates specified as a 1-by-3 row vector in meters per second-squared. The default is [0 0 0].
Orientation	Orientation of the platform with respect to the local scenario NED coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the local NED coordinate system to the current platform body coordinate system. Units are dimensionless. The default is quaternion(1,0,0,0).
AngularVelocity	Angular velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is [0 0 0].
Signatures	Cell array of signatures defining the visibility of the platform to emitters and sensors in the scenario. The default is the cell array {rcsSignature,irSignature, tsSignature}

If you specify an array of platform structures, set a unique PlatformID for each platform and set the Position field for each platform. Any other fields not specified are assigned default values.

Output Arguments

sonarsigout — Reflected sonar signals
array of `sonarEmission` objects

Reflected sonar signals, specified as an array of `sonarEmission` objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`sonarEmission` | `sonarEmitter` | `sonarSensor`

Introduced in R2018b

clearData

Clear data from specific plotter of theater plot

Syntax

```
clearData(pl)
```

Description

`clearData(pl)` clears data belonging to the plotter `pl` associated with a theater plot. This function clears data from plotters created by the following plotter methods:
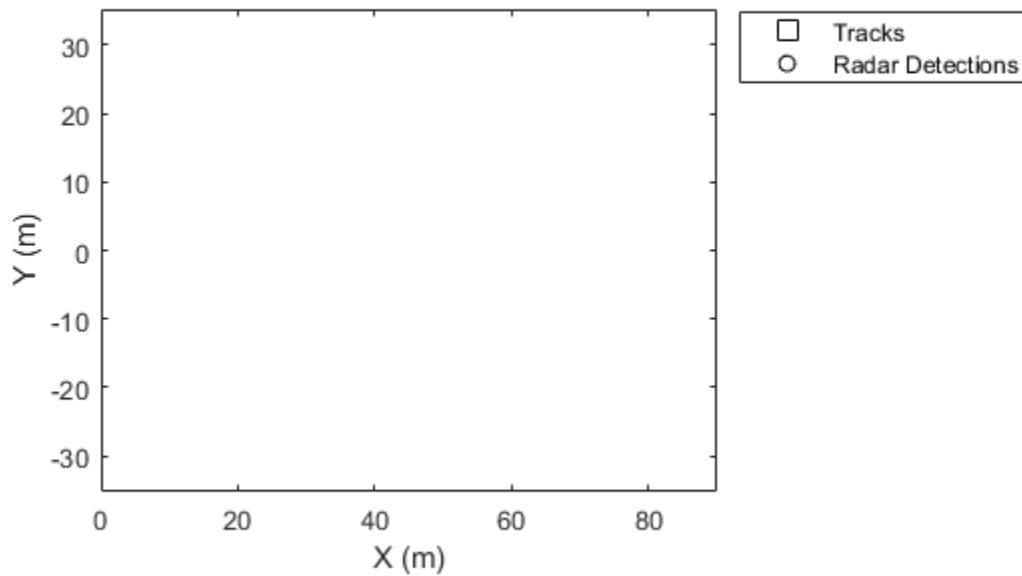
- `detectionPlotter`
- `orientationPlotter`
- `platformPlotter`
- `trackPlotter`
- `trajectoryPlotter`

Examples

Clear Specific Plotter Data

Create a theater plot. Add a track plotter and detection plotter to the theater plot.

```
tp = theaterPlot('XLim',[0,90],'YLim',[-35,35]);
tPlotter = trackPlotter(tp,'DisplayName','Tracks');
radarPlotter = detectionPlotter(tp,'DisplayName','Radar Detections');
```
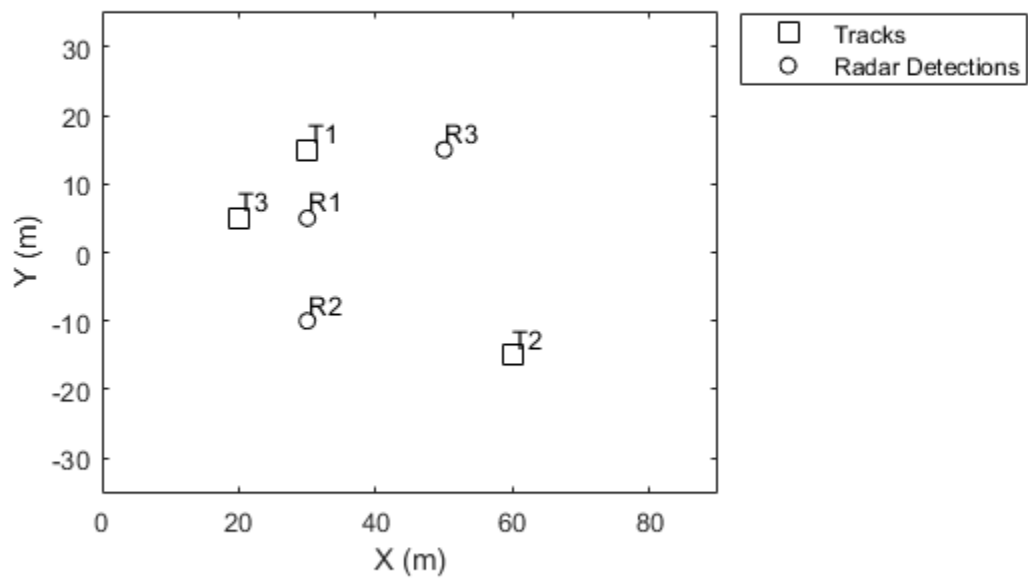
Plot a set of tracks in the track plotter.

```
trackPos = [30, 15, 1; 60, -15, 1; 20, 5, 1];
trackLabels = {'T1','T2','T3'};
plotTrack(tPlotter, trackPos, trackLabels)
```
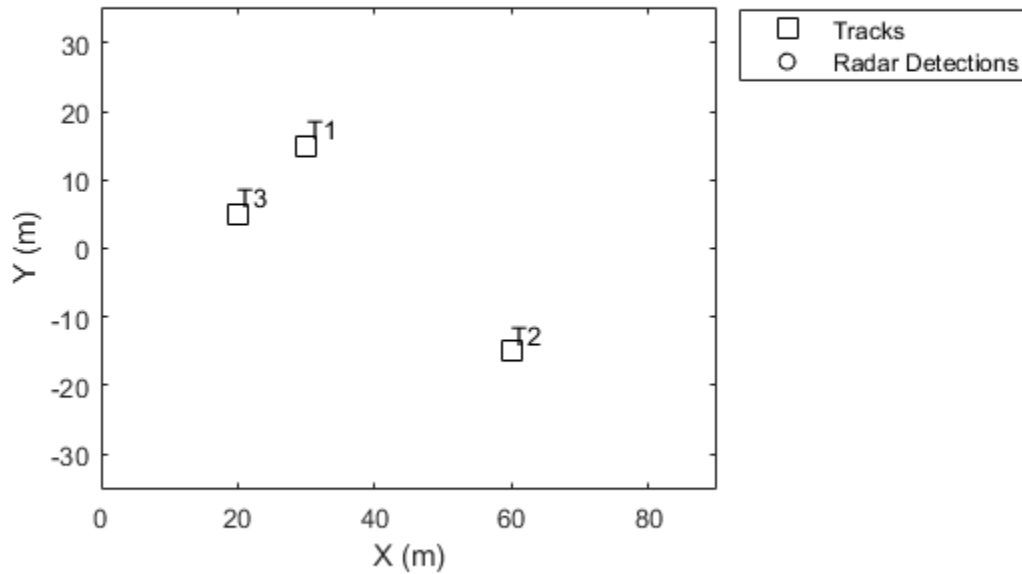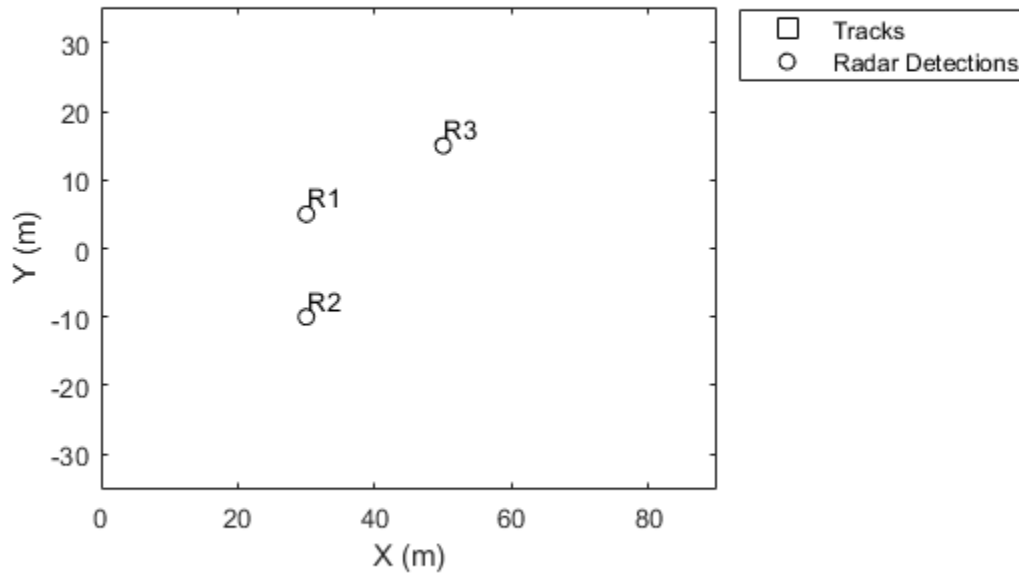
Plot a set of detections in the detection plotter.

```
detPos = [30, 5, 4; 30, -10, 2; 50, 15, 1];
detLabels = {'R1','R2','R3'};
plotDetection(radarPlotter, detPos, detLabels)
```

Delete the track plotter data.

```
clearData(tPlotter)
```

Input Arguments

pl — Specific plotter belonging to theater plot
specific plotter of theater plot `handle`

Specific plotter belonging to a theater plot, specified as a plotter handle of `theaterPlot`.

See Also

`clearPlotterData` | `findPlotter` | `theaterPlot`

Introduced in R2018b

emissionsInBody

Transform emissions to body frame of platform

Syntax

```
embody = emissionsInBody(emscene,bodyframe)
```

Description

`embody = emissionsInBody(emscene,bodyframe)` converts emissions, `emscene`, referenced to scenario coordinates into emissions, `embody`, referenced to platform body coordinates. `bodyframe` specifies the position,velocity, and orientation of the platform body.

Examples

Convert Radar Emission to Body Frame

Convert a radar emission from scenario coordinates to body frame.

Define a radar emission with respect to the scenario frame.

```
emScene = radarEmission('PlatformID',1,'EmitterIndex',1, ...
    'OriginPosition',[0 0 0])
```

```
emScene =

  radarEmission with properties:

                EIRP: 0
                 RCS: 0
          PlatformID: 1
        EmitterIndex: 1
      OriginPosition: [0 0 0]
```

```
         OriginVelocity: [0 0 0]
            Orientation: [1×1 quaternion]
            FieldOfView: [180 180]
        CenterFrequency: 300000000
              Bandwidth: 3000000
           WaveformType: 0
          ProcessingGain: 0
       PropagationRange: 0
   PropagationRangeRate: 0
```

Define the position, velocity, and orientation, of the body relative to the scenario frame.

```
bodyFrame = struct( ...
    'Position',[10 0 0], ...
    'Velocity',[5 5 0], ...
    'Orientation',quaternion([45 0 0],'eulerd','zyx','frame'));
```

Convert the emission into the body frame.

```
emBody = emissionsInBody(emScene,bodyFrame)
```

```
emBody =

  radarEmission with properties:

                   EIRP: 0
                    RCS: 0
             PlatformID: 1
           EmitterIndex: 1
         OriginPosition: [-7.0711 7.0711 0]
         OriginVelocity: [-7.0711 4.4409e-16 0]
            Orientation: [1×1 quaternion]
            FieldOfView: [180 180]
        CenterFrequency: 300000000
              Bandwidth: 3000000
           WaveformType: 0
          ProcessingGain: 0
       PropagationRange: 0
   PropagationRangeRate: 0
```

Convert Sonar Emission into Body Frame

Convert a sonar emission from scenario coordinates into body coordinates. Use `trackingScenario` to defined the motion of the body and use `sonarEmitter` to create the emission.

Set up a tracking scenario.

```
scene = trackingScenario;
```

Create a sonar emitter to mount on a platform.

```
emitter = sonarEmitter(1,'No scanning');
```

Mount the emitter on a platform in the scenario 100 meters below sea-level.

```
platTx = platform(scene,'Emitters',emitter);
platTx.Trajectory.Position = [10 0 100];
```

Create another platform in the scenario.

```
platRx = platform(scene);
platRx.Trajectory.Position = [100 0 100];
platRx.Trajectory.Orientation = quaternion([45 0 0],'eulerd', ...
    'zyx','frame');
```

Emit a signal. The emitted signal is in the scenario frame.

```
emScene = emit(platTx,scene.SimulationTime)
```

```
emScene =

  1×1 cell array

    {1×1 sonarEmission}
```

Propagate the emission through an underwater channel.

```
emPropScene = underwaterChannel(emScene,scene.Platforms)
```

```
emPropScene =
```

```
2×1 cell array

  {1×1 sonarEmission}
  {1×1 sonarEmission}
```

Convert the emission to the body frame of the second platform.

```
emBodyRx = emissionsInBody(emPropScene, platRx);
disp(emBodyRx(1))

  [1×1 sonarEmission]
```

Input Arguments

emscene — Emissions in scenario coordinates
emission object

Emissions in scenario coordinates, specified as a cell array of `radarEmission` or `sonarEmission` emission objects.

bodyframe — Body frame
structure | `Platform` object

Body frame, specified as a structure or `Platform` object. You can use a `Platform` object because it contains the necessary information. The body frame structure must contain at least these fields:

Field	Description
Position	Position of body in scenario coordinates, specified as a real-valued 1-by-3 vector. This field is required. There is no default value. Units are in meters.
Velocity	Velocity of body in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default is [0 0 0].

Field	Description
Orientation	Orientation of body with respect to the scenario coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the scenario coordinate system to the body coordinate system. Units are dimensionless. The default is `quaternion(1,0,0,0)` or, equivalently, `eye(3)`.

Because the fields in the body frame structure are a subset of the fields in a platform structure, you can use the platform structure output from the `platformPoses` method of `trackingScenario` as the input `bodyframe`.

Output Arguments

embody — Emissions in body coordinates
emission object

Emissions in body coordinates, returned as a cell array of `radarEmission` and `sonarEmission` emission objects.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
radarChannel | underwaterChannel

Objects
Platform | radarEmission | sonarEmission | trackingScenario

System Objects
radarEmitter | sonarEmitter

Introduced in R2018b

Classes in Sensor Fusion and Tracking Toolbox

correct

Correct states using direct state measurements

Syntax

```
correct(FUSE,idx,measurement,measurementCovariance)
```

Description

`correct(FUSE,idx,measurement,measurementCovariance)` corrects the state and state estimation error covariance based on the measurement and measurement covariance. The measurement maps directly to the state specified by the indices `idx`.

Input Arguments

FUSE — `MARGGPSFuser` object
object

Object of `MARGGPSFuser`, created by the `insfilter` function.

`idx` — State vector Index of measurement to correct
N-element vector of increasing integers in the range [1,22]

State vector index of measurement to correct, specified as an *N*-element vector of increasing integers in the range [1, 22].

The state values represent:

State	Units	Index
Orientation (quaternion parts)		1:4
Position (NED)	m	5:7
Velocity (NED)	m/s	8:10

State	Units	Index
Delta Angle Bias (XYZ)	rad/s	11:13
Delta Velocity Bias (XYZ)	m/s	14:16
Geomagnetic Field Vector (NED)	µT	17:19
Magnetometer Bias (XYZ)	µT	20:22

Data Types: `single` | `double`

measurement — Direct measurement of state
N-element vector

Direct measurement of state, specified as a *N*-element vector. *N* is the number of elements of the index argument, idx.

Data Types: `single` | `double`

measurementCovariance — Covariance of measurement
scalar | *N*-element vector | *N*-by-*N* matrix

Covariance of measurement, specified as a scalar, *N*-element vector, or *N*-by-*N* matrix. *N* is the number of elements of the index argument, idx.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`MARGGPSFuser` | `insfilter`

Introduced in R2018b

fusegps

Correct states using GPS data

Syntax

```
fusegps(FUSE,position,positionCovariance,velocity,
velocityCovariance)
```

Description

`fusegps(FUSE,position,positionCovariance,velocity,` `velocityCovariance)` fuses GPS data to correct the state estimate.

Input Arguments

FUSE — `MARGGPSFuser` object
object

Object of `MARGGPSFuser`, created by the `insfilter` function.

`position` — Position of GPS receiver (LLA)
3-element row vector

Position of GPS receiver in geodetic latitude, longitude, and altitude (LLA) specified as a real finite 3-element row vector. Latitude and longitude are in degrees with north and east being positive. Altitude is in meters.

Data Types: `single` | `double`

`positionCovariance` — Position measurement covariance of GPS receiver (m²)
3-by-3 matrix

Position measurement covariance of GPS receiver in m², specified as a 3-by-3 matrix.

Data Types: `single` | `double`

velocity — Velocity of GPS receiver in local NED coordinate system (m/s)
3-element row vector

Velocity of the GPS receiver in the local NED coordinate system in m/s, specified as a 3-element row vector.

Data Types: `single` | `double`

velocityCovariance — Velocity measurement covariance of GPS receiver (m/s^2)
3-by-3 matrix

Velocity measurement covariance of the GPS receiver in the local NED coordinate system in m/s^2, specified as a 3-by-3 matrix.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`MARGGPSFuser` | `insfilter`

Introduced in R2018b

fusemag

Correct states using magnetometer data

Syntax

```
fusemag(FUSE,magReadings,magReadingsCovariance)
```

Description

`fusemag(FUSE,magReadings,magReadingsCovariance)` fuses magnetometer data to correct the state estimate.

Input Arguments

FUSE — MARGGPSFuser object
object

Object of `MARGGPSFuser`, created by the `insfilter` function.

magReadings — Magnetometer readings (µT)
3-element row vector

Magnetometer readings in µT, specified as a 3-element row vector of finite real numbers.

Data Types: `single` | `double`

magReadingsCovariance — Magnetometer readings error covariance (µT^2)
scalar | 3-element row vector | 3-by-3 matrix

Magnetometer readings error covariance in µT^2, specified as a scalar, 3-element row vector, or 3-by-3 matrix.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
MARGGPSFuser | insfilter

Introduced in R2018b

pose

Current orientation and position estimate

Syntax

```
[orientation, position] = pose(FUSE)
[orientation, position] = pose(FUSE,format)
```

Description

`[orientation, position] = pose(FUSE)` returns the current estimate of the pose.

`[orientation, position] = pose(FUSE,format)` returns the current estimate of the pose with orientation in the specified orientation format.

Input Arguments

FUSE — MARGGPSFuser object
object

Object of MARGGPSFuser, created by the `insfilter` function.

format — Output orientation format
'quaternion' (default) | 'rotmat'

Output orientation format, specified as either `'quaternion'` for a `quaternion` or `'rotmat'` for a rotation matrix.

Data Types: `char` | `string`

Output Arguments

orientation — Orientation estimate in the local NED coordinate system
quaternion (default) | 3-by-3 rotation matrix

Orientation estimate in the local NED coordinate system, specified as a scalar quaternion or 3-by-3 rotation matrix. The quaternion or rotation matrix represents a frame rotation from the local NED reference frame to the body reference frame.

Data Types: `single` | `double` | `quaternion`

position — Position estimate in the local NED coordinate system (m)
3-element row vector

Position estimate in the local NED coordinate system in meters, returned as a 3-element row vector.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
MARGGPSFuser | insfilter

Introduced in R2018b

predict

Update states using accelerometer and gyroscope data

Syntax

```
predict(FUSE,accelReadings,gyroReadings)
```

Description

`predict(FUSE,accelReadings,gyroReadings)` fuses accelerometer and gyroscope data to update the state estimate.

Input Arguments

FUSE — MARGGPSFuser object
object

Object of `MARGGPSFuser`, created by the `insfilter` function.

accelReadings — Accelerometer readings in local sensor body coordinate system (m/s^2)
3-element row vector

Accelerometer readings in m/s^2, specified as a 3-element row vector.

Data Types: `single` | `double`

gyroReadings — Gyroscope readings in local sensor body coordinate system (rad/s)
3-element row vector

Gyroscope readings in rad/s, specified as a 3-element row vector.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
MARGGPSFuser | insfilter

Introduced in R2018b

reset

Reset internal states

Syntax

```
reset(FUSE)
```

Description

`reset(FUSE)` resets the State, StateCovariance, and internal integrators to their default values.

Input Arguments

FUSE — MARGGPSFuser object
object

Object of `MARGGPSFuser`, created by the `insfilter` function.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
MARGGPSFuser | `insfilter`

Introduced in R2018b

stateinfo

Display state vector information

Syntax

```
stateinfo(FUSE)
```

Description

`stateinfo(FUSE)` displays the meaning of each index of the State property and the associated units.

Input Arguments

FUSE — MARGGPSFuser object
object

Object of `MARGGPSFuser`, created by the `insfilter` function.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`MARGGPSFuser` | `insfilter`

Introduced in R2018b

MARGGPSFuser

Estimate pose from MARG and GPS data

Description

The `MARGGPSFuser` object implements sensor fusion of MARG and GPS data to estimate pose in the NED reference frame. MARG (magnetic, angular rate, gravity) data is typically derived from magnetometer, gyroscope, and accelerometer sensors. The filter uses a 22-element state vector to track the orientation quaternion, velocity, position, MARG sensor biases, and geomagnetic vector. The `MARGGPSFuser` object uses an extended Kalman filter to estimate these quantities.

Creation

Create a `MARGGPSFuser` using `insfilter`:

```
filt = insfilter('NonholonomicHeading',false,'Magnetometer',true);
```

Properties

`IMUSampleRate` — Sample rate of the IMU (Hz)
100 (default) | positive scalar

Sample rate of the inertial measurement unit (IMU) in Hz, specified as a positive scalar.

Data Types: `single` | `double`

`ReferenceLocation` — Reference location (deg, deg, meters)
[0 0 0] (default) | 3-element positive row vector

Reference location, specified as a 3-element row vector in geodetic coordinates (latitude, longitude, and altitude). Altitude is the height above the reference ellipsoid model, WGS84. The reference location units are [degrees degrees meters].

Data Types: `single` | `double`

GyroscopeNoise — Multiplicative process noise variance from gyroscope (rad/s)^2

`1e-9` (default) | scalar | 3-element row vector

Multiplicative process noise variance from the gyroscope in (rad/s)^2, specified as a scalar or 3-element row vector of positive real finite numbers.

- If `GyroscopeNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the gyroscope, respectively.

- If `GyroscopeNoise` is specified as a scalar, the single element is applied to the x, y, and z axes of the gyroscope.

Data Types: `single` | `double`

GyroscopeBiasNoise — Multiplicative process noise variance from gyroscope bias (rad/s)^2

`1e-10` (default) | positive scalar | 3-element row vector

Multiplicative process noise variance from the gyroscope bias in (rad/s)^2, specified as a scalar or 3-element row vector of positive real numbers.

- If `GyroscopeBiasNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the gyroscope bias, respectively.

- If `GyroscopeBiasNoise` is specified as a scalar, the single element is applied to each axis.

Data Types: `single` | `double`

AccelerometerNoise — Multiplicative process noise variance from accelerometer (m/s^2)^2

`1e-4` (default) | scalar | 3-element row vector

Multiplicative process noise variance from the accelerometer in (m/s^2)^2, specified as a scalar or 3-element row vector of positive real finite numbers.

- If `AccelerometerNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the accelerometer, respectively.

- If `AccelerometerNoise` is specified as a scalar, the single element is applied to each axis.

Data Types: `single` | `double`

AccelerometerBiasNoise — Multiplicative process noise variance from accelerometer bias (m/s²)²
`1e-4` (default) | positive scalar | 3-element row vector

Multiplicative process noise variance from the accelerometer bias in $(\text{m/s}^2)^2$, specified as a scalar or 3-element row vector of positive real numbers.

- If `AccelerometerBiasNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the accelerometer bias, respectively.
- If `AccelerometerBiasNoise` is specified as a scalar, the single element is applied to each axis.

Data Types: `single` | `double`

GeomagneticVectorNoise — Additive process noise for geomagnetic vector (μT²)
`1e-6` (default) | positive scalar | 3-element row vector

Additive process noise for geomagnetic vector in μT^2, specified as a scalar or 3-element row vector of positive real numbers.

- If `GeomagneticVectorNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the geomagnetic vector, respectively.
- If `GeomagneticVectorNoise` is specified as a scalar, the single element is applied to each axis.

Data Types: `single` | `double`

MagnetometerBiasNoise — Additive process noise for magnetometer bias (μT²)
`0.1` (default) | positive scalar | 3-element row vector

Additive process noise for magnetometer bias in μT^2, specified as a scalar or 3-element row vector.

- If `MagnetometerBiasNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the magnetometer bias, respectively.
- If `MagnetometerBiasNoise` is specified as a scalar, the single element is applied to each axis.

Data Types: `single` | `double`

State — State vector of extended Kalman filter
22-element column vector

State vector of the extended Kalman filter. The state values represent:

State	Units	Index
Orientation (quaternion parts)	N/A	1:4
Position (NED)	m	5:7
Velocity (NED)	m/s	8:10
Delta Angle Bias (XYZ)	rad/s	11:13
Delta Velocity Bias (XYZ)	m/s	14:16
Geomagnetic Field Vector (NED)	µT	17:19
Magnetometer Bias (XYZ)	µT	20:22

Data Types: `single` | `double`

StateCovariance — State error covariance for extended Kalman filter
`eye(22)*1e-6` (default) | 22-by-22 matrix

State error covariance for the extended Kalman filter, specified as a 22-by-22-element matrix, or real numbers.

Data Types: `single` | `double`

Object Functions

correct   Correct states using direct state measurements
fusegps   Correct states using GPS data
fusemag   Correct states using magnetometer data
pose   Current orientation and position estimate
predict   Update states using accelerometer and gyroscope data
reset   Reset internal states
stateinfo   Display state vector information

Examples

Estimate Pose of UAV

This example shows how to estimate the pose of an unmanned aerial vehicle (UAV) from logged sensor data and ground truth pose.

Load the logged sensor data and ground truth pose of an UAV.

```
load uavshort.mat
```

Initialize the `MARGGPSFuser` filter object.

```
f = insfilter;
f.IMUSampleRate = imuFs;
f.ReferenceLocation = refloc;
f.AccelerometerBiasNoise = 2e-4;
f.AccelerometerNoise = 2;
f.GyroscopeBiasNoise = 1e-16;
f.GyroscopeNoise = 1e-5;
f.MagnetometerBiasNoise = 1e-10;
f.GeomagneticVectorNoise = 1e-12;
f.StateCovariance = 1e-9*ones(22);
f.State = initstate;

gpsidx = 1;
N = size(accel,1);
p = zeros(N,3);
q = zeros(N,1,'quaternion');
```

Fuse accelerometer, gyroscope, magnetometer, and GPS data.

```
for ii = 1:size(accel,1)                  % Fuse IMU
    f.predict(accel(ii,:), gyro(ii,:));

    if ~mod(ii,fix(imuFs/2))              % Fuse magnetometer at 1/2 the IMU rate
        f.fusemag(mag(ii,:),Rmag);
    end

    if ~mod(ii,imuFs)                     % Fuse GPS once per second
        f.fusegps(lla(gpsidx,:),Rpos,gpsvel(gpsidx,:),Rvel);
        gpsidx = gpsidx + 1;
    end

    [p(ii,:),q(ii)] = pose(f);            %Log estimated pose
end
```

Calculate and display RMS errors.

```
posErr = truePos - p;
qErr = rad2deg(dist(trueOrient,q));
pRMS = sqrt(mean(posErr.^2));
qRMS = sqrt(mean(qErr.^2));
fprintf('Position RMS Error\n\tX: %.2f, Y: %.2f, Z: %.2f (meters)\n\n',pRMS(1),pRMS(2),
```

```
Position RMS Error
    X: 0.57, Y: 0.53, Z: 0.68 (meters)
```

```
fprintf('Quaternion Distance RMS Error\n\t%.2f (degrees)\n\n',qRMS);
```

```
Quaternion Distance RMS Error
    0.28 (degrees)
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`insfilter`

Topics
"Estimate Position and Orientation of a Ground Vehicle"

Introduced in R2018b

correct

Correct states using direct state measurements

Syntax

```
correct(FUSE,idx,measurement,measurementCovariance)
```

Description

`correct(FUSE,idx,measurement,measurementCovariance)` corrects the state and state estimation error covariance based on the measurement and measurement covariance. The measurement maps directly to the state specified by the indices `idx`.

Input Arguments

FUSE — `NHConstrainedIMUGPSFuser` object
object

Object of `NHConstrainedIMUGPSFuser`, created by the `insfilter` function.

idx — State vector Index of measurement to correct
N-element vector of increasing integers in the range [1,16]

State vector index of measurement to correct, specified as an *N*-element vector of increasing integers in the range [1,16].

The state values represent:

State	Units	Index
Orientation (quaternion parts)		1:4
Gyroscope bias (XYZ)	rad/s	5:7
Position (NED)	m	8:10

State	Units	Index
Velocity (NED)	m/s	11:13
Accelerometer Bias (XYZ)	m/s^2	14:16

Data Types: `single` | `double`

measurement — Direct measurement of state
N-element vector

Direct measurement of state, specified as a *N*-element vector. *N* is the number of elements of the index argument, idx.

Data Types: `single` | `double`

measurementCovariance — Covariance of measurement
scalar | *N*-element vector | *N*-by-*N* matrix

Covariance of measurement, specified as a scalar, *N*-element vector, or *N*-by-*N* matrix. *N* is the number of elements of the index argument, idx.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
NHConstrainedIMUGPSFuser | insfilter

Introduced in R2018b

fusegps

Correct states using GPS data

Syntax

```
fusegps(FUSE,position,positionCovariance,velocity,
velocityCovariance)
```

Description

`fusegps(FUSE,position,positionCovariance,velocity,`
`velocityCovariance)` fuses GPS data to correct the state estimate.

Input Arguments

FUSE — `NHConstrainedIMUGPSFuser` object
object

Object of `NHConstrainedIMUGPSFuser`, created by the `insfilter` function.

`position` — Position of GPS receiver (LLA)
3-element row vector

Position of GPS receiver in geodetic latitude, longitude, and altitude (LLA) specified as a real finite 3-element row vector. Latitude and longitude are in degrees with north and east being positive. Altitude is in meters.

Data Types: `single` | `double`

`positionCovariance` — Position measurement covariance of GPS receiver (m²)
3-by-3 matrix

Position measurement covariance of GPS receiver in m², specified as a 3-by-3 matrix.

Data Types: `single` | `double`

velocity — Velocity of GPS receiver in local NED coordinate system (m/s)
3-element row vector

Velocity of the GPS receiver in the local NED coordinate system in m/s, specified as a 3-element row vector.

Data Types: `single` | `double`

velocityCovariance — Velocity measurement covariance of GPS receiver (m/s^2)
3-by-3 matrix

Velocity measurement covariance of the GPS receiver in the local NED coordinate system in m/s^2, specified as a 3-by-3 matrix.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`NHConstrainedIMUGPSFuser` | `insfilter`

Introduced in R2018b

pose

Current orientation and position estimate

Syntax

```
[orientation, position] = pose(FUSE)
[orientation, position] = pose(FUSE,format)
```

Description

`[orientation, position] = pose(FUSE)` returns the current estimate of the pose.

`[orientation, position] = pose(FUSE,format)` returns the current estimate of the pose with orientation in the specified orientation format.

Input Arguments

FUSE — NHConstrainedIMUGPSFuser object
object

Object of `NHConstrainedIMUGPSFuser`, created by the `insfilter` function.

format — Output orientation format
`'quaternion'` (default) | `'rotmat'`

Output orientation format, specified as either `'quaternion'` for a `quaternion` or `'rotmat'` for a rotation matrix.

Data Types: `char` | `string`

Output Arguments

orientation — Orientation estimate in the local NED coordinate system
quaternion (default) | 3-by-3 rotation matrix

Orientation estimate in the local NED coordinate system, specified as a scalar quaternion or 3-by-3 rotation matrix. The quaternion or rotation matrix represents a frame rotation from the local NED reference frame to the body reference frame.

Data Types: `single` | `double` | `quaternion`

position — Position estimate in the local NED coordinate system (m)
3-element row vector

Position estimate in the local NED coordinate system in meters, returned as a 3-element row vector.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`NHConstrainedIMUGPSFuser` | `insfilter`

Introduced in R2018b

predict

Update states using accelerometer and gyroscope data

Syntax

```
predict(FUSE,accelReadings,gyroReadings)
```

Description

`predict(FUSE,accelReadings,gyroReadings)` fuses accelerometer and gyroscope data to update the state estimate.

Input Arguments

FUSE — `NHConstrainedIMUGPSFuser` object
object

Object of `NHConstrainedIMUGPSFuser`, created by the `insfilter` function.

`accelReadings` — Accelerometer readings in local sensor body coordinate system (m/s^2)
3-element row vector

Accelerometer readings in m/s^2, specified as a 3-element row vector.

Data Types: `single` | `double`

`gyroReadings` — Gyroscope readings in local sensor body coordinate system (rad/s)
3-element row vector

Gyroscope readings in rad/s, specified as a 3-element row vector.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
NHConstrainedIMUGPSFuser | insfilter

Introduced in R2018b

reset

Reset internal states

Syntax

```
reset(FUSE)
```

Description

reset(FUSE) resets the State, StateCovariance, and internal integrators to their default values.

Input Arguments

FUSE — NHConstrainedIMUGPSFuser object
object

Object of NHConstrainedIMUGPSFuser, created by the insfilter function.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
NHConstrainedIMUGPSFuser | insfilter

Introduced in R2018b

stateinfo

Display state vector information

Syntax

```
stateinfo(FUSE)
```

Description

stateinfo(FUSE) displays the meaning of each index of the State property and the associated units.

Input Arguments

FUSE — NHConstrainedIMUGPSFuser object
object

Object of NHConstrainedIMUGPSFuser, created by the insfilter function.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
NHConstrainedIMUGPSFuser | insfilter

Introduced in R2018b

NHConstrainedIMUGPSFuser

Pose estimation with nonholonomic constraints

Description

The `NHConstrainedIMUGPSFuser` object implements sensor fusion of inertial measurement unit (IMU) and GPS data to estimate pose in the NED reference frame. IMU data is derived from gyroscope and accelerometer data. The filter uses a 16-element state vector to track the orientation quaternion, velocity, position, and IMU sensor biases. The `NHConstrainedIMUGPSFuser` object uses an extended Kalman filter to estimate these quantities.

Creation

Create a `NHConstrainedIMUGPSFuser` with nonholonomic constraints using `insfilter`:

```
filt = insfilter('NonholonomicHeading', true, 'Magnetometer', false);
```

Properties

IMUSampleRate — Sample rate of the IMU (Hz)
100 (default) | positive scalar

Sample rate of the IMU in Hz, specified as a positive scalar.

Data Types: `single` | `double`

ReferenceLocation — Reference location (deg, deg, meters)
[0 0 0] (default) | 3-element positive row vector

Reference location, specified as a 3-element row vector in geodetic coordinates (latitude, longitude, and altitude). Altitude is the height above the reference ellipsoid model, WGS84. The reference location units are [degrees degrees meters].

Data Types: `single` | `double`

`DecimationFactor` — Decimation factor for kinematic constraint correction
2 (default) | positive integer scalar

Decimation factor for kinematic constraint correction, specified as a positive integer scalar.

Data Types: `single` | `double`

`GyroscopeNoise` — Multiplicative process noise variance from gyroscope (rad/s)^2
[4.8e-6 4.8e-6 4.8e-6] (default) | scalar | 3-element row vector

Multiplicative process noise variance from the gyroscope in (rad/s)^2, specified as a scalar or 3-element row vector of positive real finite numbers.

- If `GyroscopeNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the gyroscope, respectively.

- If `GyroscopeNoise` is specified as a scalar, the single element is applied to the x, y, and z axes of the gyroscope.

Data Types: `single` | `double`

`GyroscopeBiasNoise` — Multiplicative process noise variance from gyroscope bias (rad/s)^2
[4e-14 4e-14 4e-14] (default) | scalar | 3-element row vector

Multiplicative process noise variance from the gyroscope bias in (rad/s)^2, specified as a scalar or 3-element row vector of positive real finite numbers. Gyroscope bias is modeled as a lowpass filtered white noise process.

- If `GyroscopeBiasNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the gyroscope, respectively.

- If `GyroscopeBiasNoise` is specified as a scalar, the single element is applied to the x, y, and z axes of the gyroscope.

Data Types: `single` | `double`

`GyroscopeBiasDecayFactor` — Decay factor for gyroscope bias
0.999 (default) | scalar in the range [0,1]

Decay factor for gyroscope bias, specified as a scalar in the range [0,1]. A decay factor of 0 models gyroscope bias as a white noise process. A decay factor of 1 models the gyroscope bias as a random walk process.

Data Types: `single` | `double`

AccelerometerNoise — Multiplicative process noise variance from accelerometer (m/s^2)^2

`[4.8e-2 4.8e-2 4.8e-2]` (default) | scalar | 3-element row vector

Multiplicative process noise variance from the accelerometer in (m/s^2)^2, specified as a scalar or 3-element row vector of positive real finite numbers.

- If `AccelerometerNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the accelerometer, respectively.
- If `AccelerometerNoise` is specified as a scalar, the single element is applied to each axis.

Data Types: `single` | `double`

AccelerometerBiasNoise — Multiplicative process noise variance from accelerometer bias (m/s^2)^2

`[4e-14 4e-14 4e-14]` (default) | positive scalar | 3-element row vector

Multiplicative process noise variance from the accelerometer bias in (m/s^2)^2, specified as a scalar or 3-element row vector of positive real numbers. Accelerometer bias is modeled as a lowpass filtered white noise process.

- If `AccelerometerBiasNoise` is specified as a row vector, the elements correspond to the noise in the x, y, and z axes of the accelerometer, respectively.
- If `AccelerometerBiasNoise` is specified as a scalar, the single element is applied to each axis.

AccelerometerBiasDecayFactor — Decay factor for accelerometer bias

`0.9999` (default) | scalar in the range [0,1]

Decay factor for accelerometer bias, specified as a scalar in the range [0,1]. A decay factor of `0` models accelerometer bias as a white noise process. A decay factor of `1` models the accelerometer bias as a random walk process.

Data Types: `single` | `double`

State — State vector of extended Kalman filter

`[1;zeros(15,1)]` | 16-element column vector

State vector of the extended Kalman filter. The state values represent:

State	Units	Index
Orientation (quaternion parts)	N/A	1:4
Gyroscope Bias (XYZ)	rad/s	5:7
Position (NED)	m	8:10
Velocity (NED)	m/s	11:13
Accelerometer Bias (XYZ)	m/s^2	14:16

Data Types: `single` | `double`

StateCovariance — State error covariance for extended Kalman filter
`eye(16)` (default) | 16-by-16 matrix

State error covariance for the extended Kalman filter, specified as a 16-by-16-element matrix, or real numbers.

Data Types: `single` | `double`

ZeroVelocityConstraintNoise — Velocity constraints noise (m/s)²
`1e-2` (default) | nonnegative scalar

Velocity constraints noise in $(m/s)^2$, specified as a nonnegative scalar.

Data Types: `single` | `double`

Object Functions

correct   Correct states using direct state measurements
fusegps   Correct states using GPS data
pose   Current orientation and position estimate
predict   Update states using accelerometer and gyroscope data
reset   Reset internal states
stateinfo   Display state vector information

Examples

Estimate Pose of Ground Vehicle

This example shows how to estimate the pose of a ground vehicle from logged IMU and GPS sensor measurements and ground truth orientation and position.

Load the logged data of a ground vehicle following a circular trajectory.

```
load('loggedGroundVehicleCircle.mat','imuFs','localOrigin','initialState','initialState
      'gyroData','gpsFs','gpsLLA','Rpos','gpsVel','Rvel','trueOrient','truePos');
```

Initialize the `NHConstrainedIMUGPSFuser` filter object.

```
filt = insfilter('NonholonomicHeading',true,'Magnetometer',false);
filt.IMUSampleRate = imuFs;
filt.ReferenceLocation = localOrigin;
filt.State = initialState;
filt.StateCovariance = initialStateCovariance;

imuSamplesPerGPS = imuFs/gpsFs;
```

Log data for final metric computation. Use the `predict` object function to estimate filter state based on accelerometer and gyroscope data. Then correct the filter state according to GPS data.

```
numIMUSamples = size(accelData,1);
estOrient = quaternion.ones(numIMUSamples,1);
estPos = zeros(numIMUSamples,3);

gpsIdx = 1;

for idx = 1:numIMUSamples
    predict(filt,accelData(idx,:),gyroData(idx,:));        %Predict filter state

    if (mod(idx,imuSamplesPerGPS) == 0)                    %Correct filter state
        fusegps(filt,gpsLLA(gpsIdx,:),Rpos,gpsVel(gpsIdx,:),Rvel);
        gpsIdx = gpsIdx + 1;
    end

    [estPos(idx,:),estOrient(idx,:)] = pose(filt);         %Log estimated pose
end
```

Calculate and display RMS errors.

```
posd = estPos - truePos;
quatd = rad2deg(dist(estOrient,trueOrient));
```

```
msep = sqrt(mean(posd.^2));
```

```
fprintf('Position RMS Error\n\tX: %.2f, Y: %.2f, Z: %.2f (meters)\n\n',msep(1),msep(2),
```

```
Position RMS Error
    X: 0.15, Y: 0.11, Z: 0.01 (meters)
```

```
fprintf('Quaternion Distance RMS Error\n\t%.2f (degrees)\n\n',sqrt(mean(quatd.^2)));
```

```
Quaternion Distance RMS Error
    0.26 (degrees)
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
insfilter

Topics
"Estimate Position and Orientation of a Ground Vehicle"

Introduced in R2018b

accelparams class

Accelerometer sensor parameters

Description

The `accelparams` class creates an accelerometer sensor parameters object. You can use this object to model an accelerometer when simulating an IMU with `imuSensor`.

Construction

`params = accelparams` returns an ideal accelerometer sensor parameters object with default values.

`params = accelparams(Name,Value)` configures an accelerometer sensor parameters object properties using 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`). Any unspecified properties take default values.

Properties

MeasurementRange — Maximum sensor reading (m/s^2)
`inf` (default) | real positive scalar

Maximum sensor reading in m/s^2, specified as a real positive scalar.

Data Types: `single` | `double`

Resolution — Resolution of sensor measurements ((m/s^2)/LSB)
`0` (default) | real nonnegative scalar

Resolution of sensor measurements in (m/s^2)/LSB, specified as a real nonnegative scalar.

Data Types: `single` | `double`

ConstantBias — Constant sensor offset bias (m/s^2)
[0 0 0] (default) | real scalar | real 3-element row vector

Constant sensor offset bias in m/s^2, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

AxesMisalignment — Sensor axes skew (%)
[0 0 0] (default) | real scalar in the range [0,100] | real 3-element row vector in the range [0,100]

Sensor axes skew in %, specified as a real scalar or 3-element row vector with values ranging from 0 to 100. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

NoiseDensity — Power spectral density of sensor noise (m/s^2/√Hz)
[0 0 0] (default) | real scalar | real 3-element row vector

Power spectral density of sensor noise in (m/s^2/√Hz), specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

BiasInstability — Instability of the bias offset (m/s^2)
[0 0 0] (default) | real scalar | real 3-element row vector

Instability of the bias offset in m/s^2, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

RandomWalk — Integrated white noise of sensor ((m/s^2)(√Hz))
[0 0 0] (default) | real scalar | real 3-element row vector

Integrated white noise of sensor in (m/s^2)(√Hz), specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

TemperatureBias — Sensor bias from temperature ((m/s²)/°C)
[0 0 0] (default) | real scalar | real 3-element row vector

Sensor bias from temperature in (m/s^2)/°C, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

TemperatureScaleFactor — Scale factor error from temperature (%/°C)
[0 0 0] (default) | real scalar in the range [0,100] | real 3-element row vector in the range [0,100]

Scale factor error from temperature in %/°C, specified as a real scalar or real 3-element row vector with values ranging from 0 to 100. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

Examples

Generate Accelerometer Data from Stationary Inputs

Generate accelerometer data for an imuSensor object from stationary inputs.

Generate an accelerometer parameter object with a maximum sensor reading of 19.6 m/s^2 and a resolution of 0.598 $(mm/s^2)/LSB$. The constant offset bias is 0.49 m/s^2. The sensor has a power spectral density of 3920 $(\mu m/s^2)/\sqrt{Hz}$. The bias from temperature is 0.294 $(m/s^2)/^0C$. The scale factor error from temperature is 0.02% $/^0C$. The sensor axes are skewed by 2%.

```
params = accelparams('MeasurementRange',19.6,'Resolution',0.598e-3,'ConstantBias',0.49,
```

Use a sample rate of 100 Hz spaced out over 1000 samples. Create the imuSensor object using the accelerometer parameter object.

```
Fs = 100;
numSamples = 1000;
```

```
t = 0:1/Fs:(numSamples-1)/Fs;

imu = imuSensor('SampleRate', Fs, 'Accelerometer', params);
```

Generate accelerometer data from the imuSensor object.

```
orient = quaternion.ones(numSamples, 1);
acc = zeros(numSamples, 3);
angvel = zeros(numSamples, 3);

accelData = imu(acc, angvel, orient);
```
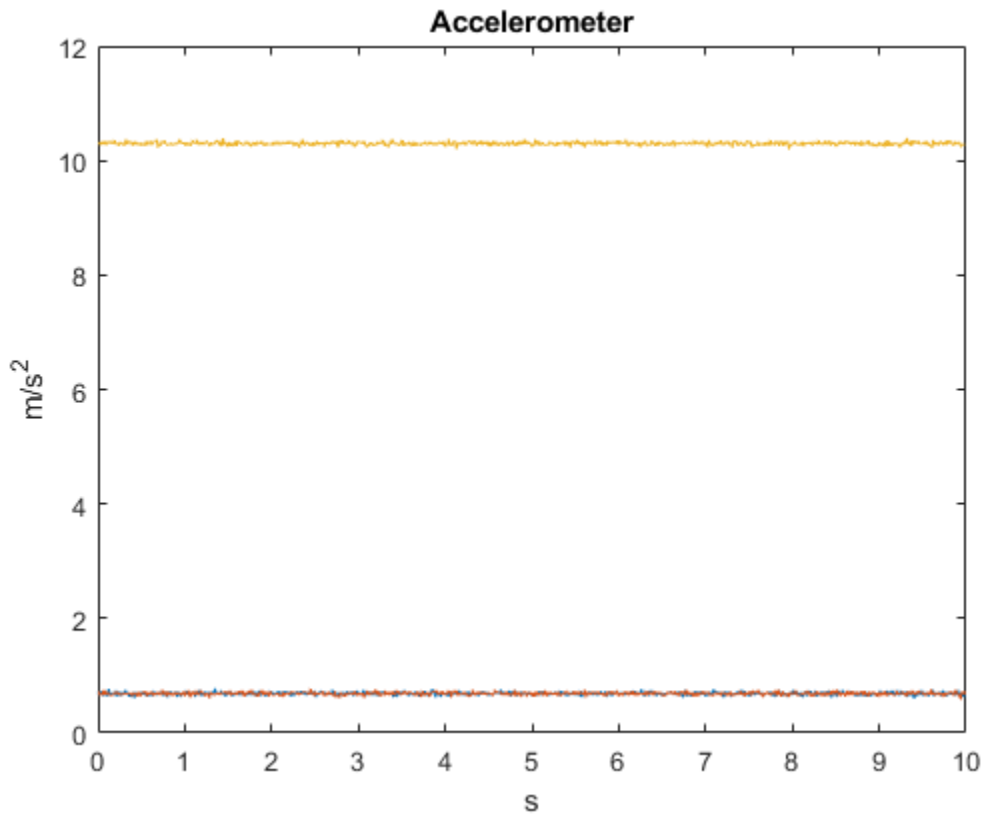
Plot the resultant accelerometer data.

```
plot(t, accelData)
title('Accelerometer')
xlabel('s')
ylabel('m/s^2')
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

System Objects
imuSensor

Classes
gyroparams | magparams

Topics
"Model IMU, GPS, and INS/GPS"

Introduced in R2018b

gyroparams class

Gyroscope sensor parameters

Description

The `gyroparams` class creates a gyroscope sensor parameters object. You can use this object to model a gyroscope when simulating an IMU with `imuSensor`.

Construction

`params = gyroparams` returns an ideal gyroscope sensor parameters object with default values.

`params = gyroparams(Name,Value)` configures `gyroparams` object properties using 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`. Any unspecified properties take default values.

Properties

MeasurementRange — Maximum sensor reading (rad/s)
Inf (default) | real positive scalar

Maximum sensor reading in rad/s, specified as a real positive scalar.

Data Types: `single` | `double`

Resolution — Resolution of sensor measurements ((rad/s)/LSB)
0 (default) | real nonnegative scalar

Resolution of sensor measurements in (rad/s)/LSB, specified as a real nonnegative scalar

Data Types: `single` | `double`

ConstantBias — Constant sensor offset bias (rad/s)
[0 0 0] (default) | real scalar | real 3-element row vector

Constant sensor offset bias in rad/s, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

AxesMisalignment — Sensor axes skew (%)
[0 0 0] (default) | real scalar in the range [0,100] | real 3-element row vector in the range [0,100]

Sensor axes skew in %, specified as a real scalar or 3-element row vector with values ranging from 0 to 100. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

NoiseDensity — Power spectral density of sensor noise ((rad/s)/√Hz)
[0 0 0] (default) | real scalar | real 3-element row vector

Power spectral density of sensor noise in (rad/s)/√Hz, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

BiasInstability — Instability of the bias offset (rad/s)
[0 0 0] (default) | real scalar | real 3-element row vector

Instability of the bias offset in rad/s, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

RandomWalk — Integrated white noise of sensor ((rad/s)(√Hz))
[0 0 0] (default) | real scalar | real 3-element row vector

Integrated white noise of sensor in (rad/s)(√Hz), specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: `single` | `double`

TemperatureBias — Sensor bias from temperature ((rad/s)/°C)
[0 0 0] (default) | real scalar | real 3-element row vector

Sensor bias from temperature in ((rad/s)/°C), specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: `single` | `double`

TemperatureScaleFactor — Scale factor error from temperature (%/°C)
[0 0 0] (default) | real scalar in the range [0,100] | real 3-element row vector in the range [0,100]

Scale factor error from temperature in (%/°C), specified as a real scalar or 3-element row vector with values ranging from 0 to 100. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: `single` | `double`

AccelerationBias — Sensor bias from linear acceleration (rad/s)/(m/s²)
[0 0 0] (default) | real scalar | real 3-element row vector

Sensor bias from linear acceleration in (rad/s)/(m/s²), specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: `single` | `double`

Examples

Generate Gyroscope Data from Stationary Inputs

Generate gyroscope data for an imuSensor object from stationary inputs.

Generate a gyroscope parameter object with a maximum sensor reading of 4.363 $\mathrm{rad/s}$ and a resolution of 1.332e-4 $\mathrm{(rad/s)/LSB}$. The constant offset bias is 0.349 $\mathrm{rad/s}$. The sensor has a power spectral density of 8.727e-4 $\mathrm{rad/s/\sqrt{Hz}}$. The bias from temperature is 0.349 $\mathrm{(rad/s^2)/^0C}$. The scale factor error from temperature is 0.2% $/^0C$. The sensor

axes are skewed by 2%. The sensor bias from linear acceleration is 0.178e-3
$(\text{rad}/\text{s})/(\text{m}/\text{s}^2)$

```
params = gyroparams('MeasurementRange',4.363,'Resolution',1.332e-04,'ConstantBias',0.34
```

Use a sample rate of 100 Hz spaced out over 1000 samples. Create the imuSensor object
using the gyroscope parameter object.

```
Fs = 100;
numSamples = 1000;
t = 0:1/Fs:(numSamples-1)/Fs;

imu = imuSensor('accel-gyro','SampleRate', Fs, 'Gyroscope', params);
```
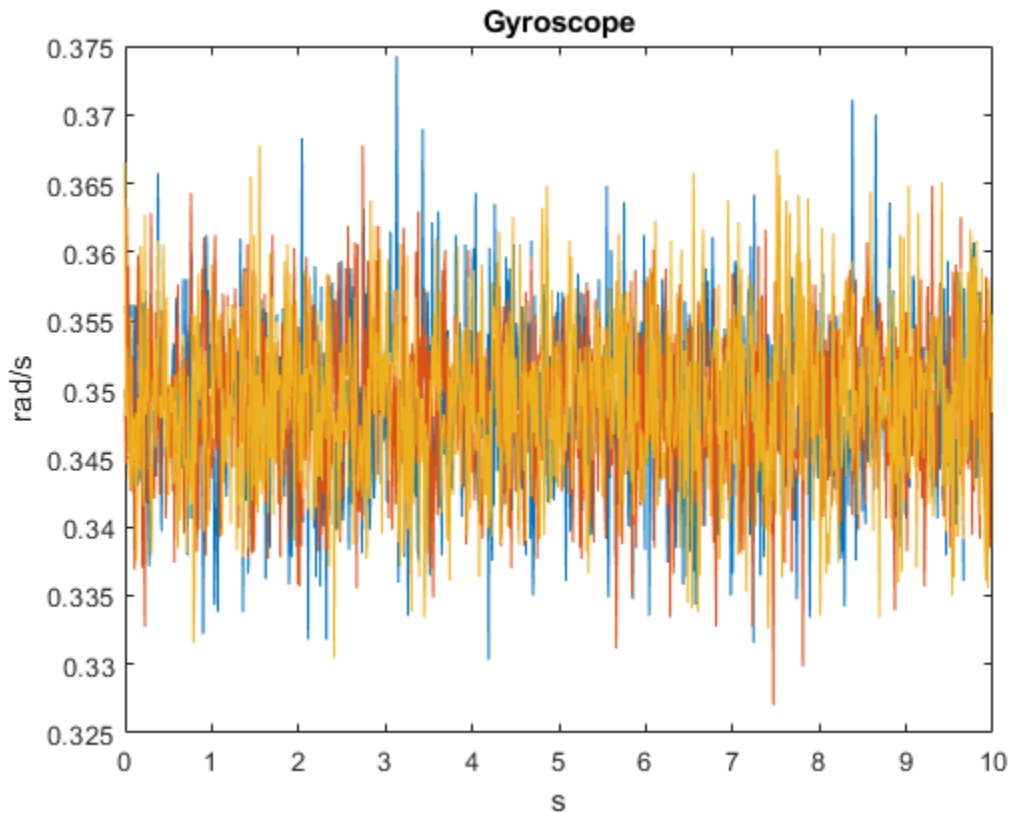
Generate gyroscope data from the imuSensor object.

```
orient = quaternion.ones(numSamples, 1);
acc = zeros(numSamples, 3);
angvel = zeros(numSamples, 3);

[~, gyroData] = imu(acc, angvel, orient);
```

Plot the resultant gyroscope data.

```
plot(t, gyroData)
title('Gyroscope')
xlabel('s')
ylabel('rad/s')
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
`accelparams` | `magparams`

System Objects
`imuSensor`

Topics
"Model IMU, GPS, and INS/GPS"

Introduced in R2018b

magparams class

Magnetometer sensor parameters

Description

The `magparams` class creates a magnetometer sensor parameters object. You can use this object to model a magnetometer when simulating an IMU with `imuSensor`.

Construction

`params = magarams` returns an ideal magnetometer sensor parameters object with default values.

`params = magparams(Name,Value)` configures `magparams` object properties using 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`. Any unspecified properties take default values.

Properties

MeasurementRange — Maximum sensor reading (µT)
`Inf` (default) | real positive scalar

Maximum sensor reading in µT, specified as a real positive scalar.

Data Types: `single` | `double`

Resolution — Resolution of sensor measurements (µT/LSB)
`0` (default) | real nonnegative scalar

Resolution of sensor measurements in µT/LSB, specified as a real nonnegative scalar

Data Types: `single` | `double`

ConstantBias — Constant sensor offset bias (µT)
[0 0 0] (default) | real scalar | real 3-element row vector

Constant sensor offset bias in µT, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

AxesMisalignment — Sensor axes skew (%)
[0 0 0] (default) | real scalar in the range [0,100] | real 3-element row vector in the range [0,100]

Sensor axes skew in %, specified as a real scalar or 3-element row vector with values ranging from 0 to 100. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

NoiseDensity — Power spectral density of sensor noise (µT/√Hz)
[0 0 0] (default) | real scalar | real 3-element row vector

Power spectral density of sensor noise in µT/√Hz, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

BiasInstability — Instability of the bias offset (µT)
[0 0 0] (default) | real scalar | real 3-element row vector

Instability of the bias offset in µT, specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: single | double

RandomWalk — Integrated white noise of sensor (µT/√Hz)
[0 0 0] (default) | real scalar | real 3-element row vector

Integrated white noise of sensor in (µT/√Hz), specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: `single` | `double`

TemperatureBias — Sensor bias from temperature (µT/°C)
[0 0 0] (default) | real scalar | real 3-element row vector

Sensor bias from temperature in (µT/°C), specified as a real scalar or 3-element row vector. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: `single` | `double`

TemperatureScaleFactor — Scale factor error from temperature (%/°C)
[0 0 0] (default) | real scalar in the range [0,100] | real 3-element row vector in the range [0,100]

Scale factor error from temperature in (%/°C), specified as a real scalar or 3-element row vector with values ranging from 0 to 100. Any scalar input is converted into a real 3-element row vector where each element has the input scalar value.

Data Types: `single` | `double`

Examples

Generate Magnetometer Data from Stationary Inputs

Generate magnetometer data for an imuSensor object from stationary inputs.

Generate a magnetometer parameter object with a maximum sensor reading of 1200 μT and a resolution of 0.1 $\mu T/LSB$. The constant offset bias is 1 μT. The sensor has a power spectral density of $\left(\dfrac{[0.6\ 0.6\ 0.9]}{\sqrt{100}} \right)\ \mu T/\sqrt{Hz}$. The bias from temperature is [0.8 0.8 2.4] $\mu T/^{0}C$. The scale factor error from temperature is 0.1 %$/^{0}C$.

```
params = magparams('MeasurementRange',1200,'Resolution',0.1,'ConstantBias',1,'NoiseDens
```

Use a sample rate of 100 Hz spaced out over 1000 samples. Create the imuSensor object using the magnetometer parameter object.

```
Fs = 100;
numSamples = 1000;
```

```
t = 0:1/Fs:(numSamples-1)/Fs;

imu = imuSensor('accel-mag','SampleRate', Fs, 'Magnetometer', params);
```

Generate magnetometer data from the imuSensor object.

```
orient = quaternion.ones(numSamples, 1);
acc = zeros(numSamples, 3);
angvel = zeros(numSamples, 3);

[~, magData] = imu(acc, angvel, orient);
```
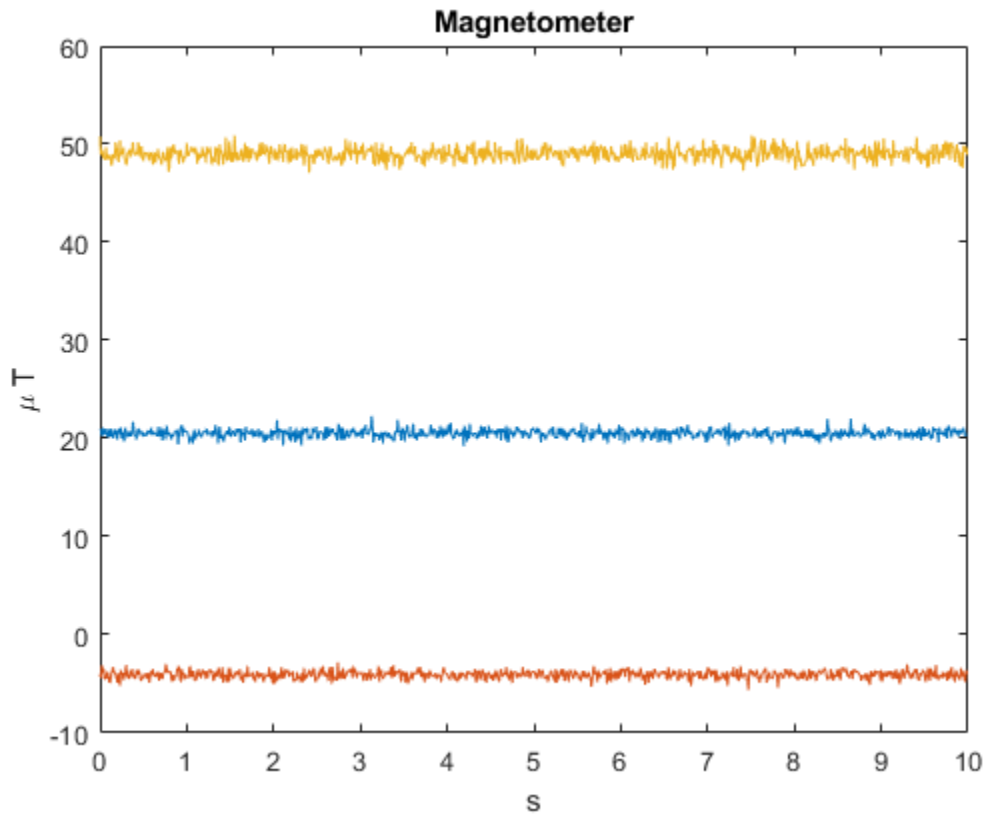
Plot the resultant magnetometer data.

```
plot(t, magData)
title('Magnetometer')
xlabel('s')
ylabel('\mu T')
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
`accelparams` | `gyroparams`

System Objects
`imuSensor`

Topics
"Model IMU, GPS, and INS/GPS"

Introduced in R2018b

objectDetection class

Create object detection report

Description

The `objectDetection` class creates and reports detections of objects in a tracking scenario. Each report contains information obtained by a sensor for a single object. You can use the `objectDetection` output as the input to trackers such as `trackerGNN` or `trackerTOMHT`.

Construction

`detection = objectDetection(time,measurement)` creates an object `detection` at the specified `time` from the specified `measurement`.

`detection = objectDetection( ___ ,Name,Value)` creates a `detection` object with properties specified as one or more `Name,Value` pair arguments. Any unspecified properties have default values. You cannot specify the Time or Measurement properties using `Name,Value` pairs.

Input Arguments

`time` — Detection time
nonnegative real scalar

Detection time, specified as a nonnegative real scalar. This argument sets the Time property.

`measurement` — Object measurement
real-valued *N*-element vector

Object measurement, specified as a real-valued *N*-element vector. The dimension *N* is determined by the type of measurement. For example, a measurement of the Cartesian coordinates implies that $N = 3$. A measurement of spherical coordinates and range rate implies that $N = 4$. This argument sets the Measurement property.

Output Arguments

detection — Detection report
objectDetection class object

Detection report, returned as an objectDetection class object. An objectDetection class object contains these properties:

Property	Definition
Time	Measurement time
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor
ObjectClassID	Object classification
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

Properties

Time — Detection time
nonnegative real scalar

Detection time, specified as a nonnegative real scalar. You cannot set this property as a name-value pair. Use the time input argument.

Example: 5.0

Data Types: double

Measurement — Object measurement
real-valued *N*-element vector

Object measurement, specified as a real-valued *N*-element vector. You cannot set this property as a name-value pair. Use the measurement input argument.

Example: [1.0;-3.4]

Data Types: double | single

MeasurementNoise — Measurement noise covariance
scalar | real positive semi-definite symmetric *N*-by-*N* matrix

Measurement noise covariance, specified as a scalar or a real positive semi-definite symmetric *N*-by-*N* matrix. *N* is the number of elements in the measurement vector. For the scalar case, the matrix is a square diagonal *N*-by-*N* matrix having the same data interpretation as the measurement.

Example: `[5.0,1.0;1.0,10.0]`

Data Types: `double` | `single`

SensorIndex — Sensor identifier
1 | positive integer

Sensor identifier, specified as a positive integer. The sensor identifier lets you distinguish between different sensors and must be unique to the sensor.

Example: 5

Data Types: `double`

ObjectClassID — Object class identifier
0 (default) | positive integer

Object class identifier, specified as a positive integer. Object class identifiers distinguish between different kinds of objects. The value `0` denotes an unknown object type. If the class identifier is nonzero, `trackerGNN` or `trackerTOMHT` immediately create a confirmed track from the detection.

Example: 1

Data Types: `double`

MeasurementParameters — Measurement function parameters
{} (default) | cell array

Measurement function parameters, specified as a cell array. The cell array contains all the arguments used by the measurement function specified by the `MeasurementFcn` property of a nonlinear tracking filter such as `trackingEKF` or `trackingUKF`. Each cell contains a single argument.

Example: `{[1;0;0],'rectangular'}`

ObjectAttributes — Object attributes
{} (default) | cell array

Object attributes passed through the tracker, specified as a cell array. These attributes are added to the output of the `trackerGNN` and `trackerTOMHT` trackers but not used by the trackers.

Example: `{[10,20,50,100],'radar1'}`

Examples

Create Detection From Position Measurement

Create a detection from a position measurement. The detection is made at a time stamp of one second from a position measurement of `[100;250;10]` in cartesian coordinates.

```
detection = objectDetection(1,[100;250;10])

detection =
  objectDetection with properties:

                   Time: 1
            Measurement: [3x1 double]
       MeasurementNoise: [3x3 double]
            SensorIndex: 1
           ObjectClassID: 0
   MeasurementParameters: {}
        ObjectAttributes: {}
```

Create Detection With Measurement Noise

Create an `objectDetection` from a time and position measurement. The detection is made at a time of one second for an object position measurement of `[100;250;10]`. Add measurement noise and set other properties using Name-Value pairs.

```
detection = objectDetection(1,[100;250;10],'MeasurementNoise',10, ...
    'SensorIndex',1,'ObjectAttributes',{'Example object',5})

detection =
  objectDetection with properties:
```

```
                    Time: 1
             Measurement: [3x1 double]
        MeasurementNoise: [3x3 double]
             SensorIndex: 1
           ObjectClassID: 0
    MeasurementParameters: {}
        ObjectAttributes: {'Example object'  [5]}
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
trackingABF | trackingCKF | trackingEKF | trackingGSF | trackingIMM |
trackingKF | trackingMSCEKF | trackingPF | trackingUKF

System Objects
irSensor | monostaticRadarSensor | radarSensor | sonarSensor | trackerGNN |
trackerTOMHT

Introduced in R2017a
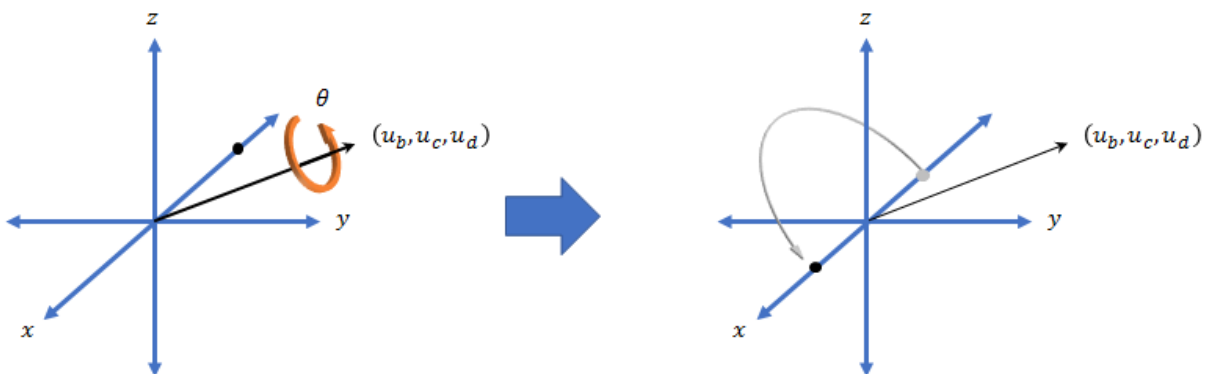
quaternion

Create a quaternion array

Description

A quaternion is a four-part hyper-complex number used in three-dimensional rotations and orientations.

A quaternion number is represented in the form $a + bi + cj + dk$, where a, b, c, and d parts are real numbers, and i, j, and k are the basis elements, satisfying the equation: $i^2 = j^2 = k^2 = ijk = -1$.

The set of quaternions, denoted by **H**, is defined within a four-dimensional vector space over the real numbers, $\mathbf{R}^4$. Every element of **H** has a unique representation based on a linear combination of the basis elements, i, j, and k.

All rotations in 3-D can be described by an axis of rotation and angle about that axis. An advantage of quaternions over rotation matrices is that the axis and angle of rotation is easy to interpret. For example, consider a point in $\mathbf{R}^3$. To rotate the point, you define an axis of rotation and an angle of rotation.

The quaternion representation of the rotation may be expressed as

$$q = \cos\left(\frac{\theta}{2}\right) + \sin\left(\frac{\theta}{2}\right)\left(u_b \mathrm{i} + u_c \mathrm{j} + u_d \mathrm{k}\right)$$

, where θ is the angle of rotation and $[u_b, u_c, \text{and } u_d]$ is the axis of rotation.

Creation

Syntax

```
quat = quaternion()
quat = quaternion(A,B,C,D)
quat = quaternion(matrix)
quat = quaternion(RV,'rotvec')
quat = quaternion(RV,'rotvecd')
quat = quaternion(RM,'rotmat',PF)
quat = quaternion(E,'euler',RS,PF)
quat = quaternion(E,'eulerd',RS,PF)
```

Description

`quat = quaternion()` creates an empty quaternion.

`quat = quaternion(A,B,C,D)` creates a quaternion array where the four quaternion parts are taken from the arrays A, B, C, and D. All the inputs must have the same size and be of the same data type.

`quat = quaternion(matrix)` creates an *N*-by-1 quaternion array from an *N*-by-4 matrix, where each column becomes one part of the quaternion.

`quat = quaternion(RV,'rotvec')` creates an *N*-by-1 quaternion array from an *N*-by-3 matrix of rotation vectors, RV. Each row of RV represents a rotation vector in radians.

`quat = quaternion(RV,'rotvecd')` creates an *N*-by-1 quaternion array from an *N*-by-3 matrix of rotation vectors, RV. Each row of RV represents a rotation vector in degrees.

`quat = quaternion(RM,'rotmat',PF)` creates an *N*-by-1 quaternion array from the 3-by-3-by-*N* array of rotation matrices, RM. PF can be either `'point'` if the Euler angles represent point rotations or `'frame'` for frame rotations.

`quat = quaternion(E,'euler',RS,PF)` creates an *N*-by-1 quaternion array from the *N*-by-3 matrix, E. Each row of E represents a set of Euler angles in radians. The angles in E are rotations about the axes in sequence RS.

`quat = quaternion(E,'eulerd',RS,PF)` creates an *N*-by-1 quaternion array from the *N*-by-3 matrix, E. Each row of E represents a set of Euler angles in degrees. The angles in E are rotations about the axes in sequence RS.

Input Arguments

`A,B,C,D` — Quaternion parts
comma-separated arrays of the same size

Parts of a quaternion, specified as four comma-separated scalars, matrices, or multi-dimensional arrays of the same size.

Example: `quat = quaternion(1,2,3,4)` creates a quaternion of the form 1 + 2i + 3j + 4k.

Example: `quat = quaternion([1,5],[2,6],[3,7],[4,8])` creates a 1-by-2 quaternion array where `quat(1,1) = 1 + 2i + 3j + 4k` and `quat(1,2) = 5 + 6i + 7j + 8k`

Data Types: `single` | `double`

`matrix` — Matrix of quaternion parts
N-by-4 matrix

Matrix of quaternion parts, specified as an *N*-by-4 matrix. Each row represents a separate quaternion. Each column represents a separate quaternion part.

Example: `quat = quaternion(rand(10,4))` creates a 10-by-1 quaternion array.

Data Types: `single` | `double`

`RV` — Matrix of rotation vectors
N-by-3 matrix

Matrix of rotation vectors, specified as an *N*-by-3 matrix. Each row of RV represents the [X Y Z] elements of a rotation vector. A rotation vector is a unit vector representing the axis of rotation scaled by the angle of rotation in radians or degrees.

To use this syntax, specify the first argument as a matrix of rotation vectors and the second argument as the `'rotvec'` or `'rotvecd'`.

Example: `quat = quaternion(rand(10,3),'rotvec')` creates a 10-by-1 quaternion array.

Data Types: `single` | `double`

RM — Rotation matrices
3-by-3 matrix | 3-by-3-by-*N* array

Array of rotation matrices, specified by a 3-by-3 matrix or 3-by-3-by-*N* array. Each page of the array represents a separate rotation matrix.

Example: `quat = quaternion(rand(3),'rotmat','point')`

Example: `quat = quaternion(rand(3),'rotmat','frame')`

Data Types: `single` | `double`

PF — Type of rotation matrix
`'point'` | `'frame'`

Type of rotation matrix, specified by `'point'` or `'frame'`.

Example: `quat = quaternion(rand(3),'rotmat','point')`

Example: `quat = quaternion(rand(3),'rotmat','frame')`

Data Types: `char` | `string`

E — Matrix of Euler angles
N-by-3 matrix

Matrix of Euler angles, specified by an *N*-by-3 matrix. If using the `'euler'` syntax, specify E in radians. If using the `'eulerd'` syntax, specify E in degrees.

Example: `quat = quaternion(E,'euler','YZY','point')`

Example: `quat = quaternion(E,'euler','XYZ','frame')`

Data Types: `single` | `double`

RS — Rotation sequence
character vector | scalar string

Rotation sequence, specified as a three-element character vector:

- `'YZY'`
- `'YXY'`
- `'ZYZ'`
- `'ZXZ'`
- `'XYX'`
- `'XZX'`
- `'XYZ'`
- `'YZX'`
- `'ZXY'`
- `'XZY'`
- `'ZYX'`
- `'YXZ'`

Assume you want to determine the new coordinates of a point when its coordinate system is rotated using frame rotation. The point is defined in the original coordinate system as:

```
point = [sqrt(2)/2,sqrt(2)/2,0];
```

In this representation, the first column represents the *x*-axis, the second column represents the *y*-axis, and the third column represents the *z*-axis.

You want to rotate the point using the Euler angle representation [45,45,0]. Rotate the point using two different rotation sequences:

- If you create a quaternion rotator and specify the 'ZYX' sequence, the frame is first rotated 45° around the *z*-axis, then 45° around the new *y*-axis.

  ```
  quatRotator = quaternion([45,45,0],'eulerd','ZYX','frame');
  newPointCoordinate = rotateframe(quatRotator,point)

  newPointCoordinate =

      0.7071   -0.0000    0.7071
  ```
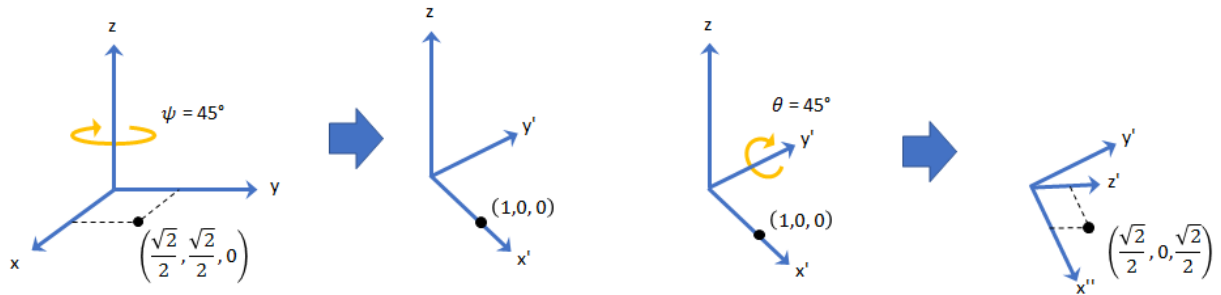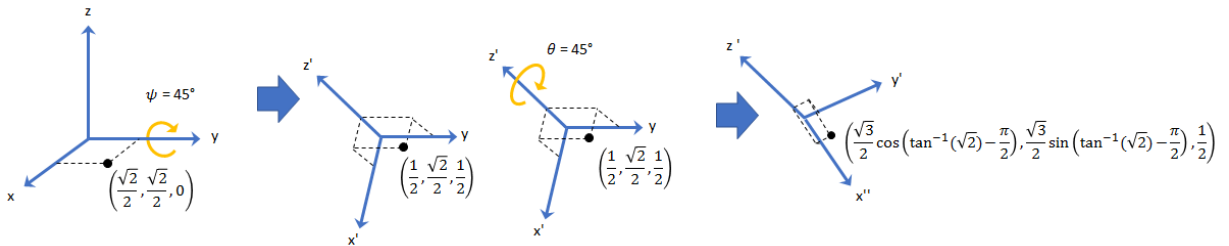
- If you create a quaternion rotator and specify the 'YZX' sequence, the frame is first rotated 45° around the *y*-axis, then 45° around the new *z*-axis.

```
quatRotator = quaternion([45,45,0],'eulerd','YZX','frame');
newPointCoordinate = rotateframe(quatRotator,point)
```

```
newPointCoordinate =

    0.8536    0.1464    0.5000
```


Data Types: char | string

Object Functions

classUnderlying	Class of parts within quaternion
compact	Convert quaternion array to N-by-4 matrix
conj	Complex conjugate of quaternion
ctranspose	Complex conjugate transpose of quaternion array
dist	Angular distance in radians
euler	Convert quaternion to Euler angles (radians)

eulerd	Convert quaternion to Euler angles (degrees)
meanrot	Quaternion mean rotation
minus, -	Quaternion subtraction
mtimes, *	Quaternion multiplication
norm	Quaternion norm
normalize	Quaternion normalization
ones	Create quaternion array with real parts set to one and imaginary parts set to zero
parts	Extract quaternion parts
prod	Product of a quaternion array
rotateframe	Quaternion frame rotation
rotatepoint	Quaternion point rotation
rotmat	Convert quaternion to rotation matrix
rotvec	Convert quaternion to rotation vector (radians)
rotvecd	Convert quaternion to rotation vector (degrees)
slerp	Spherical linear interpolation
times, .*	Element-wise quaternion multiplication
ldivide, .\	Element-wise quaternion left division
rdivide, ./	Element-wise quaternion right division
power, .^	Element-wise quaternion power
exp	Exponential of quaternion array
log	Natural logarithm of quaternion array
transpose	Transpose a quaternion array
uminus, -	Quaternion unary minus
zeros	Create quaternion array with all parts set to zero

Examples

Create Empty Quaternion

```
quat = quaternion()

quat =

  0x0 empty quaternion array
```

By default, the underlying class of the quaternion is a double.

```
classUnderlying(quat)
```

```
ans =
'double'
```

Create Quaternion by Specifying Individual Quaternion Parts

You can create a quaternion array by specifying the four parts as comma-separated
scalars, matrices, or multidimensional arrays of the same size.

Define quaternion parts as scalars.

```
A = 1.1;
B = 2.1;
C = 3.1;
D = 4.1;
quatScalar = quaternion(A,B,C,D)

quatScalar = quaternion
     1.1 + 2.1i + 3.1j + 4.1k
```

Define quaternion parts as column vectors.

```
A = [1.1;1.2];
B = [2.1;2.2];
C = [3.1;3.2];
D = [4.1;4.2];
quatVector = quaternion(A,B,C,D)

quatVector = 2x1 quaternion array
     1.1 + 2.1i + 3.1j + 4.1k
     1.2 + 2.2i + 3.2j + 4.2k
```

Define quaternion parts as matrices.

```
A = [1.1,1.3; ...
     1.2,1.4];
B = [2.1,2.3; ...
     2.2,2.4];
C = [3.1,3.3; ...
     3.2,3.4];
D = [4.1,4.3; ...
```

```
     4.2,4.4];
quatMatrix = quaternion(A,B,C,D)
```

quatMatrix = *2x2 quaternion array*
```
    1.1 + 2.1i + 3.1j + 4.1k     1.3 + 2.3i + 3.3j + 4.3k
    1.2 + 2.2i + 3.2j + 4.2k     1.4 + 2.4i + 3.4j + 4.4k
```

Define quaternion parts as three dimensional arrays.

```
A = randn(2,2,2);
B = zeros(2,2,2);
C = zeros(2,2,2);
D = zeros(2,2,2);
quatMultiDimArray = quaternion(A,B,C,D)
```

quatMultiDimArray = *2x2x2 quaternion array*
quatMultiDimArray(:,:,1) =

```
    0.53767 +       0i +       0j +       0k    -2.2588 +       0i +       0j +
     1.8339 +       0i +       0j +       0k    0.86217 +       0i +       0j +
```

quatMultiDimArray(:,:,2) =

```
    0.31877 +       0i +       0j +       0k    -0.43359 +       0i +       0j +
    -1.3077 +       0i +       0j +       0k     0.34262 +       0i +       0j +
```

Create Quaternion by Specifying Quaternion Parts Matrix

You can create a scalar or column vector of quaternions by specify an *N*-by-4 matrix of quaternion parts, where columns correspond to the quaternion parts A, B, C, and D.

Create a column vector of random quaternions.

```
quatParts = rand(3,4)
```

quatParts = *3×4*

```
    0.8147    0.9134    0.2785    0.9649
    0.9058    0.6324    0.5469    0.1576
    0.1270    0.0975    0.9575    0.9706
```

```
quat = quaternion(quatParts)
```

```
quat = 3x1 quaternion array
     0.81472 + 0.91338i +  0.2785j + 0.96489k
     0.90579 + 0.63236i + 0.54688j + 0.15761k
     0.12699 + 0.09754i + 0.95751j + 0.97059k
```

To retrieve the `quatParts` matrix from quaternion representation, use `compact`.

```
retrievedquatParts = compact(quat)
```

```
retrievedquatParts = 3×4

    0.8147    0.9134    0.2785    0.9649
    0.9058    0.6324    0.5469    0.1576
    0.1270    0.0975    0.9575    0.9706
```

Create Quaternion by Specifying Rotation Vectors

You can create an *N*-by-1 quaternion array by specifying an *N*-by-3 matrix of rotation vectors in radians or degrees. Rotation vectors are compact spatial representations that have a one-to-one relationship with normalized quaternions.

Create a scalar quaternion using a rotation vector and verify the resulting quaternion is normalized.

```
rotationVector = [0.3491,0.6283,0.3491];
quat = quaternion(rotationVector,'rotvec')
```

```
quat = quaternion
     0.92124 + 0.16994i + 0.30586j + 0.16994k
```

```
norm(quat)
```

```
ans = 1.0000
```

You can convert from quaternions to rotation vectors in radians using the `rotvec` function. Recover the `rotationVector` from the quaternion, `quat`.

```
rotvec(quat)
```

```
ans = 1×3

    0.3491    0.6283    0.3491
```

Create a scalar quaternion using a rotation vector and verify the resulting quaternion is normalized.

```
rotationVector = [20,36,20];
quat = quaternion(rotationVector,'rotvecd')

quat = quaternion
     0.92125 + 0.16993i + 0.30587j + 0.16993k
```

```
norm(quat)

ans = 1
```

You can convert from quaternions to rotation vectors in degrees using the `rotvecd` function. Recover the `rotationVector` from the quaternion, `quat`.

```
rotvecd(quat)

ans = 1×3

   20.0000   36.0000   20.0000
```

Create Quaternion by Specifying Rotation Matrices

You can create an N-by-1 quaternion array by specifying a 3-by-3-by-N array of rotation matrices. Each page of the rotation matrix array corresponds to one element of the quaternion array.

Create a scalar quaternion using a 3-by-3 rotation matrix. Specify whether the rotation matrix should be interpreted as a frame or point rotation.

```
rotationMatrix = [1 0         0; ...
                  0 sqrt(3)/2 0.5; ...
                  0 -0.5      sqrt(3)/2];
quat = quaternion(rotationMatrix,'rotmat','frame')
```

```
quat = quaternion
     0.96593 + 0.25882i +        0j +        0k
```

You can convert from quaternions to rotation matrices using the `rotmat` function. Recover the `rotationMatrix` from the quaternion, `quat`.

```
rotmat(quat,'frame')
```

```
ans = 3×3

    1.0000         0         0
         0    0.8660    0.5000
         0   -0.5000    0.8660
```

Create Quaternion by Specifying Euler Angles

You can create an *N*-by-1 quaternion array by specifying an *N*-by-3 array of Euler angles in radians or degrees.

Use the `euler` syntax to create a scalar quaternion using a 1-by-3 vector of Euler angles in radians. Specify the rotation sequence of the Euler angles and whether the angles represent a frame or point rotation.

```
E = [pi/2,0,pi/4];
quat = quaternion(E,'euler','ZYX','frame')
```

```
quat = quaternion
     0.65328 +  0.2706i +  0.2706j + 0.65328k
```

You can convert from quaternions to Euler angles using the `euler` function. Recover the Euler angles, `E`, from the quaternion, `quat`.

```
euler(quat,'ZYX','frame')
```

```
ans = 1×3

    1.5708         0    0.7854
```

Use the `eulerd` syntax to create a scalar quaternion using a 1-by-3 vector of Euler angles in degrees. Specify the rotation sequence of the Euler angles and whether the angles represent a frame or point rotation.

```
E = [90,0,45];
quat = quaternion(E,'eulerd','ZYX','frame')
```

```
quat = quaternion
     0.65328 +  0.2706i +  0.2706j + 0.65328k
```

You can convert from quaternions to Euler angles in degrees using the `eulerd` function. Recover the Euler angles, E, from the quaternion, `quat`.

```
eulerd(quat,'ZYX','frame')
```

```
ans = 1×3

   90.0000         0   45.0000
```

Quaternion Algebra

Quaternions form a noncommutative associative algebra over the real numbers. This example illustrates the rules of quaternion algebra.

Addition and Subtraction

Quaternion addition and subtraction occur part-by-part, and are commutative:

```
Q1 = quaternion(1,2,3,4)
```

```
Q1 = quaternion
     1 + 2i + 3j + 4k
```

```
Q2 = quaternion(9,8,7,6)
```

```
Q2 = quaternion
     9 + 8i + 7j + 6k
```

```
Q1plusQ2 = Q1 + Q2
```

```
Q1plusQ2 = quaternion
     10 + 10i + 10j + 10k
```

```
Q2plusQ1 = Q2 + Q1
```

```
Q2plusQ1 = quaternion
     10 + 10i + 10j + 10k
```

```
Q1minusQ2 = Q1 - Q2
```

```
Q1minusQ2 = quaternion
    -8 - 6i - 4j - 2k
```

```
Q2minusQ1 = Q2 - Q1
```

```
Q2minusQ1 = quaternion
     8 + 6i + 4j + 2k
```

You can also perform addition and subtraction of real numbers and quaternions. The first part of a quaternion is referred to as the *real* part, while the second, third, and fourth parts are referred to as the *vector*. Addition and subtraction with real numbers affect only the real part of the quaternion.

```
Q1plusRealNumber = Q1 + 5
```

```
Q1plusRealNumber = quaternion
     6 + 2i + 3j + 4k
```

```
Q1minusRealNumber = Q1 - 5
```

```
Q1minusRealNumber = quaternion
    -4 + 2i + 3j + 4k
```

Multiplication

Quaternion multiplication is determined by the products of the basis elements and the distributive law. Recall that multiplication of the basis elements, i, j, and k, are not commutative, and therefore quaternion multiplication is not commutative.

```
Q1timesQ2 = Q1 * Q2
```

```
Q1timesQ2 = quaternion
    -52 + 16i + 54j + 32k
```

```
Q2timesQ1 = Q2 * Q1
```

```
Q2timesQ1 = quaternion
    -52 + 36i + 14j + 52k
```

```
isequal(Q1timesQ2,Q2timesQ1)
```

```
ans = logical
   0
```

You can also multiply a quaternion by a real number. If you multiply a quaternion by a real number, each part of the quaternion is multiplied by the real number individually:

```
Q1times5 = Q1*5
```

```
Q1times5 = quaternion
     5 + 10i + 15j + 20k
```

Multiplying a quaternion by a real number is commutative.

```
isequal(Q1*5,5*Q1)
```

```
ans = logical
   1
```

Conjugation

The complex conjugate of a quaternion is defined such that each element of the vector portion of the quaternion is negated.

```
Q1
```

```
Q1 = quaternion
     1 + 2i + 3j + 4k
```

```
conj(Q1)
```

2-73

```
ans = quaternion
     1 - 2i - 3j - 4k
```

Multiplication between a quaternion and its conjugate is commutative:

```
isequal(Q1*conj(Q1),conj(Q1)*Q1)
```

```
ans = logical
   1
```

Quaternion Array Manipulation

You can organize quaternions into vectors, matrices, and multidimensional arrays. Built-in MATLAB® functions have been enhanced to work with quaternions.

Concatenate

Quaternions are treated as individual objects during concatenation and follow MATLAB rules for array manipulation.

```
Q1 = quaternion(1,2,3,4);
Q2 = quaternion(9,8,7,6);

qVector = [Q1,Q2]
```

```
qVector = 1x2 quaternion array
     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
```

```
Q3 = quaternion(-1,-2,-3,-4);
Q4 = quaternion(-9,-8,-7,-6);

qMatrix = [qVector;Q3,Q4]
```

```
qMatrix = 2x2 quaternion array
     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k    -9 - 8i - 7j - 6k
```

```
qMultiDimensionalArray(:,:,1) = qMatrix;
qMultiDimensionalArray(:,:,2) = qMatrix
```

```
qMultiDimensionalArray = 2x2x2 quaternion array
qMultiDimensionalArray(:,:,1) =

     1 + 2i + 3j + 4k      9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k     -9 - 8i - 7j - 6k


qMultiDimensionalArray(:,:,2) =

     1 + 2i + 3j + 4k      9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k     -9 - 8i - 7j - 6k
```

Indexing

To access or assign elements in a quaternion array, use indexing.

```
qLoc2 = qMultiDimensionalArray(2)

qLoc2 = quaternion
    -1 - 2i - 3j - 4k
```

Replace the quaternion at index two with a quaternion one.

```
qMultiDimensionalArray(2) = ones('quaternion')

qMultiDimensionalArray = 2x2x2 quaternion array
qMultiDimensionalArray(:,:,1) =

     1 + 2i + 3j + 4k      9 + 8i + 7j + 6k
     1 + 0i + 0j + 0k     -9 - 8i - 7j - 6k


qMultiDimensionalArray(:,:,2) =

     1 + 2i + 3j + 4k      9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k     -9 - 8i - 7j - 6k
```

Reshape

To reshape quaternion arrays, use the reshape function.

```
qMatReshaped = reshape(qMatrix,4,1)
```

```
qMatReshaped = 4x1 quaternion array
      1 + 2i + 3j + 4k
     -1 - 2i - 3j - 4k
      9 + 8i + 7j + 6k
     -9 - 8i - 7j - 6k
```

Transpose

To transpose quaternion vectors and matrices, use the `transpose` function.

```
qMatTransposed = transpose(qMatrix)
```

```
qMatTransposed = 2x2 quaternion array
      1 + 2i + 3j + 4k     -1 - 2i - 3j - 4k
      9 + 8i + 7j + 6k     -9 - 8i - 7j - 6k
```

Permute

To permute quaternion vectors, matrices, and multidimensional arrays, use the `permute` function.

```
qMultiDimensionalArray
```

```
qMultiDimensionalArray = 2x2x2 quaternion array
qMultiDimensionalArray(:,:,1) =

      1 + 2i + 3j + 4k      9 + 8i + 7j + 6k
      1 + 0i + 0j + 0k     -9 - 8i - 7j - 6k


qMultiDimensionalArray(:,:,2) =

      1 + 2i + 3j + 4k      9 + 8i + 7j + 6k
     -1 - 2i - 3j - 4k     -9 - 8i - 7j - 6k
```

```
qMatPermute = permute(qMultiDimensionalArray,[3,1,2])
```

```
qMatPermute = 2x2x2 quaternion array
qMatPermute(:,:,1) =

      1 + 2i + 3j + 4k      1 + 0i + 0j + 0k
      1 + 2i + 3j + 4k     -1 - 2i - 3j - 4k
```

```
qMatPermute(:,:,2) =

    9 + 8i + 7j + 6k    -9 - 8i - 7j - 6k
    9 + 8i + 7j + 6k    -9 - 8i - 7j - 6k
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Topics
"Rotations, Orientation and Quaternions"
"Lowpass Filter Orientation Using Quaternion SLERP"

Introduced in R2018a

trackingScenario

Create tracking scenario

Description

`trackingScenario` creates a tracking scenario object. A tracking scenario simulates a 3-D arena containing multiple platforms. Platforms represent anything that you want to simulate, such as aircraft, ground vehicles, or ships. Some platforms carry sensors, such as radar, sonar, or infrared. Other platforms act as sources of signals or reflect signals. Platforms can also include stationary obstacles that can influence the motion of other platforms. All platforms are modeled as points but can have aspect-dependent properties including radar cross-section or sonar target strength. You can populate a tracking scenario by calling the `platform` method for each platform you want to add. Platforms are `Platform` objects. You can create trajectories for any platform using the `kinematicTrajectory` or `waypointTrajectory` System objects. After creating the scenario, run the simulation by calling the `advance` object function.

Creation

`sc = trackingScenario` creates an empty tracking scenario with default property values.

`sc = trackingScenario(Name,Value)` configures a `trackingScenario` object with properties using 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`. Any unspecified properties take default values.

Properties

StopTime — Stop time of simulation
`Inf` (default) | positive scalar

Stop time of simulation, specified as a positive scalar. A simulation stops when either of these conditions is met:

- The stop time is reached.
- Any platform reaches the end of its trajectory and you have specified the platform `Motion` property using waypoints, `waypointTrajectory`.

Units are in seconds.

Example: `60.0`

Data Types: `double`

SimulationTime — Current time of simulation
positive scalar

This property is read-only.

Current time of the simulation, defined as a positive scalar. To reset the simulation time to zero and restart the simulation, call the `restart` method. Units are in seconds.

Data Types: `double`

UpdateRate — Frequency of simulation updates
`10.0` (default) | positive scalar

Frequency of simulation updates, specified as a positive scalar. This is the rate at which to provide successive updates of the scenario simulation. Units are in Hz.

Example: `2.0`

Data Types: `double`

IsRunning — Run-state of simulation
`true` | `false`

This property is read-only.

Run-state of simulation, defined as `true` or `false`. If the simulation is running, `IsRunning` is `true`. If the simulation has stopped, `IsRunning` is `false`. A simulation stops when either of these conditions is met:

- The stop time is reached.
- Any platform reaches the end of its trajectory, and you have specified that platform `Motion` strategy with waypoints using the `waypointTrajectory` System object™.

Units are in seconds.

Data Types: `logical`

`Platforms` — Platforms in the simulation
cell | cell array

This property is read-only.

Platforms in the scenario, returned as a cell or cell array of `Platform` objects. To add a platform to the scenario, use the `platform` object function.

Object Functions

advance	Advance tracking scenario simulation by one time step
platform	Add platform to tracking scenario
platformPoses	Positions, velocities, and orientations of all platforms in tracking scenario
platformProfiles	Profiles of platforms in tracking scenario
restart	Restart tracking scenario simulation
record	Run tracking scenario and record platform states

Examples

Create Tracking Scenario with Two Platforms

Construct a tracking scenario with two platforms following different trajectories.

```
sc = trackingScenario('UpdateRate',100.0,'StopTime',1.2);
```

Create two platforms.

```
platfm1 = platform(sc);
platfm2 = platform(sc);
```

Platform 1 follows a circular path of radius 10 m for one second. This is accomplished by placing waypoints in a circular shape, ensuring that the first and last waypoint are the same.

```
wpts1 = [0 10 0; 10 0 0; 0 -10 0; -10 0 0; 0 10 0];
time1 = [0; 0.25; .5; .75; 1.0];
platfm1.Trajectory = waypointTrajectory(wpts1, time1);
```

Platform 2 follows a straight path for one second.

```
wpts2 = [-8 -8 0; 10 10 0];
time2 = [0; 1.0];
platfm2.Trajectory = waypointTrajectory(wpts2,time2);
```

Verify the number of platforms in the scenario.

```
disp(sc.Platforms)
```

```
    [1×1 fusion.scenario.Platform]    [1×1 fusion.scenario.Platform]
```

Run the simulation and plot the current position of each platform. Use an animated line to plot the position of each platform

```
figure
grid
axis equal
axis([-12 12 -12 12])
line1 = animatedline('DisplayName','Trajectory 1','Color','b','Marker','.');
line2 = animatedline('DisplayName','Trajectory 2','Color','r','Marker','.');
title('Trajectories')
p1 = pose(platfm1);
p2 = pose(platfm2);
addpoints(line1,p1.Position(1),p1.Position(2));
addpoints(line2,p2.Position(2),p2.Position(2));

while advance(sc)
    p1 = pose(platfm1);
    p2 = pose(platfm2);
    addpoints(line1,p1.Position(1),p1.Position(2));
    addpoints(line2,p2.Position(2),p2.Position(2));
    pause(0.1)
end
```
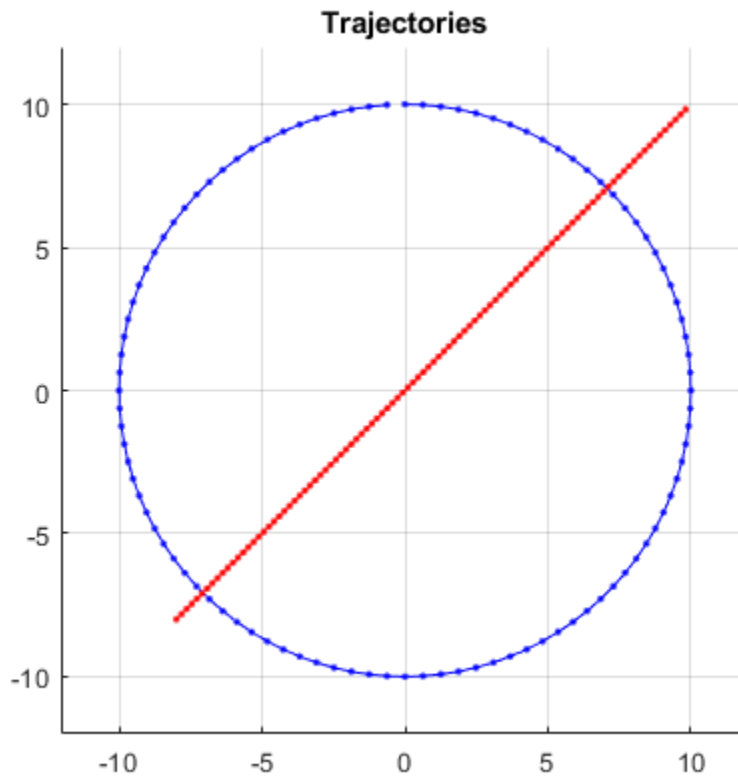
Plot the waypoints for both platforms.

```
hold on
plot(wpts1(:,1),wpts1(:,2),' ob')
text(wpts1(:,1),wpts1(:,2),"t = " + string(time1),'HorizontalAlignment','left','Vertica
plot(wpts2(:,1),wpts2(:,2),' or')
text(wpts2(:,1),wpts2(:,2),"t = " + string(time2),'HorizontalAlignment','left','Vertica
hold off
```
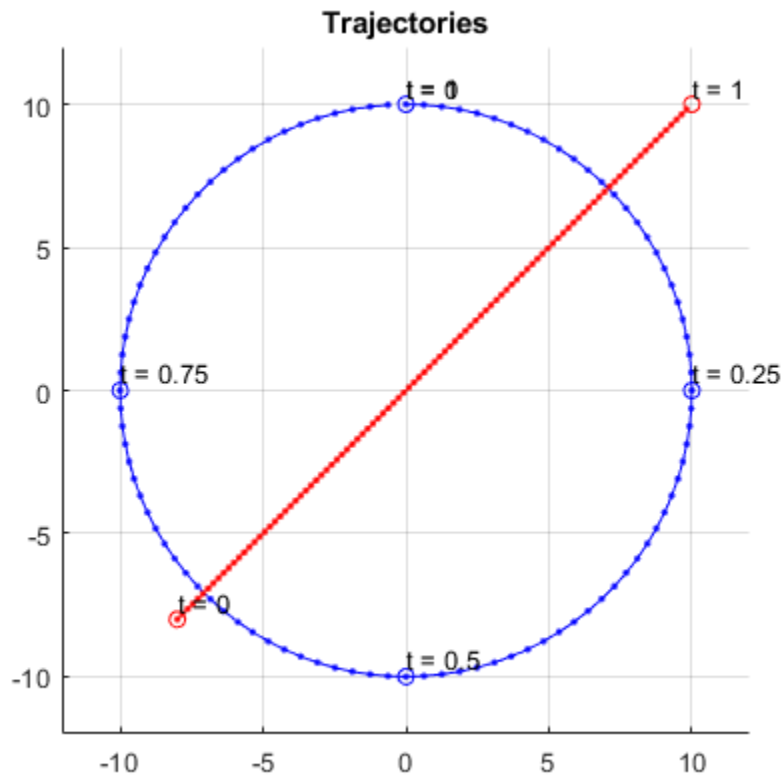
See Also

System Objects
kinematicTrajectory | waypointTrajectory

Introduced in R2018b

Platform

Platform object belonging to tracking scenario

Description

`Platform` defines a platform object belonging to a tracking scenario. Platforms represent the moving objects in a scenario and are modeled as points with aspect-dependent properties.

Creation

You can create `Platform` objects using the `platform` method of `trackingScenario`.

Properties

`PlatformID` — Scenario-defined platform identifier
1 (default) | positive integer

This property is read-only.

Scenario-defined platform identifier, specified as a positive integer. The scenario automatically assigns `PlatformID` values to each platform.

Data Types: `double`

`ClassID` — Platform classification identifier
0 (default) | nonnegative integer

Platform classification identifier specified as a nonnegative integer. You can define your own platform classification scheme and assign `ClassID` values to platforms according to the scheme. The value of 0 is reserved for an object of unknown or unassigned class.

Example: 5

Data Types: `double` | `single`

Trajectory — Platform motion
kinematicTrajectory object with default property values (default) |
waypointTrajectory object

Platform motion, specified as either a `kinematicTrajectory` or
`waypointTrajectory`, or object.

The motion defines the time evolution of the location, velocity, and orientation of a
platform.

Signature — Platform signatures
rcsSignature with default properties | cell array of signature objects

Platform signatures, specified as a cell array of `irSignature`, `rcsSignature`, and
`tsSignature` objects. A signature represents the reflection or emission pattern of a
platform such as its radar cross-section, target strength, or IR intensity.

PoseEstimator — Platform pose-estimator
insSensor object (default) | pose estimator object

A pose estimator, specified as a pose-estimator object such as `insSensor`. The pose
estimator determines platform pose with respect to the local NED scenario coordinate.
The interface of any pose estimator must match the interface of `insSensor`. By default,
pose-estimator accuracy properties are set to zero.

Emitters — Emitters mounted on platform
cell array of emitter objects

Emitters mounted on platform, specified as a cell array of emitter objects, such as
`radarEmitter` or `sonarEmitter`.

Sensors — Sensors mounted on platform
cell array of sensor objects

Sensors mounted on platform, specified as a cell array of sensor objects such as
`irSensor`, `radarSensor`, `monostaticRadarSensor`, or `sonarSensor`.

Object Functions

detect   Detect signals using platform-mounted sensors
emit   Radiate signals from emitters mounted on platform

pose   Pose of platform
targetPoses   Target positions and orientations as seen from platform

Examples

Platform Follows Circular Trajectory

Create a tracking scenario and a platform following a circular path.

```
scene = trackingScenario('UpdateRate',1/50);

% Create a platform
plat = platform(scene);

% Follow a circular trajectory 1 km in radius completing in 400 hundred seconds.
plat.Trajectory = waypointTrajectory('Waypoints', [0 1000 0; 1000 0 0; 0 -1000 0; -1000
    'TimeOfArrival', [0; 100; 200; 300; 400]);

% Perform the simulation
while scene.advance
    p = pose(plat);
    fprintf('Time = %f ', scene.SimulationTime);
    fprintf('Position = [');
    fprintf('%f ', p.Position);
    fprintf('] Velocity = [');
    fprintf('%f ', p.Velocity);
    fprintf(']\n');
end
```

```
Time = 50.000000 Position = [623.561925 626.638509 0.000000 ] Velocity = [11.378941 -9.
Time = 100.000000 Position = [1000.000000 0.000000 0.000000 ] Velocity = [1.677836 -15.
Time = 150.000000 Position = [724.510494 -677.241693 0.000000 ] Velocity = [-11.268303
Time = 200.000000 Position = [0.000000 -1000.000000 0.000000 ] Velocity = [-16.843065 -
Time = 250.000000 Position = [-926.594496 -797.673675 0.000000 ] Velocity = [-15.117346
Time = 300.000000 Position = [-1000.000000 0.000000 0.000000 ] Velocity = [9.520786 9.6
```

```
Time = 350.000000 Position = [-421.669352 137.708709 0.000000 ] Velocity = [10.727588
Time = 400.000000 Position = [-0.000000 1.000000 0.000000 ] Velocity = [6.118648 -2.380
```

See Also

Classes
rcsSignature | tsSignature

System Objects
insSensor | irSensor | kinematicTrajectory | monotstaticRadarSensor |
radarEmitter | radarSensor | sonarEmitter | sonarSensor |
waypointTrajectory

Introduced in R2018b

Platform.emit

Radiate signals from emitters mounted on platform

Syntax

```
[signals,emitterconfigs] = emit(ptfm,time)
```

Description

`[signals,emitterconfigs] = emit(ptfm,time)` returns signals, `signals`, radiated by all the emitters mounted on the platform, `ptfm`, at the specified `time`. The function also returns all emitter configurations, `emitterconfigs`.

Input Arguments

`ptfm` — Scenario platform
`Platform` object

Scenario platform, specified as a `Platform` object. To create platforms, use the `platform` method.

`time` — Emission time
`0` (default) | positive scalar

Emission time, specified as a positive scalar.

Example: `100.5`

Data Types: `single` | `double`

Output Arguments

`signals` — Signals radiated by emitters on platform
cell array of emission objects

Signals radiated by emitters on platform, returned as a cell array of `radarEmission` and `sonarEmission` objects.

emitterconfigs — Emitter configurations
structure

Emitter configurations, returned as a structure. An emitter configuration has these fields:

Field	Description
EmitterIndex	Unique emitter index
IsValidTime	Valid emission time, returned as 0 or 1. IsValidTime is 0 when emitter updates are requested at times that are between update intervals specified by UpdateInterval.
IsScanDone	IsScanDone is true when the emitter has completed a scan.
FieldOfView	Field of view of emitter.
MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current emitter frame.

Data Types: `single` | `double`

See Also
detect | pose | targetPoses

Introduced in R2018b

Platform.detect

Detect signals using platform-mounted sensors

Syntax

```
dets = detect(ptfm,time)
dets = detect(ptfm,signals,time)
dets = detect(ptfm,signals,emitterconfigs,time)
[dets,numDets] = detect( ___ )
[dets,numDets,sensorconfigs] = detect( ___ )
```

Description

`dets = detect(ptfm,time)` returns detections, `dets`, from all the sensors mounted on the platform, `ptfm`, at the specified `time`. This syntax applies when sensors do not require knowledge of any signals present in the scenario, for example, when the `monostaticRadarSensor` object property `HasInterference` is set to `false`.

`dets = detect(ptfm,signals,time)` also specifies any signals, `signals`, present in the scenario. This syntax applies when sensors require knowledge of these signals, for example, when a `radarSensor` object is configured as an EM sensor.

`dets = detect(ptfm,signals,emitterconfigs,time)` also specifies emitter configurations, `emitterconfigs`. This syntax applies when sensors require knowledge of the configurations of emitters generating signals in the scenario. For example, when an `radarSensor` object is configured as a monostatic radar.

`[dets,numDets] = detect( ___ )` also returns the number of detections, `numDets`. This output syntax can be used with any of the input syntaxes.

`[dets,numDets,sensorconfigs] = detect( ___ )` also returns all sensor configurations, `sensorconfigs`. This output syntax can be used with any of the input syntaxes.

Input Arguments

ptfm — Scenario platform
Platform object

Scenario platform, specified as a Platform object. To create platforms, use the platform method.

time — Simulation time
0 (default) | positive scalar

Simulation time specified as a positive scalar.

Example: 1.5

Data Types: single | double

signals — Signals in scenario
cell array of emission objects

Signals in the scenario, specified as a cell array of radarEmission and sonarEmission emission objects.

emitterconfigs — Emitter configurations
structure

Emitter configurations, specified as a structure. The fields of the emitter configuration are:

Field	Description
EmitterIndex	Unique emitter index
IsValidTime	Valid emission time, returned as 0 or 1. IsValidTime is 0 when emitter updates are requested at times that are between update intervals specified by UpdateInterval.
IsScanDone	IsScanDone is true when the emitter has completed a scan.
FieldOfView	Field of view of emitter.

`MeasurementParameters`	`MeasurementParameters` is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current emitter frame.

Data Types: `struct`

Output Arguments

dets — sensor detections
cell array of `objectDetection` objects

Sensor detections, returned as a cell array of `objectDetection` objects.

sensorconfigs — Sensor configurations
structure

Sensor configurations, returned as a structure. The fields of this structure are:

Field	Description
`SensorIndex`	Unique sensor index
`IsValidTime`	Valid detection time, returned as `0` or `1`. `IsValidTime` is `0` when detection updates are requested at times that are between update intervals specified by `UpdateInterval`.
`IsScanDone`	`IsScanDone` is `true` when the sensor has completed a scan.
`FieldOfView`	Field of view of sensor determines which objects fall within the sensor beam during object execution. The field of view is defined as a 2-by-1 vector of positive real values, [azfov;elfov].

MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current sensor frame.

Data Types: `struct`

`numDets` — Number of detections
nonnegative integer

Number of detections reported, returned as a nonnegative integer.

Data Types: `double`

Definitions

Object Detections

This section describes the structure of object detections.

The sensor measures the coordinates of the target. The `Measurement` and `MeasurementNoise` values are reported in the coordinate system specified by the `DetectionCoordinates` property of the sensor.

When the `DetectionCoordinates` property is `'Scenario'`, `'Body'`, or `'Sensor rectangular'`, the `Measurement` and `MeasurementNoise` values are reported in rectangular coordinates. Velocities are only reported when the range rate property, `HasRangeRate`, is `true`.

When the `DetectionCoordinates` property is `'Sensor spherical'`, the `Measurement` and `MeasurementNoise` values are reported in a spherical coordinate system derived from the sensor rectangular coordinate system. Elevation and range rate are only reported when `HasElevation` and `HasRangeRate` are `true`.

Measurements are ordered as [azimuth, elevation, range, range rate]. Reporting of elevation and range rate depends on the corresponding `HasElevation` and `HasRangeRate` property values. Angles are in degrees, range is in meters, and range rate is in meters per second.

Measurement Coordinates

DetectionCoordinates	Measurement and Measurement Noise Coordinates		
`'Scenario'`	**Coordinate Dependence on HasRangeRate**		
`'Body'`			
`'Sensor rectangular'`	**HasRangeRate**	**Coordinates**	
	true	[x; y; z; vx; vy; vz]	
	false	[x; y; z]	
`'Sensor spherical'`	**Coordinate Dependence on HasRangeRate and HasElevation**		
	HasRangeRate	**HasElevation**	**Coordinates**
	true	true	[az; el; rng; rr]
	true	false	[az; rng; rr]
	false	true	[az; el; rng]
	false	false	[az; rng]

The `MeasurementParameters` field consists of an array of structures that describe a sequence of coordinate transformations from a child frame to a parent frame or the inverse transformations (see "Frame Rotation"). The longest possible sequence of transformations is Sensor → Platform → Scenario. For example, if the detections are reported in sensor spherical coordinates and `HasINS` is set to `false`, then the sequence consists of one transformation from sensor to platform. If `HasINS` is `true`, the sequence of transformations consists of two transformations – first to platform coordinates then to scenario coordinates. Trivially, if the detections are reported in platform rectangular coordinates and `HasINS` is set to `false`, the transformation consists only of the identity.

The structure fields are shown here. Not all fields have to be present in the structure. The set of fields and their default values can depend on the type of sensor.

Field	Description

Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.
OriginPosition	Position offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
Orientation	3-by-3 real-valued orthonormal frame rotation matrix.
IsParentToChild	A logical scalar indicating if `Orientation` performs a frame rotation from the parent coordinate frame to the child coordinate frame. If `false`, `Orientation` performs a frame rotation from the child coordinate frame to the parent coordinate frame.
HasElevation	A logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if `HasElevation` is `false`, the measurements are reported assuming 0 degrees of elevation.
HasAzimuth	A logical scalar indication if azimuth is included in the measurement.
HasRange	A logical scalar indication if range is included in the measurement.

HasVelocity	A logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if `HasVelocity` is `false`, the measurements are reported as `[x y z]`. If `HasVelocity` is `true`, measurements are reported as `[x y z vx vy vz]`.
Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.

Object attributes contain additional information about a detection:

Attribute	Description
TargetIndex	Identifier of the platform, `PlatformID`, that generated the detection. For false alarms, this value is negative.
SNR	Detection signal-to-noise ratio in dB.

See Also

emit | pose | targetPoses

Introduced in R2018b

Platform.targetPoses

Target positions and orientations as seen from platform

Syntax

```
poses = targetPoses(ptfm)
```

Description

`poses = targetPoses(ptfm)` returns the `poses` of all targets in a scenario with respect to the platform `ptfm`. Targets are defined as platforms as seen by another platform and are located with respect to the coordinate system of that platform. Pose represents the position, velocity, and orientation of a target with respect to the coordinate system belonging to the platform, `ptfm`. The targets must already exist in the tracking scenario. Add targets using the `platform` method.

Input Arguments

`ptfm` — Scenario platform
`Platform` object

Scenario platform, specified as a `Platform` object. To create platforms, use the `platform` method.

Output Arguments

`poses` — Poses of all targets
structure | array of structures

Poses for all targets, returned as a structure or an array of structures. The pose of the input platform, `ptfm`, is not included. Pose consists of the position, velocity, orientation, and signature of a target in platform coordinates. The returned structure has these fields:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field with no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in platform coordinates, specified as a real-valued, 1-by-3 vector. This is a required field with no default value. Units are in meters.
Velocity	Velocity of target in platform coordinates, specified as a real-valued, 1-by-3 vector. Units are in meters per second. The default is [0 0 0].
Acceleration	Acceleration of target in platform coordinates specified as a 1-by-3 row vector. Units are in meters per second-squared. The default is [0 0 0].
Orientation	Orientation of the target with respect to platform coordinates, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the platform coordinate system to the current target body coordinate system. Units are dimensionless. The default is quaternion(1,0,0,0).
AngularVelocity	Angular velocity of target in platform coordinates, specified as a real-valued, 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is [0 0 0].

See Also

detect | emit | pose

Introduced in R2018b

Platform.pose

Pose of platform

Syntax

```
pse = pose(ptfm,type)
```

Description

`pse = pose(ptfm,type)` returns the pose, `pse`, of the platform `ptfm`, in scenario coordinates. The platform must already exist in the tracking scenario. Add platforms to a scenario using the `platform` method.

Input Arguments

`ptfm` — Scenario platform
`Platform` object

Scenario platform, specified as a `Platform` object. To create platforms, use the `platform` method.

`type` — Source of platform pose information
`'estimated'` (default) | `'true'`

Source of platform pose information, specified as `'estimated'` or `'true'`. When set to `'estimated'`, the pose is estimated using the pose estimator specified in the `PoseEstimator` property of the tracking scenario. When `'true'` is selected, the true pose of the platform is returned.

Example: `'true'`

Data Types: `char`

Output Arguments

pse — Pose of platform
structure

Pose of platform, returned as a structure. Pose consists of the position, velocity, orientation, and angular velocity of the platform with respect to scenario coordinates. The returned structure has these fields:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field with no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in scenario coordinates, specified as a real-valued 1-by-3 vector. This is a required field with no default value. Units are in meters.
Velocity	Velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default value is [0 0 0].
Acceleration	Acceleration of the platform in scenario coordinates, specified as a 1-by-3 row vector in meters per second-squared. The default value is [0 0 0].

Field	Description
`Orientation`	Orientation of the platform with respect to the local scenario NED coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. The format is specified by the `fmt` input argument. Orientation defines the frame rotation from the local NED coordinate system to the current platform body coordinate system. Units are dimensionless. The default value is `quaternion(1,0,0,0)`.
`AngularVelocity`	Angular velocity of the platform in scenario coordinates, specified as a real-valued 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is value `[0 0 0]`.

See Also

detect | emit | targetPoses

Introduced in R2018b

platform

Add platform to tracking scenario

Syntax

```
ptfm = platform(sc)
ptfm = platform(sc,Name,Value)
```

Description

`ptfm = platform(sc)` adds a `Platform` object, `ptfm`, to the tracking scenario, `sc`. The function creates a platform with default property values. Platforms are defined as points with aspect-dependent properties. Each platform is automatically assigned a unique ID specified in the `platformID` field of the `Platform` object.

`ptfm = platform(sc,Name,Value)` adds a platform with additional properties 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`. Any unspecified properties take default values.

Input Arguments

sc — Tracking scenario
`trackingScenario` object

Tracking scenario, specified as a `trackingScenario` 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 quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

`ClassID` — Platform classification identifier
`0` (default) | nonnegative integer

Platform classification identifier specified as a nonnegative integer. You can define your own platform classification scheme and assign `ClassID` values to platforms according to the scheme. The value of `0` is reserved for an object of unknown or unassigned class.

Example: 5

Data Types: `double`

`Trajectory` — Platform motion
`kinematicTrajectory` object with default property values (default) | `waypointTrajectory` object

Platform motion, specified as either a `kinematicTrajectory` or a `waypointTrajectory` object.

The motion defines the time evolution of the location, velocity, and orientation of a platform.

`Signature` — Platform signatures
`rcsSignature` with default properties | cell array of signature objects

Platform signatures, specified as a cell array of `rcsSignature`, `irSignature`, or `tsSignature` objects. A signature represents the reflection or emission pattern of a platform, such as its radar cross-section, target strength, or IR emission.

`PoseEstimator` — Platform pose estimator
`insSensor` System object (default) | pose estimator object

A pose estimator, specified as a pose estimator object. The pose estimator determines platform pose with respect to the local NED scenario coordinate. The interface of any pose estimator must match the interface of `insSensor`. By default, pose estimator accuracy properties are set to zero.

`Emitters` — Emitters mounted on platform
cell array of emitter objects

Emitters mounted on the platform, specified as a cell array of emitter objects, such as `radarEmitter` or `sonarEmitter`.

`Sensors` — Sensors mounted on platform
cell array of sensor objects

Sensors mounted on platform, specified as a cell array of sensor objects such as `irSensor`, `radarSensor`, `monostaticRadarSensor`, or `sonarSensor`.

Output Arguments

ptfm — Scenario platform
Platform object

Scenario platform, returned as a `Platform` object.

Object Functions

detect	Detect signals using platform-mounted sensors
emit	Radiate signals from emitters mounted on platform
pose	Pose of platform
targetPoses	Target positions and orientations as seen from platform

Examples

Platform Follows Circular Trajectory

Create a tracking scenario and a platform following a circular path.

```
scene = trackingScenario('UpdateRate',1/50);

% Create a platform
plat = platform(scene);

% Follow a circular trajectory 1 km in radius completing in 400 hundred seconds.
plat.Trajectory = waypointTrajectory('Waypoints', [0 1000 0; 1000 0 0; 0 -1000 0; -1000
    'TimeOfArrival', [0; 100; 200; 300; 400]);

% Perform the simulation
while scene.advance
    p = pose(plat);
    fprintf('Time = %f ', scene.SimulationTime);
    fprintf('Position = [');
    fprintf('%f ', p.Position);
```

```
    fprintf('] Velocity = [');
    fprintf('%f ', p.Velocity);
    fprintf(']\n');
end

Time = 50.000000 Position = [623.561925 626.638509 0.000000 ] Velocity = [11.378941 -9
Time = 100.000000 Position = [1000.000000 0.000000 0.000000 ] Velocity = [1.677836 -15
Time = 150.000000 Position = [724.510494 -677.241693 0.000000 ] Velocity = [-11.268303
Time = 200.000000 Position = [0.000000 -1000.000000 0.000000 ] Velocity = [-16.843065 -
Time = 250.000000 Position = [-926.594496 -797.673675 0.000000 ] Velocity = [-15.117346
Time = 300.000000 Position = [-1000.000000 0.000000 0.000000 ] Velocity = [9.520786 9.6
Time = 350.000000 Position = [-421.669352 137.708709 0.000000 ] Velocity = [10.727588 -
Time = 400.000000 Position = [-0.000000 1.000000 0.000000 ] Velocity = [6.118648 -2.380
```

See Also

Objects
Platform

System Objects
kinematicTrajectory | waypointTrajectory

Introduced in R2018b

advance

Advance tracking scenario simulation by one time step

Syntax

```
isrunning = advance(sc)
```

Description

`isrunning = advance(sc)` advances the tracking scenario simulation, `sc`, by one time step. To specify the step time, set the UpdateRate property of the `trackingScenario` object. The function returns the status, `isrunning`, of the simulation. `advance` updates a platform location only if the platform has an assigned path. You can generate assigned paths using the `Motion` property of a platform. To update platforms that have no assigned paths, you can set the `Position`, `Velocity`, `Orientation`, or `AngularVelocity` properties at any time during the simulation.

Input Arguments

sc — Tracking scenario
`trackingScenario` object

Tracking scenario, specified as a `trackingScenario` object.

Output Arguments

isrunning — Run-state of simulation
`0 | 1`

The run-state of the simulation, returned as `0` or `1`. If `isrunning` is `1`, the simulation is running. If `isrunning` is `0`, the simulation has stopped. A simulation stops when either of these conditions is met:

- The stop time is reached.
- Any platform reaches the end of its trajectory, and you have specified the platform `Motion` property using waypoints (with a `waypointTrajectory` object).

Units are in seconds.

Introduced in R2018b

platformPoses

Positions, velocities, and orientations of all platforms in tracking scenario

Syntax

```
poses = platformPoses(sc)
poses = platformPoses(sc,fmt)
```

Description

`poses = platformPoses(sc)` returns the current poses for all platforms in the tracking scenario, `sc`. Pose is the position, velocity, and orientation of a platform relative to scenario coordinates. Platforms are `Platform` objects.

`poses = platformPoses(sc,fmt)` also specifies the format, `fmt`, of the returned platform orientation.

Input Arguments

sc — Tracking scenario
`trackingScenario` object

Tracking scenario, specified as a `trackingScenario` object.

fmt — Pose orientation format
`'quaternion'` (default) | `'rotmat'`

Pose orientation format, specified as `'quaternion'` or `'rotmat'`. When specified as `'quaternion'`, the `Orientation` field of the platform pose structure is a quaternion. When specified as `'rotmat'`, the `Orientation` field is a rotation matrix.

Example: `'rotmat'`

Data Types: `char`

2-109

Output Arguments

poses — Platform poses in scenario coordinates
structures | array of structures

Poses of all platforms in the tracking scenario, returned as a structure or array of structures. The pose structure contains these fields:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field with no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in scenario coordinates, specified as a real-valued 1-by-3 vector. This is a required field with no default value. Units are in meters.
Velocity	Velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default value is [0 0 0].
Acceleration	Acceleration of the platform in scenario coordinates, specified as a 1-by-3 row vector in meters per second-squared. The default value is [0 0 0].

Field	Description
Orientation	Orientation of the platform with respect to the local scenario NED coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. The format is specified by the `fmt` input argument. Orientation defines the frame rotation from the local NED coordinate system to the current platform body coordinate system. Units are dimensionless. The default value is `quaternion(1,0,0,0)`.
AngularVelocity	Angular velocity of the platform in scenario coordinates, specified as a real-valued 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is value `[0 0 0]`.

Data Types: `struct`

Introduced in R2018b

platformProfiles

Profiles of platforms in tracking scenario

Syntax

```
profiles = platformProfiles(sc)
```

Description

`profiles = platformProfiles(sc)` returns the `profiles` of all platforms in the tracking scenario, `sc`.

Input Arguments

sc — Tracking scenario
`trackingScenario` object

Tracking scenario, specified as a `trackingScenario` object.

Output Arguments

profiles — Platform profiles
array of structures

Profiles of all platforms in the tracking scenario, returned as an array of structures. Each profile contains the signatures of a platform and identifying information. The structure contains these fields:

Field	Description
PlatformID	Scenario-defined platform identifier, defined as a positive integer

Field	Description
ClassID	User-defined platform classification identifier, defined as a nonnegative integer
Signatures	Platform signatures defined as a cell array of radar cross-section (rcsSignature), IR emission pattern (irSignature), and sonar target strength (tsSignature) objects.

See Platform for more completed definitions of the fields.

Introduced in R2018b

record

Run tracking scenario and record platform states

Syntax

```
rec = record(sc)
rec = record(sc,fmt)
```

Description

rec = record(sc) returns a record, rec, of the evolution of the tracking scenario simulation, sc. The record function starts the simulation from the beginning,

rec = record(sc,fmt) also specifies the format, fmt, of the returned platform orientation.

Input Arguments

sc — Tracking scenario
trackingScenario object

Tracking scenario, specified as a trackingScenario object.

fmt — Pose orientation format
'quaternion' (default) | 'rotmat'

Pose orientation format, specified as 'quaternion' or 'rotmat'. When specified as 'quaternion', the Orientation field of the platform pose structure is a quaternion. When specified as 'rotmat', the Orientation field is a rotation matrix.

Example: 'rotmat'

Data Types: char

Output Arguments

`rec` — Records of platform states during simulation
M-by-1 vector of structures

Records of platform states during the simulation, returned as an *M*-by-1 vector of structures. *M* is the number of time steps in the simulation. Each record corresponds to a simulation time step and contains the poses of all the platforms at that time. The record structure has these fields:

```
SimulationTime
Poses
```

The `SimulationTime` field contains the simulation time of the record. `Poses` is an *N*-by-1 vector of structures, where *N* is the number of platforms. Each `Poses` structure contains these fields:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field with no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in scenario coordinates, specified as a real-valued 1-by-3 vector. This is a required field with no default value. Units are in meters.
Velocity	Velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default value is [0 0 0].
Acceleration	Acceleration of the platform in scenario coordinates, specified as a 1-by-3 row vector in meters per second-squared. The default value is [0 0 0].

Field	Description
`Orientation`	Orientation of the platform with respect to the local scenario NED coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. The format is specified by the `fmt` input argument. Orientation defines the frame rotation from the local NED coordinate system to the current platform body coordinate system. Units are dimensionless. The default value is `quaternion(1,0,0,0)`.
`AngularVelocity`	Angular velocity of the platform in scenario coordinates, specified as a real-valued 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is value `[0 0 0]`.

Data Types: `struct`

Introduced in R2018b

restart

Restart tracking scenario simulation

Syntax

```
restart(sc)
```

Description

restart(sc) restarts the simulation of the tracking scenario, sc, from the beginning and sets the SimulationTime property of sc to zero.

Input Arguments

sc — Tracking scenario
trackingScenario object

Tracking scenario, specified as a trackingScenario object.

Introduced in R2018b

rcsSignature class

Radar cross-section pattern

Description

`rcsSignature` creates a radar cross-section (RCS) signature object. You can use this object to model an angle-dependent and frequency-dependent radar cross-section pattern. The radar cross-section determines the intensity of reflected radar signal power from a target. The object models only non-polarized signals.

Construction

`rcssig = rcsSignature` creates an `rcsSignature` object with default property values.

`rcssig = rcsSignature(Name,Value)` sets object properties using 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`. Any unspecified properties take default values.

Properties

`Pattern` — Sampled radar cross-section pattern
[10 10; 10 10] (default) | *Q*-by-*P* real-valued matrix | *Q*-by-*P*-by-*K* real-valued array

Sampled radar cross-section (RCS) pattern, specified as a scalar, a *Q*-by-*P* real-valued matrix, or a *Q*-by-*P*-by-*K* real-valued array. The pattern is an array of RCS values defined on a grid of elevation angles, azimuth angles, and frequencies. Azimuth and elevation are defined in the body frame of the target.

- *Q* is the number of RCS samples in elevation.
- *P* is the number of RCS samples in azimuth.

- *K* is the number of RCS samples in frequency.

Q, *P*, and *K* usually match the length of the vectors defined in the `Elevation`, `Azimuth`, and `Frequency` properties, respectively, with these exceptions:

- To model an RCS pattern for an elevation cut (constant azimuth), you can specify the RCS pattern as a *Q*-by-1 vector or a 1-by-*Q*-by-*K* matrix. Then, the elevation vector specified in the `Elevation` property must have length 2.
- To model an RCS pattern for an azimuth cut (constant elevation), you can specify the RCS pattern as a 1-by-*P* vector or a 1-by-*P*-by-*K* matrix. Then, the azimuth vector specified in the `Azimuth` property must have length 2.
- To model an RCS pattern for one frequency, you can specify the RCS pattern as a *Q*-by-*P* matrix. Then, the frequency vector specified in the `Frequency` property must have length 2.

Example: `[10,0;0,-5]`

Data Types: `double`

Azimuth — Azimuth angles
`[-180 180]` (default) | length-*P* real-valued vector

Azimuth angles used to define the angular coordinates of each column of the matrix or array, specified by the `Pattern` property. Specify the azimuth angles as a length-*P* vector. *P* must be greater than two. Angle units are in degrees.

Example: `[-45:0.5:45]`

Data Types: `double`

Elevation — Elevation angles
`[-90 90]` (default) | length-*Q* real-valued vector

Elevation angles used to define the coordinates of each row of the matrix or array, specified by the `Pattern` property. Specify the elevation angles as a length-*Q* vector. *Q* must be greater than two. Angle units are in degrees.

Example: `[-30:0.5:30]`

Data Types: `double`

Frequency — Pattern frequencies
`[-90 90]` (default) | length-*K* real-valued vector

Frequencies used to define the applicable RCS for each page of the `Pattern` property. Specify the frequencies as a length-*K* vector. *K* must be greater than two. Frequency units are in hertz.

Example: `[-30:0.1:30]`

Data Types: `double`

Methods

value   Radar cross-section at specified angle and frequency

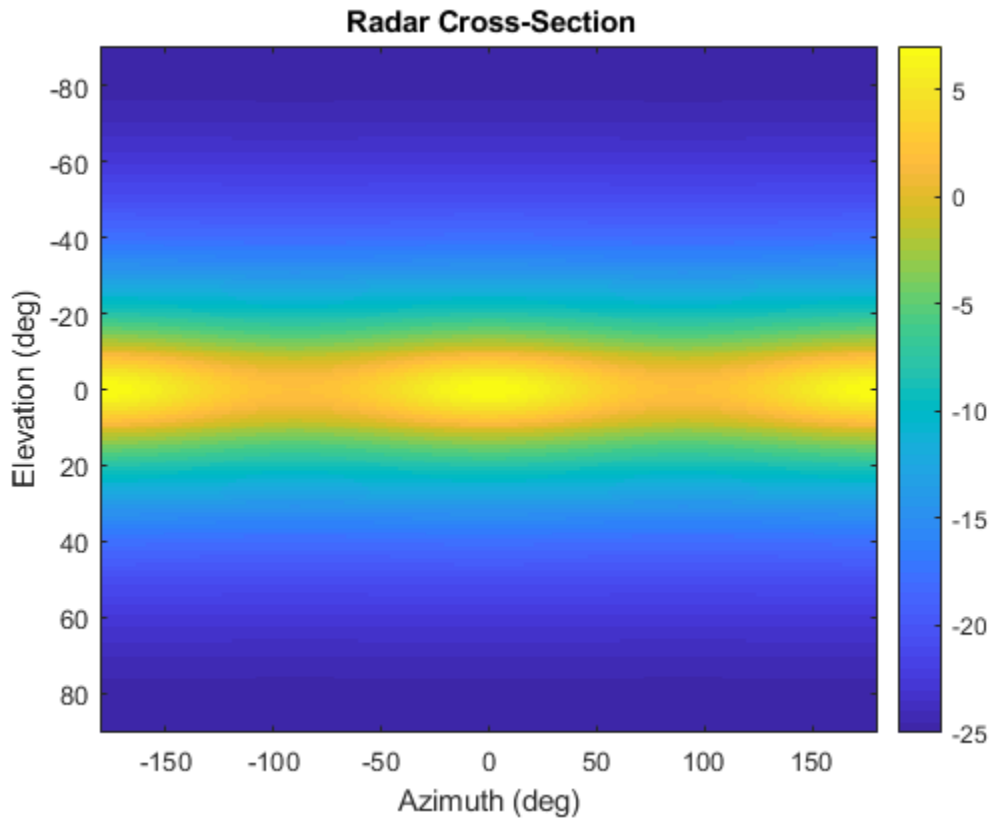# Examples

Radar Cross-Section of Ellipsoid

Specify the radar cross-section (RCS) of a triaxial ellipsoid and plot RCS values along an azimuth cut.

Specify the lengths of the axes of the ellipsoid. Units are in meters.

```
a = 0.15;
b = 0.20;
c = 0.95;
```

Create an RCS array. Specify the range of azimuth and elevation angles over which RCS is defined. Then, use an analytical model to compute the radar cross-section of the ellipsoid. Create an image of the RCS.

```
az = [-180:1:180];
el = [-90:1:90];
rcs = rcs_ellipsoid(a,b,c,az,el);
rcsdb = 10*log10(rcs);
imagesc(az,el,rcsdb)
title('Radar Cross-Section')
xlabel('Azimuth (deg)')
ylabel('Elevation (deg)')
colorbar
```

Radar Cross-Section

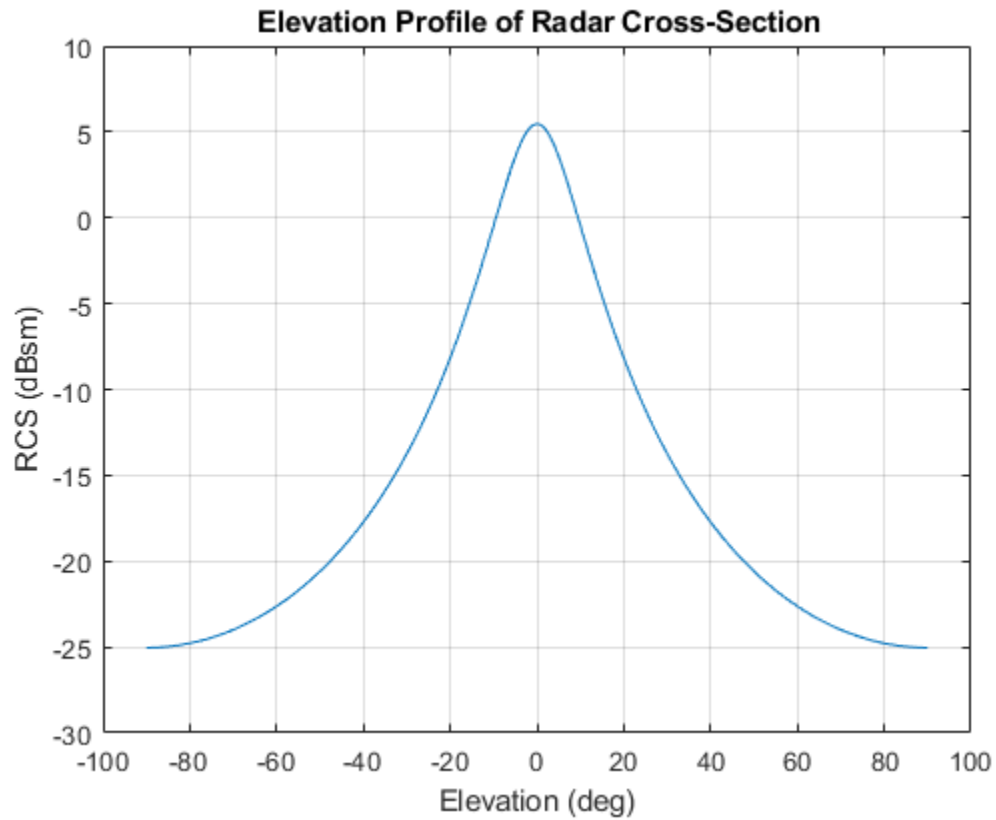Create an `rcsSignature` object and plot an elevation cut at $30°$ azimuth.

```
rcssig = rcsSignature('Pattern',rcsdb,'Azimuth',az,'Elevation',el,'Frequency',[300e6 30
rcsdb1 = value(rcssig,30,el,300e6);
plot(el,rcsdb1)
grid
title('Elevation Profile of Radar Cross-Section')
xlabel('Elevation (deg)')
ylabel('RCS (dBsm)')

function rcs = rcs_ellipsoid(a,b,c,az,el)
sinaz = sind(az);
cosaz = cosd(az);
sintheta = sind(90 - el);
```

2-121

```
costheta = cosd(90 - el);
denom = (a^2*(sintheta'.^2)*cosaz.^2 + b^2*(sintheta'.^2)*sinaz.^2 + c^2*(costheta'.^2)
rcs = (pi*a^2*b^2*c^2)./denom;
end
```


Elevation Profile of Radar Cross-Section

References

[1] Richards, Mark A. *Fundamentals of Radar Signal Processing.* New York, McGraw-Hill, 2005.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
tsSignature

Introduced in R2018b

value

Class: rcsSignature

Radar cross-section at specified angle and frequency

Syntax

```
rcsval = value(rcssig,az,el,freq)
```

Description

`rcsval = value(rcssig,az,el,freq)` returns the value, `rcsval`, of the radar cross-section (RCS) specified by the radar signature object, `rcssig`, computed at the specified azimuth `az`, elevation `el`, and frequency `freq`.

Input Arguments

`rcssig` — RCS signature object
rcsSignature object

Radar cross-section signature, specified as an `rcsSignature` object.

az — Azimuth angle
scalar | length-*M* real-valued vector

Azimuth angle, specified as scalar or length-*M* real-valued vector. Units are in degrees. The `az`, `el`, and `freq` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case the arguments are expanded to length-*M*.

Data Types: `double`

el — Elevation angle
scalar | length-*M* real-valued vector

Elevation angle, specified as scalar or length-*M* real-valued vector. The `az`, `el`, and `freq` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case the arguments are expanded to length-*M*. Units are in degrees.

Data Types: `double`

freq — RCS frequency
positive scalar | length-*M* vector with positive, real elements

RCS frequency, specified as a positive scalar or length-*M* vector with positive, real elements. The `az`, `el`, and `freq` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case the arguments are expanded to length-*M* vectors. Units are in Hertz.

Example: `100e6`

Data Types: `double`

Output Arguments

rcsval — Radar cross-section
scalar | real-valued length-*M* vector

Radar cross-section, returned as a scalar or real-valued length-*M* vector. Units are in dBsm.

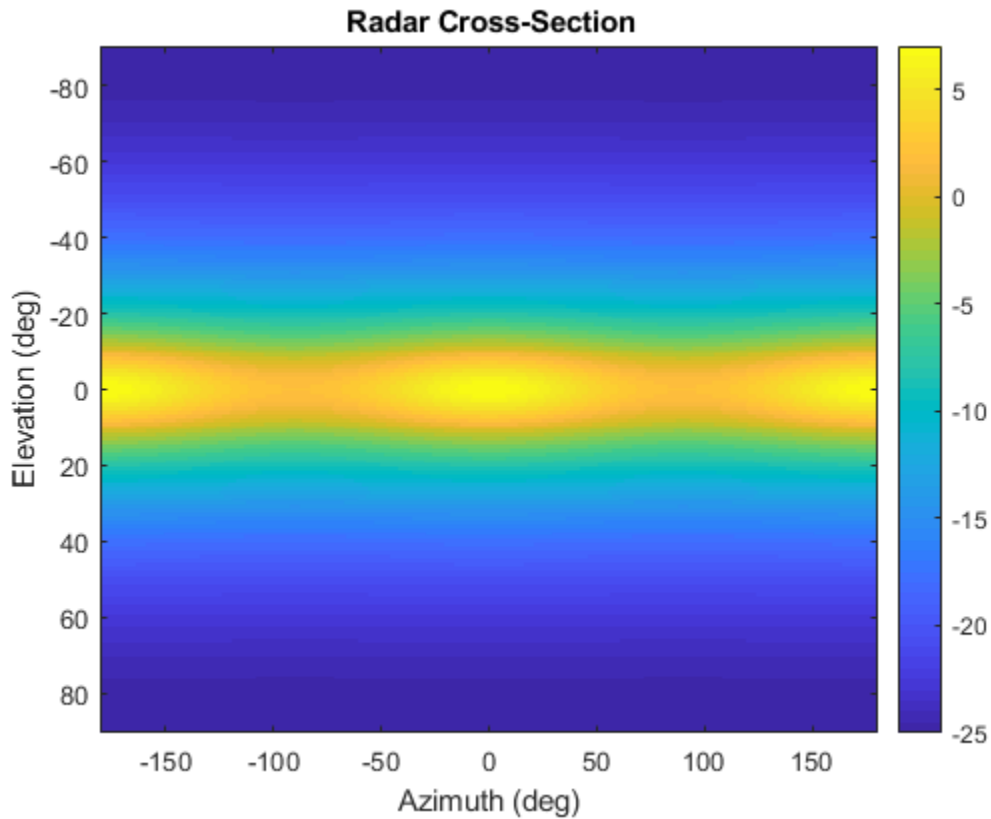# Examples

Radar Cross-Section of Ellipsoid

Specify the radar cross-section (RCS) of a triaxial ellipsoid and plot RCS values along an azimuth cut.

Specify the lengths of the axes of the ellipsoid. Units are in meters.

```
a = 0.15;
b = 0.20;
c = 0.95;
```

2-125

Create an RCS array. Specify the range of azimuth and elevation angles over which RCS is defined. Then, use an analytical model to compute the radar cross-section of the ellipsoid. Create an image of the RCS.

```
az = [-180:1:180];
el = [-90:1:90];
rcs = rcs_ellipsoid(a,b,c,az,el);
rcsdb = 10*log10(rcs);
imagesc(az,el,rcsdb)
title('Radar Cross-Section')
xlabel('Azimuth (deg)')
ylabel('Elevation (deg)')
colorbar
```

Create an `rcsSignature` object and plot an elevation cut at $30°$ azimuth.

```
rcssig = rcsSignature('Pattern',rcsdb,'Azimuth',az,'Elevation',el,'Frequency',[300e6 30
rcsdb1 = value(rcssig,30,el,300e6);
plot(el,rcsdb1)
grid
title('Elevation Profile of Radar Cross-Section')
xlabel('Elevation (deg)')
ylabel('RCS (dBsm)')

function rcs = rcs_ellipsoid(a,b,c,az,el)
sinaz = sind(az);
cosaz = cosd(az);
sintheta = sind(90 - el);
costheta = cosd(90 - el);
denom = (a^2*(sintheta'.^2)*cosaz.^2 + b^2*(sintheta'.^2)*sinaz.^2 + c^2*(costheta'.^2)
rcs = (pi*a^2*b^2*c^2)./denom;
end
```
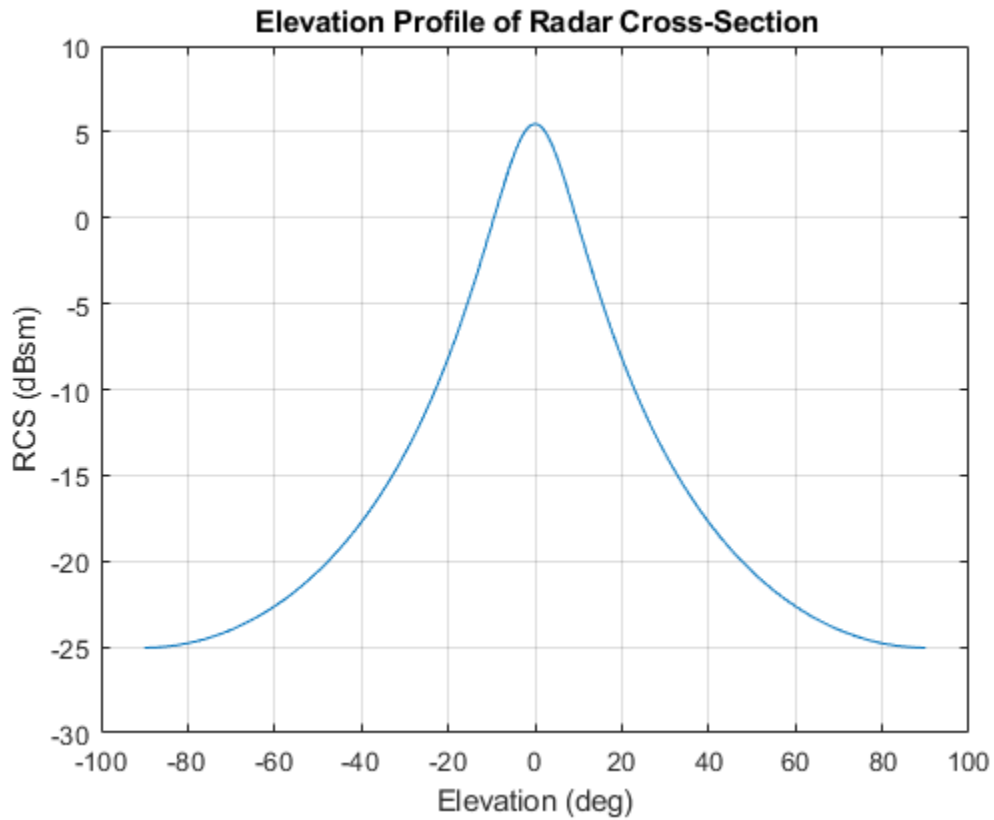
Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Introduced in R2018b

tsSignature class

Target strength pattern

Description

`tsSignature` creates a sonar target strength (TS) signature object. You can use this object to model an angle-dependent and frequency-dependent target strength pattern. Target strength determines the intensity of reflected sound signal power from a target.

Construction

`tssig = tsSignature` creates a `tsSignature` object with default property values.

`tssig = tsSignature(Name,Value)` sets object properties using 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`. Any unspecified properties take default values.

Properties

Pattern — Target strength pattern
[10 10; 10 10] (default) | *Q*-by-*P* real-valued matrix | *Q*-by-*P*-by-*K* real-valued array

Sampled target strength pattern, specified as a scalar, a *Q*-by-*P* real-valued matrix, or a *Q*-by-*P*-by-*K* real-valued array. The pattern is an array of TS values defined on a grid of elevation angles, azimuth angles, and frequencies. Azimuth and elevation are defined in the body frame of the target.

- *Q* is the number of TS samples in elevation.
- *P* is the number of TS samples in azimuth.
- *K* is the number of TS samples in frequency.

Q, *P*, and *K* usually match the length of the vectors defined in the `Elevation`, `Azimuth`, and `Frequency` properties, respectively, with these exceptions:

- To model a TS pattern for an elevation cut (constant azimuth), you can specify the TS pattern as a *Q*-by-1 vector or a 1-by-*Q*-by-*K* matrix. Then, the elevation vector specified in the `Elevation` property must have length 2.
- To model a TS pattern for an azimuth cut (constant elevation), you can specify the TS pattern as a 1-by-*P* vector or a 1-by-*P*-by-*K* matrix. Then, the azimuth vector specified in the `Azimuth` property must have length 2.
- To model a TS pattern for one frequency, you can specify the TS pattern as a *Q*-by-*P* matrix. Then, the frequency vector specified in the `Frequency` property must have length 2.

Example: `[10,0;0,-5]`

Data Types: `double`

Azimuth — Azimuth angles
`[-180 180]` (default) | length-*P* real-valued vector

Azimuth angles used to define the angular coordinates of each column of the matrix or array specified by the `Pattern` property. Specify the azimuth angles as a length-*P* vector. *P* must be greater than two. Angle units are in degrees.

Example: `[-45:0.1:45]`

Data Types: `double`

Elevation — Elevation angles
`[-90 90]` (default) | length-*Q* real-valued vector

Elevation angles used to define the coordinates of each row of the matrix or array specified by the `Pattern` property. Specify the elevation angles as a length-*Q* vector. *Q* must be greater than two. Angle units are in degrees.

Example: `[-30:0.1:30]`

Data Types: `double`

Frequency — Pattern frequencies
`[-90 90]` (default) | length-*K* real-valued vector

Frequencies used to define the applicable RCS for each page of the `Pattern` property. Specify the frequencies as a length-*K* vector. *K* must be greater than two. Frequency units are in hertz.

Example: `[-30:0.1:30]`

Data Types: `double`

Methods

value   Target strength at specified angle and frequency
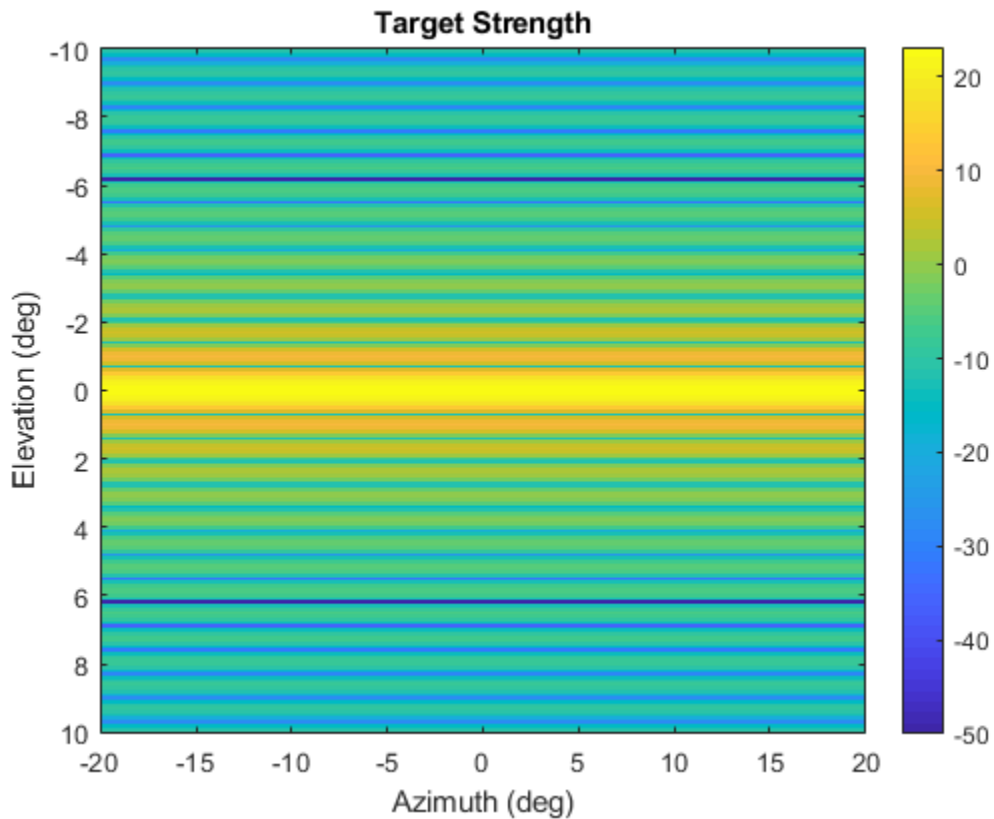
Examples

Target Strength of Rigid Cylinder

Specify the target strength (TS) of a 5m long rigid cylinder immersed in water and plot TS values along an azimuth cut. Assume the short-wavelength approximation. The cylinder radius is 2m. The speed of sound is 1520 m/s.

```
L = 5;
a = 2;
```

Create an array of target strengths at two wavelengths. First, specify the range of azimuth and elevation angles over which TS is defined. Then, use an analytical model to compute the target strength. Create an image of the TS.

```
lambda = [0.12, .1];
c = 1520.0;
az = [-20:0.1:20];
el = [-10:0.1:10];
ts1 = ts_cylinder(L,a,az,el,lambda(1));
ts2 = ts_cylinder(L,a,az,el,lambda(2));
tsdb1 = 10*log10(ts1);
tsdb2 = 10*log10(ts2);
imagesc(az,el,tsdb1)
title('Target Strength')
xlabel('Azimuth (deg)')
ylabel('Elevation (deg)')
colorbar
```

Target Strength

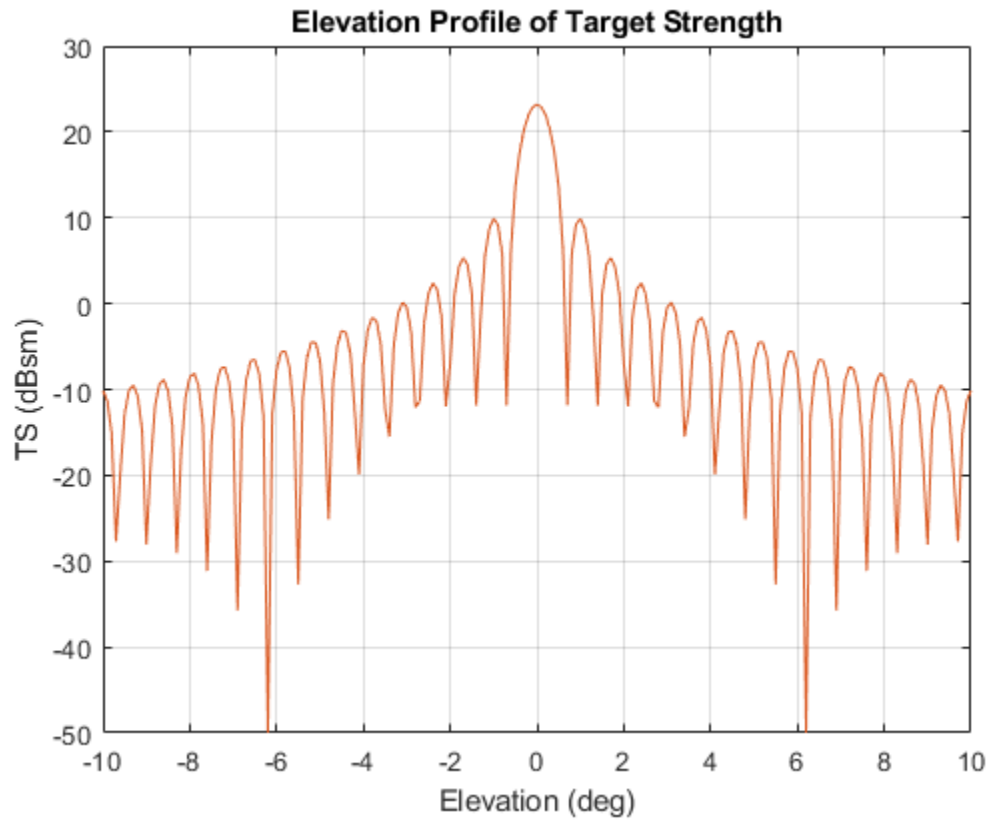Create a `tsSignature` object and plot an elevation cut at $30°$ azimuth.

```
tsdb(:,:,1) = tsdb1;
tsdb(:,:,2) = tsdb2;
freq = c./lambda;
tssig = tsSignature('Pattern',tsdb,'Azimuth',az,'Elevation',el,'Frequency',freq);
ts = value(tssig,30,el,freq(1));
plot(el,tsdb1)
grid
title('Elevation Profile of Target Strength')
xlabel('Elevation (deg)')
ylabel('TS (dBsm)')

function ts = ts_cylinder(L,a,az,el,lambda)
```

2-133

```
k = 2*pi/lambda;
beta = k*L*sind(el')*ones(size(az));
gamma = cosd(el')*ones(size(az));
ts = a*L^2*(sinc(beta).^2).*gamma.^2/2/lambda;
ts = max(ts,10^(-5));
end

function s = sinc(theta)
s = ones(size(theta));
idx = (abs(theta) <= 1e-2);
s(idx) = 1 - 1/6*(theta(idx)).^2;
s(~idx) = sin(theta(~idx))./theta(~idx);
end
```

Elevation Profile of Target Strength

References

[1] Urich, Robert J. *Principles of Underwater Sound, 3rd ed.* New York: McGraw-Hill, Inc. 2005.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
`rcsSignature`

Introduced in R2018b

value

Class: tsSignature

Target strength at specified angle and frequency

Syntax

```
tsval = value(tssig,az,el,freq)
```

Description

`tsval = value(tssig,az,el,freq)` returns the value, `tsval`, of the target strength specified by the target strength signature object, `tssig`, computed at azimuth `az`, elevation `el`, and frequency `freq`.

Input Arguments

`tssig` — Target strength signature
tsSignature object

Target strength signature, specified as a `tsSignature` object.

az — Azimuth angle
scalar | length-*M* real-valued vector

Azimuth angle, specified as scalar or length-*M* real-valued vector. Units are in degrees. The `az`, `el`, and `freq` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case the arguments are expanded to length-*M*.

Data Types: `double`

el — Elevation angle
scalar | length-*M* real-valued vector

Elevation angle, specified as scalar or length-*M* real-valued vector. The `az`, `el`, and `freq` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case the arguments are expanded to length-*M*. Units are in degrees.

Data Types: `double`

`freq` — TS frequency
positive scalar | length-*M* vector with positive, real elements

TS frequency, specified as a positive scalar or length-*M* vector with positive, real elements. The `az`, `el`, and `freq` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case the arguments are expanded to length-*M*. Units are in Hertz.

Example: `20e3`

Data Types: `double`

Output Arguments

`tssval` — Target strength
scalar | real-valued length-*M* vector

Target strength, returned as a scalar or real-valued length-*M* vector. Units are in dBsm.

Examples

Target Strength of Rigid Cylinder

Specify the target strength (TS) of a 5m long rigid cylinder immersed in water and plot TS values along an azimuth cut. Assume the short-wavelength approximation. The cylinder radius is 2m. The speed of sound is 1520 m/s.

```
L = 5;
a = 2;
```

Create an array of target strengths at two wavelengths. First, specify the range of azimuth and elevation angles over which TS is defined. Then, use an analytical model to compute the target strength. Create an image of the TS.

```
lambda = [0.12, .1];
c = 1520.0;
az = [-20:0.1:20];
el = [-10:0.1:10];
ts1 = ts_cylinder(L,a,az,el,lambda(1));
ts2 = ts_cylinder(L,a,az,el,lambda(2));
tsdb1 = 10*log10(ts1);
tsdb2 = 10*log10(ts2);
imagesc(az,el,tsdb1)
title('Target Strength')
xlabel('Azimuth (deg)')
ylabel('Elevation (deg)')
colorbar
```

Create a `tsSignature` object and plot an elevation cut at $30°$ azimuth.

```
tsdb(:,:,1) = tsdb1;
tsdb(:,:,2) = tsdb2;
freq = c./lambda;
tssig = tsSignature('Pattern',tsdb,'Azimuth',az,'Elevation',el,'Frequency',freq);
ts = value(tssig,30,el,freq(1));
plot(el,tsdb1)
grid
title('Elevation Profile of Target Strength')
xlabel('Elevation (deg)')
ylabel('TS (dBsm)')

function ts = ts_cylinder(L,a,az,el,lambda)
k = 2*pi/lambda;
beta = k*L*sind(el')*ones(size(az));
gamma = cosd(el')*ones(size(az));
ts = a*L^2*(sinc(beta).^2).*gamma.^2/2/lambda;
ts = max(ts,10^(-5));
end

function s = sinc(theta)
s = ones(size(theta));
idx = (abs(theta) <= 1e-2);
s(idx) = 1 - 1/6*(theta(idx)).^2;
s(~idx) = sin(theta(~idx))./theta(~idx);
end
```

Elevation Profile of Target Strength
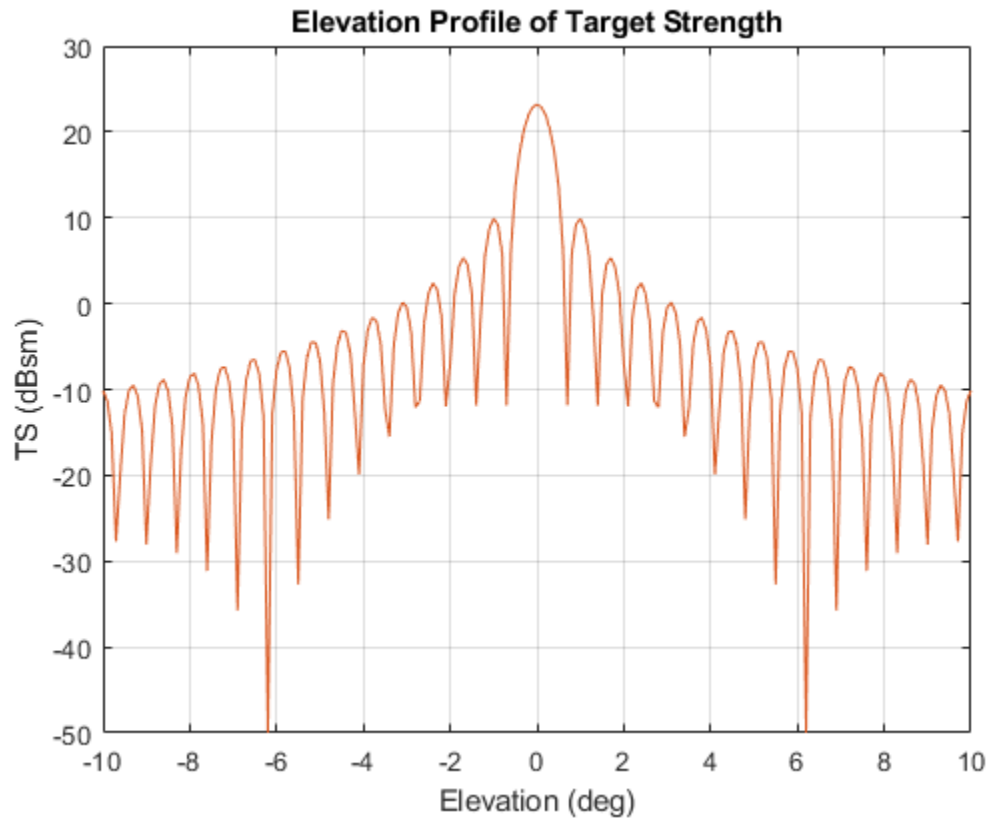
Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Introduced in R2018b

irSignature class

Infrared platform signature

Description

The `irSignature` creates an infrared (IR) signature object. You can use this object to model an angle-dependent contrast radiant intensity of a platform. The radiant intensity is with respect to the background.

Construction

`irsig = irSignature` creates an `irSignature` object with default property values.

`irsig = irSignature(Name,Value)` sets object properties using 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`. Any unspecified properties take default values.

Properties

Pattern — Sampled IR intensity pattern
[50 50; 50 50] (default) | *Q*-by-*P* real-valued matrix

Sampled contrast IR intensity pattern, specified as a scalar, a *Q*-by-*P* real-valued matrix. The pattern is an array of IR values defined on a grid of elevation angles and azimuth angles. Azimuth and elevation are defined in the body frame of the target. Units are dBw/sr.

- *Q* is the number of IR samples in elevation.
- *P* is the number of IR samples in azimuth.

Q and *P* usually match the length of the vectors defined in the `Elevation` and `Azimuth` properties, respectively, with these exceptions:

- If you want to model an IR pattern for an elevation cut (constant azimuth), you can specify the IR pattern as a *Q*-by-1 vector. Then, the elevation vector specified in the `Elevation` property must have length-2.

- If you want to model an IR pattern for an azimuth cut (constant elevation), you can specify the IR pattern as a 1-by-*P* vector. Then, the azimuth vector specified in the `Azimuth` property must have length-2.

Example: `[10,0;0,-5]`

Data Types: `double`

Azimuth — Azimuth angles
`[-180 180]` (default) | length-*P* real-valued vector

Azimuth angles used to define the angular coordinates of each column of the matrix or array specified by the `Pattern` property. Specify the azimuth angles as a length *P* vector. *P* must be greater than two. Angle units are in degrees.

Example: `[-45:0.5:45]`

Data Types: `double`

Elevation — Elevation angles
`[-90 90]` (default) | length-*Q* real-valued vector

Elevation angles used to define the coordinates of each row of the matrix or array specified by the `Pattern` property. Specify the elevation angles as a length *Q* vector. *Q* must be greater than two. Angle units are in degrees.

Example: `[-30:0.5:30]`

Data Types: `double`

Methods

value   Infrared intensity at specified angle and frequency

Examples

Create Direction-Dependent IR Signature

Create and display an IR intensity signature. The signature depends on azimuth and elevation.

Define the azimuth and elevation angle sample points.

```
az = -90:90;
el = [-30:30];
```

Create the IR intensity signature pattern.

```
pat = 50*cosd(2*el.')*cosd(az).^2;
irsig = irSignature('Pattern',pat,'Azimuth',az,'Elevation',el);
```

Display the IR pattern.

```
imagesc(irsig.Azimuth,irsig.Elevation,irsig.Pattern)
xlabel('Azimuth (deg)')
ylabel('Elevation')
title('Infrared Signature Pattern (dBw/sr)')
```

Get the IR intensity value at 25 degrees azimuth and 10 degrees elevation.

```
value(irsig,25,10)
```

```
ans =

   38.5929
```

Get IR intensity value outside of the valid elevation span.

```
value(irsig,25,35)
```

```
ans =

  -Inf
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
rcsSignature | tsSignature

Introduced in R2018b

value

Class: irSignature

Infrared intensity at specified angle and frequency

Syntax

```
irval = value(irsig,az,el)
```

Description

`irval = value(irsig,az,el)` returns the value of the IR intensity, `irval`, specified by the IR signature object, `irsig`, computed at the azimuth, `az`, and elevation, `el`.

Input Arguments

`irsig` — IR signature object
irSignature object

Radar cross-section signature, specified as an `irSignature` object.

`az` — Azimuth angle
scalar | real-valued length-*M* vector

Azimuth angle, specified as scalar or length-*M* real-valued vector. Units are in degrees. The `az`, `el`, and `freq` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case, the arguments are expanded to length-*M*.

Example: 30

Data Types: `double`

`el` — Elevation angle
scalar | real-valued length-*M* vector

Elevation angle, specified as scalar or real-valued length-*M* vector. The `az` and `el` arguments must have the same size. You can, however, specify one or two arguments as scalars, in which case, the arguments are expanded to length-*M*. Units are in degrees.

Example: `-4`

Data Types: `double`

Output Arguments

`irval` — Infrared intensity
scalar | real-valued length-*M* vector

Infrared intensity, returned as a scalar or real-valued length-*M* vector. Units are in dBw/sr.

Examples

Create Direction-Dependent IR Signature

Create and display an IR intensity signature. The signature depends on azimuth and elevation.

Define the azimuth and elevation angle sample points.

```
az = -90:90;
el = [-30:30];
```

Create the IR intensity signature pattern.

```
pat = 50*cosd(2*el.')*cosd(az).^2;
irsig = irSignature('Pattern',pat,'Azimuth',az,'Elevation',el);
```

Display the IR pattern.

```
imagesc(irsig.Azimuth,irsig.Elevation,irsig.Pattern)
xlabel('Azimuth (deg)')
ylabel('Elevation')
title('Infrared Signature Pattern (dBw/sr)')
```

Infrared Signature Pattern (dBw/sr)

Get the IR intensity value at 25 degrees azimuth and 10 degrees elevation.

```
value(irsig,25,10)
```

```
ans =

   38.5929
```

Get IR intensity value outside of the valid elevation span.

```
value(irsig,25,35)
```

```
ans =

  -Inf
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Introduced in R2018b

trackingKF class

Linear Kalman filter

Description

The `trackingKF` class creates a discrete-time linear Kalman filter used for tracking positions and velocities of target platforms. A Kalman filter is a recursive algorithm for estimating the evolving state of a process when measurements are made on the process. The filter is linear when the evolution of the state follows a linear motion model and the measurements are linear functions of the state. Both the process and the measurements can have additive noise. The filter also allows for optional controls or forces to act on the vehicle. When the process noise and measurement noise are Gaussian, the Kalman filter is the optimal minimum mean squared error (MMSE) state estimator for linear processes.

You can use this object in two ways:

- The first way is to specify explicitly the motion model. Set the motion model property, `MotionModel`, to `Custom` and then use the `StateTransitionModel` property to set the state transition matrix.

- The second way is to set the `MotionModel` property to a predefined state transition model:

Motion Model
'1D Constant Velocity'
'1D Constant Acceleration'
'2D Constant Velocity'
'2D Constant Acceleration'
'3D Constant Velocity'
'3D Constant Acceleration'

Construction

`filter = trackingKF` returns a linear Kalman filter object for a discrete-time, 2-D constant-velocity moving object. The Kalman filter uses default values for the `StateTransitionModel`, `MeasurementModel`, and `ControlModel` properties. The `MotionModel` property is set to `'2D Constant Velocity'`.

`filter = trackingKF(F,H)` specifies the state transition model, F, and the measurement model, H. The `MotionModel` property is set to `'Custom'`.

`filter = trackingKF(F,H,G)` also specifies the control model, G. The `MotionModel` property is set to `'Custom'`.

`filter = trackingKF('MotionModel',model)` sets the motion model property, `MotionModel`, to `model`.

`filter = trackingKF( ___ ,Name,Value)` configures the properties of the Kalman filter using one or more `Name,Value` pair arguments. Any unspecified properties take default values.

Properties

State — Kalman filter state
0 (default) | real-valued scalar | real-valued *M*-element vector

Kalman filter state, specified as a real-valued *M*-element vector. *M* is the size of the state vector. Typical state vector sizes are described in the `MotionModel` property. When the initial state is specified as a scalar, the state is expanded into an *M*-element vector.

You can set the state to a scalar in these cases:

- When the `MotionModel` property is set to `'Custom'`, *M* is determined by the size of the state transition model.
- When the `MotionModel` property is set to `'2D Constant Velocity'`, `'3D Constant Velocity'`, `'2D Constant Acceleration'`, or `'3D Constant Acceleration'` you must first specify the state as an *M*-element vector. You can use a scalar for all subsequent specifications of the state vector.

Example: [200;0.2;-40;-0.01]

Data Types: `double`

StateCovariance — State estimation error covariance
1 (default) | positive scalar | positive-definite real-valued *M*-by-*M* matrix

State error covariance, specified as a positive scalar or a positive-definite real-valued *M*-by-*M* matrix, where *M* is the size of the state. Specifying the value as a scalar creates a multiple of the *M*-by-*M* identity matrix. This matrix represents the uncertainty in the state.

Example: `[20 0.1; 0.1 1]`

Data Types: `double`

MotionModel — Kalman filter motion model
`'Custom'` (default) | `'1D Constant Velocity'` | `'2D Constant Velocity'` | `'3D Constant Velocity'` | `'1D Constant Acceleration'` | `'2D Constant Acceleration'` | `'3D Constant Acceleration'`

Kalman filter motion model, specified as `'Custom'` or one of these predefined models. In this case, the state vector and state transition matrix take the form specified in the table.

MotionModel	Form of State Vector	Form of State Transition Model
`'1D Constant Velocity'`	`[x;vx]`	`[1 dt; 0 1]`
`'2D Constant Velocity'`	`[x;vx;y;vy]`	Block diagonal matrix with the `[1 dt; 0 1]` block repeated for the *x* and *y* spatial dimensions
`'3D Constant Velocity'`	`[x;vx;y;vy;z;vz]`	Block diagonal matrix with the `[1 dt; 0 1]` block repeated for the *x*, *y*, and *z* spatial dimensions.
`'1D Constant Acceleration'`	`[x;vx;ax]`	`[1 dt 0.5*dt^2; 0 1 dt; 0 0 1]`

MotionModel	Form of State Vector	Form of State Transition Model
`'2D Constant Acceleration'`	`[x;vx;ax;y;vy;ay]`	Block diagonal matrix with `[1 dt 0.5*dt^2; 0 1 dt; 0 0 1]` blocks repeated for the *x* and *y* spatial dimensions
`'3D Constant Acceleration'`	`[x;vx,ax;y;vy;ay;z;vz;az]`	Block diagonal matrix with the `[1 dt 0.5*dt^2; 0 1 dt; 0 0 1]` block repeated for the *x*, *y*, and *z* spatial dimensions

When the `ControlModel` property is defined, every nonzero element of the state transition model is replaced by `dt`.

When `MotionModel` is `'Custom'`, you must specify a state transition model matrix, a measurement model matrix, and optionally, a control model matrix as input arguments to the Kalman filter.

Data Types: `char`

StateTransitionModel — State transition model between time steps

$[1\ 1\ 0\ 0;\ 0\ 1\ 0\ 0;\ 0\ 0\ 1\ 1;\ 0\ 0\ 0\ 1]$ (default) | real-valued *M*-by-*M* matrix

State transition model between time steps, specified as a real-valued *M*-by-*M* matrix. *M* is the size of the state vector. In the absence of controls and noise, the state transition model relates the state at any time step to the state at the previous step. The state transition model is a function of the filter time step size.

Example: `[1 0; 1 2]`

Dependencies

To enable this property, set `MotionModel` to `'Custom'`.

Data Types: `double`

ControlModel — Control model

`[]` (default) | *M*-by-*L* real-valued matrix

Control model, specified as an *M*-by-*L* matrix. *M* is the dimension of the state vector and *L* is the number of controls or forces. The control model adds the effect of controls on the evolution of the state.

Example: [.01 0.2]

Data Types: double

ProcessNoise — Covariance of process noise
1 (default) | positive scalar | real-valued positive-definite *M*-by-*M* matrix

Covariance of process noise, specified as a positive scalar or an *M*-by-*M* matrix where *M* is the dimension of the state. If you specify this property as a scalar, the filter uses the value as a multiplier of the *M*-by-*M* identity matrix. Process noise expresses the uncertainty in the dynamic model and is assumed to be zero-mean Gaussian white noise.

Example: [1.0 0.05; 0.05 2]

Data Types: double

MeasurementModel — Measurements model from state vector
[1 0 0 0; 0 0 1 0] (default) | real-valued *N*-by-*M* matrix

Measurement model, specified as a real-valued *N*-by-*M* matrix, where *N* is the size of the measurement vector and *M* is the size of the state vector. The measurement model is a linear matrix that determines predicted measurements from the predicted state.

Example: [1 0.5 0.01; 1.0 1 0]

Data Types: double

MeasurementNoise — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued *N*-by-*N* matrix

Covariance of the measurement noise, specified as a positive scalar or a positive-definite, real-valued *N*-by-*N* matrix, where *N* is the size of the measurement vector. If you specify this property as a scalar, the filter uses the value as a multiplier of the *N*-by-*N* identity matrix. Measurement noise represents the uncertainty of the measurement and is assumed to be zero-mean Gaussian white noise.

Example: 0.2

Data Types: double

Methods

clone	Create Linear Kalman filter object with identical property values
correct	Correct Kalman state vector and state covariance matrix
distance	Distance from measurements to predicted measurement
predict	Predict linear Kalman filter state
initialize	Initialize Kalman filter
likelihood	Measurement likelihood
residual	Measurement residual and residual covariance

Examples

Constant-Velocity Linear Kalman Filter

Create a linear Kalman filter that uses a `2D Constant Velocity` motion model. Assume that the measurement consists of the object's *x-y* location.

Specify the initial state estimate to have zero velocity.

```
x = 5.3;
y = 3.6;
initialState = [x;0;y;0];
KF = trackingKF('MotionModel','2D Constant Velocity','State',initialState);
```

Create the measured positions from a constant-velocity trajectory.

```
vx = 0.2;
vy = 0.1;
T  = 0.5;
pos = [0:vx*T:2;5:vy*T:6]';
```

Predict and correct the state of the object.

```
for k = 1:size(pos,1)
    pstates(k,:) = predict(KF,T);
    cstates(k,:) = correct(KF,pos(k,:));
end
```

Plot the tracks.

```
plot(pos(:,1),pos(:,2),'k.', pstates(:,1),pstates(:,3),'+', ...
    cstates(:,1),cstates(:,3),'o')
xlabel('x [m]')
ylabel('y [m]')
grid
xt  = [x-2 pos(1,1)+0.1 pos(end,1)+0.1];
yt = [y pos(1,2) pos(end,2)];
text(xt,yt,{'First measurement','First position','Last position'})
legend('Object position', 'Predicted position', 'Corrected position')
```

Definitions

Filter Parameters

This table relates the filter model parameters to the object properties. M is the size of the state vector and N is the size of the measurement vector. L is the size of the control model.

Model Parameter	Meaning	Specified in Property	Size
F_k	State transition model that specifies a linear model of the force-free equations of motion of the object. This model, together with the control model, determines the state at time $k+1$ as a function of the state at time k. The state transition model depends on the time step of the filter.	`StateTransitionModel`	M-by-M
H_k	Measurement model that specifies how the measurements are linear functions of the state.	`MeasurementModel`	N-by-M
G_k	Control model describing the controls or forces acting on the object.	`ControlModel`	M-by-L
x_k	Estimate of the state of the object.	`State`	M-

Model Parameter	Meaning	Specified in Property	Size
P_k	Estimated covariance matrix of the state. The covariance represents the uncertainty in the values of the state.	StateCovariance	M-by-M
Q_k	Estimate of the process noise covariance matrix at step k. Process noise is a measure of the uncertainty in your dynamic model and is assumed to be zero-mean white Gaussian noise.	ProcessNoise	M-by-M
R_k	Estimate of the measurement noise covariance at step k. Measurement noise represents the uncertainty of the measurement and is assumed to be zero-mean white Gaussian noise.	MeasurementNoise	N-by-N

Algorithms

The Kalman filter describes the motion of an object by estimating its state. The state generally consists of object position and velocity and possibly its acceleration. The state can span one, two, or three spatial dimensions. Most frequently, you use the Kalman filter to model constant-velocity or constant-acceleration motion. A linear Kalman filter assumes that the process obeys the following linear stochastic difference equation:

$$x_{k+1} = F_k x_k + G_k u_k + v_k$$

x_k is the state at step k. F_k is the state transition model matrix. G_k is the control model matrix. u_k represents known generalized controls acting on the object. In addition to the specified equations of motion, the motion may be affected by random noise perturbations, v_k. The state, the state transition matrix, and the controls together provide enough information to determine the future motion of the object in the absence of noise.

In the Kalman filter, the measurements are also linear functions of the state,

$$z_k = H_k x_k + w_k$$

where H_k is the measurement model matrix. This model expresses the measurements as functions of the state. A measurement can consist of an object position, position and velocity, or its position, velocity, and acceleration, or some function of these quantities. The measurements can also include noise perturbations, w_k.

These equations, in the absence of noise, model the actual motion of the object and the actual measurements. The noise contributions at each step are unknown and cannot be modeled. Only the noise covariance matrices are known. The state covariance matrix is updated with knowledge of the noise covariance only.

You can read a brief description of the linear Kalman filter algorithm in "Linear Kalman Filters".

References

[1] Brown, R.G. and P.Y.C. Wang. *Introduction to Random Signal Analysis and Applied Kalman Filtering*. 3rd Edition. New York: John Wiley & Sons, 1997.

[2] Kalman, R. E. "A New Approach to Linear Filtering and Prediction Problems." *Transaction of the ASME–Journal of Basic Engineering*, Vol. 82, Series D, March 1960, pp. 35–45.

[3] Blackman, Samuel. *Multiple-Target Tracking with Radar Applications*, Artech House. 1986.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- When you create a `trackingKF` object, and you specify a value other than `Custom` for the `MotionModel` value, you must specify the state vector explicitly at construction time using the `State` property. The choice of motion model determines the size of the state vector but does not specify the data type, for example, double precision or single precision. Both size and data type are required for code generation.

See Also

Functions
`initcakf` | `initcvkf`

Classes
`trackingABF` | `trackingCKF` | `trackingEKF` | `trackingGSF` | `trackingIMM` | `trackingMSCEKF` | `trackingPF` | `trackingUKF`

System Objects
`trackerGNN` | `trackerTOMHT`

Topics
"Linear Kalman Filters"

Introduced in R2017a

clone

Class: trackingKF

Create Linear Kalman filter object with identical property values

Syntax

```
filter2 = clone(filter)
```

Description

`filter2 = clone(filter)` creates another instance of the object, `filter`, having identical property values. If an object is locked, the `clone` method creates a copy that is also locked and has states initialized to the same values as the original. If an object is not locked, the `clone` method creates a new unlocked object with uninitialized states.

Input Arguments

filter — Linear Kalman filter
trackingKF object

Linear Kalman filter, specified as a `trackingKF` object.

Example: `filter = trackingKF`

Output Arguments

filter2 — Linear Kalman filter
trackingKF object

Linear Kalman filter, returned as a `trackingKF` object.

Introduced in R2017a

correct

Class: trackingKF

Correct Kalman state vector and state covariance matrix

Syntax

```
[xcorr,Pcorr] = correct(filter,z)
[xcorr,Pcorr] = correct(filter,z,zcov)
```

Description

`[xcorr,Pcorr] = correct(filter,z)` returns the corrected state vector, `xcorr`, and the corrected state error covariance matrix, `Pcorr`, of the tracking filter, `filter`, based on the current measurement, `z`. The internal state and covariance of the Kalman filter are overwritten by the corrected values.

`[xcorr,Pcorr] = correct(filter,z,zcov)` also specifies the measurement error covariance matrix, `zcov`. When specified, `zcov` is used as the measurement noise. Otherwise, measurement noise will have the value of the `MeasurementNoise` property.

The corrected state and covariance replaces the internal values of the Kalman filter.

Input Arguments

`filter` — Kalman filter
trackingKF object

Kalman filter, specified as a `trackingKF` object.

Example: `filter = trackingKF`

`z` — Object measurement
real-valued *N*-element vector

Object measurement, specified as a real-valued *N*-element vector.

Example: `[2;1]`

Data Types: `double`

`zcov` — Error covariance matrix of measurements
positive-definite real-valued *N*-by-*N* matrix

Error covariance matrix of measurements, specified as a positive-definite real-valued *N*-by-*N* matrix.

Example: `[2,1;1,20]`

Data Types: `double`

Output Arguments

`xcorr` — Corrected state
real-valued *M*-element vector

Corrected state, returned as a real-valued *M*-element vector. The corrected state represents the *a posteriori* estimate of the state vector, taking into account the current measurement.

`Pcorr` — Corrected state error covariance matrix
positive-definite real-valued *M*-by-*M* matrix

Corrected state error covariance matrix, returned as a positive-definite real-valued *M*-by-*M* matrix. The corrected covariance matrix represents the *a posteriori* estimate of the state error covariance matrix, taking into account the current measurement.

Examples

Constant-Velocity Linear Kalman Filter

Create a linear Kalman filter that uses a `2D` `Constant Velocity` motion model. Assume that the measurement consists of the object's *x-y* location.

Specify the initial state estimate to have zero velocity.

```
x = 5.3;
y = 3.6;
```

```
initialState = [x;0;y;0];
KF = trackingKF('MotionModel','2D Constant Velocity','State',initialState);
```

Create the measured positions from a constant-velocity trajectory.

```
vx = 0.2;
vy = 0.1;
T  = 0.5;
pos = [0:vx*T:2;5:vy*T:6]';
```

Predict and correct the state of the object.

```
for k = 1:size(pos,1)
    pstates(k,:) = predict(KF,T);
    cstates(k,:) = correct(KF,pos(k,:));
end
```

Plot the tracks.

```
plot(pos(:,1),pos(:,2),'k.', pstates(:,1),pstates(:,3),'+', ...
    cstates(:,1),cstates(:,3),'o')
xlabel('x [m]')
ylabel('y [m]')
grid
xt  = [x-2 pos(1,1)+0.1 pos(end,1)+0.1];
yt = [y pos(1,2) pos(end,2)];
text(xt,yt,{'First measurement','First position','Last position'})
legend('Object position', 'Predicted position', 'Corrected position')
```

Introduced in R2017a

distance

Class: trackingKF

Distance from measurements to predicted measurement

Syntax

```
dist = distance(filter,zmat)
```

Description

`dist = distance(filter,zmat)` computes the Mahalanobis distances, `dist`, between multiple candidate measurements, `zmat`, of an object and the measurement predicted from the state of the tracking filter, `filter`. The `distance` method is useful for associating measurements to tracks.

The distance computation uses the covariance of the predicted state and the covariance of the process noise. You can call the `distance` method only after calling the `predict` method.

Input Arguments

`filter` — Linear Kalman filter
`trackingKF` object

Linear Kalman filter, specified as a `trackingKF` object.

Example: `filter = trackingKF`

`zmat` — Object measurements
real-valued *K*-by-*N* matrix

Object measurements, specified as a real-valued *K*-by-*N* matrix. *N* is the number of rows in the `MeasurementModel` property. *K* is the number of candidate measurement vectors. Each row forms a single measurement vector.

Example: `[2,1;3,0]`

Data Types: `double`

Output Arguments

`dist` — Mahalanobis distances
positive real-valued *K*-element vector

Mahalanobis distances between candidate measurements and a predicted measurement, returned as a real-valued *K*-element vector. *K* is the number of candidate measurement vectors. The method computes one distance value for each measurement vector.

Introduced in R2017a

predict

Class: trackingKF

Predict linear Kalman filter state

Syntax

```
[xpred,Ppred] = predict(filter)
[xpred,Ppred] = predict(filter,u)
[xpred,Ppred] = predict(filter,F)
[xpred,Ppred] = predict(filter,F,Q)
[xpred,Ppred] = predict(filter,u,F,G)
[xpred,Ppred] = predict(filter,u,F,G,Q)
[xpred,Ppred] = predict(filter,dt)
[xpred,Ppred] = predict(filter,u,dt)
```

Description

`[xpred,Ppred] = predict(filter)` returns the predicted state vector and the predicted state error covariance matrix for the next time step based on the current time step. The predicted values overwrite the internal state vector and covariance matrix of the filter.

This syntax applies when you set the `ControlModel` to an empty matrix.

`[xpred,Ppred] = predict(filter,u)` also specifies a control input or force, u.

This syntax applies when you set the `ControlModel` to a non-empty matrix.

`[xpred,Ppred] = predict(filter,F)` also specifies the state transition model, F. Use this syntax to change the state transition model during a simulation.

This syntax applies when you set the `ControlModel` to an empty matrix.

`[xpred,Ppred] = predict(filter,F,Q)` also specifies the process noise covariance, Q. Use this syntax to change the state transition model and the process noise covariance during a simulation.

This syntax applies when you set the `ControlModel` to an empty matrix.

`[xpred,Ppred] = predict(filter,u,F,G)` also specifies the control model, `G`. Use this syntax to change the state transition model and control model during a simulation.

This syntax applies when you set the `ControlModel` to a non-empty matrix.

`[xpred,Ppred] = predict(filter,u,F,G,Q)` specifies the force or control input, `u`, the state transition model, `F`, the control model, `G`, and the process noise covariance, `Q`. Use this syntax to change the state transition model, control model, and process noise covariance during a simulation.

This syntax applies when you set the `ControlModel` to a non-empty matrix.

`[xpred,Ppred] = predict(filter,dt)` returns the predicted state and state estimation error covariance after the time step, `dt`.

This syntax applies when the `MotionModel` property is not set to `'Custom'` and the `ControlModel` property is set to an empty matrix.

`[xpred,Ppred] = predict(filter,u,dt)` also specifies a control input, `u`.

This syntax applies when the `MotionModel` property is not set to `'Custom'` and the `ControlModel` property is set to a non-empty matrix.

Input Arguments

filter — Kalman filter
trackingKF object

Kalman filter, specified as `trackingKF` object.

Example: `filter = trackingKF`

u — Control vector
real-valued *L*-element vector

Control vector, real-valued *L*-element vector.

Data Types: `double`

F — State transition model
real-valued *M*-by-*M* matrix

State transition model, specified as a real-valued *M*-by-*M* matrix where *M* is the size of the state vector.

Data Types: `double`

Q — Process noise covariance matrix
positive-definite, real-valued *M*-by-*M* matrix

Process noise covariance matrix, specified as a positive-definite, real-valued *M*-by-*M* matrix where *M* is the length of the state vector.

Data Types: `double`

G — Control model
real-valued *M*-by-*L* matrix

Control model, specified as a real-valued *M*-by-*L* matrix, where *M* is the size of the state vector and *L* is the number of independent controls.

dt — Time step
positive scalar

Time step, specified as a positive scalar. Units are in seconds.

Data Types: `double`

Output Arguments

xpred — Predicted state
real-valued *M*-element vector

Predicted state, returned as a real-valued *M*-element vector. The predicted state represents the *deducible* estimate of the state vector, propagated from the previous state using the state transition and control models.

Data Types: `double`

Ppred — Predicted state error covariance matrix
real-valued *M*-by-*M* matrix

Predicted state covariance matrix, specified as a real-valued *M*-by-*M* matrix. *M* is the size of the state vector. The predicted state covariance matrix represents the *deducible* estimate of the covariance matrix vector. The filter propagates the covariance matrix from the previous estimate.

Data Types: `double`

Examples

Constant-Velocity Linear Kalman Filter

Create a linear Kalman filter that uses a `2D Constant Velocity` motion model. Assume that the measurement consists of the object's *x-y* location.

Specify the initial state estimate to have zero velocity.

```
x = 5.3;
y = 3.6;
initialState = [x;0;y;0];
KF = trackingKF('MotionModel','2D Constant Velocity','State',initialState);
```

Create the measured positions from a constant-velocity trajectory.

```
vx = 0.2;
vy = 0.1;
T  = 0.5;
pos = [0:vx*T:2;5:vy*T:6]';
```

Predict and correct the state of the object.

```
for k = 1:size(pos,1)
    pstates(k,:) = predict(KF,T);
    cstates(k,:) = correct(KF,pos(k,:));
end
```

Plot the tracks.

```
plot(pos(:,1),pos(:,2),'k.', pstates(:,1),pstates(:,3),'+', ...
    cstates(:,1),cstates(:,3),'o')
xlabel('x [m]')
ylabel('y [m]')
grid
```

2-173

```
xt  = [x-2 pos(1,1)+0.1 pos(end,1)+0.1];
yt = [y pos(1,2) pos(end,2)];
text(xt,yt,{'First measurement','First position','Last position'})
legend('Object position', 'Predicted position', 'Corrected position')
```


Introduced in R2017a

initialize

Class: trackingKF

Initialize Kalman filter

Syntax

```
initialize(filter,X,P)
initialize(filter,X,P,Name,Value)
```

Description

initialize(filter,X,P) initializes the Kalman filter, `filter`, using the state, x, and the state covariance, P.

initialize(filter,X,P,Name,Value) initializes the Kalman filter properties using one of more name-value pairs of the filter.

Note: you cannot change the size or type of properties you are initializing.

Input Arguments

`filter` — Kalman tracking filter
Kalman filter object

Kalman tracking filter, specified as a Kalman filter object.

X — Initial Kalman filter state
vector | matrix

Initial Kalman filter state, specified as a vector or matrix.

P — Initial Kalman filter state covariance
matrix

Initial Kalman filter state covariance, specified as a matrix.

Introduced in R2018a

likelihood

Class: trackingKF

Measurement likelihood

Syntax

```
measlikelihood = likelihood(filter,zmeas)
```

Description

`measlikelihood = likelihood(filter,zmeas)` returns the likelihood of the measurement, `zmeas`, of an object tracked by the Kalman filter, `filter`.

Input Arguments

`filter` — Kalman tracking filter
Kalman filter object

Kalman tracking filter, specified as a Kalman filter object.

`zmeas` — Measurement of tracked object
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

Output Arguments

`measlikelihood` — Likelihood of measurement
scalar

Likelihood of measurement, returned as a scalar.

See Also

Introduced in R2018a

residual

Class: trackingKF

Measurement residual and residual covariance

Syntax

```
[zres,rescov] = residual(filter,zmeas)
```

Description

`[zres,rescov] = residual(filter,zmeas)` computes the residual, `zres`, between a measurement, `zmeas`, and a predicted measurement derived from the state of the Kalman filter, `filter`. The function also returns the covariance of the residual, `rescov`.

Input Arguments

`filter` — Linear Kalman tracking filter
Linear Kalman filter object

Linear Kalman tracking filter, specified as a Kalman filter object.

`zmeas` — Measurement of tracked object
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

Output Arguments

`zres` — Residual between measurement and predicted measurement
matrix

Residual between measurement and predicted measurement, returned as a matrix.

`rescov` — Covariance of residuals
matrix

Covariance of the residuals, returned as a matrix.

Algorithms

- The residual is the difference between a measurement and the value predicted by the filter. The residual d is defined as $d = z - Hx$. H is the measurement model set by the `MeasurementModel` property, x is the current filter state, and z is the current measurement.

- The covariance of the residual, S, is defined as $S = HPH' + R$ where P is the state covariance matrix, R is the measurement noise matrix set by the `MeasurementNoise` property.

Introduced in R2018a

trackingEKF class

Extended Kalman filter

Description

The `trackingEKF` class creates a discrete-time extended Kalman filter used for tracking positions and velocities of target platforms. A Kalman filter is a recursive algorithm for estimating the evolving state of a process when measurements are made on the process. The extended Kalman filter can model the evolution of a state that follows a nonlinear motion model, or when the measurements are nonlinear functions of the state, or both. The filter also allows for optional controls or forces to act on the object. The extended Kalman filter is based on the linearization of the nonlinear equations. This approach leads to a filter formulation similar to the linear Kalman filter, `trackingKF`.

The process and the measurements can have Gaussian noise which can be included in two ways:

- Noise can be added to both the process and the measurements. In this case, the sizes of the process noise and measurement noise must match the sizes of the state vector and measurement vector, respectively.

- Noises can be included in the state transition function, the measurement model function, or both. In these cases, the corresponding noise sizes are not restricted.

Construction

`filter = trackingEKF` creates an extended Kalman filter object for a discrete-time system using default values for the `StateTransitionFcn`, `MeasurementFcn`, and `State` properties. The process and measurement noises are assumed to be additive.

`filter = trackingEKF(transitionfcn,measurementfcn,state)` specifies the state transition function, `transitionfcn`, the measurement function, `measurementfcn`, and the initial state of the system, `state`.

filter = trackingEKF(___ ,Name,Value) configures the properties of the extended Kalman filter object using one or more Name,Value pair arguments. Any unspecified properties have default values.

Properties

State — Kalman filter state
real-valued *M*-element vector

Kalman filter state, specified as a real-valued *M*-element vector.

Example: [200;0.2]

Data Types: double

StateCovariance — State estimation error covariance
positive-definite real-valued *M*-by-*M* matrix

State error covariance, specified as a positive-definite real-valued *M*-by-*M* matrix where *M* is the size of the filter state. The covariance matrix represents the uncertainty in the filter state.

Example: [20 0.1; 0.1 1]

StateTransitionFcn — State transition function
function handle

State transition function, specified as a function handle. This function calculates the state vector at time step *k* from the state vector at time step *k*–1. The function can take additional input parameters, such as control inputs or time step size. The function can also include noise values.

- If HasAdditiveProcessNoise is true, specify the function using one of these syntaxes:

  x(k) = transitionfcn(x(k-1))

  x(k) = transitionfcn(x(k-1),parameters)

  where x(k) is the state at time k. The parameters term stands for all additional arguments required by the state transition function.

- If HasAdditiveProcessNoise is false, specify the function using one of these syntaxes:

```
x(k) = transitionfcn(x(k-1),w(k-1))
```

```
x(k) = transitionfcn(x(k-1),w(k-1),parameters)
```

where `x(k)` is the state at time `k` and `w(k)` is a value for the process noise at time `k`. The `parameters` argument stands for all additional arguments required by the state transition function.

Example: `@constacc`

Data Types: `function_handle`

StateTransitionJacobianFcn — State transition function Jacobian
function handle

The Jacobian of the state transition function, specified as a function handle. This function has the same input arguments as the state transition function.

- If `HasAdditiveProcessNoise` is `true`, specify the Jacobian function using one of these syntaxes:

  ```
  Jx(k) = statejacobianfcn(x(k))
  ```

  ```
  Jx(k) = statejacobianfcn(x(k),parameters)
  ```

  where `x(k)` is the state at time `k`. The `parameters` argument stands for all additional arguments required by the state transition function.

  `Jx(k)` denotes the Jacobian of the predicted state with respect to the previous state. The Jacobian is an *M*-by-*M* matrix at time `k`. The Jacobian function can take additional input parameters, such as control inputs or time step size.

- If `HasAdditiveProcessNoise` is `false`, specify the Jacobian function using one of these syntaxes:

  ```
  [Jx(k),Jw(k)] = statejacobianfcn(x(k),w(k))
  ```

  ```
  [Jx(k),Jw(k)] = statejacobianfcn(x(k),w(k),parameters)
  ```

  where `x(k)` is the state at time `k` and `w(k)` is a sample *Q*-element vector of the process noise at time `k`. *Q* is the size of the process noise covariance. Unlike the case of additive process noise, the process noise vector in the non-additive noise case need not have the same dimensions as the state vector.

2-183

Jx(k) denotes the Jacobian of the predicted state with respect to the previous state. This Jacobian is an *M*-by-*M* matrix at time *k*. The Jacobian function can take additional input parameters, such as control inputs or time step size.

Jw(k) denotes the *M*-by-*Q* Jacobian of the predicted state with respect to the process noise elements.

If not specified, the Jacobians are computed by numerical differencing at each call of the predict method. This computation can increase the processing time and numerical inaccuracy.

Example: @constaccjac

Data Types: function_handle

ProcessNoise — Process noise covariance
1 (default) | positive real-valued scalar | positive-definite real-valued matrix

Process noise covariance:

- When HasAdditiveProcessNoise is true, specify the process noise covariance as a scalar or a positive definite real-valued *M*-by-*M* matrix. *M* is the dimension of the state vector. When specified as a scalar, the matrix is a multiple of the *M*-by-*M* identity matrix.

- When HasAdditiveProcessNoise is false, specify the process noise covariance as an *Q*-by-*Q* matrix. *Q* is the size of the process noise vector.

  You must specify ProcessNoise before any call to the predict method. In later calls to predict, you can optionally specify the process noise as a scalar. In this case, the process noise matrix is a multiple of the *Q*-by-*Q* identity matrix.

Example: [1.0 0.05; 0.05 2]

HasAdditiveProcessNoise — Model additive process noise
true (default) | false

Option to model processes noise as additive, specified as true or false. When this property is true, process noise is added to the state vector. Otherwise, noise is incorporated into the state transition function.

MeasurementFcn — Measurement model function
function handle

Measurement model function, specified as a function handle. This function can be a nonlinear function that models measurements from the predicted state. Input to the function is the *M*-element state vector. The output is the *N*-element measurement vector. The function can take additional input arguments, such as sensor position and orientation.

- If `HasAdditiveMeasurementNoise` is `true`, specify the function using one of these syntaxes:

  ```
  z(k) = measurementfcn(x(k))
  ```

  ```
  z(k) = measurementfcn(x(k),parameters)
  ```

  where `x(k)` is the state at time `k` and `z(k)` is the predicted measurement at time `k`. The `parameters` term stands for all additional arguments required by the measurement function.

- If `HasAdditiveMeasurementNoise` is `false`, specify the function using one of these syntaxes:

  ```
  z(k) = measurementfcn(x(k),v(k))
  ```

  ```
  z(k) = measurementfcn(x(k),v(k),parameters)
  ```

  where `x(k)` is the state at time `k` and `v(k)` is the measurement noise at time `k`. The `parameters` argument stands for all additional arguments required by the measurement function.

Example: `@cameas`

Data Types: `function_handle`

MeasurementJacobianFcn — Jacobian of measurement function
function handle

Jacobian of the measurement function, specified as a function handle. The function has the same input arguments as the measurement function. The function can take additional input parameters, such sensor position and orientation.

- If `HasAdditiveMeasurmentNoise` is `true`, specify the Jacobian function using one of these syntaxes:

  ```
  Jmx(k) = measjacobianfcn(x(k))
  ```

  ```
  Jmx(k) = measjacobianfcn(x(k),parameters)
  ```

where `x(k)` is the state at time `k`. `Jx(k)` denotes the *N*-by-*M* Jacobian of the measurement function with respect to the state. The `parameters` argument stands for all arguments required by the measurement function.

- If `HasAdditiveMeasurmentNoise` is `false`, specify the Jacobian function using one of these syntaxes:

  `[Jmx(k),Jmv(k)] = measjacobianfcn(x(k),v(k))`

  `[Jmx(k),Jmv(k)] = measjacobianfcn(x(k),v(k),parameters)`

  where `x(k)` is the state at time `k` and `v(k)` is an *R*-dimensional sample noise vector. `Jmx(k)` denotes the *N*-by-*M* Jacobian of the measurement function with respect to the state. `Jmv(k)` denotes the Jacobian of the *N*-by-*R* measurement function with respect to the measurement noise. The `parameters` argument stands for all arguments required by the measurement function.

If not specified, measurement Jacobians are computed using numerical differencing at each call to the `correct` method. This computation can increase processing time and numerical inaccuracy.

Example: `@cameasjac`

Data Types: `function_handle`

MeasurementNoise — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix.

- When `HasAdditiveMeasurementNoise` is `true`, specify the measurement noise covariance as a scalar or an *N*-by-*N* matrix. *N* is the size of the measurement vector. When specified as a scalar, the matrix is a multiple of the *N*-by-*N* identity matrix.

- When `HasAdditiveMeasurementNoise` is `false`, specify the measurement noise covariance as an *R*-by-*R* matrix. *R* is the size of the measurement noise vector.

  You must specify `MeasurementNoise` before any call to the `correct` method. After the first call to `correct`, you can optionally specify the measurement noise as a scalar. In this case, the measurement noise matrix is a multiple of the *R*-by-*R* identity matrix.

Example: `0.2`

HasAdditiveMeasurmentNoise — Model additive measurement noise
true (default) | false

Option to enable additive measurement noise, specified as true or false. When this property is true, noise is added to the measurement. Otherwise, noise is incorporated into the measurement function.

Methods

clone	Create extended Kalman filter object with identical property values
correct	Correct Kalman state vector and state error covariance matrix
distance	Distance from measurements to predicted measurement
predict	Predict extended Kalman state vector and state error covariance matrix
initialize	Initialize extended Kalman filter
likelihood	Measurement likelihood
residual	Measurement residual and residual covariance

Examples

Constant-Velocity Extended Kalman Filter

Create a two-dimensional trackingEKF object and use name-value pairs to define the StateTransitionJacobianFcn and MeasurementJacobianFcn properties. Use the predefined constant-velocity motion and measurement models and their Jacobians.

```
EKF = trackingEKF(@constvel,@cvmeas,[0;0;0;0], ...
    'StateTransitionJacobianFcn',@constveljac, ...
    'MeasurementJacobianFcn',@cvmeasjac);
```

Run the filter. Use the predict and correct methods to propagate the state. You may call predict and correct in any order and as many times you want. Specify the measurement in Cartesian coordinates.

```
measurement = [1;1;0];
[xpred, Ppred] = predict(EKF);
[xcorr, Pcorr] = correct(EKF,measurement);
```

```
[xpred, Ppred] = predict(EKF);
[xpred, Ppred] = predict(EKF)

xpred = 4×1

    1.2500
    0.2500
    1.2500
    0.2500


Ppred = 4×4

   11.7500    4.7500         0         0
    4.7500    3.7500         0         0
         0         0   11.7500    4.7500
         0         0    4.7500    3.7500
```

Definitions

Filter Parameters

This table relates the filter model parameters to the object properties. In this table, *M* is the size of the state vector and *N* is the size of the measurement vector.

Filter Parameter	Meaning	Specified in Property	Size
f	State transition function that specifies the equations of motion of the object. This function determines the state at time k+1 as a function of the state and the controls at time k. The state transition function depends on the time-increment of the filter.	`StateTransitionFcn`	Function returns *M*-element vector
h	Measurement function that specifies how the measurements are functions of the state and measurement noise.	`MeasurementFcn`	Function returns *N*-element vector
x_k	Estimate of the object state.	`State`	*M*-element vector
P_k	State error covariance matrix representing the uncertainty in the values of the state.	`StateCovariance`	*M*-by-*M* matrix

Filter Parameter	Meaning	Specified in Property	Size
Q_k	Estimate of the process noise covariance matrix at step k. Process noise is a measure of the uncertainty in the dynamic model. It is assumed to be zero-mean white Gaussian noise.	`ProcessNoise`	*M*-by-*M* matrix when `HasAdditiveProcessNoise` is `true`. *Q*-by-*Q* matrix when `HasAdditiveProcessNoise` is `false`
R_k	Estimate of the measurement noise covariance at step k. Measurement noise reflects the uncertainty of the measurement. It is assumed to be zero-mean white Gaussian noise.	`MeasurementNoise`	*N*-by-*N* matrix when `HasAdditiveMeasurementNoise` is `true`. *R*-by-*R* when `HasAdditiveMeasurementNoise` is `false`.
F	Function determining Jacobian of propagated state with respect to previous state.	`StateTransitionJacobianFcn`	*M*-by-*M* matrix
H	Function determining Jacobians of measurement with respect to the state and measurement noise.	`MeasurementJacobianFcn`	*N*-by-*M* for state vector Jacobian and *N*-by-*R* for measurement vector Jacobian

Algorithms

The extended Kalman filter estimates the state of a process governed by this nonlinear stochastic equation:

$$x_{k+1} = f(x_k, u_k, w_k, t)$$

x_k is the state at step k. $f()$ is the state transition function. Random noise perturbations, w_k, can affect the object motion. The filter also supports a simplified form,

$$x_{k+1} = f(x_k, u_k, t) + w_k$$

To use the simplified form, set `HasAdditiveProcessNoise` to `true`.

In the extended Kalman filter, the measurements are also general functions of the state:

$$z_k = h(x_k, v_k, t)$$

$h(x_k, v_k, t)$ is the measurement function that determines the measurements as functions of the state. Typical measurements are position and velocity or some function of position and velocity. The measurements can also include noise, represented by v_k. Again, the filter offers a simpler formulation.

$$z_k = h(x_k, t) + v_k$$

To use the simplified form, set `HasAdditiveMeasurmentNoise` to `true`.

These equations represent the actual motion and the actual measurements of the object. However, the noise contribution at each step is unknown and cannot be modeled deterministically. Only the statistical properties of the noise are known.

References

[1] Brown, R.G. and P.Y.C. Wang. *Introduction to Random Signal Analysis and Applied Kalman Filtering*. 3rd Edition. New York: John Wiley & Sons, 1997.

[2] Kalman, R. E. "A New Approach to Linear Filtering and Prediction Problems." *Transactions of the ASME–Journal of Basic Engineering*, Vol. 82, Series D, March 1960, pp. 35–45.

[3] Blackman, Samuel and R. Popoli. *Design and Analysis of Modern Tracking Systems*, Artech House.1999.

[4] Blackman, Samuel. *Multiple-Target Tracking with Radar Applications*, Artech House. 1986.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initcaekf | initctekf | initcvekf

Classes
trackingABF | trackingCKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

System Objects
trackerGNN | trackerTOMHT

Topics
"Extended Kalman Filters"

Introduced in R2017a

clone

Class: trackingEKF

Create extended Kalman filter object with identical property values

Syntax

```
filter2 = clone(filter)
```

Description

`filter2 = clone(filter)` creates another instance of the object, `trackingEKF`, having identical property values. If an object is locked, the `clone` method creates a copy that is also locked and has states initialized to the same values as the original. If an object is not locked, the `clone` method creates a new unlocked object with uninitialized states.

Input Arguments

filter — Extended Kalman filter
trackingEKF object

Extended Kalman filter, specified as a `trackingEKF` object.

Example: `filter = trackingEKF`

Output Arguments

filter2 — Extended Kalman filter
trackingEKF object

Extended Kalman filter, returned as a `trackingEKF` object.

Introduced in R2017a

correct

Class: trackingEKF

Correct Kalman state vector and state error covariance matrix

Syntax

```
[xcorr,Pcorr] = correct(filter,z)
[xcorr,Pcorr] = correct(filter,z,varargin)
```

Description

`[xcorr,Pcorr] = correct(filter,z)` returns the corrected state vector, `xcorr`, and the corrected state error covariance matrix, `Pcorr`, for the extended Kalman filter defined in `filter`, based on the current measurement, `z`. The internal state and covariance of the Kalman filter are overwritten by the corrected values.

`[xcorr,Pcorr] = correct(filter,z,varargin)` also specifies any input arguments to the measurement function. These arguments are used as input to the measurement function specified in the `MeasurementFcn` property.

Input Arguments

`filter` — Extended Kalman filter
trackingEKF object

Extended Kalman filter, specified as a `trackingEKF` object.

Example: `filter = trackingEKF`

`z` — Object measurement
real-valued *N*-element vector

Object measurement, specified as a real-valued *N*-element vector.

Example: `[2;1]`

`varargin` — Measurement function arguments
comma-separated list

Measurement function arguments, specified as a comma-separated list. These arguments are the same ones that are passed into the measurement function specified by the `MeasurementFcn` property. For example, if you set `MeasurementFcn` to `@cameas`, and then call

```
[xcorr,Pcorr] = correct(filter,frame,sensorpos,sensorvel)
```

the `correct` method will internally call

```
meas = cameas(state,frame,sensorpos,sensorvel)
```

.

Output Arguments

`xcorr` — Corrected state
real-valued *M*-element vector

Corrected state, returned as a real-valued *M*-element vector. The corrected state represents the *a posteriori* estimate of the state vector, taking into account the current measurement.

`Pcorr` — Corrected state error covariance matrix
positive-definite real-valued *M*-by-*M* matrix

Corrected state error covariance matrix, returned as a positive-definite real-valued *M*-by-*M* matrix. The corrected state covariance matrix represents the *a posteriori* estimate of the state covariance matrix, taking into account the current measurement.

Introduced in R2017a

distance

Class: trackingEKF

Distance from measurements to predicted measurement

Syntax

```
dist = distance(filter,zmat)
dist = distance(filter,zmat,measurementParams)
```

Description

`dist = distance(filter,zmat)` computes the Mahalanobis distances between multiple candidate measurements of an object, `zmat`, and the predicted measurement computed by the `trackingEKF` object. The distance method is used to assign measurements to tracks.

This distance computation takes into account the covariance of the predicted state and the covariance of the process noise. You can call the `distance` method only after calling the `predict` method.

`dist = distance(filter,zmat,measurementParams)` also specifies the parameters used by the measurement function set in the `MeasurementFcn` property.

Input Arguments

`filter` — Extended Kalman filter
trackingEKF object

Extended Kalman filter, specified as a `trackingEKF` object.

Example: `filter = trackingEKF`

`zmat` — Object measurements
real-valued *K*-by-*N* matrix

Measurements, specified as a real-valued *K*-by-*N* matrix. *K* is the number of candidate measurement vectors. Each row corresponds to a candidate measurement vector.*N* is the number of rows in the output of the function specified by the `MeasurementFcn` property.

Example: `[2,1;3,0]`

Data Types: `double`

`measurementParams` — Measurement function parameters
`{}` (default) | cell array

Measurement function parameters, specified as a cell array containing arguments to the measurement function specified by the `MeasurementFcn` property. Suppose you set `MeasurementFcn` to `@cameas`, and then set these values:

`measurementParams = {frame,sensorpos,sensorpos)`

The `distance` method internally calls the following:

`cameas(state,frame,sensorpos,sensorvel)`

Data Types: `cell`

Output Arguments

`dist` — Mahalanobis distances
real-valued *K*-element vector of positive values

Mahalanobis distances between candidate measurements and the predicted measurement, returned as a real-valued *K*-element vector of positive values. There is one distance value per measurement vector.

Data Types: `double`

Introduced in R2017a

predict

Class: trackingEKF

Predict extended Kalman state vector and state error covariance matrix

Syntax

```
[xpred,Ppred] = predict(filter)
[xpred,Ppred] = predict(filter,varargin)
[xpred,Ppred] = predict( ___ ,dt)
```

Description

[xpred,Ppred] = predict(filter) returns the predicted state vector, xpred, and state error covariance matrix, Ppred, at the next time step based on the current time step. The predicted values overwrite the internal state vector and state error covariance matrix of the extended Kalman filter.

[xpred,Ppred] = predict(filter,varargin) specifies input arguments, varargin, for the state transition function set in the StateTransitionFcn property.

[xpred,Ppred] = predict(___ ,dt) also specifies the time step, dt.

Input Arguments

filter — Extended Kalman filter
trackingEKF object

Extended Kalman filter, specified as a trackingEKF object.

Example: filter = trackingEKF

varargin — State transition function arguments
comma-separated list

State transition function arguments, specified as a comma-separated list. These arguments are the same ones that are passed into the state transition function specified by the `StateTransitionFcn` property. For example, if you set the `StateTransitionFcn` property to `@constacc`, and then call

```
[xpred,Ppred] = predict(filter,dt)
```

the `predict` method will internally call

```
state = constacc(state,dt)
```

dt — Time step
positive scalar

Time step, specified as a positive scalar. Units are in seconds.

Data Types: `double`

Output Arguments

xpred — Predicted state
real-valued *M*-element vector

Predicted state, returned as a real-valued *M*-element vector. The predicted state represents the *a priori* estimate of the state vector propagated from the previous state. The prediction uses the state transition function specified in the `StateTransitionFcn` property.

Data Types: `double`

Ppred — Predicted state error covariance matrix
real-valued *M*-by-*M* matrix

Predicted state error covariance matrix, returned as a real-valued *M*-by-*M* matrix. This predicted error is the *a priori* estimate of the state error covariance matrix. `predict` uses the state transition function Jacobian specified in the `StateTransitionJacobianFcn` property.

Data Types: `double`

Introduced in R2017a

initialize

Class: trackingEKF

Initialize extended Kalman filter

Syntax

```
initialize(filterobj,X,P)
initialize(filterobj,X,P,Name,Value)
```

Description

`initialize(filterobj,X,P)` initializes the extended Kalman filter, `filterobj`, using the state, `x`, and the state covariance, `P`.

`initialize(filterobj,X,P,Name,Value)` initializes Kalman filter properties using name-value pairs.

Note: you cannot change the size or type of properties you are initializing.

Input Arguments

`filterobj` — Extended Kalman tracking filter
Extended Kalman filter object

Kalman tracking filter, specified as a Kalman filter object.

X — Initial extended Kalman filter state
vector | matrix

Initial extended Kalman filter state, specified as a vector or matrix.

P — Initial extended Kalman filter state covariance
matrix

Initial extended Kalman filter state covariance, specified as a matrix.

Introduced in R2018a

likelihood

Class: trackingEKF

Measurement likelihood

Syntax

```
measlikelihood = likelihood(filterobj,zmeas)
measlikelihood = likelihood(filterobj,zmeas,measparams)
```

Description

`measlikelihood = likelihood(filterobj,zmeas)` returns the likelihood of the measurement, `zmeas`, of an object tracked by the extended Kalman filter, `filterobj`.

`measlikelihood = likelihood(filterobj,zmeas,measparams)` also specifies measurement parameters, `measparams`.

Input Arguments

`filterobj` — Extended Kalman tracking filter
Kalman filter object

Extended Kalman tracking filter, specified as an extended Kalman filter object.

`zmeas` — Measurement of tracked object
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

`measparams` — Parameters for measurement function
{} | cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function defined in the `MeasurementFcn` property of the Extended Kalman filter, `filterobj`.

Output Arguments

`measlikelihood` — Likelihood of measurement
scalar

Likelihood of measurement, returned as a scalar.

See Also

Introduced in R2018a

residual

Class: trackingEKF

Measurement residual and residual covariance

Syntax

```
[zres,rescov] = residual(filterobj,zmeas)
[zres,rescov] = residual(filterobj,zmeas,measparams)
```

Description

`[zres,rescov] = residual(filterobj,zmeas)`computes the residual, `zres`, between a measurement, `zmeas`, and a predicted measurement produced by the Kalman filter, `filterobj`. The function also returns the covariance of the residual, `zres`.

`[zres,rescov] = residual(filterobj,zmeas,measparams)` also specifies measurement parameters, `measparams`.

Input Arguments

`filterobj` — Kalman tracking filter
Kalman filter object

Kalman tracking filter, specified as a Kalman filter object.

`zmeas` — Measurement of tracked object
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

`measparams` — Parameters for measurement function
cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function defined in the `MeasurementFcn` property of the `filterobj`

Output Arguments

`zres` — Residual between measurement and predicted measurement
matrix

Residual between measurement and predicted measurement, returned as a matrix.

`rescov` — Covariance of residuals
matrix

Covariance of the residuals, returned as a matrix.

Algorithms

- The residual is the difference between a measurement and the value predicted by the filter. The residual *d* is defined as *d = z - h(x)*. *h* is the measurement function set by the `MeasurementFcn` property, *x* is the current filter state, and *z* is the current measurement.
- The covariance of the residual, *S*, is defined as *S = HPH' + R* where *P* is the state covariance matrix, *R* is the measurement noise matrix set by the `MeasurementNoise` property.

Introduced in R2018a

trackingUKF class

Unscented Kalman filter

Description

The `trackingUKF` class creates a discrete-time unscented Kalman filter used for tracking positions and velocities of target platforms. An unscented Kalman filter is a recursive algorithm for estimating the evolving state of a process when measurements are made on the process. The unscented Kalman filter can model the evolution of a state that obeys a nonlinear motion model. The measurements can also be nonlinear functions of the state. In addition, the process and the measurements can have noise. Use an unscented Kalman filter when the current state is a nonlinear function of the previous state or when the measurements are nonlinear functions of the state or when both conditions apply. The unscented Kalman filter estimates the uncertainty about the state, and its propagation through the nonlinear state and measurement equations, using a fixed number of sigma points. Sigma points are chosen using the unscented transformation as parameterized by the `Alpha`, `Beta`, and `Kappa` properties.

Construction

`filter = trackingUKF` creates an unscented Kalman filter object for a discrete-time system using default values for the `StateTransitionFcn`, `MeasurementFcn`, and `State` properties . The process and measurement noises are assumed to be additive.

`filter = trackingUKF(transitionfcn,measurementfcn,state)` specifies the state transition function, `transitionfcn`, the measurement function, `measurementfcn`, and the initial state of the system, `state`.

`filter = trackingUKF( ___ ,Name,Value)` configures the properties of the unscented Kalman filter object using one or more `Name,Value` pair arguments. Any unspecified properties have default values.

Properties

State — Kalman filter state
real-valued *M*-element vector

Kalman filter state, specified as a real-valued *M*-element vector.

Example: `[200;0.2]`

Data Types: `double`

StateCovariance — State estimation error covariance
positive-definite real-valued *M*-by-*M* matrix

State error covariance, specified as a positive-definite real-valued *M*-by-*M* matrix where *M* is the size of the filter state. The covariance matrix represents the uncertainty in the filter state.

Example: `[20 0.1; 0.1 1]`

StateTransitionFcn — State transition function
function handle

State transition function, specified as a function handle. This function calculates the state vector at time step *k* from the state vector at time step *k*–1. The function can take additional input parameters, such as control inputs or time step size. The function can also include noise values.

- If `HasAdditiveProcessNoise` is `true`, specify the function using one of these syntaxes:

  `x(k) = transitionfcn(x(k-1))`

  `x(k) = transitionfcn(x(k-1),parameters)`

  where `x(k)` is the state at time `k`. The `parameters` term stands for all additional arguments required by the state transition function.

- If `HasAdditiveProcessNoise` is `false`, specify the function using one of these syntaxes:

  `x(k) = transitionfcn(x(k-1),w(k-1))`

  `x(k) = transitionfcn(x(k-1),w(k-1),parameters)`

where `x(k)` is the state at time `k` and `w(k)` is a value for the process noise at time `k`. The `parameters` argument stands for all additional arguments required by the state transition function.

Example: `@constacc`

Data Types: `function_handle`

ProcessNoise — Process noise covariance
1 (default) | positive real-valued scalar | positive-definite real-valued matrix

Process noise covariance:

- When `HasAdditiveProcessNoise` is `true`, specify the process noise covariance as a scalar or a positive definite real-valued *M*-by-*M* matrix. *M* is the dimension of the state vector. When specified as a scalar, the matrix is a multiple of the *M*-by-*M* identity matrix.

- When `HasAdditiveProcessNoise` is `false`, specify the process noise covariance as an *Q*-by-*Q* matrix. *Q* is the size of the process noise vector.

  You must specify `ProcessNoise` before any call to the `predict` method. In later calls to `predict`, you can optionally specify the process noise as a scalar. In this case, the process noise matrix is a multiple of the *Q*-by-*Q* identity matrix.

Example: `[1.0 0.05; 0.05 2]`

HasAdditiveProcessNoise — Model additive process noise
`true` (default) | `false`

Option to model processes noise as additive, specified as `true` or `false`. When this property is `true`, process noise is added to the state vector. Otherwise, noise is incorporated into the state transition function.

MeasurementFcn — Measurement model function
function handle

Measurement model function, specified as a function handle. This function can be a nonlinear function that models measurements from the predicted state. Input to the function is the *M*-element state vector. The output is the *N*-element measurement vector. The function can take additional input arguments, such as sensor position and orientation.

- If `HasAdditiveMeasurementNoise` is `true`, specify the function using one of these syntaxes:

```
z(k) = measurementfcn(x(k))
```

```
z(k) = measurementfcn(x(k),parameters)
```

where `x(k)` is the state at time `k` and `z(k)` is the predicted measurement at time `k`. The `parameters` term stands for all additional arguments required by the measurement function.

- If `HasAdditiveMeasurementNoise` is `false`, specify the function using one of these syntaxes:

```
z(k) = measurementfcn(x(k),v(k))
```

```
z(k) = measurementfcn(x(k),v(k),parameters)
```

where `x(k)` is the state at time `k` and `v(k)` is the measurement noise at time `k`. The `parameters` argument stands for all additional arguments required by the measurement function.

Example: `@cameas`

Data Types: `function_handle`

`MeasurementNoise` — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix.

- When `HasAdditiveMeasurementNoise` is `true`, specify the measurement noise covariance as a scalar or an *N*-by-*N* matrix. *N* is the size of the measurement vector. When specified as a scalar, the matrix is a multiple of the *N*-by-*N* identity matrix.

- When `HasAdditiveMeasurementNoise` is `false`, specify the measurement noise covariance as an *R*-by-*R* matrix. *R* is the size of the measurement noise vector.

  You must specify `MeasurementNoise` before any call to the `correct` method. After the first call to `correct`, you can optionally specify the measurement noise as a scalar. In this case, the measurement noise matrix is a multiple of the *R*-by-*R* identity matrix.

Example: `0.2`

HasAdditiveMeasurmentNoise — Model additive measurement noise
`true` (default) | `false`

Option to enable additive measurement noise, specified as `true` or `false`. When this property is `true`, noise is added to the measurement. Otherwise, noise is incorporated into the measurement function.

Alpha — Sigma point spread around state
`1.0e-3` (default) | positive scalar greater than 0 and less than or equal to 1

Sigma point spread around state, specified as a positive scalar greater than zero and less than or equal to one.

Beta — Distribution of sigma points
2 (default) | nonnegative scalar

Distribution of sigma points, specified as a nonnegative scalar. This parameter incorporates knowledge of the noise distribution of states for generating sigma points. For Gaussian distributions, setting `Beta` to 2 is optimal.

Kappa — Secondary scaling factor for generating sigma points
0 (default) | scalar from 0 to 3

Secondary scaling factor for generation of sigma points, specified as a scalar from 0 to 3. This parameter helps specify the generation of sigma points.

Methods

clone	Create unscented Kalman filter object with identical property values
correct	Correct Kalman state vector and state error covariance matrix
distance	Distance from measurements to predicted measurement
predict	Predict unscented Kalman state vector and state error covariance matrix
initialize	Initialize unscented Kalman filter
likelihood	Measurement likelihood
residual	Measurement residual and residual covariance

Examples

Constant-Velocity Unscented Kalman Filter

Create a `trackingUKF` object using the predefined constant-velocity motion model, `constvel`, and the associated measurement model, `cvmeas`. These models assume that the state vector has the form [x;vx;y;vy] and that the position measurement is in Cartesian coordinates, [x;y;z]. Set the sigma point spread property to 1e-2.

```
filter = trackingUKF(@constvel,@cvmeas,[0;0;0;0],'Alpha',1e-2);
```

Run the filter. Use the `predict` and `correct` methods to propagate the state. You can call `predict` and `correct` in any order and as many times as you want.

```
meas = [1;1;0];
[xpred, Ppred] = predict(filter);
[xcorr, Pcorr] = correct(filter,meas);
[xpred, Ppred] = predict(filter);
[xpred, Ppred] = predict(filter)

xpred = 4×1

    1.2500
    0.2500
    1.2500
    0.2500


Ppred = 4×4

   11.7500    4.7500   -0.0000    0.0000
    4.7500    3.7500   -0.0000    0.0000
   -0.0000   -0.0000   11.7500    4.7500
    0.0000    0.0000    4.7500    3.7500
```

Definitions

Filter parameters and dimensions

This table relates the filter model parameters to the object properties. M is the size of the state vector and N is the size of the measurement vector.

Filter Parameter	Meaning	Specified in Property	Size
f	State transition function that specifies the equations of motion of the object. This function determines the state at time `k+1` as a function of the state and the controls at time `k`. The state transition function depends on the time-increment of the filter.	`StateTransitionFcn`	Function returns M-element vector
h	Measurement function that specifies how the measurements are functions of the state and measurement noise.	`MeasurementFcn`	Function returns N-element vector
x_k	Estimate of the object state.	`State`	M
P_k	State error covariance matrix representing the uncertainty in the values of the state	`StateCovariance`	M-by-M

Filter Parameter	Meaning	Specified in Property	Size
Q_k	Estimate of the process noise covariance matrix at step k. Process noise is measure of the uncertainty in your dynamic model and is assumed to be zero-mean white Gaussian noise	`ProcessNoise`	*M*-by-*M* when `HasAdditiveProcessNoise` is `true`. *Q*-by-*Q* when `HasAdditiveProcessNoise` is `false`.
R_k	Estimate of the measurement noise covariance at step *k*. Measurement noise reflects the uncertainty of the measurement and is assumed to be zero-mean white Gaussian noise.	`MeasurementNoise`	*N*-by-*N* when `HasAdditiveMeasurementNoise` is `true`. *R*-by-*R* when `HasAdditiveMeasurementNoise` is `false`.
α	Determines spread of sigma points.	`Alpha`	scalar
β	*A priori* knowledge of sigma point distribution.	`Beta`	scalar
κ	Secondary scaling parameter.	`Kappa`	scalar

Algorithms

The unscented Kalman filter estimates the state of a process governed by a nonlinear stochastic equation

$$x_{k+1} = f(x_k, u_k, w_k, t)$$

where x_k is the state at step k. $f()$ is the state transition function, u_k are the controls on the process. The motion may be affected by random noise perturbations, w_k. The filter also supports a simplified form,

$$x_{k+1} = f(x_k, u_k, t) + w_k$$

To use the simplified form, set `HasAdditiveProcessNoise` to `true`.

In the unscented Kalman filter, the measurements are also general functions of the state,

$$z_k = h(x_k, v_k, t)$$

where $h(x_k, v_k, t)$ is the measurement function that determines the measurements as functions of the state. Typical measurements are position and velocity or some function of these. The measurements can include noise as well, represented by v_k. Again the class offers a simpler formulation

$$z_k = h(x_k, t) + v_k$$

To use the simplified form, set `HasAdditiveMeasurmentNoise` to `true`.

These equations represent the actual motion of the object and the actual measurements. However, the noise contribution at each step is unknown and cannot be modeled exactly. Only statistical properties of the noise are known.

References

[1] Brown, R.G. and P.Y.C. Wang. *Introduction to Random Signal Analysis and Applied Kalman Filtering*. 3rd Edition. New York: John Wiley & Sons, 1997.

[2] Kalman, R. E. "A New Approach to Linear Filtering and Prediction Problems." *Transactions of the ASME–Journal of Basic Engineering*, Vol. 82, Series D, March 1960, pp. 35–45.

[3] Wan, Eric A. and R. van der Merwe. "The Unscented Kalman Filter for Nonlinear Estimation". *Adaptive Systems for Signal Processing, Communications, and Control*. AS-SPCC, IEEE, 2000, pp.153–158.

[4] Wan, Merle. "The Unscented Kalman Filter." In *Kalman Filtering and Neural Networks*, edited by Simon Haykin. John Wiley & Sons, Inc., 2001.

[5] Sarkka S. "Recursive Bayesian Inference on Stochastic Differential Equations." Doctoral Dissertation. Helsinki University of Technology, Finland. 2006.

[6] Blackman, Samuel. *Multiple-Target Tracking with Radar Applications*. Artech House, 1986.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initcaukf | initctukf | initcvukf

Classes
trackingABF | trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF

System Objects
trackerGNN | trackerTOMHT

Introduced in R2017a

clone

Class: trackingUKF

Create unscented Kalman filter object with identical property values

Syntax

```
filter2 = clone(filter)
```

Description

`filter2 = clone(filter)` creates another instance of the object, `trackingUKF`, having identical property values. If an object is locked, the `clone` method creates a copy that is also locked and has states initialized to the same values as the original. If an object is not locked, the `clone` method creates a new unlocked object with uninitialized states.

Input Arguments

`filter` — Unscented Kalman filter
`trackingUKF` object

Unscented Kalman filter, specified as a `trackingUKF` object.

Example: `filter = trackingEKF`

Output Arguments

`filter2` — Unscented Kalman filter
`trackingUKF` object

Unscented Kalman filter, returned as a `trackingUKF` object.

Introduced in R2017a

correct

Class: trackingUKF

Correct Kalman state vector and state error covariance matrix

Syntax

```
[xcorr,Pcorr] = correct(filter,z)
[xcorr,Pcorr] = correct(filter,z,varargin)
```

Description

`[xcorr,Pcorr] = correct(filter,z)` returns the corrected state vector, `xcorr`, and the corrected state error covariance matrix, `Pcorr`, for the unscented Kalman filter defined in `filter`, based on the current measurement, `z`. The internal state and covariance of the Kalman filter are overwritten by the corrected values.

`[xcorr,Pcorr] = correct(filter,z,varargin)` also specifies any input arguments to the measurement function. These arguments are used as input to the measurement function specified in the `MeasurementFcn` property.

Input Arguments

`filter` — Unscented Kalman filter
trackingUKF object

Unscented Kalman filter, specified as a `trackingUKF` object.

Example: `filter = trackingUKF`

`z` — Object measurement
real-valued *N*-element vector

Object measurement, specified as a real-valued *N*-element vector.

Example: `[2;1]`

`varargin` — Measurement function arguments
comma-separated list

Measurement function arguments, specified as a comma-separated list. These arguments are the same ones that are passed into the measurement function specified by the `MeasurementFcn` property. For example, if you set `MeasurementFcn` to `@cameas`, and then call

```
[xcorr,Pcorr] = correct(filter,frame,sensorpos,sensorvel)
```

the `correct` method will internally call

```
meas = cameas(state,frame,sensorpos,sensorvel)
```

.

Output Arguments

`xcorr` — Corrected state
real-valued *M*-element vector

Corrected state, returned as a real-valued *M*-element vector. The corrected state represents the *a posteriori* estimate of the state vector, taking into account the current measurement.

`Pcorr` — Corrected state error covariance matrix
positive-definite real-valued *M*-by-*M* matrix

Corrected state error covariance matrix, returned as a positive-definite real-valued *M*-by-*M* matrix. The corrected state covariance matrix represents the *a posteriori* estimate of the state covariance matrix, taking into account the current measurement.

Introduced in R2017a

distance

Class: trackingUKF

Distance from measurements to predicted measurement

Syntax

```
dist = distance(filter,zmat)
dist = distance(filter,zmat,measurementParams)
```

Description

`dist = distance(filter,zmat)` computes the Mahalanobis distances between multiple candidate measurements of an object, `zmat`, and the predicted measurement computed by the `trackingUKF` object. The distance method is used to assign measurements to tracks.

This distance computation takes into account the covariance of the predicted state and the covariance of the process noise. You can call the `distance` method only after calling the `predict` method.

`dist = distance(filter,zmat,measurementParams)` also specifies the parameters used by the measurement function set in the `MeasurementFcn` property.

Input Arguments

`filter` — Unscented Kalman filter
trackingUKFobject

Unscented Kalman filter, specified as a `trackingUKF` object.

Example: `filter = trackingUKF`

`zmat` — Object measurements
real-valued *K*-by-*N* matrix

Measurements, specified as a real-valued *K*-by-*N* matrix. *K* is the number of candidate measurement vectors. Each row corresponds to a candidate measurement vector.*N* is the number of rows in the output of the function specified by the `MeasurementFcn` property.

Example: `[2,1;3,0]`

Data Types: `double`

`measurementParams` — Measurement function parameters
{} (default) | cell array

Measurement function parameters, specified as a cell array containing arguments to the measurement function specified by the `MeasurementFcn` property. Suppose you set `MeasurementFcn` to `@cameas`, and then set these values:

`measurementParams = {frame,sensorpos,sensorpos)`

The `distance` method internally calls the following:

`cameas(state,frame,sensorpos,sensorvel)`

Data Types: `cell`

Output Arguments

`dist` — Mahalanobis distances
real-valued *K*-element vector of positive values

Mahalanobis distances between candidate measurements and the predicted measurement, returned as a real-valued *K*-element vector of positive values. There is one distance value per measurement vector.

Data Types: `double`

Introduced in R2017a

predict

Class: trackingUKF

Predict unscented Kalman state vector and state error covariance matrix

Syntax

```
[xpred,Ppred] = predict(filter)
[xpred,Ppred] = predict(filter,varargin)
[xpred,Ppred] = predict( ___ ,dt)
```

Description

[xpred,Ppred] = predict(filter) returns the predicted state vector, xpred, and state error covariance matrix, Ppred, at the next time step based on the current time step. The predicted values overwrite the internal state vector and state error covariance matrix of the unscented Kalman filter.

[xpred,Ppred] = predict(filter,varargin) specifies in varargin input arguments of the state transition function set in the StateTransitionFcn property.

[xpred,Ppred] = predict(___ ,dt) also specifies the time step, dt.

Input Arguments

filter — Unscented Kalman filter
trackingUKF object

Unscented Kalman filter, specified as a trackingUKF object.

Example: filter = trackingUKF

varargin — State transition function arguments
comma-separated list

State transition function arguments, specified as a comma-separated list. These arguments are the same ones that are passed into the state transition function specified by the `StateTransitionFcn` property. For example, if you set the `StateTransitionFcn` property to `@constacc`, and then call

```
[xpred,Ppred] = predict(filter,dt)
```

the `predict` method will internally call

```
state = constacc(state,dt)
```

dt — Time step
positive scalar

Time step, specified as a positive scalar. Units are in seconds.

Data Types: `double`

Output Arguments

xpred — Predicted state
real-valued *M*-element vector

Predicted state, returned as a real-valued *M*-element vector. The predicted state represents the *a priori* estimate of the state vector propagated from the previous state. The prediction uses the state transition function specified in the `StateTransitionFcn` property.

Data Types: `double`

Ppred — Predicted state error covariance matrix
real-valued *M*-by-*M* matrix

Predicted state error covariance matrix, returned as a real-valued *M*-by-*M* matrix. This predicted error is the *a priori* estimate of the state error covariance matrix. `predict` uses the state transition function Jacobian specified in the `StateTransitionJacobianFcn` property.

Data Types: `double`

Introduced in R2017a

initialize

Class: trackingUKF

Initialize unscented Kalman filter

Syntax

```
initialize(filter,X,P)
initialize(filter,X,P,Name,Value)
```

Description

`initialize(filter,X,P)` initializes the unscented Kalman filter, `filter`, using the state, `X`, and the state covariance, `P`.

`initialize(filter,X,P,Name,Value)` initializes the Kalman filter properties using name-value pairs.

Note: you cannot change the size or type of properties you are initializing.

Input Arguments

`filter` — Unscented Kalman tracking filter
Unscented Kalman filter object

Kalman tracking filter, specified as an unscented Kalman filter object.

X — Initial unscented Kalman filter state
vector | matrix

Initial unscented Kalman filter state, specified as a vector or matrix.

P — Initial unscented Kalman filter state covariance
matrix

Initial unscented Kalman filter state covariance, specified as a matrix.

Introduced in R2018b

likelihood

Class: trackingUKF

Measurement likelihood

Syntax

```
measlikelihood = likelihood(filter,zmeas)
measlikelihood = likelihood(filter,zmeas,measparams)
```

Description

`measlikelihood = likelihood(filter,zmeas)` returns the likelihood of the measurement, `zmeas`, of an object tracked by the unscented Kalman filter, `filter`.

`measlikelihood = likelihood(filter,zmeas,measparams)` also specifies measurement parameters, `measparams`.

Input Arguments

`filter` — Unscented Kalman tracking filter
Unscented Kalman filter object

Unscented Kalman tracking filter, specified as an unscented Kalman filter object.

`zmeas` — Measurement of tracked object
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

`measparams` — Parameters for measurement function
{} | cell array

2-225

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function defined in the `MeasurementFcn` property of the unscented Kalman filter, `filter`.

Output Arguments

`measlikelihood` — Likelihood of measurement
scalar

Likelihood of measurement, returned as a scalar.

Introduced in R2018a

residual

Class: trackingUKF

Measurement residual and residual covariance

Syntax

```
[zres,rescov] = residual(filterobj,zmeas)
```

Description

`[zres,rescov] = residual(filterobj,zmeas)`computes the residual, `zres`, between a measurement, `zmeas`, and a predicted measurement produced by the Kalman filter, `filterobj`. The function also returns the covariance of the residual, `zres`.

Input Arguments

`filterobj` — Unscented Kalman tracking filter
Kalman filter object

Unscented Kalman tracking filter, specified as a Kalman filter object.

`zmeas` — Measurement of tracked object
vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

Output Arguments

`zres` — Residual between measurement and predicted measurement
matrix

Residual between measurement and predicted measurement, returned as a matrix.

`rescov` — Covariance of residuals
matrix

Covariance of the residuals, returned as a matrix.

Algorithms

- The residual is the difference between a measurement and the value predicted by the filter. The residual *d* is defined as *d = z - h(x)*. *h* is the measurement function set by the `MeasurementFcn` property, *x* is the current filter state, and *z* is the current measurement.

- The covariance of the residual, *S*, is computed as $S = R + R_p$. R_p is the state covariance matrix projected onto the measurement space and *R* is the measurement noise matrix set by the `MeasurementNoise` property.

Introduced in R2018a

radarEmission class

Emitted radar signal structure

Description

The `radarEmission` class creates a radar emission object. This object contains all the properties that describe a signal radiated by a radar source.

Construction

`signal = radarEmission` creates a `sonarEmission` object with default properties. The object represents radar signals from emitters, channels, and sensors.

`signal = radarEmission(Name,Value)` sets object properties specified by one or more `Name,Value` pair arguments. `Name` can also be 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`.

Properties

PlatformID — Platform identifier
positive integer

Platform identifier, specified as a positive integer. The emitter is mounted on the platform with this ID. Each platform identifier is unique within a scenario.

Example: 5

Data Types: `double`

EmitterIndex — Emitter identifier
positive integer

Emitter identifier, specified as a positive integer. Each emitter index is unique.

Example: 2

Data Types: `double`

`OriginPosition` — Location of emitter
[0 0 0] (default) | 1-by-3 real-valued vector

Location of the emitter in scenario coordinates, specified as a 1-by-3 real-valued vector. Units are in meters.

Example: `[100 -500 1000]`

Data Types: `double`

`OriginVelocity` — Velocity of emitter
[0 0 0] (default) | 1-by-3 real-valued vector

Velocity of the emitter in scenario coordinates, specified as a 1-by-3 real-valued vector. Units are in meters per second.

Example: `[0 -50 100]`

Data Types: `double`

`Orientation` — Orientation of emitter
quaternion(1,0,0,0) (default) | quaternion | 3-by-3 real-valued orthogonal matrix

Orientation of the emitter in scenario coordinates, specified as a quaternion or 3-by-3 real-valued orthogonal matrix.

Example: `eye(3)`

Data Types: `double`

`FieldOfView` — Field of view of emitter
[1;5] | 2-by-1 vector of positive real values

Field of view of emitter, specified as a 2-by-1 vector of positive real values, [azfov; elfov]. The field of view defines the total angular extent of the signal emitted. Each component must lie in the interval (0, 180]. Units are in degrees.

Example: `[14;7]`

Data Types: `double`

`EIRP` — Effective isotropic radiated power
0 (default) | scalar

Effective isotropic radiated power, specified as a scalar. Units are in dB.

Example: 10

Data Types: double

RCS — Cumulative radar cross-section
0 (default) | scalar

Cumulative radar cross-section, specified as a scalar. Units are in dBsm.

Example: 10

Data Types: double

CenterFrequency — Center frequency of radar signal
300e6 (default) | positive scalar

Center frequency of the signal, specified as a positive scalar. Units are in Hz.

Example: 100e6

Data Types: double

Bandwidth — Half-power bandwidth of radar signal
30e6 (default) | positive scalar

Half-power bandwidth of the radar signal, specified as a positive scalar. Units are in Hz.

Example: 5e3

Data Types: double

WaveformType — Waveform type identifier
0 (default) | nonnegative integer

Waveform type identifier, specified as a nonnegative integer.

Example: 5e3

Data Types: double

ProcessingGain — Processing gain
0 (default) | scalar

Processing gain associated with the signal waveform, specified as a scalar. Units are in dB.

2-231

Example: 10

Data Types: `double`

PropagationRange — Distance signal propagates
`0` (default) | nonnegative scalar

Total distance over which the signal has propagated, specified as a nonnegative scalar. For direct-path signals, the range is zero. Units are in meters.

Example: `1000`

Data Types: `double`

PropagationRangeRate — Range rate of signal propagation path
`0` (default) | scalar

Total range rate for the path over which the signal has propagated, specified as a scalar. For direct-path signals, the range rate is zero. Units are in meters per second.

Example: `10`

Data Types: `double`

Examples

Create Radar Emission Object

Create a `radarEmission` object with specified properties.

```
signal = radarEmission('PlatformID',10,'EmitterIndex',25, ...
    'OriginPosition',[100,3000,50],'EIRP',10,'CenterFrequency',200e6, ...
    'Bandwidth',10e3)


signal =

  radarEmission with properties:

                 EIRP: 10
                  RCS: 0
           PlatformID: 10
         EmitterIndex: 25
```

```
          OriginPosition: [100 3000 50]
          OriginVelocity: [0 0 0]
             Orientation: [1×1 quaternion]
             FieldOfView: [180 180]
         CenterFrequency: 200000000
               Bandwidth: 10000
            WaveformType: 0
           ProcessingGain: 0
        PropagationRange: 0
    PropagationRangeRate: 0
```

Detect Radar Emission with ESM Sensor

Create an radar emission and then detect the emission using a `radarSensor` object.

First, create an radar emission.

```
orient = quaternion([180 0 0],'eulerd','zyx','frame');
rfSig = radarEmission('PlatformID',1,'EmitterIndex',1,'EIRP',100, ...
    'OriginPosition',[30 0 0],'Orientation',orient);
```

Then, create an ESM sensor using `radarSensor`.

```
sensor = radarSensor(1);
```

Detect the RF emission.

```
time = 0;
[dets,numDets,config] = sensor(rfSig,time)
```

```
dets =

  1×1 cell array

    {1×1 objectDetection}


numDets =

     1
```

```
config =

  struct with fields:

            SensorIndex: 1
             IsValidTime: 1
              IsScanDone: 0
            FieldOfView: [1 5]
   MeasurementParameters: [1×1 struct]
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
emissionsInBody | radarChannel | radarEmitter | sonarEmission

Introduced in R2018b

sonarEmission class

Emitted sonar signal structure

Description

The `sonarEmission` class creates a sonar emission object. This object contains all the properties that describe a signal radiated by a sonar source.

Construction

`signal = sonarEmission` creates a `sonarEmission` object with default properties. The object represents sonar signals from emitters, channels, and sensors.

`signal = sonarEmission(Name,Value)` sets object properties specified by one or more `Name,Value` pair arguments. `Name` can also be 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`.

Properties

`PlatformID` — Platform identifier
positive integer

Platform identifier, specified as a positive integer. The emitter is mounted on the platform with this ID. Each platform identifier is unique within a scenario.

Example: 5

Data Types: `double`

`EmitterIndex` — Emitter identifier
positive integer

Emitter identifier, specified as a positive integer. Each emitter index is unique.

Example: 2

Data Types: `double`

`OriginPosition` — Location of emitter
`[0 0 0]` (default) | 1-by-3 real-valued vector

Location of the emitter in scenario coordinates, specified as a 1-by-3 real-valued vector. Units are in meters.

Example: `[100 -500 1000]`

Data Types: `double`

`OriginVelocity` — Velocity of emitter
`[0 0 0]` (default) | 1-by-3 real-valued vector

Velocity of the emitter in scenario coordinates, specified as a 1-by-3 real-valued vector. Units are in meters per second.

Example: `[0 -50 100]`

Data Types: `double`

`Orientation` — Orientation of emitter
`quaternion(1,0,0,0)` (default) | quaternion | 3-by-3 real-valued orthogonal matrix

Orientation of the emitter in scenario coordinates, specified as a quaternion or 3-by-3 real-valued orthogonal matrix.

Example: `eye(3)`

Data Types: `double`

`FieldOfView` — Field of view of emitter
`[1;5]` | 2-by-1 vector of positive real values

Field of view of emitter, specified as a 2-by-1 vector of positive real values, [azfov; elfov]. The field of view defines the total angular extent of the signal emitted. Each component must lie in the interval (0, 180]. Units are in degrees.

Example: `[14;7]`

Data Types: `double`

`SourceLevel` — Cumulative source level
`0` (default) | scalar

Cumulative source level of an emitted signal, specified as a scalar. The cumulative source level of the emitted signal in decibels is relative to the intensity of a sound wave having an rms pressure of 1 micro-pascal. Units are in dB // 1 micro-pascal.

Example: `10`

Data Types: `double`

`TargetStrength` — Cumulative target strength
`0` (default) | scalar

Cumulative target strength of the source platform emitting the signal, specified as a scalar. Units are in dB.

Example: `10`

Data Types: `double`

`CenterFrequency` — Center frequency of sonar signal
`20e3` (default) | positive scalar

Center frequency of the signal, specified as a positive scalar. Units are in Hz.

Example: `10.5e3`

Data Types: `double`

`Bandwidth` — Half-power bandwidth of sonar signal
`2e3` (default) | positive scalar

Half-power bandwidth of the sonar signal, specified as a positive scalar. Units are in Hz.

Example: `1e3`

Data Types: `double`

`WaveformType` — Waveform type identifier
`0` (default) | nonnegative integer

Waveform type identifier, specified as a nonnegative integer.

Example: `5e3`

Data Types: `double`

`ProcessingGain` — Processing gain
`0` (default) | scalar

Processing gain associated with the signal waveform, specified as a scalar. Units are in dB.

Example: `10`

Data Types: `double`

PropagationRange — Distance signal propagates
`0` (default) | nonnegative scalar

Total distance over which the signal has propagated, specified as a nonnegative scalar. For direct-path signals, the range is zero. Units are in meters.

Example: `1000`

Data Types: `double`

PropagationRangeRate — Range rate of signal propagation path
`0` (default) | scalar

Total range rate for the path over which the signal has propagated, specified as a scalar. For direct-path signals, the range rate is zero. Units are in meters per second.

Example: `10`

Data Types: `double`

Examples

Create Sonar Emission Object

Create a `sonarEmission` object with specified properties.

```
signal = sonarEmission('PlatformID',6,'EmitterIndex',2, ...
    'OriginPosition',[100,3000,50],'TargetStrength',20, ...
    'CenterFrequency',20e3,'Bandwidth',500.0)


signal =

  sonarEmission with properties:

            SourceLevel: 0
```

```
        TargetStrength: 20
           PlatformID: 6
         EmitterIndex: 2
       OriginPosition: [100 3000 50]
       OriginVelocity: [0 0 0]
          Orientation: [1×1 quaternion]
          FieldOfView: [180 180]
      CenterFrequency: 20000
            Bandwidth: 500
         WaveformType: 0
       ProcessingGain: 0
     PropagationRange: 0
 PropagationRangeRate: 0
```

Detect Sonar Emission with Passive Sensor

Create a sonar emission and then detect the emission using a `sonarSensor` object.

First, create a sonar emission.

```
orient = quaternion([180 0 0],'eulerd','zyx','frame');
sonarSig = sonarEmission('PlatformID',1,'EmitterIndex',1, ...
    'OriginPosition',[30 0 0],'Orientation',orient, ...
    'SourceLevel',140,'TargetStrength',100);
```

Then create a passive sonar sensor.

```
sensor = sonarSensor(1,'No scanning');
```

Detect the sonar emission.

```
time = 0;
[dets, numDets, config] = sensor(sonarSig,time)


dets =

  1×1 cell array

    {1×1 objectDetection}


numDets =
```

```
      1


config =

  struct with fields:

              SensorIndex: 1
              IsValidTime: 1
               IsScanDone: 1
              FieldOfView: [1 5]
    MeasurementParameters: [1×1 struct]
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
emissionsInBody | emissionsInBody | radarEmission | sonarEmitter |
underwaterChannel

Introduced in R2018b

theaterPlot

Plot objects, detections, and tracks in trackingScenario

Description

The `theaterPlot` object is used to display a plot of a `trackingScenario`. This type of plot can be used with sensors capable of detecting objects.

Creation

Syntax

```
tp = theaterPlot
tp = theaterPlot(Name,Value)
```

Description

`tp = theaterPlot` creates a theater plot in a new figure.

`tp = theaterPlot(Name,Value)` creates a theater plot in a new figure with optional input "Properties" on page 2-241 specified by one or more `Name,Value` pair arguments. Properties can be specified in any order as `Name1,Value1,...,NameN,ValueN`. Enclose each property name in quotes.

Properties

Parent — Parent axes
theaterPlot handle

Parent axes, specified as a `theaterPlot` handle. If you do not specify `Parent`, then `theaterPlot` creates axes in a new figure.

`Plotters` — Plotters created for theater plot
array of plotter objects

Plotters created for the theater plot, specified as an array of plotter objects.

`XLimits` — Limits of *x*-axis
two-element row vector

Limits of the *x*-axis, specified as a two-element row vector, [*x1*,*x2*]. The values *x1* and *x2* are the lower and upper limits, respectively, for the theater plot display. If you do not specify the limits, then the default values for the `Parent` property are used. See "Orientation, Position, and Coordinate Systems" for coordinate system definitions.

Data Types: `double`

`YLimits` — Limits of *y*-axis
two-element row vector

Limits of the *y*-axis, specified as a two-element row vector, [*y1*,*y2*]. The values *y1* and *y2* are the lower and upper limits, respectively, for the theater plot display. If you do not specify the limits, then the default values for the `Parent` property are used. See "Orientation, Position, and Coordinate Systems" for coordinate system definitions.

Data Types: `double`

`ZLimits` — Limits of *z*-axis
two-element row vector

Limits of the *z*-axis, specified as a two-element row vector, [*z1*,*z2*]. The values *z1* and *z2* are the lower and upper limits, respectively, for the theater plot display. If you do not specify the limits, then the default values for the `Parent` property are used. See "Orientation, Position, and Coordinate Systems" for coordinate system definitions.

Data Types: `double`

Object Functions

Plotter Objects

clearData	Clear data from specific plotter of theater plot
clearPlotterData	Clear plotter data from theater plot

detectionPlotter   Create detection plotter
findPlotter   Return array of plotters associated with theater plot
orientationPlotter   Create orientation plotter
platformPlotter   Create platform plotter
trackPlotter   Create track plotter
trajectoryPlotter   Create trajectory plotter

Plotting Functions

plotDetection   Plot set of detections in theater detection plotter
plotOrientation   Plot set of orientations in orientation plotter
plotPlatform   Plot set of platforms in platform plotter
plotTrack   Plot set of tracks in theater track plotter
plotTrajectory   Plot set of trajectories in trajectory plotter

Examples

Create and Display Theater Plot

Create a theater plot.

```
tp = theaterPlot('XLim',[0 90],'YLim',[-35 35],'ZLim',[0 50]);
```

Display radar detections with coordinates at $(30, -5, 5)$, $(50, -10, 10)$, and $(40, 7, 40)$. Set the view so that you are looking on the *yz*-plane. Confirm the *y*- and *z*-coordinates of the radar detections are correct.

```
radarPlotter = detectionPlotter(tp,'DisplayName','Radar Detections');
plotDetection(radarPlotter, [30 -5 5; 50 -10 10; 40 7 40])
grid on
view(90,0)
```

2-243
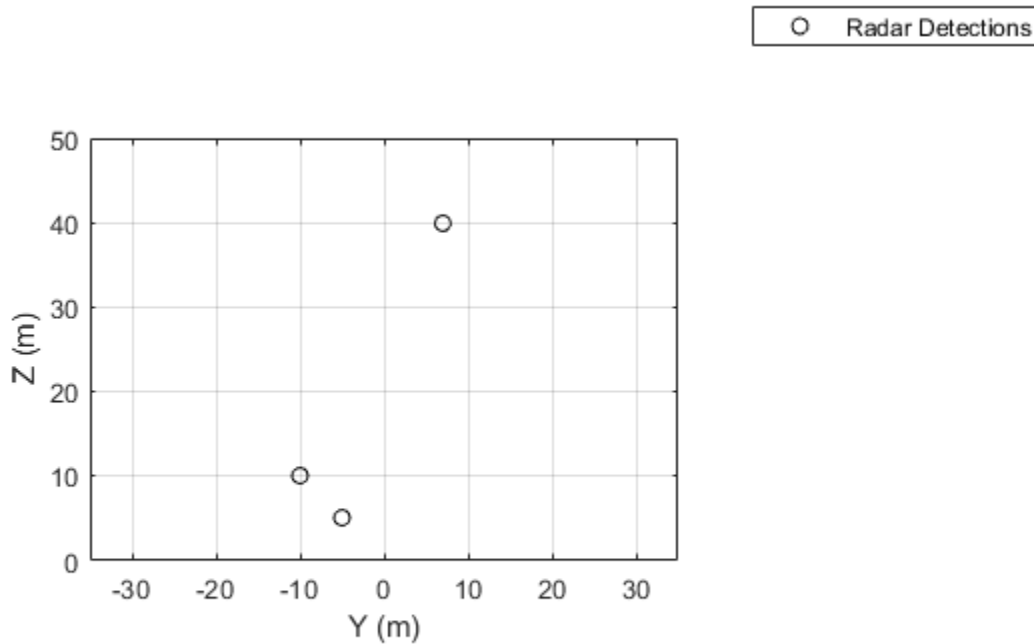
The view can be changed by opening the plot in a figure window and selecting **Tools > Rotate 3D** in the figure menu.

Limitations

You cannot use the rectangle-zoom feature in the `theaterPlot` figure.

See Also

`trackingScenario`

Introduced in R2018b

clearPlotterData

Clear plotter data from theater plot

Syntax

```
clearPlotterData(tp)
```

Description
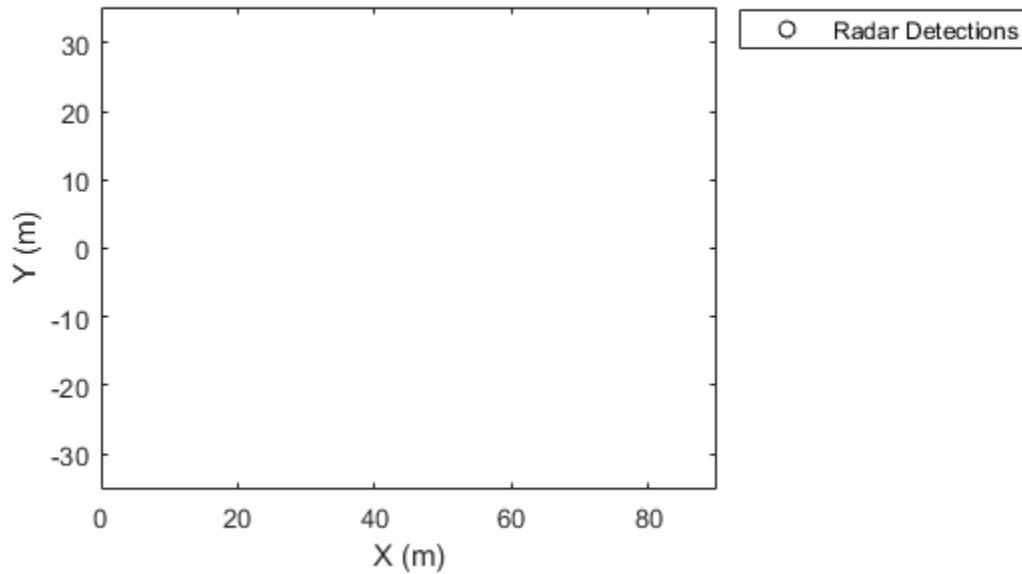
clearPlotterData(tp) clears data shown in the plot from all the plotters used in the theater plot, tp. Legend entries and coverage areas are not cleared from the plot.

Examples

Clear Plotter Data from Theater Plot

Create a theater plot and a detection plotter.

```
tp = theaterPlot('XLim',[0, 90],'YLim',[-35, 35],'ZLim',[0, 10]);
detectionPlotter(tp,'DisplayName','Radar Detections');
```
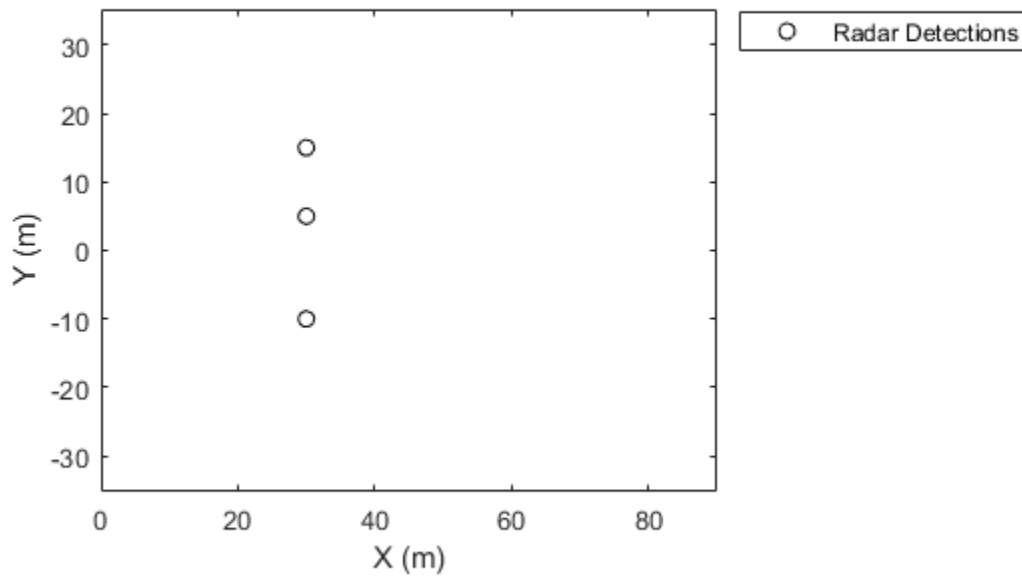
Use `findPlotter` to locate the plotter by its display name.

```
radarPlotter = findPlotter(tp,'DisplayName','Radar Detections');
```
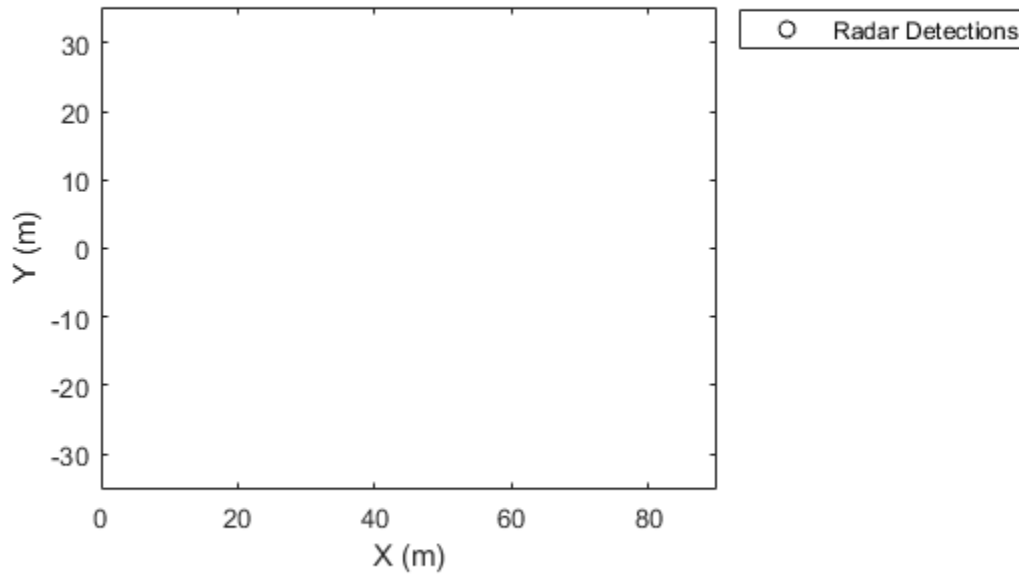
Plot three detections.

```
plotDetection(radarPlotter, [30, 5, 1; 30, -10, 2; 30, 15, 1]);
```

Clear data from the plot.

```
clearPlotterData(tp);
```

Input Arguments

tp — Theater plot
theaterPlot object

Theater plot, specified as a theaterPlot object.

See Also

clearData | findPlotter | theaterPlot

Introduced in R2018b

detectionPlotter

Create detection plotter

Syntax

```
detPlotter = detectionPlotter(tp)
detPlotter = detectionPlotter(tp,Name,Value)
```

Description

detPlotter = detectionPlotter(tp) creates a detection plotter for use with the theater plot tp.

detPlotter = detectionPlotter(tp,Name,Value) creates a detection plotter with additional options specified by one or more Name,Value pair arguments.

Examples

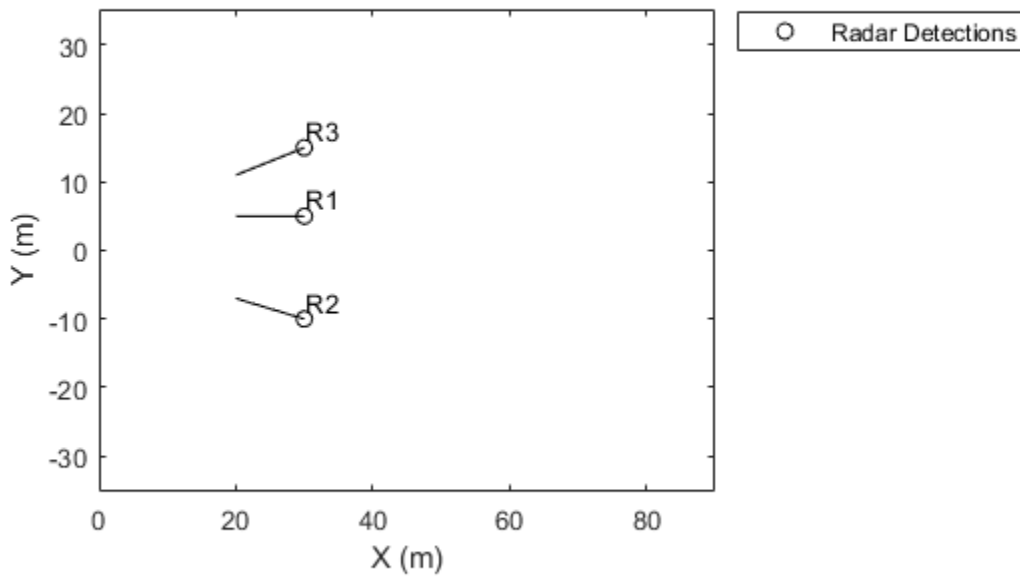**Create and Update Detections for Theater Plot**

Create a theater plot.

```
tp = theaterPlot('XLim',[0,90],'YLim',[-35,35],'ZLim',[1,10]);
```

Create a detection plotter with the name Radar Detections.

```
radarPlotter = detectionPlotter(tp,'DisplayName','Radar Detections');
```

Update the detection plotter with three detections labeled 'R1', 'R2', and 'R3' positioned in units of meters at $(30, 5, 4)$, $(30, -10, 2)$, and $(30, 15, 1)$ with corresponding velocities (in m/s) of $(-10, 0, 2)$, $(-10, 3, 1)$, and $(-10, -4, 1)$, respectively.

```
positions = [30, 5, 4; 30, -10, 2; 30, 15, 1];
velocities = [-10, 0, 2; -10, 3, 1; -10, -4, 1];
labels = {'R1','R2','R3'};
plotDetection(radarPlotter, positions, velocities, labels)
```


Input Arguments

tp — Theater plot
theaterPlot object

Theater plot, specified as a theaterPlot 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 quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MarkerSize',10`

DisplayName — Plot name to display in legend
character vector | string scalar

Plot name to display in legend, specified as the comma-separated pair consisting of `'DisplayName'` and a character vector or string scalar. If no name is specified, no entry is shown.

Example: `'DisplayName','Radar Detections'`

HistoryDepth — Number of previous updates to display
0 (default) | nonnegative integer less than or equal to 10,000

Number of previous track updates to display, specified as the comma-separated pair consisting of `'HistoryDepth'` and a nonnegative integer less than or equal to 10,000. If set to 0, then no previous updates are rendered.

Marker — Marker symbol
`'o'` (default) | character vector | string scalar

Marker symbol, specified as the comma-separated pair consisting of `'Marker'` and one of these symbols.

Value	Description
`'+'`	Plus sign
`'o'`	Circle (default)
`'*'`	Asterisk
`'.'`	Point
`'x'`	Cross
`'s'` or `'square'`	Square
`'d'` or `'diamond'`	Diamond

Value	Description
`'v'`	Downward-pointing triangle
`'^'`	Upward-pointing triangle
`'>'`	Right-pointing triangle
`'<'`	Left-pointing triangle
`'p'` or `'pentagram'`	Five-pointed star (pentagram)
`'h'` or `'hexagram'`	Six-pointed star (hexagram)
`'none'`	No marker symbol

MarkerSize — Size of marker
6 (default) | positive integer

Size of marker, specified as the comma-separated pair consisting of `'MarkerSize'` and a positive integer in points.

MarkerEdgeColor — Marker outline color
`'black'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerEdgeColor'` and a character vector, string scalar, or an RGB triplet.

MarkerFaceColor — Marker fill color
`'none'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerFaceColor'` and a character vector, string scalar, RGB triplet, or `'none'`. The default is `'none'`.

FontSize — Font size for labeling platforms
10 (default) | positive integer

Font size for labeling detections, specified as the comma-separated pair consisting of `'FontSize'` and a positive integer that represents font point size.

LabelOffset — Gap between label and positional point
[0 0 0] (default) | three-element row vector

Gap between label and positional point it annotates, specified as the comma-separated pair consisting of `'LabelOffset'` and a three-element row vector. Specify the [*x* *y* *z*] offset in meters.

VelocityScaling — Scale factor for magnitude length of velocity vectors
1 (default) | positive scalar

Scale factor for magnitude length of velocity vectors, specified as the comma-separated pair consisting of `'VelocityScaling'` and a positive scalar. The plot renders the magnitude vector value as *VK*, where *V* is the magnitude of the velocity in meters per second, and *K* is the value of `VelocityScaling`.

Tag — Tag to associate with the plotter
`'PlotterN'` (default) | character vector | string scalar

Tag to associate with the plotter, specified as the comma-separated pair consisting of `'Tag'` and a character vector or string scalar. The default value is `'PlotterN'`, where *N* is an integer that corresponds to the *N*th plotter associated with the `theaterPlot`.

Tags provide a way to identify plotter objects, for example when searching using `findPlotter`.

See Also

clearData | clearPlotterData | plotDetection | theaterPlot

Introduced in R2018b

2-255

findPlotter

Return array of plotters associated with theater plot

Syntax

```
p = findPlotter(tp)
p = findPlotter(tp,Name,Value)
```

Description

`p = findPlotter(tp)` returns the array of plotters associated with the theater plot, `tp`.

Note In general, it is faster to use the plotters directly from the plotter creation methods of `theaterPlot`. Use `findPlotter` when it is otherwise inconvenient to use the plotter handles directly.

`p = findPlotter(tp,Name,Value)` specifies one or more `Name,Value` pair arguments required to match for the theater plot.

Examples

Find Plotter in Theater Plot

Create a theater plot and generate detection and platform plotters. Set the value of the `Tag` property of the detection plotter to `'radPlot'`.

```
tp = theaterPlot('XLim',[0, 90],'YLim',[-35, 35]);
detectionPlotter(tp,'DisplayName','Radar Detections','Tag','radPlot');
platformPlotter(tp, 'DisplayName', 'Platforms');
```

Use `findPlotter` to locate the detection plotter based on its `Tag` property.

```
radarPlotter = findPlotter(tp,'Tag','radPlot')

radarPlotter =
  DetectionPlotter with properties:

        HistoryDepth: 0
              Marker: 'o'
          MarkerSize: 6
     MarkerEdgeColor: [0 0 0]
     MarkerFaceColor: 'none'
            FontSize: 10
         LabelOffset: [0 0 0]
     VelocityScaling: 1
                 Tag: 'radPlot'
         DisplayName: 'Radar Detections'
```

Use the detection plotter to display the located objects.

```
plotDetection(radarPlotter, [30, 5, 0; 30, -20, 0; 30, 15, 0]);
```
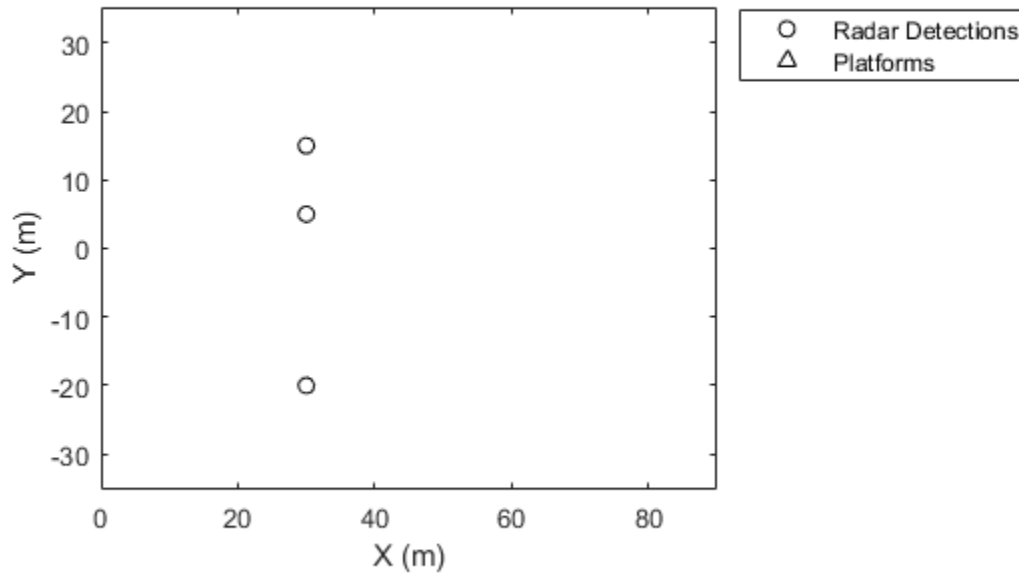
Input Arguments

tp — Theater plot
theaterPlot object

Theater plot, specified as a `theaterPlot` 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 quotes.

You can specify several name and value pair arguments in any order as
`Name1,Value1,...,NameN,ValueN`.

Example: `'Tag','thisPlotter'`

DisplayName — Display name
character vector | string scalar

Display name of the plotter to find, specified as the comma-separated pair consisting of
`'DisplayName'` and a character vector or string scalar. `DisplayName` is the plotter
name that appears in the legend. To match missing legend entries, specify `DisplayName`
as `''`.

Tag — Tag of plotter
character vector | string scalar

Tag of plotter to find, specified as the comma-separated pair consisting of `'Tag'` a
character vector or string scalar. By default, plotters have a `Tag` property with a default
value of `'PlotterN'`, where *N* is an integer that corresponds to the *N*th plotter
associated with the theater plot `tp`.

See Also
`clearData` | `clearPlotterData` | `theaterPlot`

Introduced in R2018b

orientationPlotter

Create orientation plotter

Syntax

```
oPlotter = orientationPlotter(tp)
oPlotter = orientationPlotter(tp,Name,Value)
```

Description

`oPlotter = orientationPlotter(tp)` creates an orientation plotter for use with the theater plot `tp`.

`oPlotter = orientationPlotter(tp,Name,Value)` creates an orientation plotter with additional options specified by one or more `Name,Value` pair arguments.

Examples

Show Orientation of Oscillating Device

This example shows how to animate the orientation of an oscillating device.

Load `rpy_9axis.mat`. The data in `rpy_9axis.mat` is recorded accelerometer, gyroscope, and magnetometer sensor data from a device oscillating in pitch (around *y*-axis), then yaw (around *z*-axis), then roll (around *x*-axis). The device's *x*-axis was pointing southward when recorded.

```
ld = load('rpy_9axis.mat')

ld = struct with fields:
          Fs: 200
    sensorData: [1×1 struct]
```

Set the sampling frequency. Extract the accelerometer and gyroscope data. Set the decimation factor to 2. Use `fuse` to create an indirect Kalman sensor fusion filter from the data.

```
accel = ld.sensorData.Acceleration;
gyro = ld.sensorData.AngularVelocity;
Fs   = ld.Fs;
decim = 2;
fuse = imufilter('SampleRate',Fs,'DecimationFactor',decim);
```

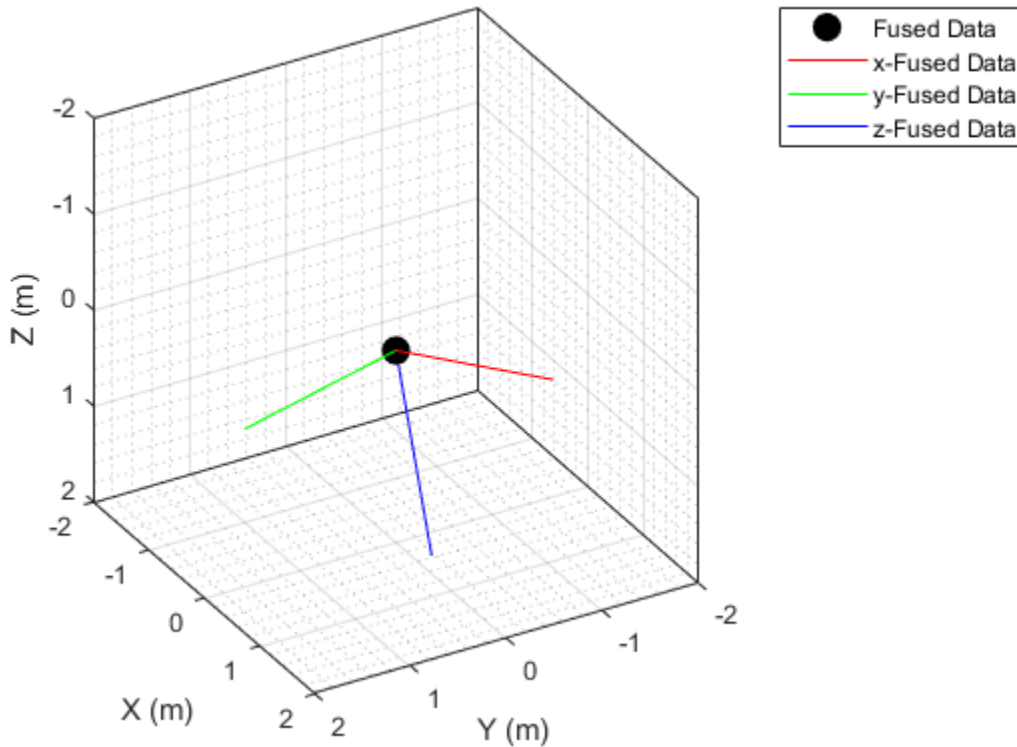Obtain the pose information of the fused data.

```
pose = fuse(accel,gyro);
```

Create a theater plot. Add to the theater plot an orientation plotter with `'DisplayName'` set to `'Fused Data'` and `'LocalAxesLength'` set to 2.

```
tp = theaterPlot('XLimit',[-2 2],'YLimit',[-2 2],'ZLimit',[-2 2]);
op = orientationPlotter(tp,'DisplayName','Fused Data',...
    'LocalAxesLength',2);
```

Loop through the pose information to animate the changing orientation.

```
for i=1:numel(pose)
    plotOrientation(op, pose(i))
    drawnow
end
```

Input Arguments

tp — Theater plot
theaterPlot object

Theater plot, specified as a `theaterPlot` 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 quotes.

You can specify several name and value pair arguments in any order as
`Name1,Value1,...,NameN,ValueN`.

Example: `'HistoryDepth',6`

DisplayName — Plot name to display in legend
character vector | string scalar

Plot name to display in legend, specified as the comma-separated pair consisting of
`'DisplayName'` and a character vector or string scalar. If no name is specified, no entry
is shown.

Example: `'DisplayName','Radar Detections'`

HistoryDepth — Number of previous track updates to display
`0` (default) | nonnegative integer less than or equal to 100

Number of previous track updates to display, specified as the comma-separated pair
consisting of `'HistoryDepth'` and a nonnegative integer less than or equal to 100. If set
to 0, then no previous updates are rendered.

Marker — Marker symbol
`'o'` (default) | character vector | string scalar

Marker symbol, specified as the comma-separated pair consisting of `'Marker'` and one of
these symbols.

Value	Description
`'+'`	Plus sign
`'o'`	Circle (default)
`'*'`	Asterisk
`'.'`	Point
`'x'`	Cross
`'s'` or `'square'`	Square
`'d'` or `'diamond'`	Diamond
`'v'`	Downward-pointing triangle
`'^'`	Upward-pointing triangle
`'>'`	Right-pointing triangle

Value	Description
`'<'`	Left-pointing triangle
`'p'` or `'pentagram'`	Five-pointed star (pentagram)
`'h'` or `'hexagram'`	Six-pointed star (hexagram)
`'none'`	No marker symbol

MarkerSize — Size of marker
10 (default) | positive integer

Size of marker, specified in points as the comma-separated pair consisting of `'MarkerSize'` and a positive integer.

MarkerEdgeColor — Marker outline color
`'black'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerEdgeColor'` and a character vector, string scalar, or an RGB triplet. The default color is `'black'`.

MarkerFaceColor — Marker fill color
`'none'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerFaceColor'` and a character vector, string scalar, RGB triplet, or `'none'`. The default is `'none'`.

FontSize — Font size for labeling tracks
10 (default) | positive integer

Font size for labeling tracks, specified as the comma-separated pair consisting of `'FontSize'` and a positive integer that represents font point size.

LabelOffset — Gap between label and positional point
[0 0 0] (default) | three-element row vector

Gap between label and positional point it annotates, specified as the comma-separated pair consisting of `'LabelOffset'` and a three-element row vector. Specify the [$x\ y\ z$] offset in meters.

LocalAxesLength — Length of line
1 (default) | positive scalar

Length of line used to denote each of the local *x*-, *y*-, and *z*-axes of the given orientation, specified as the comma-separated pair consisting of `'LocalAxesLength'` and a positive scalar. `'LocalAxesLength'` is in meters.

Tag — Tag to associate with the plotter
`'PlotterN'` (default) | character vector | string scalar

Tag to associate with the plotter, specified as the comma-separated pair consisting of `'Tag'` and a character vector or string scalar. The default value is `'PlotterN'`, where *N* is an integer that corresponds to the *N*th plotter associated with the `theaterPlot`.

Tags provide a way to identify plotter objects, for example when searching using `findPlotter`.

See Also

clearData | clearPlotterData | plotOrientation | theaterPlot

Introduced in R2018b

2-265

platformPlotter

Create platform plotter

Syntax

```
pPlotter = platformPlotter(tp)
pPlotter = platformPlotter(tp,Name,Value)
```

Description

`pPlotter = platformPlotter(tp)` creates a platform plotter for use with the theater plot, `tp`.

`pPlotter = platformPlotter(tp,Name,Value)` creates a platform plotter with additional options specified by one or more `Name,Value` pair arguments.

Examples

Create and Update Theater Plot Platforms
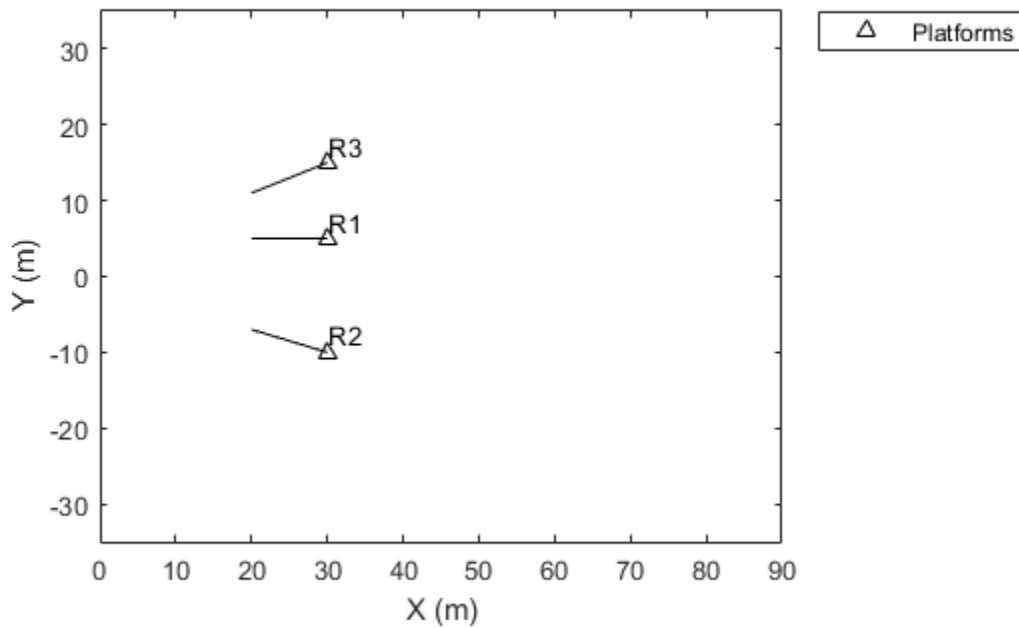
Create a theater plot.

```
tp = theaterPlot('XLim',[0,90],'YLim',[-35,35],'ZLim',[1,10]);
```

Create a platform plotter with the name `'Platforms'`.

```
plotter = platformPlotter(tp,'DisplayName','Platforms');
```

Update the theater plot with three platforms labeled, `'R1'`, `'R2'`, and `'R3'`. Position the three platforms, in units of meters, at $(30, 5, 4)$, $(30, -10, 2)$, and $(30, 15, 1)$, with corresponding velocities (in m/s) of $(-10, 0, 2)$, $(-10, 3, 1)$, and $(-10, -4, 1)$, respectively.

```
positions = [30, 5, 4; 30, -10, 2; 30, 15, 1];
velocities = [-10, 0, 2; -10, 3, 1; -10, -4, 1];
labels = {'R1','R2','R3'};
plotPlatform(plotter, positions, velocities, labels);
```


Input Arguments

tp — Theater plot
theaterPlot object

Theater plot, specified as a theaterPlot 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 quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MarkerSize',10`

DisplayName — Plot name to display in legend
character vector | string scalar

Plot name to display in legend, specified as the comma-separated pair consisting of `'DisplayName'` and a character vector or string scalar. If no name is specified, no entry is shown.

Example: `'DisplayName','Radar Detections'`

Marker — Marker symbol
`'^'` (default) | character vector | string scalar

Marker symbol, specified as the comma-separated pair consisting of `'Marker'` and one of these values.

Value	Description
`'+'`	Plus sign
`'o'`	Circle
`'*'`	Asterisk
`'.'`	Point
`'x'`	Cross
`'s'` or `'square'`	Square
`'d'` or `'diamond'`	Diamond
`'v'`	Downward-pointing triangle
`'^'`	Upward-pointing triangle (default)
`'>'`	Right-pointing triangle
`'<'`	Left-pointing triangle
`'p'` or `'pentagram'`	Five-pointed star (pentagram)

Value	Description
`'h'` or `'hexagram'`	Six-pointed star (hexagram)
`'none'`	No marker symbol

`MarkerSize` — Size of marker
6 | positive integer

Size of marker, specified as the comma-separated pair consisting of `'MarkerSize'` and a positive integer in points.

`MarkerEdgeColor` — Marker outline color
`'black'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerEdgeColor'` and a character vector, string scalar, or an RGB triplet.

`MarkerFaceColor` — Marker fill color
`'none'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerFaceColor'` and a character vector, string scalar, RGB triplet, or `'none'`. The default is `'none'`.

`FontSize` — Font size for labeling platforms
10 (default) | positive integer

Font size for labeling platforms, specified in font points size as the comma-separated pair consisting of `'FontSize'` and a positive integer.

`LabelOffset` — Gap between label and positional point
[0 0 0] (default) | three-element row vector

Gap between label and positional point it annotates, specified as the comma-separated pair consisting of `'LabelOffset'` and a three-element row vector. Specify the [x y z] offset in meters.

`VelocityScaling` — Scale factor for magnitude length of velocity vectors
1 (default) | positive scalar

Scale factor for magnitude length of velocity vectors, specified as the comma-separated pair consisting of `'VelocityScaling'` and a positive scalar. The plot renders the

magnitude vector value as *VK*, where *V* is the magnitude of the velocity in meters per second, and *K* is the value of `VelocityScaling`.

Tag — Tag to associate with the plotter
`'PlotterN'` (default) | character vector | string scalar

Tag to associate with the plotter, specified as the comma-separated pair consisting of `'Tag'` and a character vector or string scalar. The default value is `'PlotterN'`, where *N* is an integer that corresponds to the *N*th plotter associated with the `theaterPlot`.

Tags provide a way to identify plotter objects, for example when searching using `findPlotter`.

See Also

`clearData` | `clearPlotterData` | `plotPatform` | `theaterPlot`

Introduced in R2018b

plotDetection

Plot set of detections in theater detection plotter

Syntax

```
plotDetection(detPlotter,positions)
plotDetection(detPlotter,positions,velocities)
plotDetection(detPlotter,positions, ___ ,labels)
plotDetection(detPlotter,positions, ___ ,covariances)
```

Description

`plotDetection(detPlotter,positions)` specifies positions of *M* detected objects whose positions are plotted by the detection plotter `detPlotter`. Specify the positions as an *M*-by-3 matrix, where each column of the matrix corresponds to the *x*-, *y*-, and *z*-coordinates of the detected object locations.

`plotDetection(detPlotter,positions,velocities)` also specifies the corresponding velocities of the detections. Velocities are plotted as line vectors emanating from the center positions of the detections. If specified, `velocities` must have the same dimensions as `positions`.

`plotDetection(detPlotter,positions, ___ ,labels)` also specifies a cell vector of length *M* whose elements contain the text labels corresponding to the *M* detections specified in the positions matrix. If omitted, no labels are plotted.

`plotDetection(detPlotter,positions, ___ ,covariances)` also specifies the covariances of the *M* detection uncertainties, where the covariances are a 3-by-3-by-*M* matrix of covariances that are centered at the positions of each detection. The uncertainties are plotted as an ellipsoid

Examples

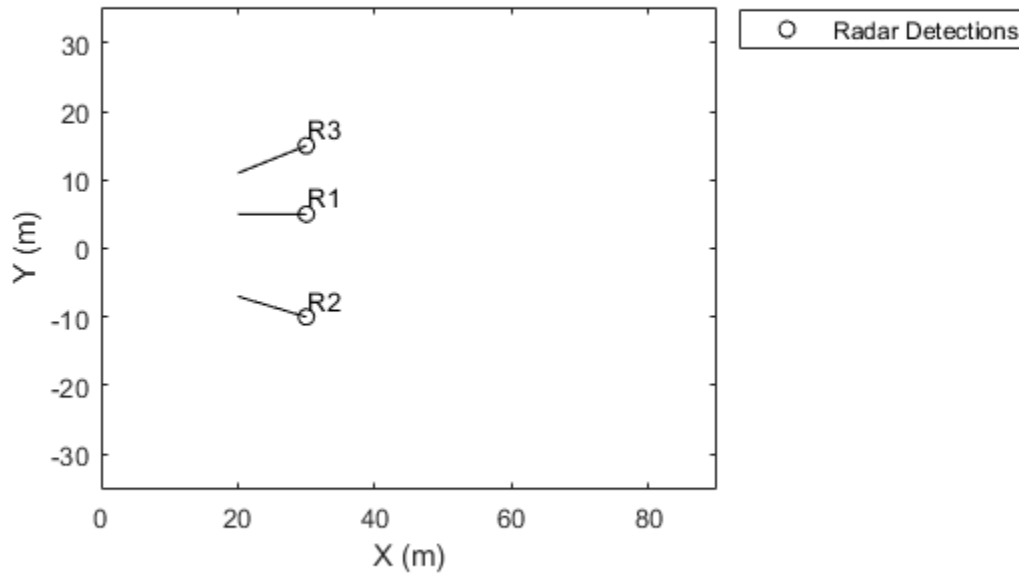**Create and Update Detections for Theater Plot**

Create a theater plot.

```
tp = theaterPlot('XLim',[0,90],'YLim',[-35,35],'ZLim',[1,10]);
```

Create a detection plotter with the name Radar Detections.

```
radarPlotter = detectionPlotter(tp,'DisplayName','Radar Detections');
```

Update the detection plotter with three detections labeled 'R1', 'R2', and 'R3' positioned in units of meters at $(30, 5, 4)$, $(30, -10, 2)$, and $(30, 15, 1)$ with corresponding velocities (in m/s) of $(-10, 0, 2)$, $(-10, 3, 1)$, and $(-10, -4, 1)$, respectively.

```
positions = [30, 5, 4; 30, -10, 2; 30, 15, 1];
velocities = [-10, 0, 2; -10, 3, 1; -10, -4, 1];
labels = {'R1','R2','R3'};
plotDetection(radarPlotter, positions, velocities, labels)
```

Input Arguments

detPlotter — Detection plotter
detectionPlotter object

Detection plotter, specified as a detectionPlotter object.

positions — Detection positions
real-valued matrix

Detection positions, specified as an *M*-by-3 real-valued matrix, where *M* is the number of detections. Each column of the matrix corresponds to the *x*-, *y*-, and *z*-coordinates of the detection positions in meters.

`velocities` — Detection velocities
real-valued matrix

Detection velocities, specified as an *M*-by-3 real-valued matrix, where *M* is the number of detections. Each column of the matrix corresponds to the *x*-, *y*-, and *z*-velocities of the detections. If specified, `velocities` must have the same dimensions as `positions`.

`labels` — Detection labels
cell array

Detection labels, specified as a *M*-by-1 cell array of character vectors, where *M* is the number of detections. The input argument `labels` contains the text labels corresponding to the *M* detections specified in `positions`. If `labels` is omitted, no labels are plotted.

`covariances` — Detection uncertainties
real-valued array

Detection uncertainties of *M* tracked objects, specified as a 3-by-3-by-*M* real-valued array of covariances. The covariances are centered at the positions of each detection and are plotted as an ellipsoid.

See Also

clearData | clearPlotterData | detectionPlotter | theaterPlot

Introduced in R2018b

plotOrientation

Plot set of orientations in orientation plotter

Syntax

```
plotOrientation(oPlotter,orientations)
plotOrientation(oPlotter,roll,pitch,yaw)
plotOrientation(oPlotter, ___ ,positions)
plotOrientation(oPlotter, ___ ,positions,labels)
```

Description

`plotOrientation(oPlotter,orientations)` specifies the orientations of *M* objects to show for the orientation plotter, `oPlotter`. The `orientations` argument can be either an *M*-by-1 array of quaternions, or a 3-by-3-by-*M* array of rotation matrices.

`plotOrientation(oPlotter,roll,pitch,yaw)` specifies the orientations of *M* objects to show for the orientation plotter, `oPlotter`. The arguments `roll`, `pitch`, and `yaw` are *M*-by-1 vectors measured in degrees.

`plotOrientation(oPlotter, ___ ,positions)` also specifies the positions of the objects as an *M*-by-3 matrix. Each column of `positions` corresponds to the *x*-, *y*-, and *z*-coordinates of the object locations, respectively.

`plotOrientation(oPlotter, ___ ,positions,labels)` also specifies the labels as an *M*-by-1 cell array of character vectors that correspond to the *M* orientations.

Examples

Show Orientation of Oscillating Device

This example shows how to animate the orientation of an oscillating device.

Load `rpy_9axis.mat`. The data in `rpy_9axis.mat` is recorded accelerometer, gyroscope, and magnetometer sensor data from a device oscillating in pitch (around *y*-axis), then yaw (around *z*-axis), then roll (around *x*-axis). The device's *x*-axis was pointing southward when recorded.

```
ld = load('rpy_9axis.mat')

ld = struct with fields:
          Fs: 200
    sensorData: [1×1 struct]
```

Set the sampling frequency. Extract the accelerometer and gyroscope data. Set the decimation factor to 2. Use `fuse` to create an indirect Kalman sensor fusion filter from the data.

```
accel = ld.sensorData.Acceleration;
gyro = ld.sensorData.AngularVelocity;
Fs  = ld.Fs;
decim = 2;
fuse = imufilter('SampleRate',Fs,'DecimationFactor',decim);
```
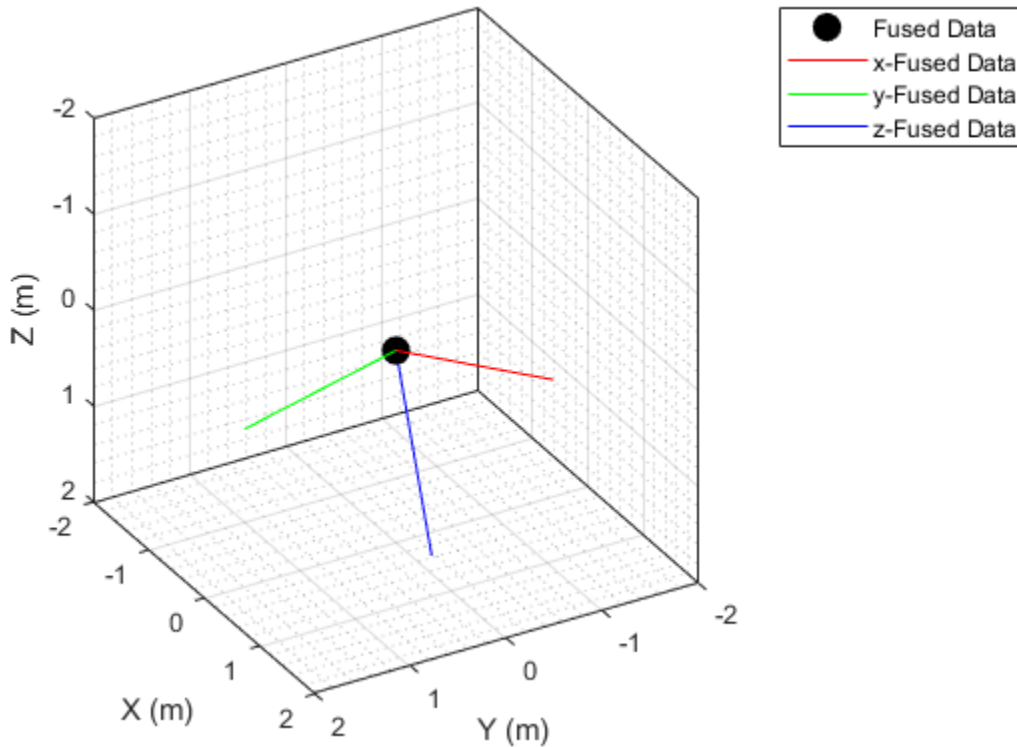
Obtain the pose information of the fused data.

```
pose = fuse(accel,gyro);
```

Create a theater plot. Add to the theater plot an orientation plotter with `'DisplayName'` set to `'Fused Data'` and `'LocalAxesLength'` set to 2.

```
tp = theaterPlot('XLimit',[-2 2],'YLimit',[-2 2],'ZLimit',[-2 2]);
op = orientationPlotter(tp,'DisplayName','Fused Data',...
    'LocalAxesLength',2);
```

Loop through the pose information to animate the changing orientation.

```
for i=1:numel(pose)
    plotOrientation(op, pose(i))
    drawnow
end
```

Input Arguments

oPlotter — Orientation plotter
orientationPlotter object

Orientation plotter, specified as an orientationPlotter object.

orientations — Orientations
quaternion array | real-valued array

Orientations of *M* objects, specified as either an *M*-by-1 array of quaternions, or a 3-by-3-by-*M* array of rotation matrices.

`roll, pitch, yaw` — Roll, pitch, yaw
real-valued vectors

Roll, pitch, and yaw angles defining the orientations of M objects, specified as M-by-1 vectors. Angles are measured in degrees.

`positions` — Object positions
[0 0 0] (default) | real-valued matrix

Object positions, specified as an M-by-3 real-valued matrix, where M is the number of objects. Each column of the matrix corresponds to the x-, y-, and z-coordinates of the objects locations in meters. The default value of `positions` is at the origin.

`labels` — Object labels
cell array

Object labels, specified as a M-by-1 cell array of character vectors, where M is the number of objects. `labels` contains the text labels corresponding to the M objects specified in `positions`. If `labels` is omitted, no labels are plotted.

See Also

clearData | clearPlotterData | orientationPlotter | theaterPlot

Introduced in R2018b

plotPlatform

Plot set of platforms in platform plotter

Syntax

```
plotPlatform(platPlotter,positions)
plotPlatform(platPlotter,positions,velocities)
plotPlatform(platPlotter,positions,labels)
plotPlatform(platPlotter,positions,velocities,labels)
```

Description

`plotPlatform(platPlotter,positions)` specifies positions of M platforms whose positions are plotted by `platPlotter`. Specify the positions as an M-by-3 matrix, where each column of the matrix corresponds to the x-, y-, and z-coordinates of the platform locations.

`plotPlatform(platPlotter,positions,velocities)` also specifies the corresponding velocities of the platforms. Velocities are plotted as line vectors emanating from the positions of the platforms. If specified, velocities must have the same dimensions as positions.

`plotPlatform(platPlotter,positions,labels)` also specifies a cell vector of length M whose elements contain the text labels corresponding to the M platforms specified in the positions matrix. If omitted, no labels are plotted.

`plotPlatform(platPlotter,positions,velocities,labels)` specifies velocities and text labels corresponding to the M platforms specified in the positions matrix.

Examples

Create and Update Theater Plot Platforms
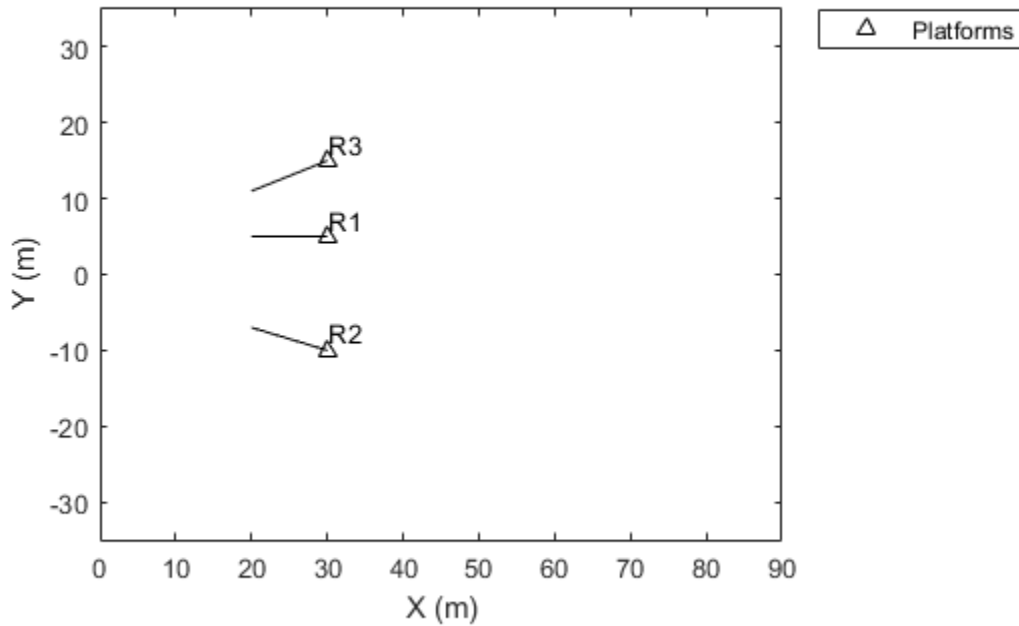
Create a theater plot.

```
tp = theaterPlot('XLim',[0,90],'YLim',[-35,35],'ZLim',[1,10]);
```

Create a platform plotter with the name `'Platforms'`.

```
plotter = platformPlotter(tp,'DisplayName','Platforms');
```

Update the theater plot with three platforms labeled, `'R1'`, `'R2'`, and `'R3'`. Position the three platforms, in units of meters, at $(30, 5, 4)$, $(30, -10, 2)$, and $(30, 15, 1)$, with corresponding velocities (in m/s) of $(-10, 0, 2)$, $(-10, 3, 1)$, and $(-10, -4, 1)$, respectively.

```
positions = [30, 5, 4; 30, -10, 2; 30, 15, 1];
velocities = [-10, 0, 2; -10, 3, 1; -10, -4, 1];
labels = {'R1','R2','R3'};
plotPlatform(plotter, positions, velocities, labels);
```

Input Arguments

platPlotter — Platform plotter
platformPlotter object

Platform plotter, specified as a platformPlotter object.

positions — Platform positions
real-valued matrix

Platform positions, specified as an *M*-by-3 real-valued matrix, where *M* is the number of platforms. Each column of the matrix corresponds to the *x*-, *y*-, and *z*-coordinates of the platform locations in meters.

velocities — Platform velocities
real-valued matrix

Platform velocities, specified as an *M*-by-3 real-valued matrix, where *M* is the number of platforms. Each column of the matrix corresponds to the *x*, *y*, and *z* velocities of the platforms. If specified, `velocities` must have the same dimensions as `positions`.

labels — Platform labels
cell array

Platform labels, specified as an *M*-by-1 cell array of character vectors, where *M* is the number of platforms. `labels` contains the text labels corresponding to the *M* platforms specified in `positions`. If `labels` is omitted, no labels are plotted.

See Also
`platformPlotter` | `theaterPlot`

Introduced in R2018b

plotTrack

Plot set of tracks in theater track plotter

Syntax

```
plotTrack(tPlotter,positions)
plotTrack(tPlotter,positions,velocities)
plotTrack( ___ ,covariances)
plotTrack(tPlotter,positions, ___ ,labels)
plotTrack(tPlotter,positions, ___ ,labels,trackIDs)
```

Description

plotTrack(tPlotter,positions) specifies positions of *M* tracked objects whose positions are plotted by the track plotter tPlotter. Specify the positions as an *M*-by-3 matrix, where each column of positions corresponds to the *x*-, *y*-, and *z*-coordinates of the object locations.

plotTrack(tPlotter,positions,velocities) also specifies the corresponding velocities of the objects. Velocities are plotted as line vectors emanating from the positions of the detections. If specified, velocities must have the same dimensions as positions. If unspecified, no velocity information is plotted.

plotTrack(___ ,covariances) also specifies the covariances of the *M* track uncertainties. The input argument covariances is a 3-by-3-by-*M* array of covariances that are centered at the track positions. The uncertainties are plotted as an ellipsoid. You can use this syntax with any of the previous syntaxes.

plotTrack(tPlotter,positions, ___ ,labels) also specifies the labels and positions of the *M* objects whose positions are estimated by a tracker. The input argument labels is an *M*-by-1 cell array of character vectors that correspond to the *M* detections specified in positions. If omitted, no labels are plotted.

plotTrack(tPlotter,positions, ___ ,labels,trackIDs) also specifies the unique track identifiers for each track when the 'ConnectHistory' on page 2-0 property of tPlotter is set to 'on'. The input argument trackIDs can be an *M*-by-1

array of unique integer values, an *M*-by-1 array of strings, or an *M*-by-1 cell array of unique character vectors.

If `trackIDs` is omitted when `'ConnectHistory'` is `'on'`, then the track identifiers are derived from the labels input instead. The `trackIDs` input is ignored when `'ConnectHistory'` is `'off'`.

Examples

Plot Tracks in Theater Plot

Create a theater plot. Create a track plotter with `DisplayName` set to `'Tracks'` and with `HistoryDepth` set to 5.

```
tp = theaterPlot('XLim',[0,90],'YLim',[-35,35]);
tPlotter = trackPlotter(tp,'DisplayName','Tracks','HistoryDepth',5);
```

Update the track plotter with three tracks labeled `'T1'`, `'T2'`, and `'T3'` with start positions in units of meters all starting at (30, 5, 1) with corresponding velocities (in m/s) of (3, 0, 1), (3, 2, 2) and (3, -3, 5), respectively. Update the tracks with the velocities for ten iterations.

```
positions = [30, 5, 1; 30, 5, 1; 30, 5, 1];
velocities = [3, 0, 1; 3, 2, 2; 3, -3, 5];
labels = {'T1','T2','T3'};
for i=1:10
    plotTrack(tPlotter, positions, velocities, labels)
    positions = positions + velocities;
end
```

This animation loops through all the generated plots.

Plot Track Uncertainties

Create a theater plot. Create a track plotter with `DisplayName` set to `'Uncertain Track'`.

```
tp = theaterPlot('Xlim',[0 5],'Ylim',[0 5]);
tPlotter = trackPlotter(tp,'DisplayName','Uncertain Track');
```

Update the track plotter with a track at a position in meters (2,2,1) and velocity (in meters/second) of (1,1,3). Also create a random 3-by-3 covariance matrix representing track uncertainties. For purposes of reproducibility, set the random seed to the default value.

```
positions = [2, 2, 1];
velocities = [1, 1, 3];
rng default
covariences = randn(3,3);
```

Plot the track with the covariances plotted as an ellipsoid.

```
plotTrack(tPlotter,positions,velocities,covariences)
```
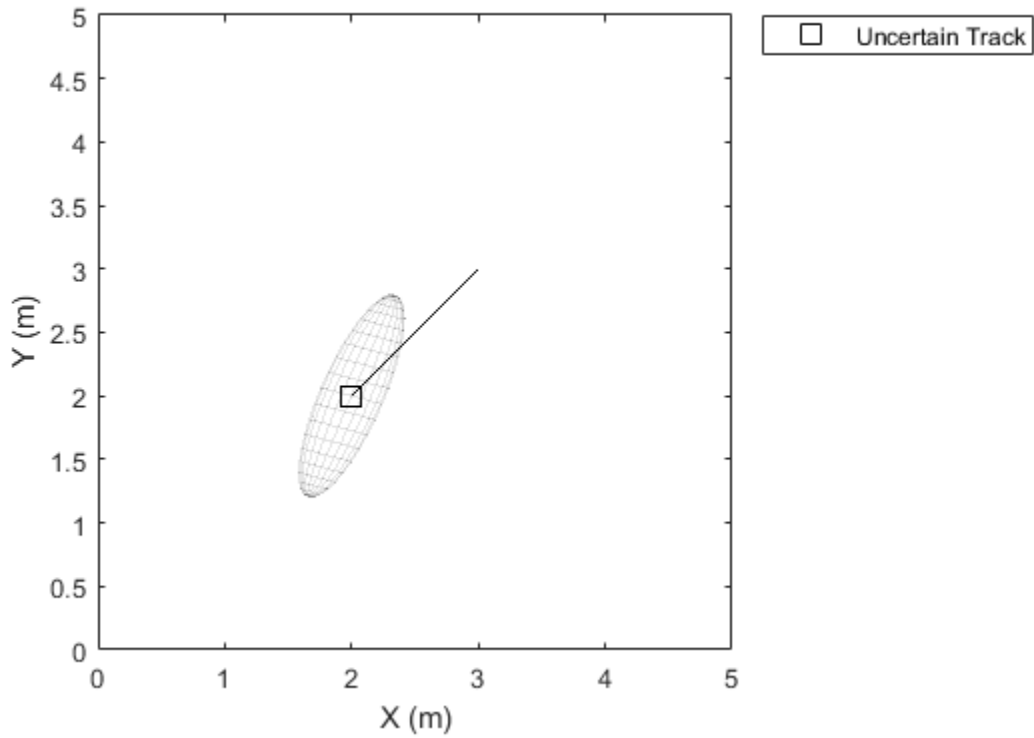
Input Arguments

tPlotter — Track plotter
trackPlotter object

Track plotter, specified as a trackPlotter object.

positions — Tracked object positions
real-valued matrix

Tracked object positions, specified as an *M*-by-3 real-valued matrix, where *M* is the number of objects. Each column of positions corresponds to the *x*-, *y*-, and *z*-coordinates of the object locations in meters.

velocities — Tracked object velocities
real-valued matrix

Tracked object velocities, specified as an *M*-by-3 real-valued matrix, where *M* is the number of objects. Each column of velocities corresponds to the *x*, *y*, and *z* velocities of the objects. If specified, velocities must have the same dimensions as positions.

covariances — Track uncertainties
real-valued array

Track uncertainties of *M* tracked objects, specified as a 3-by-3-by-*M* real-valued array of covariances. The covariances are centered at the track positions, and are plotted as an ellipsoid.

labels — Tracked object labels
cell array

Tracked object labels, specified as a *M*-by-1 cell array of character vectors, where *M* is the number of objects. The argument labels contains the text labels corresponding to the *M* objects specified in positions. If labels is omitted, no labels are plotted.

trackIDs — Unique track identifiers
integer vector | string array | cell array

Unique track identifiers for the *M* tracked objects, specified as an *M*-by-1 integer vector, an *M*-by-1 array of strings, or an *M*-by-1 cell array of character vectors. The elements of trackIDs must be unique.

The `trackIDs` input is ignored when the property 'ConnectHistory' of `tPlotter` is `'off'`. If `trackIDs` is omitted when `'ConnectHistory'` is `'on'`, then the track identifiers are derived from the labels input instead.

See Also

clearData | clearPlotterData | theaterPlot | trackPlotter

Introduced in R2018b

plotTrajectory

Plot set of trajectories in trajectory plotter

Syntax

```
plotTrajectory(trajPlotter,trajCoordList)
```

Description

`plotTrajectory(trajPlotter,trajCoordList)` specifies the trajectories to show in the trajectory plotter, `trajPlotter`. The input argument `trajCoordList` is a cell array of *M*-by-3 matrices, where *M* is the number of points in the trajectory. Each matrix in `trajCoordList` can have a different number of rows. The first, second, and third columns of each matrix correspond to the *x*-, *y*-, and *z*-coordinates of a curve through *M* points that represent the corresponding trajectory.

Examples

Moving Platform on a Trajectory

This example shows how to create an animation of a platform moving on a trajectory.

First, create a `trackingScenario` and add waypoints for a trajectory.

```
ts = trackingScenario;
height = 100;
d = 1;
wayPoints = [ ...
    -30    -25   height;
    -30     25-d height;
    -30+d   25   height;
    -10-d   25   height;
    -10     25-d height;
    -10    -25+d height;
```

```
    -10+d -25   height;
    10-d -25    height;
    10   -25+d height;
    10    25-d height;
    10+d  25    height;
    30-d  25    height;
    30    25-d height;
    30   -25+d height;
    30   -25    height];
```

Specify a time for each waypoint.

```
elapsedTime = linspace(0,10,size(wayPoints,1));
```

Next, create a platform in the tracking scenario and add trajectory information using the `trajectory` method.

```
target = platform(ts);
traj = waypointTrajectory('Waypoints',wayPoints,'TimeOfArrival',elapsedTime);
target.Trajectory = traj;
```

Record the tracking scenario to retrieve the platform's trajectory.

```
r = record(ts);
pposes = [r(:).Poses];
pposition = vertcat(pposes.Position);
```

Create a theater plot to display the recorded trajectory.

```
tp = theaterPlot('XLim',[-40 40],'YLim',[-40 40]);
trajPlotter = trajectoryPlotter(tp,'DisplayName','Trajectory');
plotTrajectory(trajPlotter,{pposition})
```

Animate using the `platformPlotter`.

```
restart(ts);
trajPlotter = platformPlotter(tp,'DisplayName','Platform');

while advance(ts)
    p = pose(target,'true');
    plotPlatform(trajPlotter, p.Position);
    pause(0.1)

end
```

This animation loops through all the generated plots.

Input Arguments

trajPlotter — Trajectory plotter
trajectoryPlotter object

Trajectory plotter, specified as a trajectoryPlotter object.

trajCoordList — Coordinates of trajectories
cell array

Coordinates of trajectories to show, specified as a cell array of *M*-by-3 matrices, where *M* is the number of points in the trajectory. Each matrix in trajCoordList can have a

different number of rows. The first, second, and third columns of each matrix correspond to the *x-*, *y-*, and *z*-coordinates of a curve through *M* points that represent the corresponding trajectory.

Example: `coordList = {[1 2 3; 4 5 6; 7,8,9];[4 2 1; 4 3 1];[4 4 4; 3 1 2; 9 9 9; 1 0 2]}` specifies three different trajectories.

See Also

`clearData` | `clearPlotterData` | `theaterPlot` | `trajectoryPlotter`

Introduced in R2018b

trackPlotter

Create track plotter

Syntax

```
tPlotter = trackPlotter(tp)
tPlotter = trackPlotter(tp,Name,Value)
```

Description

`tPlotter = trackPlotter(tp)` creates a track plotter for use with the theater plot `tp`.

`tPlotter = trackPlotter(tp,Name,Value)` creates a track plotter with additional options specified by one or more `Name,Value` pair arguments.

Examples

Plot Tracks in Theater Plot

Create a theater plot. Create a track plotter with `DisplayName` set to `'Tracks'` and with `HistoryDepth` set to 5.

```
tp = theaterPlot('XLim',[0,90],'YLim',[-35,35]);
tPlotter = trackPlotter(tp,'DisplayName','Tracks','HistoryDepth',5);
```

Update the track plotter with three tracks labeled `'T1'`, `'T2'`, and `'T3'` with start positions in units of meters all starting at (30, 5, 1) with corresponding velocities (in m/s) of (3, 0, 1), (3, 2, 2) and (3, -3, 5), respectively. Update the tracks with the velocities for ten iterations.

```
positions = [30, 5, 1; 30, 5, 1; 30, 5, 1];
velocities = [3, 0, 1; 3, 2, 2; 3, -3, 5];
labels = {'T1','T2','T3'};
for i=1:10
    plotTrack(tPlotter, positions, velocities, labels)
    positions = positions + velocities;
end
```

This animation loops through all the generated plots.

Input Arguments

tp — Theater plot
theaterPlot object

Theater plot, specified as a theaterPlot 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 quotes.

You can specify several name and value pair arguments in any order as
`Name1,Value1,...,NameN,ValueN`.

Example: `'MarkerSize',10`

DisplayName — Plot name to display in legend
character vector | string scalar

Plot name to display in legend, specified as the comma-separated pair consisting of
`'DisplayName'` and a character vector or string scalar. If no name is specified, no entry
is shown.

Example: `'DisplayName','Radar Detections'`

HistoryDepth — Number of previous track updates to display
`0` (default) | nonnegative integer less than or equal to 10,000

Number of previous track updates to display, specified as the comma-separated pair
consisting of `'HistoryDepth'` and a nonnegative integer less than or equal to 10,000. If
set to 0, then no previous updates are rendered.

ConnectHistory — Connect tracks flag
`'off'` (default) | `'on'`

Connect tracks flag, specified as either `'on'` or `'off'`. When set to `'on'`, tracks with the
same label or track identifier between consecutive updates are connected with a line. This
property can only be specified when creating the `trackPlotter`. The default is `'off'`.

To use the trackIDs on page 2-0   input argument of `plotTrack`, `'ConnectHistory'`
must be `'on'`. If trackIDs on page 2-0   is omitted when `'ConnectHistory'` is `'on'`,
then the track identifiers are derived from the labels input instead.

ColorizeHistory — Colorize track history
`'off'` (default) | `'on'`

Colorize track history, specified as either `'on'` or `'off'`. When set to `'on'`, tracks with
the same label or track identifier between consecutive updates are connected with a line
of a different color. This property can only be specified when creating the
`trackPlotter`.The default is `'off'`.

`ColorizedHistory` is applicable only when `ConnectHistory` is `'on'`.

Marker — Marker symbol
`'s'` (default) | character vector | string scalar

Marker symbol, specified as the comma-separated pair consisting of `'Marker'` and one of these symbols.

Value	Description
`'+'`	Plus sign
`'o'`	Circle
`'*'`	Asterisk
`'.'`	Point
`'x'`	Cross
`'s'` or `'square'`	Square (default)
`'d'` or `'diamond'`	Diamond
`'v'`	Downward-pointing triangle
`'^'`	Upward-pointing triangle
`'>'`	Right-pointing triangle
`'<'`	Left-pointing triangle
`'p'` or `'pentagram'`	Five-pointed star (pentagram)
`'h'` or `'hexagram'`	Six-pointed star (hexagram)
`'none'`	No marker symbol

MarkerSize — Size of marker
10 (default) | positive integer

Size of marker, specified as the comma-separated pair consisting of `'MarkerSize'` and a positive integer in points.

MarkerEdgeColor — Marker outline color
`'black'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerEdgeColor'` and a character vector, string scalar, or an RGB triplet.

MarkerFaceColor — Marker fill color
`'none'` (default) | character vector | string scalar | RGB triplet

Marker outline color, specified as the comma-separated pair consisting of `'MarkerFaceColor'` and a character vector, string scalar, RGB triplet, or `'none'`. The default is `'none'`.

FontSize — Font size for labeling tracks
10 (default) | positive integer

Font size for labeling tracks, specified as the comma-separated pair consisting of `'FontSize'` and a positive integer that represents font point size.

LabelOffset — Gap between label and positional point
[0 0 0] (default) | three-element row vector

Gap between label and positional point it annotates, specified as the comma-separated pair consisting of `'LabelOffset'` and a three-element row vector. Specify the [x y z] offset in meters.

VelocityScaling — Scale factor for magnitude length of velocity vectors
1 (default) | positive scalar

Scale factor for magnitude length of velocity vectors, specified as the comma-separated pair consisting of `'VelocityScaling'` and a positive scalar. The plot renders the magnitude vector value as VK, where V is the magnitude of the velocity in meters per second, and K is the value of `VelocityScaling`.

Tag — Tag to associate with the plotter
`'PlotterN'` (default) | character vector | string scalar

Tag to associate with the plotter, specified as the comma-separated pair consisting of `'Tag'` and a character vector or string scalar. The default value is `'PlotterN'`, where N is an integer that corresponds to the Nth plotter associated with the `theaterPlot`.

Tags provide a way to identify plotter objects, for example when searching using `findPlotter`.

See Also
`clearData` | `clearPlotterData` | `plotTrack` | `theaterPlot`

Introduced in R2018b

trajectoryPlotter

Create trajectory plotter

Syntax

```
trajPlotter = trajectoryPlotter(tp)
trajPlotter = trajectoryPlotter(tp,Name,Value)
```

Description

`trajPlotter = trajectoryPlotter(tp)` creates a trajectory plotter for use with the theater plot `tp`.

`trajPlotter = trajectoryPlotter(tp,Name,Value)` creates a trajectory plotter with additional options specified by one or more `Name,Value` pair arguments.

Examples

Moving Platform on a Trajectory

This example shows how to create an animation of a platform moving on a trajectory.

First, create a `trackingScenario` and add waypoints for a trajectory.

```
ts = trackingScenario;
height = 100;
d = 1;
wayPoints = [ ...
    -30    -25    height;
    -30     25-d  height;
    -30+d   25    height;
    -10-d   25    height;
    -10     25-d  height;
    -10    -25+d  height;
```

```
    -10+d -25    height;
    10-d -25    height;
    10    -25+d height;
    10     25-d height;
    10+d  25    height;
    30-d  25    height;
    30     25-d height;
    30    -25+d height;
    30    -25    height];
```

Specify a time for each waypoint.

```
elapsedTime = linspace(0,10,size(wayPoints,1));
```

Next, create a platform in the tracking scenario and add trajectory information using the `trajectory` method.

```
target = platform(ts);
traj = waypointTrajectory('Waypoints',wayPoints,'TimeOfArrival',elapsedTime);
target.Trajectory = traj;
```

Record the tracking scenario to retrieve the platform's trajectory.

```
r = record(ts);
pposes = [r(:).Poses];
pposition = vertcat(pposes.Position);
```

Create a theater plot to display the recorded trajectory.

```
tp = theaterPlot('XLim',[-40 40],'YLim',[-40 40]);
trajPlotter = trajectoryPlotter(tp,'DisplayName','Trajectory');
plotTrajectory(trajPlotter,{pposition})
```

Animate using the `platformPlotter`.

```
restart(ts);
trajPlotter = platformPlotter(tp,'DisplayName','Platform');

while advance(ts)
    p = pose(target,'true');
    plotPlatform(trajPlotter, p.Position);
    pause(0.1)

end
```

This animation loops through all the generated plots.

Input Arguments

tp — Theater plot
theaterPlot object

Theater plot, specified as a `theaterPlot` 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 quotes.

You can specify several name and value pair arguments in any order as
`Name1,Value1,...,NameN,ValueN`.

Example: `'LineStyle','--'`

`DisplayName` — Plot name to display in legend
character vector | string scalar

Plot name to display in legend, specified as the comma-separated pair consisting of
`'DisplayName'` and a character vector or string scalar. If no name is specified, no entry
is shown.

Example: `'DisplayName','Radar Detections'`

`Color` — Trajectory color
`'gray'` (default) | character vector | string scalar | RGB triplet

Trajectory color, specified as the comma-separated pair consisting of `'Color'` and a
character vector, string scalar, or an RGB triplet.

`LineStyle` — Line style
`':'` (default) | `'-'` | `'--'` | `'-.'`

Line style used to plot the trajectory, specified as one of these values.

Value	Description
`':'`	Dotted line (default)
`'-'`	Solid line
`'--'`	Dashed line
`'-.'`	Dash-dotted line

`LineWidth` — Line width
`0.5` (default) | positive scalar

Line width of the trajectory, specified in points size as the comma-separated pair
consisting of `'LineWidth'` and a positive scalar.

`Tag` — Tag to associate with the plotter
`'PlotterN'` (default) | character vector | string scalar

Tag to associate with the plotter, specified as the comma-separated pair consisting of `'Tag'` and a character vector or string scalar. The default value is `'PlotterN'`, where *N* is an integer that corresponds to the *N*th plotter associated with the `theaterPlot`.

Tags provide a way to identify plotter objects, for example when searching using `findPlotter`.

See Also

`clearData` | `clearPlotterData` | `plotTrajectory` | `theaterPlot`

Introduced in R2018b

trackingABF

Alpha-beta filter for object tracking

Description

The `trackingABF` object represents an alpha-beta filter designed for object tracking for an object that follows a linear motion model and has a linear measurement model. Linear motion is defined by constant velocity or constant acceleration. Use the filter to predict the future location of an object, to reduce noise for a detected location, or to help associate multiple objects with their tracks.

Creation

Syntax

```
abf = trackingABF
abf = trackingABF(Name,Value)
```

Description

`abf = trackingABF` returns an alpha-beta filter for a discrete time, 2-D constant velocity system. The motion model is named `'2D Constant Velocity'` with the state defined as `[x; vx; y; vy]`.

`abf = trackingABF(Name,Value)` specifies the properties of the filter using one or more `Name,Value` pair arguments. Any unspecified properties take default values.

Properties

MotionModel — Model of target motion
'2D Constant Velocity' (default) | '1D Constant Velocity' | '3D Constant
Velocity' | '1D Constant Acceleration' | '2D Constant Acceleration' | '3D
Constant Acceleration'

Model of target motion, specified as a character vector or string. Specifying 1D, 2D, or 3D
specifies the dimension of the target's motion. Specifying Constant Velocity assumes
that the target motion is a constant velocity at each simulation step. Specifying Constant
Acceleration assumes that the target motion is a constant acceleration at each
simulation step.

Data Types: char | string

State — Filter state
real-valued *M*-element vector | scalar

Filter state, specified as a real-valued *M*-element vector. A scalar input is extended to an
M-element vector. The state vector is the concatenated states from each dimension. For
example, if MotionModel is set to '3D Constant Acceleration', the state vector is
in the form: [x; x'; x''; y; y'; y''; z; z'; z''] where ' and '' indicate first
and second order derivatives, respectively.

Example: [200;0.2;150;0.1;0;0.25]

Data Types: double

StateCovariance — State estimation error covariance
M-by-*M* matrix | scalar

State error covariance, specified as an *M*-by-*M* matrix, where *M* is the size of the filter
state. A scalar input is extended to an *M*-by-*M* matrix. The covariance matrix represents
the uncertainty in the filter state.

Example: eye(6)

ProcessNoise — Process noise covariance
D-by-*D* matrix | scalar

Process noise covariance, specified as a scalar or a *D*-by-*D* matrix, where *D* is the
dimensionality of motion. For example, if MotionModel is '2D Constant Velocity',
then *D* = 2. A scalar input is extended to a *D*-by-*D* matrix.

Example: [20 0.1; 0.1 1]

MeasurementNoise — Measurement noise covariance
D-by-*D* matrix | scalar

Measurement noise covariance, specified as a scalar or a *D*-by-*D* matrix, where *D* is the dimensionality of motion. For example, if `MotionModel` is `'2D Constant Velocity'`, then *D* = 2. A scalar input is extended to a *M*-by-*M* matrix.

Example: [20 0.1; 0.1 1]

Coefficients — Alpha-beta filter coefficients
row vector | scalar

Alpha-beta filter coefficients, specified as a scalar or row vector. A scalar input is extended to a row vector. If you specify constant velocity in the `MotionModel` property, the coefficients are `[alpha beta]`. If you specify constant acceleration in the `MotionModel` property, the coefficients are `[alpha beta gamma]`.

Example: [20 0.1]

Object Functions

predict	Predict state and state estimation error covariance
correct	Correct state and state estimation error covariance
distance	Distances between measurements and predicted measurements
residual	Measurement residual and residual noise
likelihood	Likelihood of measurement
clone	Copy filter for object tracking

Examples

Run `trackingABF` Filter

This example shows how to create and run a `trackingABF` filter. Call the `predict` and `correct` functions to track an object and correct the state estimation based on measurements.

Create the filter. Specify the initial state.

```
state = [1;2;3;4];
abf = trackingABF('State',state);
```

Call `predict` to get the predicted state and covariance of the filter. Use a 0.5 sec time step.

```
[xPred,pPred] = predict(abf, 0.5);
```

Call `correct` with a given measurement.

```
meas = [1;1];
[xCorr,pCorr] = correct(abf, meas);
```

Continue to predict the filter state. Specify the desired time step in seconds if necessary.

```
[xPred,pPred] = predict(abf);          % Predict over 1 second
[xPred,pPred] = predict(abf,2);        % Predict over 2 seconds
```

Modify the filter coefficients and correct again with a new measurement.

```
abf.Coefficients = [0.4 0.2];
[xCorr,pCorr] = correct(abf,[8;14]);
```

See Also

Functions
clone | constvel | correct | cvmeas | distance | likelihood | predict | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2018b

trackingCKF

Cubature Kalman filter for object tracking

Description

The `trackingCKF` object represents a cubature Kalman filter designed for tracking objects that follow a nonlinear motion model or are measured by a nonlinear measurement model. Use the filter to predict the future location of an object, to reduce noise in a measured location, or to help associate multiple object dections with their tracks.

The cubature Kalman filter estimates the uncertainty of the state and the propagation of that uncertainty through the nonlinear state and measurement equations. There are a fixed number of cubature points chosen based on the spherical-radial transformation to guarantee an exact approximation of a Guassian distribution up to the third moment. As a result, the corresponding filter is the same as an unscented Kalman filter, `trackingUKF`, with `Alpha = 1`, `Beta = 0`, and `Kappa = 0`.

Creation

Syntax

```
ckf = trackingCKF
ckf = trackingCKF(transitionFcn,measuremntFcn,state)
ckf = trackingCKF( ___ ,Name,Value)
```

Description

`ckf = trackingCKF` returns a cubature Kalman filter object with default state transition function, measurement function, state, and additive noise model.

`ckf = trackingCKF(transitionFcn,measuremntFcn,state)` specifies the `StateTranstionFcn`, `MeasurementFcn`, and `State` properties directly.

`ckf = trackingCKF( ___ ,Name,Value)` specifies the properties of the Kalman filter using one or more `Name,Value` pair arguments. Any unspecified properties take default values.

Properties

State — Kalman filter state
real-valued *M*-element vector

Kalman filter state, specified as a real-valued *M*-element vector.

Example: `[200;0.2;150;0.1;0;0.25]`

Data Types: `double`

StateCovariance — State estimation error covariance
positive-definite real-valued *M*-by-*M* matrix

State error covariance, specified as a positive-definite real-valued *M*-by-*M* matrix, where *M* is the size of the filter state. The covariance matrix represents the uncertainty in the filter state.

Example: `eye(6)`

StateTransitionFcn — State transition function
function handle

State transition function, specified as a function handle. This function calculates the state vector at time step *k* from the state vector at time step *k*–1. The function can take additional input parameters, such as control inputs or time step size. The function can also include noise values.

- If `HasAdditiveProcessNoise` is `true`, specify the function using one of these syntaxes:

  `x(k) = transitionfcn(x(k-1))`

  `x(k) = transitionfcn(x(k-1),parameters)`

  where `x(k)` is the state at time `k`. The `parameters` term stands for all additional arguments required by the state transition function.

- If `HasAdditiveProcessNoise` is `false`, specify the function using one of these syntaxes:

```
x(k) = transitionfcn(x(k-1),w(k-1))

x(k) = transitionfcn(x(k-1),w(k-1),parameters)
```

where $x(k)$ is the state at time k, and $w(k)$ is a value for the process noise at time k. The `parameters` argument stands for all additional arguments required by the state transition function.

Example: `@constacc`

Dependencies

This parameter depends on the `HasAdditiveNoise` property.

Data Types: `function_handle`

ProcessNoise — Process noise covariance
1 (default) | positive real-valued scalar | positive-definite real-valued matrix

Process noise covariance:

- When `HasAdditiveProcessNoise` is `true`, specify the process noise covariance as a scalar or a positive-definite real-valued *M*-by-*M* matrix. *M* is the dimension of the state vector. When specified as a scalar, the matrix is a multiple of the *M*-by-*M* identity matrix.

- When `HasAdditiveProcessNoise` is `false`, specify the process noise covariance as a *Q*-by-*Q* matrix. *Q* is the size of the process noise vector.

  Specify `ProcessNoise` before any call to the `predict` method. In later calls to `predict`, you can optionally specify the process noise as a scalar. In this case, the process noise matrix is a multiple of the *Q*-by-*Q* identity matrix.

Example: `[1.0 0.05 0; 0.05 1.0 2.0; 0 2.0 1.0]`

Dependencies

This parameter depends on the `HasAdditiveNoise` property.

HasAdditiveProcessNoise — Model additive process noise
`true` (default) | `false`

Option to model process noise as additive, specified as `true` or `false`. When this property is `true`, process noise is added to the state vector. Otherwise, noise is incorporated into the state transition function.

MeasurementFcn — Measurement model function
function handle

Measurement model function, specified as a function handle. This function can be a nonlinear function that models measurements from the predicted state. Input to the function is the *M*-element state vector. The output is the *N*-element measurement vector. The function can take additional input arguments, such as sensor position and orientation.

- If `HasAdditiveMeasurementNoise` is `true`, specify the function using one of these syntaxes:

  `z(k) = measurementfcn(x(k))`

  `z(k) = measurementfcn(x(k),parameters)`

  where `x(k)` is the state at time `k`, and `z(k)` is the predicted measurement at time `k`. The `parameters` term stands for all additional arguments required by the measurement function.

- If `HasAdditiveMeasurementNoise` is `false`, specify the function using one of these syntaxes:

  `z(k) = measurementfcn(x(k),v(k))`

  `z(k) = measurementfcn(x(k),v(k),parameters)`

  where `x(k)` is the state at time `k`, and `v(k)` is the measurement noise at time `k`. The `parameters` argument stands for all additional arguments required by the measurement function.

Example: `@cameas`

Dependencies

This parameter depends on the `HasAdditiveNoise` property.

Data Types: `function_handle`

MeasurementNoise — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance:.

- When `HasAdditiveMeasurementNoise` is `true`, specify the measurement noise covariance as a scalar or an *N*-by-*N* matrix. *N* is the size of the measurement vector. When specified as a scalar, the matrix is a multiple of the *N*-by-*N* identity matrix.

- When `HasAdditiveMeasurementNoise` is `false`, specify the measurement noise covariance as an *R*-by-*R* matrix. *R* is the size of the measurement noise vector.

  Specify `MeasurementNoise` before any call to the `correct` method. After the first call to `correct`, you can optionally specify the measurement noise as a scalar. In this case, the measurement noise matrix is a multiple of the *R*-by-*R* identity matrix.

Example: `0.2`

Dependencies

This parameter depends on the `HasAdditiveNoise` property.

HasAdditiveMeasurmentNoise — Model additive measurement noise
`true` (default) | `false`

Option to enable additive measurement noise, specified as `true` or `false`. When this property is `true`, noise is added to the measurement. Otherwise, noise is incorporated into the measurement function.

Object Functions

predict	Predict state and state estimation error covariance
correct	Correct state and state estimation error covariance
distance	Distances between measurements and predicted measurements
residual	Measurement residual and residual noise
likelihood	Likelihood of measurement
clone	Copy filter for object tracking

Examples

Run `trackingCKF` Filter

This example shows how to create and run a `trackingCKF` filter. Call the `predict` and `correct` functions to track an object and correct the state estimation based on measurements.

Create the filter. Specify the constant velocity motion model, the measurement model, and the initial state.

```
state = [0;0;0;0;0;0];
ckf = trackingCKF(@constvel,@cvmeas,state);
```

Call `predict` to get the predicted state and covariance of the filter. Use a 0.5 second time step.

```
[xPred,pPred] = predict(ckf,0.5);
```

Call `correct` with a given measurement.

```
meas = [1;1;0];
[xCorr,pCorr] = correct(ckf,meas);
```

Continue to predict the filter state. Specify the desired time step in seconds if necessary.

```
[xPred,pPred] = predict(ckf);        % Predict over 1 second
[xPred,pPred] = predict(ckf,2);      % Predict over 2 seconds
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
clone | constvel | correct | cvmeas | distance | likelihood | predict | residual

Objects
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

Introduced in R2018b

trackingGSF

Guassian-sum filter for object tracking

Description

The `trackingGSF` object represents a Gaussian-sum filter designed for object tracking. You can define the state probability density function by a set of finite Gaussian-sum components. Use this filter for tracking objects that require a multi-model description due to incomplete observability of state through measurements. For example, this filter can be used as a range-parameterized extended Kalman filter when the detection contains only angle measurements.

Creation

Syntax

```
gsf = trackingGSF
gsf = trackingGSF(trackingFilters)
gsf = trackingGSF(trackingFilters,modelProbabilities)
gsf = trackingGSF( ___ ,'MeasurementNoise',measNoise)
```

Description

`gsf = trackingGSF` returns a Gaussian-sum filter with two constant velocity extended Kalman filters (`trackingEKF`) with equal initial weight.

`gsf = trackingGSF(trackingFilters)` specifies the Gaussian components of the filter in `trackingFilters`. The initial weights of the filters are assumed to be equal.

`gsf = trackingGSF(trackingFilters,modelProbabilities)` specifies the initial weight of the Gaussian components in `modelProbabilities` and sets the `ModelProbabilties` property.

gsf = trackingGSF(___ ,'MeasurementNoise',measNoise) specifies the measurement noise of the filter. The MeasurementNoise property is set for each Gaussian component.

Properties

State — Weighted estimate of filter state
real-valued *M*-element vector

This property is read-only.

Weighted estimate of filter state, specified as a real-valued *M*-element vector. This state is estimated based on the weighted combination of filters in TrackingFilters. Use ModelProbabilities to change the weights.

Example: [200;0.2]

Data Types: single | double

StateCovariance — State estimation error covariance
positive-definite real-valued *M*-by-*M* matrix

This property is read-only.

State error covariance, specified as a positive-definite real-valued *M*-by-*M* matrix, where *M* is the size of the filter state. The covariance matrix represents the uncertainty in the filter state. This state covariance is estimated based on the weighted combination of filters in TrackingFilters. Use ModelProbabilities to change the weights.

Example: [20 0.1; 0.1 1]

Data Types: single | double

TrackingFilters — List of filters
{trackingEKF,trackingEKF} (default) | cell array of tracking filters

List of filters, specified as a cell array of tracking filters. Specify these filters when creating the object. By default, the filters have equal probability. Specify modelProbabilities if the filters have different probabilities.

Note The state of each filter must be the same size and have the same physical meaning.

Data Types: `cell`

ModelProbabilities — Weight of each filter
[0.5 0.5] (default) | vector of probabilities between 0 and 1

Weight of each filter, specified as a vector of probabilities from 0 to 1. By default, the weight of each component of the filter is equal.

Data Types: `single` | `double`

MeasurementNoise — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix. The matrix is a square with side lengths equal to the number of measurements. A scalar input is extended to a square diagonal matrix.

Specify `MeasurementNoise` before any call to the `correct` method. After the first call to `correct`, you can optionally specify the measurement noise as a scalar. In this case, the measurement noise matrix is a multiple of the R-by-R identity matrix, where R is the number of measurements.

Example: `0.2`

Data Types: `single` | `double`

Object Functions

predict	Predict state and state estimation error covariance
correct	Correct state and state estimation error covariance
distance	Distances between measurements and predicted measurements
residual	Measurement residual and residual noise
clone	Copy filter for object tracking
initialize	Initialize state and covariance of filter

Examples

Run `trackingGSF` Filter

This example shows how to create and run a `trackingGSF` filter. Specify three extended Kalman filters (EKFs) as the components of the Gaussian-sum filter. Call the `predict` and

`correct` functions to track an object and correct the state estimate based on measurements.

Create three EKFs each with a state distributed around `[0;0;0;0;0;0]` and running on position measurements. Specify them as the input to the `trackingGSF` filter.

```
filters = cell(3,1);
filter{1} = trackingEKF(@constvel,@cvmeas,rand(6,1),'MeasurementNoise',eye(3));
filter{2} = trackingEKF(@constvel,@cvmeas,rand(6,1),'MeasurementNoise',eye(3));
filter{3} = trackingEKF(@constvel,@cvmeas,rand(6,1),'MeasurementNoise',eye(3));
gsf = trackingGSF(filter);
```

Call `predict` to get the predicted state and covariance of the filter. Use a 0.1 sec time step.

```
[x_pred, P_pred] = predict(gsf,0.1);
```

Call `correct` with a given measurement.

```
meas = [0.5;0.2;0.3];
[xCorr,pCorr] = correct(gsf,meas);
```

Compute the distance between the filter and a different measurement.

```
d = distance(gsf,[0;0;0]);
```

References

[1] Alspach, Daniel, and Harold Sorenson. "Nonlinear Bayesian estimation using Gaussian sum approximations." *IEEE Transactions on Automatic Control.* Vol 17, No. 4, 1972, pp. 439-448.

See Also

`trackingCKF` | `trackingEKF` | `trackingMSCEKF` | `trackingPF` | `trackingUKF`

Introduced in R2018b

trackingIMM

Interacting multiple model (IMM) filter for object tracking

Description

The `trackingIMM` object represents an interacting multiple model (IMM) filter designed for tracking objects that are highly maneuverable. Use the filter to predict the future location of an object, to reduce noise in the detected location, or help associate multiple object detections with their tracks.

The IMM filter deals with the multiple motion models in the Bayesian framework. This method resolves the target motion uncertainty by using multiple models at a time for a maneuvering target. The IMM algorithm processes all the models simultaneously and switches between models according to their updated weights.

Creation

Syntax

```
imm = trackingIMM
imm = trackingIMM(trackingFilters)
imm = trackingIMM(trackingFilters,modelConversionFcn)
imm = trackingIMM(trackingFilters,modelConversionFcn,
transitionProbabilities)
imm = trackingIMM( ___ ,Name,Value)
```

Description

`imm = trackingIMM` returns an IMM filter object with default tracking filters `{trackingEKF,trackingEKF,trackingEKF}` with the motion models set as constant velocity, constant acceleration, and constant turn, respectively. The filter uses the default conversion function, `@switchimm`.

`imm = trackingIMM(trackingFilters)` specifies the TrackingFilters property and sets all other properties to default values.

`imm = trackingIMM(trackingFilters,modelConversionFcn)` also specifies the ModelConversionFcn property.

`imm = trackingIMM(trackingFilters,modelConversionFcn, transitionProbabilities)` also specifies the TransitionProbabilities property.

`imm = trackingIMM( ___ ,Name,Value)` specifies the properties of the filter using one or more `Name,Value` pair arguments. Any unspecified properties take default values. Specify any other input arguments from previous syntaxes first.

Properties

State — Filter state
`[0;0;0;0;0;0]` (default) | real-valued *M*-element vector

Filter state, specified as a real-valued *M*-element vector. Specify the initial state when creating the object using name-value pairs.

Data Types: `single` | `double`

StateCovariance — State estimation error covariance
`diag([1 100 1 100 1 100])` (default) | *M*-by-*M* matrix | scalar

State error covariance, specified as an *M*-by-*M* matrix, where *M* is the size of the filter state. A scalar input is extended to an *M*-by-*M* matrix. The covariance matrix represents the uncertainty in the filter state. Specify the initial state covariance when creating the object using name-value pairs.

Example: `eye(6)`

Data Types: `single` | `double`

TrackingFilters — List of filters
`{trackingEKF,trackingEKF,trackingEKF}` (default) | cell array of tracking filters

List of filters, specified as a cell array of tracking filters. By default, the filters have equal probability. Specify `ModelProbabilities` if the filters have different probabilities.

Data Types: `cell`

ModelConversionFcn — Function to convert state or state covariance
@switchimm (default) | function handle

Function to convert the state or state covariance, specified as a function handle. The function converts the state or state covariance from one model type to another. The function signature is:

```
function x2 = modelConversionFcn(modelType1,x1,modelType2)
```

The modelType1 and modelType2 inputs are the names of the two model names. x1 specifies the State or StateCovariance of the first model. x2 outputs the State or StateCovariance

Data Types: function_handle

TransitionProbabilities — Probability of filter model transitions
0.9 (default) | positive real scalar | *L*-element vector | *L*-by-*L* matrix

Probability of filter model transitions, specified as a positive real scalar, *L*-element vector, or *L*-by-*L* matrix, where *L* is the number of filters:

- When specified as a scalar, the probability is uniform for staying on each filter. The remaining probability (1-*p*) is distributed evenly across the other motion models.
- When specified as a vector, each element defines the probability of staying on each filter. The remaining probability (1-*p*) is distributed evenly across the other motion models.
- When specified as a matrix, the *(j,k)* element defines the probability of transitioning from the *j*th filter to the *k*th filter. All elements must lie on the interval [0,1], and each row and column must sum to 1.

Example: 0.75

Data Types: single | double

MeasurementNoise — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix. When specified as a scalar, the matrix is a multiple of the *N*-by-*N* identity matrix. *N* is the size of the measurement vector.

Specify MeasurementNoise before any call to the correct method.

Example: 0.2

ModelProbabilities — Weight of each filter
`1/L*ones(L)` (default) | vector of probabilities between 0 and 1

Weight of each filter, specified as a vector of probabilities from 0 to 1. By default, the weight of each component of the filter is equal. *L* is the number of filters.

Data Types: `single` | `double`

Object Functions

predict	Predict state and state estimation error covariance
correct	Correct state and state estimation error covariance
distance	Distances between measurements and predicted measurements
residual	Measurement residual and residual noise
clone	Copy filter for object tracking
initialize	Initialize state and covariance of filter

Examples

Run `trackingIMM` Filter

This example shows how to create and run an interacting multiple model (IMM) filter using a `trackingIMM` object. Call the `predict` and `correct` functions to track an object and correct the state estimate based on measurements.

Create the filter. Use name-value pairs to specify additional properties of the object.

```
detection = objectDetection(0, [1;1;0], 'MeasurementNoise', [1 0.2 0; 0.2 2 0; 0 0 1]);
filter = {initctekf(detection);initcvekf(detection)};
modelConv = @switchimm;
transProb = [0.9,0.9];
imm = trackingIMM('State',[1;1;3;1;5;1;1],'StateCovariance',eye(7),...
    'TransitionProbabilities',transProb,'TrackingFilters',filter,...
    'ModelConversionFcn',modelConv);
```

Call `predict` to get the predicted state and covariance of the filter. Use a 0.5 sec time step.

```
[xPred,pPred] = predict(imm,0.5);
```

Call `correct` with a given measurement.

```
meas = [1;1;0];
[xCorr,pCorr] = correct(imm,meas);
```

Continue to predict the filter state. Specify the desired time step in seconds if necessary.

```
[xPred,pPred] = predict(imm);        % Predict over 1 second
[xPred,pPred] = predict(imm,2);      % Predict over 2 seconds
```

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
constacc | constturn | constvel | trackingCKF | trackingEKF | trackingGSF | trackingKF | trackingUKF

Introduced in R2018b

trackingMSCEKF

Extended Kalman filter for object tracking in modified spherical coordinates (MSC)

Description

The `trackingMSCEKF` object represents an extended Kalman filter (EKF) for object tracking in modified spherical coordinates (MSC) using angle-only measurements from a single observer. Use the filter to predict the future location of an object in the MSC frame or associate multiple object detections with their tracks. You can specify the observer maneuver or acceleration required by the state-transition functions (`@constantvelmsc` and `@constantvelmscjac`) by using the `ObserverInput` property.

The following properties are fixed for the `trackingMSCEKF` object:

- `StateTransitionFcn` - `@constvelmsc`
- `StateTransitionJacobianFcn` - `@constvelmscjac`
- `MeasurementFcn` - `@cvmeasmsc`
- `MeasurementJacobianFcn` - `@cvmeasmscjac`
- `HasAdditiveProcessNoise` - `false`
- `HasAdditiveMeasurementNoise` - `true`

Creation

Syntax

```
mscekf = trackingMSCEKF
mscekf = trackingMSCEKF(Name,Value)
```

2-331

Description

`mscekf = trackingMSCEKF` returns an extended Kalman filter to use the MSC state-transition and measurement functions with object trackers. The default `State` implies a static target at 1 meter from the observer at zero azimuth and elevation.

`mscekf = trackingMSCEKF(Name,Value)` specifies the properties of the filter using one or more `Name,Value` pair arguments. Any unspecified properties take default values.

Properties

State — Filter state
[0;0;0;0;1;0] (default) | real-valued *M*-element vector

Filter state, specified as a real-valued *M*-element vector. *M* is either 4 for 2-D tracking or 6 for 3-D tracking.

Example: `[az;azRate;1/r;rDot/r]` for 2-D tracking and `[az;omega;el;elRate;1/r;rDot/r]` for 3-D tracking

Data Types: `double`

StateCovariance — State estimation error covariance
1 (default) | *M*-by-*M* matrix | scalar

State error covariance, specified as an *M*-by-*M* matrix where *M* is the size of the filter state. A scalar input is extended to an *M*-by-*M* matrix. The covariance matrix represents the uncertainty in the filter state. *M* is either 4 for 2-D tracking or 6 for 3-D tracking.

Example: `eye(6)`

StateTransitionFcn — State transition function
`@constvelmsc` (default)

This property is read-only.

State transition function, specified as a function handle. This function calculates the state vector at time step *k* from the state vector at time step *k*–1. For the `trackingMSCEKF` object, the transition function is fixed to `@constvelmsc`.

Data Types: `function_handle`

StateTransitionJacobianFcn — State transition function Jacobian
@constvelmscjac (default)

This property is read-only.

The Jacobian of the state transition function, specified as a function handle. This function has the same input arguments as the state transition function. For the trackingMSCEKF object, the transition function Jacobian is fixed to @constvelmsc.

Data Types: function_handle

ProcessNoise — Process noise covariance
1 (default) | positive real-valued scalar | positive-definite real-valued matrix

Process noise covariance, specified as a *Q*-by-*Q* matrix. *Q* is either 2 or 3. The process noise represents uncertainty in the acceleration of the target.

Specify ProcessNoise before any call to the predict method. In later calls to predict, you can optionally specify the process noise as a scalar. In this case, the process noise matrix is a multiple of the *Q*-by-*Q* identity matrix.

Example: [1.0 0.05; 0.05 2]

ObserverInput — Acceleration or maneuver of observer
[0;0;0] (default) | *M/2*-element vector | *M*-element vector

Acceleration or maneuver of the observer, specified as a three-element vector. To specify an acceleration, use an *M/2* vector, where *M* is either 4 for 2-D tracking or 6 for 3-D tracking. To specify a maneuver, give an *M*-element vector.

Example: [1;2;3]

HasAdditiveProcessNoise — Model additive process noise
false (default)

This property is read-only.

Model additive process noise, specified as false. For the trackingMSCEKF object, this property is fixed to false.

MeasurementFcn — Measurement model function
@cvmeasmsc (default)

This property is read-only.

Measurement model function, specified as a function handle, `@cvmeasmsc`. Input to the function is the *M*-element state vector. The output is the *N*-element measurement vector. For the `trackingMSCEKF` object, the measurement model function is fixed to `@cvmeasmsc`.

Data Types: `function_handle`

MeasurementJacobianFcn — Jacobian of measurement function
`@cvmeasmscjac`

This property is read-only.

Jacobian of the measurement function, specified as a function handle. The function has the same input arguments as the measurement function. For the `trackingMSCEKF` object, the Jacobian of the measurement function is fixed to `@cvmeasmscjac`.

Data Types: `function_handle`

MeasurementNoise — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix. When specified as a scalar, the matrix is a multiple of the *N*-by-*N* identity matrix. *N* is the size of the measurement vector.

Specify `MeasurementNoise` before any call to the `correct` method.

Example: `0.2`

HasAdditiveMeasurementNoise — Model additive measurement noise
`true` (default)

This property is read-only.

Model additive process noise, specified as `true`. For the `trackingMSCEKF` object, this property is fixed to `true`.

Object Functions

predict   Predict state and state estimation error covariance
correct   Correct state and state estimation error covariance
distance   Distances between measurements and predicted measurements

residual   Measurement residual and residual noise
clone   Copy filter for object tracking
initialize   Initialize state and covariance of filter

Examples

Create MSC-EKF Tracking Object for 3-D Motion Model

This example shows how to make an extended Kalman filter (EKF) for object tracking in modified spherical coordinates (MSC). Create the filter, predict the state, and correct the state estimate using measurement observations.

Create the filter for a 3-D motion model. Specify the state estimates for the MSC frame.

```
az = 0.1;
azRate = 0;
r = 1000;
rDot = 10;
el = 0.3;
elRate = 0;
omega = azRate*cos(el);

mscekf = trackingMSCEKF('State',[az;omega;el;elRate;1/r;rDot/r]);
```

Predict the filter state using a constant observer acceleration.

```
mscekf.ObserverInput = [1;2;3];
predict(mscekf); % Default time 1 second.
predict(mscekf,0.1); % Predict using dt = 0.1 second.
```

Correct the filter state using an angle-only measurement.

```
meas = [5;18]; %degrees
correct(mscekf,meas);
```

See Also
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingPF

Introduced in R2018b

trackingPF

Particle filter for object tracking

Description

The `trackingPF` object represents an object tracker that follows a nonlinear motion model or that is measured by a nonlinear measurement model. The filter uses a set of discrete particles to approximate the posterior distribution of the state. The particle filter can be applied to arbitrary nonlinear system models. The process and measurement noise can follow an arbitrary non-Gaussian distribution.

The particles are generated using various resampling methods defined by `ResamplingMethod`.

Creation

Syntax

```
pf = trackingPF
pf = trackingPF(transitionFcn,measuremntFcn,state)
pf = trackingPF( ___ ,Name,Value)
```

Description

`pf = trackingPF` returns a `trackingPF` object with state transition function, `@constvel`, measurement function, `@cvmeas`, and a distribution of particles around the state, `[0;0;0;0]`, with unit covariance in each dimension. The filter assumes an additive Gaussian process noise model and Gaussian likelihood calculations.

`pf = trackingPF(transitionFcn,measuremntFcn,state)` specifies the `StateTranstionFcn`, `MeasurementFcn`, and `State` properties directly. The filter assumes a unit coverience around the state.

`pf = trackingPF( ___ ,Name,Value)` specifies the properties of the particle filter using one or more `Name,Value` pair arguments. Any unspecified properties take default values.

Properties

State — Current filter state
real-valued *M*-element vector

This property is read-only.

Current filter state, specified as a real-valued *M*-element vector. The current state is calculated from `Particles` and `Weight` using the specified `StateEstimationMethod`. *M* is the `NumStateVariables`. `StateOrientation` determines if the state is given as a row or column vector.

Example: `[0.1;0.05;0.04;-0.01]`

Data Types: `double`

StateCovariance — State estimation error covariance
M-by-*M* matrix

This property is read-only.

State error covariance, specified as an *M*-by-*M* matrix, where *M* is the size of the filter state. The current state covariance is calculated from `Particles` and `Weight` using the specified `StateEstimationMethod`. *M* is the `NumStateVariables`. The covariance matrix represents the uncertainty in the filter state.

IsStateVariableCircular — Indicates if state variables have circular distribution
`[0 0 0 0]` (default) | *M*-element vector of zeros and ones

This property is read-only.

Indicates if state variables have circular distribution, specified as an *M*-element vector of zeros and ones. Values of `1` indicate it does have a circular distribution. The probability density function of a circular variable takes on angular values in the range `[-pi,pi]`.

StateOrientation — Orientation of state vector
`'column'` (default) | `'row'`

Orientation of state vector, specified as `'column'` or `'row'`.

Note If you set the orientation to `'row'`, the default `StateTransitionFcn` and `MeasurementFcn` are not supported. All state transtion functions and measurement functions provided (`constvel` and `cvmeas`, for example) assume a `'column'` orientation.

StateTransitionFcn — State transition function
@constvel (default) | function handle

State transition function, specified as a function handle. The state transition function evolves the system state from each particle. The callback function accepts at least one input argument, `prevParticles`, that represents the system at the previous time step. If `StateOrientation` is `'row'`, the particles are input as a `NumParticles`-by-`NumStateVariables` array. If `StateOrientation` is `'column'`, the particles are input as a `NumStateVariables`-by-`NumParticles` array.

Additional input arguments can be provided with `varargin`, which are passed to the `predict` function. The function signature is:

```
function predictParticles = stateTranstionFcn(prevParticles,varargin)
```

Dependencies

This parameter depends on the `StateOrientation` property.

Data Types: `function_handle`

ProcessNoiseSamplingFcn — Function to generate noise sample for each particle
@gaussianSampler (default) | function handle

Function to generate noise sample for each particle, specified as a function handle. The function signature is:

```
function noiseSample = processNoiseSamplingFcn(pf)
```

- When `HasAdditiveProcessNoise` is `false`, this function outputs a noise sample as a W-by-N matrix, where W is the number of process noise terms, and N is the number of particles.

- When `HasAdditiveProcessNoise` is `true`, this function outputs a noise sample as an *M*-by-*N* matrix, where *M* is the number of state variables, and *N* is the number of particles.

To generate a sample from a non-Gaussian distribution, use this property with a custom function handle.

Dependencies

This parameter depends on the `HasAdditiveProcessNoise` property.

Data Types: `function_handle`

ProcessNoise — Process noise covariance
1 (default) | positive real-valued scalar | positive-definite real-valued matrix

Process noise covariance:

- When `HasAdditiveProcessNoise` is `true`, specify the process noise covariance as a scalar or a positive definite real-valued *M*-by-*M* matrix. *M* is the dimension of the state vector. When specified as a scalar, the matrix is a multiple of the *M*-by-*M* identity matrix.

- When `HasAdditiveProcessNoise` is `false`, specify the process noise covariance as a *Q*-by-*Q* matrix. *Q* is the size of the process noise vector.

  Specify `ProcessNoise` before any call to the `predict` method. In later calls to `predict`, you can optionally specify the process noise as a scalar. In this case, the process noise matrix is a multiple of the *Q*-by-*Q* identity matrix.

If `ProcessNoiseSamplingFcn` is specified as `@gaussianSample`, this property defines the Gaussian noise covariance of the process.

Example: `[1.0 0.05; 0.05 2]`

Dependencies

This parameter depends on the `HasAdditiveProcessNoise` property.

HasAdditiveProcessNoise — Model additive process noise
`true` (default) | `false`

Option to model processes noise as additive, specified as `true` or `false`. When this property is `true`, process noise is added to the state vector. Otherwise, noise is incorporated into the state transition function.

MeasurementFcn — Measurement model function
@cvmeas (default) | function handle

Measurement model function, specified as a function handle. This function calculates the measurements given the current particles' state. Additional input arguments can be provided with varargin. The function signature is:

```
function predictedParticles = measurementFcn(particles,varargin)
```

Data Types: function_handle

MeasurementLikelihoodFcn — Callback function calculating the likelihood of sensor measurements
@gaussianLikelihood (default) | function handle

Callback function calculating the likelihood of sensor measurements, specified as a function handle. Once a sensor measurement is available, this callback function calculates the likelihood that the measurement is consistent with the state hypothesis of each particle.

The callback function accepts at least three input arguments, pf, predictedParticles, and measurement. There are two function signatures:

```
function likelihood = measurementLikelihoodFcn(pf,predictedParticles,measurement,vararg
```

```
function [likelihood,distance] = measurementLikelihoodFcn(pf,predictedParticles,measure
```

pf is the particle filter object.

predictedParticles represents the set of particles returned from MeasurementFcn. If StateOrientation is 'row', the particles are input as a NumParticles-by-NumStateVariables array. If StateOrientation is 'column', the particles are input as a NumStateVariables-by-NumParticles array.

measurement is the state measurement at the current time step.

varargin allows you to specify additional inputs to the correct function.

The callback output, likelihood, is a vector of length NumParticles, which is the likelihood of the given measurement for each particle state hypothesis.

The optional output, distance, allows you to specify the distance calculations returned by the distance function.

Data Types: `function_handle`

MeasurementNoise — Measurement noise covariance
1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix. When specified as a scalar, the matrix is a multiple of the *N*-by-*N* identity matrix. *N* is the size of the measurement vector.

If `MeasurementLikelihoodFcn` is specified as `@gaussianLikelihood`, this property is used to specify the Gaussian noise covariance of the measurement.

Example: `0.2`

Particles — State hypothesis of each particle
matrix

State hypotheiss of each particle, specified as a matrix. If `StateOrientation` is `'row'` the particles are a `NumParticles`-by-`NumStateVariables` array. If `StateOrientation` is `'column'`, the particles are a `NumStateVariables`-by-`NumParticles` array.

Each row or column corresponds to the state hypothesis of a single particle.

Data Types: `double`

Weights — Particle weights
`ones(1,NumParticles)` (default) | vector

Particle weights, specified as a vector. The vector is either a row or column vector based on `StateOrientation`. Each row or column is the weight associated with the same row or column in `Particles`.

Data Types: `double`

NumStateVariables — Number of state variables
4 (default) | integer

Number of state variables, specified as an integer. The `State` is comprised of this number of state variables.

NumParticles — Number of particles used
1000 (default) | integer

Number of particles used by the filter, specified as an integer. Each particle represents a state hypothesis.

ResamplingPolicy — Policy settings for triggering resampling
trackingResamplingPolicy object

Policy settings for triggering resampling, specified as a trackingResamplingPolicy object. The resampling can be triggered either at fixed intervals or dynamically based on the number of effective particles.

ResamplingMethod — Method used for particle resampling
'multinomial' (default) | 'systemic' | 'stratified' | 'residual'

Method used for particle resampling, specified as 'multinomial', 'systemic', 'stratified', or 'residual'.

StateEstimationMethod — Method used for state estimation
'mean' (default) | 'maxweight'

Method used for state estimation, specified as 'mean' or 'maxweight'.

Object Functions

predict   Predict state and state estimation error covariance
correct   Correct state and state estimation error covariance
distance   Distances between measurements and predicted measurements
residual   Measurement residual and residual noise
clone   Copy filter for object tracking

Examples

Run trackingPF Filter

This example shows how to create and run a trackingPF filter. Call the predict and correct functions to track an object and correct the state estimate based on measurements.

Create the filter. Specify the initial state and state covariance. Specify the number of particles and that there is additive process noise.

```
state = [0;0;0;0];
stateCov = 10*eye(4);
pf = trackingPF(@constvel,@cvmeas,state,'StateCovariance',stateCov,...
    'NumParticles',2500,'HasAdditiveProcessNoise',true);
```

Call `predict` to get the predicted state and covariance of the filter. Use a 0.5 sec time step.

```
[xPred,pPred] = predict(pf,0.5);
```

You can also modify the particles in the filter to carry a multi-model state hypothesis. Modify the `Particle` property with particles around multiple states after initialization.

```
state1 = [0;0;0;0];
stateCov1 = 10*eye(4);
state2 = [100;0;100;0];
stateCov2 = 10*eye(4);

pf.Particles(:,1:1000) = (state1 + chol(stateCov1)*randn(4,1000));
pf.Particles(:,1001:2000) = (state2 + chol(stateCov2)*randn(4,1000));
```

Call `correct` with a given measurement.

```
meas = [1;1;0];
[xCorr,pCorr] = correct(pf,meas);
```

Continue to predict the filter state. Specify the desired time step in seconds if necessary.

```
[xPred,pPred] = predict(pf);        % Predict over 1 second
[xPred,pPred] = predict(pf,2);      % Predict over 2 seconds
```

References

[1] Arulampalam, M.S., S. Maskell, N. Gordon, and T. Clapp. "A Tutorial on Particle Filters for Online Nonlinear/Non-Gaussian Bayesian Tracking." *IEEE Transactions on Signal Processing.* Vol. 50, No. 2, Feb 2002, pp. 174-188.

[2] Chen, Z. "Bayesian Filtering: From Kalman Filters to Particle Filters, and Beyond." *Statistics*. Vol. 182, No. 1, 2003, pp. 1-69.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
constvel | cvmeas | trackingCKF | trackingEKF | trackingKF | trackingUKF

Introduced in R2018b

trackScoreLogic

Confirm and delete tracks based on track score

Description

The `trackScoreLogic` object determines if a track should be confirmed or deleted based on the track score (also known as the log likelihood of a track). A track should be confirmed if the current track score is greater than or equal to the confirmation threshold. A track should be deleted if the current track score has decreased relative to the maximum track score by the deletion threshold.

The confirmation and deletion decisions contribute to the track management by a `trackerGNN` or `trackerTOMHT`.

Creation

Syntax

```
logic = trackScoreLogic
logic = trackScoreLogic(Name,Value,...)
```

Description

`logic = trackScoreLogic` creates a `trackScoreLogic` object with default confirmation and deletion thresholds.

`logic = trackScoreLogic(Name,Value,...)` specifies the `ConfirmationThreshold` and `DeletionThreshold` properties of the track score logic object using one or more `Name,Value` pair arguments. Any unspecified properties take default values.

Properties

`ConfirmationThreshold` — Confirmation threshold
20 (default) | positive scalar

Confirmation threshold, specified as a positive scalar. If the logic score is above this threshold, then the track is confirmed.

Data Types: `single` | `double`

`DeletionThreshold` — Deletion threshold
-5 (default) | negative scalar

Deletion threshold, specified as a negative scalar. If the value of `Score - MaxScore` is more negative than the deletion threshold, then the track is deleted.

Data Types: `single` | `double`

`Score` — Current track logic score
numeric scalar

This property is read-only.

Current track logic score, specified as a numeric scalar.

`MaxScore` — Maximum track logic score
numeric scalar

This property is read-only.

Maximum track logic score, specified as a numeric scalar.

Object Functions

init	Initialize track logic with first hit
hit	Update track logic with subsequent hit
miss	Update track logic with miss
sync	Synchronize scores of trackScoreLogic objects
mergeScores	Update track score by track merging
checkConfirmation	Check if track should be confirmed
checkDeletion	Check if track should be deleted

output	Get current state of track logic
reset	Reset state of track logic
clone	Create copy of track logic

Examples

Create and Update Score-Based Logic

Create a score-based logic. Specify the confirmation threshold as 20 and the deletion threshold as -5.

```
scoreLogic = trackScoreLogic('ConfirmationThreshold',20,'DeletionThreshold',-5)
```

```
scoreLogic =
  trackScoreLogic with properties:

    ConfirmationThreshold: 20
        DeletionThreshold: -5
                    Score: 0
                 MaxScore: 0
```

Specify the probability of detection (`pd`), the probability of false alarm (`pfa`), the volume of a sensor detection bin (`volume`), and the new target rate in a unit volume (`beta`). Initialize the logic using these parameters. The first update to the logic is a hit.

```
pd = 0.9;      % Probability of detection
pfa = 1e-6;    % Probability of false alarm
volume = 1;    % Volume of a sensor detection bin
beta = 0.1;    % New target rate in a unit volume

init(scoreLogic,volume,beta,pd,pfa);

disp(['Score and MaxScore: ', num2str(output(scoreLogic))])
```

```
Score and MaxScore: 11.4076      11.4076
```

Update the logic four more times, where only the odd updates register a hit. The score increases with each hit and decreases with each miss. The confirmation flag is `true` whenever the current score is larger than 20.

```
for i = 2:5

    isOdd = logical(mod(i,2));
    if isOdd
        likelihood = 0.05 + 0.05*rand(1);
        hit(scoreLogic,volume,likelihood)
    else
        miss(scoreLogic)
    end

    confFlag = checkConfirmation(scoreLogic);
    delFlag = checkDeletion(scoreLogic);
    disp(['Score and MaxScore: ', num2str(output(scoreLogic)), ...
      '. Confirmation Flag: ',num2str(confFlag), ...
      '. Deletion Flag: ',num2str(delFlag)'])
end
```

```
Score and MaxScore: 9.10498      11.4076. Confirmation Flag: 0. Deletion Flag: 0
Score and MaxScore: 19.9389      19.9389. Confirmation Flag: 0. Deletion Flag: 0
Score and MaxScore: 17.6364      19.9389. Confirmation Flag: 0. Deletion Flag: 0
Score and MaxScore: 28.9996      28.9996. Confirmation Flag: 1. Deletion Flag: 0
```

Update the logic with a miss three times. The deletion flag is `true` by the end of the third miss, because the difference between the current score and maximum score is greater than five.

```
for i = 1:3
    miss(scoreLogic)

    confFlag = checkConfirmation(scoreLogic);
    delFlag = checkDeletion(scoreLogic);
    disp(['Score and MaxScore: ', num2str(output(scoreLogic)), ...
      '. Confirmation Flag: ',num2str(confFlag), ...
      '. Deletion Flag: ',num2str(delFlag)])
end
```

```
Score and MaxScore: 26.6971      28.9996. Confirmation Flag: 1. Deletion Flag: 0
Score and MaxScore: 24.3945      28.9996. Confirmation Flag: 1. Deletion Flag: 0
Score and MaxScore: 22.0919      28.9996. Confirmation Flag: 1. Deletion Flag: 1
```

Tips

- If you specify either `ConfirmationThreshold` or `DeletionThreshold` in single precision, then the `trackScoreLogic` object converts the other property to single precision and performs computations in single precision.

References

[1] Blackman, S., and R. Popoli. *Design and Analysis of Modern Tracking Systems*. Boston, MA: Artech House, 1999.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`trackHistoryLogic` | `trackerGNN`

Topics
"Introduction to Track Logic"

Introduced in R2018b

mergeScores

Update track score by track merging

Syntax

```
mergeScores(scoreLogic1,scoreLogic2)
```

Description

mergeScores(scoreLogic1,scoreLogic2) updates the score of scoreLogic1 by merging the score with the score of scoreLogic2. Score merging increases the score of scoreLogic1 by log(1+exp(score2-score1)).

Examples

Merge Score Logics

Create a score logic using the default confirmation and deletion thresholds. Initialize the score logic.

```
scoreLogic1 = trackScoreLogic;
volume = 1.3; % Volume of a sensor detection bin
beta1 = 1e-5;   % New target rate in a unit volume
init(scoreLogic1,volume,beta1);
disp(['Score and MaxScore of ScoreLogic1: ', num2str(output(scoreLogic1))])
```

```
Score and MaxScore of ScoreLogic1: 2.4596      2.4596
```

Create a copy of the score logic.

```
scoreLogic2 = clone(scoreLogic1);
```

Specify the likelihood that the detection is assigned to the track, the probability of detection (pd) and the probability of false alarm (pfa). Update the second score logic with a hit.

```
likelihood = 0.05 + 0.05*rand(1);
pd = 0.8;
pfa = 1e-3;
hit(scoreLogic2,volume,likelihood,pd,pfa)
disp(['Score and MaxScore of ScoreLogic2: ', num2str(output(scoreLogic2))])
```

```
Score and MaxScore of ScoreLogic2: 7.0068      7.0068
```

Merge the score of `scoreLogic1` with the score of `scoreLogic2`. The score of `scoreLogic2` is larger, therefore the merged score of `scoreLogic1` increases.

```
mergeScores(scoreLogic1,scoreLogic2)
disp(['Score and MaxScore of merged ScoreLogic1: ', num2str(output(scoreLogic1))])
```

```
Score and MaxScore of merged ScoreLogic1: 7.0173      7.0173
```

Input Arguments

scoreLogic1 — Track score logic to update
`trackScoreLogic` object

Track score logic to update, specified as a `trackScoreLogic` object.

scoreLogic2 — Reference track score logic
`trackScoreLogic` object

Reference track score logic, specified as a `trackScoreLogic` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`clone` | `sync`

Introduced in R2018b

sync

Synchronize scores of `trackScoreLogic` objects

Syntax

```
sync(scoreLogic1,scoreLogic2)
```

Description

`sync(scoreLogic1,scoreLogic2)` sets the values of `'Score on page 2-0  '` and `'MaxScore on page 2-0   '` of `scoreLogic1` to the values of `scoreLogic2`.

Examples

Synchronize Track Score Logics

Create a score logic using the default confirmation and deletion thresholds.

```
scoreLogic1 = trackScoreLogic

scoreLogic1 =
  trackScoreLogic with properties:

    ConfirmationThreshold: 20
        DeletionThreshold: -5
                    Score: 0
                 MaxScore: 0
```

Create a second score logic, specifying the confirmation threshold as 30 and the deletion threshold as -10.

```
scoreLogic2 = trackScoreLogic('ConfirmationThreshold',30,'DeletionThreshold',-10)

scoreLogic2 =
  trackScoreLogic with properties:
```

```
      ConfirmationThreshold: 30
          DeletionThreshold: -10
                      Score: 0
                   MaxScore: 0
```

Initialize the two score logics using different target rates in a unit volume.

```
volume = 1.3; % Volume of a sensor detection bin

beta1 = 0.1;    % New target rate in a unit volume
init(scoreLogic1,volume,beta1);
disp(['Score and MaxScore of ScoreLogic1: ', num2str(output(scoreLogic1))])
```

```
Score and MaxScore of ScoreLogic1: 11.6699      11.6699
```

```
beta2 = 0.3;    % New target rate in a unit volume
init(scoreLogic2,volume,beta2);
disp(['Score and MaxScore of ScoreLogic2: ', num2str(output(scoreLogic2))])
```

```
Score and MaxScore of ScoreLogic2: 12.7685      12.7685
```

Specify the likelihood that a detection is assigned to the track. Then, update the second score logic with a hit.

```
likelihood = 0.05 + 0.05*rand(1);
hit(scoreLogic2,volume,likelihood)
```

```
disp(['Score and MaxScore of ScoreLogic2: ', num2str(output(scoreLogic2))])
```

```
Score and MaxScore of ScoreLogic2: 24.3413      24.3413
```

Synchronize `scoreLogic1` to have the same 'Score' and 'MaxScore' as `scoreLogic2`. The `sync` function does not modify the confirmation or deletion thresholds. To verify this, display the properties of both score logic objects.

```
sync(scoreLogic1,scoreLogic2)
scoreLogic1
```

```
scoreLogic1 =
  trackScoreLogic with properties:

      ConfirmationThreshold: 20
          DeletionThreshold: -5
                      Score: 24.3413
```

```
              MaxScore: 24.3413


scoreLogic2

scoreLogic2 =
  trackScoreLogic with properties:

    ConfirmationThreshold: 30
        DeletionThreshold: -10
                    Score: 24.3413
                 MaxScore: 24.3413
```

Input Arguments

scoreLogic1 — Track score logic to synchronize
trackScoreLogic object

Track score logic to synchronize, specified as a trackScoreLogic object.

scoreLogic2 — Reference track score logic
trackScoreLogic object

Reference track score logic, specified as a trackScoreLogic object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
clone | mergeScores

Introduced in R2018b

trackHistoryLogic

Confirm and delete tracks based on recent track history

Description

The `trackHistoryLogic` object determines if a track should be confirmed or deleted based on the track history. A track should be confirmed if there are at least *Mc* hits in the recent *Nc* updates. A track should be deleted if there are at least *Md* misses in the recent *Nd* updates.

The confirmation and deletion decisions contribute to the track management by a `trackerGNN`.

Creation

Syntax

```
logic = trackHistoryLogic
logic = trackHistoryLogic(Name,Value,...)
```

Description

`logic = trackHistoryLogic` creates a `trackHistoryLogic` object with default confirmation and deletion thresholds.

`logic = trackHistoryLogic(Name,Value,...)` specifies the `ConfirmationThreshold` and `DeletionThreshold` properties of the track history logic object using one or more `Name,Value` pair arguments. Any unspecified properties take default values.

Properties

`ConfirmationThreshold` — Confirmation threshold
[2 3] (default) | positive integer scalar | 2-element vector of positive integers

Confirmation threshold, specified as a positive integer scalar or 2-element vector of positive integers. If the logic score is above this threshold, the track is confirmed. `ConfirmationThreshold` has the form [$Mc\ Nc$], where Mc is the number of hits required for confirmation in the recent Nc updates. When specified as a scalar, then Mc and Nc have the same value.

Example: [3 5]

Data Types: `single` | `double`

`DeletionThreshold` — Deletion threshold
[6 6] (default) | positive integer scalar | 2-element vector of positive integers

Deletion threshold, specified as a positive integer scalar or 2-element vector of positive integers. If the logic score is above this threshold, the track is deleted. `DeletionThreshold` has the form [$Md\ Nd$], where Md is the number of misses required for deletion in the recent Nd updates. When specified as a scalar, then Md and Nd have the same value.

Example: [5 5]

Data Types: `single` | `double`

`History` — Track history
logical vector

This property is read-only.

Track history, specified as a logical vector of length N, where N is the larger of `ConfirmationThreshold(2)` and `DeletionThreshold(2)`. The first element is the most recent update. A `true` value indicates a hit and a `false` value indicates a miss.

Object Functions

init	Initialize track logic with first hit
hit	Update track logic with subsequent hit
miss	Update track logic with miss

checkConfirmation	Check if track should be confirmed
checkDeletion	Check if track should be deleted
output	Get current state of track logic
reset	Reset state of track logic
clone	Create copy of track logic

Examples

Create and Update History-Based Logic

Create a history-based logic. Specify confirmation threshold values *Mc* and *Nc* as the vector [3 5]. Specify deletion threshold values *Md* and *Nd* as the vector [6 7].

```
historyLogic = trackHistoryLogic('ConfirmationThreshold',[3 5], ...
    'DeletionThreshold',[6 7])

historyLogic =
  trackHistoryLogic with properties:

    ConfirmationThreshold: [3 5]
        DeletionThreshold: [6 7]
                  History: [0 0 0 0 0 0 0]
```

Initialize the logic, which records a hit as the first update to the logic.

```
init(historyLogic)
history = historyLogic.History;
disp(['History: [',num2str(history),'].']);

History: [1  0  0  0  0  0  0].
```

Update the logic four more times, where only the odd updates register a hit. The confirmation flag is `true` by the end of the fifth update, because three hits (*Mc*) are counted in the most recent five updates (*Nc*).

```
for i = 2:5
    isOdd = logical(mod(i,2));
    if isOdd
        hit(historyLogic)
    else
        miss(historyLogic)
```

```
    end

    history = historyLogic.History;
    confFlag = checkConfirmation(historyLogic);
    delFlag = checkDeletion(historyLogic,true,i);
    disp(['History: [',num2str(history),']. Confirmation Flag: ',num2str(confFlag), ..
        '. Deletion Flag: ',num2str(delFlag)']);
end

History: [0  1  0  0  0  0  0]. Confirmation Flag: 0. Deletion Flag: 0
History: [1  0  1  0  0  0  0]. Confirmation Flag: 0. Deletion Flag: 0
History: [0  1  0  1  0  0  0]. Confirmation Flag: 0. Deletion Flag: 0
History: [1  0  1  0  1  0  0]. Confirmation Flag: 1. Deletion Flag: 0
```

Update the logic with a miss six times. The deletion flag is `true` by the end of the fifth update, because six misses (*Md*) are counted in the most recent seven updates (*Nd*).

```
for i = 1:6
    miss(historyLogic);

    history = historyLogic.History;
    confFlag = checkConfirmation(historyLogic);
    delFlag = checkDeletion(historyLogic);
    disp(['History: [',num2str(history),']. Confirmation Flag: ',num2str(confFlag), ..
        '. Deletion Flag: ',num2str(delFlag)']);
end

History: [0  1  0  1  0  1  0]. Confirmation Flag: 0. Deletion Flag: 0
History: [0  0  1  0  1  0  1]. Confirmation Flag: 0. Deletion Flag: 0
History: [0  0  0  1  0  1  0]. Confirmation Flag: 0. Deletion Flag: 0
History: [0  0  0  0  1  0  1]. Confirmation Flag: 0. Deletion Flag: 0
History: [0  0  0  0  0  1  0]. Confirmation Flag: 0. Deletion Flag: 1
History: [0  0  0  0  0  0  1]. Confirmation Flag: 0. Deletion Flag: 1
```

References

[1] Blackman, S., and R. Popoli. *Design and Analysis of Modern Tracking Systems*. Boston, MA: Artech House, 1999.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`trackScoreLogic` | `trackerGNN`

Topics
"Introduction to Track Logic"

Introduced in R2018b

checkConfirmation

Check if track should be confirmed

Syntax

```
tf = checkConfimation(historyLogic)
tf = checkConfimation(scoreLogic)
```

Description

`tf = checkConfimation(historyLogic)` returns a flag that is `true` when at least *Mc* out of *Nc* recent updates of the track history logic object `historyLogic` are `true`.

`tf = checkConfimation(scoreLogic)` returns a flag that is `true` when the track should be confirmed based on the track score.

Examples

Check Confirmation of History-Based Logic

Create a history-based logic. Specify confirmation threshold values *Mc* and *Nc* as the vector [2 3]. Specify deletion threshold values *Md* and *Nd* as the vector [3 3].

```
historyLogic = trackHistoryLogic('ConfirmationThreshold',[2 3], ...
    'DeletionThreshold',[3 3])

historyLogic =
  trackHistoryLogic with properties:

    ConfirmationThreshold: [2 3]
        DeletionThreshold: [3 3]
                  History: [0 0 0]
```

2-363

Initialize the logic, which records a hit as the first update to the logic. The confirmation flag is `false` because the number of hits is less than two (*Mc*).

```
init(historyLogic)
history = output(historyLogic);
confFlag = checkConfirmation(historyLogic);
disp(['History: [',num2str(history),']. Confirmation Flag: ',num2str(confFlag)]);

History: [1  0  0]. Confirmation Flag: 0
```

Update the logic with a hit. The confirmation flag is `true` because two hits (*Mc*) are counted in the most recent three updates (*Nc*).

```
hit(historyLogic)
history = output(historyLogic);
confFlag = checkConfirmation(historyLogic);
disp(['History: [',num2str(history),']. Confirmation Flag: ',num2str(confFlag)]);

History: [1  1  0]. Confirmation Flag: 1
```

Check Confirmation of Score-Based Logic

Create a score-based logic, specifying the confirmation threshold. The logic uses the default deletion threshold.

```
scoreLogic = trackScoreLogic('ConfirmationThreshold',8);
```

Specify the probability of detection (`pd`), the probability of false alarm (`pfa`), the volume of a sensor detection bin (`volume`), and the new target rate in a unit volume (`beta`).

```
pd = 0.8;
pfa = 1e-3;
volume = 1.3;
beta = 0.1;
```

Initialize the logic using these parameters. The first update to the logic is a hit.

```
init(scoreLogic,volume,beta,pd,pfa);
disp(['Score and MaxScore: ', num2str(output(scoreLogic))]);

Score and MaxScore: 4.6444      4.6444
```

The confirmation flag is `false` because the score is less than the confirmation threshold.

```
confirmationFlag = checkConfirmation(scoreLogic)

confirmationFlag = logical
   0
```

Specify the likelihood that the detection is assigned to the track. Then, update the logic with a hit. The current score and maximum score increase.

```
likelihood = 0.05 + 0.05*rand(1);
hit(scoreLogic,volume,likelihood,pd,pfa)
disp(['Score and MaxScore: ', num2str(output(scoreLogic))])

Score and MaxScore: 9.1916      9.1916
```

The confirmation flag is now true because the score is greater than the confirmation threshold.

```
confirmationFlag = checkConfirmation(scoreLogic)

confirmationFlag = logical
   1
```

Input Arguments

historyLogic — Track history logic
trackHistoryLogic

Track history logic, specified as a trackHistoryLogic object.

scoreLogic — Track score logic
trackScoreLogic object

Track score logic, specified as a trackScoreLogic object.

Output Arguments

tf — Track should be confirmed
true | false

Track should be confirmed, returned as `true` or `false`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
checkDeletion | hit | miss | output

Introduced in R2018b

checkDeletion

Check if track should be deleted

Syntax

```
tf = checkDeletion(historyLogic)
tf = checkDeletion(historyLogic,tentativeTrack,age)
tf = checkDeletion(scoreLogic)
```

Description

`tf = checkDeletion(historyLogic)` returns a flag that is `true` when at least *Md* out of *Nd* recent updates of the track history logic object `historyLogic` are `false`.

`tf = checkDeletion(historyLogic,tentativeTrack,age)` returns a flag that is `true` when the track is tentative and there are not enough detections to allow it to confirm. Use the logical flag `tentativeTrack` to indicate if the track is tentative and provide `age` as a numerical scalar.

`tf = checkDeletion(scoreLogic)` returns a flag that is `true` when the track should be deleted based on the track score.

Examples

Check Deletion of History-Based Logic

Create a history-based logic. Specify confirmation threshold values *Mc* and *Nc* as the vector [2 3]. Specify deletion threshold values *Md* and *Nd* as the vector [4 5].

```
historyLogic = trackHistoryLogic('ConfirmationThreshold',[2 3], ...
    'DeletionThreshold',[4 5])

historyLogic =
  trackHistoryLogic with properties:
```

```
       ConfirmationThreshold: [2 3]
           DeletionThreshold: [4 5]
                     History: [0 0 0 0 0]
```

Initialize the logic, which records a hit as the first update to the logic. The confirmation flag is `false` because the number of hits is less than two (*Mc*).

```
init(historyLogic)
history = output(historyLogic);
checkConfirmation(historyLogic)

ans = logical
   0
```

```
delFlag = checkDeletion(historyLogic);
disp(['History: [',num2str(history),']. Deletion Flag: ',num2str(delFlag)]);

History: [1  0  0  0  0]. Deletion Flag: 1
```

Update the logic with a hit. The confirmation flag is `true` because two hits (*Mc*) are counted in the most recent three updates (*Nc*).

```
hit(historyLogic)
history = output(historyLogic);
checkConfirmation(historyLogic)

ans = logical
   1
```

```
delFlag = checkDeletion(historyLogic);
disp(['History: [',num2str(history),']. Deletion Flag: ',num2str(delFlag)]);

History: [1  1  0  0  0]. Deletion Flag: 0

miss(historyLogic)
history = output(historyLogic);
checkConfirmation(historyLogic)

ans = logical
   1
```

```
delFlag = checkDeletion(historyLogic);
disp(['History: [',num2str(history),']. Deletion Flag: ',num2str(delFlag)]);

History: [0  1  1  0  0]. Deletion Flag: 0

miss(historyLogic)
history = output(historyLogic);
delFlag = checkDeletion(historyLogic);
checkConfirmation(historyLogic)

ans = logical
   0


disp(['History: [',num2str(history),']. Deletion Flag: ',num2str(delFlag)]);

History: [0  0  1  1  0]. Deletion Flag: 0
```

Check Deletion of Tentative Track

Create a history-based logic. Specify confirmation threshold values *Mc* and *Nc* as the vector [2 3]. Specify deletion threshold values *Md* and *Nd* as the vector [4 5].

```
historyLogic = trackHistoryLogic('ConfirmationThreshold',[2 3], ...
    'DeletionThreshold',5)

historyLogic =
  trackHistoryLogic with properties:

    ConfirmationThreshold: [2 3]
        DeletionThreshold: [5 5]
                  History: [0 0 0 0 0]
```

Initialize the logic, which records a hit as the first update to the logic. Then, record two misses.

```
init(historyLogic)
miss(historyLogic)
miss(historyLogic)
history = output(historyLogic)

history = 1x5 logical array
```

2-369

```
   0   0   1   0   0
```

The confirmation flag is `false` because the number of hits in the most recent 3 updates (*Nc*) is less than 2 (*Mc*).

```
confirmationFlag = checkConfirmation(historyLogic)
```

```
confirmationFlag = logical
   0
```

Check the deletion flag as if the track were not tentative. The deletion flag is `false` because the number of misses in the most recent 5 updates (*Nm*) is less than 4 (*Mc*).

```
deletionFlag = checkDeletion(historyLogic)
```

```
deletionFlag = logical
   0
```

Recheck the deletion flag, treating the track as tentative with an age of 3. The tentative deletion flag is `true` because there are not enough detections to allow the track to confirm.

```
tentativeDeletionFlag = checkDeletion(historyLogic,true,3)
```

```
tentativeDeletionFlag = logical
   1
```

Check Deletion of Score-Based Logic

Create a score-based logic, specifying the deletion threshold. The logic uses the default confirmation threshold.

```
scoreLogic = trackScoreLogic('DeletionThreshold',-1);
```

Specify the probability of detection (`pd`), the probability of false alarm (`pfa`), the volume of a sensor detection bin (`volume`), and the new target rate in a unit volume (`beta`).

```
pd = 0.8;
pfa = 1e-3;
```

```
volume = 1.3;
beta = 0.1;
```

Initialize the logic using these parameters. The first update to the logic is a hit.

```
init(scoreLogic,volume,beta,pd,pfa);
disp(['Score and MaxScore: ', num2str(output(scoreLogic))]);
```

Score and MaxScore: 4.6444   4.6444

Update the logic with a miss. The current score decreases.

```
miss(scoreLogic,pd,pfa)
disp(['Score and MaxScore: ', num2str(output(scoreLogic))])
```

Score and MaxScore: 3.036   4.6444

The deletion flag is `true` because the current score is smaller than the maximum score by more than 1. In other words, `scoreLogic.Score - scoreLogic.MaxScore` is more negative than the deletion threshold, -1.

```
deletionFlag = checkDeletion(scoreLogic)
```

deletionFlag = *logical*
   1

Input Arguments

historyLogic — Track history logic
trackHistoryLogic

Track history logic, specified as a `trackHistoryLogic` object.

tentativeTrack — Track is tentative
false | true

Track is tentative, specified as `false` or `true`. Use `tentativeTrack` to indicate if the track is tentative.

age — Number of updates
numeric scalar

Number of updates since track initialization, specified as a numeric scalar.

`scoreLogic` — Track score logic
`trackScoreLogic` object

Track score logic, specified as a `trackScoreLogic` object.

Output Arguments

`tf` — Track can be deleted
`true` | `false`

Track can be deleted, returned as `true` or `false`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`checkConfirmation` | `hit` | `miss` | `output`

Introduced in R2018b

clone

Create copy of track logic

Syntax

```
clonedLogic = clone(logic)
```

Description

clonedLogic = clone(logic) returns a copy of the current track logic object, logic.

Examples

Clone Track History Logic

Create a history-based logic. Specify confirmation threshold values *Mc* and *Nc* as the vector [3 5]. Specify deletion threshold values *Md* and *Nd* as the vector [6 7].

```
historyLogic = trackHistoryLogic('ConfirmationThreshold',[3 5], ...
    'DeletionThreshold',[6 7])

historyLogic =
  trackHistoryLogic with properties:

    ConfirmationThreshold: [3 5]
        DeletionThreshold: [6 7]
                  History: [0 0 0 0 0 0 0]
```

Initialize the logic, which records a hit as the first update to the logic.

```
init(historyLogic)
```

Update the logic four more times, where only the odd updates register a hit.

```
for i = 2:5
    isOdd = logical(mod(i,2));
    if isOdd
        hit(historyLogic)
    else
        miss(historyLogic)
    end
end
```

Get the current state of the logic.

```
history = output(historyLogic)

history = 1x7 logical array

   1   0   1   0   1   0   0
```

Create a copy of the logic. The clone has the same confirmation threshold, deletion threshold, and history as the original history logic.

```
clonedLogic = clone(historyLogic)

clonedLogic =
  trackHistoryLogic with properties:

    ConfirmationThreshold: [3 5]
        DeletionThreshold: [6 7]
                  History: [1 0 1 0 1 0 0]
```

Input Arguments

logic — Track logic
trackHistoryLogic object | trackScoreLogic object

Track logic, specified as a trackHistoryLogic object or trackScoreLogic object.

Output Arguments

clonedLogic — Cloned track logic
trackHistoryLogic object | trackScoreLogic object

Cloned track logic, returned as a trackHistoryLogic object or trackScoreLogic object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
mergeScores | sync

Introduced in R2018b

hit

Update track logic with subsequent hit

Syntax

```
hit(historyLogic)

hit(scoreLogic,volume,likelihood)
hit(scoreLogic,volume,likelihood,pd,pfa)
```

Description

`hit(historyLogic)` updates the track history with a hit.

`hit(scoreLogic,volume,likelihood)` updates the track score in a case of a hit, given the likelihood of a detection being assigned to the track.

`hit(scoreLogic,volume,likelihood,pd,pfa)` updates the track score in a case of a hit, specifying the probability of detection `pd` and probability of false alarm `pfa`.

Examples

Update History Logic with Hit

Create a history-based logic with the default confirmation and deletion thresholds.

```
historyLogic = trackHistoryLogic;
```

Initialize the logic, which records a hit as the first update to the logic. The first element of the 'History' property, which indicates the most recent update, is 1.

```
init(historyLogic)
history = historyLogic.History;
disp(['History: [',num2str(history),'].']);
```

```
History: [1  0  0  0  0  0].
```

Update the logic with a hit. The first two elements of the 'History' property are 1.

```
hit(historyLogic)
history = historyLogic.History;
disp(['History: [',num2str(history),'].']);
```

```
History: [1  1  0  0  0  0].
```

Update Score Logic with Hit

Create a score-based logic with default confirmation and deletion thresholds.

```
scoreLogic = trackScoreLogic;
```

Specify the probability of detection (pd), the probability of false alarm (pfa), the volume of a sensor detection bin (volume), and the new target rate in a unit volume (beta).

```
pd = 0.9;
pfa = 1e-6;
volume = 1.3;
beta = 0.1;
```

Initialize the logic using these parameters. The first update to the logic is a hit.

```
init(scoreLogic,volume,beta,pd,pfa);
disp(['Score and MaxScore: ', num2str(output(scoreLogic))]);
```

```
Score and MaxScore: 11.6699       11.6699
```

Specify the likelihood that the detection is assigned to the track.

```
likelihood = 0.05 + 0.05*rand(1);
```

Update the logic with a hit. The current score and maximum score increase.

```
hit(scoreLogic,volume,likelihood)
disp(['Score and MaxScore: ', num2str(output(scoreLogic))])
```

```
Score and MaxScore: 23.3221       23.3221
```

Input Arguments

`historyLogic` — Track history logic
`trackHistoryLogic`

Track history logic, specified as a `trackHistoryLogic` object.

`scoreLogic` — Track score logic
`trackScoreLogic` object

Track score logic, specified as a `trackScoreLogic` object.

`volume` — Volume of sensor detection bin
nonnegative scalar

Volume of sensor detection bin, specified as a nonnegative scalar. For example, a 2-D radar will have a sensor bin volume of (*azimuth resolution in radians*) * (*range*) * (*range resolution*).

Data Types: `single` | `double`

`likelihood` — Likelihood of a detection being assigned to the track
numeric vector

Likelihood of a detection being assigned to the track, specified as a numeric vector of length *m*.

Data Types: `single` | `double`

pd — Probability of detection
`0.9` (default) | nonnegative scalar

Probability of detection, specified as a nonnegative scalar.

Data Types: `single` | `double`

`pfa` — Probability of false alarm
`1e-6` (default) | nonnegative scalar

Probability of false alarm, specified as a nonnegative scalar.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
checkConfirmation | checkDeletion | init | miss

Introduced in R2018b

init

Initialize track logic with first hit

Syntax

```
init(historyLogic)
```

```
init(scoreLogic,volume,beta)
init(scoreLogic,volume,beta,pd,pfa)
```

Description

`init(historyLogic)` initializes the track history logic with the first hit.

`init(scoreLogic,volume,beta)` initializes the track score logic with the first hit, using default probabilities of detection and false alarm.

`init(scoreLogic,volume,beta,pd,pfa)` initializes the track score logic with the first hit, specifying the probability of detection `pd` and probability of false alarm `pfa`.

Examples

Initialize History-Based Logic

Create a history-based logic with default confirmation and deletion thresholds.

```
historyLogic = trackHistoryLogic

historyLogic =
  trackHistoryLogic with properties:

    ConfirmationThreshold: [2 3]
        DeletionThreshold: [6 6]
                  History: [0 0 0 0 0 0]
```

Initialize the logic, which records a hit as the first update to the logic.

```
init(historyLogic)
history = historyLogic.History;
disp(['History: [',num2str(history),'].']);
```

```
History: [1  0  0  0  0  0].
```

Initialize Score-Based Logic

Create a score-based logic with default confirmation and deletion thresholds.

```
scoreLogic = trackScoreLogic
```

```
scoreLogic =
  trackScoreLogic with properties:

    ConfirmationThreshold: 20
        DeletionThreshold: -5
                    Score: 0
                 MaxScore: 0
```

Specify the probability of detection (`pd`), the probability of false alarm (`pfa`), the volume of a sensor detection bin (`volume`), and the new target rate in a unit volume (`beta`).

```
pd = 0.9;
pfa = 1e-6;
volume = 1.3;
beta = 0.1;
```

Initialize the logic using these parameters. The first update to the logic is a hit.

```
init(scoreLogic,volume,beta,pd,pfa);
```

Display the current and maximum score of the logic. Since the logic has been updated once, the current score is equal to the maximum score.

```
currentScore = scoreLogic.Score
```

```
currentScore = 11.6699
```

```
maximumScore = scoreLogic.MaxScore
```

```
maximumScore = 11.6699
```

Input Arguments

`historyLogic` — Track history logic
`trackHistoryLogic` object

Track history logic, specified as a `trackHistoryLogic` object.

`scoreLogic` — Track score logic
`trackScoreLogic` object

Track score logic, specified as a `trackScoreLogic` object.

`volume` — Volume of sensor detection bin
nonnegative scalar

Volume of sensor detection bin, specified as a nonnegative scalar. For example, a 2-D radar will have a sensor bin volume of (*azimuth resolution in radians*) * (*range*) * (*range resolution*).

Data Types: `single` | `double`

`beta` — Rate of new targets in unit volume
nonnegative scalar

Rate of new targets in unit volume, specified as a nonnegative scalar.

Data Types: `single` | `double`

`pd` — Probability of detection
`0.9` (default) | nonnegative scalar

Probability of detection, specified as a nonnegative scalar.

Data Types: `single` | `double`

`pfa` — Probability of false alarm
`1e-6` (default) | nonnegative scalar

Probability of false alarm, specified as a nonnegative scalar.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`checkConfirmation` | `checkDeletion` | `hit` | `miss`

Introduced in R2018b

miss

Update track logic with miss

Syntax

```
miss(historyLogic)
```

```
miss(scoreLogic)
miss(scoreLogic,pd,pfa)
```

Description

`miss(historyLogic)` updates the track history with a miss.

`miss(scoreLogic)` updates the track score in a case of a miss, using default probabilities of detection and false alarm.

`miss(scoreLogic,pd,pfa)` updates the track score in a case of a miss, specifying the probability of detection `pd` and probability of false alarm `pfa`.

Examples

Update History Logic with Miss

Create a history-based logic with the default confirmation and deletion thresholds.

```
historyLogic = trackHistoryLogic;
```

Initialize the logic, which records a hit as the first update to the logic. The first element of the 'History' property, which indicates the most recent update, is 1.

```
init(historyLogic)
history = historyLogic.History;
disp(['History: [',num2str(history),'].']);
```

```
History: [1  0  0  0  0  0].
```

Update the logic with a miss. The first element of the 'History' property is 0.

```
miss(historyLogic)
history = historyLogic.History;
disp(['History: [',num2str(history),'].']);
```

```
History: [0  1  0  0  0  0].
```

Update Score Logic with Miss

Create a score-based logic with default confirmation and deletion thresholds.

```
scoreLogic = trackScoreLogic;
```

Specify the probability of detection (pd), the probability of false alarm (pfa), the volume of a sensor detection bin (volume), and the new target rate in a unit volume (beta).

```
pd = 0.9;
pfa = 1e-6;
volume = 1.3;
beta = 0.1;
```

Initialize the logic using these parameters. The first update to the logic is a hit.

```
init(scoreLogic,volume,beta,pd,pfa);
disp(['Score and MaxScore: ', num2str(output(scoreLogic))]);
```

```
Score and MaxScore: 11.6699      11.6699
```

Update the logic with a miss. The current score decreases, but the maximum score does not change.

```
miss(scoreLogic,pd,pfa)
disp(['Score and MaxScore: ', num2str(output(scoreLogic))])
```

```
Score and MaxScore: 9.36735      11.6699
```

2-385

Input Arguments

`historyLogic` — Track history logic
`trackHistoryLogic`

Track history logic, specified as a `trackHistoryLogic` object.

`scoreLogic` — Track score logic
`trackScoreLogic` object

Track score logic, specified as a `trackScoreLogic` object.

`pd` — Probability of detection
`0.9` (default) | nonnegative scalar

Probability of detection, specified as a nonnegative scalar.

Data Types: `single` | `double`

`pfa` — Probability of false alarm
`1e-6` (default) | nonnegative scalar

Probability of false alarm, specified as a nonnegative scalar.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`checkConfirmation` | `checkDeletion` | `hit` | `init`

Introduced in R2018b

output

Get current state of track logic

Syntax

```
history = output(historyLogic)
scores = output(scoreLogic)
```

Description

`history = output(historyLogic)` returns the recent history updates of the track history logic object, `historyLogic`.

`scores = output(scoreLogic)` returns in `scores` the current score and maximum score of track score logic object, `scoreLogic`.

Examples

Get Recent History of History-Based Logic

Create a history-based logic. Specify confirmation threshold values *Mc* and *Nc* as the vector [3 5]. Specify deletion threshold values *Md* and *Nd* as the vector [6 7].

```
historyLogic = trackHistoryLogic('ConfirmationThreshold',[3 5], ...
    'DeletionThreshold',[6 7]);
```

Get the recent history of the logic. The history vector has a length of 7, which is the greater of *Nc* and *Nd*. All values are 0 because the logic is not initialized.

```
h = output(historyLogic)
```

h = *1x7 logical array*

```
  0   0   0   0   0   0   0
```

Initialize the logic, then get the recent history of the logic. The first element, which indicates the most recent update, is 1.

```
init(historyLogic);
h = output(historyLogic)
```

h = *1x7 logical array*

   1   0   0   0   0   0   0

Update the logic with a hit, then get the recent history of the logic.

```
hit(historyLogic);
h = output(historyLogic)
```

h = *1x7 logical array*

   1   1   0   0   0   0   0

Get Current Score of Score-Based Logic

Create a score-based logic with default confirmation and deletion thresholds.

```
scoreLogic = trackScoreLogic;
```

Get the current and maximum score of the logic. Both scores are 0 because the logic is not initialized.

```
s = output(scoreLogic)
```

s = *1×2*

    0   0

Specify the volume of a sensor detection bin (`volume`), and the new target rate in a unit volume (`beta`). Initialize the logic using these parameters and the default probabilities of detection and false alarm. The first update to the logic is a hit.

```
volume = 1.3;
beta = 0.1;
init(scoreLogic,volume,beta);
```

Get the current and maximum score of the logic.

```
s = output(scoreLogic)
```

s = *1×2*

   11.6699   11.6699

Update the logic with a miss, then get the updated scores.

```
miss(scoreLogic)
s = output(scoreLogic)
```

s = *1×2*

    9.3673   11.6699

Input Arguments

historyLogic — Track history logic
trackHistoryLogic

Track history logic, specified as a trackHistoryLogic object.

scoreLogic — Track score logic
trackScoreLogic object

Track score logic, specified as a trackScoreLogic object.

Output Arguments

history — Recent history
logical vector

Recent track history of `historyLogic`, returned as a logical vector. The length of the vector is the same as the length of the `History` property of the `historyLogic`. The first element is the most recent update. A `true` value indicates a hit and a `false` value indicates a miss.

scores — Current and maximum scores
1-by-2 numeric vector

Current and maximum scores of `scoreLogic`, returned as a 1-by-2 numeric vector. The first element specifies the current score. The second element specifies the maximum score.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`checkConfirmation` | `checkDeletion` | `hit` | `miss`

Introduced in R2018b

reset

Reset state of track logic

Syntax

```
reset(logic)
```

Description

reset(logic) resets the track logic object, logic.

Examples

Reset Track Score Logic

Create a score-based logic using the default confirmation threshold and deletion threshold. Get the current state of the logic. The current and maximum score are both 0.

```
scoreLogic = trackScoreLogic;
score = output(scoreLogic)
```

score = *1×2*

```
     0      0
```

Initialize the logic, then get the current state of the logic.

```
volume = 1.3;
beta = 0.1;
init(scoreLogic,volume,beta);
score = output(scoreLogic)
```

score = *1×2*

```
    11.6699    11.6699
```

Reset the logic, then get the current state of the logic. The current and maximum score are both 0.

```
reset(scoreLogic)
score = output(scoreLogic)

score = 1×2

    0    0
```

Input Arguments

`logic` — Track logic
`trackHistoryLogic` object | `trackScoreLogic` object

Track logic, specified as a `trackHistoryLogic` object or `trackScoreLogic` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`init`

Introduced in R2018b

System Objects in Sensor Fusion and Tracking Toolbox

ahrsfilter System object

Orientation from accelerometer, gyroscope, and magnetometer readings

Description

The `ahrsfilter` System object fuses accelerometer, magnetometer, and gyroscope sensor data to estimate device orientation.

To estimate device orientation:

1 Create the `ahrsfilter` 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

```
FUSE = ahrsfilter
FUSE = ahrsfilter(Name,Value)
```

Description

`FUSE = ahrsfilter` returns an indirect Kalman filter System object, `FUSE`, for sensor fusion of accelerometer, gyroscope, and magnetometer data to estimate device orientation and angular velocity. The filter uses a 12-element state vector to track the estimation error for the orientation, the gyroscope bias, the linear acceleration, and the magnetic disturbance.

`FUSE = ahrsfilter(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default 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).

SampleRate — Input sample rate of sensor data (Hz)
`100` (default) | positive scalar

Input sample rate of the sensor data in Hz, specified as a positive scalar.

Tunable: No

Data Types: `single` | `double`

DecimationFactor — Decimation factor
`1` (default) | positive integer scalar

Decimation factor by which to reduce the input sensor data rate as part of the fusion algorithm, specified as a positive integer scalar.

The number of rows of the inputs –– `accelReadings`, `gyroReadings`, and `magReadings` –– must be a multiple of the decimation factor.

Data Types: `single` | `double`

AccelerometerNoise — Variance of accelerometer signal noise ((m/s^2)^2)
`0.00019247` (default) | positive real scalar

Variance of accelerometer signal noise in (m/s^2)^2, specified as a positive real scalar.

Tunable: Yes

Data Types: `single` | `double`

MagnetometerNoise — Variance of magnetometer signal noise (µT^2)
`0.1` (default) | positive real scalar

Variance of magnetometer signal noise in µT^2, specified as a positive real scalar.

Tunable: Yes

Data Types: `single` | `double`

GyroscopeNoise — Variance of gyroscope signal noise ((rad/s)²)
`9.1385e-5` (default) | positive real scalar

Variance of gyroscope signal noise in $(rad/s)^2$, specified as a positive real scalar.

Tunable: Yes

Data Types: `single` | `double`

GyroscopeDriftNoise — Variance of gyroscope offset drift ((rad/s)²)
`3.0462e-13` (default) | positive real scalar

Variance of gyroscope offset drift in $(rad/s)^2$, specified as a positive real scalar.

Tunable: Yes

Data Types: `single` | `double`

LinearAccelerationNoise — Variance of linear acceleration noise (m/s²)²
`0.0096236` (default) | positive real scalar

Variance of linear acceleration noise in $(m/s^2)^2$, specified as a positive real scalar. Linear acceleration is modeled as a lowpass-filtered white noise process.

Tunable: Yes

Data Types: `single` | `double`

LinearAcclerationDecayFactor — Decay factor for linear acceleration drift
`0.5` (default) | scalar in the range [0,1]

Decay factor for linear acceleration drift, specified as a scalar in the range [0,1]. If linear acceleration is changing quickly, set `LinearAcclerationDecayFactor` to a lower value. If linear acceleration changes slowly, set `LinearAcclerationDecayFactor` to a higher value. Linear acceleration drift is modeled as a lowpass-filtered white noise process.

Tunable: Yes

Data Types: `single` | `double`

MagneticDisturbanceNoise — Variance of magnetic disturbance noise (µT^2)
`0.5` (default) | real finite positive scalar

Variance of magnetic disturbance noise in µT^2, specified as a real finite positive scalar.

Tunable: Yes

Data Types: `single` | `double`

MagneticDisturbanceDecayFactor — Decay factor for magnetic disturbance
`0.5` (default) | positive scalar in the range [0,1]

Decay factor for magnetic disturbance, specified as a positive scalar in the range [0,1]. Magnetic disturbance is modeled as a first order Markov process.

Tunable: Yes

Data Types: `single` | `double`

InitialProcessNoise — Covariance matrix for process noise
12-by-12 matrix

Covariance matrix for process noise, specified as a 12-by-12 matrix. The default is:

```
  Columns 1 through 6

  0.000006092348396                 0                 0                 0
                0   0.000006092348396                 0                 0
                0                 0   0.000006092348396                 0
                0                 0                 0   0.000076154354947
                0                 0                 0                 0   0.00
                0                 0                 0                 0
                0                 0                 0                 0
                0                 0                 0                 0
                0                 0                 0                 0
                0                 0                 0                 0
                0                 0                 0                 0
                0                 0                 0                 0

  Columns 7 through 12

                0                 0                 0                 0
                0                 0                 0                 0
                0                 0                 0                 0
                0                 0                 0                 0
```

0	0	0	0		
0	0	0	0		
0.009623610000000	0	0	0		
0	0.009623610000000	0	0		
0	0	0.009623610000000	0		
0	0	0	0.600000000000000		
0	0	0	0	0.60	
0	0	0	0		

The initial process covariance matrix accounts for the error in the process model.

Data Types: `single` | `double`

ExpectedMagneticFieldStrength — Expected estimate of magnetic field strength (µT)
50 (default) | real positive scalar

Expected estimate of magnetic field strength in µT, specified as a real positive scalar. The expected magnetic field strength is an estimate of the magnetic field strength of the Earth at the current location.

Tunable: Yes

Data Types: `single` | `double`

OrientationFormat — Output orientation format
`'quaternion'` (default) | `'Rotation matrix'`

Output orientation format, specified as `'quaternion'` or `'Rotation matrix'`. The size of the output depends on the input size, *N*, and the output orientation format:

- `'quaternion'` –– Output is an *N*-by-1 `quaternion`.
- `'Rotation matrix'` –– Output is a 3-by-3-by-*N* rotation matrix.

Data Types: `char` | `string`

Usage

Syntax

```
[orientation,angularVelocity] = FUSE(accelReadings,gyroReadings,
magReadings)
```

Description

`[orientation,angularVelocity] = FUSE(accelReadings,gyroReadings,
magReadings)` fuses accelerometer, gyroscope, and magnetometer data to compute orientation and angular velocity measurements. The algorithm assumes that the device is stationary before the first call.

Input Arguments

accelReadings — Accelerometer readings in sensor body coordinate system (m/s^2)
N-by-3 matrix

Accelerometer readings in the sensor body coordinate system in m/s^2, specified as an *N*-by-3 matrix. *N* is the number of samples, and the three columns of `accelReadings` represent the [*x y z*] measurements. Accelerometer readings are assumed to correspond to the sample rate specified by the SampleRate property.

Data Types: `single` | `double`

gyroReadings — Gyroscope readings in sensor body coordinate system (rad/s)
N-by-3 matrix

Gyroscope readings in the sensor body coordinate system in rad/s, specified as an *N*-by-3 matrix. *N* is the number of samples, and the three columns of `gyroReadings` represent the [*x y z*] measurements. Gyroscope readings are assumed to correspond to the sample rate specified by the SampleRate property.

Data Types: `single` | `double`

magReadings — Magnetometer readings in sensor body coordinate system (µT)
N-by-3 matrix

Magnetometer readings in the sensor body coordinate system in µT, specified as an *N*-by-3 matrix. *N* is the number of samples, and the three columns of `magReadings` represent the [*x y z*] measurements. Magnetometer readings are assumed to correspond to the sample rate specified by the SampleRate property.

Data Types: `single` | `double`

Output Arguments

`orientation` — Orientation that rotates quantities from local NED coordinate system to sensor body coordinate system
M-by-1 array of quaternions (default) | 3-by-3-by-*M* array

Orientation that can rotate quantities from the local NED coordinate system to a body coordinate system, returned as quaternions or an array. The size and type of `orientation` depends on whether the OrienationFormat property is set to `'quaternion'` or `'Rotation matrix'`:

- `'quaternion'` –– the output is an *M*-by-1 vector of quaternions, with the same underlying data type as the inputs
- `'Rotation matrix'` –– the output is a 3-by-3-by-*M* array of rotation matrices the same data type as the inputs

The number of input samples, *N*, and the DecimationFactor property determine *M*.

You can use `orientation` in a `rotateframe` function to rotate quantities from a local NED system to a sensor body coordinate system.

Data Types: `quaternion` | `single` | `double`

`angularVelocity` — Angular velocity in sensor body coordinate system (rad/s)
M-by-3 array (default)

Angular velocity with gyroscope bias removed in the sensor body coordinate system in rad/s, returned as an *M*-by-3 array. The number of input samples, *N*, and the `DecimationFactor` property determine *M*.

Data Types: `single` | `double`

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

Estimate Orientation Using `ahrsfilter`

Load the `rpy_9axis` file, which contains recorded accelerometer, gyroscope, and magnetometer sensor data from a device oscillating in pitch (around *y*-axis), then yaw (around *z*-axis), and then roll (around *x*-axis). The file also contains the sample rate of the recording.

```
load 'rpy_9axis' sensorData Fs
accelerometerReadings = sensorData.Acceleration;
gyroscopeReadings = sensorData.AngularVelocity;
magnetometerReadings = sensorData.MagneticField;
```

Create an `ahrsfilter` System object™ with `SampleRate` set to the sample rate of the sensor data. Specify a decimation factor of two to reduce the computational cost of the algorithm.

```
decim = 2;
fuse = ahrsfilter('SampleRate',Fs,'DecimationFactor',decim);
```

Pass the accelerometer readings, gyroscope readings, and magnetometer readings to the `ahrsfilter` object, `fuse`, to output an estimate of the sensor body orientation over time. By default, the orientation is output as a vector of quaternions.

```
q = fuse(accelerometerReadings,gyroscopeReadings,magnetometerReadings);
```

Orientation is defined by angular displacement required to rotate a parent coordinate system to a child coordinate system. Plot the orientation in Euler angles in degrees over time.

`ahrsfilter` correctly estimates the change in orientation over time, including the south-facing initial orientation.

```
time = (0:decim:size(accelerometerReadings,1)-1)/Fs;

plot(time,eulerd(q,'ZYX','frame'))
title('Orientation Estimate')
legend('z-axis', 'y-axis', 'x-axis')
ylabel('Rotation (degrees)')
```
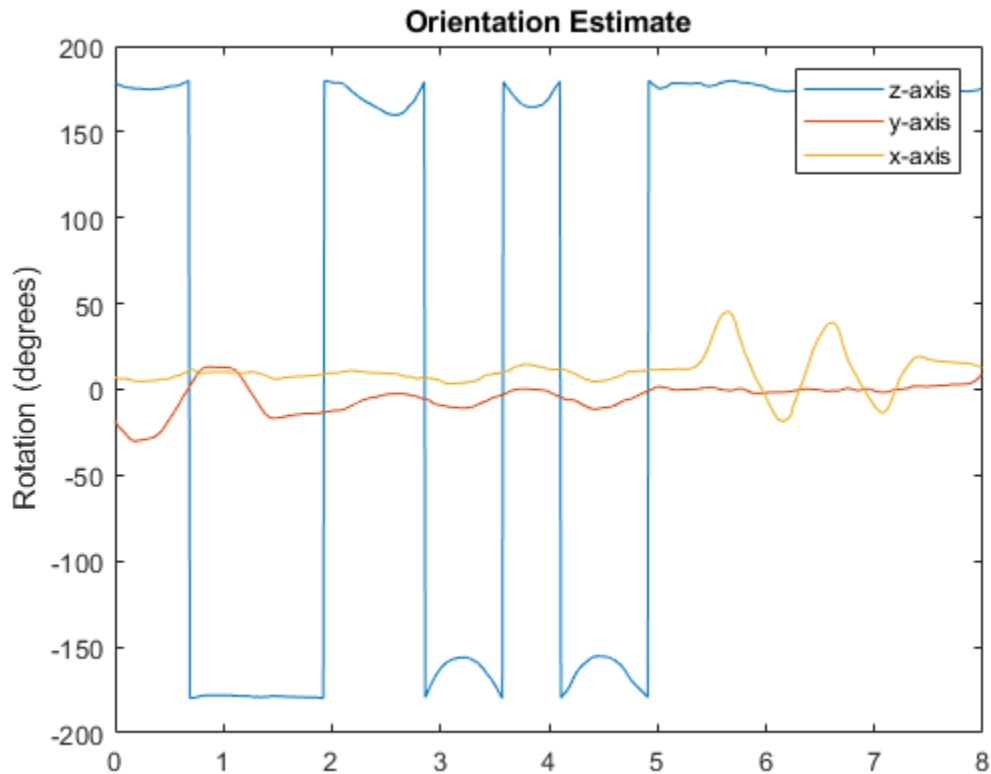
Simulate Magnetic Jamming on ahrsFilter

This example shows how performance of the ahrsfilter System object™ is affected by magnetic jamming.

Load StationaryIMUReadings, which contains accelerometer, magnetometer, and gyroscope readings from a stationary IMU.

```
load 'StationaryIMUReadings.mat' accelReadings magReadings gyroReadings SampleRate

numSamples = size(accelReadings,1);
```

The `ahrsfilter` uses magnetic field strength to stabilize its orientation against the assumed constant magnetic field of the Earth. However, there are many natural and man-made objects which output magnetic fields and can confuse the algorithm. To account for the presence of transient magnetic fields, you can set the `MagneticDisturbanceNoise` property on the `ahrsfilter` object.

Create an `ahrsfilter` object with the decimation factor set to 2 and note the default expected magnetic field strength.

```
decim = 2;
FUSE = ahrsfilter('SampleRate',SampleRate,'DecimationFactor',decim);
```

Fuse the IMU readings using the attitude and heading reference system (AHRS) filter, and then visualize the orientation of the sensor body over time. The orientation fluctuates at the beginning and stabilizes after approximately 60 seconds.

```
orientation = FUSE(accelReadings,gyroReadings,magReadings);

orientationEulerAngles = eulerd(orientation,'ZYX','frame');
time = (0:decim:(numSamples-1))'/SampleRate;

figure(1)
plot(time,orientationEulerAngles(:,1), ...
     time,orientationEulerAngles(:,2), ...
     time,orientationEulerAngles(:,3))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
legend('z-axis','y-axis','x-axis')
title('Filtered IMU Data')
```

Filtered IMU Data
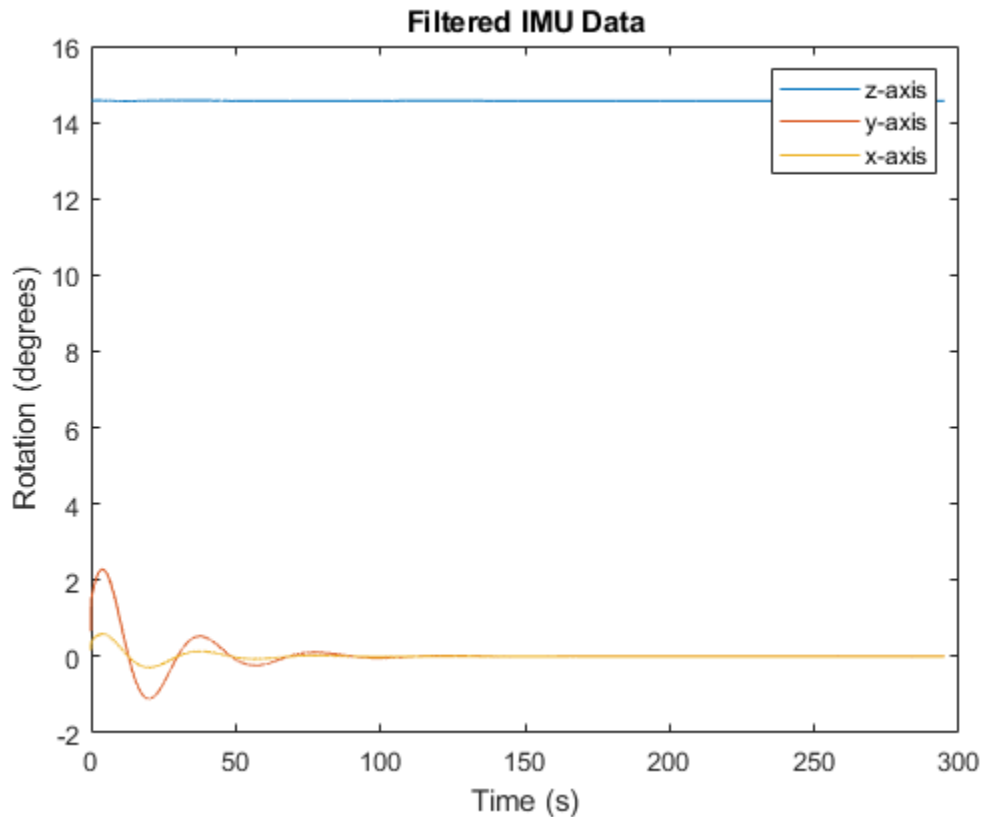
Mimic magnetic jamming by adding a transient, strong magnetic field to the magnetic field recorded in the `magReadings`. Visualize the magnetic field jamming.

```
jamStrength = [10,5,2];
startStop = (50*SampleRate):(150*SampleRate);
jam = zeros(size(magReadings));
jam(startStop,:) = jamStrength.*ones(numel(startStop),3);

magReadings = magReadings + jam;

figure(2)
plot(time,magReadings(1:decim:end,:))
xlabel('Time (s)')
ylabel('Magnetic Field Strength (\mu T)')
```

3-13

```
title('Simulated Magnetic Field with Jamming')
legend('z-axis','y-axis','x-axis')
```


Run the simulation again using the `magReadings` with magnetic jamming. Plot the results and note the decreased performance in orientation estimation.

```
reset(FUSE)
orientation = FUSE(accelReadings,gyroReadings,magReadings);

orientationEulerAngles = eulerd(orientation,'ZYX','frame');

figure(3)
plot(time,orientationEulerAngles(:,1), ...
    time,orientationEulerAngles(:,2), ...
```

```
    time,orientationEulerAngles(:,3))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
legend('z-axis','y-axis','x-axis')
title('Filtered IMU Data with Magnetic Disturbance and Default Properties')
```
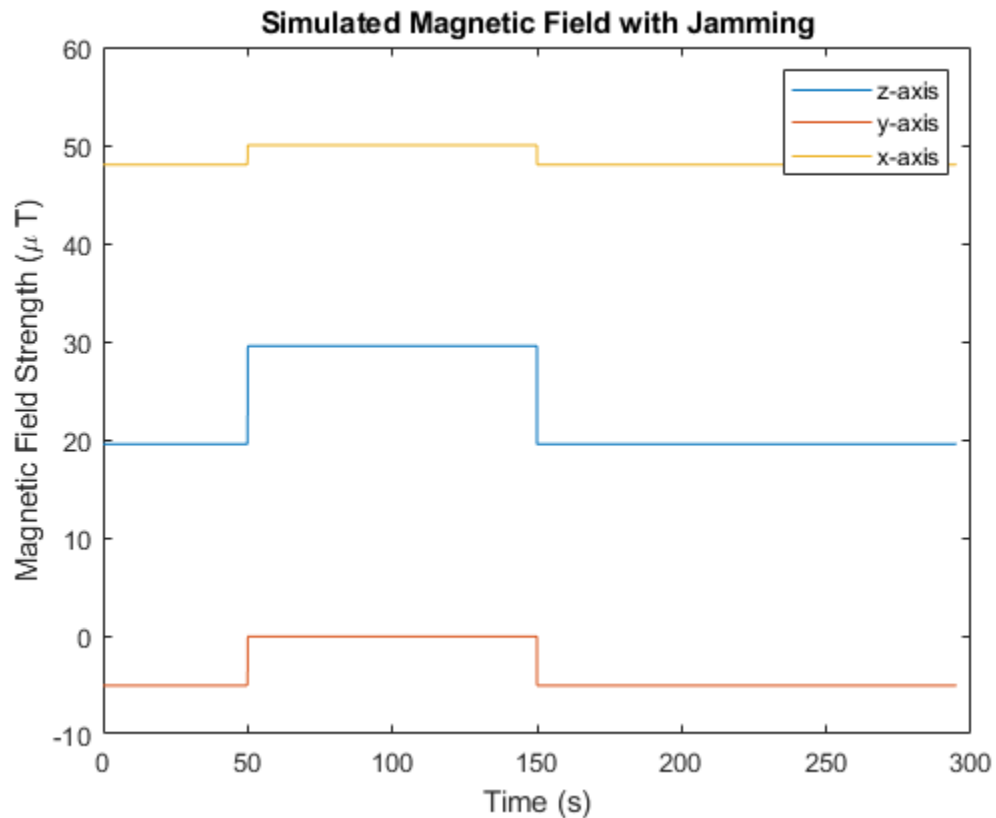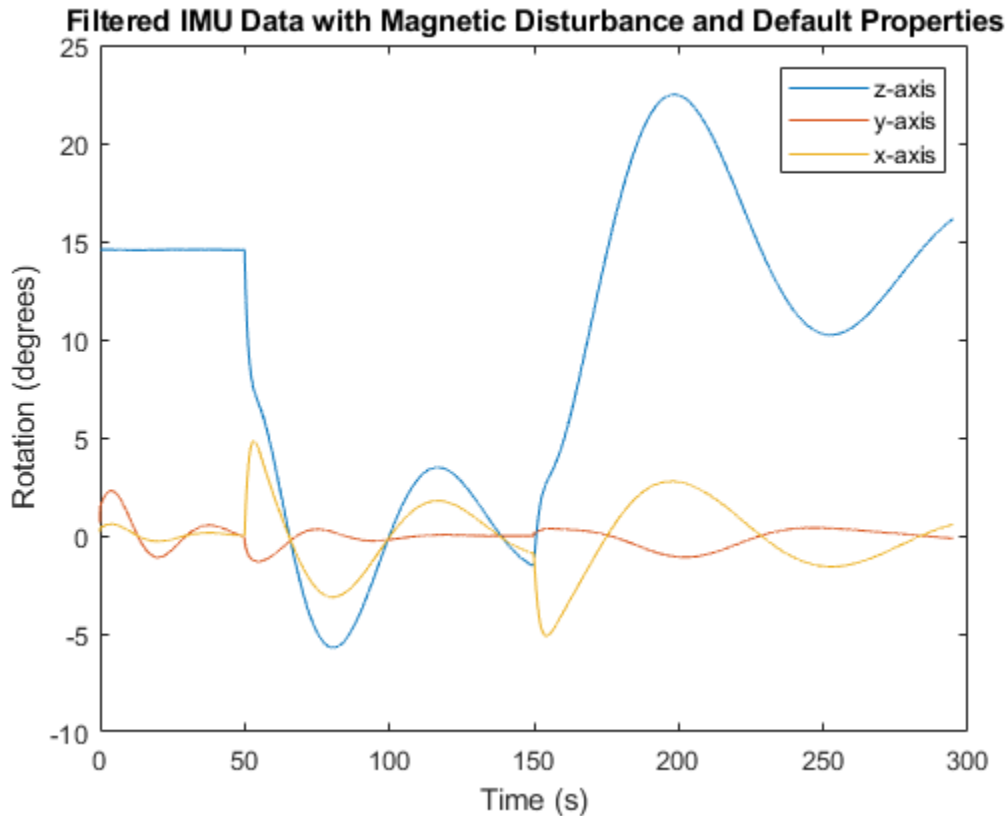

Filtered IMU Data with Magnetic Disturbance and Default Properties

The magnetic jamming was misinterpreted by the AHRS filter, and the sensor body orientation was incorrectly estimated. You can compensate for jamming by increasing the `MagneticDisturbanceNoise` property. Increasing the `MagneticDisturbanceNoise` property increases the assumed noise range for magnetic disturbance, and the entire magnetometer signal is weighted less in the underlying fusion algorithm of `ahrsfilter`.

Set the `MagneticDisturbanceNoise` to `200` and run the simulation again.

The orientation estimation output from `ahrsfilter` is more accurate and less affected by the magnetic transient. However, because the magnetometer signal is weighted less in the underlying fusion algorithm, the algorithm may take more time to restabilize.

```
reset(FUSE)
FUSE.MagneticDisturbanceNoise = 20;

orientation = FUSE(accelReadings,gyroReadings,magReadings);

orientationEulerAngles = eulerd(orientation,'ZYX','frame');

figure(4)
plot(time,orientationEulerAngles(:,1), ...
     time,orientationEulerAngles(:,2), ...
     time,orientationEulerAngles(:,3))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
legend('z-axis','y-axis','x-axis')
title('Filtered IMU Data with Magnetic Disturbance and Modified Properties')
```
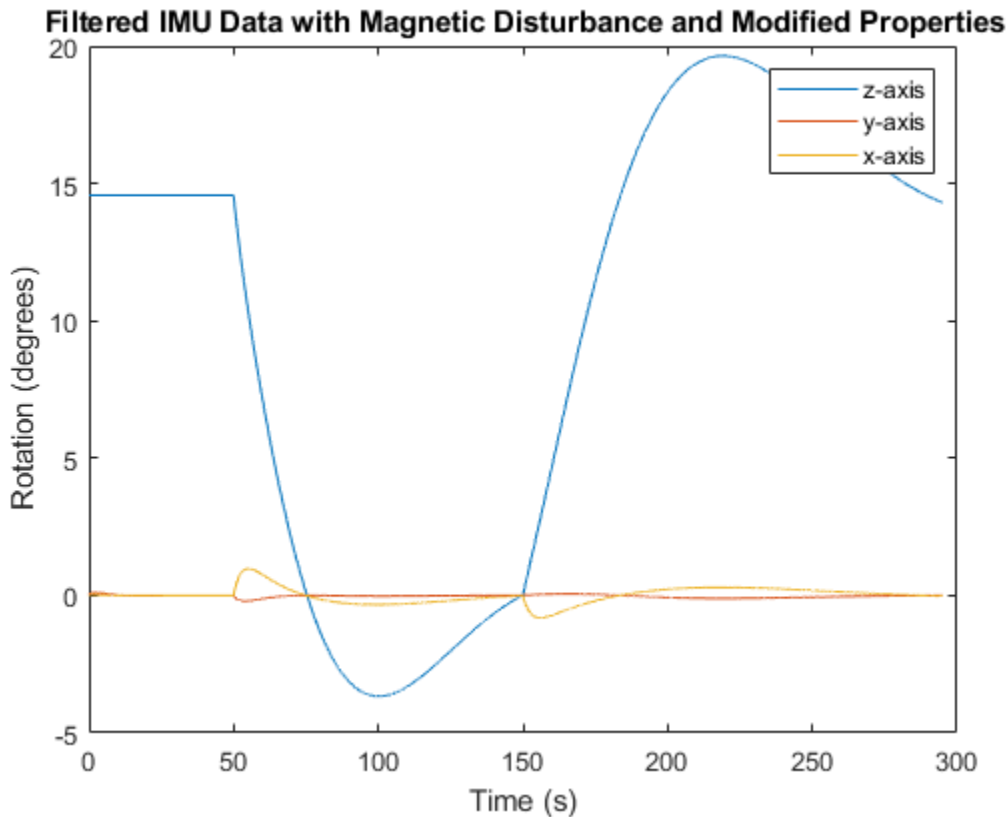
Track Shaking 9-Axis IMU

This example uses the `ahrsfilter` System object™ to fuse 9-axis IMU data from a sensor body that is shaken. Plot the quaternion distance between the object and its final resting position to visualize performance and how quickly the filter converges to the correct resting position. Then tune parameters of the `ahrsfilter` so that the filter converges more quickly to the ground-truth resting position.

Load `IMUReadingsShaken` into your current workspace. This data was recorded from an IMU that was shaken then laid in a resting position. Visualize the acceleration, magnetic field, and angular velocity as recorded by the sensors.

```
load 'IMUReadingsShaken' accelReadings gyroReadings magReadings SampleRate
numSamples = size(accelReadings,1);
time = (0:(numSamples-1))'/SampleRate;

figure(1)
subplot(3,1,1)
plot(time,accelReadings)
title('Accelerometer Reading')
ylabel('Acceleration (m/s^2)')

subplot(3,1,2)
plot(time,magReadings)
title('Magnetometer Reading')
ylabel('Magnetic Field (\muT)')

subplot(3,1,3)
plot(time,gyroReadings)
title('Gyroscope Reading')
ylabel('Angular Velocity (rad/s)')
xlabel('Time (s)')
```
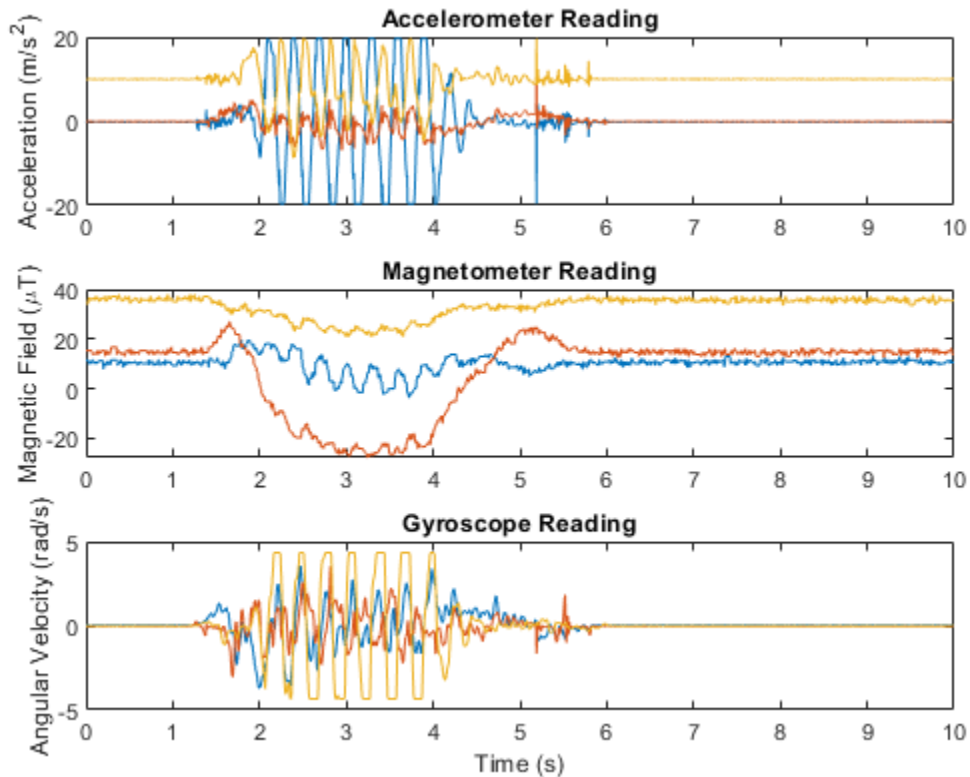
Create an `ahrsfilter` and then fuse the IMU data to determine orientation. The orientation is returned as a vector of quaternions; convert the quaternions to Euler angles in degrees. Visualize the orientation of the sensor body over time by plotting the Euler angles required, at each time step, to rotate the global coordinate system to the sensor body coordinate system.

```
fuse = ahrsfilter('SampleRate',SampleRate);
orientation = fuse(accelReadings,gyroReadings,magReadings);

orientationEulerAngles = eulerd(orientation,'ZYX','frame');

figure(2)
plot(time,orientationEulerAngles(:,1), ...
     time,orientationEulerAngles(:,2), ...
```

```
        time,orientationEulerAngles(:,3))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation over Time')
legend('Rotation around z-axis', ...
       'Rotation around y-axis', ...
       'Rotation around x-axis')
```
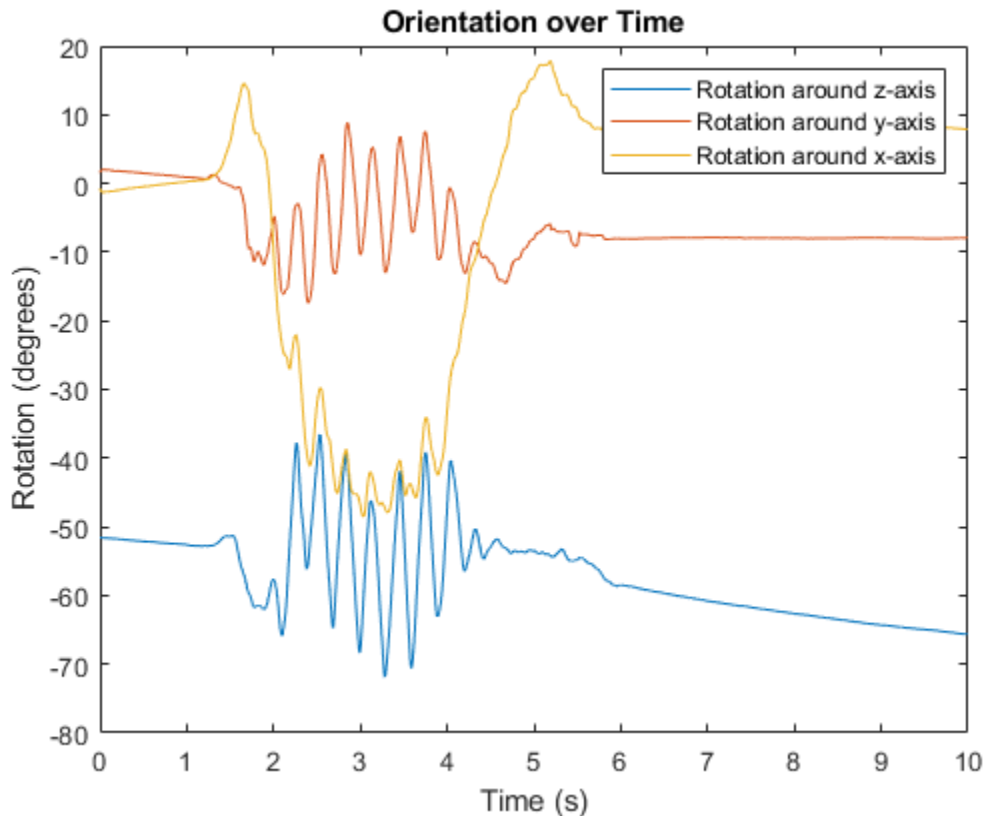

In the IMU recording, the shaking stops after approximately six seconds. Determine the resting orientation so that you can characterize how fast the `ahrsfilter` converges.

To determine the resting orientation, calculate the averages of the magnetic field and acceleration for the final four seconds and then use the `ecompass` function to fuse the data.

Visualize the quaternion distance from the resting position over time.

```
restingOrientation = ecompass(mean(accelReadings(6*SampleRate:end,:)), ...
                              mean(magReadings(6*SampleRate:end,:)));
```

```
figure(3)
plot(time,rad2deg(dist(restingOrientation,orientation)))
hold on
xlabel('Time (s)')
ylabel('Quaternion Distance (degrees)')
```
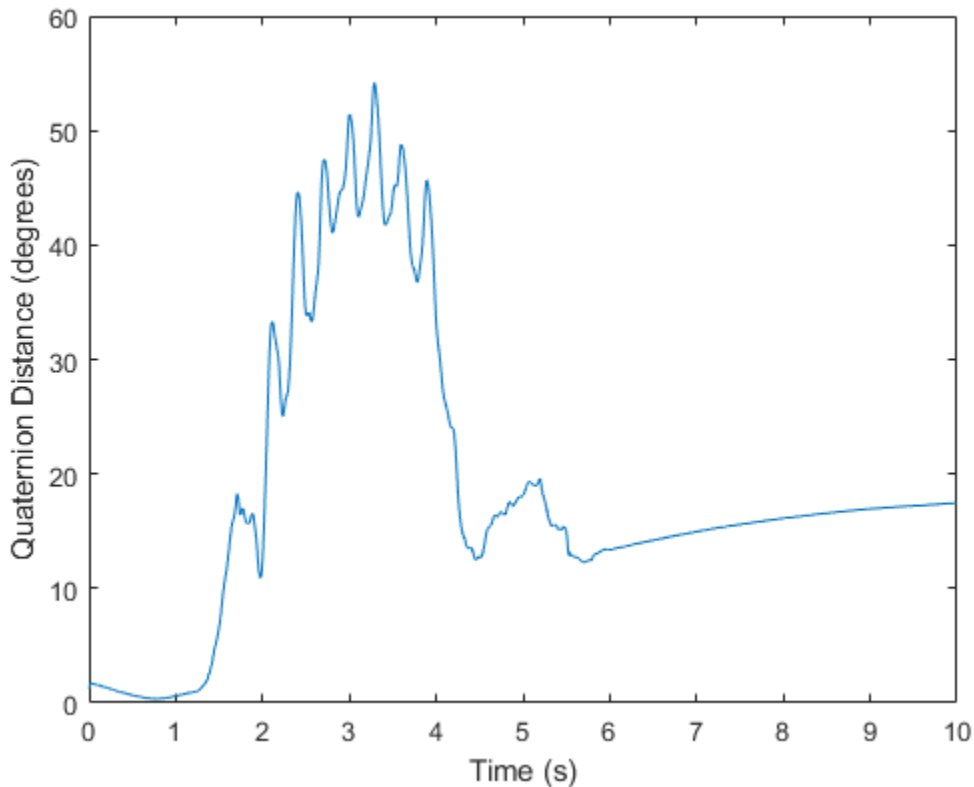

Modify the default `ahrsfilter` properties so that the filter converges to gravity more quickly. Increase the `GyroscopeDriftNoise` to `1e-2` and decrease the `LinearAccelerationNoise` to `1e-4`. This instructs the `ahrsfilter` algorithm to

weigh gyroscope data less and accelerometer data more. Because the `accelerometer` data provides the stabilizing and consistent gravity vector, the resulting orientation converges more quickly.

Reset the filter, fuse the data, and plot the results.

```
fuse.LinearAccelerationNoise = 1e-4;
fuse.GyroscopeDriftNoise     = 1e-2;
reset(fuse)

orientation = fuse(accelReadings,gyroReadings,magReadings);

figure(3)
plot(time,rad2deg(dist(restingOrientation,orientation)))
legend('Default AHRS Filter','Tuned AHRS Filter')
```
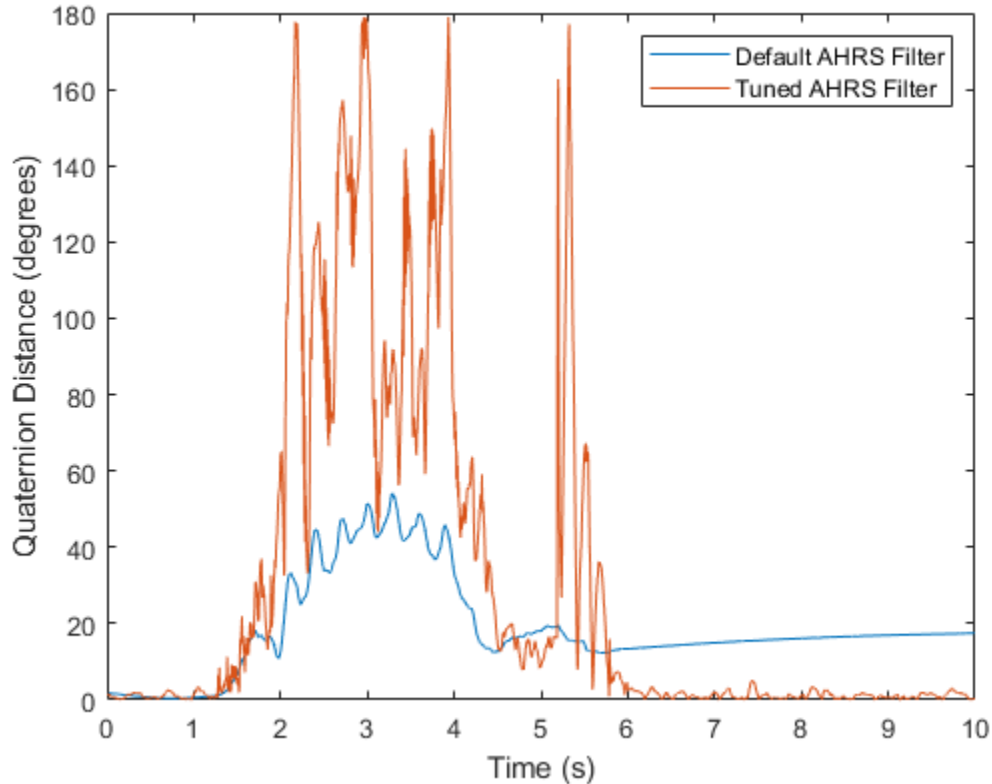
Algorithms

The `ahrsfilter` uses the nine-axis Kalman filter structure described in [1]. The algorithm attempts to track the errors in orientation, gyroscope offset, linear acceleration, and magnetic disturbance to output the final orientation and angular velocity. Instead of tracking the orientation directly, the indirect Kalman filter models the error process, x, with a recursive update:

$$
x_k = \begin{bmatrix} \theta_k \\ b_k \\ a_k \\ d_k \end{bmatrix} = F_k \begin{bmatrix} \theta_{k-1} \\ b_{k-1} \\ a_{k-1} \\ d_{k-1} \end{bmatrix} + w_k
$$

where x_k is a 12-by-1 vector consisting of:

- θ_k -- 3-by-1 orientation error vector, in degrees, at time k
- b_k -- 3-by-1 gyroscope zero rate offset vector, in deg/s, at time k
- a_k -- 3-by-1 acceleration error vector measured in the sensor frame, in g, at time k
- d_k -- 3-by-1 magnetic disturbance error vector measured in the sensor frame, in µT, at time k

and where w_k is a 12-by-1 additive noise vector, and F_k is the state transition model.

Because x_k is defined as the error process, the *a priori* estimate is always zero, and therefore the state transition model, F_k, is zero. This insight results in the following reduction of the standard Kalman equations:

Standard Kalman equations:

$$
\begin{aligned}
x_k^- &= F_k x_{k-1}^+ \\
P_k^- &= F_k P_{k-1}^+ F_k^T + Q_k
\end{aligned}
$$

$$
\begin{aligned}
Y_k &= z_k - H_k x_k^- \\
S_k &= R_k + H_k P_k^- H_k^T \\
K_k &= P_k^- H_k^T \left(S_k \right)^{-1} \\
x_k^+ &= x_k^- + K_k Y_k \\
P_k^+ &= P_k^- - K_k H_k P_k^-
\end{aligned}
$$

Kalman equations used in this algorithm:

$$x_k^- = 0$$

$$P_k^- = Q_k$$

$$Y_k = z_k$$

$$S_k = R_k + H_k P_k^- H_k^T$$

$$K_k = P_k^- H_k^T \left(S_k \right)^{-1}$$

$$x_k^+ = K_k Y_k$$

$$P_k^+ = P_k^- - K_k H_k P_k^-$$

where:

- x_k^- -- predicted (*a priori*) state estimate; the error process
- P_k^- -- predicted (*a priori*) estimate covariance
- y_k -- innovation
- S_k -- innovation covariance
- K_k -- Kalman gain
- x_k^+ -- updated (*a posteriori*) state estimate
- P_k^+ -- updated (*a posteriori*) estimate covariance

k represents the iteration, the superscript $^+$ represents an *a posteriori* estimate, and the superscript $^-$ represents an *a priori* estimate.

The graphic and following steps describe a single frame-based iteration through the algorithm.

Before the first iteration, the `accelReadings`, `gyroReadings`, and `magReadings` inputs are chunked into `DecimationFactor`-by-3 frames. For each chunk, the algorithm uses the most current accelerometer and magnetometer readings corresponding to the chunk of gyroscope readings.

Detailed Overview

Walk through the algorithm for an explanation of each stage of the detailed overview.

Model

The algorithm models acceleration and angular change as linear processes.

The orientation for the current frame is predicted by first estimating the angular change from the previous frame:

$$\Delta\varphi_{N\times 3} = \frac{\left(gyroReadings_{N\times 3} - gyroOffset_{1\times 3}\right)}{fs}$$

where *N* is the decimation factor specified by the DecimationFactor property and *fs* is the sample rate specified by the SampleRate property.

The angular change is converted into quaternions using the `rotvec quaternion` construction syntax:

$$\Delta Q_{N \times 1} = \mathtt{quaternion}(\Delta \varphi_{N \times 3}, \text{'rotvec'})$$

The previous orientation estimate is updated by rotating it by ΔQ:

$$q_{1 \times 1}^{-} = \left(q_{1 \times 1}^{+} \right) \left(\prod_{n=1}^{N} \Delta Q_n \right)$$

During the first iteration, the orientation estimate, q^{-}, is initialized by `ecompass`.

The gravity vector is interpreted as the third column of the quaternion, q^{-}, in rotation matrix form:

$$g_{1 \times 3} = \left(rPrior(:, 3) \right)^{T}$$

See [1] for an explanation of why the third column of *rPrior* can be interpreted as the gravity vector.

A second gravity vector estimation is made by subtracting the decayed linear acceleration estimate of the previous iteration from the accelerometer readings:

$$gAccel_{1 \times 3} = accelReadings_{1 \times 3} - linAccelprior_{1 \times 3}$$

Earth's magnetic vector is estimated by rotating the magnetic vector estimate from the previous iteration by the *a priori* orientation estimate, in rotation matrix form:

$$mGyro_{1 \times 3} = \left((rPrior) \left(m^{T} \right) \right)^{T}$$

Error Model
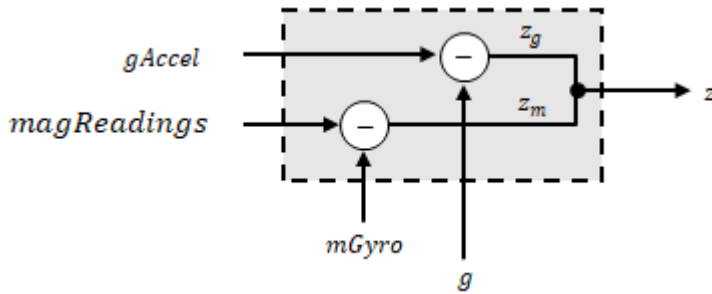
The error model combines two differences:

- The difference between the gravity estimate from the accelerometer readings and the gravity estimate from the gyroscope readings: $z_g\ =\ g\ -\ gAccel$

- The difference between the magnetic vector estimate from the gyroscope readings and the magnetic vector estimate from the magnetometer:

  $z_m\ =\ mGyro\ -\ magReadings$

Magnetometer Correct

The magnetometer correct estimates the error in the magnetic vector estimate and detects magnetic jamming.
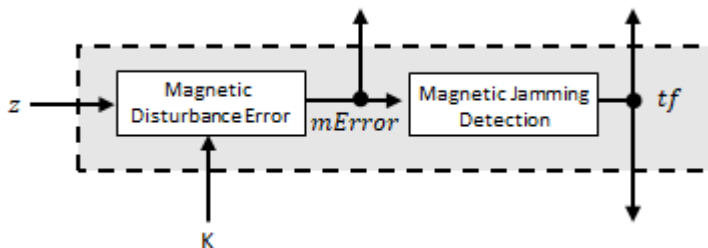
The magnetic disturbance error is calculated by matrix multiplication of the Kalman gain associated with the magnetic vector with the error signal:

$$mError_{3\times1} = \left(\left(K(10:12, :)_{3\times6}\right)\left(z_{1\times6}\right)^{\mathrm{T}}\right)^{\mathrm{T}}$$

The Kalman gain, *K*, is the Kalman gain calculated in the current iteration.

Magnetic jamming is determined by verifying that the power of the detected magnetic disturbance is less than or equal to four times the power of the expected magnetic field strength:

$$tf = \begin{cases} \texttt{true} & \texttt{if} \quad \sum |mError|^2 > (4)(\texttt{ExpectedMagneticFieldStre} \\ \texttt{false} & \texttt{else} \end{cases}$$

ExpectedMagneticFieldStrength is a property of `ahrsfilter`.

Kalman Equations

The Kalman equations use the gravity estimate derived from the gyroscope readings, *g*, the magnetic vector estimate derived from the gyroscope readings, *mGyro*, and the observation of the error process, *z*, to update the Kalman gain and intermediary covariance matrices. The Kalman gain is applied to the error signal, *z*, to output an *a posteriori* error estimate, x^+.
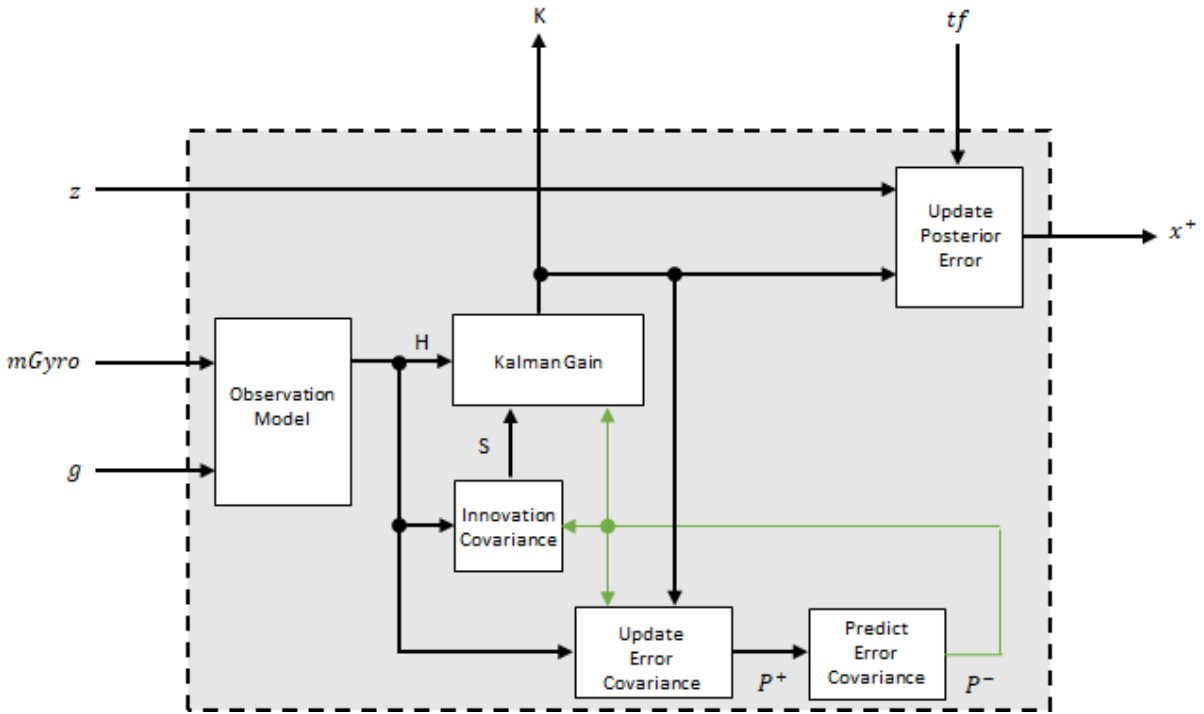
The observation model maps the 1-by-3 observed states, *g* and *mGyro*, into the 6-by-12 true state, *H*.

The observation model is constructed as:

$$
H_{3\times 9} =
\begin{bmatrix}
0 & g_z & -g_y & 0 & -\kappa g_z & \kappa g_y & 1 & 0 & 0 & 0 & 0 & 0 \\
-g_z & 0 & g_x & \kappa g_z & 0 & -\kappa g_x & 0 & 1 & 0 & 0 & 0 & 0 \\
g_y & -g_x & 0 & -\kappa g_y & \kappa g_x & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & m_z & -m_y & 0 & -\kappa m_z & -\kappa m_y & 0 & 0 & 0 & -1 & 0 & 0 \\
-m_z & 0 & m_x & \kappa m_z & 0 & -\kappa m_x & 0 & 0 & 0 & 0 & -1 & 0 \\
m_y & -m_x & 0 & -\kappa m_y & \kappa m_x & 0 & 0 & 0 & 0 & 0 & 0 & -1
\end{bmatrix}
$$

where g_x, g_y, and g_z are the x-, y-, and z-elements of the gravity vector estimated from the *a priori* orientation, respectively. m_x, m_y, and m_z are the x-, y-, and z-elements of the magnetic vector estimated from the *a priori* orientation, respectively. κ is a constant determined by the SampleRate and DecimationFactor properties: κ = `DecimationFactor/SampleRate`.

See sections 7.3 and 7.4 of [1] for a derivation of the observation model.

The innovation covariance is a 6-by-6 matrix used to track the variability in the measurements. The innovation covariance matrix is calculated as:

$$S_{6x6} = R_{6x6} + \left(H_{6x12} \right) \left(P^-_{12x12} \right) \left(H_{6x12} \right)^T$$

where

- H is the observation model matrix
- P^- is the predicted (*a priori*) estimate of the covariance of the observation model calculated in the previous iteration
- R is the covariance of the observation model noise, calculated as:

$$R_{6\times6} = \begin{bmatrix} accel_{noise} & 0 & 0 & 0 & 0 & 0 \\ 0 & accel_{noise} & 0 & 0 & 0 & 0 \\ 0 & 0 & accel_{noise} & 0 & 0 & 0 \\ 0 & 0 & 0 & mag_{noise} & 0 & 0 \\ 0 & 0 & 0 & 0 & mag_{noise} & 0 \\ 0 & 0 & 0 & 0 & 0 & mag_{noise} \end{bmatrix}$$

where

$$accel_{noise} = \texttt{AccelerometerNoise} + \texttt{LinearAccelerationNoise} + \kappa^2 \left(\texttt{Gyr}\right.$$

and

$$mag_{noise} = \texttt{MagnetometerNoise} + \texttt{MagneticDisturbanceNoise} + \kappa^2 \left(\texttt{Gyros}\right.$$

The following properties define the observation model noise variance:

- κ –– DecimationFactor/SampleRate
- AccelerometerNoise
- LinearAccelerationNoise
- GyroscopeDriftNoise
- GyroscopeNoise
- MagneticDisturbanceNoise
- MagnetometerNoise

The error estimate covariance is a 12-by-12 matrix used to track the variability in the state.

The error estimate covariance matrix is updated as:

$$P^+_{12 \times 12} = P^-_{12 \times 12} - \left(K_{12 \times 6} \right) \left(H_{6 \times 12} \right) \left(P^-_{12 \times 12} \right)$$

where K is the Kalman gain, H is the measurement matrix, and P^- is the error estimate covariance calculated during the previous iteration.

The error estimate covariance is a 12-by-12 matrix used to track the variability in the state. The *a priori* error estimate covariance, P^-, is set to the process noise covariance, Q, determined during the previous iteration. Q is calculated as a function of the *a posteriori* error estimate covariance, P^+. When calculating Q, it is assumed that the cross-correlation terms are negligible compared to the autocorrelation terms, and are set to zero:

$$
Q = \begin{bmatrix}
P^+(1) \ + \ \kappa^2 P^+(40) \ + \ \beta \ + \ \eta & 0 & 0 \\
0 & P^+(14) \ + \ \kappa^2 P^+(53) \ + \ \beta \ + \ \eta & 0 \\
0 & 0 & P^+(27) \ + \ \kappa^2 P^+(66 \\
-\kappa \left(P^+(40) \ + \ \beta \right) & 0 & 0 \\
0 & -\kappa \left(P^+(53) \ + \ \beta \right) & 0 \\
0 & 0 & -\kappa \left(P^+(66 \right. \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
$$

where

- P^+ –– is the updated (*a posteriori*) error estimate covariance
- κ –– DecimationFactor/SampleRate
- β –– GyroscopeDriftNoise
- η –– GyroscopeNoise
- ν –– LinearAcclerationDecayFactor
- ξ –– LinearAccelerationNoise
- σ –– MagneticDisturbanceDecayFactor
- γ –– MagneticDisturbanceNoise

See section 10.1 of [1] for a derivation of the terms of the process error matrix.

The Kalman gain matrix is a 12-by-6 matrix used to weight the innovation. In this algorithm, the innovation is interpreted as the error process, z.

The Kalman gain matrix is constructed as:

$$K_{12 \times 6} = \left(P^-_{12 \times 12} \right) \left(H_{6 \times 12} \right)^T \left(\left(S_{6 \times 6} \right)^T \right)^{-1}$$

where

- P^- –– predicted error covariance
- H –– observation model
- S –– innovation covariance

The *a posterior* error estimate is determined by combining the Kalman gain matrix with the error in the gravity vector and magnetic vector estimations:

$$x_{12 \times 1} = \left(K_{12 \times 6} \right) \left(z_{1 \times 6} \right)^T$$

If magnetic jamming is detected in the current iteration, the magnetic vector error signal is ignored, and the *a posterior* error estimate is calculated as:

$$x_{9 \times 1} = \left(K(1:9,\ 1:3) \right) \left(z_g \right)^T$$

Correct

The orientation estimate is updated by multiplying the previous estimation by the error:

$$q^+ = \left(q^-\right)\left(\theta^+\right)$$

The linear acceleration estimation is updated by decaying the linear acceleration estimation from the previous iteration and subtracting the error:

$$linAccelPrior = (linAccelPrior_{k-1})v - b^+$$

where

- ν -- LinearAcclerationDecayFactor

The gyroscope offset estimation is updated by subtracting the gyroscope offset error from the gyroscope offset from the previous iteration:

$$gyroOffset = gyroOffset_{k-1} - a^+$$

Compute Angular Velocity

To estimate angular velocity, the frame of `gyroReadings` are averaged and the gyroscope offset computed in the previous iteration is subtracted:

$$angularVelocity_{1\times3} = \frac{\sum gyroReadings_{N\times3}}{N} - gyroOffset_{1\times3}$$

where *N* is the decimation factor specified by the `DecimationFactor` property.

The gyroscope offset estimation is initialized to zeros for the first iteration.

Update Magnetic Vector

If magnetic jamming was not detected in the current iteration, the magnetic vector estimate, *m*, is updated using the *a posteriori* magnetic disturbance error and the *a posteriori* orientation.

The magnetic disturbance error is converted to the NED frame:

$$mErrorNED_{1\times3} = \left(\left(rPost_{3\times3}\right)^T (mError_{1\times3})^T \right)^T$$

The magnetic disturbance error in the NED frame is subtracted from the previous magnetic vector estimate and then interpreted as inclination:

$$\mathbf{M} = m - mErrorNED$$

3-37

$$inclination = \text{atan2}(\mathbf{M}(3), \mathbf{M}(1))$$

The inclination is converted to a constrained magnetic vector estimate for the next iteration:

$$m(1) = \left(\texttt{ExpectedMagneticFieldStrength}\right)\left(\cos(inclination)\right)$$

$$m(2) = 0$$

$$m(3) = \left(\texttt{ExpectedMagneticFieldStrength}\right)\left(\sin(inclination)\right)$$

ExpectedMagneticFieldStrength is a property of `ahrsfilter`.

References

[1] Open Source Sensor Fusion. https://github.com/memsindustrygroup/Open-Source-Sensor-Fusion/tree/master/docs

[2] Roetenberg, D., H.J. Luinge, C.T.M. Baten, and P.H. Veltink. "Compensation of Magnetic Disturbances Improves Inertial and Magnetic Sensing of Human Body Segment Orientation." *IEEE Transactions on Neural Systems and Rehabilitation Engineering.* Vol. 13. Issue 3, 2005, pp. 395-405.

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
ecompass | gpsSensor | imuSensor | imufilter | quaternion

Topics
"Determine Orientation Using Inertial Sensors"

Introduced in R2018b

imufilter System object

Orientation from accelerometer and gyroscope readings

Description

The `imufilter` System object fuses accelerometer and gyroscope sensor data to estimate device orientation.

To estimate device orientation:

1 Create the `imufilter` 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

```
FUSE = imufilter
FUSE = imufilter(Name,Value)
```

Description

`FUSE = imufilter` returns an indirect Kalman filter System object, `FUSE`, for fusion of accelerometer and gyroscope data to estimate device orientation. The filter uses a nine-element state vector to track error in the orientation estimate, the gyroscope bias estimate, and the linear acceleration estimate.

`FUSE = imufilter(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: FUSE = imufilter('SampleRate',200,'GyroscopeNoise',1e-6) creates a System object, FUSE, with a 200 Hz sample rate and gyroscope noise set to 1e-6 radians per second squared.

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).

SampleRate — Sample rate of input sensor data (Hz)
100 (default) | positive finite scalar

Sample rate of the input sensor data in Hz, specified as a positive finite scalar.

Tunable: No

Data Types: single | double | uint8 | uint16 | uint32 | uint64 | int8 | int16 | int32 | int64

DecimationFactor — Decimation factor
1 (default) | positive integer scalar

Decimation factor by which to reduce the sample rate of the input sensor data, specified as a positive integer scalar.

The number of rows of the inputs, `accelReadings` and `gyroReadings`, must be a multiple of the decimation factor.

Tunable: No

Data Types: single | double | uint8 | uint16 | uint32 | uint64 | int8 | int16 | int32 | int64

AccelerometerNoise — Variance of accelerometer signal noise ($(m/s^2)^2$)
0.00019247 (default) | positive real scalar

Variance of accelerometer signal noise in $(m/s^2)^2$, specified as a positive real scalar.

Tunable: Yes

Data Types: `single` | `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

`GyroscopeNoise` — Variance of gyroscope signal noise ($(rad/s)^2$)
`9.1385e-5` (default) | positive real scalar

Variance of gyroscope signal noise in $(rad/s)^2$, specified as a positive real scalar.

Tunable: Yes

Data Types: `single` | `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

`GyroscopeDriftNoise` — Variance of gyroscope offset drift ($(rad/s)^2$)
`3.0462e-13` (default) | positive real scalar

Variance of gyroscope offset drift in $(rad/s)^2$, specified as a positive real scalar.

Tunable: Yes

Data Types: `single` | `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

`LinearAccelerationNoise` — Variance of linear acceleration noise ($((m/s^2)^2)$)
`0.0096236` (default) | positive real scalar

Variance of linear acceleration noise in $(m/s^2)^2$, specified as a positive real scalar. Linear acceleration is modeled as a lowpass filtered white noise process.

Tunable: Yes

Data Types: `single` | `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

`LinearAcclerationDecayFactor` — Decay factor for linear acceleration drift
`0.5` (default) | scalar in the range [0,1]

Decay factor for linear acceleration drift, specified as a scalar in the range [0,1]. If linear acceleration is changing quickly, set `LinearAccelerationDecayFactor` to a lower value. If linear acceleration changes slowly, set `LinearAccelerationDecayFactor` to a

higher value. Linear acceleration drift is modeled as a lowpass-filtered white noise process.

Tunable: Yes

Data Types: `single` | `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

InitialProcessNoise — Covariance matrix for process noise
9-by-9 matrix

Covariance matrix for process noise, specified as a 9-by-9 matrix. The default is:

```
Columns 1 through 6

   0.000006092348396                   0                   0                   0                   0                   0
                   0   0.000006092348396                   0                   0                   0                   0
                   0                   0   0.000006092348396                   0                   0                   0
                   0                   0                   0   0.000076154354947                   0                   0
                   0                   0                   0                   0   0.000076154354947                   0
                   0                   0                   0                   0                   0   0.000076154354947
                   0                   0                   0                   0                   0                   0
                   0                   0                   0                   0                   0                   0
                   0                   0                   0                   0                   0                   0

Columns 7 through 9

                   0                   0                   0
                   0                   0                   0
                   0                   0                   0
                   0                   0                   0
                   0                   0                   0
                   0                   0                   0
   0.009623610000000                   0                   0
                   0   0.009623610000000                   0
                   0                   0   0.009623610000000
```

The initial process covariance matrix accounts for the error in the process model.

Data Types: `single` | `double` | `uint8` | `uint16` | `uint32` | `uint64` | `int8` | `int16` | `int32` | `int64`

OrientationFormat — Output orientation format
`'quaternion'` (default) | `'Rotation matrix'`

Output orientation format, specified as `'quaternion'` or `'Rotation matrix'`. The size of the output depends on the input size, N, and the output orientation format:

- `'quaternion'` –– Output is an N-by-1 `quaternion`.
- `'Rotation matrix'` –– Output is a 3-by-3-by-N rotation matrix.

Data Types: `char` | `string`

Usage

Syntax

```
[orientation,angularVelocity] = FUSE(accelReadings,gyroReadings)
```

Description

`[orientation,angularVelocity] = FUSE(accelReadings,gyroReadings)` fuses accelerometer and gyroscope readings to compute orientation and angular velocity measurements. The algorithm assumes that the device is stationary before the first call.

Input Arguments

`accelReadings` — Accelerometer readings in sensor body coordinate system (m/s^2)
N-by-3 matrix

Accelerometer readings in the sensor body coordinate system in m/s^2, specified as an *N*-by-3 matrix. *N* is the number of samples, and the three columns of `accelReadings` represent the [*x y z*] measurements. Accelerometer readings are assumed to correspond to the sample rate specified by the SampleRate property.

Data Types: `single` | `double`

`gyroReadings` — Gyroscope readings in sensor body coordinate system (rad/s)
N-by-3 matrix

Gyroscope readings in the sensor body coordinate system in rad/s, specified as an *N*-by-3 matrix. *N* is the number of samples, and the three columns of `gyroReadings` represent the [*x y z*] measurements. Gyroscope readings are assumed to correspond to the sample rate specified by the SampleRate property.

Data Types: `single` | `double`

Output Arguments

`orientation` — Orientation that rotates quantities from global coordinate system to sensor body coordinate system
M-by-1 vector of quaternions (default) | 3-by-3-by-*M* array

Orientation that can rotate quantities from a global coordinate system to a body coordinate system, returned as quaternions or an array. The size and type of `orientation` depends on whether the OrienationFormat property is set to `'quaternion'` or `'Rotation matrix'`:

- `'quaternion'` –– The output is an *M*-by-1 vector of quaternions, with the same underlying data type as the inputs.
- `'Rotation matrix'` –– The output is a 3-by-3-by-*M* array of rotation matrices the same data type as the inputs.

The number of input samples, *N*, and the DecimationFactor property determine *M*.

You can use `orientation` in a `rotateframe` function to rotate quantities from a global coordinate system to a sensor body coordinate system.

Data Types: `quaternion` | `single` | `double`

`angularVelocity` — Angular velocity in sensor body coordinate system (rad/s)
M-by-3 array (default)

Angular velocity with gyroscope bias removed in the sensor body coordinate system in rad/s, returned as an *M*-by-3 array. The number of input samples, *N*, and the DecimationFactor property determine *M*.

Data Types: `single` | `double`

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

Estimate Orientation from IMU data

Load the `rpy_9axis` file, which contains recorded accelerometer, gyroscope, and magnetometer sensor data from a device oscillating in pitch (around *y*-axis), then yaw (around *z*-axis), and then roll (around *x*-axis). The file also contains the sample rate of the recording.

```
load 'rpy_9axis.mat' sensorData Fs

accelerometerReadings = sensorData.Acceleration;
gyroscopeReadings = sensorData.AngularVelocity;
```

Create an `imufilter` System object™ with sample rate set to the sample rate of the sensor data. Specify a decimation factor of two to reduce the computational cost of the algorithm.

```
decim = 2;
fuse = imufilter('SampleRate',Fs,'DecimationFactor',decim);
```

Pass the accelerometer readings and gyroscope readings to the `imufilter` object, `fuse`, to output an estimate of the sensor body orientation over time. By default, the orientation is output as a vector of quaternions.

```
q = fuse(accelerometerReadings,gyroscopeReadings);
```

Orientation is defined by the angular displacement required to rotate a parent coordinate system to a child coordinate system. Plot the orientation in Euler angles in degrees over time.

`imufilter` fusion correctly estimates the change in orientation from an assumed north-facing initial orientation. However, the device's *x*-axis was pointing southward when

recorded. To correctly estimate the orientation relative to the true initial orientation or relative to NED, use `ahrsfilter`.

```
time = (0:decim:size(accelerometerReadings,1)-1)/Fs;
```

```
plot(time,eulerd(q,'ZYX','frame'))
title('Orientation Estimate')
legend('Z-axis', 'Y-axis', 'X-axis')
xlabel('Time (s)')
ylabel('Rotation (degrees)')
```

Model Tilt Using Gyroscope and Accelerometer Readings

Model a tilting IMU that contains an accelerometer and gyroscope using the `imuSensor` System object™. Use ideal and realistic models to compare the results of orientation tracking using the `imufilter` System object.

Load a struct describing ground-truth motion and a sample rate. The motion struct describes sequential rotations:

1 yaw: 120 degrees over two seconds

2 pitch: 60 degrees over one second

3 roll: 30 degrees over one-half second

4 roll: -30 degrees over one-half second

5 pitch: -60 degrees over one second

6 yaw: -120 degrees over two seconds

In the last stage, the motion struct combines the 1st, 2nd, and 3rd rotations into a single-axis rotation. The acceleration, angular velocity, and orientation are defined in the local NED coordinate system.

```
load y120p60r30.mat motion fs
accNED = motion.Acceleration;
angVelNED = motion.AngularVelocity;
orientationNED = motion.Orientation;

numSamples = size(motion.Orientation,1);
t = (0:(numSamples-1)).'/fs;
```

Create an ideal IMU sensor object and a default IMU filter object.

```
IMU = imuSensor('accel-gyro','SampleRate',fs);

aFilter = imufilter('SampleRate',fs);
```

In a loop:

1 Simulate IMU output by feeding the ground-truth motion to the IMU sensor object.

2 Filter the IMU output using the default IMU filter object.

```
orientation = zeros(numSamples,1,'quaternion');
for i = 1:numSamples
```

```
    [accelBody,gyroBody] = IMU(accNED(i,:),angVelNED(i,:),orientationNED(i,:));

    orientation(i) = aFilter(accelBody,gyroBody);

end
release(aFilter)
```

Plot the orientation over time.

```
figure(1)
plot(t,eulerd(orientation,'ZYX','frame'))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation Estimation -- Ideal IMU Data, Default IMU Filter')
legend('Z-axis','Y-axis','X-axis')
```

Modify properties of your `imuSensor` to model real-world sensors. Run the loop again and plot the orientation estimate over time.

```
IMU.Accelerometer = accelparams( ...
    'MeasurementRange',19.62, ...
    'Resolution',0.00059875, ...
    'ConstantBias',0.4905, ...
    'AxesMisalignment',2, ...
    'NoiseDensity',0.003924, ...
    'BiasInstability',0, ...
    'TemperatureBias', [0.34335 0.34335 0.5886], ...
    'TemperatureScaleFactor',0.02);
IMU.Gyroscope = gyroparams( ...
    'MeasurementRange',4.3633, ...
```

```
        'Resolution',0.00013323, ...
        'AxesMisalignment',2, ...
        'NoiseDensity',8.7266e-05, ...
        'TemperatureBias',0.34907, ...
        'TemperatureScaleFactor',0.02, ...
        'AccelerationBias',0.00017809, ...
        'ConstantBias',[0.3491,0.5,0]);

orientationDefault = zeros(numSamples,1,'quaternion');
for i = 1:numSamples

    [accelBody,gyroBody] = IMU(accNED(i,:),angVelNED(i,:),orientationNED(i,:));

    orientationDefault(i) = aFilter(accelBody,gyroBody);

end
release(aFilter)

figure(2)
plot(t,eulerd(orientationDefault,'ZYX','frame'))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation Estimation -- Realistic IMU Data, Default IMU Filter')
legend('Z-axis','Y-axis','X-axis')
```

The ability of the `imufilter` to track the ground-truth data is significantly reduced when modeling a realistic IMU. To improve performance, modify properties of your `imufilter` object. These values were determined empirically. Run the loop again and plot the orientation estimate over time.

```
aFilter.GyroscopeNoise          = 7.6154e-7;
aFilter.AccelerometerNoise       = 0.0015398;
aFilter.GyroscopeDriftNoise       = 3.0462e-12;
aFilter.LinearAccelerationNoise = 0.00096236;
aFilter.InitialProcessNoise      = aFilter.InitialProcessNoise*10;

orientationNondefault = zeros(numSamples,1,'quaternion');
for i = 1:numSamples
    [accelBody,gyroBody] = IMU(accNED(i,:),angVelNED(i,:),orientationNED(i,:));
```

```
    orientationNondefault(i) = aFilter(accelBody,gyroBody);
end
release(aFilter)

figure(3)
plot(t,eulerd(orientationNondefault,'ZYX','frame'))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation Estimation -- Realistic IMU Data, Nondefault IMU Filter')
legend('Z-axis','Y-axis','X-axis')
```

To quantify the improved performance of the modified `imufilter`, plot the quaternion distance between the ground-truth motion and the orientation as returned by the `imufilter` with default and nondefault properties.

```
qDistDefault = rad2deg(dist(orientationNED,orientationDefault));
qDistNondefault = rad2deg(dist(orientationNED,orientationNondefault));

figure(4)
plot(t,[qDistDefault,qDistNondefault])
title('Quaternion Distance from True Orientation')
legend('Realistic IMU Data, Default IMU Filter', ...
       'Realistic IMU Data, Nondefault IMU Filter')
xlabel('Time (s)')
ylabel('Quaternion Distance (degrees)')
```

Remove Bias from Angular Velocity Measurement

This example shows how to remove gyroscope bias from an IMU using `imufilter`.

Use `kinematicTrajectory` to create a trajectory with a constant angular velocity about the *y*- and *z*-axes.

```
duration = 60*5;
fs = 20;
numSamples = duration * fs;

angVelBody = repmat([0,0.5,0.25],numSamples,1);
```

```
accBody = zeros(numSamples,3);

traj = kinematicTrajectory('SampleRate',fs);

[~,qNED,~,accNED,angVelNED] = traj(accBody,angVelBody);
```

Create an `imuSensor` System object™, IMU, with a nonideal gyroscope. Call IMU with the ground-truth acceleration, angular velocity, and orientation.

```
IMU = imuSensor('accel-gyro', ...
    'Gyroscope',gyroparams('BiasInstability',0.003,'ConstantBias',0.3), ...
    'SampleRate',fs);

[accelReadings, gyroReadingsBody] = IMU(accNED,angVelNED,qNED);
```

Create an `imufilter` System object, `fuse`. Call `fuse` with the modeled accelerometer readings and gyroscope readings.

```
fuse = imufilter('SampleRate',fs);

[~,angVelBodyRecovered] = fuse(accelReadings,gyroReadingsBody);
```

Plot the ground-truth angular velocity, the gyroscope readings, and the recovered angular velocity for each axis.

The angular velocity returned from the `imufilter` compensates for the effect of the gyroscope bias over time and converges to the true angular velocity.

```
time = (0:numSamples-1)'/fs;

figure(1)
plot(time,angVelBody(:,3), ...
    time,gyroReadingsBody(:,3), ...
    time,angVelBodyRecovered(:,3))
title('X-axis')
legend('True Angular Velocity', ...
       'Gyroscope Readings', ...
       'Recovered Angular Velocity')
ylabel('Angular Velocity (rad/s)')

figure(2)
plot(time,angVelBody(:,2), ...
    time,gyroReadingsBody(:,2), ...
    time,angVelBodyRecovered(:,2))
title('Y-axis')
```

```
ylabel('Angular Velocity (rad/s)')

figure(3)
plot(time,angVelBody(:,1), ...
     time,gyroReadingsBody(:,1), ...
     time,angVelBodyRecovered(:,1))
title('Z-axis')
ylabel('Angular Velocity (rad/s)')
xlabel('Time (s)')
```
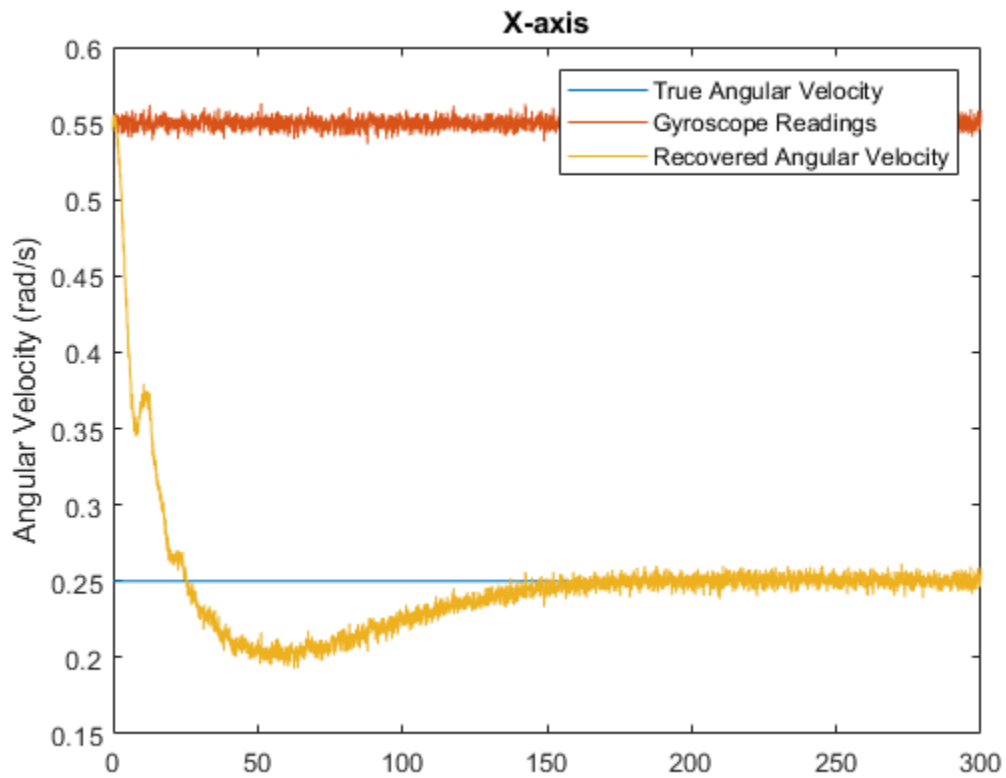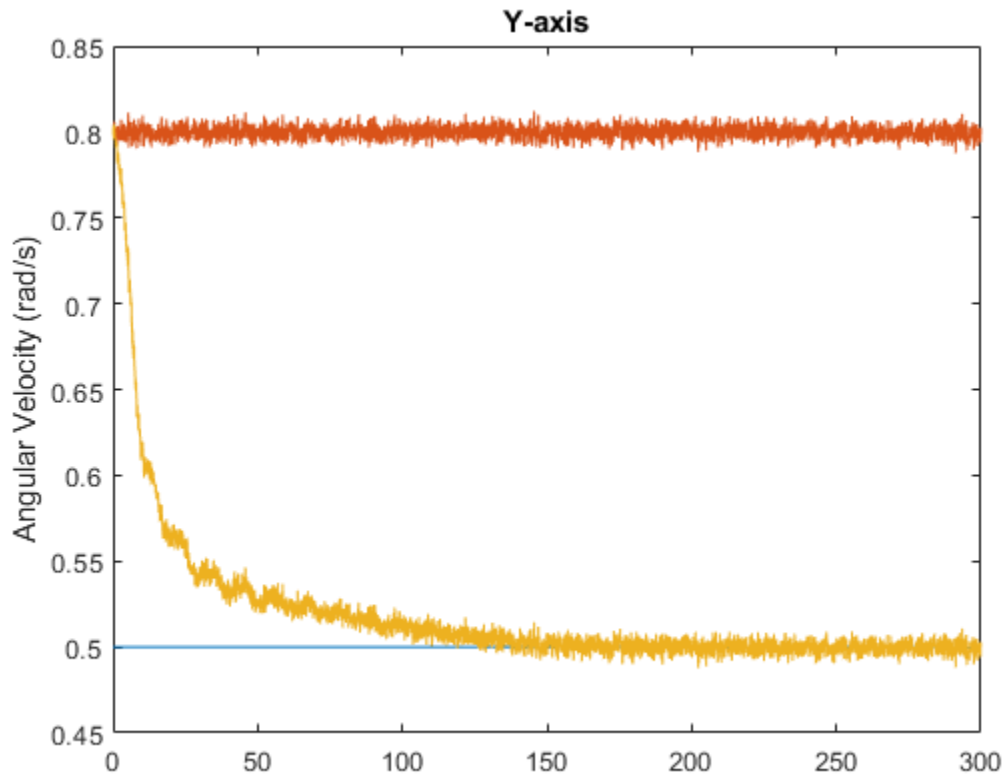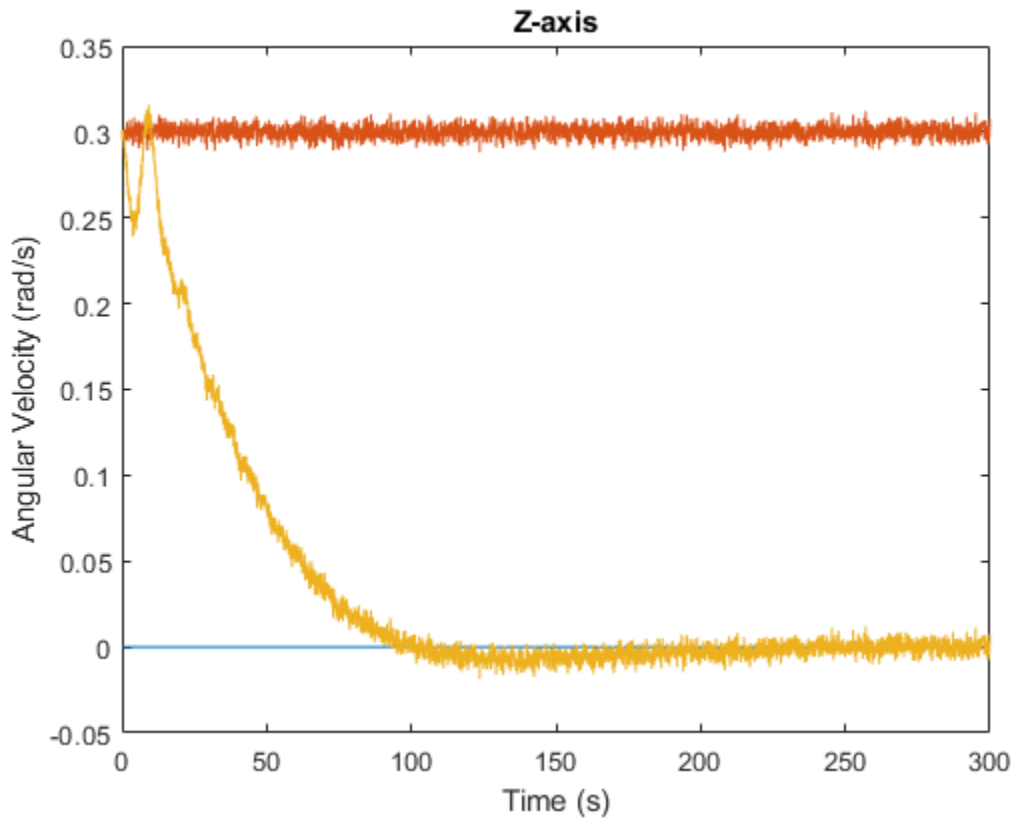
Algorithms

The `imufilter` uses the six-axis Kalman filter structure described in [1]. The algorithm attempts to track the errors in orientation, gyroscope offset, and linear acceleration to output the final orientation and angular velocity. Instead of tracking the orientation directly, the indirect Kalman filter models the error process, x, with a recursive update:

$$x_k = \begin{bmatrix} \theta_k \\ b_k \\ a_k \end{bmatrix} = F_k \begin{bmatrix} \theta_{k-1} \\ b_{k-1} \\ a_{k-1} \end{bmatrix} + w_k$$

where x_k is a 9-by-1 vector consisting of:

- θ_k –– 3-by-1 orientation error vector, in degrees, at time k
- b_k –– 3-by-1 gyroscope zero rate offset vector, in deg/s, at time k
- a_k –– 3-by-1 acceleration error vector measured in the sensor frame, in g, at time k
- w_k –– 9-by-1 additive noise vector
- F_k –– state transition model

Because x_k is defined as the error process, the *a priori* estimate is always zero, and therefore the state transition model, F_k, is zero. This insight results in the following reduction of the standard Kalman equations:

Standard Kalman equations:

$$
\begin{aligned}
x_k^- &= F_k x_{k-1}^+ \\
P_k^- &= F_k P_{k-1}^+ F_k^T + Q_k
\end{aligned}
$$

$$
\begin{aligned}
y_k &= z_k - H_k x_k^- \\
S_k &= R_k + H_k P_k^- H_k^T \\
K_k &= P_k^- H_k^T \left(S_k \right)^{-1} \\
x_k^+ &= x_k^- + K_k y_k \\
P_k^+ &= P_k^- - K_k H_k P_k^-
\end{aligned}
$$

Kalman equations used in this algorithm:

$$x_k^- = 0$$

$$P_k^- = Q_k$$

$$Y_k = z_k$$

$$S_k = R_k + H_k P_k^- H_k^T$$

$$K_k = P_k^- H_k^T \left(S_k \right)^{-1}$$

$$x_k^+ = K_k Y_k$$

$$P_k^+ = P_k^- - K_k H_k P_k^-$$

where

- x_k^- -- predicted (*a priori*) state estimate; the error process
- P_k^- -- predicted (*a priori*) estimate covariance
- y_k -- innovation
- S_k -- innovation covariance
- K_k -- Kalman gain
- x_k^+ -- updated (*a posteriori*) state estimate
- P_k^+ -- updated (*a posteriori*) estimate covariance

k represents the iteration, the superscript $^+$ represents an *a posteriori* estimate, and the superscript $^-$ represents an *a priori* estimate.

The graphic and following steps describe a single frame-based iteration through the algorithm.

Before the first iteration, the `accelReadings` and `gyroReadings` inputs are chunked into 1-by-3 frames and `DecimationFactor`-by-3 frames, respectively. The algorithm uses the most current accelerometer readings corresponding to the chunk of gyroscope readings.

Detailed Overview

Step through the algorithm for an explanation of each stage of the detailed overview.

Model

The algorithm models acceleration and angular change as linear processes.

The orientation for the current frame is predicted by first estimating the angular change from the previous frame:

$$\Delta\varphi_{N\times3} \;=\; \frac{\left(gyroReadings_{N\times3} \;-\; gyroOffset_{1\times3}\right)}{fs}$$

where N is the decimation factor specified by the `DecimationFactor` property, and fs is the sample rate specified by the `SampleRate` property.

The angular change is converted into quaternions using the `rotvec quaternion` construction syntax:

$$\Delta Q_{N\times1} = \texttt{quaternion}(\Delta\boldsymbol{\varphi}_{N\times3}, \texttt{'rotvec'})$$

The previous orientation estimate is updated by rotating it by ΔQ:

$$q_{1\times1}^{-} = \left(q_{1\times1}^{+}\right)\left(\prod_{n=1}^{N}\Delta Q_n\right)$$

During the first iteration, the orientation estimate, q^-, is initialized by `ecompass` with an assumption that the *x*-axis points north.

The gravity vector is interpreted as the third column of the quaternion, q^-, in rotation matrix form:

$$g_{1\times3} = \left(rPrior(:,3)\right)^{T}$$

See `ecompass` for an explanation of why the third column of *rPrior* can be interpreted as the gravity vector.

A second gravity vector estimation is made by subtracting the decayed linear acceleration estimate of the previous iteration from the accelerometer readings:

$$gAccel_{1\times3} = accelReadings_{1\times3} - linAccelprior_{1\times3}$$

Error Model

The error model is the difference between the gravity estimate from the accelerometer readings and the gravity estimate from the gyroscope readings: $z = g - gAccel$.
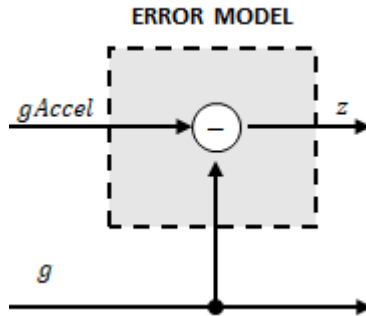
ERROR MODEL

$g.Accel$

g

z

Kalman Equations

The Kalman equations use the gravity estimate derived from the gyroscope readings, g, and the observation of the error process, z, to update the Kalman gain and intermediary covariance matrices. The Kalman gain is applied to the error signal, z, to output an *a posteriori* error estimate, x^+.

KALMAN EQUATIONS
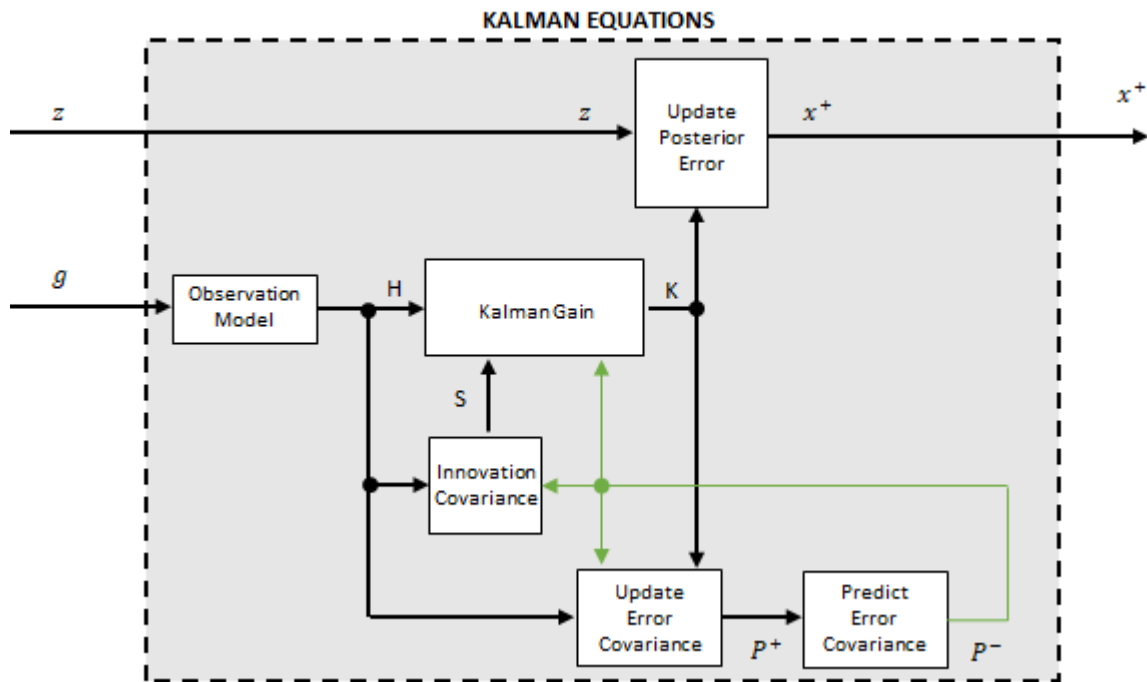
The observation model maps the 1-by-3 observed state, g, into the 3-by-9 true state, H.

The observation model is constructed as:

$$
H_{3\times 9} = \begin{bmatrix}
0 & g_z & -g_y & 0 & -\kappa g_z & \kappa g_y & 1 & 0 & 0 \\
-g_z & 0 & g_x & \kappa g_z & 0 & -\kappa g_x & 0 & 1 & 0 \\
g_y & -g_x & 0 & -\kappa g_y & \kappa g_x & 0 & 0 & 0 & 1
\end{bmatrix}
$$

where g_x, g_y, and g_z are the x-, y-, and z-elements of the gravity vector estimated from the orientation, respectively. κ is a constant determined by the SampleRate and DecimationFactor properties: κ = DecimationFactor/SampleRate.

See sections 7.3 and 7.4 of [1] for a derivation of the observation model.

The innovation covariance is a 3-by-3 matrix used to track the variability in the measurements. The innovation covariance matrix is calculated as:

$$S_{3x3} = R_{3x3} + \left(H_{3x9}\right)\left(P^{-}_{9x9}\right)\left(H_{3x9}\right)^{T}$$

where

- H is the observation model matrix
- P^{-} is the predicted (*a priori*) estimate of the covariance of the observation model calculated in the previous iteration
- R is the covariance of the observation model noise, calculated as:

$$R_{3\times3} = \left(\lambda + \xi + \kappa\left(\beta + \eta\right)\right)\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

The following properties define the observation model noise variance:

- κ –– (DecimationFactor/SampleRate)^2
- β –– GyroscopeDriftNoise
- η –– GyroscopeNoise
- λ –– AccelerometerNoise
- ξ –– LinearAccelerationNoise

The error estimate covariance is a 9-by-9 matrix used to track the variability in the state.

The error estimate covariance matrix is updated as:

$$P^{+}_{9\times9} = P^{-}_{9\times9} - \left(K_{9\times3}\right)\left(H_{3\times9}\right)\left(P^{-}_{9x9}\right)$$

where K is the Kalman gain, H is the measurement matrix, and P^{-} is the error estimate covariance calculated during the previous iteration.

The error estimate covariance is a 9-by-9 matrix used to track the variability in the state. The *a priori* error estimate covariance, P^{-}, is set to the process noise covariance, Q,

determined during the previous iteration. Q is calculated as a function of the *a posteriori* error estimate covariance, P^+. When calculating Q, the cross-correlation terms are assumed to be negligible compared to the autocorrelation terms, and are set to zero:

$$
Q = \begin{bmatrix}
P^+(1\,1) + \kappa^2 P^+(3\,1) + \beta + \eta & 0 & 0 \\
0 & P^+(1\,1) + \kappa^2 P^+(4\,1) + \beta + \eta & 0 \\
0 & 0 & P^+(2\,1) + \kappa^2 P^+(5\,1) \\
-\kappa\left(P^+(3\,1) + \beta\right) & 0 & 0 \\
0 & P^+(4\,1) + \beta & 0 \\
0 & 0 & P^+(5\,1) + \beta \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
$$

where

- P^+ –– is the updated (*a posteriori*) error estimate covariance
- κ –– DecimationFactor/SampleRate
- β –– GyroscopeDriftNoise
- η –– GyroscopeNoise
- ν –– LinearAcclerationDecayFactor
- ξ –– LinearAccelerationNoise

See section 10.1 of [1] for a derivation of the terms of the process error matrix.

The Kalman gain matrix is a 9-by-3 matrix used to weight the innovation. In this algorithm, the innovation is interpreted as the error process, z.

The Kalman gain matrix is constructed as:

$$
K_{9 \times 3} = \left(P^-_{9 \times 9}\right)\left(H_{3 \times 9}\right)^T \left(\left(S_{3 \times 3}\right)^T\right)^{-1}
$$

where

- P^- –- predicted error covariance
- H –- observation model
- S –- innovation covariance

The posterior error estimate is determined by combining the Kalman gain matrix with the error in the gravity vector estimations:

$$x_{9 \times 1} = \left(K_{9 \times 3} \right) \left(z_{1 \times 3} \right)^T$$

Correct

The orientation estimate is updated by multiplying the previous estimation by the error:

$$q^+ = \left(q^-\right)\left(\theta^+\right)$$

The linear acceleration estimation is updated by decaying the linear acceleration estimation from the previous iteration and subtracting the error:

$$linAccelPrior = (linAccelPrior_{k-1})v - b^+$$

where

- v -- LinearAccelerationDecayFactor

The gyroscope offset estimation is updated by subtracting the gyroscope offset error from the gyroscope offset from the previous iteration:

$$gyroOffset = gyroOffset_{k-1} - a^+$$

Compute Angular Velocity

To estimate angular velocity, the frame of `gyroReadings` are averaged and the gyroscope offset computed in the previous iteration is subtracted:

$$angularVelocity_{1\times3} = \frac{\sum gyroReadings_{N\times3}}{N} - gyroOffset_{1\times3}$$

where N is the decimation factor specified by the `DecimationFactor` property.

The gyroscope offset estimation is initialized to zeros for the first iteration.

References

[1] Open Source Sensor Fusion. https://github.com/memsindustrygroup/Open-Source-Sensor-Fusion/tree/master/docs

[2] Roetenberg, D., H.J. Luinge, C.T.M. Baten, and P.H. Veltink. "Compensation of Magnetic Disturbances Improves Inertial and Magnetic Sensing of Human Body

Segment Orientation." *IEEE Transactions on Neural Systems and Rehabilitation Engineering*. Vol. 13. Issue 3, 2005, pp. 395-405.

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
ahrsfilter | ecompass | gpsSensor | imuSensor | quaternion

Topics
"Determine Orientation Using Inertial Sensors"

Introduced in R2018b

insSensor System object

Inertial navigation and GPS simulation model

Description

The `insSensor` System object models data output from an inertial navigation and GPS.

To model output from an inertial navigation and GPS:

1   Create the `insSensor` 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

```
INS = insSensor
INS = insSensor(Name,Value)
```

Description

`INS = insSensor` returns a System object, `INS`, that models an inertial navigation and GPS reading based on an inertial input signal.

`INS = insSensor(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default 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).

RollAccuracy — Accuracy of roll measurement (deg)
`0.2` (default) | nonnegative real scalar

Accuracy of the roll measurement of the sensor body in degrees, specified as a nonnegative real scalar.

Roll is defined as rotation around the *x*-axis of the sensor body. Roll noise is modeled as a white noise process. `RollAccuracy` sets the standard deviation, in degrees, of the roll measurement noise.

Tunable: Yes

Data Types: `single` | `double`

PitchAccuracy — Accuracy of pitch measurement (deg)
`0.2` (default) | nonnegative real scalar

Accuracy of the pitch measurement of the sensor body in degrees, specified as a nonnegative real scalar.

Pitch is defined as rotation around the *y*-axis of the sensor body. Pitch noise is modeled as a white noise process. `PitchAccuracy` defines the standard deviation, in degrees, of the pitch measurement noise.

Tunable: Yes

Data Types: `single` | `double`

YawAccuracy — Accuracy of yaw measurement (deg)
`1` (default) | nonnegative real scalar

Accuracy of the yaw measurement of the sensor body in degrees, specified as a nonnegative real scalar.

Yaw is defined as rotation around the *z*-axis of the sensor body. Yaw noise is modeled as a white noise process. `YawAccuracy` defines the standard deviation, in degrees, of the yaw measurement noise.

Tunable: Yes

Data Types: `single` | `double`

PositionAccuracy — Accuracy of position measurement (m)
`1` (default) | nonnegative real scalar

Accuracy of the position measurement of the sensor body in meters, specified as a nonnegative real scalar.

Position noise is modeled as a white noise process. `PositionAccuracy` defines the standard deviation, in meters, of the position measurement noise.

Tunable: Yes

Data Types: `single` | `double`

VelocityAccuracy — Accuracy of velocity measurement (m/s)
`0.05` (default) | nonnegative real scalar

Accuracy of the velocity measurement of the sensor body in meters per second, specified as a nonnegative real scalar.

Velocity noise is modeled as a white noise process. `VelocityAccuracy` defines the standard deviation, in meters per second, of the velocity measurement noise.

Tunable: Yes

Data Types: `single` | `double`

RandomStream — Random number source
`'Global stream'` (default) | `'mt19937ar with seed'`

Random number source, specified as a character vector:

- `'Global stream'` –– Random numbers are generated using the current global random number stream.

- `'mt19937ar with seed'` –– Random numbers are generated using the mt19937ar algorithm with the seed specified by the `Seed` property.

Data Types: `char` | `string`

Seed — Initial seed
67 (default) | nonnegative integer scalar

Initial seed of an mt19937ar random number generator algorithm, specified as a real, nonnegative integer scalar.

Dependencies

To enable this property, set `RandomStream` to `'mt19937ar with seed'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Usage

Syntax

`measurement = INS(motion)`

Description

`measurement = INS(motion)` models the data received from an inertial navigation and GPS reading. The measurement is based on the input signal, `motion`.

Input Arguments

`motion` — Ground-truth sensor body motion in local NED
struct

`motion` is a struct with the following fields:

- `'Position'` –– Position of the sensor body in the local NED coordinate system specified as a real finite N-by-3 array in meters. N is the number of samples in the current frame.

- **'Velocity'** –– Velocity of the sensor body in the local NED coordinate system specified as a real finite *N*-by-3 array in meters per second. *N* is the number of samples in the current frame.

- **'Orientation'** –– Orientation of the sensor body with respect to the local NED coordinate system specified as a `quaternion` *N*-element column vector or a single or double 3-by-3-by-*N* rotation matrix. Each quaternion or rotation matrix is a frame rotation from the local NED coordinate system to the current sensor body coordinate system. *N* is the number of samples in the current frame.

Example: `motion = struct('Position',[0,0,0],'Velocity', [0,0,0],'Orientation',quaternion([1,0,0,0]))`

Output Arguments

measurement — Measurement of sensor body motion in local NED
struct

`measurement` is a struct with the following fields:

- **'Position'** –– Position measurement of the sensor body in the local NED coordinate system specified as a real finite *N*-by-3 array in meters. *N* is the number of samples in the current frame.

- **'Velocity'** –– Velocity measurement of the sensor body in the local NED coordinate system specified as a real finite *N*-by-3 array in meters per second. *N* is the number of samples in the current frame.

- **'Orientation'** –– Orientation measurement of the sensor body with respect to the local NED coordinate system specified as a quaternion *N*-element column vector or a single or double 3-by-3-by-*N* rotation matrix. Each quaternion or rotation matrix is a frame rotation from the local NED coordinate system to the current sensor body coordinate system. *N* is the number of samples in the current frame.

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

Generate INS Measurements from Stationary Input

Create a motion struct that defines a stationary position at the local NED origin. Because the platform is stationary, you only need to define a single sample. Assume the ground-truth motion is sampled for 10 seconds with a 100 Hz sample rate. Create a default `insSensor` System object™. Preallocate variables to hold output from the `insSensor` object.

```
Fs = 100;
duration = 10;
numSamples = Fs*duration;

motion = struct( ...
    'Position', zeros(1,3), ...
    'Velocity', zeros(1,3), ...
    'Orientation', ones(1,1,'quaternion'));

INS = insSensor;

positionMeasurements = zeros(numSamples,3);
velocityMeasurements = zeros(numSamples,3);
orientationMeasurements = zeros(numSamples,1,'quaternion');
```

In a loop, call `INS` with the stationary motion struct to return the position, velocity, and orientation measurements in the local NED coordinate system. Log the position, velocity, and orientation measurements.

```
for i = 1:numSamples

    measurements = INS(motion);

    positionMeasurements(i,:) = measurements.Position;
```

```
        velocityMeasurements(i,:) = measurements.Velocity;
        orientationMeasurements(i) = measurements.Orientation;

end
```

Convert the orientation from quaternions to Euler angles for visualization purposes. Plot the position, velocity, and orientation measurements over time.

```
orientationMeasurements = eulerd(orientationMeasurements,'ZYX','frame');

t = (0:(numSamples-1))/Fs;

subplot(3,1,1)
plot(t,positionMeasurements)
title('Position')
xlabel('Time (s)')
ylabel('Position (m)')
legend('North','East','Down')

subplot(3,1,2)
plot(t,velocityMeasurements)
title('Velocity')
xlabel('Time (s)')
ylabel('Velocity (m/s)')
legend('North','East','Down')

subplot(3,1,3)
plot(t,orientationMeasurements)
title('Orientation')
xlabel('Time (s)')
ylabel('Rotation (degrees)')
legend('Roll', 'Pitch', 'Yaw')
```
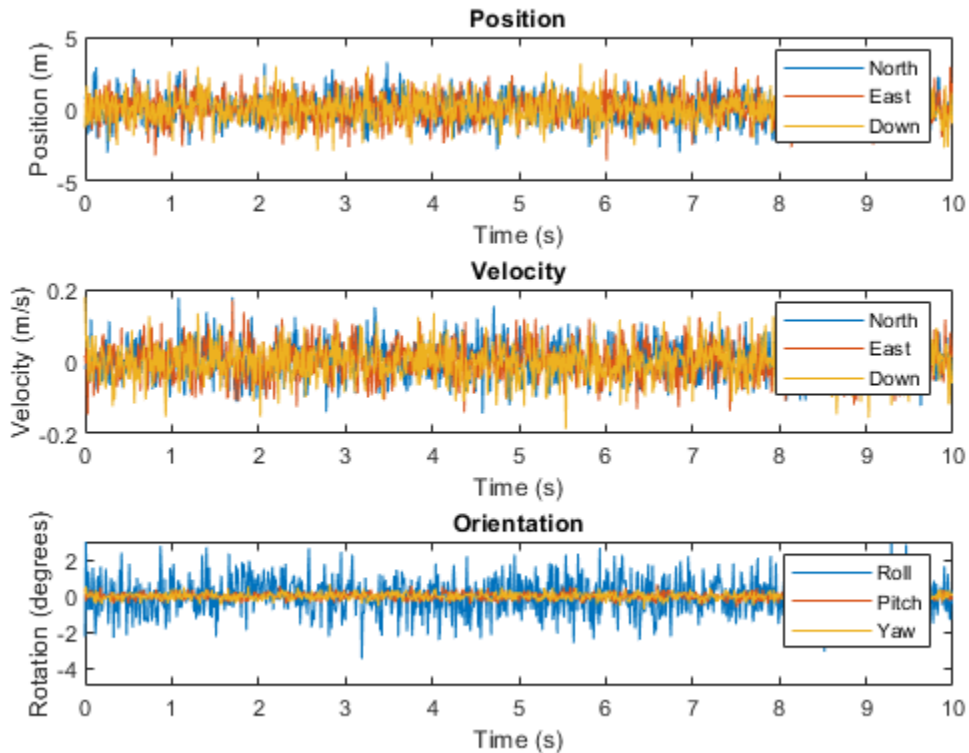
Generate INS Measurements for a Scenario

Generate INS measurements using the `insSensor` System object™. Use `waypointTrajectory` to generate the ground-truth path. Use `trackingScenario` to organize the simulation and visualize the motion.

Specify the ground-truth trajectory as a figure-eight path in the North-East plane. Use a 50 Hz sample rate and 5 second duration.

```
Fs = 50;
duration = 5;
numSamples = Fs*duration;
```

```
t = (0:(numSamples-1)).'/Fs;

a = 2;

x = a.*sqrt(2).*cos(t) ./ (sin(t).^2 + 1);
y = sin(t) .* x;
z = zeros(numSamples,1);

waypoints = [x,y,z];

path = waypointTrajectory('Waypoints',waypoints,'TimeOfArrival',t);
```

Create an `insSensor` System object to model receiving INS data. Set the `PositionAccuracy` to `0.1`.

```
ins = insSensor('PositionAccuracy',0.1);
```

Create a tracking scenario with a single platform whose motion is defined by `path`.

```
scenario = trackingScenario('UpdateRate',Fs);
quadcopter = platform(scenario);
quadcopter.Trajectory = path;
```

Create a theater plot to visualize the ground-truth `quadcopter` motion and the quadcopter motion measurements modeled by `insSensor`.

```
tp = theaterPlot('XLimits',[-3, 3],'YLimits', [-3, 3]);
quadPlotter = platformPlotter(tp, ...
    'DisplayName', 'Ground-Truth Motion', ...
    'Marker', 's', ...
    'MarkerFaceColor','blue');
insPlotter = detectionPlotter(tp, ...
    'DisplayName','INS Measurement', ...
    'Marker','d', ...
    'MarkerFaceColor','red');
```
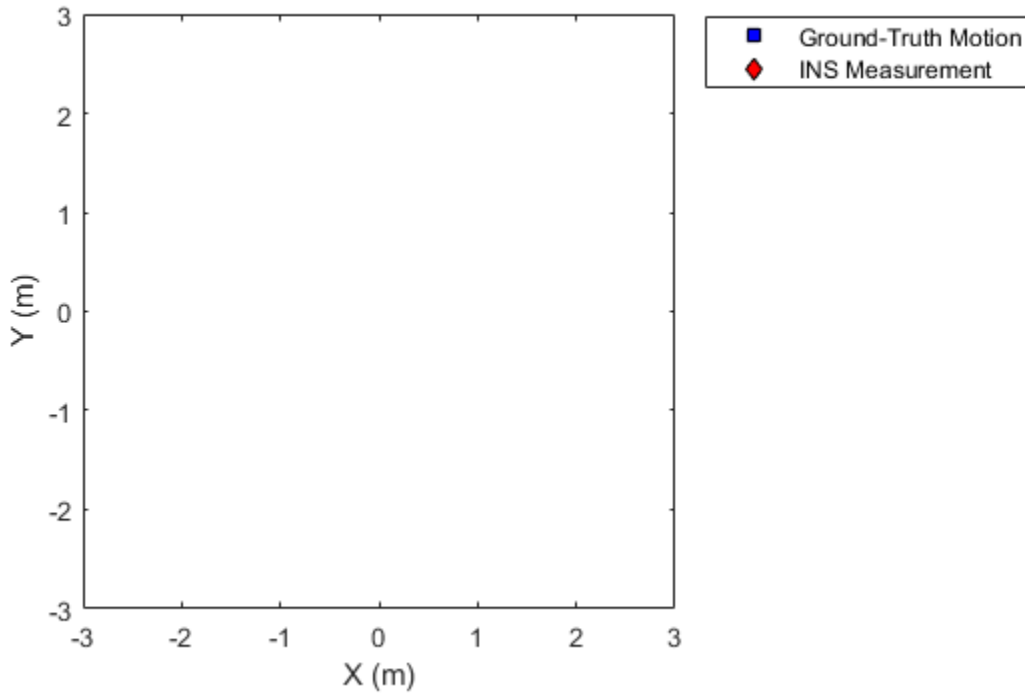
In a loop, advance the scenario until it is complete. For each time step, get the current motion sample, model INS measurements for the motion, and then plot the result.

```
while advance(scenario)
    motion = platformPoses(scenario,'quaternion');

    insMeas = ins(motion);

    plotPlatform(quadPlotter,motion.Position);
    plotDetection(insPlotter,insMeas.Position);

    pause(1/scenario.UpdateRate)
end
```
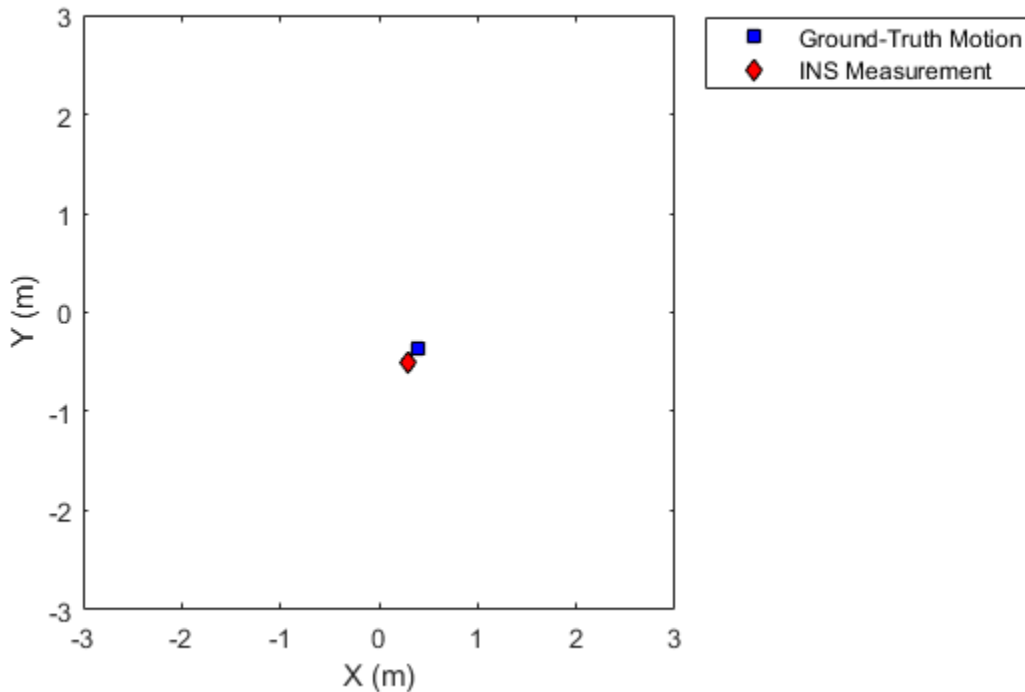
Generate INS Measurements for a Turning Platform

Generate INS measurements using the `insSensor` System object™. Use `waypointTrajectory` to generate the ground-truth path.

Specify a ground-truth orientation that begins with the sensor body *x*-axis aligned with North and ends with the sensor body *x*-axis aligned with East. Specify waypoints for an arc trajectory and a time-of-arrival vector for the corresponding waypoints. Use a 100 Hz sample rate. Create a `waypointTrajectory` System object with the waypoint constraints, and set `SamplesPerFrame` so that the entire trajectory is output with one call.

```
eulerAngles = [0,0,0; ...
               0,0,0; ...
               90,0,0; ...
               90,0,0];
orientation = quaternion(eulerAngles,'eulerd','ZYX','frame');

r = 20;
waypoints = [0,0,0; ...
             100,0,0; ...
             100+r,r,0; ...
             100+r,100+r,0];

toa = [0,10,10+(2*pi*r/4),20+(2*pi*r/4)];

Fs = 100;
numSamples = floor(Fs*toa(end));

path = waypointTrajectory('Waypoints',waypoints, ...
    'TimeOfArrival',toa, ...
    'Orientation',orientation, ...
    'SampleRate',Fs, ...
    'SamplesPerFrame',numSamples);
```

Create an `insSensor` System object to model receiving INS data. Set the `PositionAccuracy` to `0.1`.

```
ins = insSensor('PositionAccuracy',0.1);
```

Call the waypoint trajectory object, `path`, to generate the ground-truth motion. Call the INS simulator, `ins`, with the ground-truth motion to generate INS measurements.

```
[motion.Position,motion.Orientation,motion.Velocity] = path();
insMeas = ins(motion);
```

Convert the orientation returned by `ins` to Euler angles in degrees for visualization purposes. Plot the full path and orientation over time.

```
orientationMeasurementEuler = eulerd(insMeas.Orientation,'ZYX','frame');

subplot(2,1,1)
plot(insMeas.Position(:,1),insMeas.Position(:,2));
title('Path')
xlabel('North (m)')
ylabel('East (m)')
```

3-83

```
subplot(2,1,2)
t = (0:(numSamples-1)).'/Fs;
plot(t,orientationMeasurementEuler(:,1), ...
     t,orientationMeasurementEuler(:,2), ...
     t,orientationMeasurementEuler(:,3));
title('Orientation')
legend('Yaw','Pitch','Roll')
xlabel('Time (s)')
ylabel('Rotation (degrees)')
```
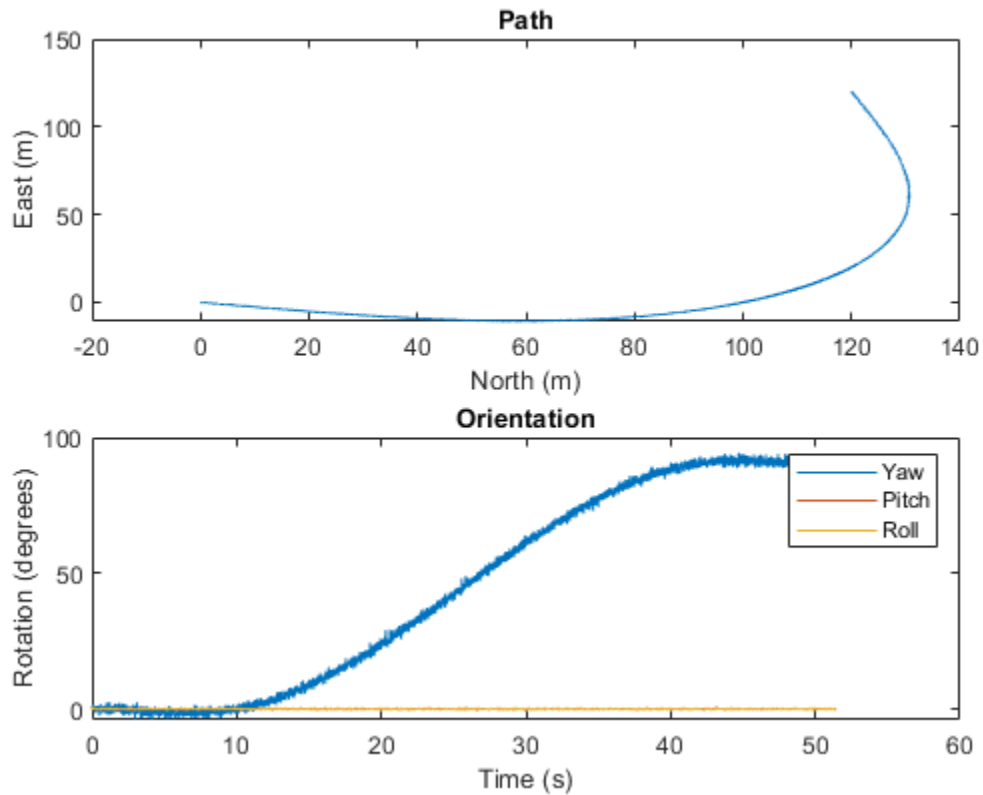
Extended Capabilities

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

System Objects
gpsSensor | imuSensor

Topics
"Model IMU, GPS, and INS/GPS"

Introduced in R2018b

gpsSensor System object

GPS receiver simulation model

Description

The `gpsSensor` System object models data output from a Global Positioning System (GPS) receiver.

To model a GPS receiver:

1 Create the `gpsSensor` 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

```
GPS = gpsSensor
GPS = gpsSensor(Name,Value)
```

Description

`GPS = gpsSensor` returns a System object, `GPS`, that computes a Global Positioning System receiver reading based on a local position and velocity input signal. The default reference position in geodetic coordinates is

- latitude: 0° N
- longitude: 0° E
- altitude: 0 m

GPS = gpsSensor(Name,Value) sets each property Name to the specified Value. Unspecified properties have default 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).

UpdateRate — Update rate of receiver (Hz)
1 (default) | positive real scalar

Update rate of the receiver in Hz, specified as a positive real scalar.

Data Types: single | double

ReferenceLocation — Origin of local NED reference frame
[0 0 0] (default) | [degrees degrees meters]

Reference location, specified as a 3-element row vector in geodetic coordinates (latitude, longitude, and altitude). Altitude is the height above the reference ellipsoid model, WGS84. The reference location is in [degrees degrees meters]. The degree format is decimal degrees (DD).

Data Types: single | double

HorizontalPositionAccuracy — Horizontal position accuracy (m)
1.6 (default) | nonnegative real scalar

Horizontal position accuracy in meters, specified as a nonnegative real scalar. The horizontal position accuracy specifies the standard deviation of the noise in the horizontal position measurement.

Tunable: Yes

Data Types: single | double

VerticalPositionAccuracy — Vertical position accuracy (m)
3 (default) | nonnegative real scalar

Vertical position accuracy in meters, specified as a nonnegative real scalar. The vertical position accuracy specifies the standard deviation of the noise in the vertical position measurement.

Tunable: Yes

Data Types: single | double

VelocityAccuracy — Velocity accuracy (m/s)
0.1 (default) | nonnegative real scalar

Velocity accuracy in meters per second, specified as a nonnegative real scalar. The velocity accuracy specifies the standard deviation of the noise in the velocity measurement.

Tunable: Yes

Data Types: single | double

DecayFactor — Global position noise decay factor
0.999 (default) | scalar in the range [0,1]

Global position noise decay factor, specified as a scalar in the range [0,1].

A decay factor of 0 models the global position noise as a white noise process. A decay factor of 1 models the global position noise as a random walk process.

Tunable: Yes

Data Types: single | double

RandomStream — Random number source
'Global stream' (default) | 'mt19937ar with seed'

Random number source, specified as a character vector or string:

- 'Global stream' –– Random numbers are generated using the current global random number stream.
- 'mt19937ar with seed' –– Random numbers are generated using the mt19937ar algorithm with the seed specified by the Seed property.

Data Types: `char` | `string`

Seed — Initial seed
67 (default) | nonnegative integer scalar

Initial seed of an mt19937ar random number generator algorithm, specified as a nonnegative integer scalar.

Dependencies

To enable this property, set `RandomStream` to `'mt19937ar with seed'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Usage

Syntax

`[position,velocity,groundspeed,course] = GPS(truePosition, trueVelocity)`

Description

`[position,velocity,groundspeed,course] = GPS(truePosition, trueVelocity)` computes global navigation satellite system receiver readings from the position and velocity inputs.

Input Arguments

`truePosition` — Position of GPS receiver in local NED coordinate system (m)
N-by-3 matrix

Position of the GPS receiver in the local NED coordinate system in meters, specified as a real finite *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: `single` | `double`

trueVelocity — Velocity of GPS receiver in local NED coordinate system (m/s)
N-by-3 matrix

Velocity of GPS receiver in the local NED coordinate system in meters per second, specified as a real finite *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: single | double

Output Arguments

position — Position in LLA coordinate system
N-by-3 matrix

Position of the GPS receiver in the geodetic latitude, longitude, and altitude (LLA) coordinate system, returned as a real finite *N*-by-3 array. Latitude and longitude are in degrees with North and East being positive. Altitude is in meters.

N is the number of samples in the current frame.

Data Types: single | double

velocity — Velocity in local NED coordinate system (m/s)
N-by-3 matrix

Velocity of the GPS receiver in the local NED coordinate system in meters per second, returned as a real finite *N*-by-3 array.

N is the number of samples in the current frame.

Data Types: single | double

groundspeed — Magnitude of horizontal velocity in local NED coordinate system (m/s)
N-by-1 column vector

Magnitude of the horizontal velocity of the GPS receiver in the local NED coordinate system in meters per second, returned as a real finite *N*-by-1 column vector.

N is the number of samples in the current frame.

Data Types: single | double

`course` — Direction of horizontal velocity in local NED coordinate system (°)
N-by-1 column vector

Direction of the horizontal velocity of the GPS receiver in the local NED coordinate system in degrees, returned as a real finite *N*-by-1 column of values between 0 and 360. North corresponds to 360 degrees and East corresponds to 90 degrees.

N is the number of samples in the current frame.

Data Types: `single` | `double`

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

Generate GPS Position Measurements From Stationary Input

Create a `gpsSensor` System object™ to model GPS receiver data. Assume a typical one Hz sample rate and a 1000-second simulation time. Define the reference location in terms of latitude, longitude, and altitude (LLA) of Natick, MA (USA). Define the sensor as stationary by specifying the true position and velocity with zeros.

```
fs = 1;
duration = 1000;
numSamples = duration*fs;

refLoc = [42.2825 -71.343 53.0352];
```

```
truePosition = zeros(numSamples,3);
trueVelocity = zeros(numSamples,3);

gps = gpsSensor('UpdateRate',fs,'ReferenceLocation',refLoc);
```

Call `gps` with the specified `truePosition` and `trueVelocity` to simulate receiving GPS data for a stationary platform.

```
position = gps(truePosition,trueVelocity);
```

Plot the true position and the GPS sensor readings for position.

```
t = (0:(numSamples-1))/fs;

subplot(3, 1, 1)
plot(t, position(:,1), ...
     t, ones(numSamples)*refLoc(1))
title('GPS Sensor Readings')
ylabel('Latitude (degrees)')

subplot(3, 1, 2)
plot(t, position(:,2), ...
     t, ones(numSamples)*refLoc(2))
ylabel('Longitude (degrees)')

subplot(3, 1, 3)
plot(t, position(:,3), ...
     t, ones(numSamples)*refLoc(3))
ylabel('Altitute (m)')
xlabel('Time (s)')
```
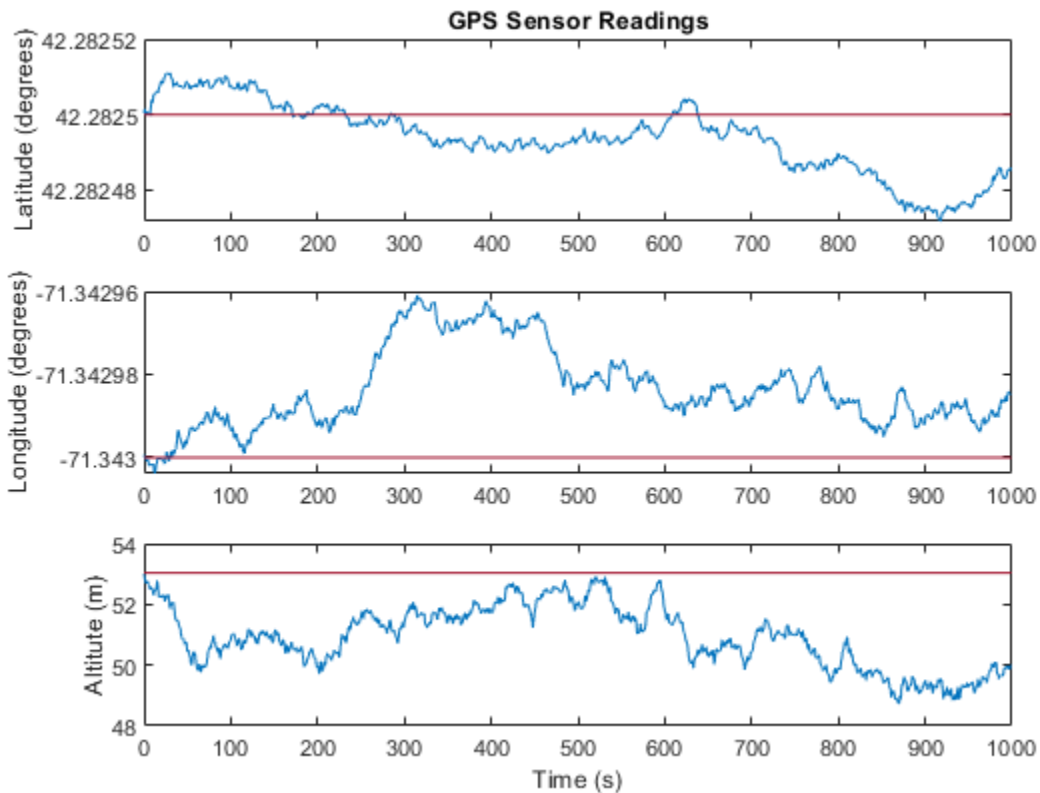
The position readings have noise controlled by `HorizontalPositionAccuracy`, `VerticalPositionAccuracy`, `VelocityAccuracy`, and `DecayFactor`. The `DecayFactor` property controls the drift in the noise model. By default, `DecayFactor` is set to `0.999`, which approaches a random walk process. To observe the effect of the `DecayFactor` property:

1 Reset the `gps` object.

2 Set `DecayFactor` to `0.5`.

3 Call `gps` with variables specifying a stationary position.

4 Plot the results.

The GPS position readings now oscillate around the true position.

```
reset(gps)
gps.DecayFactor = 0.5;
position = gps(truePosition,trueVelocity);

subplot(3, 1, 1)
plot(t, position(:,1), ...
     t, ones(numSamples)*refLoc(1))
title('GPS Sensor Readings - Decay Factor = 0.5')
ylabel('Latitude (degrees)')

subplot(3, 1, 2)
plot(t, position(:,2), ...
     t, ones(numSamples)*refLoc(2))
ylabel('Longitude (degrees)')

subplot(3, 1, 3)
plot(t, position(:,3), ...
     t, ones(numSamples)*refLoc(3))
ylabel('Altitute (m)')
xlabel('Time (s)')
```
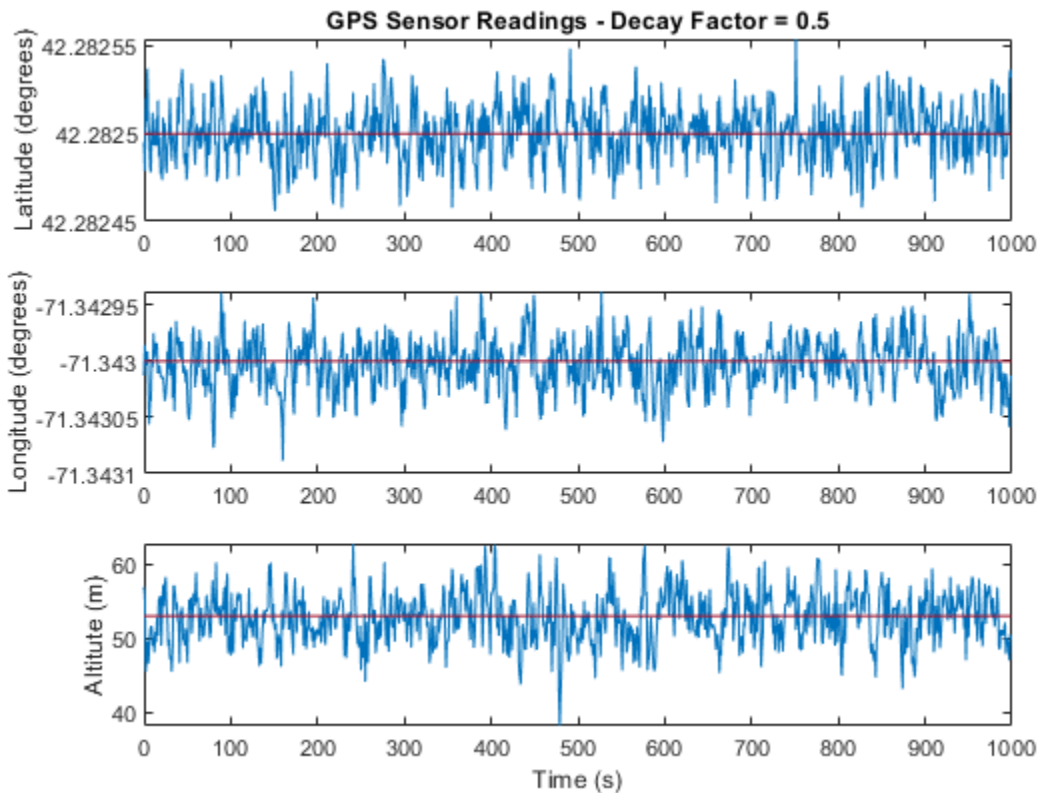
Relationship Between Groundspeed and Course Accuracy

GPS receivers achieve greater course accuracy as groundspeed increases. In this example, you create a GPS receiver simulation object and simulate the data received from a platform that is accelerating from a stationary position.

Create a default `gpsSensor` System object™ to model data returned by a GPS receiver.

```
GPS = gpsSensor
```

```
GPS =
```

```
gpsSensor with properties:

                 UpdateRate: 1                        Hz
          ReferenceLocation: [0 0 0]                  [deg deg m]
 HorizontalPositionAccuracy: 1.6                      m
   VerticalPositionAccuracy: 3                        m
           VelocityAccuracy: 0.1                      m/s
               RandomStream: 'Global stream'
                DecayFactor: 0.999
```

Create matrices to describe the position and velocity of a platform in the NED coordinate system. The platform begins from a stationary position and accelerates to 60 m/s North-East over 60 seconds, then has a vertical acceleration to 2 m/s over 2 seconds, followed by a 2 m/s rate of climb for another 8 seconds. Assume a constant velocity, such that the velocity is the simple derivative of the position.

```
duration = 70;
numSamples = duration*GPS.UpdateRate;

course = 45*ones(duration,1);
groundspeed = [(1:60)';60*ones(10,1)];

Nvelocity    = groundspeed.*sind(course);
Evelocity    = groundspeed.*cosd(course);
Dvelocity    = [zeros(60,1);-1;-2*ones(9,1)];
NEDvelocity = [Nvelocity,Evelocity,Dvelocity];

Ndistance    = cumsum(Nvelocity);
Edistance    = cumsum(Evelocity);
Ddistance    = cumsum(Dvelocity);
NEDposition = [Ndistance,Edistance,Ddistance];
```

Model GPS measurement data by calling the GPS object with your velocity and position matrices.

```
[~,~,groundspeedMeasurement,courseMeasurement] = GPS(NEDposition,NEDvelocity);
```

Plot the groundspeed and the difference between the true course and the course returned by the GPS simulator.

As groundspeed increases, the accuracy of the course increases. Note that the velocity increase during the last ten seconds has no effect, because the additional velocity is not in the ground plane.

```
t = (0:numSamples-1)/GPS.UpdateRate;

subplot(2,1,1)
plot(t,groundspeed);
ylabel('Speed (m/s)')
title('Relationship Between Groundspeed and Course Accuracy')

subplot(2,1,2)
courseAccuracy = courseMeasurement - course;
plot(t,courseAccuracy)
xlabel('Time (s)');
ylabel('Course Accuracy (degrees)')
```
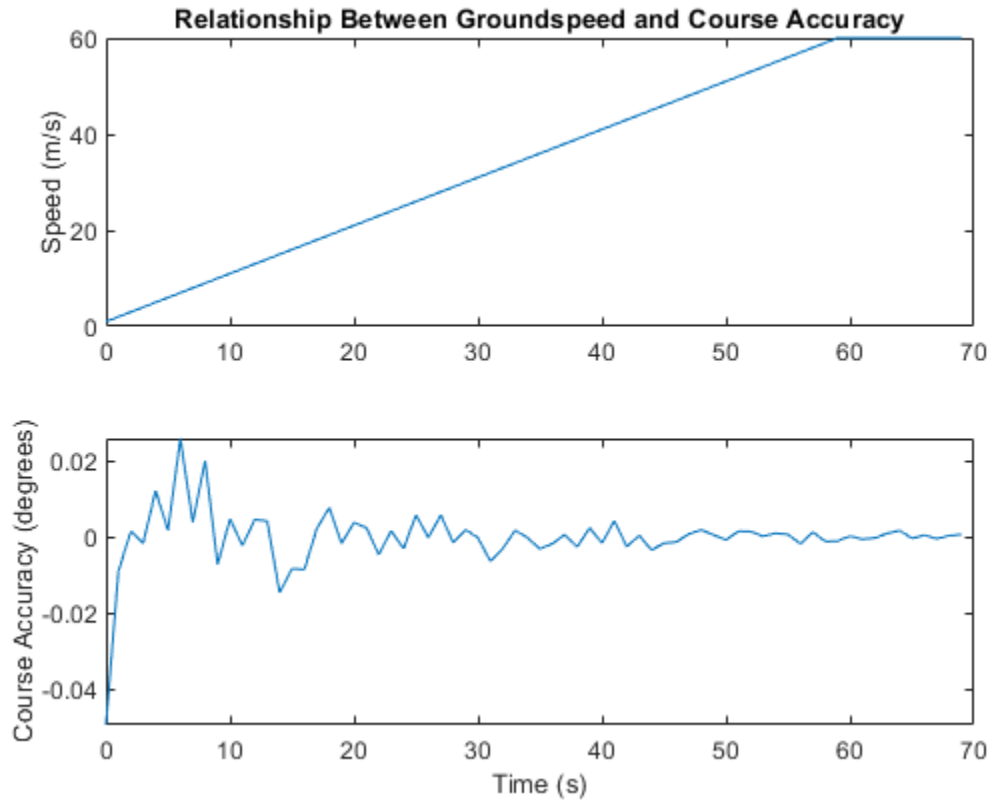
Model GPS Receiver Data

Simulate GPS data received during a trajectory from the city of Natick, MA, to Boston, MA.

Define the decimal degree latitude and longitude for the city of Natick, MA USA, and Boston, MA USA. For simplicity, set the altitude for both locations to zero.

```
NatickLLA = [42.27752809999999, -71.34680909999997, 0];
BostonLLA = [42.3600825, -71.05888010000001, 0];
```

Define a motion that can take a platform from Natick to Boston in 20 minutes. Set the origin of the local NED coordinate system as Natick. Create a waypointTrajectory object to output the trajectory 10 samples at a time.

```
fs = 1;
duration = 60*20;

bearing = 68; % degrees
distance = 25.39e3; % meters
distanceEast = distance*sind(bearing);
distanceNorth = distance*cosd(bearing);

NatickNED = [0,0,0];
BostonNED = [distanceNorth,distanceEast,0];

trajectory = waypointTrajectory( ...
    'Waypoints', [NatickNED;BostonNED], ...
    'TimeOfArrival',[0;duration], ...
    'SamplesPerFrame',10, ...
    'SampleRate',fs);
```

Create a gpsSensor object to model receiving GPS data for the platform. Set the HorizontalPositionalAccuracy to 25 and the DecayFactor to 0.25 to emphasize the noise. Set the ReferenceLocation to the Natick coordinates in LLA.

```
GPS = gpsSensor( ...
    'HorizontalPositionAccuracy',25, ...
    'DecayFactor',0.25, ...
    'UpdateRate',fs, ...
    'ReferenceLocation',NatickLLA);
```

Open a figure and plot the position of Natick and Boston in LLA. Ignore altitude for simplicity.

3-99

In a loop, call the `gpsSensor` object with the ground-truth trajectory to simulate the received GPS data. Plot the ground-truth trajectory and the model of received GPS data.

```
figure(1)
plot(NatickLLA(1),NatickLLA(2),'ko', ...
     BostonLLA(1),BostonLLA(2),'kx')
xlabel('Latitude (degrees)')
ylabel('Longitude (degrees)')
title('GPS Sensor Data for Natick to Boston Trajectory')
hold on

while ~isDone(trajectory)
    [truePositionNED,~,trueVelocityNED] = trajectory();
    reportedPositionLLA = GPS(truePositionNED,trueVelocityNED);

    figure(1)
    plot(reportedPositionLLA(:,1),reportedPositionLLA(:,2),'r.')
end
```

GPS Sensor Data for Natick to Boston Trajectory
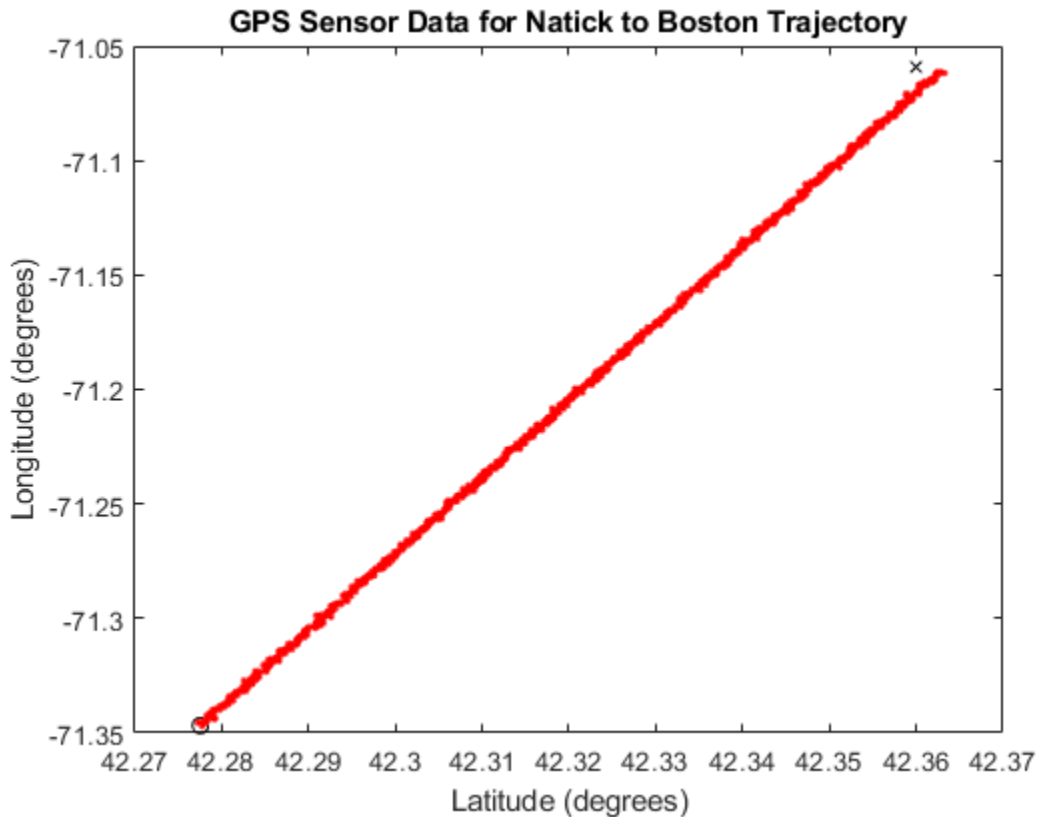
As a best practice, release System objects when complete.

```
release(GPS)
release(trajectory)
```

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

System Objects
imuSensor | insSensor

Topics
"Model IMU, GPS, and INS/GPS"

Introduced in R2018b

radarSensor System object

Generate detections from radar emissions

Description

The `radarSensor` System object returns a statistical model to generate detections from radar emissions. You can generate detections from active or passive radar, and Electronic Support Measures (ESM) radars. You can use the `radarSensor` object in a scenario that models moving and stationary platforms using `trackingScenario`. The radar sensor can simulate real detections with added random noise and also generate false alarm detections. In addition, you can use this object to create input to trackers such as `trackerGNN` or `trackerTOMHT`.

This object enables you to configure a scanning radar. A scanning radar changes the look angle between updates by stepping the mechanical and electronic position of the beam in increments of the angular span specified in the `FieldOfView` property. The radar scans the total region in azimuth and elevation defined by the radar mechanical scan limits, `MechanicalScanLimits`, and electronic scan limits, `ElectronicScanLimits`. If the scanning limits for azimuth or elevation are set to `[0 0]`, then no scanning is performed along that dimension for that scan mode. If the maximum mechanical scan rate for azimuth or elevation is set to zero, then no mechanical scanning is performed along that dimension.

Using a single-exponential mode, the radar computes range and elevation biases caused by propagation through the troposphere. A range bias means that measured ranges are greater than the line-of-sight range to the target. Elevation bias means that the measured elevations are above their true elevations. Biases are larger when the line-of-sight path between the radar and target passes through lower altitudes because the atmosphere is thicker at these altitudes.

To generate radar detections:

1 Create the `radarSensor` 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

```
sensor = radarSensor
sensor = radarSensor(Name,Value)

sensor = radarSensor('No scanning')
sensor = radarSensor('Raster')
sensor = radarSensor('Rotator')
sensor = radarSensor('Sector')
sensor = radarSensor(SensorIndex, ___ )
```

Description

`sensor = radarSensor` creates a radar detection generator object with default property values.

`sensor = radarSensor(Name,Value)` sets properties using one or more name-value pairs. Enclose each property name in quotes. For example, `radarSensor('DetectionCoordinates','Sensor cartesian','MaxRange', 200)` creates a radar detection generator that reports detections in the sensor Cartesian coordinate system and has a maximum detection range of 200 meters.

`sensor = radarSensor('No scanning')` is a convenience syntax that creates a `radarSensor` that stares along the radar antenna boresight direction. No mechanical or electronic scanning is performed. This syntax sets the `ScanMode` property to `'No scanning'`.

`sensor = radarSensor('Raster')` is a convenience syntax that creates a `radarSensor` object that mechanically scans a raster pattern. The raster span is 90° in azimuth from –45° to +45° and in elevation from the horizon to 10° above the horizon. See "Raster Scanning" on page 3-129 for the properties set by this syntax.

`sensor = radarSensor('Rotator')` is a convenience syntax that creates a `radarSensor` object that mechanically scans 360° in azimuth by mechanically rotating the antenna at a constant rate. When you set `HasElevation` to `true`, the radar antenna mechanically points towards the center of the elevation field of view. See "Rotator Scanning" on page 3-129 for the properties set by this syntax.

sensor = radarSensor('Sector') is a convenience syntax to create a radarSensor object that mechanically scans a 90° azimuth sector from –45° to +45°. Setting HasElevation to true, points the radar antenna towards the center of the elevation field of view. You can change the ScanMode to 'Electronic' to electronically scan the same azimuth sector. In this case, the antenna is not mechanically tilted in an electronic sector scan. Instead, beams are stacked electronically to process the entire elevation spanned by the scan limits in a single dwell. See "Sector Scanning" on page 3-130 for the properties set by this syntax.

sensor = radarSensor(SensorIndex, ___) specifies the sensor ID, SensorIndex, as an input argument instead of using the SensorIndex name-value pair.

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).

SensorIndex — Unique sensor identifier
positive integer

Unique sensor identifier, specified as a positive integer. This property distinguishes detections that come from different sensors in a multi-sensor system. This property must be defined before you can execute the object.

Example: 5

Data Types: double

UpdateRate — Sensor update rate
1 (default) | positive scalar

Sensor update rate, specified as a positive scalar. This interval must be an integer multiple of the simulation time interval defined by trackingScenario. The trackingScenario object calls the radar sensor at simulation time intervals. The radar generates new detections at intervals defined by the reciprocal of the UpdateRate

property. Any update requested to the sensor between update intervals contains no detections. Units are in hertz.

Example: 5

Data Types: `double`

`DetectionMode` — Detection mode
`'ESM'` (default) | `'monostatic'`

Detection mode, specified as `'ESM'` or `'onostatic'`. When set to `'ESM'`, the sensor operates passively and can model ESM and RWR systems. When set to `'monostatic'`, the sensor generates detections from reflected signals originating from a collocated radar emitter.

Example: `'Monostatic'`

Data Types: `char` | `string`

`EmitterIndex` — Unique monostatic emitter index
positive integer

Unique monostatic emitter index, specified as a positive integer. The emitter index identifies the monostatic emitter providing the reference signal to the sensor.

Example: 404

Dependencies

Set this property when the `DetectionMode` property is set to `'Monostatic'`.

Data Types: `double`

`MountingLocation` — Sensor location on platform
`[0 0 0]` (default) | 1-by-3 real-valued vector

Sensor location on platform, specified as a 1-by-3 real-valued vector. This property defines the coordinates of the sensor with respect to the platform origin. The default value specifies that the sensor origin is at the origin of its platform. Units are in meters.

Example: `[.2 0.1 0]`

Data Types: `double`

`MountingAngles` — Orientation of sensor
`[0 0 0]` (default) | 3-element real-valued vector

Orientation of the sensor with respect to the platform, specified as a three-element real-valued vector. Each element of the vector corresponds to an intrinsic Euler angle rotation that carries the body axes of the platform to the sensor axes. The three elements define the rotations around the *z*-, *y*-, and *x*-axes, in that order. The first rotation rotates the platform axes around the *z*-axis. The second rotation rotates the carried frame around the rotated *y*-axis. The final rotation rotates the frame around the carried *x*-axis. Units are in degrees.

Example: `[10 20 -15]`

Data Types: `double`

FieldOfView — Fields of view of sensor
`[1;5]` | real-valued 2-by-1 vector of positive real-values

Fields of view of sensor, specified as a 2-by-1 vector of positive real values, [azfov;elfov]. The field of view defines the total angular extent spanned by the sensor. Each component must lie in the interval (0,180]. Targets outside of the field of view of the radar are not detected. Units are in degrees.

Example: `[14;7]`

Data Types: `double`

ScanMode — Scanning mode of radar
`'Mechanical'` (default) | `'Electronic'` | `'Mechanical and electronic'` | `'No scanning'`

Scanning mode of radar, specified as `'Mechanical'`, `'Electronic'`, `'Mechanical and electronic'`, or `'No scanning'`.

Scan Modes

ScanMode	Purpose
'Mechanical'	The radar scans mechanically across the azimuth and elevation limits specified by the MechanicalScanLimits property. The scan direction increments by the radar field of view angle between dwells.
'Electronic'	The radar scans electronically across the azimuth and elevation limits specified by the ElectronicScanLimits property. The scan direction increments by the radar field of view angle between dwells.
'Mechanical and electronic'	The radar mechanically scans the antenna boresight across the mechanical scan limits and electronically scans beams relative to the antenna boresight across the electronic scan limits. The total field of regard scanned in this mode is the combination of the mechanical and electronic scan limits. The scan direction increments by the radar field of view angle between dwells.
'No scanning'	The radar beam points along the antenna boresight defined by the mountingAngles property.

Example: 'No scanning'

Data Types: char

MaxMechanicalScanRate — Maximum mechanical scan rate
[75;75] (default) | nonnegative scalar | real-valued 2-by-1 vector with nonnegative entries

Maximum mechanical scan rate, specified as a nonnegative scalar or real-valued 2-by-1 vector with nonnegative entries.

When HasElevationis true, specify the scan rate as a 2-by-1 column vector of nonnegative entries [maxAzRate; maxElRate]. maxAzRate is the maximum scan rate in azimuth and maxElRate is the maximum scan rate in elevation.

When `HasElevation` is `false`, specify the scan rate as a nonnegative scalar representing the maximum mechanical azimuth scan rate.

Scan rates set the maximum rate at which the radar can mechanically scan. The radar sets its scan rate to step the radar mechanical angle by the field of regard. If the required scan rate exceeds the maximum scan rate, the maximum scan rate is used. Units are degrees per second.

Example: [5;10]

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

MechanicalScanLimits — Angular limits of mechanical scan directions of radar
[0 360;-10 0] (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of mechanical scan directions of radar, specified as a real-valued 1-by-2 row vector, or a real-valued 2-by-2 matrix. The mechanical scan limits define the minimum and maximum mechanical angles the radar can scan from its mounted orientation.

When `HasElevation` is `true`, the scan limits take the form [minAz maxAz; minEl maxEl]. minAz and maxAz represent the minimum and maximum limits of the azimuth angle scan. minEl and maxEl represent the minimum and maximum limits of the elevation angle scan. When HasElevation is `false`, the scan limits take the form [minAz maxAz]. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits cannot span more than 360° and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: [-90 90;0 85]

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

MechanicalAngle — Current mechanical scan angle
scalar | real-valued 2-by-1 vector

This property is read-only.

Current mechanical scan angle of radar, returned as a scalar or real-valued 2-by-1 vector. When HasElevation is `true`, the scan angle takes the form [Az; El]. Az and El represent the azimuth and elevation scan angles, respectively, relative to the mounted angle of the radar on the platform. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

`ElectronicScanLimits` — Angular limits of electronic scan directions of radar
[`-45 45;-45 45`] (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of electronic scan directions of radar, specified as a real-valued 1-by-2 row vector, or a real-valued 2-by-2 matrix. The electronic scan limits define the minimum and maximum electronic angles the radar can scan from its current mechanical direction.

When HasElevation is `true`, the scan limits take the form [minAz maxAz; minEl maxEl]. minAz and maxAz represent the minimum and maximum limits of the azimuth angle scan. minEl and maxEl represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form [minAz maxAz]. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: [`-90 90;0 85`]

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

`ElectronicAngle` — Current electronic scan angle
electronic scalar | nonnegative scalar

This property is read-only.

Current electronic scan angle of radar, returned as a scalar or 1-by-2 column vector. When `HasElevation` is `true`, the scan angle takes the form [Az;El]. Az and El represent the azimuth and elevation scan angles, respectively. When HasElevation is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

LookAngle — Look angle of sensor
scalar | real-valued 2-by-1 vector

This property is read-only.

Look angle of sensor, specified as a scalar or real-valued 2-by-1 vector. Look angle is a combination of the mechanical angle and electronic angle depending on the `ScanMode` property.

ScanMode	LookAngle
`'Mechanical'`	`MechnicalAngle`
`'Electronic'`	`ElectronicAngle`
`'Mechanical and Electronic'`	`MechnicalAngle + ElectronicAngle`
`'No scanning'`	`0`

When HasElevation is `true`, the look angle takes the form [Az;El]. Az and El represent the azimuth and elevation look angles, respectively. When `HasElevation` is `false`, the look angle is a scalar representing the azimuth look angle.

HasElevation — Enable radar elevation scan and measurements
`false` (default) | `true`

Enable the radar to measure target elevation angles and to scan in elevation, specified as `false` or `true`. Set this property to `true` to model a radar sensor that can estimate target elevation and scan in elevation.

Data Types: `logical`

CenterFrequency — Center frequency of radar band
positive scalar

Center frequency of radar band, specified as a positive scalar. Units are in hertz.

Example: `100e6`

Data Types: `double`

Bandwidth — Radar waveform bandwidth
positive scalar

Radar waveform bandwidth, specified as a positive scalar. Units are in hertz.

Example: `100e3`

Data Types: `double`

WaveformTypes — Types of detected waveforms
0 (default) | nonnegative integer-valued *L*-element vector

Types of detected waveforms, specified as a nonnegative integer-valued *L*-element vector.

Example: `[1 4 5]`

Data Types: `double`

ConfusionMatrix — Probability of correct classification of detected waveform
positive scalar | real-valued nonnegative *L*-element vector | real-valued nonnegative *L*-by-*L* matrix

Probability of correct classification of a detected waveform, specified as a positive scalar, a real-valued nonnegative *L*-element vector, or a real-valued nonnegative *L*-by-*L* matrix. Matrix values lie from 0 through 1 and matrix rows must sum to 1. *L* is the number of waveform types detectable by the sensor, as indicated by the value set in the `WaveformTypes` property. The (i,j) matrix element represents the probability of classifying the ith waveform as the jth waveform. When specified as a scalar from 0 through 1, the value is expanded along the diagonal of the confusion matrix. When specified as a vector, it must have the same number of elements as the WaveformTypes property. When defined as a scalar or a vector, the off diagonal values are set to (1-val)/(L-1).

Data Types: `double`

Sensitivity — Minimum operational sensitivity of receiver
`-50` (default) | scalar

Minimum operational sensitivity of receiver, specified as a scalar. Sensitivity includes isotropic antenna receiver gain. Units are in dBmi.

Example: -10

Data Types: `double`

`DetectionThreshold` — Minimum SNR required to declare a detection
5 (default) | scalar

Minimum SNR required to declare a detection, specified as a scalar. Units are in dB.

Example: -1

Data Types: `double`

`FalseAlarmRate` — False alarm rate
`1e-6` (default) | positive scalar

False alarm report rate within each radar resolution cell, specified as a positive scalar in the range $[10^{-7}, 10^{-3}]$. Units are dimensionless. Resolution cells are determined from the AzimuthResolution and RangeResolution properties, and the ElevationResolution and RangeRateResolution properties when they are enabled.

Example: `1e-5`

Data Types: `double`

`AzimuthResolution` — Azimuth resolution of radar
1 (default) | positive scalar

Azimuth resolution of the radar, specified as a positive scalar. The azimuth resolution defines the minimum separation in azimuth angle at which the radar can distinguish two targets. The azimuth resolution is typically the 3-dB downpoint of the azimuth angle beamwidth of the radar. Units are in degrees.

Data Types: `double`

`ElevationResolution` — Elevation resolution of radar
1 (default) | positive scalar

Elevation resolution of the radar, specified as a positive scalar. The elevation resolution defines the minimum separation in elevation angle at which the radar can distinguish two targets. The elevation resolution is typically the 3dB-downpoint in elevation angle beamwidth of the radar. Units are in degrees.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

RangeResolution — Range resolution of radar
100 (default) | positive scalar

Range resolution of the radar, specified as a positive scalar. The range resolution defines the minimum separation in range at which the radar can distinguish between two targets. Units are in meters.

Data Types: `double`

RangeRateResolution — Range rate resolution of radar
10 (default) | positive scalar

Range rate resolution of the radar, specified as a positive scalar. The range rate resolution defines the minimum separation in range rate at which the radar can distinguish between two targets. Units are in meters per second.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

AzimuthBiasFraction — Azimuth bias fraction
0.1 (default) | nonnegative scalar

Azimuth bias fraction of the radar, specified as a nonnegative scalar. The azimuth bias is expressed as a fraction of the azimuth resolution specified in `AzimuthResolution`. This value sets a lower bound on the azimuthal accuracy of the radar. This value is dimensionless.

Data Types: `double`

ElevationBiasFraction — Elevation bias fraction
0.1 (default) | nonnegative scalar

Elevation bias fraction of the radar, specified as a nonnegative scalar. Elevation bias is expressed as a fraction of the elevation resolution specified by the value of the `ElevationResolution` property. This value sets a lower bound on the elevation accuracy of the radar. This value is dimensionless.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

RangeBiasFraction — Range bias fraction
`0.05` (default) | nonnegative scalar

Range bias fraction of the radar, specified as a nonnegative scalar. Range bias is expressed as a fraction of the range resolution specified in `RangeResolution`. This property sets a lower bound on the range accuracy of the radar. This value is dimensionless.

Data Types: `double`

RangeRateBiasFraction — Range rate bias fraction
`0.05` (default) | nonnegative scalar

Range rate bias fraction of the radar, specified as a nonnegative scalar. Range rate bias is expressed as a fraction of the range rate resolution specified in `RangeRateResolution`. This property sets a lower bound on the range-rate accuracy of the radar. This value is dimensionless.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

HasRangeRate — Enable radar to measure range rate
`false` (default) | `true`

Enable the radar to measure target range rates, specified as `false` or `true`. Set this property to `true` to model a radar sensor that can measure target range rate. Set this property to `false` to model a radar sensor that cannot measure range rate.

Data Types: `logical`

HasRangeAmbiguities — Enable range ambiguities
`false` (default) | `true`

Enable range ambiguities, specified as `false` or `true`. Set this property to `true` to enable range ambiguities by the sensor. In this case, the sensor cannot resolve range ambiguities for targets at ranges beyond the MaxUnambiguousRange are wrapped into the interval `[0 MaxUnambiguousRange]`. When `false`, targets are reported at their unambiguous range.

Data Types: `logical`

HasRangeRateAmbiguities — Enable range-rate ambiguities
`false` (default) | `true`

Enable range-rate ambiguities, specified as `false` or `true`. Set to `true` to enable range-rate ambiguities by the sensor. When `true`, the sensor does not resolve range rate ambiguities and target range rates beyond the `MaxUnambiguousRadialSpeed` are wrapped into the interval `[0,MaxUnambiguousRadialSpeed]`. When `false`, targets are reported at their unambiguous range rate.

Dependencies

To enable this property, set the HasRangeRate property to `true`.

Data Types: `logical`

MaxUnambiguousRange — Maximum unambiguous detection range
`100e3` (default) | positive scalar

Maximum unambiguous range, specified as a positive scalar. Maximum unambiguous range defines the maximum range for which the radar can unambiguously resolve the range of a target. When HasRangeAmbiguitiesis set to `true`, targets detected at ranges beyond the maximum unambiguous range are wrapped into the range interval `[0,MaxUnambiguousRange]`. This property applies to true target detections when you set the `HasRangeAmbiguities` property to `true`.

This property also applies to false target detections when you set the `HasFalseAlarms` property to `true`. In this case, the property defines the maximum range for false alarms.

Units are in meters.

Example: `5e3`

Dependencies

To enable this property, set the `HasRangeAmbiguities` property to `true` or set the `HasFalseAlarms` property to `true`.

Data Types: `double`

MaxUnambiguousRadialSpeed — Maximum unambiguous radial speed
`200` (default) | positive scalar

Maximum unambiguous radial speed, specified as a positive scalar. Radial speed is the magnitude of the target range rate. Maximum unambiguous radial speed defines the radial speed for which the radar can unambiguously resolve the range rate of a target. When `HasRangeRateAmbiguities` is set to `true`, targets detected at range rates beyond the maximum unambiguous radial speed are wrapped into the range rate interval `[-MaxUnambiguousRadialSpeed, MaxUnambiguousRadialSpeed]`. This property applies to true target detections when you set `HasRangeRateAmbiguities` property to `true`.

This property also applies to false target detections obtained when you set both the `HasRangeRate` and `HasFalseAlarms` properties to `true`. In this case, the property defines the maximum radial speed for which false alarms can be generated.

Units are in meters per second.

Dependencies

To enable this property, set `HasRangeRate` and `HasRangeRateAmbiguities` to `true` and/or set `HasRangeRate` and `HasFalseAlarms` to `true`.

Data Types: `double`

HasINS — Enable inertial navigation system (INS) input
`false` (default) | `true`

Enable the optional input argument that passes the current estimate of the sensor platform pose to the sensor, specified as `false` or `true`. When `true`, pose information is added to the `MeasurementParameters` structure of the reported detections. Pose information lets tracking and fusion algorithms estimate the state of the target detections in the north-east-down (NED) frame.

Data Types: `logical`

HasNoise — Enable addition of noise to radar sensor measurements
`true` (default) | `false`

Enable addition of noise to radar sensor measurements, specified as `true` or `false`. Set this property to `true` to add noise to the radar measurements. Otherwise, the measurements have no noise. Even if you set `HasNoise` to `false`, the object still computes the `MeasurementNoise` property of each detection.

Data Types: `logical`

HasFalseAlarms — Enable creating false alarm radar detections
`true` (default) | `false`

Enable creating false alarm radar measurements, specified as `true` or `false`. Set this property to `true` to report false alarms. Otherwise, only actual detections are reported.

Data Types: `logical`

MaxNumDetectionsSource — Source of maximum number of detections reported
`'Auto'` (default) | `'Property'`

Source of maximum number of detections reported by the sensor, specified as `'Auto'` or `'Property'`. When this property is set to `'Auto'`, the sensor reports all detections. When this property is set to `'Property'`, the sensor reports up to the number of detections specified by the `MaxNumDetections` property.

Data Types: `char`

MaxNumDetections — Maximum number of reported detections
`50` (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. Detections are reported in order of distance to the sensor until the maximum number is reached.

Dependencies

To enable this property, set the `MaxNumDetectionsSource` property to `'Property'`.

Data Types: `double`

DetectionCoordinates — Coordinate system of reported detections
`'Body'` (default) | `'Scenario'` | `'Sensor rectangular` | `'Sensor spherical'`

Coordinate system of reported detections, specified as:

- `'Scenario'` — Detections are reported in the rectangular scenario coordinate frame. The scenario coordinate system is defined as the local NED frame at simulation start time. To enable this value, set the `HasINS` property to `true`.

- `'Body'` — Detections are reported in the rectangular body system of the sensor platform.

- `'Sensor rectangular'` — Detections are reported in the radar sensor rectangular body coordinate system.

- 'Sensor spherical' — Detections are reported in a spherical coordinate system derived from the sensor rectangular body coordinate system. This coordinate system is centered at the radar sensor and aligned with the orientation of the radar on the platform.

Example: 'Sensor spherical'

Data Types: char

Usage

Syntax

```
dets = sensor(radarsigs,simTime)
dets = sensor(radarsigs,txconfigs,simTime)
dets = sensor( ___ ,ins,simTime)
[dets,numDets,config] = sensor( ___ )
```

Description

dets = sensor(radarsigs,simTime) creates ESM radar detections, dets, from radar emissions, radarsigs, at the current simulation time, simTime. The sensor generates detections at the rate defined by the UpdateRate property.

dets = sensor(radarsigs,txconfigs,simTime) also specifies emitter configurations, txconfigs, at the current simulation time.

dets = sensor(___ ,ins,simTime) also specifies the inertial navigation system (INS) estimated sensor platform pose, ins. INS information is used by tracking and fusion algorithms to estimate the target positions in the NED frame.

To enable this syntax, set the HasINS property to true.

[dets,numDets,config] = sensor(___) also returns the number of valid detections reported, numValidDets, and the configuration of the sensor, config, at the current simulation time.

Input Arguments

`radarsigs` — Radar emissions
array of radar emission objects

Radar emissions, specified as an array of `radarEmission` objects.

`txconfigs` — Emitter configurations
array of structures

Emitter configurations, specified as an array of structures. Each structure has these fields:

Field	Description
EmitterIndex	Unique emitter index
IsValidTime	Valid emission time, returned as `0` or `1`. `IsValidTime` is `0` when emitter updates are requested at times that are between update intervals specified by `UpdateInterval`.
IsScanDone	`IsScanDone` is `true` when the emitter has completed a scan.
FieldOfView	Field of view of emitter.
MeasurementParameters	`MeasurementParameters` is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current emitter frame.

Data Types: `struct`

`ins` — Platform pose from INS
structure

Sensor platform pose obtained from the inertial navigation system (INS), specified as a structure.

Platform pose information from an inertial navigation system (INS) is a structure which has these fields:

Field	Definition
Position	Position of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters.
Velocity	Velocity of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters per second.
Orientation	Orientation of the INS with respect to the local NED coordinate system specified as a scalar quaternion or a 3-by-3 real-valued orthonormal frame rotation matrix. Defines the frame rotation from the local NED coordinate system to the current INS body coordinate system. This is also referred to as a "parent to child" rotation.

Dependencies

To enable this argument, set the `HasINS` property to `true`.

Data Types: `struct`

simTime — Current simulation time
nonnegative scalar

Current simulation time, specified as a positive scalar. The `trackingScenario` object calls the scan radar sensor at regular time intervals. The radar sensor generates new detections at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Example: `10.5`

Data Types: `double`

Output Arguments

dets — sensor detections
cell array of `objectDetection` objects

Sensor detections, returned as a cell array of `objectDetection` objects. Each object has these properties:

Property	Definition
`Time`	Measurement time
`Measurement`	Object measurements
`MeasurementNoise`	Measurement noise covariance matrix
`SensorIndex`	Unique ID of the sensor
`ObjectClassID`	Object classification
`MeasurementParameters`	Parameters used by initialization functions of nonlinear Kalman tracking filters
`ObjectAttributes`	Additional information passed to tracker

`Measurement` and `MeasurementNoise` are reported in the coordinate system specified by the `DetectionCoordinates` property.

numDets — Number of detections
nonnegative integer

Number of detections reported, returned as a nonnegative integer.

- When the `MaxNumDetectionsSource` property is set to `'Auto'`, `numDets` is set to the length of `dets`.
- When the `MaxNumDetectionsSource` property is set to `'Property'`, `dets` is a cell array with length determined by the `MaxNumDetections` property. No more than `MaxNumDetections` number of detections are returned. If the number of detections is fewer than `MaxNumDetections`, the first `numDets` elements of `dets` hold valid detections. The remaining elements of `dets` are set to the default value.

Data Types: `double`

config — Current sensor configuration
structure

Current sensor configuration, specified as a structure. This output can be used to determine which objects fall within the radar beam during object execution.

Field	Description

SensorIndex	Unique sensor index
IsValidTime	Valid detection time, returned as 0 or 1. IsValidTime is 0 when detection updates are requested at times that are between update intervals specified by UpdateInterval.
IsScanDone	IsScanDone is true when the sensor has completed a scan.
FieldOfView	Field of view of sensor determines which objects fall within the sensor beam during object execution. The field of view is defined as a 2-by-1 vector of positive real values, [azfov;elfov].
MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current sensor frame.

Data Types: struct

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 Radar Emission with ESM Sensor

Create an radar emission and then detect the emission using a `radarSensor` object.

First, create an radar emission.

```
orient = quaternion([180 0 0],'eulerd','zyx','frame');
rfSig = radarEmission('PlatformID',1,'EmitterIndex',1,'EIRP',100, ...
    'OriginPosition',[30 0 0],'Orientation',orient);
```

Then, create an ESM sensor using `radarSensor`.

```
sensor = radarSensor(1);
```

Detect the RF emission.

```
time = 0;
[dets,numDets,config] = sensor(rfSig,time)


dets =

  1×1 cell array

    {1×1 objectDetection}


numDets =

     1


config =

  struct with fields:

             SensorIndex: 1
             IsValidTime: 1
              IsScanDone: 0
              FieldOfView: [1 5]
```

```
MeasurementParameters: [1×1 struct]
```

Definitions

Object Detections

The sensor measures the coordinates of the target. The `Measurement` and `MeasurementNoise` values are reported in the coordinate system specified by the `DetectionCoordinates` property of the sensor.

When the `DetectionCoordinates` property is `'Scenario'`, `'Body'`, or `'Sensor rectangular'`, the `Measurement` and `MeasurementNoise` values are reported in rectangular coordinates. Velocities are only reported when the range rate property, `HasRangeRate`, is `true`.

When the `DetectionCoordinates` property is `'Sensor spherical'`, the `Measurement` and `MeasurementNoise` values are reported in a spherical coordinate system derived from the sensor rectangular coordinate system. Elevation and range rate are only reported when `HasElevation` and `HasRangeRate` are `true`.

Measurements are ordered as [azimuth, elevation, range, range rate]. Reporting of elevation and range rate depends on the corresponding `HasElevation` and `HasRangeRate` property values. Angles are in degrees, range is in meters, and range rate is in meters per second.

Measurement Coordinates

DetectionCoordinates	Measurement and Measurement Noise Coordinates		
'Scenario'	**Coordinate Dependence on HasRangeRate**		
'Body'			
'Sensor rectangular'	**HasRangeRate**		**Coordinates**
	true		[x; y; z; vx; vy; vz]
	false		[x; y; z]
'Sensor spherical'	**Coordinate Dependence on HasRangeRate and HasElevation**		
	HasRangeRate	**HasElevation**	**Coordinates**
	true	true	[az; el; rng; rr]
	true	false	[az; rng; rr]
	false	true	[az; el; rng]
	false	false	[az; rng]

The `MeasurementParameters` field consists of an array of structures that describe a sequence of coordinate transformations from a child frame to a parent frame or the inverse transformations (see "Frame Rotation"). The longest possible sequence of transformations is Sensor → Platform → Scenario. For example, if the detections are reported in sensor spherical coordinates and `HasINS` is set to `false`, then the sequence consists of one transformation from sensor to platform. If `HasINS` is `true`, the sequence of transformations consists of two transformations – first to platform coordinates then to scenario coordinates. Trivially, if the detections are reported in platform rectangular coordinates and `HasINS` is set to `false`, the transformation consists only of the identity.

The structure fields are shown here. Not all fields have to be present in the structure. The set of fields and their default values can depend on the type of sensor.

Field	Description

`Frame`	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.
`OriginPosition`	Position offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
`OriginVelocity`	Velocity offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
`Orientation`	3-by-3 real-valued orthonormal frame rotation matrix.
`IsParentToChild`	A logical scalar indicating if `Orientation` performs a frame rotation from the parent coordinate frame to the child coordinate frame. If `false`, `Orientation` performs a frame rotation from the child coordinate frame to the parent coordinate frame.
`HasElevation`	A logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if `HasElevation` is `false`, the measurements are reported assuming 0 degrees of elevation.
`HasAzimuth`	A logical scalar indication if azimuth is included in the measurement.
`HasRange`	A logical scalar indication if range is included in the measurement.

HasVelocity	A logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if `HasVelocity` is `false`, the measurements are reported as `[x y z]`. If `HasVelocity` is `true`, measurements are reported as `[x y z vx vy vz]`.
Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.

Object attributes contain additional information about a detection.

Attribute	Description
TargetIndex	Identifier of the platform, `PlatformID`, that generated the detection. For false alarms, this value is negative.
EmitterIndex	Index of the emitter from which the detected signal was emitted.
SNR	Detection signal-to-noise ratio in dB.
CenterFrequency	• Measured center frequency of the detected radar signal. Units are in Hz. • This attribute is present only when the `DetectionMode` property is set to `'ESM'`.
Bandwidth	• Measured bandwidth of the detected radar signal, Units are in Hz. • This attribute is present only when the `DetectionMode` property is set to `'ESM'`.

WaveformType	• Identifier of the waveform type that was classified by the ESM sensor for the detected signal.
	• This attribute is present only when the DetectionMode property is set to 'ESM'.

Convenience Syntaxes

The convenience syntaxes set several properties together to model a specific type of radar.

Sets ScanMode to 'No scanning'.

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
HasElevation	true
MaxMechanicalScanRate	[75;75]
MechanicalScanLimits	[-45 45; -10 0]
ElectronicScanLimits	[-45 45; -10 0]

You can change the ScanMode property to 'Electronic' to perform an electronic raster scan over the same volume as a mechanical scan.

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
FieldOfView	[1:10]
HasElevation	false or true
MechanicalScanLimits	[0 360; -10 0]

ElevationResolution	10/sqrt(12)

This syntax sets these properties:

Property	**Value**
ScanMode	'Mechanical'
FieldOfView	[1;10]
HasElevation	false
MechanicalScanLimits	[-45 45; -10 0]
ElectronicScanLimits	[-45 45; -10 0]
ElevationResolution	10/sqrt(12)

Changing the ScanMode property to 'Electronic' lets you perform an electronic raster scan over the same volume as a mechanical scan.

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

Classes
objectDetection | radarEmission

Functions
targetPoses

System Objects
monostaticRadarSensor | trackerGNN | trackerTOMHT

Introduced in R2018b

irSensor System object

Generate infrared detections for tracking scenario

Description

The `irSensor` System object creates a statistical model for generatng detections from sonar emissions. You can generate detections from active or passive sonar systems. You can use the `irSensor` object in a scenario that models moving and stationary platforms using `trackingScenario`. The sonar sensor can simulate real detections with added random noise and also generate false alarm detections. In addition, you can use this object to create input to trackers such as `trackerGNN` or `trackerTOMHT`.

This object enables you to configure a mechanically scanning sensor. An infrared scanning sensor changes the look angle between updates by stepping the mechanical position of the beam in increments of the angular span specified in the `FieldOfView` property. The infrared sensor scans the total region in azimuth and elevation defined by the sonar electronic scan limits, `MechanicalScanLimits`. If the scanning limits for azimuth or elevation are set to `[0 0]`, no scanning is performed along that dimension for that scan mode. If the maximum electronic scan rate for azimuth or elevation is set to zero, no electronic scanning is performed along that dimension.

To generate infrared detections:

1   Create the `irSensor` 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

```
sensor = irSensor
```

```
sensor = irSensor(Name,Value)

sensor = irSensor('No scanning')
sensor = irSensor('Raster')
sensor = irSensor('Rotator')
sensor = irSensor('Sector')
sensor = irSensor(SensorIndex, ___ )
```

Description

`sensor = irSensor` creates an infrared detection generator object with default property values.

`sensor = irSensor(Name,Value)` sets properties using one or more name-value pairs. Enclose each property name in quotes. For example, `irSensor('UpdateRate', 1,'CutoffFrequency',20e3)` creates an infrared sensor that reports detections at an update rate of 1 Hz and a cut off frequency of 20 kHz.

`sensor = irSensor('No scanning')` is a convenience syntax that creates an `irSensor` that stares along the sensor boresight direction. No mechanical scanning is performed. This syntax sets the `ScanMode` property to `'No scanning'`.

`sensor = irSensor('Raster')` is a convenience syntax that creates an `irSensor` object that mechanically scans a raster pattern. The raster span is 90° in azimuth from –45° to +45° and in elevation from the horizon to 10° above the horizon. See "Raster Scanning" on page 3-178 for the properties set by this syntax.

`sensor = irSensor('Rotator')` is a convenience syntax that creates an `irSensor` object that mechanically scans 360° in azimuth by electronically rotating the sensor at a constant rate. When you set `HasElevation` to `true`, the infrared sensor mechanically points towards the center of the elevation field of view. See "Rotator Scanning" on page 3-178 for the properties set by this syntax.

`sensor = irSensor('Sector')` is a convenience syntax to create an `irSensor` object that mechanically scans a 90° azimuth sector from –45° to +45°. Setting `HasElevation` to `true`, points the infrared sensor towards the center of the elevation field of view. Beams are stacked mechanically to process the entire elevation spanned by the scan limits in a single dwell. See "Sector Scanning" on page 3-130 for the properties set by this syntax.

`sensor = irSensor(SensorIndex, ___ )` specifies the sensor ID, `irSensor`, as an input argument instead of using the `SensorIndex` name-value pair.

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).

SensorIndex — Unique sensor identifier
positive integer

Unique sensor identifier, specified as a positive integer. This property distinguishes detections that come from different sensors in a multi-sensor system. This property must be defined before you can execute the object.

Example: 5

Data Types: `double`

UpdateRate — Sensor update rate
1 (default) | positive scalar

Sensor update rate, specified as a positive scalar. This interval must be an integer multiple of the simulation time interval defined by `trackingScenario`. The `trackingScenario` object calls the sonar sensor at simulation time intervals. The sonar generates new detections at intervals defined by the reciprocal of the `UpdateRate` property. Any update requested to the sensor between update intervals contains no detections. Units are in hertz.

Example: 5

Data Types: `double`

ScanMode — Scanning mode of sonar
'Electronic' (default) | 'No scanning'

Scanning mode of sonar, specified as `'Electronic'` or `'No scanning'`.

Scan Modes

ScanMode	Purpose
`'Electronic'`	The sonar scans electronically across the azimuth and elevation limits specified by the `ElectronicScanLimits` property. The scan direction increments by the sonar field of view angle between dwells.
`'No scanning'`	The sonar beam points along the transducer boresight defined by the `mountingAngles` property.

Example: `'No scanning'`

Data Types: `char`

`MountingLocation` — Sensor location on platform
`[0 0 0]` (default) | 1-by-3 real-valued vector

Sensor location on platform, specified as a 1-by-3 real-valued vector. This property defines the coordinates of the sensor with respect to the platform origin. The default value specifies that the sensor origin is at the origin of its platform. Units are in meters.

Example: `[.2 0.1 0]`

Data Types: `double`

`MountingAngles` — Orientation of sensor
`[0 0 0]` (default) | 3-element real-valued vector

Orientation of the sensor with respect to the platform, specified as a three-element real-valued vector. Each element of the vector corresponds to an intrinsic Euler angle rotation that carries the body axes of the platform to the sensor axes. The three elements define the rotations around the *z*-, *y*-, and *x*-axes, in that order. The first rotation rotates the platform axes around the *z*-axis. The second rotation rotates the carried frame around the rotated *y*-axis. The final rotation rotates the frame around the carried *x*-axis. Units are in degrees.

Example: `[10 20 -15]`

Data Types: `double`

`FieldOfView` — Fields of view of sensor
`[1;5]` | real-valued 2-by-1 vector of positive real-values

Fields of view of sensor, specified as a 2-by-1 vector of positive real values, [azfov;elfov]. The field of view defines the total angular extent spanned by the sensor. Each component must lie in the interval (0,180). Targets outside of the field of view of the sonar are not detected. Units are in degrees.

Example: `[14;7]`

Data Types: `double`

MaxMechanicalScanRate — Maximum mechanical scan rate

`[75;75]` (default) | nonnegative scalar | real-valued 2-by-1 vector with nonnegative entries

Maximum mechanical scan rate, specified as a nonnegative scalar or real-valued 2-by-1 vector with nonnegative entries.

When HasElevation is `true`, specify the scan rate as a 2-by-1 column vector of nonnegative entries [maxAzRate; maxElRate]. maxAzRate is the maximum scan rate in azimuth and maxElRate is the maximum scan rate in elevation.

When `HasElevation` is `false`, specify the scan rate as a nonnegative scalar representing the maximum mechanical azimuth scan rate.

Scan rates set the maximum rate at which the infrared sensor can mechanically scan. The sensor sets its scan rate to step the mechanical angle by the field of regard. If the required scan rate exceeds the maximum scan rate, the maximum scan rate is used. Units are degrees per second.

Example: `[5;10]`

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

MechanicalScanLimits — Angular limits of mechanical scan directions of sensor

`[0 360;-10 0]` (default) | real-valued, 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of mechanical scan directions of sensor, specified as a real-valued, 1-by-2 row vector or a real-valued 2-by-2 matrix. The mechanical scan limits define the minimum and maximum mechanical angles the sensor can scan from its mounted orientation.

When `HasElevation` is `true`, the scan limits take the form [minAz maxAz; minEl maxEl]. minAz and maxAz represent the minimum and maximum limits of the azimuth angle scan. minEl and maxEl represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form [minAz maxAz]. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits cannot span more than 360° and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: `[-90 90;0 85]`

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'`.

Data Types: `double`

`MechanicalAngle` — Current mechanical scan angle
scalar | real-valued 2-by-1 vector

This property is read-only.

Current mechanical scan angle of sonar, returned as a scalar or real-valued 2-by-1 vector. When HasElevation is `true`, the scan angle takes the form [Az; El]. Az and El represent the azimuth and elevation scan angles, respectively, relative to the mounted angle of the sonar on the platform. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Data Types: `double`

`LookAngle` — Look angle of sensor
scalar | real-valued 2-by-1 vector

This property is read-only.

Look angle of sensor, specified as a scalar or real-valued 2-by-1 vector. Look angle depends on the mechanical angle set in the `ScanMode` property.

ScanMode	LookAngle
`'Mechanical'`	`MechanicalAngle`
`'No scanning'`	`0`

When HasElevation is `true`, the look angle takes the form [Az;El]. Az and El represent the azimuth and elevation look angles, respectively. When `HasElevation` is `false`, the look angle is a scalar representing the azimuth look angle.

LensDiameter — Lens diameter
`8.0e-2` (default) | positive scalar

Lens diameter, specified as a positive scalar. Units are in meters.

Example: `0.1`

Data Types: `double`

FocalLength — Focal length of sensor circular lens
`800` (default) | scalar

Focal length of sensor circular lens, specified as a scalar. The focal length in pixels is $f = F s$, where F is the focal length in millimeters and s is the number of pixels per millimeter. Units are in pixels.

Example: `500`

Data Types: `double`

NumDetectors — Number of infrared detectors in sensor imaging plane
`[1000 1000]` | positive, real-valued, two-element vector

Number of infrared detectors in the sensor imaging plane, specified as a positive, real-valued, two-element vector. The first element defines the number of rows in the imaging plane and the second element defines the number of columns in the imaging plane. The number of rows corresponds to the sensor elevation resolution and the number of columns corresponds to the sensor azimuth resolution.

Example: `[500 750]`

Data Types: `double`

CutoffFrequency — Cut off frequency of sensor modulation transfer function
`20e3` | positive scalar

Cut off frequency of the sensor modulation transfer function (MTF), specified as a positive scalar. Units are in hertz.

Example: `30.5e3`

Data Types: `double`

DetectorArea — Area of infrared detector element
1.44e-6 | positive scalar

Area of an infrared detector element or pixel, specified as a positive scalar. Units are in square-meters.

Example: 3.0e-5

Data Types: double

Detectivity — Specific detectivity of detector material
1.2e10 | positive scalar

Specific detectivity of the detector material, specified as a positive scalar. Units are cm-sqrt(Hz)/W.

Example: .9e10

Data Types: double

NoiseEquivalentBandwidth — Noise equivalent bandwidth of sensor
30 (default) | positive scalar

Noise equivalent bandwidth of sensor, specified as a positive scalar. Units are in Hz.

Example: 100

Data Types: double

FalseAlarmRate — False alarm rate
1e-6 (default) | positive scalar

False alarm report rate within each resolution cell, specified as a positive scalar in the range $[10^{-7}, 10^{-3}]$. Units are dimensionless. Resolution cells are determined from the AzimuthResolution property and the ElevationResolution property when enabled.

Example: 1e-5

Data Types: double

AzimuthResolution — Azimuth resolution of sonar
1 (default) | positive scalar

Azimuth resolution of the sonar, specified as a positive scalar. The azimuth resolution defines the minimum separation in azimuth angle at which the sonar can distinguish two

targets. The azimuth resolution is typically the 3-dB downpoint of the azimuth angle beamwidth of the sonar. Units are in degrees.

Data Types: `double`

ElevationResolution — Elevation resolution of sonar
`1` (default) | positive scalar

Elevation resolution of the sonar, specified as a positive scalar. The elevation resolution defines the minimum separation in elevation angle at which the sonar can distinguish two targets. The elevation resolution is typically the 3-dB downpoint in the elevation angle beamwidth of the sonar. Units are in degrees.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

AzimuthBiasFraction — Azimuth bias fraction
`0.1` (default) | nonnegative scalar

Azimuth bias fraction of the sonar, specified as a nonnegative scalar. The azimuth bias is expressed as a fraction of the azimuth resolution specified in `AzimuthResolution`. This value sets a lower bound on the azimuthal accuracy of the sonar. This value is dimensionless.

Data Types: `double`

ElevationBiasFraction — Elevation bias fraction
`0.1` (default) | nonnegative scalar

Elevation bias fraction of the sonar, specified as a nonnegative scalar. Elevation bias is expressed as a fraction of the elevation resolution specified by the value of the `ElevationResolution` property. This value sets a lower bound on the elevation accuracy of the sonar. This value is dimensionless.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

HasElevation — Enable sonar elevation scan and measurements
`false` (default) | `true`

Enable the sonar to measure target elevation angles and to scan in elevation, specified as `false` or `true`. Set this property to `true` to model a sonar sensor that can estimate target elevation and scan in elevation.

Data Types: `logical`

HasINS — Enable inertial navigation system (INS) input
`false` (default) | `true`

Enable the optional input argument that passes the current estimate of the sensor platform pose to the sensor, specified as `false` or `true`. When `true`, pose information is added to the `MeasurementParameters` structure of the reported detections. Pose information lets tracking and fusion algorithms estimate the state of the target detections in the north-east-down (NED) frame.

Data Types: `logical`

HasNoise — Enable addition of noise to sonar sensor measurements
`true` (default) | `false`

Enable addition of noise to sonar sensor measurements, specified as `true` or `false`. Set this property to `true` to add noise to the sonar measurements. Otherwise, the measurements have no noise. Even if you set `HasNoise` to `false`, the object still computes the `MeasurementNoise` property of each detection.

Data Types: `logical`

HasFalseAlarms — Enable creating false alarm sonar detections
`true` (default) | `false`

Enable creating false alarm sonar measurements, specified as `true` or `false`. Set this property to `true` to report false alarms. Otherwise, only actual detections are reported.

Data Types: `logical`

MaxNumDetectionsSource — Source of maximum number of detections reported
`'Auto'` (default) | `'Property'`

Source of maximum number of detections reported by the sensor, specified as `'Auto'` or `'Property'`. When this property is set to `'Auto'`, the sensor reports all detections. When this property is set to `'Property'`, the sensor reports up to the number of detections specified by the `MaxNumDetections` property.

Data Types: `char`

MaxNumDetections — Maximum number of reported detections
50 (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. Detections are reported in order of distance to the sensor until the maximum number is reached.

Dependencies

To enable this property, set the `MaxNumDetectionsSource` property to `'Property'`.

Data Types: `double`

Usage

Syntax

```
dets = sensor(targets,simTime)
dets = sensor(targets,ins,simTime)
[dets,numDets,config] = sensor( ___ )
```

Description

`dets = sensor(targets,simTime)` creates infrared detections, `dets`, from sensor measurements taken of `targets` at the current simulation time, `simTime`. The sensor can generate detections for multiple targets simultaneously.

`dets = sensor(targets,ins,simTime)` also specifies the INS estimated pose information, `ins`, for the sensor platform. INS information is used by tracking and fusion algorithms to estimate the target positions in the NED frame.

To enable this syntax, set the `HasINS` property to `true`.

`[dets,numDets,config] = sensor( ___ )` also returns the number of valid detections reported, `numValidDets`, and the configuration of the sensor, `config`, at the current simulation time.

Input Arguments

`targets` — Tracking scenario target poses
structure | structure array

Tracking scenario target poses, specified as a structure or array of structures. Each structure corresponds to a target. You can generate this structure using the `targetPoses` method of a platform. You can also create such a structure manually. The table shows the required fields of the structure:

Field	Description
`PlatformID`	Unique identifier for the platform, specified as a scalar positive integer. This is a required field with no default value.
`ClassID`	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
`Position`	Position of target in platform coordinates, specified as a real-valued, 1-by-3 vector. This is a required field with no default value. Units are in meters.
`Velocity`	Velocity of target in platform coordinates, specified as a real-valued, 1-by-3 vector. Units are in meters per second. The default is `[0 0 0]`.
`Acceleration`	Acceleration of target in platform coordinates specified as a 1-by-3 row vector. Units are in meters per second-squared. The default is `[0 0 0]`.

Field	Description
`Orientation`	Orientation of the target with respect to platform coordinates, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the platform coordinate system to the current target body coordinate system. Units are dimensionless. The default is `quaternion(1,0,0,0)`.
`AngularVelocity`	Angular velocity of target in platform coordinates, specified as a real-valued, 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is `[0 0 0]`.

The values of the `Position`, `Velocity`, and `Orientation` fields are defined with respect to the platform coordinate system.

simTime — Current simulation time
nonnegative scalar

Current simulation time, specified as a positive scalar. The `trackingScenario` object calls the infrared sensor at regular time intervals. The sensor generates new detections at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Example: `10.5`

Data Types: `double`

ins — Platform pose from INS
structure

Sensor platform pose obtained from the inertial navigation system (INS), specified as a structure.

Platform pose information from an inertial navigation system (INS) is a structure which has these fields:

Field	Definition
Position	Position of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters.
Velocity	Velocity of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters per second.
Orientation	Orientation of the INS with respect to the local NED coordinate system specified as a scalar quaternion or a 3-by-3 real-valued orthonormal frame rotation matrix. Defines the frame rotation from the local NED coordinate system to the current INS body coordinate system. This is also referred to as a "parent to child" rotation.

Dependencies

To enable this argument, set the `HasINS` property to `true`.

Data Types: `struct`

interference — Interfering or jamming signal
structure

Interfering or jamming signal, specified as a structure.

Dependencies

To enable this argument, set the `HasInterference` property to `true`.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

dets — sensor detections
cell array of `objectDetection` objects

Sensor detections, returned as a cell array of `objectDetection` objects. Each object has these properties:

Property	Definition
`Time`	Measurement time
`Measurement`	Object measurements
`MeasurementNoise`	Measurement noise covariance matrix
`SensorIndex`	Unique ID of the sensor
`ObjectClassID`	Object classification
`MeasurementParameters`	Parameters used by initialization functions of nonlinear Kalman tracking filters
`ObjectAttributes`	Additional information passed to tracker

`Measurement` and `MeasurementNoise` are reported in the coordinate system specified by the `DetectionCoordinates` property.

numDets — Number of detections
nonnegative integer

Number of detections reported, returned as a nonnegative integer.

- When the `MaxNumDetectionsSource` property is set to `'Auto'`, `numDets` is set to the length of `dets`.

- When the `MaxNumDetectionsSource` property is set to `'Property'`, `dets` is a cell array with length determined by the `MaxNumDetections` property. No more than `MaxNumDetections` number of detections are returned. If the number of detections is fewer than `MaxNumDetections`, the first `numDets` elements of `dets` hold valid detections. The remaining elements of `dets` are set to the default value.

Data Types: `double`

config — Current sensor configuration
structure

Current sensor configuration, specified as a structure. This output can be used to determine which objects fall within the sensor beam during object execution.

Field	Description

SensorIndex	Unique sensor index
IsValidTime	Valid detection time, returned as 0 or 1. IsValidTime is 0 when detection updates are requested at times that are between update intervals specified by UpdateInterval.
IsScanDone	IsScanDone is true when the sensor has completed a scan.
FieldOfView	Field of view of sensor determines which objects fall within the sensor beam during object execution. The field of view is defined as a 2-by-1 vector of positive real values, [azfov;elfov].
MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current sensor frame.

Data Types: struct

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

Detection Using Infrared Sensor

Detect a target with an infrared sensor.

First create a target structure.

```
tgt = struct( ...
    'PlatformID',1, ...
    'Position',[10e3 0 0], ...
    'Speed',900*1e3/3600);
```

Then create an IR sensor.

```
sensor = irSensor(1);
```

Generate detection from target.

```
time = 0;
[dets,numDets,config] = sensor(tgt,time)
```

```
dets =

  1×1 cell array

    {1×1 objectDetection}


numDets =

     1


config =

  struct with fields:

            SensorIndex: 1
            IsValidTime: 1
             IsScanDone: 0
            FieldOfView: [64.0108 64.0108]
```

```
MeasurementParameters: [1×1 struct]
```

Definitions

Object Detections

The sensor measures the coordinates of the target. The `Measurement` and `MeasurementNoise` values are reported in the coordinate system specified by the `DetectionCoordinates` property of the sensor.

When the `DetectionCoordinates` property is `'Scenario'`, `'Body'`, or `'Sensor rectangular'`, the `Measurement` and `MeasurementNoise` values are reported in rectangular coordinates. Velocities are only reported when the range rate property, `HasRangeRate`, is `true`.

When the `DetectionCoordinates` property is `'Sensor spherical'`, the `Measurement` and `MeasurementNoise` values are reported in a spherical coordinate system derived from the sensor rectangular coordinate system. Elevation and range rate are only reported when `HasElevation` and `HasRangeRate` are `true`.

Measurements are ordered as [azimuth, elevation, range, range rate]. Reporting of elevation and range rate depends on the corresponding `HasElevation` and `HasRangeRate` property values. Angles are in degrees, range is in meters, and range rate is in meters per second.

Measurement Coordinates

DetectionCoordinates	Measurement and Measurement Noise Coordinates		
`'Scenario'`	**Coordinate Dependence on HasRangeRate**		
`'Body'`			
`'Sensor rectangular'`	**HasRangeRate**	**Coordinates**	
	true	[x; y; z; vx; vy; vz]	
	false	[x; y; z]	
`'Sensor spherical'`	**Coordinate Dependence on HasRangeRate and HasElevation**		
	HasRangeRate	**HasElevation**	**Coordinates**
	true	true	[az; el; rng; rr]
	true	false	[az; rng; rr]
	false	true	[az; el; rng]
	false	false	[az; rng]

The `MeasurementParameters` field consists of an array of structures that describe a sequence of coordinate transformations from a child frame to a parent frame or the inverse transformations (see "Frame Rotation"). The longest possible sequence of transformations is Sensor → Platform → Scenario. For example, if the detections are reported in sensor spherical coordinates and `HasINS` is set to `false`, then the sequence consists of one transformation from sensor to platform. If `HasINS` is `true`, the sequence of transformations consists of two transformations – first to platform coordinates then to scenario coordinates. Trivially, if the detections are reported in platform rectangular coordinates and `HasINS` is set to `false`, the transformation consists only of the identity.

The structure fields are shown here. Not all fields have to be present in the structure. The set of fields and their default values can depend on the type of sensor.

Field	Description

Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, Frame is set to 'rectangular'. When detections are reported in spherical coordinates, Frame is set 'spherical' for the first struct.
OriginPosition	Position offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
Orientation	3-by-3 real-valued orthonormal frame rotation matrix.
IsParentToChild	A logical scalar indicating if Orientation performs a frame rotation from the parent coordinate frame to the child coordinate frame. If false, Orientation performs a frame rotation from the child coordinate frame to the parent coordinate frame.
HasElevation	A logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the measurements are reported assuming 0 degrees of elevation.
HasAzimuth	A logical scalar indication if azimuth is included in the measurement.
HasRange	A logical scalar indication if range is included in the measurement.

HasVelocity	A logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if `HasVelocity` is `false`, the measurements are reported as `[x y z]`. If `HasVelocity` is `true`, measurements are reported as `[x y z vx vy vz]`.
Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.

Object attributes contain additional information about a detection:

Attribute	Description
TargetIndex	Identifier of the platform, `PlatformID`, that generated the detection. For false alarms, this value is negative.
SNR	Detection signal-to-noise ratio in dB.

Convenience Syntaxes

The convenience syntaxes set several properties together to model a specific type of infrared sensor.

Sets `ScanMode` to 'No scanning'.

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'

HasElevation	true
MaxMechanicalScanRate	[75;75]
MechanicalScanLimits	[-45 45; -10 0]
ElectronicScanLimits	[-45 45; -10 0]

You can change the `ScanMode` property to `'Electronic'` to perform an electronic raster scan over the same volume as a mechanical scan.

This syntax sets these properties:

Property	**Value**
ScanMode	'Mechanical'
FieldOfView	[1:10]
HasElevation	false or true
MechanicalScanLimits	[0 360; -10 0]
ElevationResolution	10/sqrt(12)

This syntax sets these properties:

Property	**Value**
ScanMode	'Mechanical'
FieldOfView	[1;10]
HasElevation	false
MechanicalScanLimits	[-45 45; -10 0]
ElectronicScanLimits	[-45 45; -10 0]
ElevationResolution	10/sqrt(12)

Changing the `ScanMode` property to `'Electronic'` lets you perform an electronic raster scan over the same volume as a mechanical scan.

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

Classes
objectDetection

Functions
targetPoses

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

sonarSensor System object

Generate detections from sonar emissions

Description

The `sonarSensor` System object creates a statistical model for generating detections from infrared emissions. You can generate detections from active or passive sonar systems. You can use the `sonarSensor` object in a scenario that models moving and stationary platforms using `trackingScenario`. The infrared sensor can simulate real detections with added random noise and also generate false alarm detections. In addition, you can use this object to create input to trackers such as `trackerGNN` or `trackerTOMHT`.

This object enables you to configure an electronically scanning sonar. A scanning sonar changes the look angle between updates by stepping the electronic position of the beam in increments of the angular span specified in the `FieldOfView` property. The sonar scans the total region in azimuth and elevation defined by the sonar electronic scan limits, `ElectronicScanLimits`. If the scanning limits for azimuth or elevation are set to `[0 0]`, no scanning is performed along that dimension for that scan mode. If the maximum electronic scan rate for azimuth or elevation is set to zero, no electronic scanning is performed along that dimension.

To generate sonar detections:

1 Create the `sonarSensor` 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

```
sensor = sonarSensor
```

```
sensor = sonarSensor(Name,Value)

sensor = sonarSensor('No scanning')
sensor = sonarSensor('Raster')
sensor = sonarSensor('Rotator')
sensor = sonarSensor('Sector')
sensor = sonarSensor(SensorIndex, ___ )
```

Description

`sensor = sonarSensor` creates a sonar detection generator object with default property values.

`sensor = sonarSensor(Name,Value)` sets properties using one or more name-value pairs. Enclose each property name in quotes. For example, `sonarSensor('DetectionCoordinates','Sensor cartesian','MaxRange', 200)` creates a sonar detection generator that reports detections in the sensor Cartesian coordinate system and has a maximum detection range of 200 meters.

`sensor = sonarSensor('No scanning')` is a convenience syntax that creates a `sonarSensor` that stares along the sonar transducer boresight direction. No electronic scanning is performed. This syntax sets the `ScanMode` property to `'No scanning'`.

`sensor = sonarSensor('Raster')` is a convenience syntax that creates a `sonarSensor` object that electronically scans a raster pattern. The raster span is 90° in azimuth from –45° to +45° and in elevation from the horizon to 10° above the horizon. See "Raster Scanning" on page 3-178 for the properties set by this syntax.

`sensor = sonarSensor('Rotator')` is a convenience syntax that creates a `sonarSensor` object that electronically scans 360° in azimuth by electronically rotating the transducer at a constant rate. When you set `HasElevation` to `true`, the sonar transducer electronically points towards the center of the elevation field of view. See "Rotator Scanning" on page 3-178 for the properties set by this syntax.

`sensor = sonarSensor('Sector')` is a convenience syntax to create a `sonarSensor` object that electronically scans a 90° azimuth sector from –45° to +45°. Setting `HasElevation` to `true`, points the sonar transducer towards the center of the elevation field of view. Beams are stacked electronically to process the entire elevation spanned by the scan limits in a single dwell. See "Sector Scanning" on page 3-130 for the properties set by this syntax.

sensor = sonarSensor(SensorIndex, ___) specifies the sensor ID, `SensorIndex`, as an input argument instead of using the `SensorIndex` name-value pair.

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).

SensorIndex — Unique sensor identifier
positive integer

Unique sensor identifier, specified as a positive integer. This property distinguishes detections that come from different sensors in a multi-sensor system. This property must be defined before you can execute the object.

Example: 5

Data Types: `double`

UpdateRate — Sensor update rate
1 (default) | positive scalar

Sensor update rate, specified as a positive scalar. This interval must be an integer multiple of the simulation time interval defined by `trackingScenario`. The `trackingScenario` object calls the sonar sensor at simulation time intervals. The sonar generates new detections at intervals defined by the reciprocal of the `UpdateRate` property. Any update requested to the sensor between update intervals contains no detections. Units are in hertz.

Example: 5

Data Types: `double`

DetectionMode — Detection mode
'passive' (default) | 'monostatic'

Detection mode, specified as `'passive'` or `'monostatic'`. When set to `'passive'`, the sensor operates passively. When set to `'monostatic'`, the sensor generates detections from reflected signals originating from a collocated sonar emitter.

Example: `'Monostatic'`

Data Types: `char` | `string`

EmitterIndex — Unique monostatic emitter index
positive integer

Unique monostatic emitter index, specified as a positive integer. The emitter index identifies the monostatic sonar emitter providing the reference signal to the sensor.

Example: `404`

Dependencies

Set this property when the `DetectionMode` property is set to `'monostatic'`.

Data Types: `double`

MountingLocation — Sensor location on platform
`[0 0 0]` (default) | 1-by-3 real-valued vector

Sensor location on platform, specified as a 1-by-3 real-valued vector. This property defines the coordinates of the sensor with respect to the platform origin. The default value specifies that the sensor origin is at the origin of its platform. Units are in meters.

Example: `[.2 0.1 0]`

Data Types: `double`

MountingAngles — Orientation of sensor
`[0 0 0]` (default) | 3-element real-valued vector

Orientation of the sensor with respect to the platform, specified as a three-element real-valued vector. Each element of the vector corresponds to an intrinsic Euler angle rotation that carries the body axes of the platform to the sensor axes. The three elements define the rotations around the z-, y-, and x-axes, in that order. The first rotation rotates the platform axes around the z-axis. The second rotation rotates the carried frame around the rotated y-axis. The final rotation rotates the frame around the carried x-axis. Units are in degrees.

Example: `[10 20 -15]`

Data Types: `double`

`FieldOfView` — Fields of view of sensor
[1;5] | real-valued 2-by-1 vector of positive real-values

Fields of view of sensor, specified as a 2-by-1 vector of positive real values, [azfov;elfov]. The field of view defines the total angular extent spanned by the sensor. Each component must lie in the interval (0,180]. Targets outside of the field of view of the sonar are not detected. Units are in degrees.

Example: `[14;7]`

Data Types: `double`

`ScanMode` — Scanning mode of sonar
`'Electronic'` (default) | `'No scanning'`

Scanning mode of sonar, specified as `'Electronic'` or `'No scanning'`.

Scan Modes

ScanMode	Purpose
`'Electronic'`	The sonar scans electronically across the azimuth and elevation limits specified by the `ElectronicScanLimits` property. The scan direction increments by the sonar field of view angle between dwells.
`'No scanning'`	The sonar beam points along the transducer boresight defined by the `mountingAngles` property.

Example: `'No scanning'`

Data Types: `char`

`MechanicalAngle` — Current mechanical scan angle
scalar | real-valued 2-by-1 vector

This property is read-only.

Current mechanical scan angle of sonar, returned as a scalar or real-valued 2-by-1 vector. When HasElevation is `true`, the scan angle takes the form [Az; El]. Az and El represent the azimuth and elevation scan angles, respectively, relative to the mounted angle of the

sonar on the platform. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Data Types: `double`

`ElectronicScanLimits` — Angular limits of electronic scan directions of sonar
`[-45 45;-45 45]` (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of electronic scan directions of sonar, specified as a real-valued, 1-by-2 row vector or a real-valued 2-by-2 matrix. The electronic scan limits define the minimum and maximum electronic angles the sonar can scan from its current mechanical direction.

When HasElevation is `true`, the scan limits take the form [minAz maxAz; minEl maxEl]. minAz and maxAz represent the minimum and maximum limits of the azimuth angle scan. minEl and maxEl represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form [minAz maxAz]. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: `[-90 90;0 85]`

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'`.

Data Types: `double`

`ElectronicAngle` — Current electronic scan angle
electronic scalar | nonnegative scalar

This property is read-only.

Current electronic scan angle of sonar, returned as a scalar or 1-by-2 column vector. When `HasElevation` is `true`, the scan angle takes the form [Az;El]. Az and El represent the azimuth and elevation scan angles, respectively. When HasElevation is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'`.

Data Types: `double`

LookAngle — Look angle of sensor
scalar | real-valued 2-by-1 vector

This property is read-only.

Look angle of sensor, specified as a scalar or real-valued 2-by-1 vector. Look angle depends on the electronic angle set in the `ScanMode` property.

ScanMode	LookAngle
'Electronic'	ElectronicAngle
'No scanning'	0

When HasElevation is `true`, the look angle takes the form [Az;El]. Az and El represent the azimuth and elevation look angles, respectively. When `HasElevation` is `false`, the look angle is a scalar representing the azimuth look angle.

HasElevation — Enable sonar elevation scan and measurements
`false` (default) | `true`

Enable the sonar to measure target elevation angles and to scan in elevation, specified as `false` or `true`. Set this property to `true` to model a sonar sensor that can estimate target elevation and scan in elevation.

Data Types: `logical`

CenterFrequency — Center frequency of sonar band
`20e3` (default) | positive scalar

Center frequency of sonar band, specified as a positive scalar. Units are in hertz.

Example: `25.5e3`

Data Types: `double`

Bandwidth — Sonar waveform bandwidth
`2e3` | positive scalar

Sonar waveform bandwidth, specified as a positive scalar. Units are in hertz.

Example: `1.5e3`

Data Types: `double`

3-161

WaveformTypes — Types of detected waveforms
0 (default) | nonnegative integer-valued *L*-element vector

Types of detected waveforms, specified as a nonnegative integer-valued *L*-element vector.

Example: [1 4 5]

Data Types: double

ConfusionMatrix — Probability of correct classification of detected waveform
1 (default) | positive scalar | real-valued nonnegative *L*-element vector | real-valued nonnegative *L*-by-*L* matrix

Probability of correct classification of a detected waveform, specified as a positive scalar, a real-valued nonnegative *L*-element vector, or a real-valued nonnegative *L*-by-*L* matrix. Matrix values range from 0 through 1 and matrix rows must sum to 1. *L* is the number of waveform types that the sensor can detect, as indicated by the value set in the WaveformTypes property. The (i,j) matrix element represents the probability of classifying the ith waveform as the jth waveform. When specified as a scalar from 0 through 1, the value is expanded along the diagonal of the confusion matrix. When specified as a vector, it must have the same number of elements as the WaveformTypes property. When defined as a scalar or a vector, the off diagonal values are set to (1-val)/(L-1).

Data Types: double

AmbientNoiseLevel — Spectrum-level ambient isotropic noise
70 (default) | scalar

Spectrum-level ambient isotropic noise, specified as a scalar. Units are in dB relative to the intensity of a plane wave with 1 µPa rms pressure in a 1-hertz frequency band.

Example: 25

Data Types: double

FalseAlarmRate — False alarm rate
1e-6 (default) | positive scalar

False alarm report rate within each resolution cell, specified as a positive scalar in the range *[10^{-7},10^{-3}]*. Units are dimensionless. Resolution cells are determined from the AzimuthResolutionproperty and the ElevationResolution property when enabled.

Example: 1e-5

Data Types: `double`

AzimuthResolution — Azimuth resolution of sonar

1 (default) | positive scalar

Azimuth resolution of the sonar, specified as a positive scalar. The azimuth resolution defines the minimum separation in azimuth angle at which the sonar can distinguish two targets. The azimuth resolution is typically the 3-dB downpoint of the azimuth angle beamwidth of the sonar. Units are in degrees.

Data Types: `double`

ElevationResolution — Elevation resolution of sonar

1 (default) | positive scalar

Elevation resolution of the sonar, specified as a positive scalar. The elevation resolution defines the minimum separation in elevation angle at which the sonar can distinguish two targets. The elevation resolution is typically the 3-dB downpoint in the elevation angle beamwidth of the sonar. Units are in degrees.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

RangeResolution — Range resolution of sonar

100 (default) | positive scalar

Range resolution of the sonar, specified as a positive scalar. The range resolution defines the minimum separation in range at which the sonar can distinguish between two targets. Units are in meters.

Data Types: `double`

RangeRateResolution — Range rate resolution of sonar

10 (default) | positive scalar

Range rate resolution of the sonar, specified as a positive scalar. The range rate resolution defines the minimum separation in range rate at which the sonar can distinguish between two targets. Units are in meters per second.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

AzimuthBiasFraction — Azimuth bias fraction
`0.1` (default) | nonnegative scalar

Azimuth bias fraction of the sonar, specified as a nonnegative scalar. The azimuth bias is expressed as a fraction of the azimuth resolution specified in `AzimuthResolution`. This value sets a lower bound on the azimuthal accuracy of the sonar. This value is dimensionless.

Data Types: `double`

ElevationBiasFraction — Elevation bias fraction
`0.1` (default) | nonnegative scalar

Elevation bias fraction of the sonar, specified as a nonnegative scalar. Elevation bias is expressed as a fraction of the elevation resolution specified by the value of the `ElevationResolution` property. This value sets a lower bound on the elevation accuracy of the sonar. This value is dimensionless.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

RangeBiasFraction — Range bias fraction
`0.05` (default) | nonnegative scalar

Range bias fraction of the sonar, specified as a nonnegative scalar. Range bias is expressed as a fraction of the range resolution specified in `RangeResolution`. This property sets a lower bound on the range accuracy of the sonar. This value is dimensionless.

Data Types: `double`

RangeRateBiasFraction — Range rate bias fraction
`0.05` (default) | nonnegative scalar

Range rate bias fraction of the sonar, specified as a nonnegative scalar. Range rate bias is expressed as a fraction of the range rate resolution specified in `RangeRateResolution`. This property sets a lower bound on the range-rate accuracy of the sonar. This value is dimensionless.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

HasRangeRate — Enable sonar to measure range rate
`false` (default) | `true`

Enable the sonar to measure target range rates, specified as `false` or `true`. Set this property to `true` to model a sonar sensor that can measure target range rate. Set this property to `false` to model a sonar sensor that cannot measure range rate.

Data Types: `logical`

HasRangeAmbiguities — Enable range ambiguities
`false` (default) | `true`

Enable range ambiguities, specified as `false` or `true`. Set this property to `true` to enable range ambiguities by the sensor. In this case, the sensor cannot resolve range ambiguities for targets at ranges beyond the MaxUnambiguousRange are wrapped into the interval `[0 MaxUnambiguousRange]`. When `false`, targets are reported at their unambiguous range.

Data Types: `logical`

HasRangeRateAmbiguities — Enable range-rate ambiguities
`false` (default) | `true`

Enable range-rate ambiguities, specified as `false` or `true`. Set to `true` to enable range-rate ambiguities by the sensor. When `true`, the sensor does not resolve range rate ambiguities and target range rates beyond the `MaxUnambiguousRadialSpeed` are wrapped into the interval `[0,MaxUnambiguousRadialSpeed]`. When `false`, targets are reported at their unambiguous range rate.

Dependencies

To enable this property, set the HasRangeRate property to `true`.

Data Types: `logical`

MaxUnambiguousRange — Maximum unambiguous detection range
`100e3` (default) | positive scalar

Maximum unambiguous range, specified as a positive scalar. Maximum unambiguous range defines the maximum range for which the sonar can unambiguously resolve the range of a target. When HasRangeAmbiguities is set to `true`, targets detected at ranges beyond the maximum unambiguous range are wrapped into the range interval `[0,MaxUnambiguousRange]`. This property applies to true target detections when you set the `HasRangeAmbiguities` property to `true`.

This property also applies to false target detections when you set the `HasFalseAlarms` property to `true`. In this case, the property defines the maximum range for false alarms.

Units are in meters.

Example: `5e3`

Dependencies

To enable this property, set the `HasRangeAmbiguities` property to `true` or set the `HasFalseAlarms` property to `true`.

Data Types: `double`

MaxUnambiguousRadialSpeed — Maximum unambiguous radial speed
200 (default) | positive scalar

Maximum unambiguous radial speed, specified as a positive scalar. Radial speed is the magnitude of the target range rate. Maximum unambiguous radial speed defines the radial speed for which the sonar can unambiguously resolve the range rate of a target. When `HasRangeRateAmbiguities` is set to `true`, targets detected at range rates beyond the maximum unambiguous radial speed are wrapped into the range rate interval `[-MaxUnambiguousRadialSpeed, MaxUnambiguousRadialSpeed]`. This property applies to true target detections when you set `HasRangeRateAmbiguities` property to `true`.

This property also applies to false target detections obtained when you set both the `HasRangeRate` and `HasFalseAlarms` properties to `true`. In this case, the property defines the maximum radial speed for which false alarms can be generated.

Units are in meters per second.

Dependencies

To enable this property, set `HasRangeRate` and `HasRangeRateAmbiguities` to `true` and/or set `HasRangeRate` and `HasFalseAlarms` to `true`.

Data Types: double

HasINS — Enable inertial navigation system (INS) input
false (default) | true

Enable the optional input argument that passes the current estimate of the sensor platform pose to the sensor, specified as false or true. When true, pose information is added to the MeasurementParameters structure of the reported detections. Pose information lets tracking and fusion algorithms estimate the state of the target detections in the north-east-down (NED) frame.

Data Types: logical

HasNoise — Enable addition of noise to sonar sensor measurements
true (default) | false

Enable addition of noise to sonar sensor measurements, specified as true or false. Set this property to true to add noise to the sonar measurements. Otherwise, the measurements have no noise. Even if you set HasNoise to false, the object still computes the MeasurementNoise property of each detection.

Data Types: logical

HasFalseAlarms — Enable creating false alarm sonar detections
true (default) | false

Enable creating false alarm sonar measurements, specified as true or false. Set this property to true to report false alarms. Otherwise, only actual detections are reported.

Data Types: logical

MaxNumDetectionsSource — Source of maximum number of detections reported
'Auto' (default) | 'Property'

Source of maximum number of detections reported by the sensor, specified as 'Auto' or 'Property'. When this property is set to 'Auto', the sensor reports all detections. When this property is set to 'Property', the sensor reports up to the number of detections specified by the MaxNumDetections property.

Data Types: char

MaxNumDetections — Maximum number of reported detections
50 (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. Detections are reported in order of distance to the sensor until the maximum number is reached.

Dependencies

To enable this property, set the `MaxNumDetectionsSource` property to `'Property'`.

Data Types: `double`

DetectionCoordinates — Coordinate system of reported detections
`'Body'` (default) | `'Scenario'` | `'Sensor rectangular` | `'Sensor spherical'`

Coordinate system of reported detections, specified as:

- `'Scenario'` — Detections are reported in the rectangular scenario coordinate frame. The scenario coordinate system is defined as the local NED frame at simulation start time. To enable this value, set the `HasINS` property to `true`.
- `'Body'` — Detections are reported in the rectangular body system of the sensor platform.
- `'Sensor rectangular'` — Detections are reported in the sonar sensor rectangular body coordinate system.
- `'Sensor spherical'` — Detections are reported in a spherical coordinate system derived from the sensor rectangular body coordinate system. This coordinate system is centered at the sonar sensor and aligned with the orientation of the sonar on the platform.

Example: `'Sensor spherical'`

Data Types: `char`

Usage

Syntax

```
dets = sensor(sonarsigs,simTime)
dets = sensor(sonarsigs,txconfigs,simTime)
dets = sensor( ___ ,ins,simTime)
[dets,numDets,config] = sensor( ___ )
```

Description

`dets = sensor(sonarsigs,simTime)` creates passive detections, `dets`, from sonar emissions, `sonarsigs`, at the current simulation time, `simTime`. The sensor generates detections at the rate defined by the `UpdateRate` property.

`dets = sensor(sonarsigs,txconfigs,simTime)` also specifies emitter configurations, `txconfigs`, at the current simulation time.

`dets = sensor( ___ ,ins,simTime)` also specifies the inertial navigation system (INS) estimated sensor platform pose, `ins`. INS information is used by tracking and fusion algorithms to estimate the target positions in the NED frame.

To enable this syntax, set the `HasINS` property to `true`.

`[dets,numDets,config] = sensor( ___ )` also returns the number of valid detections reported, `numValidDets`, and the configuration of the sensor, `config`, at the current simulation time.

Input Arguments

sonarsigs — Sonar emissions
array of sonar emission objects

Sonar emissions, specified as an array of `sonarEmission` objects.

txconfigs — Emitter configurations
array of structures

Emitter configurations, specified as an array of structures. Each structure has these fields:

Field	Description
EmitterIndex	Unique emitter index
IsValidTime	Valid emission time, returned as `0` or `1`. `IsValidTime` is `0` when emitter updates are requested at times that are between update intervals specified by `UpdateInterval`.

IsScanDone	IsScanDone is `true` when the emitter has completed a scan.
FieldOfView	Field of view of emitter.
MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current emitter frame.

Data Types: `struct`

`ins` — Platform pose from INS
structure

Sensor platform pose obtained from the inertial navigation system (INS), specified as a structure.

Platform pose information from an inertial navigation system (INS) is a structure which has these fields:

Field	Definition
Position	Position of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters.
Velocity	Velocity of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters per second.
Orientation	Orientation of the INS with respect to the local NED coordinate system specified as a scalar quaternion or a 3-by-3 real-valued orthonormal frame rotation matrix. Defines the frame rotation from the local NED coordinate system to the current INS body coordinate system. This is also referred to as a "parent to child" rotation.

Dependencies

To enable this argument, set the `HasINS` property to `true`.

Data Types: `struct`

simTime — Current simulation time
nonnegative scalar

Current simulation time, specified as a positive scalar. The `trackingScenario` object calls the sonar sensor at regular time intervals. The sonar sensor generates new detections at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Example: `10.5`

Data Types: `double`

Output Arguments

dets — sensor detections
cell array of `objectDetection` objects

Sensor detections, returned as a cell array of `objectDetection` objects. Each object has these properties:

Property	Definition
`Time`	Measurement time
`Measurement`	Object measurements
`MeasurementNoise`	Measurement noise covariance matrix
`SensorIndex`	Unique ID of the sensor
`ObjectClassID`	Object classification
`MeasurementParameters`	Parameters used by initialization functions of nonlinear Kalman tracking filters
`ObjectAttributes`	Additional information passed to tracker

`Measurement` and `MeasurementNoise` are reported in the coordinate system specified by the `DetectionCoordinates` property.

numDets — Number of detections
nonnegative integer

Number of detections reported, returned as a nonnegative integer.

- When the MaxNumDetectionsSource property is set to 'Auto', numDets is set to the length of dets.
- When the MaxNumDetectionsSource property is set to 'Property', dets is a cell array with length determined by the MaxNumDetections property. No more than MaxNumDetections number of detections are returned. If the number of detections is fewer than MaxNumDetections, the first numDets elements of dets hold valid detections. The remaining elements of dets are set to the default value.

Data Types: double

config — Current sensor configuration
structure

Current sensor configuration, specified as a structure. This output can be used to determine which objects fall within the sonar beam during object execution.

Field	Description
SensorIndex	Unique sensor index
IsValidTime	Valid detection time, returned as 0 or 1. IsValidTime is 0 when detection updates are requested at times that are between update intervals specified by UpdateInterval.
IsScanDone	IsScanDone is true when the sensor has completed a scan.
FieldOfView	Field of view of sensor determines which objects fall within the sensor beam during object execution. The field of view is defined as a 2-by-1 vector of positive real values, [azfov;elfov].

MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current sensor frame.

Data Types: `struct`

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 Sonar Emission with Passive Sensor

Create a sonar emission and then detect the emission using a `sonarSensor` object.

First, create a sonar emission.

```
orient = quaternion([180 0 0],'eulerd','zyx','frame');
sonarSig = sonarEmission('PlatformID',1,'EmitterIndex',1, ...
    'OriginPosition',[30 0 0],'Orientation',orient, ...
    'SourceLevel',140,'TargetStrength',100);
```

Then create a passive sonar sensor.

```
sensor = sonarSensor(1,'No scanning');
```

Detect the sonar emission.

```
time = 0;
[dets, numDets, config] = sensor(sonarSig,time)

dets =

  1×1 cell array

    {1×1 objectDetection}


numDets =

     1


config =

  struct with fields:

            SensorIndex: 1
            IsValidTime: 1
             IsScanDone: 1
            FieldOfView: [1 5]
    MeasurementParameters: [1×1 struct]
```

Definitions

Object Detections

The sensor measures the coordinates of the target. The `Measurement` and `MeasurementNoise` values are reported in the coordinate system specified by the `DetectionCoordinates` property of the sensor.

When the `DetectionCoordinates` property is `'Scenario'`, `'Body'`, or `'Sensor rectangular'`, the `Measurement` and `MeasurementNoise` values are reported in rectangular coordinates. Velocities are only reported when the range rate property, `HasRangeRate`, is `true`.

When the `DetectionCoordinates` property is `'Sensor spherical'`, the `Measurement` and `MeasurementNoise` values are reported in a spherical coordinate system derived from the sensor rectangular coordinate system. Elevation and range rate are only reported when `HasElevation` and `HasRangeRate` are `true`.

Measurements are ordered as [azimuth, elevation, range, range rate]. Reporting of elevation and range rate depends on the corresponding `HasElevation` and `HasRangeRate` property values. Angles are in degrees, range is in meters, and range rate is in meters per second.

Measurement Coordinates

DetectionCoordinates	Measurement and Measurement Noise Coordinates		
`'Scenario'`	**Coordinate Dependence on HasRangeRate**		
`'Body'`			
`'Sensor rectangular'`	**HasRangeRate**	**Coordinates**	
	true	[x; y; z; vx; vy; vz]	
	false	[x; y; z]	
`'Sensor spherical'`	**Coordinate Dependence on HasRangeRate and HasElevation**		
	HasRangeRate	**HasElevation**	**Coordinates**
	true	true	[az; el; rng; rr]
	true	false	[az; rng; rr]
	false	true	[az; el; rng]
	false	false	[az; rng]

The `MeasurementParameters` field consists of an array of structures that describe a sequence of coordinate transformations from a child frame to a parent frame or the inverse transformations (see "Frame Rotation"). The longest possible sequence of transformations is Sensor → Platform → Scenario. For example, if the detections are reported in sensor spherical coordinates and `HasINS` is set to `false`, then the sequence consists of one transformation from sensor to platform. If `HasINS` is `true`, the sequence

of transformations consists of two transformations – first to platform coordinates then to scenario coordinates. Trivially, if the detections are reported in platform rectangular coordinates and `HasINS` is set to `false`, the transformation consists only of the identity.

The structure fields are shown here. Not all fields have to be present in the structure. The set of fields and their default values can depend on the type of sensor.

Field	Description
Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.
OriginPosition	Position offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
Orientation	3-by-3 real-valued orthonormal frame rotation matrix.
IsParentToChild	A logical scalar indicating if `Orientation` performs a frame rotation from the parent coordinate frame to the child coordinate frame. If `false`, `Orientation` performs a frame rotation from the child coordinate frame to the parent coordinate frame.
HasElevation	A logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if `HasElevation` is `false`, the measurements are reported assuming 0 degrees of elevation.
HasAzimuth	A logical scalar indication if azimuth is included in the measurement.

HasRange	A logical scalar indication if range is included in the measurement.
HasVelocity	A logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if `HasVelocity` is `false`, the measurements are reported as `[x y z]`. If `HasVelocity` is `true`, measurements are reported as `[x y z vx vy vz]`.
Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.

Object attributes contain additional information about a detection.

Attribute	Description
TargetIndex	Identifier of the platform, `PlatformID`, that generated the detection. For false alarms, this value is negative.
EmitterIndex	Index of the emitter from which the detected signal was emitted.
SNR	Detection signal-to-noise ratio in dB.
CenterFrequency	• Measured center frequency of the detected sonar signal. Units are in Hz. • This attribute is present only when the `DetectionMode` property is set to `'passive'`.

Bandwidth	• Measured bandwidth of the detected sonar signal, Units are in Hz.
	• This attribute is present only when the `DetectionMode` property is set to `'passive'`.
WaveformType	• Identifier of the waveform type that was classified by a passive sensor for the detected signal.
	• This attribute is present only when the `DetectionMode` property is set to `'passive'`.

Convenience Syntaxes

The convenience syntaxes set several properties together to model a specific type of sonar.

Sets `ScanMode` to 'No scanning'.

This syntax sets these properties:

Property	Value
ScanMode	`'Electronic'`
HasElevation	true
ElectronicScanLimits	`[-45 45; -10 0]`

This syntax sets these properties:

Property	Value
ScanMode	`'Electronic'`
FieldOfView	`[1:10]`
HasElevation	false or true
ElevationResolution	10/sqrt(12)

This syntax sets these properties:

Property	Value
ScanMode	`'Electronic'`
FieldOfView	`[1;10]`
HasElevation	`false`
ElectronicScanLimits	`[-45 45; -10 0]`
ElevationResolution	`10/sqrt(12)`

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

Classes
objectDetection | sonarEmission

Functions
targetPoses

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

radarEmitter System object

Radar signals and interferences generator

Description

The `radarEmitter` System object creates an emitter to simulate radar emissions. You can use the `radarEmitter` object in a scenario that detects and tracks moving and stationary platforms. Construct a scenario using `trackingScenario`.

A radar emitter changes the look angle between updates by stepping the mechanical and electronic position of the beam in increments of the angular span specified in the `FieldOfView` property. The radar scans the total region in azimuth and elevation defined by the radar mechanical and electronic scan limits, `MechanicalScanLimits` and `ElectronicScanLimits`, respectively. If the scan limits for azimuth or elevation are set to `[0 0]`, then no scanning is performed along that dimension for that scan mode. If the maximum mechanical scan rate for azimuth or elevation is set to zero, then no mechanical scanning is performed along that dimension.

To generate radar detections:

1   Create the `radarEmitter` 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

```
emitter = radarEmitter
emitter = radarEmitter(Name,Value)

emitter = radarEmitter('No scanning')
```

```
emitter = radarEmitter('Raster')
emitter = radarEmitter('Rotator')
emitter = radarEmitter('Sector')
emitter = radarEmitter(EmitterIndex, ___ )
```

Description

`emitter = radarEmitter` creates a radar emitter object with default property values.

`emitter = radarEmitter(Name,Value)` sets properties using one or more name-value pairs. Enclose each property name in quotes. For example, `radarEmitter('CenterFrequency',2e6)` creates a radar emitter creates detections in the emitter Cartesian coordinate system and has a maximum detection range of 200 meters.

`emitter = radarEmitter('No scanning')` is a convenience syntax that creates a `radarEmitter` that stares along the radar antenna boresight direction. No mechanical or electronic scanning is performed. This syntax sets the `ScanMode` property to `'No scanning'`.

`emitter = radarEmitter('Raster')` is a convenience syntax that creates a `radarEmitter` object that mechanically scans a raster pattern. The raster span is 90° in azimuth from –45° to +45° and in elevation from the horizon to 10° above the horizon. See "Raster Scanning" on page 3-304 for the properties set by this syntax.

`emitter = radarEmitter('Rotator')` is a convenience syntax that creates a `radarEmitter` object that mechanically scans 360° in azimuth by mechanically rotating the antenna at a constant rate. When you set `HasElevation` to `true`, the radar antenna mechanically points towards the center of the elevation field of view. See "Rotator Scanning" on page 3-305 for the properties set by this syntax.

`emitter = radarEmitter('Sector')` is a convenience syntax to create a `radarEmitter` object that mechanically scans a 90° azimuth sector from –45° to +45°. Setting `HasElevation` to `true`, points the radar antenna towards the center of the elevation field of view. You can change the `ScanMode` to `'Electronic'` to electronically scan the same azimuth sector. In this case, the antenna is not mechanically tilted in an electronic sector scan. Instead, beams are stacked electronically to process the entire elevation spanned by the scan limits in a single dwell. See "Sector Scanning" on page 3-305 for the properties set by this syntax.

`emitter = radarEmitter(EmitterIndex, ___ )` specifies the emitter ID, `EmitterIndex`, as an input argument instead of using the `EmitterIndex` name-value pair.

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).

EmitterIndex — Emitter identifier
positive integer

Emitter identifier, specified as a positive integer. Each emitter index is unique.

Example: 2

Data Types: `double`

UpdateRate — Emitter update rate
1 (default) | positive scalar

Emitter update rate, specified as a positive scalar. The emitter generates new emissions at intervals defined by the reciprocal of the `UpdateRate` property. This interval must be an integer multiple of the simulation time interval defined in `trackingScenario`. Any update requested from the emitter between update intervals contains no emissions. Units are in hertz.

Example: 5

Data Types: `double`

MountingLocation — Emitter location on platform
[0 0 0] (default) | 1-by-3 real-valued vector

Emitter location on platform, specified as a 1-by-3 real-valued vector. This property defines the coordinates of the emitter with respect to the platform origin. The default value specifies that the emitter origin is at the origin of its platform. Units are in meters.

Example: [.2 0.1 0]

Data Types: double

MountingAngles — Orientation of emitter
[0 0 0] (default) | 3-element real-valued vector

Orientation of the emitter with respect to the platform, specified as a three-element real-valued vector. Each element of the vector corresponds to an intrinsic Euler angle rotation that carries the body axes of the platform to the emitter axes. The three elements define the rotations around the *z*, *y*, and *x* axes respectively, in that order. The first rotation rotates the platform axes around the *z*-axis. The second rotation rotates the carried frame around the rotated *y*-axis. The final rotation rotates carried frame around the carried *x*-axis. Units are in degrees.

Example: [10 20 -15]

Data Types: double

FieldOfView — Fields of view of emitter
[1;5] | real-valued 2-by-1 vector of positive real-values

Fields of view of emitter, specified as a 2-by-1 vector of positive real values, [azfov;elfov]. The field of view defines the total angular extent spanned by the emitter. Each component must lie in the interval *(0,180]*. Units are in degrees.

Example: [14;7]

Data Types: double

ScanMode — Scanning mode of radar
'Mechanical' (default) | 'Electronic' | 'Mechanical and electronic' | 'No scanning'

Scanning mode of radar, specified as 'Mechanical', 'Electronic', 'Mechanical and electronic', or 'No scanning'.

Scan Modes

ScanMode	Purpose
`'Mechanical'`	The radar scans mechanically across the azimuth and elevation limits specified by the `MechanicalScanLimits` property. The scan direction increments by the radar field of view angle between dwells.
`'Electronic'`	The radar scans electronically across the azimuth and elevation limits specified by the `ElectronicScanLimits` property. The scan direction increments by the radar field of view angle between dwells.
`'Mechanical and electronic'`	The radar mechanically scans the antenna boresight across the mechanical scan limits and electronically scans beams relative to the antenna boresight across the electronic scan limits. The total field of regard scanned in this mode is the combination of the mechanical and electronic scan limits. The scan direction increments by the radar field of view angle between dwells.
`'No scanning'`	The radar beam points along the antenna boresight defined by the `mountingAngles` property.

Example: `'No scanning'`

Data Types: `char`

MaxMechanicalScanRate — Maximum mechanical scan rate
[75;75] (default) | nonnegative scalar | real-valued 2-by-1 vector with nonnegative entries

Maximum mechanical scan rate, specified as a nonnegative scalar or real-valued 2-by-1 vector with nonnegative entries.

When `HasElevation` is `true`, specify the scan rate as a 2-by-1 column vector of nonnegative entries, [maxAzRate; maxElRate]. maxAzRate is the maximum scan rate in azimuth and maxElRate is the maximum scan rate in elevation.

When `HasElevation` is `false`, specify the scan rate as a nonnegative scalar representing the maximum mechanical azimuth scan rate.

Scan rates set the maximum rate at which the radar can mechanically scan. The radar sets its scan rate to step the radar mechanical angle by the field of regard. If the required scan rate exceeds the maximum scan rate, the maximum scan rate is used. Units are degrees per second.

Example: `[5,10]`

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

MechanicalScanLimits — Angular limits of mechanical scan directions of radar
`[0 360; -10 0]` (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of mechanical scan directions of radar, specified as a real-valued 1-by-2 row vector or a real-valued 2-by-2 matrix. The mechanical scan limits define the minimum and maximum mechanical angles the radar can scan from its mounted orientation.

When `HasElevation` is `true`, the scan limits take the form `[minAz maxAz; minEl maxEl]`. `minAz` and `maxAz` represent the minimum and maximum limits of the azimuth angle scan. `minEl` and `maxEl` represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form `[minAz maxAz]`. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits cannot span more than 360° and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: `[-90 90;0 85]`

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

MechanicalAngle — Current mechanical scan angle
scalar | real-valued 2-by-1 vector

This property is read-only.

Current mechanical scan angle of radar, returned as a scalar or real-valued 2-by-1 vector. When `HasElevation` is `true`, the scan angle takes the form `[Az;El]`. `Az` and `El` represent the azimuth and elevation scan angles, respectively, relative to the mounted angle of the radar on the platform. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

ElectronicScanLimits — Angular limits of electronic scan directions of radar
`[-45 45;-45 45]` (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of electronic scan directions of radar, specified as a real-valued 1-by-2 row vector or a real-valued 2-by-2 matrix. The electronic scan limits define the minimum and maximum electronic angles the radar can scan from its current mechanical direction.

When `HasElevation` is `true`, the scan limits take the form `[minAz maxAz; minEl maxEl]`. `minAz` and `maxAz` represent the minimum and maximum limits of the azimuth angle scan. `minEl` and `maxEl` represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form `[minAz maxAz]`. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: `[-90 90; 0 85]`

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

ElectronicAngle — Current electronic scan angle
electronic scalar | nonnegative scalar

This property is read-only.

Current electronic scan angle of radar, returned as a scalar or 1-by-2 column vector. When `HasElevation` is `true`, the scan angle takes the form `[Az;El]`. `Az` and `El` represent the azimuth and elevation scan angles, respectively. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

LookAngle — Look angle of emitter
scalar | real-valued 2-by-1 vector

This property is read-only.

Look angle of emitter, specified as a scalar or real-valued 2-by-1 vector. Look angle is a combination of the mechanical angle and electronic angle depending on the `ScanMode` property. When `HasElevation` is `true`, the look angle takes the form `[Az;El]`. `Az` and `El` represent the azimuth and elevation look angles, respectively. When `HasElevation` is `false`, the look angle is a scalar representing the azimuth look angle.

ScanMode	LookAngle
'Mechanical'	MechnicalAngle
'Electronic'	ElectronicAngle
'Mechanical and Electronic'	MechnicalAngle + ElectronicAngle
'No scanning'	0

Data Types: `double`

HasElevation — Enable radar elevation scan and measurements
`false` (default) | `true`

Enable the radar to measure target elevation angles and to scan in elevation, specified as `false` or `true`. Set this property to `true` to model a radar emitter that can estimate target elevation and scan in elevation.

Data Types: `logical`

EIRP — Effective isotropic radiated power
`100` (default) | scalar

Effective isotropic radiated power of the transmitter, specified as a scalar. EIRP is the root mean squared power input to a lossless isotropic antenna that gives the same power density in the far field as the actual transmitter. EIRP is equal to the power input to the transmitter antenna (in dBW) plus the transmitter isotropic antenna gain. Units are in dBi.

Data Types: `double`

CenterFrequency — Center frequency of radar band
positive scalar

Center frequency of radar band, specified as a positive scalar. Units are in hertz.

Example: `100e6`

Data Types: `double`

Bandwidth — Radar waveform bandwidth
positive scalar

Radar waveform bandwidth, specified as a positive scalar. Units are in hertz.

Example: `100e3`

Data Types: `double`

WaveformTypes — Types of detected waveforms
0 (default) | nonnegative integer-valued *L*-element vector

Types of detected waveforms, specified as a nonnegative integer-valued *L*-element vector.

Example: `[1 4 5]`

Data Types: `double`

ProcessingGain — Processing gain
0 (default) | scalar

Processing gain when demodulating an emitted signal waveform, specified as a scalar. Processing gain is achieved by emitting a signal over a bandwidth which is greater than the minimum bandwidth necessary to send the information contained in the signal. Units are in dB.

Example: `20`

Data Types: `double`

Usage

Syntax

```
radarsigs = emitter(platform,simTime)
[radarsigs,config] = emitter(platform,simTime)
```

Description

`radarsigs = emitter(platform,simTime)` creates radar signals, `radarsigs`, from emitter on the `platform` at the current simulation time, `simTime`. The emitter object can simultaneously generate signals from multiple emitters on the platform.

`[radarsigs,config] = emitter(platform,simTime)` also returns the emitter configurations, `config`, at the current simulation time.

Input Arguments

`platform` — emitter platform
object | structure

Emitter platform, specified as a platform object, `Platform`, or a platform structure:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field which has no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in scenario coordinates, specified as a real-valued 1-by-3 vector. This is a required field. There is no default value. Units are in meters.

Field	Description
Velocity	Velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default is [0 0 0].
Speed	Speed of the platform in the scenario frame specified as a real scalar. When speed is specified, the platform velocity is aligned with its orientation. Specify either the platform speed or velocity, but not both. Units are in meters per second The default is 0.
Acceleration	Acceleration of the platform in scenario coordinates specified as a 1-by-3 row vector in meters per second-squared. The default is [0 0 0].
Orientation	Orientation of the platform with respect to the local scenario NED coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the local NED coordinate system to the current platform body coordinate system. Units are dimensionless. The default is quaternion(1,0,0,0).
AngularVelocity	Angular velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is [0 0 0].
Signatures	Cell array of signatures defining the visibility of the platform to emitters and sensors in the scenario. The default is the cell array {rcsSignature,irSignature, tsSignature}

`simTime` — Current simulation time

nonnegative scalar

Current simulation time, specified as a positive scalar. The `trackingScenario` object calls the radar sensor at regular time intervals. The radar emitter generates new signals at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the emitter between update intervals contain no detections. Units are in seconds.

Example: `10.5`

Data Types: `double`

Output Arguments

`radarsigs` — Radar emissions

array of radar emission objects

Radar emissions, returned as an array of `radarEmission` objects.

`config` — Current emitter configuration

structure array

Current emitter configurations, returned as an array of structures.

Field	Description
`EmitterIndex`	Unique emitter index
`IsValidTime`	Valid emission time, returned as `0` or `1`. `IsValidTime` is `0` when emitter updates are requested at times that are between update intervals specified by `UpdateInterval`.
`IsScanDone`	`IsScanDone` is `true` when the emitter has completed a scan.
`FieldOfView`	Field of view of emitter.

3-191

MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current emitter frame.

Data Types: `struct`

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

Model Radar Jammer

Create an emitter that stares from the front of a jammer.

Create a platform to mount the jammer on.

```
plat = struct( ...
    'PlatformID', 1, ...
    'Position', [0 0 0]);
```

Create an emitter that stares from the front of the jamming platform.

```
jammer = radarEmitter(1,'No scanning');
```

Emit the jamming waveform.

```
time = 0;
sig = jammer(plat, time)


sig =

  radarEmission with properties:

                   EIRP: 100
                    RCS: 0
             PlatformID: 1
           EmitterIndex: 1
         OriginPosition: [0 0 0]
         OriginVelocity: [0 0 0]
            Orientation: [1×1 quaternion]
            FieldOfView: [1 5]
        CenterFrequency: 300000000
              Bandwidth: 3000000
           WaveformType: 0
         ProcessingGain: 0
      PropagationRange: 0
  PropagationRangeRate: 0
```

Model Radar Emitter for Air Traffic Control Tower

Model an radar emitter for an air traffic control tower.

Simulate one full rotation of the tower.

```
rpm = 12.5;
scanrate = rpm*360/60;
fov = [1.4;5];
updaterate = scanrate/fov(1);
```

Create a `trackingScenario` object to manage the motion of the platforms.

```
scene = trackingScenario('UpdateRate', updaterate, ...
    'StopTime', 60/rpm);
```

Add a platform to the scenario to host the air traffic control tower.

```
tower = platform(scene);
```

3-193

Create an emitter that provides 360 degree surveillance.

```
radarTx = radarEmitter(1,'Rotator', ...
    'UpdateRate',updaterate, ...
    'MountingLocation',[0 0 -15], ...
    'MaxMechanicalScanRate',scanrate, ...
    'FieldOfView',fov);
```

Attach the emitter to the tower.

```
tower.Emitters = radarTx
```

```
tower =

  Platform with properties:

        PlatformID: 1
           ClassID: 0
        Trajectory: [1x1 kinematicTrajectory]
     PoseEstimator: [1x1 insSensor]
          Emitters: {[1x1 radarEmitter]}
           Sensors: {}
        Signatures: {[1x1 rcsSignature]  [1x1 irSignature]  [1x1 tsSignature]}
```

Rotate the antenna and emit the radar waveform.

```
loggedData = struct('Time', zeros(0,1), ...
    'Orientation', quaternion.zeros(0, 1));
while advance(scene)
    time = scene.SimulationTime;
    txSig = emit(tower, time);
    loggedData.Time = [loggedData.Time; time];
    loggedData.Orientation = [loggedData.Orientation; ...
        txSig{1}.Orientation];
end
```

Plot the emitter azimuth direction.

```
angles = eulerd(loggedData.Orientation, 'zyx', 'frame');
plot(loggedData.Time, angles(:,1))
title('Emitted Azimuth')
xlabel('Time (s)')
ylabel('Azimuth (deg)')
```
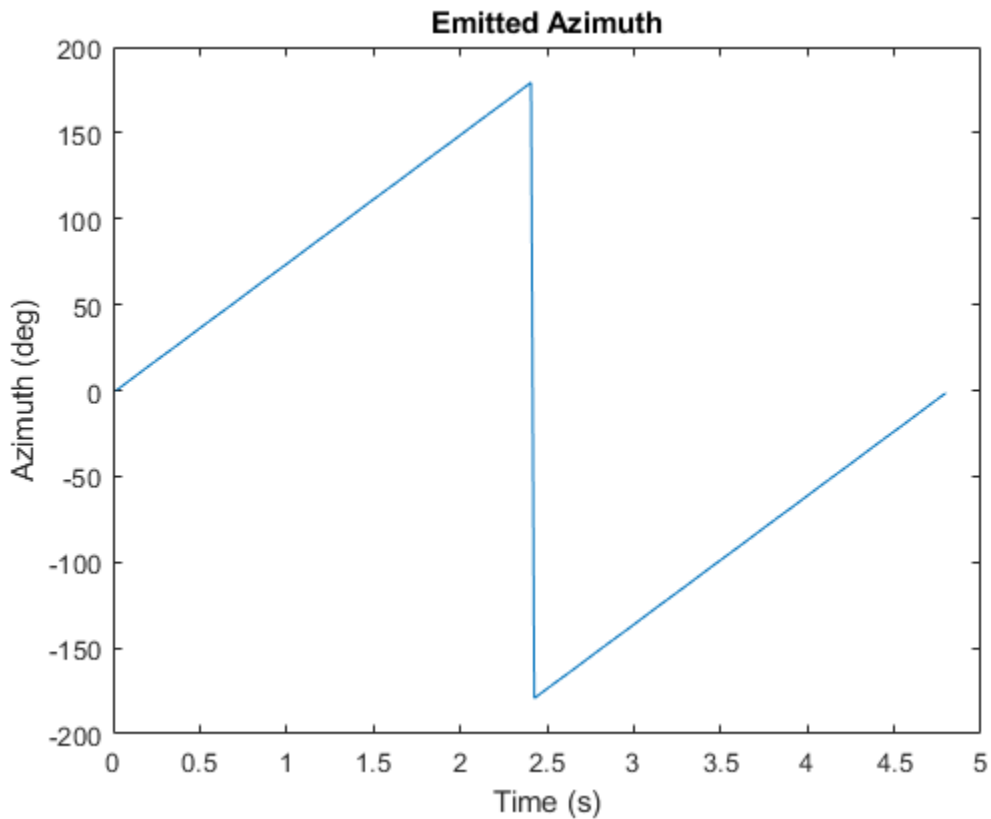
Definitions

Convenience Syntaxes

The convenience syntaxes set several properties together to model a specific type of radar emitter.

Sets `ScanMode` to 'No scanning'.

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
HasElevation	true
MaxMechanicalScanRate	[75;75]
MechanicalScanLimits	[-45 45; -10 0]
ElectronicScanLimits	[-45 45; -10 0]

You can change the ScanMode property to 'Electronic' to perform an electronic raster scan over the same volume as a mechanical scan.

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
FieldOfView	[1:10]
HasElevation	false or true
MechanicalScanLimits	[0 360; -10 0]
ElevationResolution	10/sqrt(12)

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
FieldOfView	[1;10]
HasElevation	false
MechanicalScanLimits	[-45 45; -10 0]
ElectronicScanLimits	[-45 45; -10 0]
ElevationResolution	10/sqrt(12)

Changing the ScanMode property to 'Electronic' lets you perform an electronic raster scan over the same volume as a mechanical scan.

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

Classes
platform | radarEmission

Functions
emissionsInBody | targetPoses

System Objects
monostaticRadarSensor | radarSensor

Introduced in R2018b

sonarEmitter System object

coustic signals and interferences generator

Description

The `sonarEmitter` System object creates an emitter to simulate sonar emissions. You can use the `sonarEmitter` object in a scenario that detects and tracks moving and stationary platforms. Construct a scenario using `trackingScenario`.

A sonar emitter changes the look angle between updates by stepping the mechanical and electronic position of the beam in increments of the angular span specified in the `FieldOfView` property. The sonar emitter scans the total region in azimuth and elevation defined by the sonar mechanical and electronic scan limits, `MechanicalScanLimits` and `ElectronicScanLimits`, respectively. If the scan limits for azimuth or elevation are set to `[0 0]`, then no scanning is performed along that dimension for that scan mode. If the maximum mechanical scan rate for azimuth or elevation is set to zero, then no mechanical scanning is performed along that dimension.

To generate sonar detections:

1   Create the `sonarEmitter` 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

```
emitter = sonarEmitter
emitter = sonarEmitter(Name,Value)

emitter = sonarEmitter('No scanning')
```

```
emitter = sonarEmitter('Raster')
emitter = sonarEmitter('Rotator')
emitter = sonarEmitter('Sector')
emitter = sonarEmitter(EmitterIndex, ___ )
```

Description

`emitter = sonarEmitter` creates a sonar emitter object with default property values.

`emitter = sonarEmitter(Name,Value)` sets properties using one or more name-value pairs. Enclose each property name in quotes. For example, `sonarEmitter('CenterFrequency',2e6)` creates a sonar emitter creates detections in the emitter Cartesian coordinate system and has a maximum detection range of 200 meters.

`emitter = sonarEmitter('No scanning')` is a convenience syntax that creates a `sonarEmitter` that stares along the sonar transducer boresight direction. No mechanical or electronic scanning is performed. This syntax sets the `ScanMode` property to `'No scanning'`.

`emitter = sonarEmitter('Raster')` is a convenience syntax that creates a `sonarEmitter` object that mechanically scans a raster pattern. The raster span is 90° in azimuth from –45° to +45° and in elevation from the horizon to 10° above the horizon. See "Raster Scanning" on page 3-304 for the properties set by this syntax.

`emitter = sonarEmitter('Rotator')` is a convenience syntax that creates a `sonarEmitter` object that mechanically scans 360° in azimuth by mechanically rotating the sonar at a constant rate. When you set `HasElevation` to `true`, the sonar mechanically points towards the center of the elevation field of view. See "Rotator Scanning" on page 3-305 for the properties set by this syntax.

`emitter = sonarEmitter('Sector')` is a convenience syntax to create a `sonarEmitter` object that mechanically scans a 90° azimuth sector from –45° to +45°. Setting `HasElevation` to `true`, points the sonar towards the center of the elevation field of view. You can change the `ScanMode` to `'Electronic'` to electronically scan the same azimuth sector. In this case, the sonar is not mechanically tilted in an electronic sector scan. Instead, beams are stacked electronically to process the entire elevation spanned by the scan limits in a single dwell. See "Sector Scanning" on page 3-305 for the properties set by this syntax.

`emitter = sonarEmitter(EmitterIndex, ___ )` specifies the emitter ID, `EmitterIndex`, as an input argument instead of using the `EmitterIndex` name-value pair.

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).

EmitterIndex — Emitter identifier
positive integer

Emitter identifier, specified as a positive integer. Each emitter index is unique.

Example: 2

Data Types: `double`

UpdateRate — Emitter update rate
1 (default) | positive scalar

Emitter update rate, specified as a positive scalar. The emitter generates new emissions at intervals defined by the reciprocal of the `UpdateRate` property. This interval must be an integer multiple of the simulation time interval defined in `trackingScenario`. Any update requested from the emitter between update intervals contains no emissions. Units are in hertz.

Example: 5

Data Types: `double`

MountingLocation — Emitter location on platform
[0 0 0] (default) | 1-by-3 real-valued vector

Emitter location on platform, specified as a 1-by-3 real-valued vector. This property defines the coordinates of the emitter with respect to the platform origin. The default value specifies that the emitter origin is at the origin of its platform. Units are in meters.

Example: [.2 0.1 0]

Data Types: double

MountingAngles — Orientation of emitter
[0 0 0] (default) | 3-element real-valued vector

Orientation of the emitter with respect to the platform, specified as a three-element real-valued vector. Each element of the vector corresponds to an intrinsic Euler angle rotation that carries the body axes of the platform to the emitter axes. The three elements define the rotations around the z, y, and x axes respectively, in that order. The first rotation rotates the platform axes around the z-axis. The second rotation rotates the carried frame around the rotated y-axis. The final rotation rotates carried frame around the carried x-axis. Units are in degrees.

Example: [10 20 -15]

Data Types: double

FieldOfView — Fields of view of emitter
[1;5] | real-valued 2-by-1 vector of positive real-values

Fields of view of emitter, specified as a 2-by-1 vector of positive real values, [azfov;elfov]. The field of view defines the total angular extent spanned by the emitter. Each component must lie in the interval *(0,180]*. Units are in degrees.

Example: [14;7]

Data Types: double

ScanMode — Scanning mode of sonar
'Mechanical' (default) | 'Electronic' | 'Mechanical and electronic' | 'No scanning'

Scanning mode of sonar, specified as 'Mechanical', 'Electronic', 'Mechanical and electronic', or 'No scanning'.

Scan Modes

ScanMode	Purpose
`'Electronic'`	The sonar scans electronically across the azimuth and elevation limits specified by the `ElectronicScanLimits` property. The scan direction increments by the sonar field of view angle between dwells.
`'No scanning'`	The sonar beam points along the antenna boresight defined by the `mountingAngles` property.

Example: `'No scanning'`

Data Types: `char`

`ElectronicScanLimits` — Angular limits of electronic scan directions of sonar
`[-45 45;-45 45]` (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of electronic scan directions of sonar, specified as a real-valued 1-by-2 row vector or a real-valued 2-by-2 matrix. The electronic scan limits define the minimum and maximum electronic angles the sonar can scan from its current mechanical direction.

When `HasElevation` is `true`, the scan limits take the form `[minAz maxAz; minEl maxEl]`. `minAz` and `maxAz` represent the minimum and maximum limits of the azimuth angle scan. `minEl` and `maxEl` represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form `[minAz maxAz]`. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: `[-90 90; 0 85]`

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

ElectronicAngle — Current electronic scan angle
electronic scalar | nonnegative scalar

This property is read-only.

Current electronic scan angle of sonar, returned as a scalar or 1-by-2 column vector. When `HasElevation` is `true`, the scan angle takes the form `[Az;El]`. Az and El represent the azimuth and elevation scan angles, respectively. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

LookAngle — Look angle of emitter
scalar | real-valued 2-by-1 vector

This property is read-only.

Look angle of emitter, specified as a scalar or real-valued 2-by-1 vector. Look angle is a combination of the mechanical angle and electronic angle depending on the `ScanMode` property. When `HasElevation` is `true`, the look angle takes the form `[Az;El]`. Az and El represent the azimuth and elevation look angles, respectively. When `HasElevation` is `false`, the look angle is a scalar representing the azimuth look angle.

ScanMode	LookAngle
`'Mechanical'`	MechnicalAngle
`'Electronic'`	ElectronicAngle
`'Mechanical and Electronic'`	MechnicalAngle + ElectronicAngle
`'No scanning'`	0

Data Types: `double`

HasElevation — Enable sonar elevation scan and measurements
`false` (default) | `true`

Enable the sonar to measure target elevation angles and to scan in elevation, specified as `false` or `true`. Set this property to `true` to model a sonar emitter that can estimate target elevation and scan in elevation.

Data Types: `logical`

SourceLevel — Sonar source level
140 (default) | scalar

Sonar source level, specified as a scalar. Source level is relative to the intensity of a sound wave having an rms pressure of 1 µPa. Units are in dB//1 µPa.

Data Types: `double`

CenterFrequency — Center frequency of sonar band
positive scalar

Center frequency of sonar band, specified as a positive scalar. Units are in hertz.

Example: `100e6`

Data Types: `double`

Bandwidth — Sonar waveform bandwidth
positive scalar

Sonar waveform bandwidth, specified as a positive scalar. Units are in hertz.

Example: `100e3`

Data Types: `double`

WaveformTypes — Types of detected waveforms
0 (default) | nonnegative integer-valued *L*-element vector

Types of detected waveforms, specified as a nonnegative integer-valued *L*-element vector.

Example: `[1 4 5]`

Data Types: `double`

ProcessingGain — Processing gain
0 (default) | scalar

Processing gain when demodulating an emitted signal waveform, specified as a scalar. Processing gain is achieved by emitting a signal over a bandwidth which is greater than the minimum bandwidth necessary to send the information contained in the signal. Units are in dB.

Example: `20`

Data Types: `double`

Usage

Syntax

```
sonarsigs = emitter(platform,simTime)
[sonarsigs,config] = emitter(platform,simTime)
```

Description

`sonarsigs = emitter(platform,simTime)` creates sonar signals, `sonarsigs`, from emitter on the `platform` at the current simulation time, `simTime`. The emitter object can simultaneously generate signals from multiple emitters on the platform.

`[sonarsigs,config] = emitter(platform,simTime)` also returns the emitter configurations, `config`, at the current simulation time.

Input Arguments

`platform` — emitter platform
object | structure

Emitter platform, specified as a platform object, `Platform`, or a platform structure:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field which has no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.

Field	Description
Position	Position of target in scenario coordinates, specified as a real-valued 1-by-3 vector. This is a required field. There is no default value. Units are in meters.
Velocity	Velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. Units are in meters per second. The default is [0 0 0].
Speed	Speed of the platform in the scenario frame specified as a real scalar. When speed is specified, the platform velocity is aligned with its orientation. Specify either the platform speed or velocity, but not both. Units are in meters per second The default is 0.
Acceleration	Acceleration of the platform in scenario coordinates specified as a 1-by-3 row vector in meters per second-squared. The default is [0 0 0].
Orientation	Orientation of the platform with respect to the local scenario NED coordinate frame, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the local NED coordinate system to the current platform body coordinate system. Units are dimensionless. The default is quaternion(1,0,0,0).
AngularVelocity	Angular velocity of platform in scenario coordinates, specified as a real-valued 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is [0 0 0].

Field	Description
Signatures	Cell array of signatures defining the visibility of the platform to emitters and sensors in the scenario. The default is the cell array {rcsSignature,irSignature, tsSignature}

simTime — Current simulation time
nonnegative scalar

Current simulation time, specified as a positive scalar. The trackingScenario object calls the sonar emitter at regular time intervals. The sonar emitter generates new signals at intervals defined by the UpdateInterval property. The value of the UpdateInterval property must be an integer multiple of the simulation time interval. Updates requested from the emitter between update intervals contain no detections. Units are in seconds.

Example: 10.5

Data Types: double

Output Arguments

sonarsigs — Sonar emissions
array of sonar emission objects

Sonar emissions, returned as an array of sonarEmission objects.

config — Current emitter configuration
structure array

Current emitter configurations, returned as an array of structures.

Field	Description
EmitterIndex	Unique emitter index

IsValidTime	Valid emission time, returned as 0 or 1. `IsValidTime` is 0 when emitter updates are requested at times that are between update intervals specified by `UpdateInterval`.
IsScanDone	`IsScanDone` is `true` when the emitter has completed a scan.
FieldOfView	Field of view of emitter.
MeasurementParameters	`MeasurementParameters` is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current emitter frame.

Data Types: `struct`

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

Reflect Sonar Emission from Platform within Tracking Scenario

Reflect a sonar emission from a platform defined within a `trackingScenario`.

Create a tracking scenario object.

```
scenario = trackingScenario;
```

Create an `sonarEmitter`.

```
emitter = sonarEmitter(1);
```

Mount the emitter on a platform within the scenario.

```
plat = platform(scenario,'Emitters',emitter);
```

Add another platform to reflect the emitted signal.

```
tgt = platform(scenario);
tgt.Trajectory.Position = [30 0 0];
```

Emit the signal using the `emit` object function of a `platform` .

```
txSigs = emit(plat, scenario.SimulationTime)


txSigs =

  sonarEmission with properties:

              SourceLevel: 140
           TargetStrength: 0
               PlatformID: 1
             EmitterIndex: 1
           OriginPosition: [0 0 0]
           OriginVelocity: [0 0 0]
              Orientation: [1×1 quaternion]
              FieldOfView: [1 5]
          CenterFrequency: 20000
                Bandwidth: 2000
             WaveformType: 0
           ProcessingGain: 0
        PropagationRange: 0
    PropagationRangeRate: 0
```

Reflect the signal from the platforms in the scenario.

```
sigs = underwaterChannel(txSigs, scenario.Platforms)


sigs =
```

```
sonarEmission with properties:

            SourceLevel: 140
         TargetStrength: 0
             PlatformID: 1
           EmitterIndex: 1
         OriginPosition: [0 0 0]
         OriginVelocity: [0 0 0]
            Orientation: [1×1 quaternion]
            FieldOfView: [1 5]
        CenterFrequency: 20000
              Bandwidth: 2000
           WaveformType: 0
          ProcessingGain: 0
       PropagationRange: 0
   PropagationRangeRate: 0
```

Definitions

Convenience Syntaxes

The convenience syntaxes set several properties together to model a specific type of sonar emitter.

Sets `ScanMode` to 'No scanning'.

This syntax sets these properties:

Property	Value
ScanMode	'Electronic'
HasElevation	true
ElectronicScanLimits	[-45 45; -10 0]

This syntax sets these properties:

Property	Value
ScanMode	'Electronic'
FieldOfView	[1:10]
HasElevation	false or true
ElevationResolution	10/sqrt(12)

This syntax sets these properties:

Property	Value
ScanMode	'Electronic'
FieldOfView	[1;10]
HasElevation	false
ElectronicScanLimits	[-45 45; -10 0]
ElevationResolution	10/sqrt(12)

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

Classes
platform | sonarEmission

Functions
emissionsInBody | targetPoses

3-211

System Objects
`sonarSensor`

Introduced in R2018b

kinematicTrajectory System object

Rate-driven trajectory generator

Description

The `kinematicTrajectory` System object generates trajectories using specified acceleration and angular velocity.

To generate a trajectory from rates:

1 Create the `kinematicTrajectory` 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

```
trajectory = kinematicTrajectory
trajectory = kinematicTrajectory(Name,Value)
```

Description

`trajectory = kinematicTrajectory` returns a System object, `trajectory`, that generates a trajectory based on acceleration and angular velocity.

`trajectory = kinematicTrajectory(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `trajectory = kinematicTrajectory('SampleRate',200,'Position',[0,1,10])` creates a kinematic trajectory System object, `trajectory`, with a sample rate of 200 Hz and the initial position set to [0,1,10].

3-213

Properties

If a property is *tunable*, you can change its value at any time.

SampleRate — Sample rate of trajectory (Hz)
100 (default) | positive scalar

Sample rate of trajectory in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: single | double

Position — Position state in local NED coordinate system (m)
[0 0 0] (default) | 3-element row vector

Position state in the local NED coordinate system in meters, specified as a three-element row vector.

Tunable: Yes

Data Types: single | double

Velocity — Velocity state in local NED coordinate system (m/s)
[0 0 0] (default) | 3-element row vector

Velocity state in the local NED coordinate system in m/s, specified as a three-element row vector.

Tunable: Yes

Data Types: single | double

Orientation — Orientation state in local NED coordinate system
quaternion(1,0,0,0) (default) | scalar quaternion | 3-by-3 real matrix

Orientation state in the local NED coordinate system, specified as a scalar quaternion or 3-by-3 real matrix. The orientation is a frame rotation from the local NED coordinate system to the current body frame.

Tunable: Yes

Data Types: quaternion | single | double

AccelerationSource — Source of acceleration state
`'Input'` (default) | `'Property'`

Source of acceleration state, specified as `'Input'` or `'Property'`.

- `'Input'` –– specify acceleration state as an input argument to the kinematic trajectory object
- `'Property'` –– specify acceleration state by setting the `Acceleration` property

Tunable: No

Data Types: `char` | `string`

Acceleration — Acceleration state (m/s²)
`[0 0 0]` (default) | three-element row vector

Acceleration state in m/s^2, specified as a three-element row vector.

Tunable: Yes

Dependencies

To enable this property, set AccelerationSource to `'Property'`.

Data Types: `single` | `double`

AngularVelocitySource — Source of angular velocity state
`'Input'` (default) | `'Property'`

Source of angular velocity state, specified as `'Input'` or `'Property'`.

- `'Input'` –– specify angular velocity state as an input argument to the kinematic trajectory object
- `'Property'` –– specify angular velocity state by setting the `AngularVelocity` property

Tunable: No

Data Types: `char` | `string`

AngularVelocity — Angular velocity state (rad/s)
`[0 0 0]` (default) | three-element row vector

Angular velocity state in rad/s, specified as a three-element row vector.

Tunable: Yes

Dependencies

To enable this property, set AngularVelocitySource to `'Property'`.

Data Types: `single` | `double`

SamplesPerFrame — Number of samples per output frame
1 (default) | positive integer

Number of samples per output frame, specified as a positive integer.

Tunable: No

Dependencies

To enable this property, set AngularVelocitySource to `'Property'` and AccelerationSource to `'Property'`.

Data Types: `single` | `double`

Usage

Syntax

```
[position,orientation,velocity,acceleration,angularVelocity] =
trajectory(bodyAcceleration,bodyAngularVelocity)
[position,orientation,velocity,acceleration,angularVelocity] =
trajectory(bodyAngularVelocity)
[position,orientation,velocity,acceleration,angularVelocity] =
trajectory(bodyAcceleration)
[position,orientation,velocity,acceleration,angularVelocity] =
trajectory()
```

Description

`[position,orientation,velocity,acceleration,angularVelocity] =
trajectory(bodyAcceleration,bodyAngularVelocity)` outputs the trajectory

state and then updates the trajectory state based on `bodyAcceleration` and `bodyAngularVelocity`.

This syntax is only valid if `AngularVelocitySource` is set to `'Input'` and `AccelerationSource` is set to `'Input'`.

`[position,orientation,velocity,acceleration,angularVelocity] = trajectory(bodyAngularVelocity)` outputs the trajectory state and then updates the trajectory state based on `bodyAngularAcceleration`.

This syntax is only valid if `AngularVelocitySource` is set to `'Input'` and `AccelerationSource` is set to `'Property'`.

`[position,orientation,velocity,acceleration,angularVelocity] = trajectory(bodyAcceleration)` outputs the trajectory state and then updates the trajectory state based on `bodyAcceleration`.

This syntax is only valid if `AngularVelocitySource` is set to `'Property'` and `AccelerationSource` is set to `'Input'`.

`[position,orientation,velocity,acceleration,angularVelocity] = trajectory()` outputs the trajectory state and then updates the trajectory state.

This syntax is only valid if `AngularVelocitySource` is set to `'Property'` and `AccelerationSource` is set to `'Property'`.

Input Arguments

bodyAcceleration — Acceleration in body coordinate system (m/s²)
N-by-3 matrix

Acceleration in the body coordinate system in meters per second squared, specified as an *N*-by-3 matrix.

N is the number of samples in the current frame.

bodyAngularVelocity — Angular velocity in body coordinate system (rad/s)
N-by-3 matrix

Angular velocity in the body coordinate system in radians per second, specified as an *N*-by-3 matrix.

N is the number of samples in the current frame.

Output Arguments

`position` — Position in local NED coordinate system (m)
N-by-3 matrix

Position in the local NED coordinate system in meters, returned as an *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: `single` | `double`

`orientation` — Orientation in local NED coordinate system
N-element quaternion column vector | 3-by-3-by-*N* real array

Orientation in the local NED coordinate system, returned as an *N*-by-1 quaternion column vector or a 3-by-3-by-*N* real array. Each quaternion or 3-by-3 rotation matrix is a frame rotation from the local NED coordinate system to the current body coordinate system.

N is the number of samples in the current frame.

Data Types: `single` | `double`

`velocity` — Velocity in local NED coordinate system (m/s)
N-by-3 matrix

Velocity in the local NED coordinate system in meters per second, returned as an *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: `single` | `double`

`acceleration` — Acceleration in local NED coordinate system (m/s^2)
N-by-3 matrix

Acceleration in the local NED coordinate system in meters per second squared, returned as an *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: `single` | `double`

angularVelocity — Angular velocity in local NED coordinate system (rad/s)
N-by-3 matrix

Angular velocity in the local NED coordinate system in radians per second, returned as an *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: `single` | `double`

Object Functions

step   Run System object algorithm

Examples

Create Default `kinematicTrajectory`

Create a default `kinematicTrajectory` System object™ and explore the relationship between input, properties, and the generated trajectories.

```
trajectory = kinematicTrajectory


trajectory =

  kinematicTrajectory with properties:

              SampleRate: 100
                Position: [0 0 0]
             Orientation: [1x1 quaternion]
                Velocity: [0 0 0]
      AccelerationSource: 'Input'
   AngularVelocitySource: 'Input'
```

By default, the `kinematicTrajectory` object has an initial position of [0 0 0] and an initial velocity of [0 0 0]. Orientation is described by a quaternion one (1 + 0i + 0j + 0k).

The `kinematicTrajectory` object maintains a visible and writable state in the properties `Position`, `Velocity`, and `Orientation`. When you call the object, the state is output and then updated.

For example, call the object by specifying an acceleration and angular velocity relative to the body coordinate system.

```
bodyAcceleration = [5,5,0];
bodyAngularVelocity = [0,0,1];
[position,orientation,velocity,acceleration,angularVelocity] = trajectory(bodyAccelera
```

```
position =

     0     0     0
```

```
orientation =

  quaternion


     1 + 0i + 0j + 0k
```

```
velocity =

     0     0     0
```

```
acceleration =

     5     5     0
```

```
angularVelocity =

     0     0     1
```

The position, orientation, and velocity output from the `trajectory` object correspond to the state reported by the properties before calling the object. The `trajectory` state is updated after being called and is observable from the properties:

```
trajectory
```

```
trajectory =

  kinematicTrajectory with properties:

              SampleRate: 100
                Position: [2.5000e-04 2.5000e-04 0]
             Orientation: [1x1 quaternion]
                Velocity: [0.0500 0.0500 0]
      AccelerationSource: 'Input'
   AngularVelocitySource: 'Input'
```

The `acceleration` and `angularVelocity` output from the `trajectory` object correspond to the `bodyAcceleration` and `bodyAngularVelocity`, except that they are returned in the NED coordinate system. Use the `orientation` output to rotate `acceleration` and `angularVelocity` to the body coordinate system and verify they are approximately equivalent to `bodyAcceleration` and `bodyAngularVelocity`.

```
rotatedAcceleration = rotatepoint(orientation,acceleration)
rotatedAngularVelocity = rotatepoint(orientation,angularVelocity)


rotatedAcceleration =

    5    5    0


rotatedAngularVelocity =

    0    0    1
```

The `kinematicTrajectory` System object™ enables you to modify the trajectory state through the properties. Set the position to [0,0,0] and then call the object with a specified acceleration and angular velocity in the body coordinate system. For illustrative purposes, clone the `trajectory` object before modifying the `Position` property. Call both objects and observe that the positions diverge.

```
trajectoryClone = clone(trajectory);
trajectory.Position = [0,0,0];

position = trajectory(bodyAcceleration,bodyAngularVelocity)
clonePosition = trajectoryClone(bodyAcceleration,bodyAngularVelocity)
```

```
position =

     0     0     0


clonePosition =

   1.0e-03 *

   0.2500    0.2500         0
```

Create Oscillating Trajectory

This example shows how to create a trajectory oscillating along the North axis of a local NED coordinate system using the `kinematicTrajectory` System object™.

Create a default `kinematicTrajectory` object. The default initial orientation is aligned with the local NED coordinate system.

```
traj = kinematicTrajectory


traj =

  kinematicTrajectory with properties:

                SampleRate: 100
                  Position: [0 0 0]
               Orientation: [1x1 quaternion]
                  Velocity: [0 0 0]
        AccelerationSource: 'Input'
    AngularVelocitySource: 'Input'
```

Define a trajectory for a duration of 10 seconds consisting of rotation around the East axis (pitch) and an oscillation along North axis of the local NED coordinate system. Use the default `kinematicTrajectory` sample rate.

```
fs = traj.SampleRate;
duration = 10;
```

```
numSamples = duration*fs;

cyclesPerSecond = 1;
samplesPerCycle = fs/cyclesPerSecond;
numCycles = ceil(numSamples/samplesPerCycle);
maxAccel = 20;

triangle = [linspace(maxAccel,1/fs-maxAccel,samplesPerCycle/2), ...
    linspace(-maxAccel,maxAccel-(1/fs),samplesPerCycle/2)]';
oscillation = repmat(triangle,numCycles,1);
oscillation = oscillation(1:numSamples);

accNED = [zeros(numSamples,2),oscillation];

angVelNED = zeros(numSamples,3);
angVelNED(:,2) = 2*pi;
```

Plot the acceleration control signal.

```
timeVector = 0:1/fs:(duration-1/fs);

figure(1)
plot(timeVector,oscillation)
xlabel('Time (s)')
ylabel('Acceleration (m/s)^2')
title('Acceleration in Local NED Coordinate System')
```
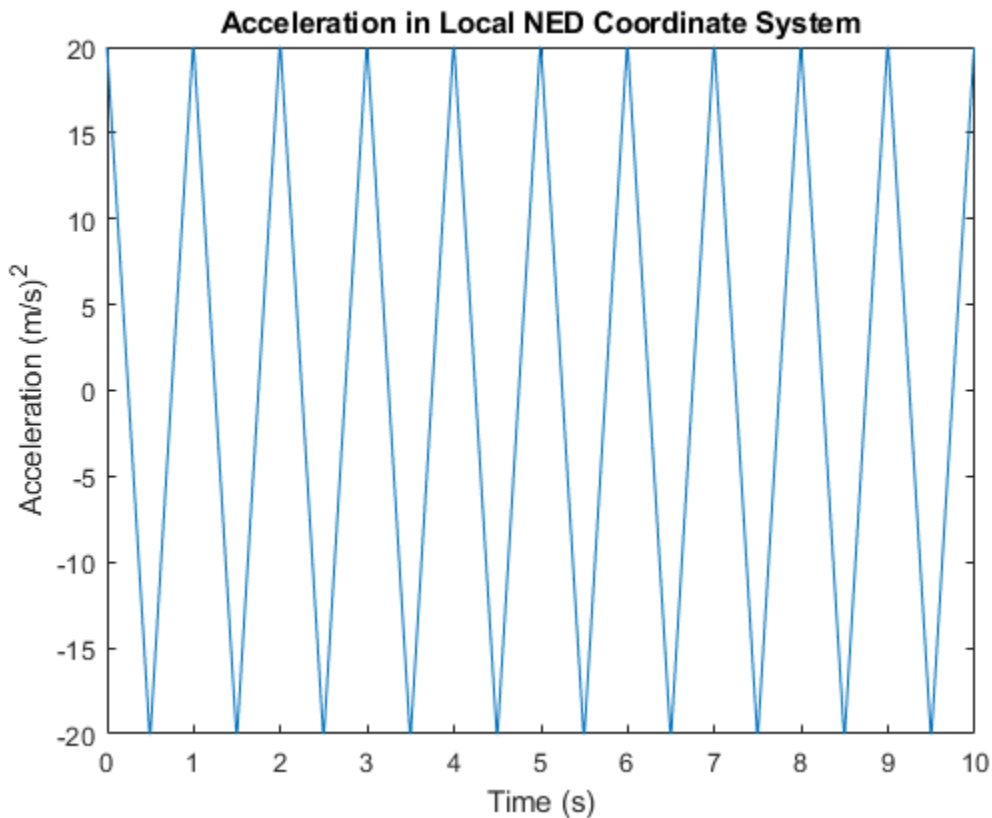
Generate the trajectory sample-by-sample in a loop. The `kinematicTrajectory` System object assumes the acceleration and angular velocity inputs are in the local sensor body coordinate system. Rotate the acceleration and angular velocity control signals from the NED coordinate system to the sensor body coordinate system using `rotateframe` and the `Orientation` state. Update a 3-D plot of the position at each time. Add `pause` to mimic real-time processing. Once the loop is complete, plot the position over time. Rotating the `accNED` and `angVelNED` control signals to the local body coordinate system assures the motion stays along the Down axis.

```
figure(2)
plotHandle = plot3(traj.Position(1),traj.Position(2),traj.Position(3),'bo');
grid on
xlabel('North')
```

```matlab
ylabel('East')
zlabel('Down')
axis([-1 1 -1 1 0 1.5])
hold on

q = ones(numSamples,1,'quaternion');
for ii = 1:numSamples
     accBody = rotateframe(traj.Orientation,accNED(ii,:));
     angVelBody = rotateframe(traj.Orientation,angVelNED(ii,:));

    [pos(ii,:),q(ii),vel,ac] = traj(accBody,angVelBody);

    set(plotHandle,'XData',pos(ii,1),'YData',pos(ii,2),'ZData',pos(ii,3))

    pause(1/fs)
end

figure(3)
plot(timeVector,pos(:,1),'bo',...
     timeVector,pos(:,2),'r.',...
     timeVector,pos(:,3),'g.')
xlabel('Time (s)')
ylabel('Position (m)')
title('NED Position Over Time')
legend('North','East','Down')
```
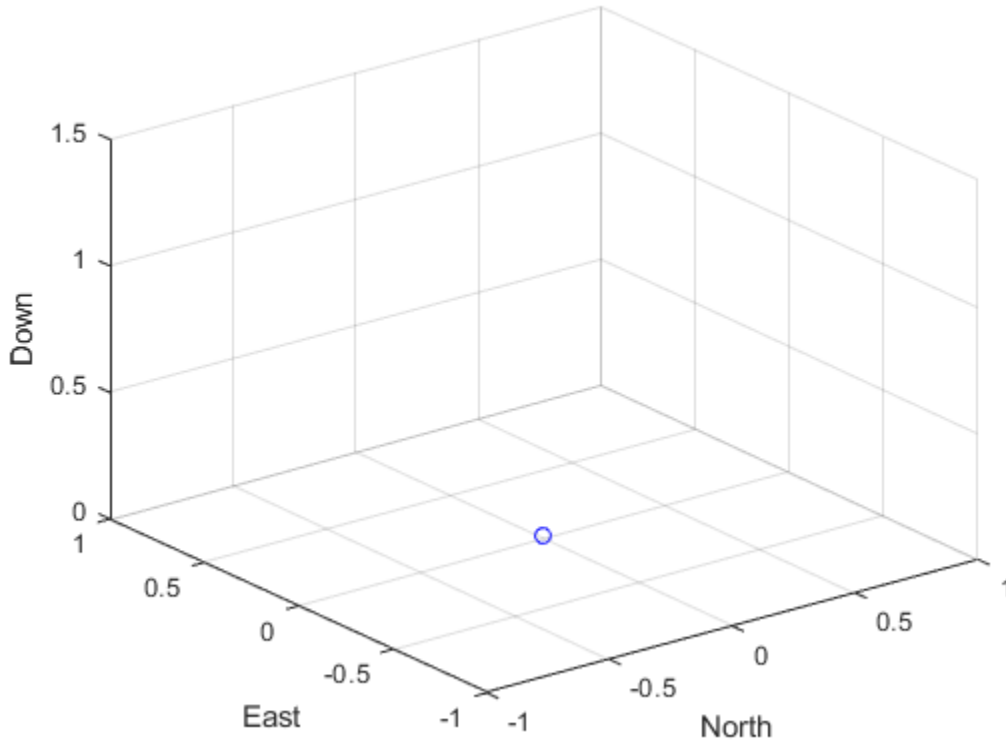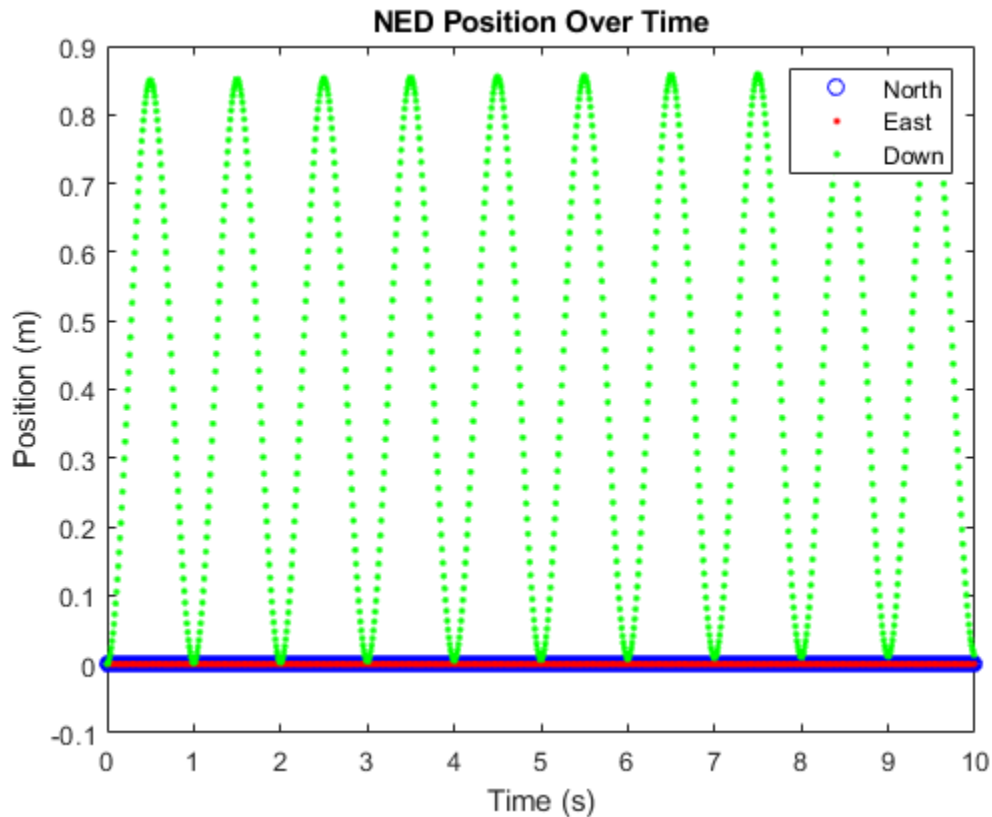
Convert the recorded orientation to Euler angles and plot. Although the orientation of the platform changed over time, the acceleration always acted along the North axis.

```
figure(4)
eulerAngles = eulerd(q,'ZYX','frame');
plot(timeVector,eulerAngles(:,1),'bo',...
     timeVector,eulerAngles(:,2),'r.',...
     timeVector,eulerAngles(:,3),'g.')
axis([0,duration,-180,180])
legend('Roll','Pitch','Yaw')
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation')
```

3-227
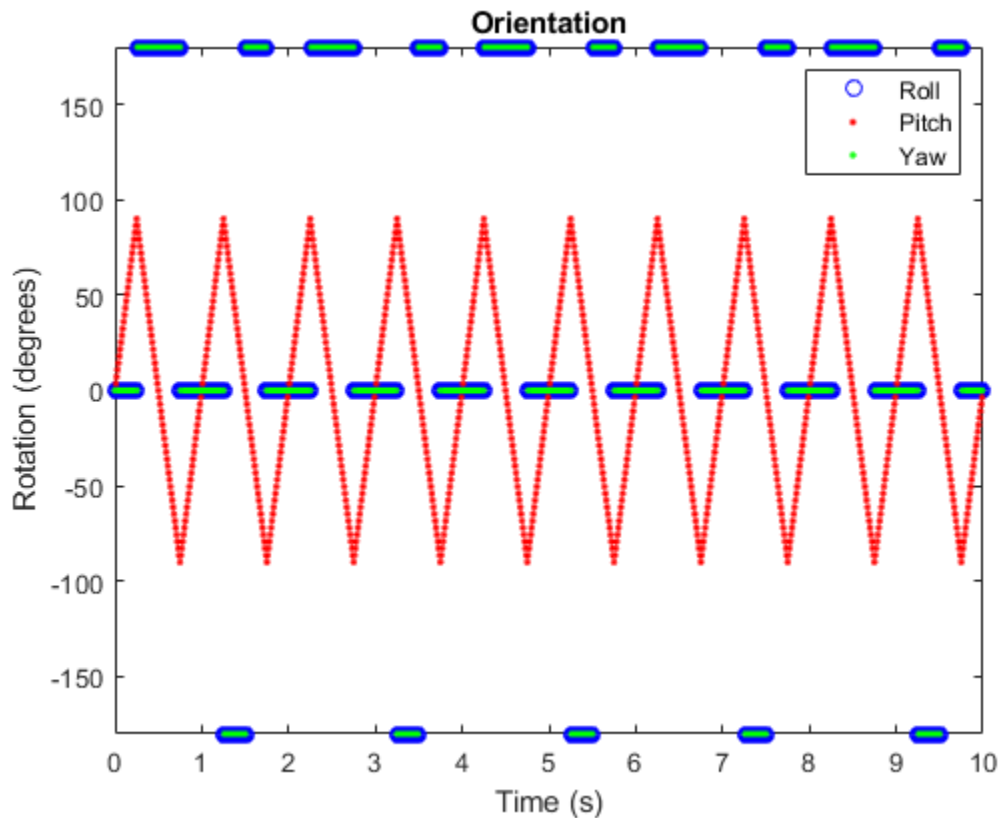
Generate a Coil Trajectory

This example shows how to generate a coil trajectory using the `kinematicTrajectory` System object™.

Create a circular trajectory for a 1000 second duration and a sample rate of 10 Hz. Set the radius of the circle to 5000 meters and the speed to 80 meters per second. Set the climb rate to 100 meters per second and the pitch to 15 degrees. Specify the initial orientation as pointed in the direction of motion.

```
duration = 1000; % seconds
fs = 10;         % Hz
```

```
N = duration*fs; % number of samples

radius = 5000;   % meters
speed = 80;      % meters per second
climbRate = 50;  % meters per second
initialYaw = 90; % degrees
pitch = 15;      % degrees

initPos = [radius, 0, 0];
initVel = [0, speed, climbRate];
initOrientation = quaternion([initialYaw,pitch,0],'eulerd','zyx','frame');

trajectory = kinematicTrajectory('SampleRate',fs, ...
    'Velocity',initVel, ...
    'Position',initPos, ...
    'Orientation',initOrientation);
```

Specify a constant acceleration and angular velocity in the body coordinate system. Rotate the body frame to account for the pitch.

```
accBody = zeros(N,3);
accBody(:,2) = speed^2/radius;
accBody(:,3) = 0.2;

angVelBody = zeros(N,3);
angVelBody(:,3) = speed/radius;

pitchRotation = quaternion([0,pitch,0],'eulerd','zyx','frame');
angVelBody = rotateframe(pitchRotation,angVelBody);
accBody = rotateframe(pitchRotation,accBody);
```

Call `trajectory` with the specified acceleration and angular velocity in the body coordinate system. Plot the position, orientation, and speed over time.

```
[position, orientation, velocity] = trajectory(accBody,angVelBody);

eulerAngles = eulerd(orientation,'ZYX','frame');
speed = sqrt(sum(velocity.^2,2));

timeVector = (0:(N-1))/fs;

figure(1)
plot3(position(:,1),position(:,2),position(:,3))
xlabel('North (m)')
ylabel('East (m)')
```

3-229

```matlab
zlabel('Down (m)')
title('Position')
grid on

figure(2)
plot(timeVector,eulerAngles(:,1),...
     timeVector,eulerAngles(:,2),...
     timeVector,eulerAngles(:,3))
axis([0,duration,-180,180])
legend('Yaw (Rotation Around Down)','Pitch (Rotation Around East)','Roll (Rotation Arou
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation')

figure(3)
plot(timeVector,speed)
xlabel('Time (s)')
ylabel('Speed (m/s)')
title('Speed')
```
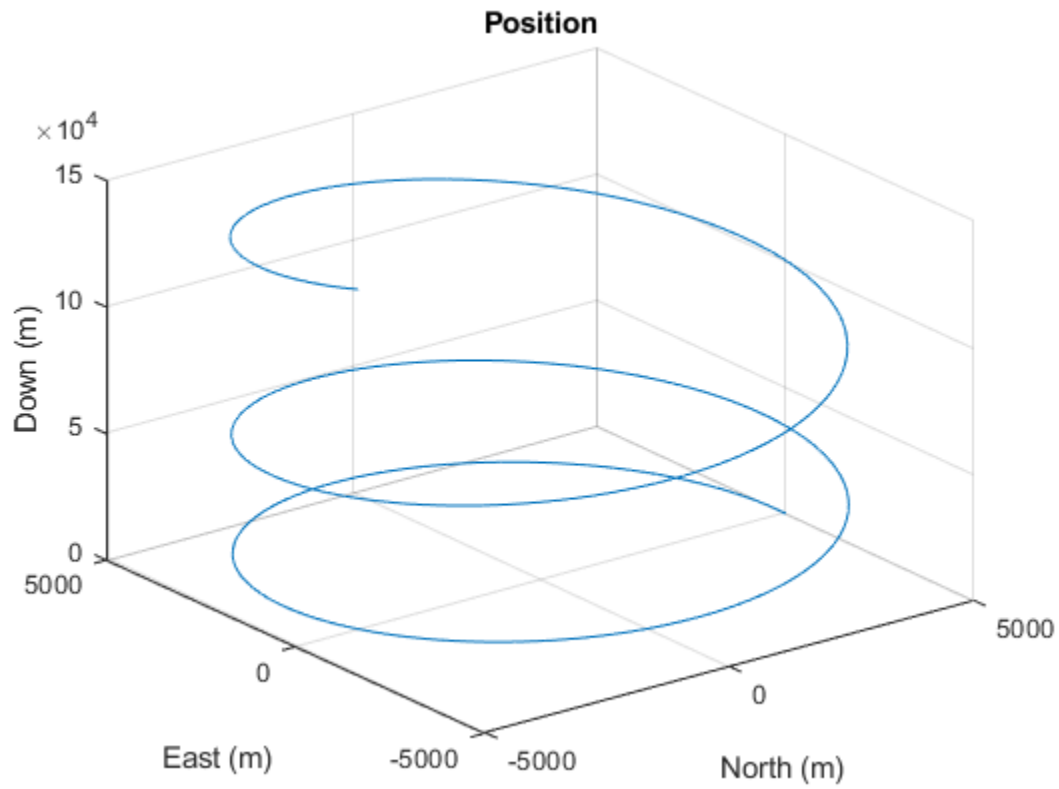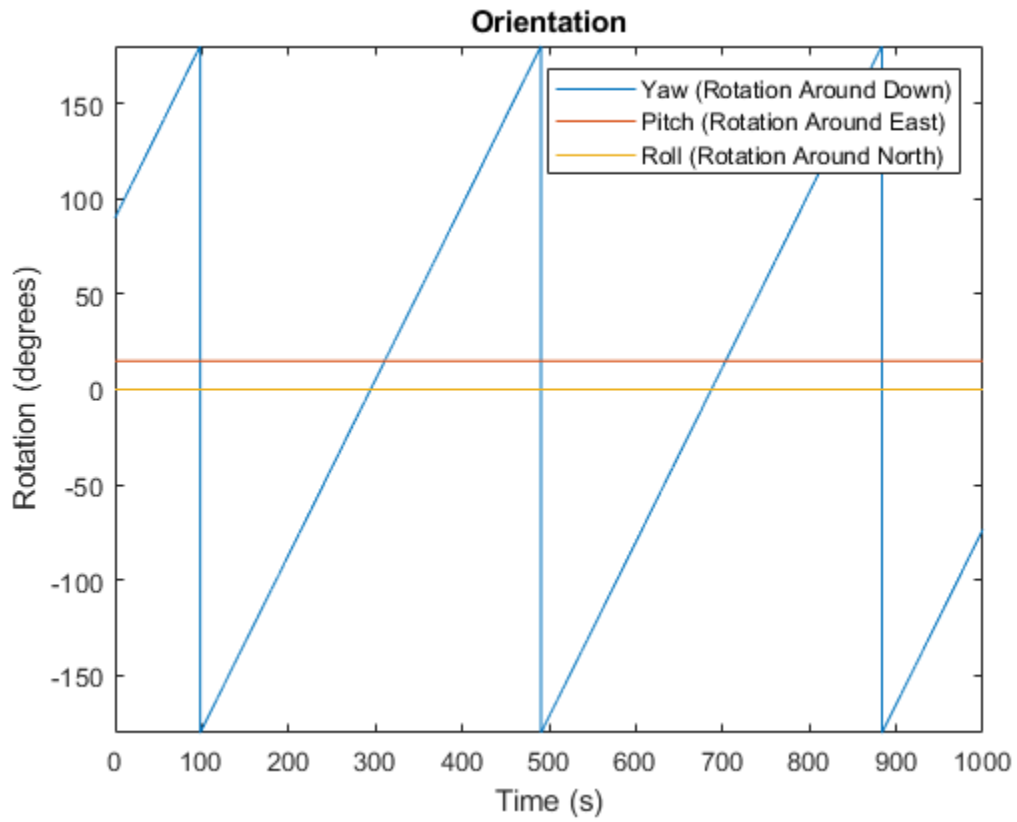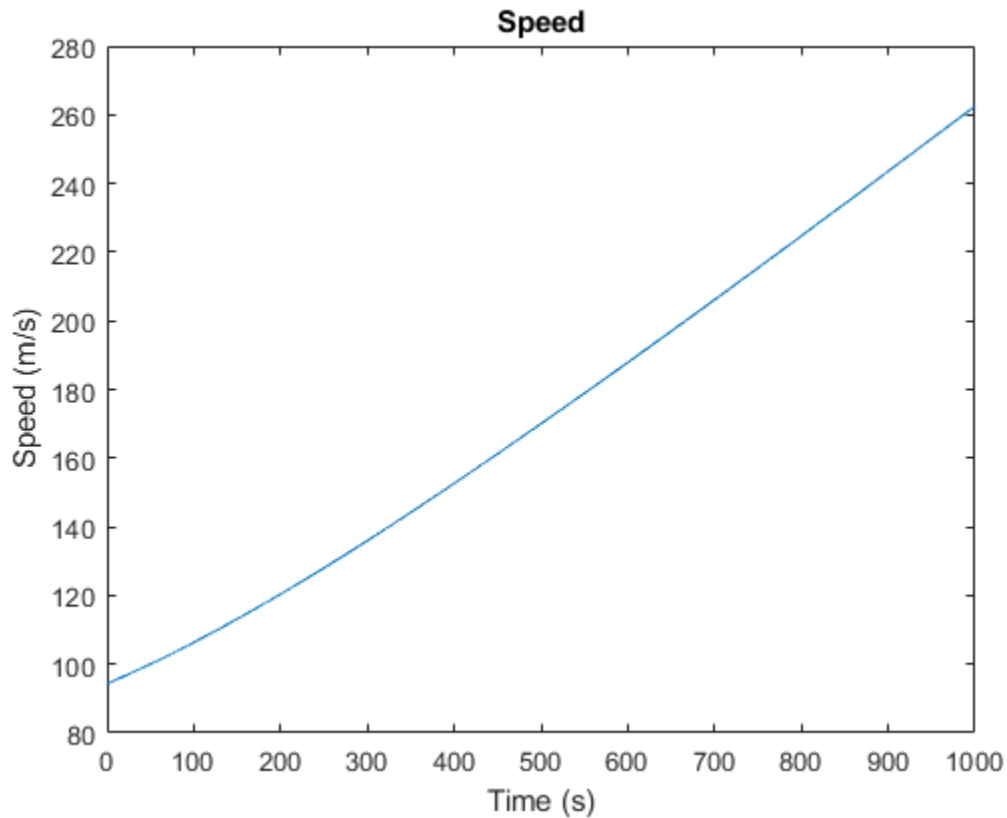
Speed

Generate Spiraling Circular Trajectory with No Inputs

Define a constant angular velocity and constant acceleration that describe a spiraling circular trajectory.

```
Fs = 100;
r = 10;
speed = 2.5;
initialYaw = 90;

initPos = [r 0 0];
initVel = [0 speed 0];
```

```
initOrient = quaternion([initialYaw 0 0], 'eulerd', 'ZYX', 'frame');

accBody = [0 speed^2/r 0.01];
angVelBody = [0 0 speed/r];
```

Create a kinematic trajectory object.

```
traj = kinematicTrajectory('SampleRate',Fs, ...
    'Position',initPos, ...
    'Velocity',initVel, ...
    'Orientation',initOrient, ...
    'AccelerationSource','Property', ...
    'Acceleration',accBody, ...
    'AngularVelocitySource','Property', ...
    'AngularVelocity',angVelBody);
```

Call the kinematic trajectory object in a loop and log the position output. Plot the position over time.

```
N = 10000;
pos = zeros(N, 3);
for i = 1:N
    pos(i,:) = traj();
end

plot3(pos(:,1), pos(:,2), pos(:,3))
title('Position')
xlabel('X (m)')
ylabel('Y (m)')
zlabel('Z (m)')
```
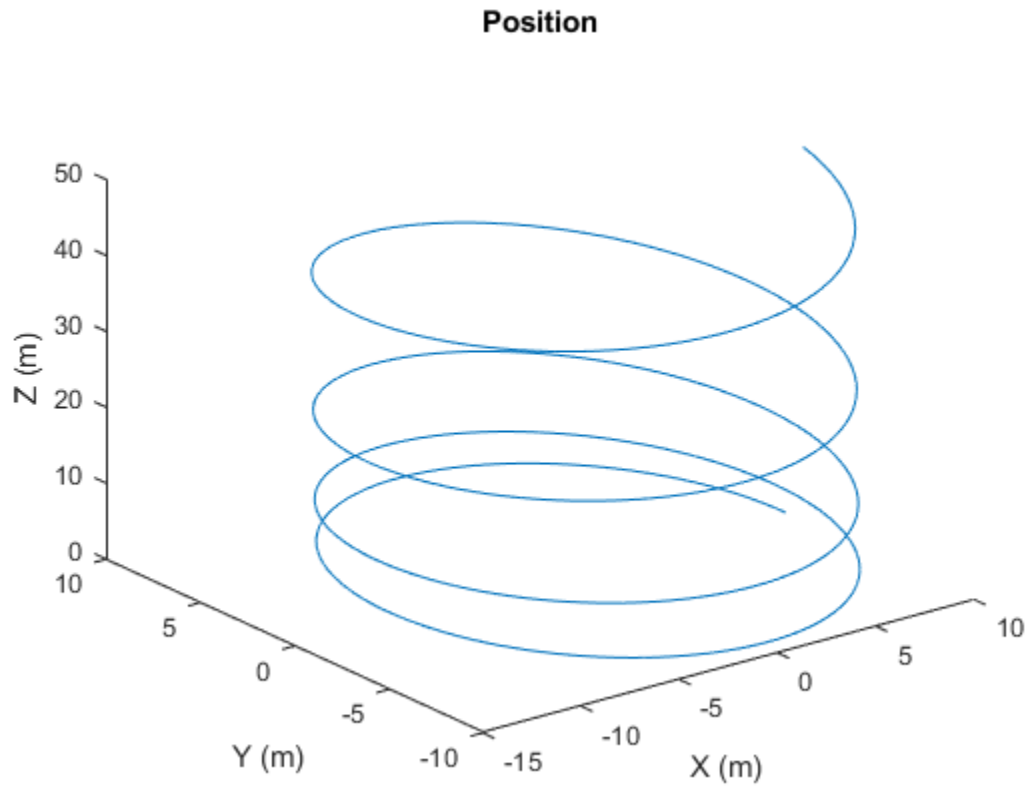
Position

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

"System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also

trackingScenario | waypointTrajectory

Introduced in R2018b

waypointTrajectory System object

Waypoint trajectory generator

Description

The `waypointTrajectory` System object generates trajectories using specified waypoints. When you create the System object, you can optionally specify the time of arrival, velocity, and orientation at each waypoint.

To generate a trajectory from waypoints:

1   Create the `waypointTrajectory` object and set its properties.
2   Call the object as if it were a function.

To learn more about how System objects work, see What Are System Objects? (MATLAB).

Creation

Syntax

```
trajectory = waypointTrajectory
trajectory = waypointTrajectory(Waypoints,TimeOfArrival)
trajectory = waypointTrajectory(Waypoints,TimeOfArrival,Name,Value)
```

Description

`trajectory = waypointTrajectory` returns a System object, `trajectory`, that generates a trajectory based on default stationary waypoints.

`trajectory = waypointTrajectory(Waypoints,TimeOfArrival)` specifies the `Waypoints` that the generated trajectory passes through and the `TimeOfArrival` at each waypoint.

`trajectory = waypointTrajectory(Waypoints,TimeOfArrival,Name,Value)` sets each creation argument or property `Name` to the specified `Value`. Unspecified properties and creation arguments have default or inferred values.

Example: `trajectory = waypointTrajectory([10,10,0;20,20,0;20,20,10], [0,0.5,10])` creates a waypoint trajectory System object, `trajectory`, that starts at waypoint `[10,10,0]`, and then passes through `[20,20,0]` after 0.5 seconds and `[20,20,10]` after 10 seconds.

Creation Arguments

Creation arguments are properties which are set during creation of the System object and cannot be modified later. If you do not explicitly set a creation argument value, the property value is inferred.

If you specify any creation argument, then you must specify both the Waypoints and TimeOfArrival creation arguments. You can specify `Waypoints` and `TimeOfArrival` as value-only arguments or name-value pairs.

Waypoints — Positions in the NED coordinate system (m)
N-by-3 matrix

Positions in the NED coordinate system in meters, specified as an *N*-by-3 matrix. The columns of the matrix correspond to the North, East, and Down axes, respectively. The rows of the matrix, *N*, correspond to individual waypoints.

Dependencies

To set this property, you must also set valid values for the TimeOfArrival property.

Data Types: `double`

TimeOfArrival — Time at each waypoint (s)
N-element column vector of nonnegative increasing numbers

Time corresponding to arrival at each waypoint in seconds, specified as an *N*-element column vector. The first element of `TimeOfArrival` must be `0`. The number of samples, *N*, must be the same as the number of samples (rows) defined by `Waypoints`.

Dependencies

To set this property, you must also set valid values for the Waypoints property.

Data Types: `double`

Velocities — Velocity in NED coordinate system at each waypoint (m/s)
N-by-3 matrix

Velocity in the NED coordinate system at each way point in meters per second, specified as an *N*-by-3 matrix. The columns of the matrix correspond to the North, East, and Down axes, respectively. The number of samples, *N*, must be the same as the number of samples (rows) defined by `Waypoints`.

Dependencies

To set this property, you must also set valid values for the Waypoints and TimeOfArrival properties.

Data Types: `double`

Orientation — Orientation at each waypoint
N-element quaternion column vector | 3-by-3-by-*N* array of real numbers

Orientation at each waypoint, specified as an *N*-element `quaternion` column vector or 3-by-3-by-*N* array of real numbers. The number of quaternions or rotation matrices, *N*, must be the same as the number of samples (rows) defined by `Waypoints`.

If `Orientation` is specified by quaternions, the underlying class must be `double`.

Dependencies

To set this property, you must also set valid values for the Waypoints and TimeOfArrival properties.

Data Types: `quaternion` | `double`

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).

SampleRate — Sample rate of trajectory (Hz)
100 (default) | positive scalar

Sample rate of trajectory in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `double`

SamplesPerFrame — Number of samples in output
1 (default) | positive scalar integer

Number of samples in the output, specified as a positive scalar integer.

Tunable: No

Data Types: `double`

Usage

Syntax

```
[position, orientation, velocity, acceleration, angularVelocity] =
trajectory()
```

Description

`[position, orientation, velocity, acceleration, angularVelocity] =`
`trajectory()` outputs a frame of trajectory data based on specified creation arguments
and properties.

Output Arguments

position — Position in local NED coordinate system (m)
M-by-3 matrix

Position in the local NED coordinate system in meters, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

orientation — Orientation in local NED coordinate system
M-element quaternion column vector | 3-by-3-by-*M* real array

Orientation in the local NED coordinate system, returned as an *M*-by-1 `quaternion` column vector or a 3-by-3-by-*M* real array.

Each quaternion or 3-by-3 rotation matrix is a frame rotation from the local NED coordinate system to the current body coordinate system.

M is specified by the SamplesPerFrame property.

Data Types: `double`

velocity — Velocity in local NED coordinate system (m/s)
M-by-3 matrix

Velocity in the local NED coordinate system in meters per second, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

acceleration — Acceleration in local NED coordinate system (m/s²)
M-by-3 matrix

Acceleration in the local NED coordinate system in meters per second squared, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

angularVelocity — Angular velocity in local NED coordinate system (rad/s)
M-by-3 matrix

Angular velocity in the local NED coordinate system in radians per second, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

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 `waypointTrajectory`

waypointInfo   Get waypoint information table

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
isDone   End-of-data status

Examples

Create Default `waypointTrajectory`

```
trajectory = waypointTrajectory


trajectory =

  waypointTrajectory with properties:

        SampleRate: 100
    SamplesPerFrame: 1
```

Inspect the default waypoints and times of arrival by calling `waypointInfo`. By default, the waypoints indicate a stationary position for one second.

```
waypointInfo(trajectory)


ans =
```

```
  2x2 table

    TimeOfArrival      Waypoints
    _____    _____

          0          0    0    0
          1          0    0    0
```

Create Square Trajectory

Create a square trajectory and examine the relationship between waypoint constraints, sample rate, and the generated trajectory.

Create a square trajectory by defining the vertices of the square. Define the orientation at each waypoint as pointing in the direction of motion. Specify a 1 Hz sample rate and use the default `SamplesPerFrame` of 1.

```matlab
waypoints = [0,0,0; ... % Initial position
             0,1,0; ...
             1,1,0; ...
             1,0,0; ...
             0,0,0];    % Final position

toa = 0:4; % time of arrival

orientation = quaternion([0,0,0; ...
                          45,0,0; ...
                          135,0,0; ...
                          225,0,0; ...
                          0,0,0], ...
                          'eulerd','ZYX','frame');

trajectory = waypointTrajectory(waypoints, ...
    'TimeOfArrival',toa, ...
    'Orientation',orientation, ...
    'SampleRate',1);
```

Create a figure and plot the initial position of the platform.

```matlab
figure(1)
plot(waypoints(1,1),waypoints(1,2),'b*')
```

3-243

```matlab
title('Position')
axis([-1,2,-1,2])
axis square
xlabel('X')
ylabel('Y')
grid on
hold on
```


In a loop, step through the trajectory to output the current position and current orientation. Plot the current position and log the orientation. Use `pause` to mimic real-time processing.

```matlab
orientationLog = zeros(toa(end)*trajectory.SampleRate,1,'quaternion');
count = 1;
```

```
while ~isDone(trajectory)
    [currentPosition,orientationLog(count)] = trajectory();

    plot(currentPosition(1),currentPosition(2),'bo')

    pause(trajectory.SamplesPerFrame/trajectory.SampleRate)
    count = count + 1;
end
hold off
```


Convert the orientation quaternions to Euler angles for easy interpretation, and then plot orientation over time.

```
figure(2)
eulerAngles = eulerd([orientation(1);orientationLog],'ZYX','frame');
plot(toa,eulerAngles(:,1),'ko', ...
     toa,eulerAngles(:,2),'bd', ...
     toa,eulerAngles(:,3),'r.');
title('Orientation Over Time')
legend('Rotation around Z-axis','Rotation around Y-axis','Rotation around X-axis')
xlabel('Time (seconds)')
ylabel('Rotation (degrees)')
grid on
```
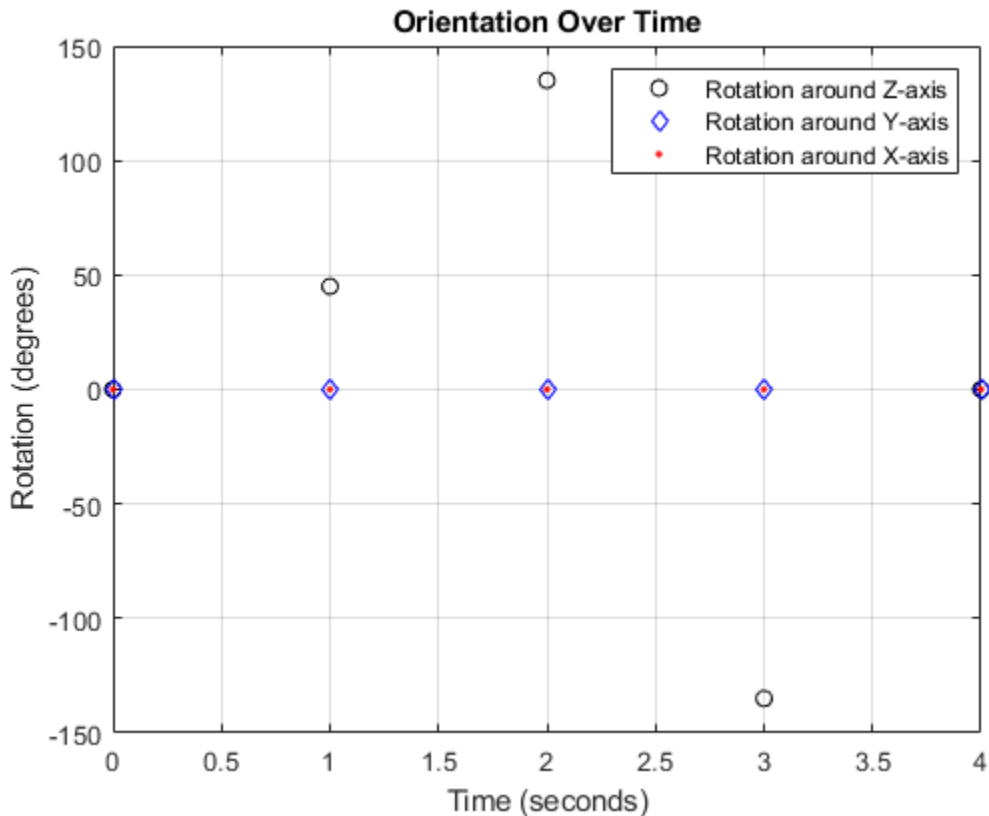

So far, the trajectory object has only output the waypoints that were specified during construction. To interpolate between waypoints, increase the sample rate to a rate faster

than the time of arrivals of the waypoints. Set the `trajectory` sample rate to 100 Hz and call `reset`.

```
trajectory.SampleRate = 100;
reset(trajectory)
```

Create a figure and plot the initial position of the platform. In a loop, step through the trajectory to output the current position and current orientation. Plot the current position and log the orientation. Use `pause` to mimic real-time processing.

```
figure(1)
plot(waypoints(1,1),waypoints(1,2),'b*')
title('Position')
axis([-1,2,-1,2])
axis square
xlabel('X')
ylabel('Y')
grid on
hold on

orientationLog = zeros(toa(end)*trajectory.SampleRate,1,'quaternion');
count = 1;
while ~isDone(trajectory)
    [currentPosition,orientationLog(count)] = trajectory();

    plot(currentPosition(1),currentPosition(2),'bo')

    pause(trajectory.SamplesPerFrame/trajectory.SampleRate)
    count = count + 1;
end
hold off
```

The trajectory output now appears circular. This is because the waypointTrajectory
System object™ minimizes the acceleration and angular velocity when interpolating,
which results in smoother, more realistic motions in most scenarios.

Convert the orientation quaternions to Euler angles for easy interpretation, and then plot
orientation over time. The orientation is also interpolated.

```
figure(2)
eulerAngles = eulerd([orientation(1);orientationLog],'ZYX','frame');
t = 0:1/trajectory.SampleRate:4;
plot(t,eulerAngles(:,1),'ko', ...
     t,eulerAngles(:,2),'bd', ...
     t,eulerAngles(:,3),'r.');
title('Orientation Over Time')
```

```
legend('Rotation around Z-axis','Rotation around Y-axis','Rotation around X-axis')
xlabel('Time (seconds)')
ylabel('Rotation (degrees)')
grid on
```
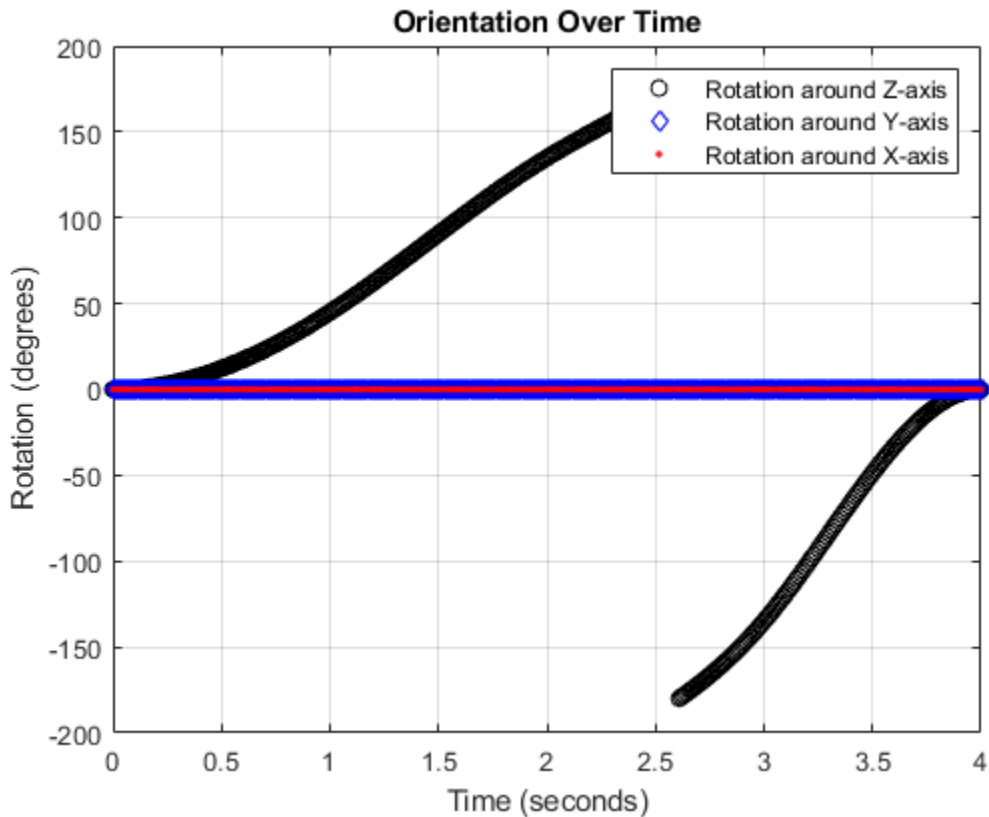

The `waypointTrajectory` algorithm interpolates the waypoints to create a smooth trajectory. To return to the square trajectory, provide more waypoints, especially around sharp changes. To track corresponding times, waypoints, and orientation, specify all the trajectory info in a single matrix.

```
                % Time, Waypoint, Orientation
trajectoryInfo = [0,    0,0,0,    0,0,0; ... % Initial position
                  0.1, 0,0.1,0,  0,0,0; ...
```

```
                    0.9, 0,0.9,0,  0,0,0; ...
                    1,   0,1,0,    45,0,0; ...
                    1.1, 0.1,1,0,  90,0,0; ...

                    1.9, 0.9,1,0,  90,0,0; ...
                    2,   1,1,0,    135,0,0; ...
                    2.1, 1,0.9,0,  180,0,0; ...

                    2.9, 1,0.1,0,  180,0,0; ...
                    3,   1,0,0,    225,0,0; ...
                    3.1, 0.9,0,0,  270,0,0; ...

                    3.9, 0.1,0,0,  270,0,0; ...
                    4,   0,0,0,    270,0,0];    % Final position

trajectory = waypointTrajectory(trajectoryInfo(:,2:4), ...
    'TimeOfArrival',trajectoryInfo(:,1), ...
    'Orientation',quaternion(trajectoryInfo(:,5:end),'eulerd','ZYX','frame'), ...
    'SampleRate',100);
```

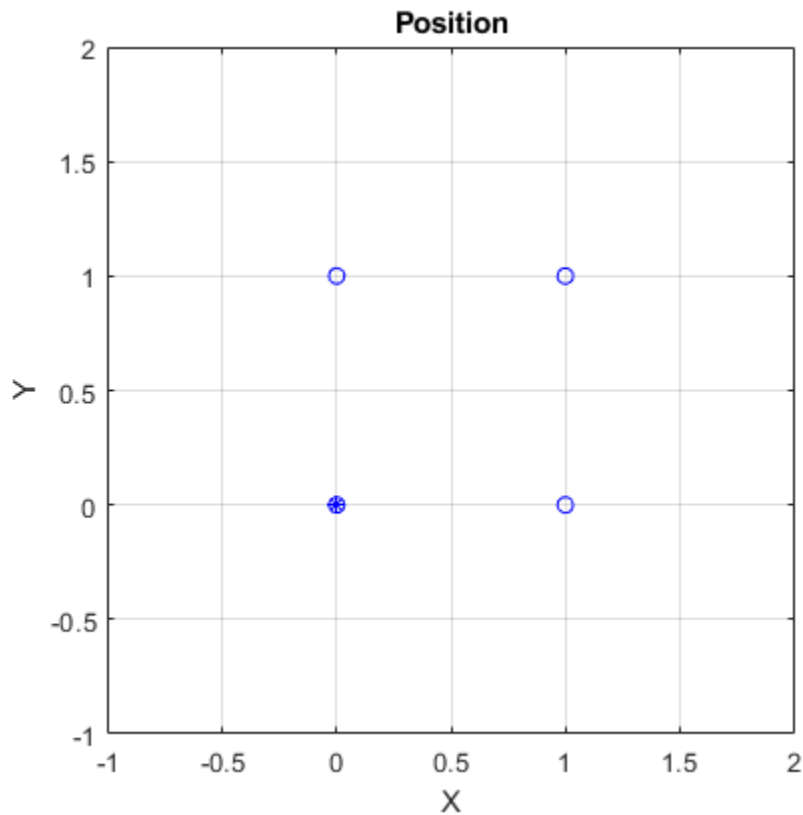Create a figure and plot the initial position of the platform. In a loop, step through the trajectory to output the current position and current orientation. Plot the current position and log the orientation. Use `pause` to mimic real-time processing.

```
figure(1)
plot(waypoints(1,1),waypoints(1,2),'b*')
title('Position')
axis([-1,2,-1,2])
axis square
xlabel('X')
ylabel('Y')
grid on
hold on

orientationLog = zeros(toa(end)*trajectory.SampleRate,1,'quaternion');
count = 1;
while ~isDone(trajectory)
   [currentPosition,orientationLog(count)] = trajectory();

   plot(currentPosition(1),currentPosition(2),'bo')

   pause(trajectory.SamplesPerFrame/trajectory.SampleRate)
   count = count+1;
```

```
end
hold off
```


The trajectory output now appears more square-like, especially around the vertices with waypoints.

Convert the orientation quaternions to Euler angles for easy interpretation, and then plot orientation over time.

```
figure(2)
eulerAngles = eulerd([orientation(1);orientationLog],'ZYX','frame');
t = 0:1/trajectory.SampleRate:4;
eulerAngles = plot(t,eulerAngles(:,1),'ko', ...
                   t,eulerAngles(:,2),'bd', ...
```

```
                        t,eulerAngles(:,3),'r.');
title('Orientation Over Time')
legend('Rotation around Z-axis', ...
       'Rotation around Y-axis', ...
       'Rotation around X-axis', ...
       'Location', 'SouthWest')
xlabel('Time (seconds)')
ylabel('Rotation (degrees)')
grid on
```
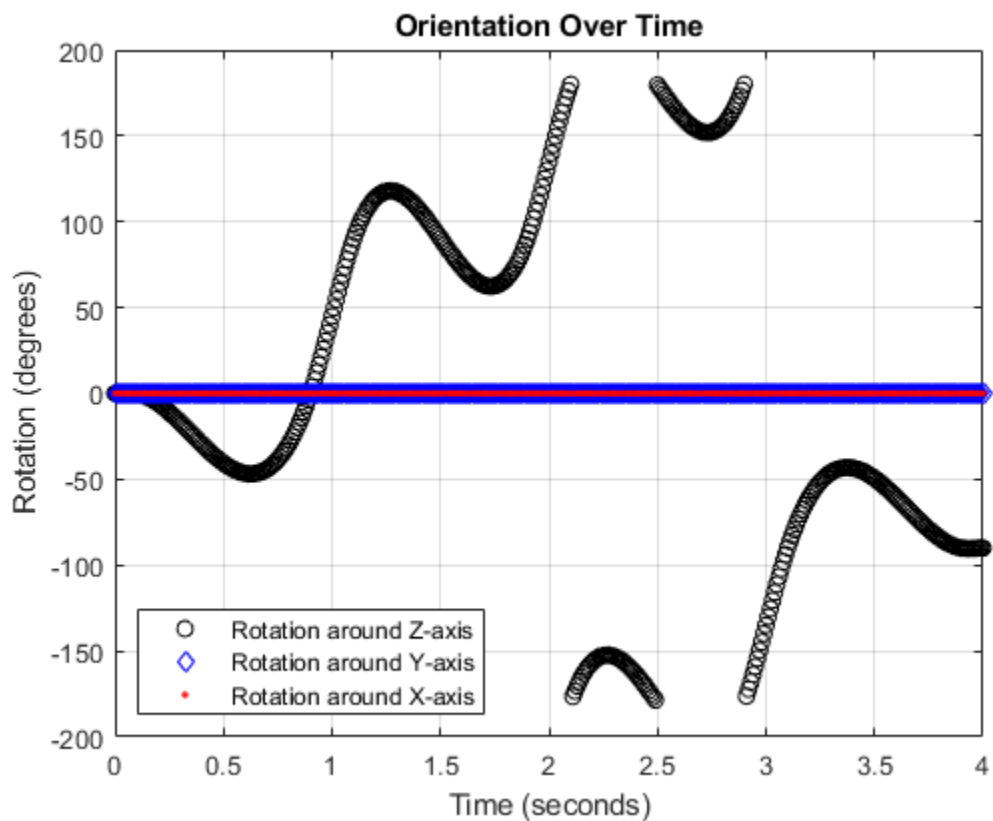
Create Arc Trajectory

This example shows how to create an arc trajectory using the `waypointTrajectory` System object™. `waypointTrajectory` creates a path through specified waypoints that minimizes acceleration and angular velocity. After creating an arc trajectory, you restrict the trajectory to be within preset bounds.

Create an Arc Trajectory

Define a constraints matrix consisting of waypoints, times of arrival, and orientation for an arc trajectory. The generated trajectory passes through the waypoints at the specified times with the specified orientation. The `waypointTrajectory` System object requires orientation to be specified using quaternions or rotation matrices. Convert the Euler angles saved in the constrains matrix to quaternions when specifying the `Orientation` property.

```
            % Arrival,  Waypoints,  Orientation
constraints = [0,     20,20,0,     90,0,0;
               3,     50,20,0,     90,0,0;
               4,     58,15.5,0,   162,0,0;
               5.5,   59.5,0,0     180,0,0];

trajectory = waypointTrajectory(constraints(:,2:4), ...
    'TimeOfArrival',constraints(:,1), ...
    'Orientation',quaternion(constraints(:,5:7),'eulerd','ZYX','frame'));
```

Call `waypointInfo` on `trajectory` to return a table of your specified constraints. The creation properties `Waypoints`, `TimeOfArrival`, and `Orientation` are variables of the table. The table is convenient for indexing while plotting.

```
tInfo = waypointInfo(trajectory)


tInfo =

  4×3 table

    TimeOfArrival         Waypoints              Orientation
    _____     _____     _____

          0           20       20        0     [1×1 quaternion]
          3           50       20        0     [1×1 quaternion]
          4           58     15.5        0     [1×1 quaternion]
```

```
        5.5        59.5        0        0    [1×1 quaternion]
```

The trajectory object outputs the current position, velocity, acceleration, and angular velocity at each call. Call `trajectory` in a loop and plot the position over time. Cache the other outputs.

```matlab
figure(1)
plot(tInfo.Waypoints(1,1),tInfo.Waypoints(1,2),'b*')
title('Position')
axis([20,65,0,25])
xlabel('North')
ylabel('East')
grid on
daspect([1 1 1])
hold on

orient = zeros(tInfo.TimeOfArrival(end)*trajectory.SampleRate,1,'quaternion');
vel = zeros(tInfo.TimeOfArrival(end)*trajectory.SampleRate,3);
acc = vel;
angVel = vel;

count = 1;
while ~isDone(trajectory)
    [pos,orient(count),vel(count,:),acc(count,:),angVel(count,:)] = trajectory();

    plot(pos(1),pos(2),'bo')

    pause(trajectory.SamplesPerFrame/trajectory.SampleRate)
    count = count + 1;
end
```
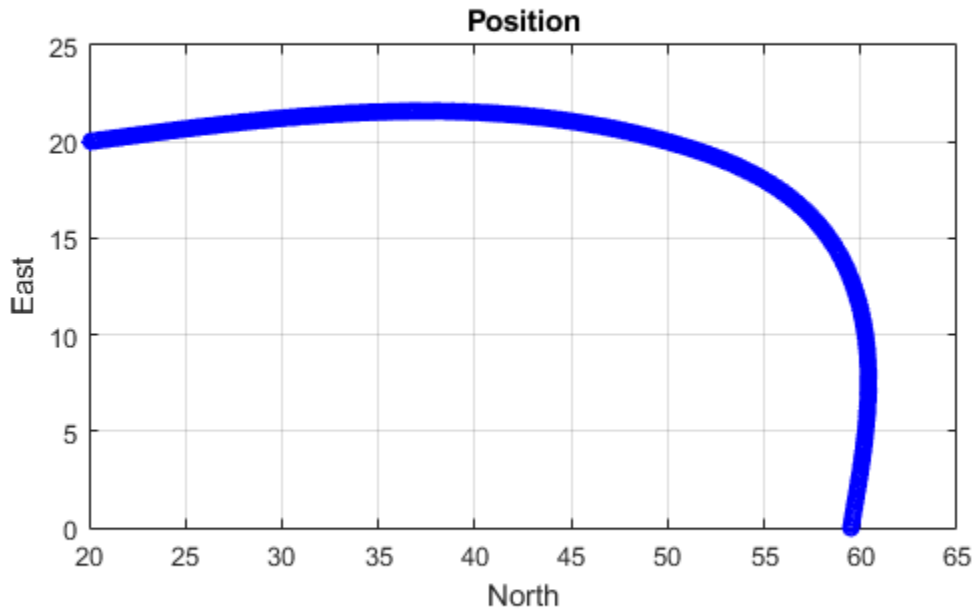
Inspect the orientation, velocity, acceleration, and angular velocity over time. The waypointTrajectory System object™ creates a path through the specified constraints that minimized acceleration and angular velocity.

```
figure(2)
timeVector = 0:(1/trajectory.SampleRate):tInfo.TimeOfArrival(end);
eulerAngles = eulerd([tInfo.Orientation{1};orient],'ZYX','frame');
plot(timeVector,eulerAngles(:,1), ...
     timeVector,eulerAngles(:,2), ...
     timeVector,eulerAngles(:,3));
title('Orientation Over Time')
legend('Rotation around Z-axis', ...
       'Rotation around Y-axis', ...
       'Rotation around X-axis', ...
```

```
        'Location','southwest')
xlabel('Time (seconds)')
ylabel('Rotation (degrees)')
grid on

figure(3)
plot(timeVector(2:end),vel(:,1), ...
     timeVector(2:end),vel(:,2), ...
     timeVector(2:end),vel(:,3));
title('Velocity Over Time')
legend('North','East','Down')
xlabel('Time (seconds)')
ylabel('Velocity (m/s)')
grid on

figure(4)
plot(timeVector(2:end),acc(:,1), ...
     timeVector(2:end),acc(:,2), ...
     timeVector(2:end),acc(:,3));
title('Acceleration Over Time')
legend('North','East','Down','Location','southwest')
xlabel('Time (seconds)')
ylabel('Acceleration (m/s^2)')
grid on

figure(5)
plot(timeVector(2:end),angVel(:,1), ...
     timeVector(2:end),angVel(:,2), ...
     timeVector(2:end),angVel(:,3));
title('Angular Velocity Over Time')
legend('North','East','Down')
xlabel('Time (seconds)')
ylabel('Angular Velocity (rad/s)')
grid on
```

3-257
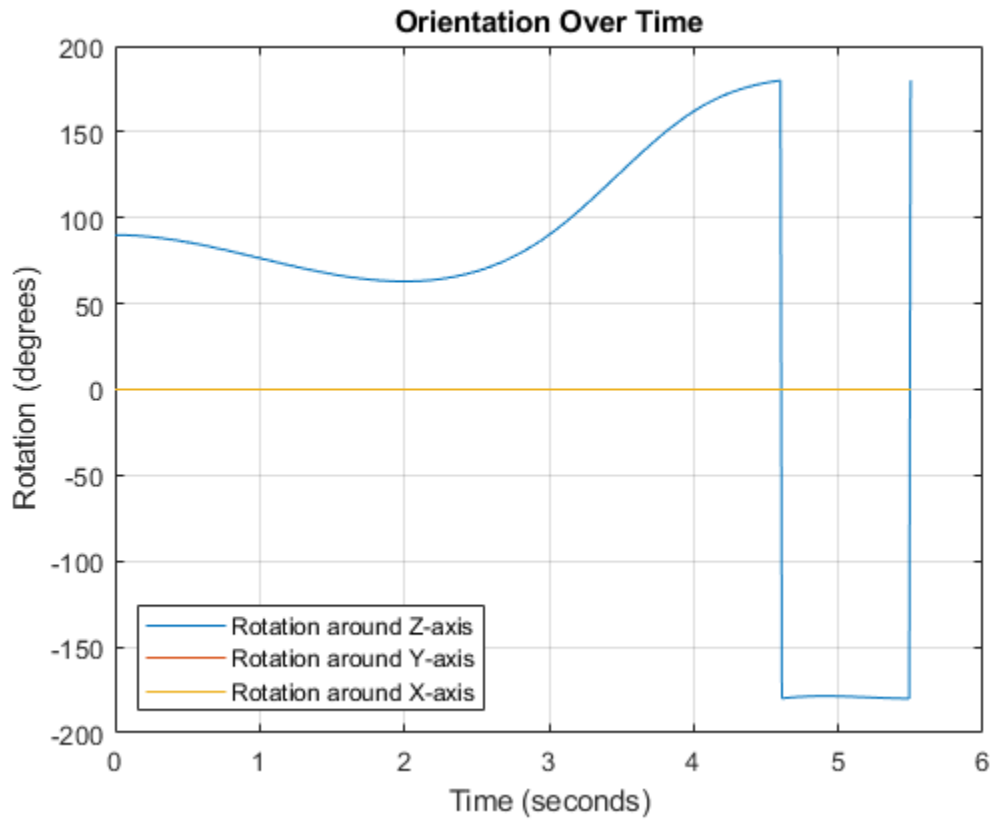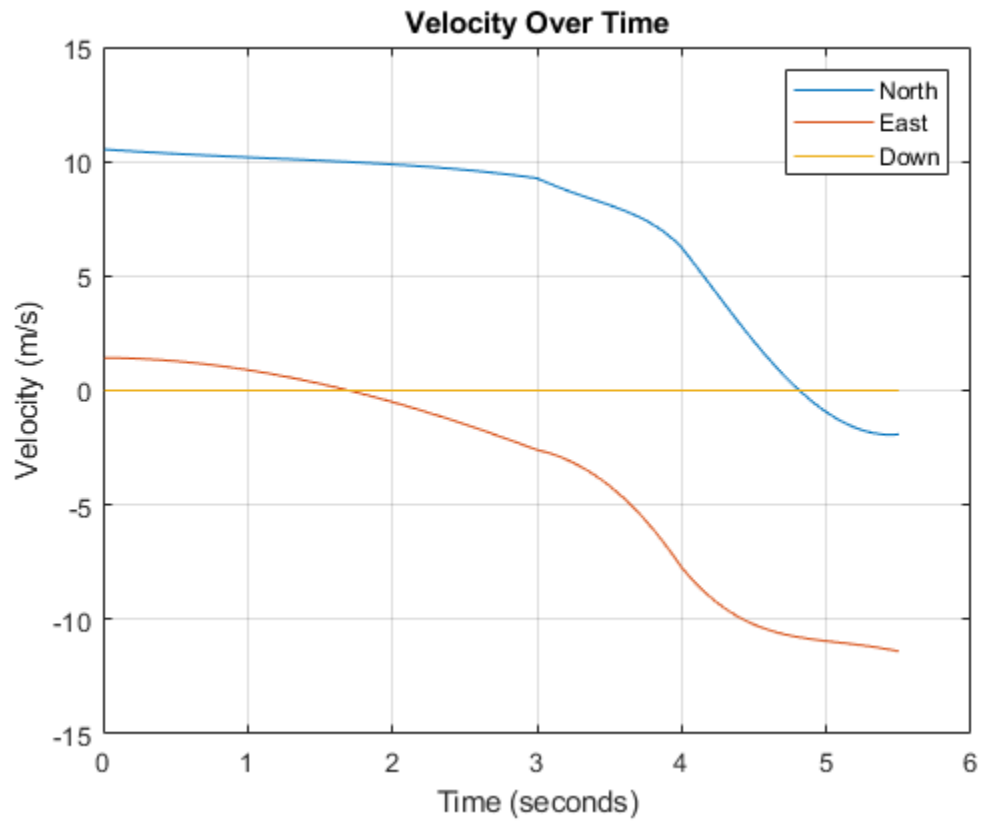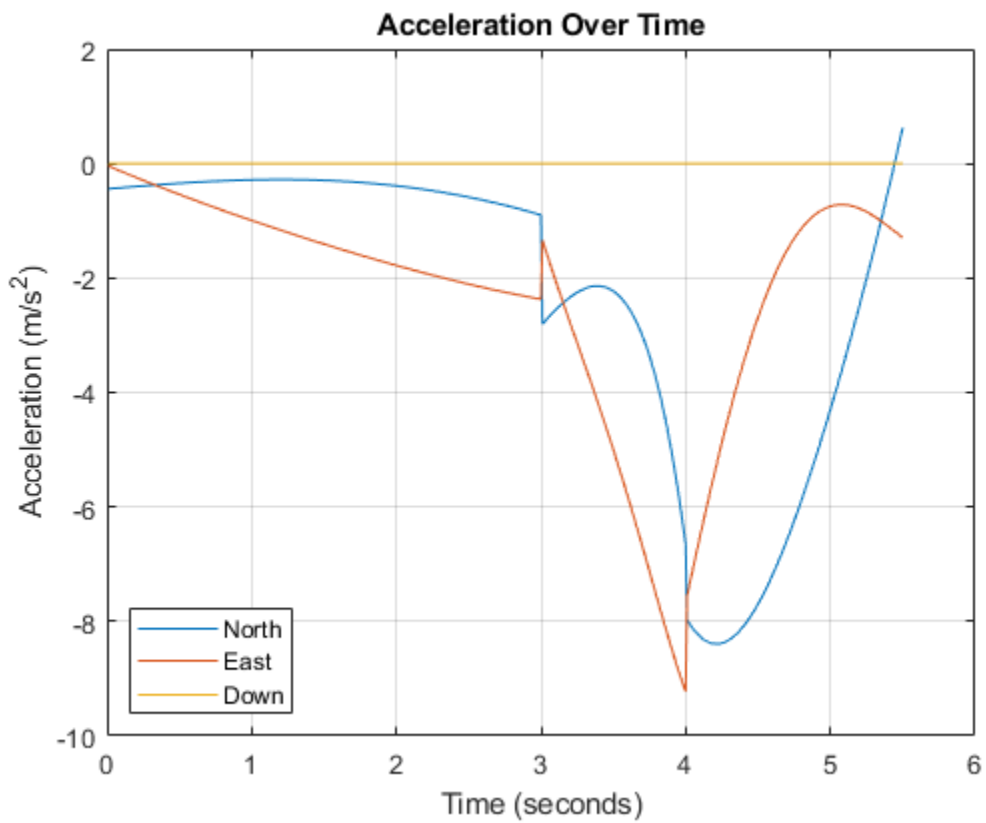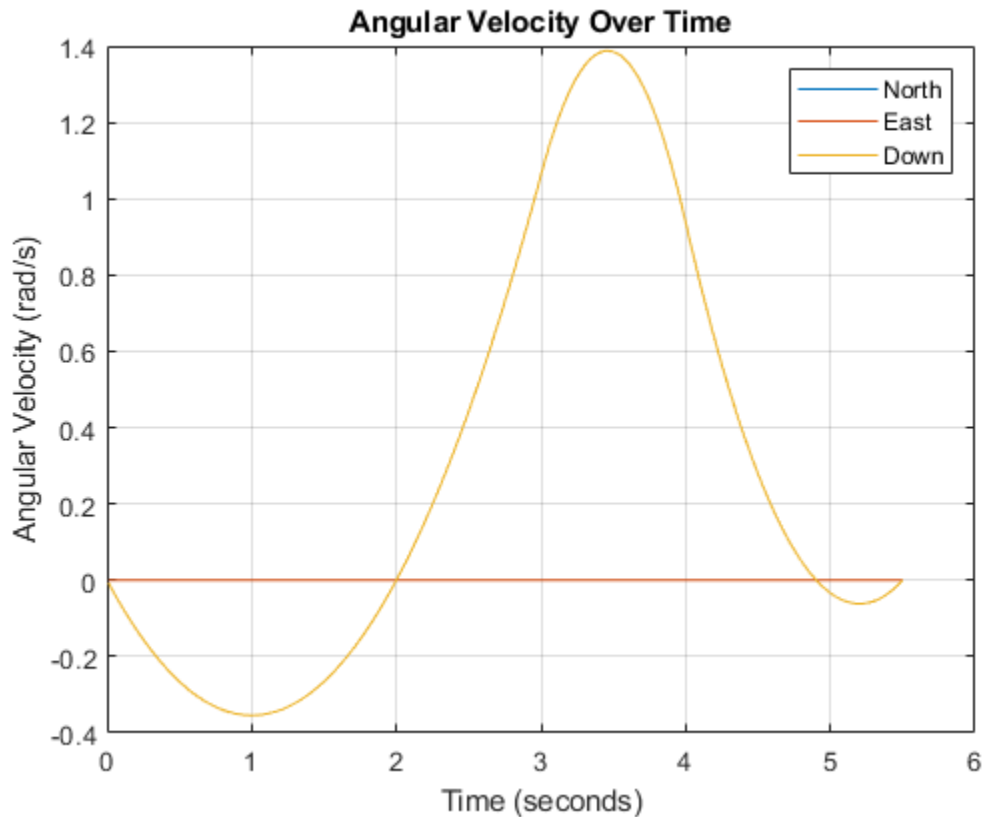
Restrict Arc Trajectory Within Preset Bounds

You can specify additional waypoints to create trajectories within given bounds. Create upper and lower bounds for the arc trajectory.

```
figure(1)
xUpperBound = [(20:50)';50+10*sin(0:0.1:pi/2)';60*ones(11,1)];
yUpperBound = [20.5.*ones(31,1);10.5+10*cos(0:0.1:pi/2)';(10:-1:0)'];

xLowerBound = [(20:49)';50+9*sin(0:0.1:pi/2)';59*ones(11,1)];
yLowerBound = [19.5.*ones(30,1);10.5+9*cos(0:0.1:pi/2)';(10:-1:0)'];

plot(xUpperBound,yUpperBound,'r','LineWidth',2);
plot(xLowerBound,yLowerBound,'r','LineWidth',2)
```
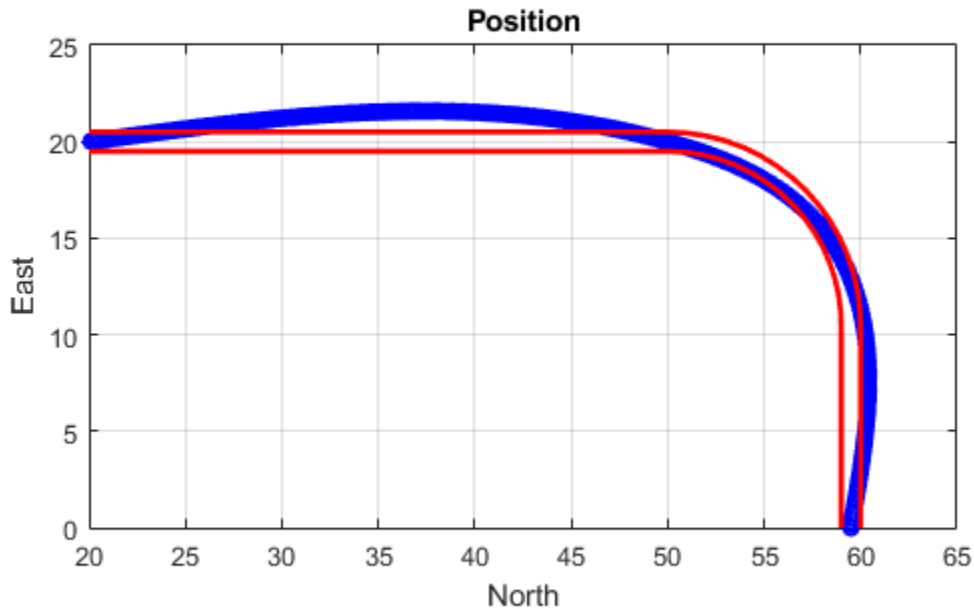
To create a trajectory within the bounds, add additional waypoints. Create a new
`waypointTrajectory` System object™, and then call it in a loop to plot the generated
trajectory. Cache the orientation, velocity, acceleration, and angular velocity output from
the `trajectory` object.

```
              % Time,  Waypoint,      Orientation
constraints = [0,      20,20,0,       90,0,0;
               1.5,    35,20,0,       90,0,0;
               2.5     45,20,0,       90,0,0;
               3,      50,20,0,       90,0,0;
               3.3,    53,19.5,0,     108,0,0;
               3.6,    55.5,18.25,0,  126,0,0;
               3.9,    57.5,16,0,     144,0,0;
               4.2,    59,14,0,       162,0,0;
```

```
                4.5,   59.5,10,0      180,0,0;
                5,     59.5,5,0       180,0,0;
                5.5,   59.5,0,0       180,0,0];

trajectory = waypointTrajectory(constraints(:,2:4), ...
    'TimeOfArrival',constraints(:,1), ...
    'Orientation',quaternion(constraints(:,5:7),'eulerd','ZYX','frame'));
tInfo = waypointInfo(trajectory);

figure(1)
plot(tInfo.Waypoints(1,1),tInfo.Waypoints(1,2),'b*')

count = 1;
while ~isDone(trajectory)
   [pos,orient(count),vel(count,:),acc(count,:),angVel(count,:)] = trajectory();

   plot(pos(1),pos(2),'gd')

   pause(trajectory.SamplesPerFrame/trajectory.SampleRate)
   count = count + 1;
end
```
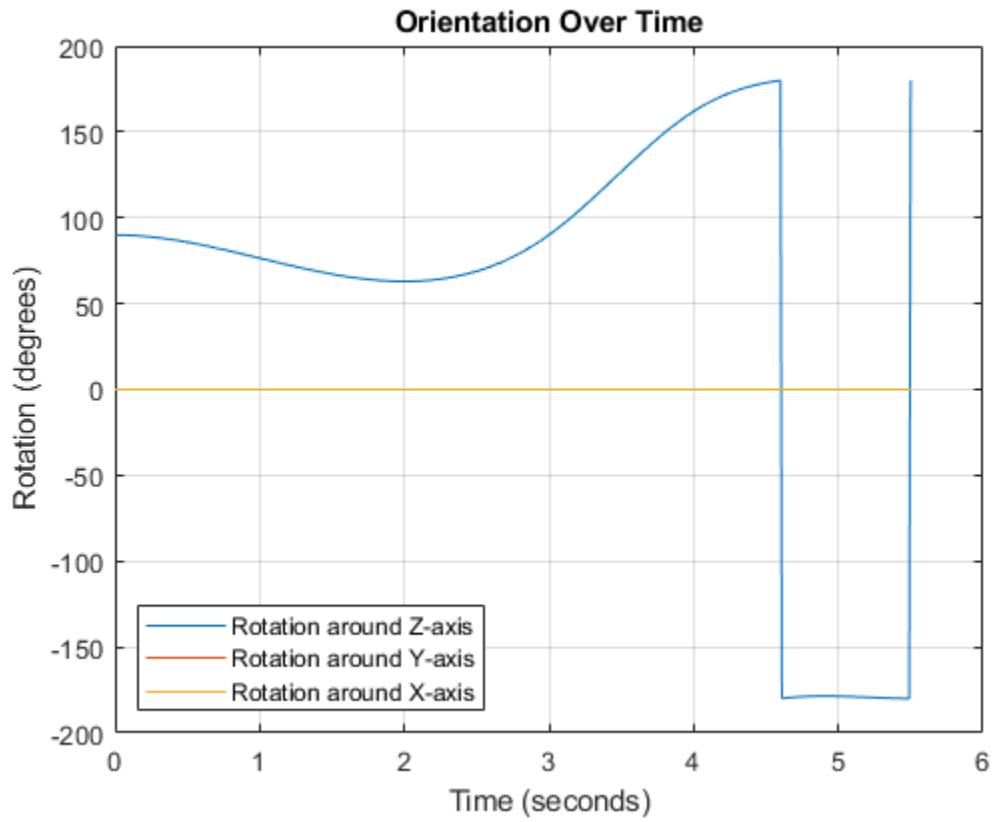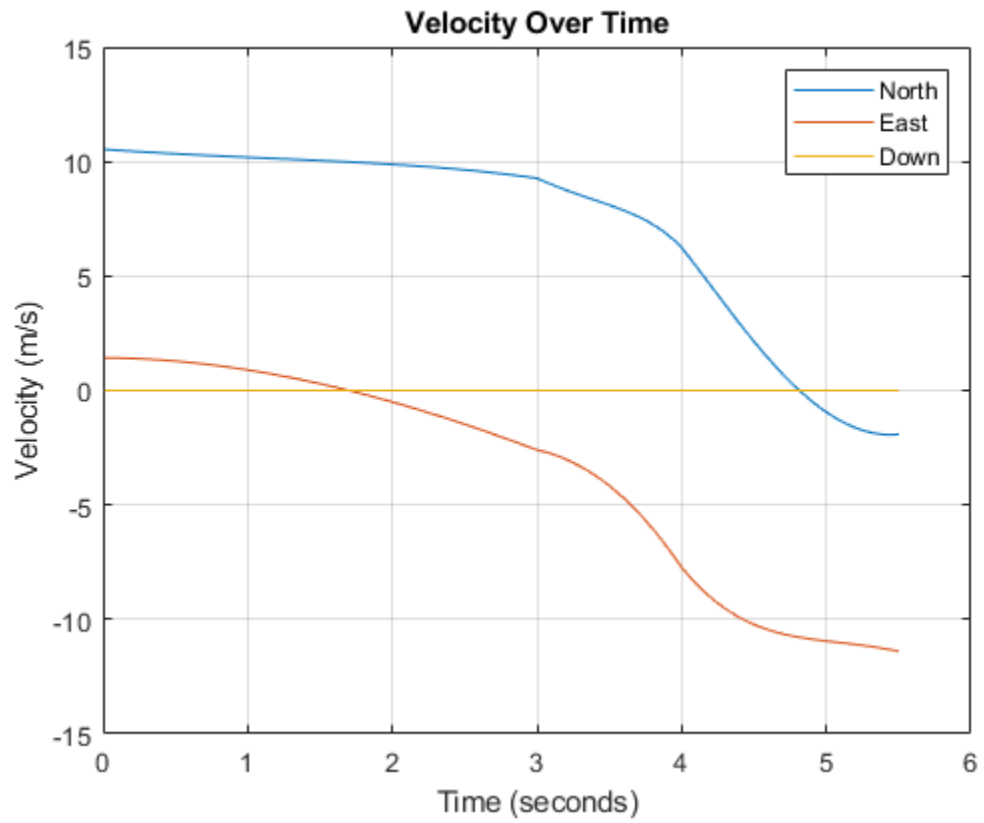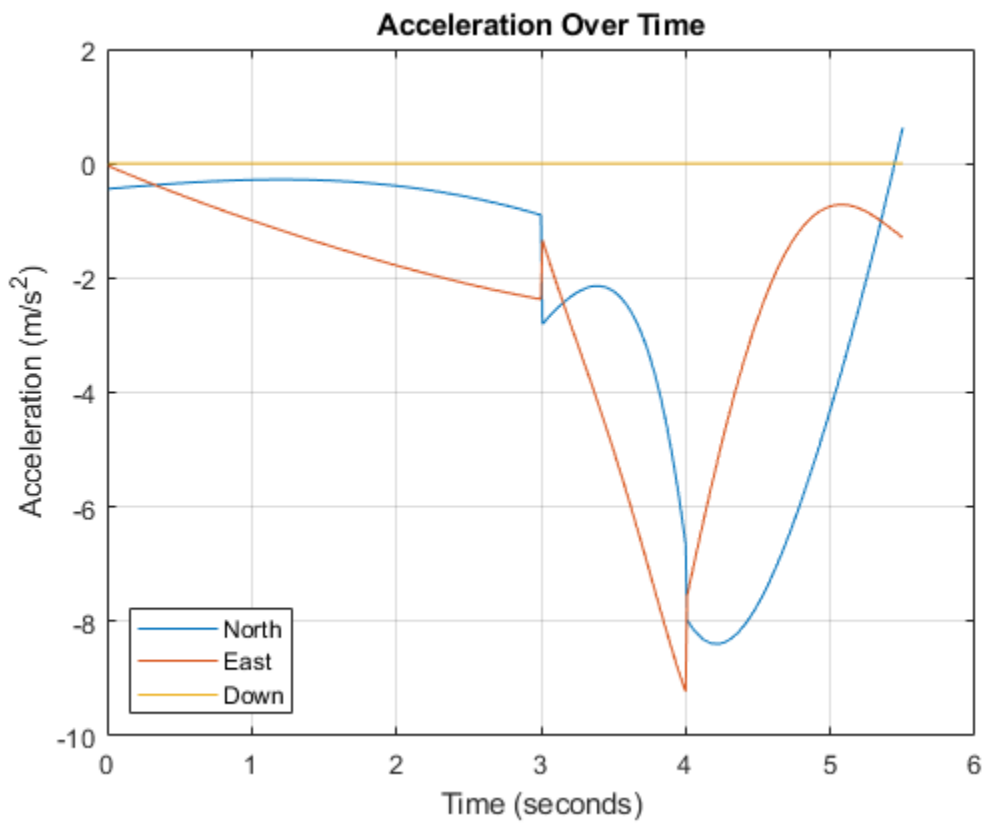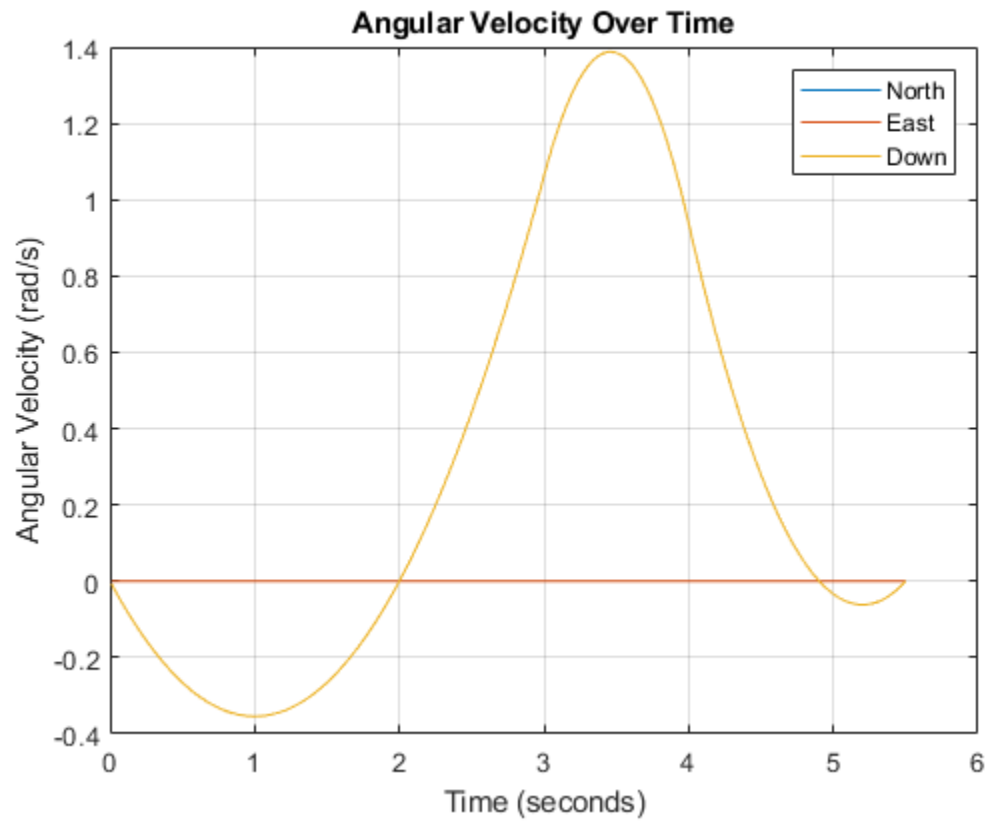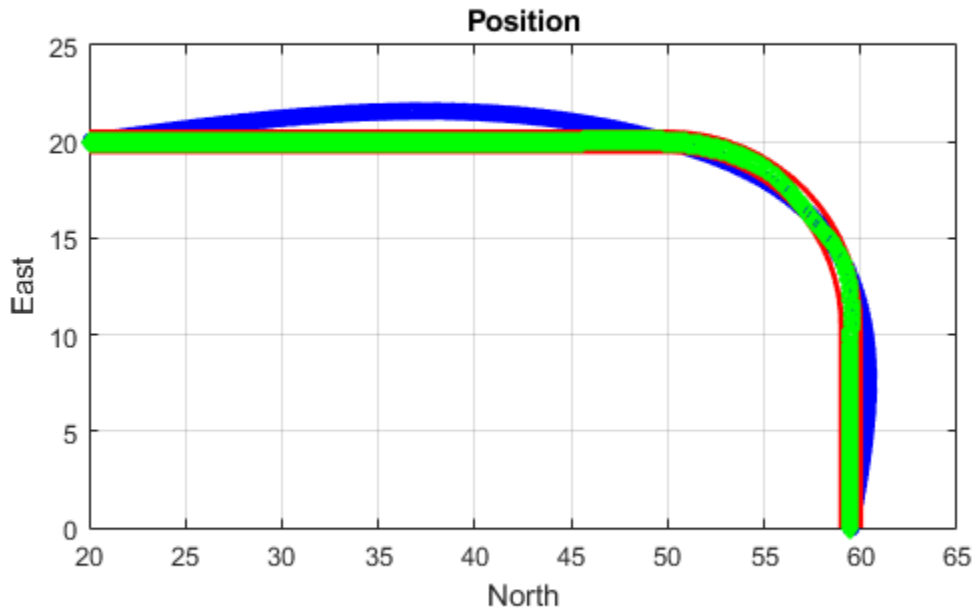
The generated trajectory now fits within the specified boundaries. Visualize the orientation, velocity, acceleration, and angular velocity of the generated trajectory.

```matlab
figure(2)
timeVector = 0:(1/trajectory.SampleRate):tInfo.TimeOfArrival(end);
eulerAngles = eulerd(orient,'ZYX','frame');
plot(timeVector(2:end),eulerAngles(:,1), ...
    timeVector(2:end),eulerAngles(:,2), ...
    timeVector(2:end),eulerAngles(:,3));
title('Orientation Over Time')
legend('Rotation around Z-axis', ...
       'Rotation around Y-axis', ...
       'Rotation around X-axis', ...
       'Location','southwest')
```

```matlab
xlabel('Time (seconds)')
ylabel('Rotation (degrees)')
grid on

figure(3)
plot(timeVector(2:end),vel(:,1), ...
     timeVector(2:end),vel(:,2), ...
     timeVector(2:end),vel(:,3));
title('Velocity Over Time')
legend('North','East','Down')
xlabel('Time (seconds)')
ylabel('Velocity (m/s)')
grid on

figure(4)
plot(timeVector(2:end),acc(:,1), ...
     timeVector(2:end),acc(:,2), ...
     timeVector(2:end),acc(:,3));
title('Acceleration Over Time')
legend('North','East','Down')
xlabel('Time (seconds)')
ylabel('Acceleration (m/s^2)')
grid on

figure(5)
plot(timeVector(2:end),angVel(:,1), ...
     timeVector(2:end),angVel(:,2), ...
     timeVector(2:end),angVel(:,3));
title('Angular Velocity Over Time')
legend('North','East','Down')
xlabel('Time (seconds)')
ylabel('Angular Velocity (rad/s)')
grid on
```

Note that while the generated trajectory now fits within the spatial boundaries, the acceleration and angular velocity of the trajectory are somewhat erratic. This is due to over-specifying waypoints.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

The object function, `waypointInfo`, does not support code generation.

3-273

Usage notes and limitations:

See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

kinematicTrajectory | trackingScenario

Introduced in R2018b

waypointInfo

Get waypoint information table

Syntax

```
trajectoryInfo = waypointInfo(trajectory)
```

Description

`trajectoryInfo = waypointInfo(trajectory)` returns a table of waypoints, times of arrival, velocities, and orientation for the `trajectory` System object

Input Arguments

`trajectory` — Object of `waypointTrajectory`
object

Object of the `waypointTrajectory` System object.

Output Arguments

`trajectoryInfo` — Trajectory information
table

Trajectory information, returned as a table with variables corresponding to set creation properties: Waypoints, TimeOfArrival, Velocities, and Orientation.

The trajectory information table always has variables `Waypoints` and `TimeOfArrival`. If the `Velocities` property is set during construction, the trajectory information table additionally returns velocities. If the `Orientation` property is set during construction, the trajectory information table additionally returns orientation.

See Also

kinematicTrajectory | waypointTrajectory

Introduced in R2018b

monostaticRadarSensor System object

Generate radar detections for tracking scenario

Description

The `monostaticRadarSensor` System object generates detections of targets by a monostatic surveillance scanning radar. You can use the `monostaticRadarSensor` object in a scenario containing moving and stationary platforms such as one created using `trackingScenario`. The `monostaticRadarSensor` object can simulate real detections with added random noise and also generate false alarm detections. In addition, you can use the detections generated by this object as input to trackers such as `trackerGNN` or `trackerTOMHT`.

This object enable you to configure a scanning radar. A scanning radar changes its look angle by stepping the mechanical and electronic position of the beam in increments of the angular span specified in the `FieldOfView` property. The radar scans the total region in azimuth and elevation defined by the radar mechanical and electronic scan limits, `MechanicalScanLimits` and `ElectronicScanLimits`. If the scanning limits for azimuth or elevation are set to `[0 0]`, then no scanning is performed along that dimension for that scan mode. If the maximum mechanical scan rate for azimuth or elevation is set to zero, then no mechanical scanning is performed along that dimension.

Using a single-exponential mode, the radar computes range and elevation biases caused by propagation through the troposphere. A range bias means that measured ranges are greater than the line-of-sight range to the target. Elevation bias means that the measured elevations are above their true elevations. Biases are larger when the line-of-sight path between the radar and target passes through lower altitudes because the atmosphere is thicker.

To generate radar detections:

1   Create the `monostaticRadarSensor` 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).

3-277

Creation

Syntax

```
sensor = monostaticRadarSensor
sensor = monostaticRadarSensor(Name,Value)

sensor = monostaticRadarSensor('No scanning')
sensor = monostaticRadarSensor('Raster')
sensor = monostaticRadarSensor('Rotator')
sensor = monostaticRadarSensor('Sector')
sensor = monostaticRadarSensor(SensorIndex, ___ )
```

Description

`sensor = monostaticRadarSensor` creates a radar detection generator object with default property values.

`sensor = monostaticRadarSensor(Name,Value)` sets properties using one or more name-value pairs. Enclose each property name in quotes. For example, `monostaticRadarSensor('DetectionCoordinates','Sensor cartesian','MaxRange',200)` creates a radar detection generator that reports detections in the sensor Cartesian coordinate system and has a maximum detection range of 200 meters.

`sensor = monostaticRadarSensor('No scanning')` is a convenience syntax that creates a `monostaticRadarSensor` that only points along the radar antenna boresight direction. No mechanical or electronic scanning is performed. This syntax sets the `ScanMode` property to `'No scanning'`.

`sensor = monostaticRadarSensor('Raster')` is a convenience syntax that creates a `monostaticRadarSensor` object that mechanically scans a raster pattern. The raster span is 90° in azimuth from –45° to +45° and in elevation from the horizon to 10° above the horizon. See "Raster Scanning" on page 3-304 for the properties set by this syntax.

`sensor = monostaticRadarSensor('Rotator')` is a convenience syntax that creates a `monostaticRadarSensor` object that mechanically scans 360° in azimuth by mechanically rotating the antenna at a constant rate. When you set `HasElevation` to

true, the radar antenna mechanically points towards the center of the elevation field of view. See "Rotator Scanning" on page 3-305 for the properties set by this syntax.

sensor = monostaticRadarSensor('Sector') is a convenience syntax to create a monostaticRadarSensor object that mechanically scans a 90° azimuth sector from –45° to +45°. Setting HasElevation to true points the radar antenna towards the center of the elevation field of view. You can change the ScanMode to 'Electronic' to electronically scan the same azimuth sector. In this case, the antenna is not mechanically tilted in an electronic sector scan. Instead, beams are stacked electronically to process the entire elevation spanned by the scan limits in a single dwell. See "Sector Scanning" on page 3-305 for the properties set by this syntax.

sensor = monostaticRadarSensor(SensorIndex, ___) specifies the sensor ID, SensorIndex, as an input argument instead of using the SensorIndex name-value pair.

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).

SensorIndex — Unique sensor identifier
positive integer

Unique sensor identifier, specified as a positive integer. This property distinguishes detections that come from different sensors in a multi-sensor system. This property must be defined before you can use the object.

Data Types: double

UpdateRate — Sensor update rate
1 (default) | positive scalar

Sensor update rate, specified as a positive scalar. This interval must be an integer multiple of the simulation time interval defined by trackingScenario. The trackingScenario object calls the radar scanning sensor at simulation time intervals.

The radar generates new detections at intervals defined by the reciprocal of the `UpdateRate` property. Any update requested to the sensor between update intervals contains no detections. Units are in hertz.

Example: 5

Data Types: `double`

`MountingLocation` — Sensor location on platform
`[0 0 0]` (default) | 1-by-3 real-valued vector

Sensor location on platform, specified as a 1-by-3 real-valued vector. This property defines the coordinates of the sensor with respect to the platform origin. The default value specifies that the sensor origin is at the origin of its platform. Units are in meters.

Example: `[.2 0.1 0]`

Data Types: `double`

`MountingAngles` — Orientation of sensor
`[0 0 0]` (default) | 3-element real-valued vector

Orientation of the sensor with respect to the platform, specified as a three-element real-valued vector. Each element of the vector corresponds to an intrinsic Euler angle rotation that carries the body axes of the platform to the sensor axes. The three elements define the rotations around the *z*-, *y*-, and *x*-axes, in that order. The first rotation rotates the platform axes around the *z*-axis. The second rotation rotates the carried frame around the rotated *y*-axis. The final rotation rotates the frame around the carried *x*-axis. Units are in degrees.

Example: `[10 20 -15]`

Data Types: `double`

`FieldOfView` — Fields of view of sensor
`[1;5]` | 2-by-1 vector of positive real values

Fields of view of sensor, specified as a 2-by-1 vector of positive real values, [azfov;elfov]. The field of view defines the total angular extent spanned by the sensor. Each component must lie in the interval (0,180). Targets outside of the field of view of the radar are not detected. Units are in degrees.

Example: `[14;7]`

Data Types: `double`

HasRangeAmbiguities — Enable range ambiguities
false (default) | true

Enable range ambiguities, specified as `false` or `true`. Set this property to `true` to enable range ambiguities by the sensor. In this case, the sensor cannot resolve range ambiguities for targets at ranges beyond the MaxUnambiguousRange are wrapped into the interval [0 MaxUnambiguousRange]. When `false`, targets are reported at their unambiguous range.

Data Types: logical

MaxUnambiguousRange — Maximum unambiguous detection range
100e3 (default) | positive scalar

Maximum unambiguous range, specified as a positive scalar. Maximum unambiguous range defines the maximum range for which the radar can unambiguously resolve the range of a target. When HasRangeAmbiguities is set to `true`, targets detected at ranges beyond the maximum unambiguous range are wrapped into the range interval [0,MaxUnambiguousRange]. This property applies to true target detections when you set the `HasRangeAmbiguities` property to `true`.

This property also applies to false target detections when you set the `HasFalseAlarms` property to `true`. In this case, the property defines the maximum range for false alarms.

Units are in meters.

Example: 5e3

Dependencies

To enable this property, set the `HasRangeAmbiguities` property to `true` or set the `HasFalseAlarms` property to `true`.

Data Types: double

HasRangeRateAmbiguities — Enable range-rate ambiguities
false (default) | true

Enable range-rate ambiguities, specified as `false` or `true`. Set to `true` to enable range-rate ambiguities by the sensor. When `true`, the sensor does not resolve range rate ambiguities and target range rates beyond the MaxUnambiguousRadialSpeed are wrapped into the interval [0,MaxUnambiguousRadialSpeed]. When `false`, targets are reported at their unambiguous range rate.

Dependencies

To enable this property, set the HasRangeRate property to `true`.

Data Types: `logical`

MaxUnambiguousRadialSpeed — Maximum unambiguous radial speed
200 (default) | positive scalar

Maximum unambiguous radial speed, specified as a positive scalar. Radial speed is the magnitude of the target range rate. Maximum unambiguous radial speed defines the radial speed for which the radar can unambiguously resolve the range rate of a target. When `HasRangeRateAmbiguities` is set to `true`, targets detected at range rates beyond the maximum unambiguous radial speed are wrapped into the range rate interval `[-MaxUnambiguousRadialSpeed, MaxUnambiguousRadialSpeed]`. This property applies to true target detections when you set `HasRangeRateAmbiguities` property to `true`.

This property also applies to false target detections obtained when you set both the `HasRangeRate` and `HasFalseAlarms` properties to `true`. In this case, the property defines the maximum radial speed for which false alarms can be generated.

Units are in meters per second.

Dependencies

To enable this property, set `HasRangeRate` and `HasRangeRateAmbiguities` to `true` and/or set `HasRangeRate` and `HasFalseAlarms` to `true`.

Data Types: `double`

ScanMode — Scanning mode of radar
'Mechanical' (default) | 'Electronic' | 'Mechanical and electronic' | 'No scanning'

Scanning mode of radar, specified as `'Mechanical'`, `'Electronic'`, `'Mechanical and electronic'`, or `'No scanning'`.

Scan Modes

ScanMode	Purpose
`'Mechanical'`	The radar scans mechanically across the azimuth and elevation limits specified by the `MechanicalScanLimits` property. The scan direction increments by the radar field of view angle between dwells.
`'Electronic'`	The radar scans electronically across the azimuth and elevation limits specified by the `ElectronicScanLimits` property. The scan direction increments by the radar field of view angle between dwells.
`'Mechanical and electronic'`	The radar mechanically scans the antenna boresight across the mechanical scan limits and electronically scans beams relative to the antenna boresight across the electronic scan limits. The total field of regard scanned in this mode is the combination of the mechanical and electronic scan limits. The scan direction increments by the radar field of view angle between dwells.
`'No scanning'`	The radar beam points along the antenna boresight defined by the `MountingAngles` property.

Example: `'No scanning'`

MaxMechanicalScanRate — Maximum mechanical scan rate
[75;75] (default) | nonnegative scalar | real-valued 2-by-1 vector with nonnegative entries

Maximum mechanical scan rate, specified as a nonnegative scalar or real-valued 2-by-1 vector with nonnegative entries.

When HasElevation is `true`, specify the scan rate as a 2-by-1 column vector of nonnegative entries [maxAzRate; maxElRate]. maxAzRate is the maximum scan rate in azimuth and maxElRate is the maximum scan rate in elevation.

When `HasElevation` is `false`, specify the scan rate as a nonnegative scalar representing the maximum mechanical azimuth scan rate.

Scan rates set the maximum rate at which the radar can mechanically scan. The radar sets its scan rate to step the radar mechanical angle by the field of regard. If the required scan rate exceeds the maximum scan rate, the maximum scan rate is used. Units are degrees per second.

Example: `[5;10]`

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

`MechanicalScanLimits` — Angular limits of mechanical scan directions of radar
`[0 360;-10 0]` (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of mechanical scan directions of radar, specified as a real-valued 1-by-2 row vector or a real-valued 2-by-2 matrix. The mechanical scan limits define the minimum and maximum mechanical angles the radar can scan from its mounted orientation.

When `HasElevation` is `true`, the scan limits take the form [minAz maxAz; minEl maxEl]. minAz and maxAz represent the minimum and maximum limits of the azimuth angle scan. minEl and maxEl represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form [minAz maxAz]. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits cannot span more than 360° and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: `[-90 90;0 85]`

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

`MechanicalAngle` — Current mechanical scan angle
scalar | real-valued 2-by-1 vector

This property is read-only.

Current mechanical scan angle of radar, returned as a scalar or real-valued 2-by-1 vector. When `HasElevation` is `true`, the scan angle takes the form [Az; El]. Az and El represent the azimuth and elevation scan angles, respectively, relative to the mounted angle of the radar on the platform. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Mechanical'` or `'Mechanical and electronic'`.

Data Types: `double`

`ElectronicScanLimits` — Angular limits of electronic scan directions of radar
`[-45 45;-45 45]` (default) | real-valued 1-by-2 row vector | real-valued 2-by-2 matrix

Angular limits of electronic scan directions of radar, specified as a real-valued 1-by-2 row vector or a real-valued 2-by-2 matrix. The electronic scan limits define the minimum and maximum electronic angles the radar can scan from its current mechanical direction.

When `HasElevation` is `true`, the scan limits take the form [minAz maxAz; minEl maxEl]. minAz and maxAz represent the minimum and maximum limits of the azimuth angle scan. minEl and maxEl represent the minimum and maximum limits of the elevation angle scan. When `HasElevation` is `false`, the scan limits take the form [minAz maxAz]. If you specify the scan limits as a 2-by-2 matrix but set `HasElevation` to `false`, the second row of the matrix is ignored.

Azimuthal scan limits and elevation scan limits must lie within the closed interval [-90° 90°]. Units are in degrees.

Example: `[-90 90;0 85]`

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

`ElectronicAngle` — Current electronic scan angle
electronic scalar | nonnegative scalar

This property is read-only.

Current electronic scan angle of radar, returned as a scalar or 1-by-2 column vector. When `HasElevation` is `true`, the scan angle takes the form [Az;El]. Az and El represent the azimuth and elevation scan angles, respectively. When `HasElevation` is `false`, the scan angle is a scalar representing the azimuth scan angle.

Dependencies

To enable this property, set the `ScanMode` property to `'Electronic'` or `'Mechanical and electronic'`.

Data Types: `double`

LookAngle — Look angle of sensor
scalar | real-valued 2-by-1 vector

This property is read-only.

Look angle of sensor, specified as a scalar or real-valued 2-by-1 vector. Look angle is a combination of the mechanical angle and electronic angle depending on the `ScanMode` property.

ScanMode	**LookAngle**
`'Mechanical'`	`MechnicalAngle`
`'Electronic'`	`ElectronicAngle`
`'Mechanical and Electronic'`	`MechnicalAngle + ElectronicAngle`
`'No scanning'`	`0`

When `HasElevation` is `true`, the look angle takes the form [Az;El]. Az and El represent the azimuth and elevation look angles, respectively. When `HasElevation` is `false`, the look angle is a scalar representing the azimuth look angle.

DetectionProbability — Probability of detecting a target
`0.9` | positive scalar less than or equal to 1

Probability of detecting a target, specified as a positive scalar less than or equal to one. This quantity defines the probability of detecting a target with a radar cross-section, ReferenceRCS, at the reference detection range, ReferenceRange.

Example: `0.95`

Data Types: `double`

FalseAlarmRate — False alarm rate

`1e-6` (default) | positive scalar

False alarm report rate within each radar resolution cell, specified as a positive scalar in the range $[10^{-7}, 10^{-3}]$. Units are dimensionless. Resolution cells are determined from the AzimuthResolution and RangeResolution properties, and the ElevationResolution and RangeRateResolution properties when they are enabled.

Example: `1e-5`

Data Types: `double`

ReferenceRange — Reference range for given probability of detection

`100e3` (default) | positive scalar

Reference range for the given probability of detection and the given reference radar cross-section (RCS), specified as a positive scalar. The reference range is the range at which a target having a radar cross-section specified by `ReferenceRCS` is detected with a probability of detection specified by `DetectionProbability`. Units are in meters.

Example: `25e3`

Data Types: `double`

ReferenceRCS — Reference radar cross-section for given probability of detection

`0` (default) | scalar

Reference radar cross-section (RCS) for given a probability of detection and reference range, specified as a scalar. The reference RCS is the RCS value at which a target is detected with probability specified by `DetectionProbability` at `ReferenceRange`. Units are in dBsm.

Example: `-10`

Data Types: `double`

RadarLoopGain — Radar loop gain

scalar

This property is read-only.

Radar loop gain, returned as a scalar. `RadarLoopGain` depends on the values of the `DetectionProbability`, `ReferenceRange`, `ReferenceRCS`, and `FalseAlarmRate` properties. Radar loop gain is a function of the reported signal-to-noise ratio of the radar, *SNR*, the target radar cross-section, *RCS*, and the target range, *R*. The function is

$$SNR = \text{RadarLoopGain} + RCS - 40\log10(R) \qquad\qquad (3\text{-}1)$$

where *SNR* and *RCS* are in dB and dBsm, respectively, and range is in meters. Radar loop gain is in dB.

Data Types: `double`

HasElevation — Enable radar elevation scan and measurements
`false` (default) | `true`

Enable the radar to measure target elevation angles and to scan in elevation, specified as `false` or `true`. Set this property to `true` to model a radar sensor that can estimate target elevation and scan in elevation.

Data Types: `logical`

HasRangeRate — Enable radar to measure range rate
`false` (default) | `true`

Enable the radar to measure target range rates, specified as `false` or `true`. Set this property to `true` to model a radar sensor that can measure target range rate. Set this property to `false` to model a radar sensor that cannot measure range rate.

Data Types: `logical`

AzimuthResolution — Azimuth resolution of radar
1 (default) | positive scalar

Azimuth resolution of the radar, specified as a positive scalar. The azimuth resolution defines the minimum separation in azimuth angle at which the radar can distinguish two targets. The azimuth resolution is typically the 3dB downpoint of the azimuth angle beamwidth of the radar. Units are in degrees.

Data Types: `double`

ElevationResolution — Elevation resolution of radar
1 (default) | positive scalar

Elevation resolution of the radar, specified as a positive scalar. The elevation resolution defines the minimum separation in elevation angle at which the radar can distinguish two targets. The elevation resolution is typically the 3dB-downpoint in elevation angle beamwidth of the radar. Units are in degrees.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

RangeResolution — Range resolution of radar
`100` (default) | positive scalar

Range resolution of the radar, specified as a positive scalar. The range resolution defines the minimum separation in range at which the radar can distinguish between two targets. Units are in meters.

Data Types: `double`

RangeRateResolution — Range rate resolution of radar
`10` (default) | positive scalar

Range rate resolution of the radar, specified as a positive scalar. The range rate resolution defines the minimum separation in range rate at which the radar can distinguish between two targets. Units are in meters per second.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

AzimuthBiasFraction — Azimuth bias fraction
`0.1` (default) | nonnegative scalar

Azimuth bias fraction of the radar, specified as a nonnegative scalar. The azimuth bias is expressed as a fraction of the azimuth resolution specified in `AzimuthResolution`. This value sets a lower bound on the azimuthal accuracy of the radar. This value is dimensionless.

Data Types: `double`

ElevationBiasFraction — Elevation bias fraction
`0.1` (default) | nonnegative scalar

Elevation bias fraction of the radar, specified as a nonnegative scalar. Elevation bias is expressed as a fraction of the elevation resolution specified by the value of the `ElevationResolution` property. This value sets a lower bound on the elevation accuracy of the radar. This value is dimensionless.

3-289

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: `double`

RangeBiasFraction — Range bias fraction
`0.05` (default) | nonnegative scalar

Range bias fraction of the radar, specified as a nonnegative scalar. Range bias is expressed as a fraction of the range resolution specified in `RangeResolution`. This property sets a lower bound on the range accuracy of the radar. This value is dimensionless.

Data Types: `double`

RangeRateBiasFraction — Range rate bias fraction
`0.05` (default) | nonnegative scalar

Range rate bias fraction of the radar, specified as a nonnegative scalar. Range rate bias is expressed as a fraction of the range rate resolution specified in `RangeRateResolution`. This property sets a lower bound on the range-rate accuracy of the radar. This value is dimensionless.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

HasINS — Enable inertial navigation system (INS) input
`false` (default) | `true`

Enable the optional input argument that passes the current estimate of the sensor platform pose to the sensor, specified as `false` or `true`. When `true`, pose information is added to the `MeasurementParameters` structure of the reported detections. Pose information lets tracking and fusion algorithms estimate the state of the target detections in the north-east-down (NED) frame.

Data Types: `logical`

HasNoise — Enable addition of noise to radar sensor measurements
`true` (default) | `false`

Enable addition of noise to radar sensor measurements, specified as `true` or `false`. Set this property to `true` to add noise to the radar measurements. Otherwise, the measurements have no noise. Even if you set `HasNoise` to `false`, the object still computes the `MeasurementNoise` property of each detection.

Data Types: `logical`

HasFalseAlarms — Enable creating false alarm radar detections
`true` (default) | `false`

Enable creating false alarm radar measurements, specified as `true` or `false`. Set this property to `true` to report false alarms. Otherwise, only actual detections are reported.

Data Types: `logical`

MaxNumDetectionsSource — Source of maximum number of detections reported
`'Auto'` (default) | `'Property'`

Source of maximum number of detections reported by the sensor, specified as `'Auto'` or `'Property'`. When this property is set to `'Auto'`, the sensor reports all detections. When this property is set to `'Property'`, the sensor reports up to the number of detections specified by the `MaxNumDetections` property.

Data Types: `char`

MaxNumDetections — Maximum number of reported detections
50 (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. Detections are reported in order of distance to the sensor until the maximum number is reached.

Dependencies

To enable this property, set the `MaxNumDetectionsSource` property to `'Property'`.

Data Types: `double`

DetectionCoordinates — Coordinate system of reported detections
`'Body'` (default) | `'Scenario'` | `'Sensor rectangular'` | `'Sensor spherical'`

Coordinate system of reported detections, specified as:

- `'Scenario'` — Detections are reported in the rectangular scenario coordinate frame. The scenario coordinate system is defined as the local NED frame at simulation start time. To enable this value, set the `HasINS` property to `true`.
- `'Body'` — Detections are reported in the rectangular body system of the sensor platform.
- `'Sensor rectangular'` — Detections are reported in the radar sensor rectangular body coordinate system.
- `'Sensor spherical'` — Detections are reported in a spherical coordinate system derived from the sensor rectangular body coordinate system. This coordinate system is centered at the radar sensor and aligned with the orientation of the radar on the platform.

Example: `'Sensor spherical'`

Data Types: `char`

HasInterference — Enable RF interference input
`false` (default) | `true`

Enable RF interference input, specified as `false` or `true`. When `true`, you can add RF interference using an input argument of the object.

Data Types: `logical`

Bandwidth — Radar waveform bandwidth
positive scalar

Radar waveform bandwidth, specified as a positive scalar. Units are in hertz.

Example: `100e3`

Data Types: `double`

CenterFrequency — Center frequency of radar band
positive scalar

Center frequency of radar band, specified as a positive scalar. Units are in hertz.

Example: `100e6`

Data Types: `double`

Sensitivity — Minimum operational sensitivity of receiver
`-50` (default) | scalar

Minimum operational sensitivity of receiver, specified as a scalar. Sensitivity includes isotropic antenna receiver gain. Units are in dBmi.

Example: `-10`

Data Types: `double`

Usage

Syntax

```
dets = sensor(targets,simTime)
dets = sensor(targets,ins,simTime)
dets = sensor(targets,interference,simTime)
[dets,numDets,config] = sensor( ___ )
```

Description

`dets = sensor(targets,simTime)` creates radar detections, `dets`, from sensor measurements taken of `targets` at the current simulation time, `simTime`. The sensor can generate detections for multiple targets simultaneously.

`dets = sensor(targets,ins,simTime)` also specifies the INS-estimated pose information, `ins`, for the sensor platform. INS information is used by tracking and fusion algorithms to estimate the target positions in the NED frame.

To enable this syntax, set the `HasINS` property to `true`.

`dets = sensor(targets,interference,simTime)` also specifies an interference signal, `interference`.

To enable this syntax, set the `HasInterference` property to `true`.

`[dets,numDets,config] = sensor( ___ )` also returns the number of valid detections reported, `numDets`, and the configuration of the sensor, `config`, at the current simulation time. You can use these output arguments with any of the previous input syntaxes.

Input Arguments

`targets` — Tracking scenario target poses
structure | structure array

Tracking scenario target poses, specified as a structure or array of structures. Each structure corresponds to a target. You can generate this structure using the `targetPoses` method of a platform. You can also create such a structure manually. The table shows the required fields of the structure:

Field	Description
PlatformID	Unique identifier for the platform, specified as a scalar positive integer. This is a required field with no default value.
ClassID	User-defined integer used to classify the type of target, specified as a nonnegative integer. Zero is reserved for unclassified platform types and is the default value.
Position	Position of target in platform coordinates, specified as a real-valued, 1-by-3 vector. This is a required field with no default value. Units are in meters.
Velocity	Velocity of target in platform coordinates, specified as a real-valued, 1-by-3 vector. Units are in meters per second. The default is [0 0 0].
Acceleration	Acceleration of target in platform coordinates specified as a 1-by-3 row vector. Units are in meters per second-squared. The default is [0 0 0].

Field	Description
Orientation	Orientation of the target with respect to platform coordinates, specified as a scalar quaternion or a 3-by-3 rotation matrix. Orientation defines the frame rotation from the platform coordinate system to the current target body coordinate system. Units are dimensionless. The default is `quaternion(1,0,0,0)`.
AngularVelocity	Angular velocity of target in platform coordinates, specified as a real-valued, 1-by-3 vector. The magnitude of the vector defines the angular speed. The direction defines the axis of clockwise rotation. Units are in degrees per second. The default is `[0 0 0]`.

The values of the `Position`, `Velocity`, and `Orientation` fields are defined with respect to the platform coordinate system.

simTime — Current simulation time
nonnegative scalar

Current simulation time, specified as a positive scalar. The `trackingScenario` object calls the scan radar sensor at regular time intervals. The radar sensor generates new detections at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Data Types: `double`

ins — Platform pose from INS
structure

Platform pose information from an inertial navigation system (INS) is a structure which has these fields:

Field	Definition

Position	Position of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters.
Velocity	Velocity of the GPS receiver in the local NED coordinate system specified as a real-valued 1-by-3 vector. Units are in meters per second.
Orientation	Orientation of the INS with respect to the local NED coordinate system specified as a scalar quaternion or a 3-by-3 real-valued orthonormal frame rotation matrix. Defines the frame rotation from the local NED coordinate system to the current INS body coordinate system. This is also referred to as a "parent to child" rotation.

Dependencies

To enable this argument, set the `HasINS` property to `true`.

Data Types: `struct`

`interference` — Interfering or jamming signal
array of `radarEmission` objects

Interfering or jamming signal, specified as an array of `radarEmission` objects.

Dependencies

To enable this argument, set the `HasInterference` property to `true`.

Data Types: `double`
Complex Number Support: Yes

Output Arguments

dets — sensor detections
cell array of `objectDetection` objects

Sensor detections, returned as a cell array of `objectDetection` objects. For a high level view of object detections, see `objectDetection` objects. Each object has these

properties but the contents of the properties depend on the specific sensor. For the `monostaticRadarSensor`, see "Object Detections" on page 3-301.

Property	Definition
`Time`	Measurement time
`Measurement`	Object measurements
`MeasurementNoise`	Measurement noise covariance matrix
`SensorIndex`	Unique ID of the sensor
`ObjectClassID`	Object classification
`MeasurementParameters`	Parameters used by initialization functions of nonlinear Kalman tracking filters
`ObjectAttributes`	Additional information passed to tracker

For the `Measurement` and `MeasurementNoise` are reported in the coordinate system specified by the `DetectionCoordinates` property.

numDets — Number of detections
nonnegative integer

Number of detections reported, returned as a nonnegative integer.

- When the `MaxNumDetectionsSource` property is set to `'Auto'`, `numDets` is set to the length of `dets`.
- When the `MaxNumDetectionsSource` property is set to `'Property'`, `dets` is a cell array with length determined by the `MaxNumDetections` property. The maximum number of detections returned is `MaxNumDetections`. If the number of detections is fewer than `MaxNumDetections`, the first `numDets` elements of `dets` hold valid detections. The remaining elements of `dets` are set to the default value.

Data Types: `double`

config — Current sensor configuration
structure

Current sensor configuration, specified as a structure. This output can be used to determine which objects fall within the radar beam during object execution.

Field	Description

SensorIndex	Unique sensor index
IsValidTime	Valid detection time, returned as 0 or 1. IsValidTime is 0 when detection updates are requested at times that are between update intervals specified by UpdateInterval.
IsScanDone	IsScanDone is true when the sensor has completed a scan.
FieldOfView	Field of view of sensor determines which objects fall within the sensor beam during object execution. The field of view is defined as a 2-by-1 vector of positive real values, [azfov;elfov].
MeasurementParameters	MeasurementParameters is an array of structures containing the coordinate frame transforms needed to transform positions and velocities in the top-level frame to the current sensor frame.

Data Types: struct

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

Air-Traffic Control Tower Radar

Simulate a radar scenario.

```
sc = trackingScenario('UpdateRate',1);
```

Create an airport control tower with a surveillance radar located 15 meters above the ground. The radar rotates at 12.5 rpm and its field of view in azimuth is 5 degrees and its field of view in elevation is 10 degrees.

```
rpm = 12.5;
fov = [5;10]; % [azimuth; elevation]
scanrate = rpm*360/60;
updaterate = scanrate/fov(1) % Hz

radar = monostaticRadarSensor(1,'Rotator', ...
    'UpdateRate',updaterate, ...
    'MountingLocation',[0 0 -15], ...
    'MaxMechanicalScanRate',scanrate, ...
    'FieldOfView',fov, ...
    'AzimuthResolution',fov(1));
towermotion = kinematicTrajectory('SampleRate',1,'Position',[0 0 0],'Velocity',[0 0 0])
tower = platform(sc,'ClassID',1,'Trajectory',towermotion);
aircraft1motion = kinematicTrajectory('SampleRate',1,'Position',[10000 0 1000],'Veloci
aircraft1 = platform(sc,'ClassID',2,'Trajectory',aircraft1motion);
aircraft2motion = kinematicTrajectory('SampleRate',1,'Position',[5000 5000 200],'Veloc
aircraft2 = platform(sc,'ClassID',2,'Trajectory',aircraft2motion);
```

```
updaterate =

    15
```

Perform 5 scans.

```
detBuffer = {};
scanCount = 0;
while advance(sc)
    simTime = sc.SimulationTime;
    targets = targetPoses(tower);
    [dets,numDets,config] = radar(targets,simTime);
    detBuffer = [detBuffer;dets];
    if config.IsScanDone
            scanCount = scanCount + 1;
```

```
            if scanCount == 5;
                break;
            end
    end
end
```

Plot detections

```
tp = theaterPlot;
clrs = lines(3);
rp = platformPlotter(tp,'DisplayName','Radar','Marker','s',...
    'MarkerFaceColor',clrs(1,:));
pp = platformPlotter(tp,'DisplayName','Truth',...
    'MarkerFaceColor',clrs(2,:));
dp = detectionPlotter(tp,'DisplayName','Detections',...
    'MarkerFaceColor',clrs(3,:));
plotPlatform(rp,[0 0 0])
plotPlatform(pp,[targets(1).Position; targets(2).Position])
if ~isempty(detBuffer)
    detPos = cellfun(@(d)d.Measurement(1:3),detBuffer,...
        'UniformOutput',false);
    detPos = cell2mat(detPos')';
    plotDetection(dp,detPos)
end
```

Definitions

Object Detections

The sensor measures the coordinates of the target. The `Measurement` and `MeasurementNoise` values are reported in the coordinate system specified by the `DetectionCoordinates` property of the sensor.

When the `DetectionCoordinates` property is `'Scenario'`, `'Body'`, or `'Sensor rectangular'`, the `Measurement` and `MeasurementNoise` values are reported in

rectangular coordinates. Velocities are only reported when the range rate property, HasRangeRate, is true.

When the DetectionCoordinates property is 'Sensor spherical', the Measurement and MeasurementNoise values are reported in a spherical coordinate system derived from the sensor rectangular coordinate system. Elevation and range rate are only reported when HasElevation and HasRangeRate are true.

Measurements are ordered as [azimuth, elevation, range, range rate]. Reporting of elevation and range rate depends on the corresponding HasElevation and HasRangeRate property values. Angles are in degrees, range is in meters, and range rate is in meters per second.

Measurement Coordinates

DetectionCoordinates	Measurement and Measurement Noise Coordinates		
'Scenario'	**Coordinate Dependence on HasRangeRate**		
'Body'			
'Sensor rectangular'	**HasRangeRate**	**Coordinates**	
	true	[x; y; z; vx; vy; vz]	
	false	[x; y; z]	
'Sensor spherical'	**Coordinate Dependence on HasRangeRate and HasElevation**		
	HasRangeRate	**HasElevation**	**Coordinates**
	true	true	[az; el; rng; rr]
	true	false	[az; rng; rr]
	false	true	[az; el; rng]
	false	false	[az; rng]

The MeasurementParameters field consists of an array of structures that describe a sequence of coordinate transformations from a child frame to a parent frame or the inverse transformations (see "Frame Rotation"). The longest possible sequence of transformations is Sensor → Platform → Scenario. For example, if the detections are

reported in sensor spherical coordinates and `HasINS` is set to `false`, then the sequence consists of one transformation from sensor to platform. If `HasINS` is `true`, the sequence of transformations consists of two transformations – first to platform coordinates then to scenario coordinates. Trivially, if the detections are reported in platform rectangular coordinates and `HasINS` is set to `false`, the transformation consists only of the identity.

The structure fields are shown here. Not all fields have to be present in the structure. The set of fields and their default values can depend on the type of sensor.

Field	Description
`Frame`	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.
`OriginPosition`	Position offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
`OriginVelocity`	Velocity offset of the origin of the frame relative to the parent frame, represented as a 3-by-1 vector.
`Orientation`	3-by-3 real-valued orthonormal frame rotation matrix.
`IsParentToChild`	A logical scalar indicating if `Orientation` performs a frame rotation from the parent coordinate frame to the child coordinate frame. If `false`, `Orientation` performs a frame rotation from the child coordinate frame to the parent coordinate frame.
`HasElevation`	A logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if `HasElevation` is `false`, the measurements are reported assuming 0 degrees of elevation.

HasAzimuth	A logical scalar indication if azimuth is included in the measurement.
HasRange	A logical scalar indication if range is included in the measurement.
HasVelocity	A logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if `HasVelocity` is `false`, the measurements are reported as `[x y z]`. If `HasVelocity` is `true`, measurements are reported as `[x y z vx vy vz]`.
Frame	Enumerated type indicating the frame used to report measurements. When detections are reported using a rectangular coordinate system, `Frame` is set to `'rectangular'`. When detections are reported in spherical coordinates, `Frame` is set `'spherical'` for the first `struct`.

Object attributes contain additional information about a detection:

Attribute	Description
TargetIndex	Identifier of the platform, `PlatformID`, that generated the detection. For false alarms, this value is negative.
SNR	Detection signal-to-noise ratio in dB.

Convenience Syntaxes

The convenience syntaxes set several properties together to model a specific type of radar.

Sets `ScanMode` to `'No scanning'`.

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
HasElevation	true
MaxMechanicalScanRate	[75;75]
MechanicalScanLimits	[-45 45;-10 0]
ElectronicScanLimits	[-45 45;-10 0]

You can change the ScanMode property to 'Electronic' to perform an electronic raster scan over the same volume as a mechanical scan.

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
FieldOfView	[1:10]
HasElevation	false or true
MechanicalScanLimits	[0 360;-10 0]
ElevationResolution	10/sqrt(12)

This syntax sets these properties:

Property	Value
ScanMode	'Mechanical'
FieldOfView	[1;10]
HasElevation	false
MechanicalScanLimits	[-45 45;-10 0]
ElectronicScanLimits	[-45 45;-10 0]
ElevationResolution	10/sqrt(12)

Changing the ScanMode property to 'Electronic' lets you perform an electronic raster scan over the same volume as a mechanical scan.

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

Classes
objectDetection | radarEmission

Functions
targetPoses

System Objects
trackerGNN | trackerTOMHT

Introduced in R2018b

trackAssignmentMetrics System object

Track establishment, maintenance, and deletion metrics

Description

The `trackAssignmentMetrics` System object compares tracks from a multi-object tracking system against known truth by automatic assignment of tracks to the known truths at each track update. An assignment distance metric determines the maximum distance for which a track can be assigned to the truth object. A divergence distance metric determines when a previously assigned track can be reassigned to a different truth object when the distance exceeds another set threshold.

To generate track assignment metrics:

1   Create the `trackAssignmentMetrics` 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

```
assignmentMetics = trackAssignmentMetrics
assignmentMetics = trackAssignmentMetrics(Name,Value)
```

Description

`assignmentMetics = trackAssignmentMetrics` creates a `trackAssignmentMetrics` System object, `assignmentMetics`, with default property values.

`assignmentMetics = trackAssignmentMetrics(Name,Value)` sets properties for the `trackAssignmentMetrics` object using one or more name-value pairs. For example,

assignmentMetics = trackAssignmentMetrics('AssignmentThreshold',5) creates a trackAssignmentMetrics object with an assignment threshold of 5. Enclose property names in quotes.

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).

AssignmentThreshold — Maximum permitted assignment distance
1 (default) | nonnegative scalar

Maximum permitted assignment distance between a newly encountered or divergent track and a truth object, specified as a nonnegative scalar. For distances beyond this value, assignments between the track and the truth cannot take place. Units are in normalized estimation error squared (NEES).

Data Types: single | double

DivergenceThreshold — Maximum permitted divergence distance
2 (default) | nonnegative scalar

Maximum permitted divergence distance between a track state and the state of an assigned truth object, specified as a nonnegative scalar. For distances beyond this value, tracks are eligible for reassignment to a different truth object. Units are in NEES.

Data Types: single | double

DistanceFunctionFormat — Distance function format
'built-in' (default) | 'custom'

Distance function format specified as 'built-in' or 'custom'.

- 'built-in' – Enable the MotionModel, AssignmentDistance, and DivergenceDistance properties. These properties are convenient interfaces when

using tracks reported by any built-in multi-object tracker, and truths reported by the `platformPoses` object function of a `trackingScenario` object.

- `'custom'` – Enable custom properties: `AssignmentDistanceFcn`, `DivergenceDistanceFcn`, `IsInsideCoverageAreaFcn`, `TruthIdentifierFcn`, `TrackIdentifierFcns`. You can use these properties to construct acceptance or divergence distances, coverage areas, and identifiers for arbitrary 'tracks' and 'truths' input arrays.

MotionModel — Desired platform motion model
`'constvel'` (default) | `'constacc'` | `'constturn'`

Desired platform motion model, specified as `'constvel'`, `'constacc'`, or `'constturn'`. This property selects the motion model used by the `tracks` input. The motion model governs the outputs when the object is executed.

The motion models expect the `'State'` field to have a column vector as follows:

- `'constvel'` - Position is in elements [1 3 5], velocity in elements [2 4 6].
- `'constacc'` - Position is in elements [1 4 7], velocity in elements [2 5 8], and acceleration in elements [3 6 9].
- `'constturn'` - Position is in elements [1 3 6], velocity in elements [2 4 7], and yaw rate in element 5.

The `'StateCovariance'` field of the `tracks` input must have position, velocity, and turn information in the rows and columns corresponding to the `'State'` field position and velocity input selector.

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'built-in'`.

AssignmentDistance — Type of assignment distance
`'posnees'` (default) | `'velnees'` | `'posabserr'` | `'velabserr'`

Type of assignment distance, specified as `'posnees'`, `'velnees'`, `'posabserr'`, or `'velabserr'`. The type specifies the physical quantity used for assignment. When a new track is detected or a track becomes divergent, the track is compared against truth using this quantity. The assignment seeks the closest truth within the threshold defined by the `AssignmentThreshold` property.

- `'posnees'` – NEES error of track position

- `'velnees'` – NEES error in track velocity
- `'posabserr'` – Absolute error of track position
- `'velabserr'` – Absolute error of track velocity

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'built-in'`.

DivergenceDistance — Type of assignment distance
`'posnees'` (default) | `'velnees'` | `'posabserr'` | `'velabserr'`

Type of divergence distance, specified as `'posnees'`, `'velnees'`, `'posabserr'`, or `'velabserr'`. The type specifies the physical quantity used for assessing divergence. When a track was previously assigned to truth, the distance between them is compared to this quantity on subsequent update steps. Any track whose divergence distance to its truth assignment exceeds the value of `DivergenceThreshold` is considered divergent and can be reassigned to a new truth.

- `'posnees'` – NEES error of track position
- `'velnees'` – NEES error in track velocity
- `'posabserr'` – Absolute error of track position
- `'velabserr'` – Absolute error of track velocity

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'built-in'`.

AssignmentDistanceFcn — Assignment distance function
function handle

Assignment distance function, specified as a function handle. This function determines the assignment distance of truth to tracks. Whenever a new track is detected or a track becomes divergent, the track is compared against all truths passed in at each object update. Use this function to find the closest truth within the threshold defined by the `AssignmentThreshold` property.

The function must have the following syntax:

```
dist = assignmentdistance(onetrack,onetruth)
```

The function must return a nonnegative assignment distance, `dist`, typically expressed in units of NEES. `onetrack` is an element of the `tracks` array input argument at object update. `onetruth` is an element of the `truths` array input argument.

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

DivergenceDistanceFcn — Divergence distance function
function handle

Divergence distance function, specified as a function handle. This function determines the divergence distance of truths to tracks. If the divergence distance from a track to its truth assignment exceeds the `DivergenceThreshold`, the track is considered divergent and can be reassigned to a new truth.

The function must have the following syntax:

```
dist = divergencedistance(onetrack,onetruth)
```

The function must return a non-negative divergence distance, `dist`, typically expressed in units of NEES. `onetrack` is an element of the `tracks` array input argument at object update. `onetruthtruth` is an element of the `truths` array input argument.

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

IsInsideCoverageAreaFcn — Detectable truth object
function handle

Detectable 'truth' object, specified as a function handle. This function determines when a 'truth' object is inside the coverage area of the sensors and is therefore detectable.

The function must have the following syntax:

```
status = isinsidecoveragearea(truths)
```

and return a logical array, `status`. `status` is true when the truth objects, `truths`, are within the coverage area. `truths` is the same truths array input argument at object update. `status` must have the same size as `truths`.

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

`TrackIdentifierFcn` — Track identifier function
function handle

Track identifier function for the track input at object update, specified as a function handle. The track identifiers are unique string or numeric values.

The function must have the following syntax

`trackids = trackidentifier(tracks)`

and return a numeric array, `trackids`. `trackids` must have the same size as `tracks` input argument. `tracks` is the same tracks array input argument at object update.

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

`TruthIdentifierFcn` — Truth identifier function
function handle

Truth identifier function for the truth input at object update, specified as a function handle. The truth identifiers are unique string or numeric values.

The function must have the following syntax

`truthids = truthidentifier(truths)`

and return a numeric array, `truthids`. `truthids` must have the same size as the `truths` input argument. `truths` is the same truth array input argument at object update.

Dependencies

To enable this property, set the `DistanceFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

`InvalidTrackIdentifier` — Track identifier for invalid assignment
NaN (default) | scalar | string

Track identifier for invalid assignment, specified as a scalar or string. This value is returned when the track assignment is invalid. The value must be of the same class as returned by the function handle specified in `TrackIdentifierFcn`.

Example: -1

Data Types: `single` | `double` | `string`

`InvalidTruthIdentifier` — Truth identifier for invalid assignment
`NaN` (default) | scalar | string

Truth identifier for invalid assignment, specified as a scalar or string. This value is returned when the truth assignment is invalid. The value must be of the same class as returned by the function handle specified in `TruthIdentifierFcn`.

Example: -1

Data Types: `single` | `double` | `string`

Usage

To compute metrics, call the track assignment metrics with arguments, as if it were a function (described here).

Syntax

`[tracksummary,truthsummary] = assignmentMetics(tracks,truths)`

Description

`[tracksummary,truthsummary] = assignmentMetics(tracks,truths)` returns structures, `tracksummary` and `truthsummary`, containing cumulative metrics across all `tracks` and `truths`, obtained from the previous object update.

Input Arguments

`tracks` — Track information
structure | array of structures

Track information, specified as a structure or array of structures. For built-in trackers such as `trackerGNN` or `trackerTOMHT`, the structure contains `'State'`, `'StateCovariance'`, and `'TrackID'` information.

Data Types: `struct`

truths — Truth information
structure | array of structures

Truth information, specified as a structure or array of structures. When using a `trackingScenario`, truth information can be obtained from the `platformPoses` object function.

Data Types: `struct`

Output Arguments

tracksummary — Cumulative track assignment metrics
structure

Cumulative metrics over all tracks, returned as a structure. The metrics are computed over all tracks since the last call to the `reset` object function. The structure has these fields:

Field	Description
TotalNumTracks	The total number of unique track identifiers encountered
NumFalseTracks	The number of tracks never assigned to any truth
MaxSwapCount	Maximum number of track swaps of each track. A track swap occurs whenever a track is assigned to a different truth.
TotalSwapCount	Total number of track swaps of each track. A track swap occurs whenever a track is assigned to a different truth.
MaxDivergenceCount	Maximum number of divergences. A track is divergent when the result of the `DivergenceDistanceFcn` is greater than the divergence threshold.

`TotalDivergenceCount`	Total number of divergences. A track is divergent when the result of the divergence distance function is greater than the divergence threshold.
`MaxDivergenceLength`	Maximum number of updates during which each track was in a divergent state
`TotalDivergenceLength`	Total number of updates during which each track was in a divergent state
`MaxRedundancyCount`	The maximum number of additional tracks assigned to the same truth
`TotalRedundancyCount`	The total number of additional tracks assigned to the same truth
`MaxRedundancyLength`	Maximum number of updates during which each track was in a redundant state
`TotalRedundancyLength`	Total number of updates during which each track was in a redundant state

Data Types: `struct`

`truthsummary` — Cumulative truth assignment metrics
structure

Cumulative assignment metrics over all truths, returned as a structure. The metrics are computed over all truths since the last call to the `reset` object function. The structure has these fields:

Field	Description
`TotalNumTruths`	The total number of unique truth identifiers encountered
`NumMissingTruths`	The number of truths never established with any track
`MaxEstablishmentLength`	Maximum number of updates before a truth was associated with any track while inside the coverage area. The lengths of missing truths do not count toward this summary metric.

TotalEstablishmentLength	Total number of updates before a truth was associated with any track while inside the coverage area. The lengths of missing truths do not count toward this summary metric.
MaxBreakCount	Maximum number of times each truth was unassociated by any track after being established.
TotalBreakCount	Total number of times each truth was unassociated by any track after being established.
MaxBreakLength	Maximum number of updates during which each truth was in a broken state
TotalBreakLength	Total number of updates during which each truth was in a broken state

Data Types: `struct`

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 `trackAssignmentMetrics`

currentAssignment   Mapping of tracks to truth
trackMetricsTable   Compare tracks to truth
truthMetricsTable   Compare truth to tracks

Common to All System Objects

release   Release resources and allow changes to System object property values and
            input characteristics
reset   Reset internal states of System object
isLocked   Determine if System object is in use
clone   Create duplicate System object

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =
```

```
  4×15 table

    TrackID    AssignedTruthID    Surviving    TotalLength    DeletionStatus    Deleti
    _____    _____    _____    _____    _____    _____

       1             NaN            false         1120            false
       2             NaN            false         1736            false
       6              3             true          1138            false
       8              2             true           662            false
```

Show the truth metrics table.

```
truthMetricsTable(tam)

ans =

  2×10 table

    TruthID    AssociatedTrackID    DeletionStatus    TotalLength    BreakStatus    Bre
    _____    _____    _____    _____    _____    ___

       2              8                 false            2678           false
       3              6                 false            2678           false
```

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
```

```
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```


Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =
```

```
2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
       8       129.26    12.739     1.6745      0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745      0.2453
       3       44.712    20.988    0.05974     0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2       129.7      42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448      0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)

ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       258.21    65.078     2.2514      0.93359
       3       134.41    48.253     0.96314     0.49183
```

See Also

System Objects
monostaticRadarSensor | trackErrorMetrics | trackerGNN | trackerTOMHT

Introduced in R2018b

currentAssignment

Mapping of tracks to truth

Syntax

```
[trackIDs,truthIDs] = currentAssignment(assignmentMetric)
```

Description

[trackIDs,truthIDs] = currentAssignment(assignmentMetric) returns the assignment of tracks to truth after the most recent update of the assignmentMetric System object. The assignment is returned as a vector of track identifiers, trackIDs, and truth identifiers, truthIDs. Corresponding elements of the trackIDs and truthIDs vectors define the assignments.

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
```

```
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =

  4×15 table

    TrackID     AssignedTruthID     Surviving     TotalLength     DeletionStatus     Deletio
    _____     _____     _____     _____     _____     _____

        1             NaN             false          1120             false
        2             NaN             false          1736             false
        6              3              true           1138             false
        8              2              true            662             false
```

Show the truth metrics table.

```
truthMetricsTable(tam)
```

```
ans =

  2×10 table
```

TruthID	AssociatedTrackID	DeletionStatus	TotalLength	BreakStatus	Bre
2	8	false	2678	false	
3	6	false	2678	false	

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

```
     8      129.26    12.739     1.6745       0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745      0.2453
       3       44.712    20.988    0.05974      0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2       129.7      42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448     0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

Input Arguments

`assignmentMetric` — Track assignment metrics object
`trackAssignmentMetrics` System object

Track assignment metrics object, specified as a `trackAssignmentMetrics` System object.

Output Arguments

`trackIDs` — Track identifiers
vector

Track identifiers, returned as a vector. `trackIDs` and `truthIDs` have the same size. Corresponding elements of `trackIDs` and `truthIDs` represent a track-truth assignment.

`truthIDs` — Truth identifiers
vector

Truth identifiers, returned as a vector. `trackIDs` and `truthIDs` have the same size. Corresponding elements of `trackIDs` and `truthIDs` represent a track-truth assignment.

Introduced in R2018b

trackMetricsTable

Compare tracks to truth

Syntax

```
metricsTable = trackMetricsTable(assignmentMetric)
```

Description

`metricsTable = trackMetricsTable(assignmentMetric)` returns a table of metrics, `metricsTable`, for all tracks in the track assignment metrics object, `assignmentMetric`.

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =

  4×15 table
```

TrackID	AssignedTruthID	Surviving	TotalLength	DeletionStatus	Deletio
1	NaN	false	1120	false	
2	NaN	false	1736	false	
6	3	true	1138	false	
8	2	true	662	false	

Show the truth metrics table.

```
truthMetricsTable(tam)
```

```
ans =

  2×10 table
```

TruthID	AssociatedTrackID	DeletionStatus	TotalLength	BreakStatus	Bre

```
        2              8                 false              2678              false
        3              6                 false              2678              false
```

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

```
       8      129.26    12.739      1.6745       0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745      0.2453
       3       44.712    20.988     0.05974     0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2       129.7      42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448      0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

Input Arguments

assignmentMetric — Track assignment metrics object
trackAssignmentMetrics System object

Track assignment metrics object, specified as a trackAssignmentMetrics System object.

Output Arguments

metricsTable — Track metrics table
table

Track metrics table, returned as a table. Each row of the table represents a track. The table has these columns:

Column	Description
TrackID	Unique track identifier
AssignedTruthID	Unique truth identifier. If the track is not assigned to any truth, or the track was not reported in the last update, then the value of AssignedTruthID is NaN.
Surviving	True if the track was reported in the last update
TotalLength	Number of updates in which this track was reported
DeletionStatus	True if the track was previously assigned to a truth that was deleted while inside its coverage area.

`DeletionLength`	The number of updates in which the track was following a deleted truth
`DivergenceStatus`	`True` when the divergence distance between this track and its corresponding truth exceeds the divergence threshold
`DivergenceCount`	Number of times this track entered a divergent state
`DivergenceLength`	Number of updates in which this track was in a divergent state
`RedundancyStatus`	`True` if this track is assigned to a truth already associated with another track
`RedundancyCount`	Number of times this track entered a redundant state
`RedundancyLength`	Number of updates for which this track was in a redundant state
`FalseTrackStatus`	`True` if the track was not assigned to any truth
`FalseTrackLength`	Number of updates in which the track was unassigned
`SwapCount`	Number of times the track was assigned to a new truth object

Introduced in R2018b

truthMetricsTable

Compare truth to tracks

Syntax

```
metricsTable = truthMetricsTable(assignmentMetric)
```

Description

`metricsTable = truthMetricsTable(assignmentMetric)` returns a table of metrics, `metricsTable`, for all truths in the `assignmentMetric` System object.

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =

  4×15 table

    TrackID    AssignedTruthID    Surviving    TotalLength    DeletionStatus    Deleti
    _____    _____    _____    _____    _____    _____

       1             NaN            false         1120             false           (
       2             NaN            false         1736             false           (
       6              3             true          1138             false           (
       8              2             true           662             false           (
```

Show the truth metrics table.

```
truthMetricsTable(tam)
```

```
ans =

  2×10 table

    TruthID    AssociatedTrackID    DeletionStatus    TotalLength    BreakStatus    Bre
    _____    _____    _____    _____    _____    ___

       2               8               false            2678           false
```

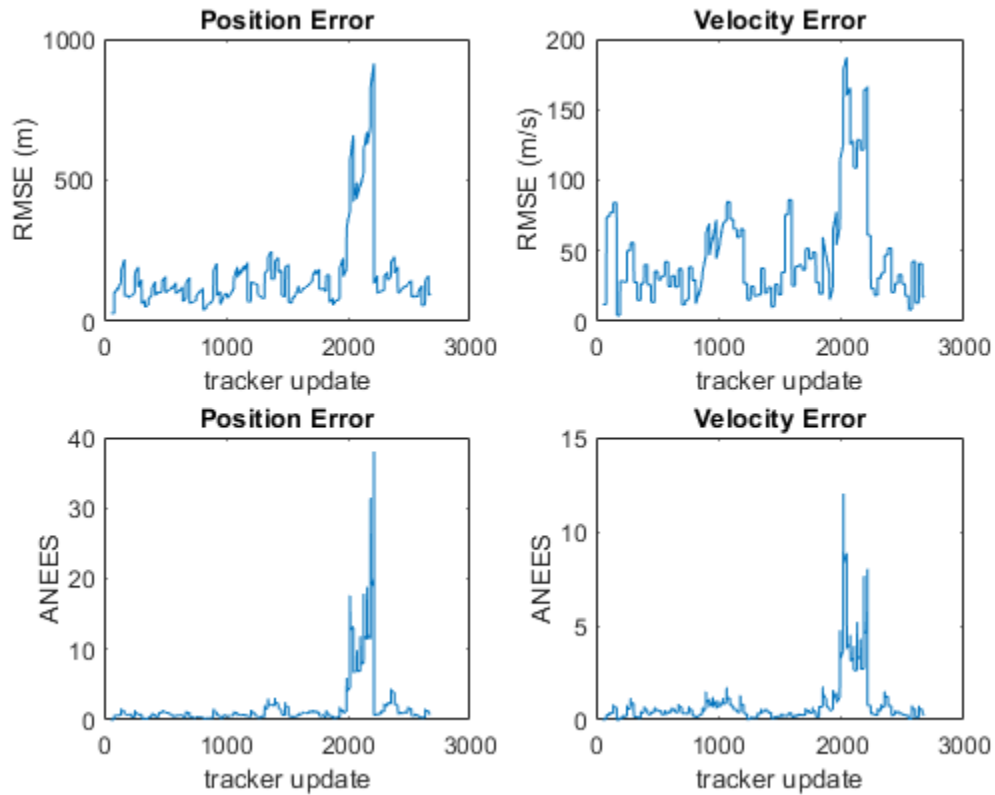|				
3	6	false	2678	false

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

```
         8        129.26    12.739     1.6745        0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745       0.2453
       3       44.712    20.988    0.05974      0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2       129.7      42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448     0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

Input Arguments

assignmentMetric — Track assignment metrics object
trackAssignmentMetrics System object

Track assignment metrics object, specified as a trackAssignmentMetrics System object.

Output Arguments

metricsTable — Truth metrics table
table

Truth metrics table, returned as a table. Each row of the table represents a truth. The table has these columns:

TruthID	Unique truth identifier
AssignedTrackID	Unique identifier of the associated track
DeletionStatus	False if the truth was reported in the last update
TotalLength	Number of updates this truth was reported
DeletionLength	The number of updates in which the track was following a deleted truth
BreakStatus	True when an established truth no longer has any track assigned with it
BreakCount	Number of times this truth entered a broken state

BreakLength	Number of updates in which this truth was in a broken state
InCoverageArea	True if this truth object is inside the coverage area
EstablishmentStatus	True if the truth is associated to any track
EstablishmentLength	Number of updates before this truth was associated to any track while inside the coverage area

Introduced in R2018b

trackErrorMetrics System object

Track error and NEES

Description

The `trackErrorMetrics` System object compares tracks from a multi-object tracking system against known truth by automatic assignment of tracks to known truth at each track update.

To generate track assignment metrics:

1 Create the `trackErrorMetrics` 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

```
errorMetrics = trackErrorMetrics
errorMetrics = trackErrorMetrics(Name,Value)
```

Description

`errorMetrics = trackErrorMetrics` creates a `trackErrorMetrics` System object with default property values.

`errorMetrics = trackErrorMetrics(Name,Value)` sets properties for the `trackErrorMetrics` object using one or more name-value pairs. For example, `metrics = trackErrorMetrics('MotionModel','constvel')` creates a `trackErrorMetrics` object with a constant velocity motion model. Enclose property names in quotes.

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).

ErrorFunctionFormat — Error function format
'built-in' (default) | 'custom'

Error function format specified as `'built-in'` or `'custom'`.

- `'built-in'` – Enable the `MotionModel` property.

  This property is a convenient interface when using tracks reported by any built-in multi-object tracker, and truths reported by the `platformPoses` object function of a `trackingScenario` object. The default estimation error function assumes `tracks` and `truths` are arrays of structures or arrays of objects.

- `'custom'` – Enable custom properties: `EstimationErrorLabels`, `EstimationErrorFcn`, `TruthIdentifierFcn`, and `TrackIdentifierFcns`. These properties can be used to construct error functions for arbitrary tracks and truths input arrays.

EstimationErrorLabels — Labels for outputs of error estimation function
'posMSE' (default) | array of strings | cell array of character vectors

Labels for outputs of error estimation function, specified as an array of strings or cell array of character vectors. The number of labels must correspond to the number of outputs of the error estimation function. Specify the error estimation functions using the `ErrorEstimationFcn` property.

Example: {'posMSE','velMSE'}

Dependencies

To enable this property, set the `ErrorFunctionFormat` property to `'custom'`.

Data Types: char | string

EstimationErrorFcn — Error estimation function
function handle

Error estimation function, specified as a function handle. The function determines estimation errors of truths to tracks.

The error estimation function can have multiple scalar outputs and must have the following syntax.

```
[out1,out2, ...,outN] = estimationerror(onetrack,onetruth)
```

The number of outputs must match the number of entries in the labels array specified in the `EstimationErrorLabels` property.

`onetrack` is an element of the `tracks` array passed in as input `trackErrorMetric` at object updates. `onetruth` is an element of the `truths` array passed in at object updates. The `trackErrorMetrics` object averages each output arithmetically when reporting across tracks or truths.

Example: `@errorFunction`

Dependencies

To enable this property, set the `ErrorFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

TrackIdentifierFcn — Track identifier function
`@trackIDFunction` (default) | function handle

Track identifier function, specified as a function handle. Specifies the track identifiers for the `tracks` input at object update. The track identifiers are unique string or numeric values.

The track identifier function must have the following syntax:

```
trackID = trackIDentifier(tracks)
```

`tracks` is the same as the `tracks` array passed as input for `trackErrorMetric` at object update. `trackID` is the same size as `tracks`. The default identification function handle, `@defaultTrackIdentifier`, assumes `tracks` is an array of structures or objects with a `'TrackID'` field name or property.

Dependencies

To enable this property, set the `ErrorFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

TruthIdentifierFcn — Truth identifier function
`@truthIDFunction` (default) | function handle

Truth identifier function, specified as a function handle. Specifies the truth identifiers for the `truths` input at object update. The truth identifiers are unique string or numeric values.

The truth identifier function must have the following syntax:

```
truthID = truthIDentifier(truths)
```

`truths` is the same as the `truths` array passed as input for `trackErrorMetric` updates. `truthID` must have the same size as `truths`. The default identification function handle, `@defaultTruthIdentifier`, assumes `truths` is an array or structures or objects with a `'PlatformID'` field name or property.

Dependencies

To enable this property, set the `ErrorFunctionFormat` property to `'custom'`.

Data Types: `function_handle`

Usage

To estimate errors, call the track error metrics object with arguments, as if it were a function (described here).

Syntax

```
[posRMSE,velRMSE,posANEES,velANEES] = errorMetrics(tracks,trackIDs,
truths,truthIDs)
[posRMSE,velRMSE,accRMSE,posANEES,velANEES,accANEES] = errorMetrics(
tracks,trackIDs,truths,truthIDs)
[posRMSE,velRMSE,yawRateRMSE,posANEES,velANEES,yawRateANEES] =
errorMetrics(tracks,trackIDs,truths,truthIDs)
```

```
[out1,out2, ... ,outN] = errorMetrics(tracks,trackIDs,truths,
truthIDs)
```

Description

`[posRMSE,velRMSE,posANEES,velANEES] = errorMetrics(tracks,trackIDs, truths,truthIDs)` returns the metrics

- `posRMSE` – Position root mean squared error
- `velRMSE` – Velocity root mean squared error
- `posANEES` – Position average normalized-estimation error squared
- `velANEES` – Velocity average normalized-estimation error squared.

for constant velocity motion. `trackIDs` is the set of track identifiers for all tracks. `truthIDs` is the set of truth identifiers. `tracks` are the set of tracks, and `truths` are the set of truths. `trackIDs` and `truthIDs` are each a vector whose corresponding elements match the track and truth identifiers found in `tracks` and `truths`, respectively.

To enable this syntax, set the `ErrorFunctionFormat` property to `'built-in'` and the `MotionModel` property to `'constvel'`.

`[posRMSE,velRMSE,accRMSE,posANEES,velANEES,accANEES] = errorMetrics( tracks,trackIDs,truths,truthIDs)` also returns the metrics

- `accRMS` – Acceleration root mean squared error
- `accANEES` – acceleration average NEES

for constant acceleration motion.

To enable this syntax, set the `ErrorFunctionFormat` property to `'built-in'` and the `MotionModel` property to `'constacc'`.

`[posRMSE,velRMSE,yawRateRMSE,posANEES,velANEES,yawRateANEES] = errorMetrics(tracks,trackIDs,truths,truthIDs)` also returns the metrics

- `yawRateRMSE` – yaw rate root mean squared error.
- `yawRateANEES` – yaw rate average normalized-estimation error squared.

for constant turn rate motion.

To enable this syntax, set the `ErrorFunctionFormat` property to `'built-in'` and the `MotionModel` property to `'constturn'`.

`[out1,out2, ... ,outN] = errorMetrics(tracks,trackIDs,truths,`
`truthIDs)` returns the user-defined metrics `out1`, `out2`, … , `outN`.

To enable this syntax, set the `ErrorFunctionFormat` property to `'custom'`. The number of outputs corresponds to the number of elements listed in the `EstimationErrorLabels` property, and must match the number of outputs in the `EstimationErrorFcn`. The results of the estimation errors are averaged arithmetically over all track-to-truth assignments.

Input Arguments

`tracks` — Track information
structure | array of structures

Track information, specified as a structure or array of structures. For built-in trackers such as `trackerGNN` or `trackerTOMHT`, the structure contains `'State'`, `'StateCovariance'`, and `'TrackID'` information.

Data Types: `struct`

`trackIDs` — Track identifiers
real-valued vector

Track identifiers, specified as a real-valued vector. `trackIDs` elements match the tracks found in `tracks`.

`truths` — Truth information
structure | array of structures

Truth information, specified as a structure or array of structures. When using a `trackingScenario`, truth information can be obtained from the `platformPoses` object function.

Data Types: `struct`

`truthIDs` — Truth identifiers
real-valued vector

Truth identifiers, specified as a real-valued vector. `truthIDs` elements match the truths found in `truths`.

Output Arguments

posRMSE — Position root mean squared error
scalar

Position root mean squared error, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

velRMSE — Velocity root mean squared error
scalar

Velocity root mean squared error, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

accRMSE — Acceleration root mean squared error
scalar

Acceleration root mean squared error, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

yawRateRMSE — Yaw rate root mean squared error
scalar

Yaw rate root mean squared error, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

posANEES — Position average normalized estimation error squared
scalar

Position average normalized estimation error squared, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

velANEES — Velocity average normalized estimation error squared
scalar

Velocity average normalized estimation error squared, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

accANEES — Acceleration average normalized estimation error squared
scalar

Acceleration average normalized estimation error squared, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

yawRateANEES — Yaw rate average normalized estimation error squared
scalar

Yaw rate average normalized estimation error squared, returned as a scalar.

Dependencies

To enable this argument, set the `ErrorFunctionFormat` property to `'built-in'`.

out1, out2, outN — Custom error metric outputs
scalar

Custom error metric outputs, returned as scalars. These errors are the output of the error estimation function specified in the `EstmationErrorFcn` property.

Dependencies

To enable these arguments, set the `ErrorFunctionFormat` property to `'custom'`.

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 `trackErrorMetrics`

cumulativeTrackMetrics	Cumulative metrics for recent tracks
cumulativeTruthMetrics	Cumulative metrics for recent truths
currentTrackMetrics	Metrics for recent tracks
currentTruthMetrics	Metrics for recent truths

Common to All System Objects

release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object
isLocked	Determine if System object is in use
clone	Create duplicate System object

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
```

```
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =
```

  4×15 table

TrackID	AssignedTruthID	Surviving	TotalLength	DeletionStatus	Deletio
1	NaN	false	1120	false	
2	NaN	false	1736	false	
6	3	true	1138	false	
8	2	true	662	false	

Show the truth metrics table.

```
truthMetricsTable(tam)
```

```
ans =
```

  2×10 table

TruthID	AssociatedTrackID	DeletionStatus	TotalLength	BreakStatus	Bre
2	8	false	2678	false	
3	6	false	2678	false	

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

3-353

```
      8       129.26    12.739     1.6745        0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745       0.2453
       3       44.712    20.988     0.05974      0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2       129.7      42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448      0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

See Also

System Objects
monostaticRadarSensor | trackAssignmentMetrics | trackerGNN |
trackerTOMHT

Introduced in R2018b

cumulativeTrackMetrics

Cumulative metrics for recent tracks

Syntax

```
metricsTable = cumulativeTrackMetrics(errorMetrics)
```

Description

`metricsTable = cumulativeTrackMetrics(errorMetrics)` returns a table of cumulative metrics, `metricsTable`, for every track identifier provided in the most recent update.

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =

  4×15 table

    TrackID    AssignedTruthID    Surviving    TotalLength    DeletionStatus    Deletic
    _____    _____    _____    _____    _____    _____

       1            NaN             false          1120            false          (
       2            NaN             false          1736            false          (
       6             3              true           1138            false          (
       8             2              true            662            false          (
```

Show the truth metrics table.

```
truthMetricsTable(tam)
```

```
ans =

  2×10 table

    TruthID    AssociatedTrackID    DeletionStatus    TotalLength    BreakStatus    Bre
    _____    _____    _____    _____    _____    ___
```

3-357

```
        2              8            false        2678        false
        3              6            false        2678        false
```
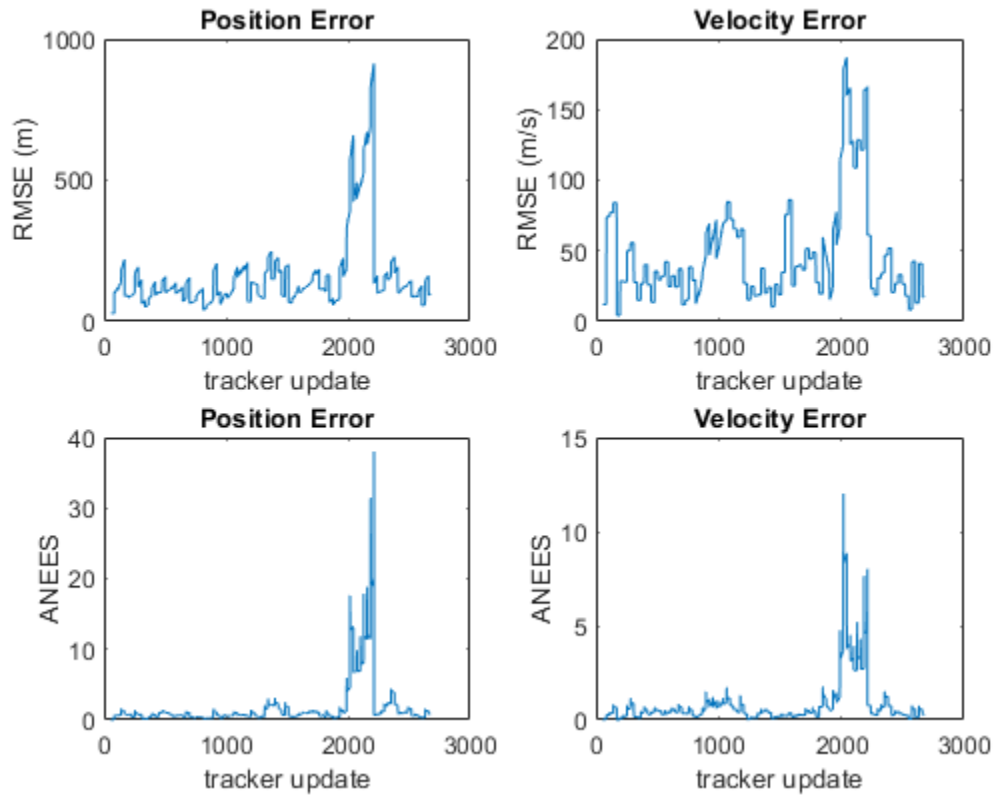
Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

```
        8        129.26    12.739    1.6745       0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745      0.2453
       3       44.712    20.988    0.05974      0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2        129.7     42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448      0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

Input Arguments

errorMetrics — Error metrics object
trackErrorMetrics System object

Error metrics object, specified as a trackErrorMetrics System object.

Output Arguments

metricsTable — Track error metrics
table

Track error metrics, returned as a table.

- When you set the ErrorFunctionFormat property of the input error metrics object to 'built-in', the table columns depend on the setting of the MotionModel property.

Motion Model	Table Columns
'constvel'	posRMSE, velRMSE, posANEES, velANEES
'constacc'	posRMSE, velRMSE, accRMSE, posANEES, velANEES, accANEES
'constturn'	posRMSE, velRMSE, yawRateRMSE, posANEES, velANEES, yawRateANEES

RMSE denotes root mean squared error and ANEES denotes average normalized estimation error.

- When you set the ErrorFunctionFormat property to 'custom', the table contains the arithmetically averaged values of the custom metrics output from the error function.

Introduced in R2018b

cumulativeTruthMetrics

Cumulative metrics for recent truths

Syntax

```
metricsTable = cumulativeTruthMetrics(errorMetrics)
```

Description

`metricsTable = cumulativeTruthMetrics(errorMetrics)` returns a table of cumulative metrics, `metricsTable`, for every truth identifier provided in the most recent update.

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =

  4×15 table
```

TrackID	AssignedTruthID	Surviving	TotalLength	DeletionStatus	Deletio
1	NaN	false	1120	false	(
2	NaN	false	1736	false	(
6	3	true	1138	false	(
8	2	true	662	false	(

Show the truth metrics table.

```
truthMetricsTable(tam)
```

```
ans =

  2×10 table
```

TruthID	AssociatedTrackID	DeletionStatus	TotalLength	BreakStatus	Bre

```
           2                    8                    false                2678                    false
           3                    6                    false                2678                    false
```

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

```
    8       129.26    12.739    1.6745      0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745      0.2453
       3       44.712    20.988    0.05974     0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2        129.7     42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448     0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

3-367

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

Input Arguments

errorMetrics — Error metrics object
trackErrorMetrics System object

Error metrics object, specified as a trackErrorMetrics System object.

Output Arguments

metricsTable — Truth error metrics
table

Truth error metrics, returned as a table.

- When you set the ErrorFunctionFormat property of the input error metrics object to 'built-in', the table columns depend on the setting of the MotionModel property.

Motion Model	Table Columns
'constvel'	posRMSE, velRMSE, posANEES, velANEES
'constacc'	posRMSE, velRMSE, accRMSE, posANEES, velANEES, accANEES
'constturn'	posRMSE, velRMSE, yawRateRMSE, posANEES, velANEES, yawRateANEES

RMSE denotes root mean squared error and ANEES denotes average normalized estimation error.

- When you set the ErrorFunctionFormat property to 'custom', the table contains the arithmetically averaged values of the custom metrics output from the error function.

Introduced in R2018b

currentTrackMetrics

Metrics for recent tracks

Syntax

```
metricsTable = currentTrackMetrics(errorMetrics)
```

Description

`metricsTable = currentTrackMetrics(errorMetrics)` returns a table of metrics, `metricsTable`, for every track identifier provided in the most recent update.

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

ans =

  4×15 table

TrackID	AssignedTruthID	Surviving	TotalLength	DeletionStatus	Deleti
1	NaN	false	1120	false	
2	NaN	false	1736	false	
6	3	true	1138	false	
8	2	true	662	false	

Show the truth metrics table.

```
truthMetricsTable(tam)
```

ans =

  2×10 table

TruthID	AssociatedTrackID	DeletionStatus	TotalLength	BreakStatus	Bre
2	8	false	2678	false	

3-371

3	6	false	2678	false

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

```
        8        129.26     12.739      1.6745       0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID     posRMS     velRMS     posANEES     velANEES
    _____     _____     _____     _____     _____

       2        129.26     12.739      1.6745       0.2453
       3        44.712     20.988     0.05974       0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID     posRMS     velRMS     posANEES     velANEES
    _____     _____     _____     _____     _____

       1        117.69     43.951     0.58338      0.44127
       2         129.7      42.8      0.81094      0.42509
       6        371.35     87.083      4.5208       1.6952
       8        130.45     53.914      1.0448      0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

Input Arguments

errorMetrics — Error metrics object
trackErrorMetrics System object

Error metrics object, specified as a trackErrorMetrics System object.

Output Arguments

metricsTable — Track error metrics
table

Track error metrics, returned as a table:

- When you set the ErrorFunctionFormat property of the input error metrics object to 'built-in', the table columns depend on the setting of the MotionModel property.

Motion Model	Table Columns
'constvel'	posRMSE, velRMSE, posANEES, velANEES
'constacc'	posRMSE, velRMSE, accRMSE, posANEES, velANEES, accANEES
'constturn'	posRMSE, velRMSE, yawRateRMSE, posANEES, velANEES, yawRateANEES

RMSE denotes root mean squared error and ANEES denotes average normalized estimation error.

- When you set the ErrorFunctionFormat property to 'custom', the table contains the arithmetically averaged values of the custom metrics output from the error function.

Introduced in R2018b

currentTruthMetrics

Metrics for recent truths

Syntax

```
metricsTable = currentTruthMetrics(errorMetrics)
```

Description

`metricsTable = currentTruthMetrics(errorMetrics)` returns a table of metrics, `metricsTable`, for every truth identifier provided in the most recent update.

Examples

Assignment and Error Metrics for Two Tracked Targets

Examine the assignments and errors for a system tracking two targets.

First, load the stored track data.

```
load trackmetricex tracklog truthlog
```

Create objects to analyze assignment and error metrics.

```
tam = trackAssignmentMetrics;
tem = trackErrorMetrics;
```

Create the output variables.

```
posRMSE = zeros(numel(tracklog),1);
velRMSE = zeros(numel(tracklog),1);
posANEES = zeros(numel(tracklog),1);
velANEES = zeros(numel(tracklog),1);
```

Loop over all tracks to:

- Extract the tracks and ground truth at the *i* th tracker update.
- Analyze and retrieve the current track-to-truth assignment.
- Analyze instantaneous error metrics over all tracks and truths.

```
for i=1:numel(tracklog)
    tracks = tracklog{i};
    truths = truthlog{i};
    [trackAM,truthAM] = tam(tracks, truths);
    [trackIDs,truthIDs] = currentAssignment(tam);
    [posRMSE(i),velRMSE(i),posANEES(i),velANEES(i)] = ...
        tem(tracks,trackIDs,truths,truthIDs);
end
```

Show the track metrics table.

```
trackMetricsTable(tam)
```

```
ans =

  4×15 table

    TrackID    AssignedTruthID    Surviving    TotalLength    DeletionStatus    Deletio
    _____    _____    _____    _____    _____    _____

       1            NaN             false         1120            false           (
       2            NaN             false         1736            false           (
       6             3              true          1138            false           (
       8             2              true           662            false           (
```

Show the truth metrics table.

```
truthMetricsTable(tam)
```

```
ans =

  2×10 table

    TruthID    AssociatedTrackID    DeletionStatus    TotalLength    BreakStatus    Bre
    _____    _____    _____    _____    _____    ___

       2               8                false            2678           false
```

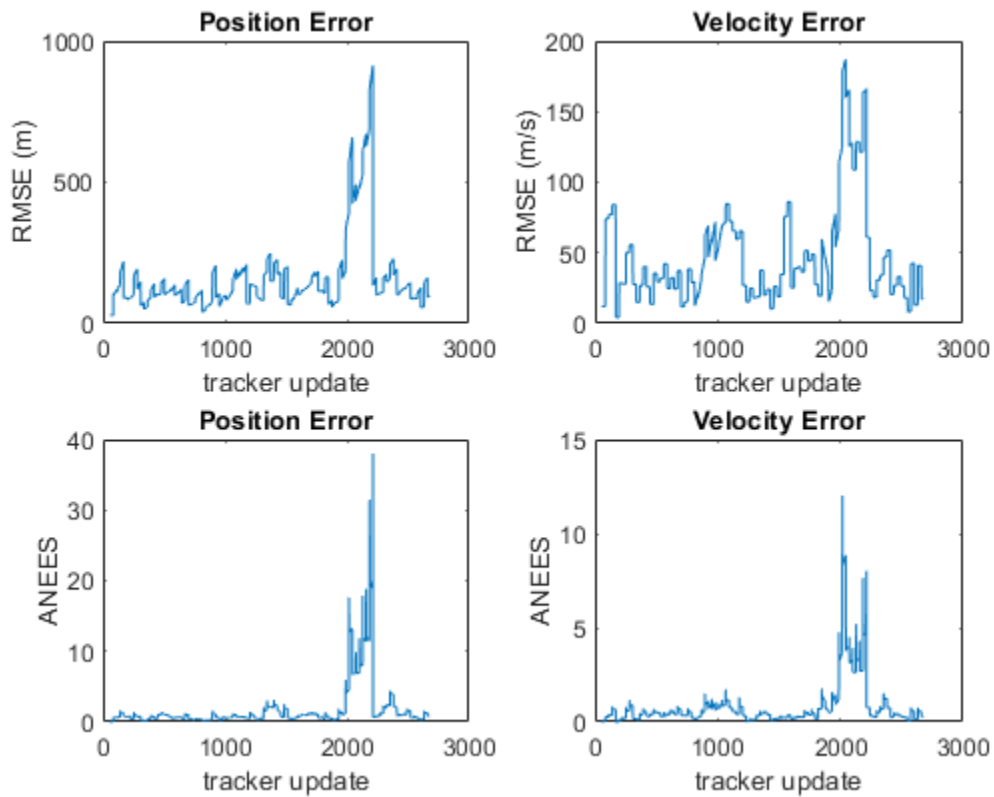|				
3	6	false	2678	false

Plot the RMSE and ANEES error metrics.

```
subplot(2,2,1)
plot(posRMSE)
title('Position Error')
xlabel('tracker update')
ylabel('RMSE (m)')

subplot(2,2,2)
plot(velRMSE)
title('Velocity Error')
xlabel('tracker update')
ylabel('RMSE (m/s)')

subplot(2,2,3)
plot(posANEES)
title('Position Error')
xlabel('tracker update')
ylabel('ANEES')

subplot(2,2,4)
plot(velANEES)
title('Velocity Error')
xlabel('tracker update')
ylabel('ANEES')
```

Show the current error metrics for each individual recorded track.

```
currentTrackMetrics(tem)
```

```
ans =

  2×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       6       44.712    20.988    0.05974     0.31325
```

```
     8       129.26    12.739    1.6745      0.2453
```

Show the current error metrics for each individual recorded truth object.

```
currentTruthMetrics(tem)
```

```
ans =

  2×5 table

    TruthID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       2       129.26    12.739     1.6745      0.2453
       3       44.712    20.988    0.05974     0.31325
```

Show the cumulative error metrics for each individual recorded track.

```
cumulativeTrackMetrics(tem)
```

```
ans =

  4×5 table

    TrackID    posRMS    velRMS    posANEES    velANEES
    _____    _____    _____    _____    _____

       1       117.69    43.951    0.58338     0.44127
       2       129.7      42.8     0.81094     0.42509
       6       371.35    87.083     4.5208      1.6952
       8       130.45    53.914     1.0448     0.44813
```

Show the cumulative error metrics for each individual recorded truth object.

```
cumulativeTruthMetrics(tem)
```

```
ans =

  2×5 table
```

TruthID	posRMS	velRMS	posANEES	velANEES
2	258.21	65.078	2.2514	0.93359
3	134.41	48.253	0.96314	0.49183

Input Arguments

errorMetrics — Error metrics object
trackErrorMetrics System object

Error metrics object, specified as a trackErrorMetrics System object.

Output Arguments

metricsTable — Truth error metrics
table

Truth error metrics, returned as a table.

- When you set the ErrorFunctionFormat property of the input error metrics object to 'built-in', the table columns depend on the setting of the MotionModel property.

Motion model	Table Columns
'constvel'	posRMSE, velRMSE, posANEES, velANEES.
'constacc'	posRMSE, velRMSE, accRMSE, posANEES, velANEES, accANEES
'constturn'	posRMSE, velRMSE, yawRateRMSE, posANEES, velANEES, yawRateANEES

RMSE denotes root mean squared error and ANEES denotes average normalized estimation error.

- When you set the ErrorFunctionFormat property to 'custom', the table contains the arithmetically averaged values of the custom metrics output from the error function.

Introduced in R2018b

trackerTOMHT System object

Multi-hypothesis, multi-sensor, multi-object tracker

Description

The `trackerTOMHT` System object is a multi-hypothesis tracker capable of processing detections of many targets from multiple sensors. The tracker initializes, confirms, predicts, corrects, and deletes tracks. Inputs to the tracker are detection reports generated by `objectDetection`, `radarSensor`, `monostaticRadarSensor`, `irSensor`, or `sonarSensor` objects. The tracker estimates the state vector and state vector covariance matrix for each track. The tracker assigns detections based on a track-oriented, multi-hypothesis approach. Each detection is assigned to at least one track. If the detection cannot be assigned to any track, the tracker creates a track.

Any new track starts in a *tentative* state. If enough detections are assigned to a tentative track, its status changes to *confirmed*. If the detection already has a known classification (the `ObjectClassID` field of the returned track is nonzero), that track is confirmed immediately. When a track is confirmed, the multi-object tracker considers the track to represent a physical object. If detections are not assigned to the track within a specifiable number of updates, the track is deleted. For an overview of how the tracker functions, see "Algorithms" on page 3-399.

To track objects using the multi-hypothesis tracker:

1 Create the `trackerTOMHT` 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

```
tracker = trackerTOMHT
```

```
tracker = trackerTOMHT(Name,Value)
```

Description

`tracker = trackerTOMHT` creates a `trackerTOMHT` System object with default property values.

`tracker = trackerTOMHT(Name,Value)` sets properties for the multi-object tracker using one or more name-value pairs. For example, `trackerTOMHT('FilterInitializationFcn',@initcvukf,'MaxNumTracks', 100)` creates a multi-object tracker that uses a constant-velocity, unscented Kalman filter and allows a maximum of 100 tracks. Enclose each property name in quotes.

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).

FilterInitializationFcn — Filter initialization function
@initcvekf (default) | function handle | character vector

Filter initialization function, specified as a function handle or as a character vector containing the name of a valid filter initialization function. The tracker uses a filter initialization function when creating new tracks.

Sensor Fusion and Tracking Toolbox supplies many initialization functions that you can use to specify `FilterInitializationFcn`.

Initialization Function	Function Definition
initcvabf	Initialize constant-velocity alpha-beta filter
initcaabf	Initialize constant-acceleration alpha-beta filter

Initialization Function	Function Definition
`initcvekf`	Initialize constant-velocity extended Kalman filter.
`initcackf`	Initialize constant-acceleration cubature filter.
`initctckf`	Initialize constant-turn-rate cubature filter.
`initcvckf`	Initialize constant-velocity cubature filter.
`initcapf`	Initialize constant-acceleration particle filter.
`initctpf`	Initialize constant-turn-rate particle filter.
`initcvpf`	Initialize constant-velocity particle filter.
`initcvkf`	Initialize constant-velocity linear Kalman filter.
`initcvukf`	Initialize constant-velocity unscented Kalman filter.
`initcaekf`	Initialize constant-acceleration extended Kalman filter.
`initcakf`	Initialize constant-acceleration linear Kalman filter.
`initcaukf`	Initialize constant-acceleration unscented Kalman filter.
`initctekf`	Initialize constant-turn-rate extended Kalman filter.
`initctukf`	Initialize constant-turn-rate unscented Kalman filter.
`initcvmscekf`	Initialize constant-velocity modified spherical coordinates extended Kalman filter.
`initrpekf`	Initialize constant-velocity range-parametrized extended Kalman filter.
`initapekf`	Initialize constant-velocity angle-parametrized extended Kalman filter.
`initekfimm`	Initialize tracking IMM filter.

You can also write your own initialization function. The function must have the following syntax:

```
filter = filterInitializationFcn(detection)
```

The input to this function is a detection report like those created by `objectDetection`. The output of this function must be an object belonging to one of the filter classes: `trackingKF`, `trackingEKF`, `trackingUKF`, `trackingCKF`, `trackingPF`, `trackingMSCEKF`, `trackingGSF`, `trackingIMM`, or `trackingAB`.

To guide you in writing this function, you can examine the details of the supplied functions from within MATLAB. For example:

```
type initcvekf
```

Data Types: `function_handle` | `char`

MaxNumTracks — Maximum number of tracks
100 (default) | positive integer

Maximum number of tracks that the tracker can maintain, specified as a positive integer.

Data Types: `single` | `double`

MaxNumSensors — Maximum number of sensors
20 (default) | positive integer

Maximum number of sensors that can be connected to the tracker, specified as a positive integer. `MaxNumSensors` must be greater than or equal to the largest value of `SensorIndex` found in all the detections used to update the tracker. `SensorIndex` is a property of an `objectDetection` object. The `MaxNumSensors` property determines how many sets of `ObjectAttributes` fields each output track can have.

Data Types: `single` | `double`

MaxNumHypotheses — Maximum number of hypotheses to maintain
5 (default) | positive integer

Maximum number of hypotheses maintained by the tracks in cases of ambiguity, specified as a positive integer. Larger values increase the computational load.

Example: 10

Data Types: `single` | `double`

`MaxNumBranches` — Maximum number of track branches per track
3 (default) | positive scalar

Set the maximum number of track branches (hypotheses) allowed for each track. Larger values increase the computational load.

Data Types: `single` | `double`

`MaxNumHistoryScans` — Maximum number of scans maintained in the branch history
4 (default) | positive integer

Maximum number of scans maintained in the branch history, specified as a positive integer. The number of track history scans is typically from 2 through 6. Larger values increase the computational load.

Example: 6

Data Types: `single` | `double`

`AssignmentThreshold` — Detection assignment threshold
30*[0.3 0.7 1] (default) | positive scalar | 1-by-3 vector of positive values

Detection assignment threshold, specified as a positive scalar or 1-by-3 vector of non-decreasing positive values, $[C_1, C_2, C_3]$. If specified as a scalar, the specified value, *val*, will be expanded to *[0.3,0.7,1]*val*.

The thresholds control (1) the assignment of a detection to a track, (2) the creation of a new branch from a detection, and (3) the creation of a new branch from an unassigned track. The threshold values must satisfy: C_1 <= C_2 <= C_3.

- C_1 defines a distance such that if a track has an assigned detection with lower distance than C_1, the track is no longer considered unassigned and does not create an unassigned track branch.

- C_2 defines a distance that if a detection has been assigned to a track with lower distance than C_2, the detection is no longer considered unassigned and does not create a new track branch.

- C_3 defines the maximum distance for assigning a detection to a track.

Tips:

- Increase the value of C_3 if there are detections that should be assigned to tracks but are not. Decrease the value if there are detections that are assigned to tracks they should not be assigned to (too far away).
- Increasing the values C_1 and C_2 helps control the number of track branches that are created. However, doing so reduces the number of branches (hypotheses) each track has.

Data Types: `single` | `double`

ConfirmationThreshold — Minimum score required to confirm track
`20` (default) | positive scalar

Minimum score required to confirm a track, specified as a positive scalar. Any track with a score higher than this threshold is confirmed.

Example: `12`

Data Types: `single` | `double`

DeletionThreshold — Maximum score drop for track deletion
`-7` (default) | scalar

The maximum score drop before a track is deleted, specified as a scalar. Any track with a score that falls by more than this parameter from the maximum score is deleted. Deletion threshold is affected by the probability of false alarm.

Example: `12`

Data Types: `single` | `double`

DetectionProbability — Probability of detection used for track score
`0.9` (default) | positive scalar between 0 and 1

Probability of detection, specified as a positive scalar between 0 and 1. This property is used to compute track score.

Example: `0.5`

Data Types: `single` | `double`

FalseAlarmRate — Probability of false alarm used for track score
`1e-6` (default) | scalar

The probability of false alarm, specified as a scalar. This property is used to compute track score.

Example: `1e-5`

Data Types: `single` | `double`

Beta — Rate of new tracks per unit volume
1 (default) | positive scalar

The rate of new tracks per unit volume, specified as a positive scalar. The rate of new tracks is used in calculating the track score during track initialization.

Example: `2.5`

Data Types: `single` | `double`

Volume — Volume of sensor measurement bin
1 (default) | positive scalar

The volume of a sensor measurement bin, specified as a positive scalar. For example, if a radar produces a 4-D measurement, which includes azimuth, elevation, range, and range rate, the 4-D volume is defined by the radar angular beam width, the range bin width and the range-rate bin width. Volume is used in calculating the track score when initializing and updating a track.

Example: `1.5`

Data Types: `single` | `double`

MinBranchProbability — Minimum probability required to keep track
`.001` (default) | positive scalar

Minimum probability required to keep a track, specified as a positive scalar less than one. Any track with lower probability is pruned. Typical values are 0.001 to 0.005.

Example: `.003`

Data Types: `single` | `double`

NScanPruning — N-scan pruning method
`'None'` (default) | `'Hypothesis'`

N-scan pruning method, specified as `'None'` or `'Hypothesis'`. In N-scan pruning, branches that belong to the same track are pruned (deleted) if, in the N-scans history, they contradict the most likely branch for the same track. The most-likely branch is defined in one of two ways:

- `'None'` – No N-scan pruning is performed.
- `'Hypothesis'` – The chosen branch is in the most likely hypothesis.

Example: `'Hypothesis'`

`HasCostMatrixInput` — Enable cost matrix input
`false` (default) | `true`

Enable a cost matrix, specified as `false` or `true`. If `true`, you can provide an assignment cost matrix as an input argument at object update time.

Data Types: `logical`

`HasDetectableBranchIDsInput` — Enable input of detectable branch IDs
`false` (default) | `true`

Enable the input of detectable branch IDs at each object update, specified as `false` or `true`. Set this property to `true` if you want to provide a list of detectable branch IDs. This list tells the tracker of all branches that the sensors are expected to detect and, optionally, the probability of detection for each branch.

Data Types: `logical`

`OutputRepresentation` — Track output method
`'Tracks'` (default) | `'Hypothesis'` | `'Clusters'`

Track output method, specified as `'Tracks'`, `'Hypothesis'`, or `'Clusters'`.

- `'Tracks'` – Output the centroid of each track based on its track branches.
- `'Hypothesis'` – Output branches that are in certain hypotheses. If you choose this option, list the hypotheses to output using the `HypothesesToOutput` property.
- `'Clusters'` – Output the centroid of each cluster. Similar to `'Tracks'` output, but includes all tracks within a cluster.

Data Types: `char`

`HypothesesToOutput` — Indices of hypotheses to output
1 (default) | positive integer | array of positive integers

Indices of hypotheses to output, specified as an array of positive integers. The indices must all be less than or equal to the maximum number of hypotheses provided by the tracker.

Tunable: Yes

Data Types: `single` | `double`

`NumTracks` — Number of tracks maintained by tracker
nonnegative integer

This property is read-only.

Number of tracks maintained by the tracker, returned as a nonnegative integer.

Data Types: `double`

`NumConfirmedTracks` — Number of confirmed tracks
nonnegative integer

This property is read-only.

Number of confirmed tracks, returned as a nonnegative integer. If the `IsConfirmed` field of an output track structure is `true`, the track is confirmed.

Data Types: `double`

Usage

To process detections and update tracks, call the tracker with arguments, as if it were a function (described here).

Syntax

```
confirmedTracks = tracker(detections,time)
confirmedTracks = tracker(detections,time,costMatrix)
confirmedTracks = tracker( ___ ,detectableBranchIDs)
[confirmedTracks,tentativeTracks,allTracks] = tracker( ___ )
[ ___ ,analysisInformation] = tracker( ___ )
```

Description

`confirmedTracks = tracker(detections,time)` returns a list of confirmed tracks that are updated from a list of detections, `detections`, at the update time, `time`. Confirmed tracks are corrected and predicted to the update time.

`confirmedTracks = tracker(detections,time,costMatrix)` also specifies a cost matrix, `costMatrix`.

To enable this syntax, set the `HasCostMatrixInput` property to `true`.

`confirmedTracks = tracker( ___ ,detectableBranchIDs)` also specifies a list of expected detectable branches, `detectableBranchIDs`.

To enable this syntax, set the `HasDetectableBranchIDsInput` property to `true`.

`[confirmedTracks,tentativeTracks,allTracks] = tracker( ___ )` also returns a list of tentative tracks, `tentativeTracks`, and a list of all tracks, `allTracks`.

`[ ___ ,analysisInformation] = tracker( ___ )` also returns information, `analysisInformation`, useful for track analysis.

Input Arguments

detections — Detection list
cell array of `objectDetection` objects

Detection list, specified as a cell array of `objectDetection` objects. The `Time` property value of each `objectDetection` object must be less than or equal to the current update time, `time`, and greater than the previous time value used to update the tracker.

time — Time of update
scalar

Time of update, specified as a scalar. The tracker updates all tracks to this time. Units are in seconds.

`time` must be greater than or equal to the largest `Time` property value of the `objectDetection` objects in the input `detections` list. `time` must increase in value with each update to the tracker.

Data Types: `single` | `double`

costMatrix — Cost matrix
real-valued *N*-by-*M* matrix

Cost matrix, specified as a real-valued *N*-by-*M* matrix, where *N* is the number of branches, and *M* is the number of current detections. The cost matrix rows must be in the same order as the list of branches. The columns must be in the same order as the list of detections. Obtain the correct order of the list of branches using the `getBranches` object function. Matrix columns correspond to the detections.

At the first update of the object or when the tracker has no previous tracks, specify the cost matrix to have a size of `[0,numDetections]`. Note that the cost must be calculated so that lower costs indicate a higher likelihood of assigning a detection to a track. To prevent certain detections from being assigned to certain tracks, set the appropriate cost matrix entry to `Inf`.

Dependencies

To enable this argument, set the `HasCostMatrixInput` property to `true`.

Data Types: `double` | `single`

detectableBranchIDs — Detectable branch IDs
real-valued *M*-by-1 vector | real-valued *M*-by-2 matrix

Detectable branch IDs, specified as a real-valued *M*-by-1 vector or *M*-by-2 matrix. Detectable branches are branches that the sensors expect to detect. The first column of the matrix contains a list of branch IDs of tracks reported in the `branchID` field of the track output arguments. The second column contains the detection probability for the branch. Sensors can report detection probability, but if not reported, detection probabilities are obtained from the `DetectionProbability` property.

Branches whose identifiers are not included in `detectableBranchIDs` are considered as undetectable. The track deletion logic does not count the lack of detection as a 'miss' for branch deletion purposes.

Dependencies

To enable this input argument, set the `HasDetectableBranchIDs` property to `true`.

Data Types: `single` | `double`

Output Arguments

`confirmedTracks` — Confirmed tracks
structure | array of structures

Confirmed tracks, returned as a structure or array of structures. Each structure corresponds to a track. A track is confirmed if its score is greater than the confirmation threshold specified in the `ConfirmationThreshold` property. In that case, the `IsConfirmed` field of the structure is `true`. The fields of the structure are defined "Track Structure" on page 3-398.

Data Types: `struct`

`tentativeTracks` — Tentative tracks
structure | array of structures

Tentative tracks, returned as a structure or array of structures. Each structure corresponds to a track. A track is tentative if its score is less than or equal to the confirmation threshold specified in the `ConfirmationThreshold` property. In that case, the `IsConfirmed` field of the structure is `false`. The fields of the structure are defined in "Track Structure" on page 3-398.

Data Types: `struct`

`allTracks` — All tracks
structure

All tracks, returned as a structure or array of structures. Each structure corresponds to a track. The set of all tracks consists of confirmed and tentative tracks. The fields of the structure are defined in "Track Structure" on page 3-398.

Data Types: `struct`

`analysisInformation` — Additional information for analyzing track updates
structure

Additional information for analyzing track updates, returned as a structure. The fields of this structure are:

Field	Description
`BranchIDsAtStepBeginning`	Branch IDs when update began.

CostMatrix	Cost of assignment matrix.
Assignments	Assignments returned from `assignTOMHT`.
UnassignedTracks	IDs of unassigned branches returned from the tracker
UnassignedDetections	IDs of unassigned detections returned from `trackerTOMHT`.
InitialBranchHistory	Branch history after branching and before pruning.
InitialBranchScores	Branch scores before pruning.
KeptBranchHistory	Branch history after initial pruning.
KeptBranchScores	Branch scores after initial pruning.
Clusters	Logical array mapping branches to clusters. Branches belong in the same cluster if they share detections in their history or belong to the same track, either directly or through other branches. Such branches are incompatible.
TrackIncompatibility	Branch incompatibility matrix. The (i,j) element is true if the i-th and j-th branches have shared detections in their history or belong to the same track.
GlobalHypotheses	Logical matrix mapping branches to global hypotheses. Compatible branches can belong in the same hypotheses.
GlobalHypScores	Total score of global hypotheses.
PrunedBranches	Logical array of branches that the `pruneTrackBranches` function determines to be pruned.
GlobalBranchProbabilities	Global probability of each branch existing in the global hypotheses.
BranchesDeletedByPruning	Branches deleted by the tracker.
BranchIDsAtStepEnd	Branch IDs when the update ended.

Data Types: `struct`

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 `trackerTOMHT`

getTrackFilterProperties	Obtain track filter properties
setTrackFilterProperties	Set track filter properties
getBranches	Lists track branches
predictTrackToTime	Predict track state

Common to All System Objects

release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object
isLocked	Determine if System object is in use
clone	Create duplicate System object

Examples

Track Two Objects Using trackerTOMHT

Create the `trackerTOMHT` System object with a constant-velocity Kalman filter initialization function, `initcvkf`.

```
tracker = trackerTOMHT('FilterInitializationFcn',@initcvkf, ...
    'ConfirmationThreshold',20, ...
    'DeletionThreshold',-7, ...
    'MaxNumHypotheses',10);
```

Update the tracker with two detections having nonzero |ObjectClassID|s . The detections immediately create confirmed tracks.

```
detections = {objectDetection(1,[10;0],'SensorIndex',1, ...
    'ObjectClassID',5,'ObjectAttributes',{struct('ID',1)}); ...
    objectDetection(1,[0;10],'SensorIndex',1, ...
```

```
     'ObjectClassID',2,'ObjectAttributes',{struct('ID',2)})};
time = 2;
tracks = tracker(detections,time);
```

Find and display the positions and velocities.

```
positionSelector = [1 0 0 0; 0 0 1 0];
velocitySelector = [0 1 0 0; 0 0 0 1];
positions = getTrackPositions(tracks,positionSelector)
velocities = getTrackVelocities(tracks,velocitySelector)


positions =

   10.0000        0
        0   10.0000


velocities =

     0      0
     0      0
```

Definitions

Track Structure

Track information is returned as an array of structures with the following fields:

Field	Description
TrackID	Integer that identifies the track.
BranchID	Unique integer that identifies the track branch (hypothesis).
UpdateTime	Time to which the track is updated.
Age	Number of updates since track initialization.
State	Value of state vector at update time.

StateCovariance	Uncertainty covariance matrix.
TrackLogic	The track logic used. Values are either 'History' or 'Score'.
TrackLogicState	The current state of the track logic. • For 'History' track logic, a 1-by-Q logical array, where Q is the greater of N or R from the confirmation and deletion thresholds. • For 'Score' track logic, a 1-by-2 numerical array in the form: [currentScore, maxScore].
IsConfirmed	True if the track is assumed to be of a real target.
IsCoasted	True if the track has been updated without a detection (predicted).
ObjectClassID	An integer value representing the object classification. Zero is reserved for 'unknown'.
ObjectAttributes	A cell array of cells. Each cell captures the object attributes reported by the corresponding sensor.

Algorithms

Tracker Logic Flow

When you process detections using the tracker, track creation and management follow these steps.

1 The tracker attempts to assign detections to existing tracks.

2 The track allows for multiple hypotheses about the assignment of detections to tracks.

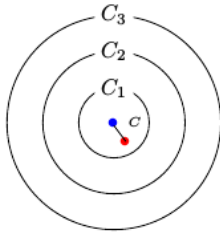3 Unassigned detections result in the creation of new tracks.

4   Assignments of detections to tracks create branches for the assigned tracks.

5   Tracks with no assigned detections are coasted (predicted).

6   All track branches are scored. Branches with low initial scores are pruned.

7   Clusters of branches that share detections (incompatible branches) in their history are generated.

8   Global hypotheses of compatible branches are formulated and scored.

9   Branches are scored based on their existence in the global hypotheses. Low-scored branches are pruned.

10   Additional pruning is performed based on N-scan history.

11   All tracks are corrected and predicted to the input time.

Assignment Thresholds for Multi-Hypothesis Tracker

Three assignment thresholds, C_1 , C_2, and C_3, control (1) the assignment of a detection to a track, (2) the creation of a new branch from a detection, and (3) the creation of a new branch from an unassigned track. The threshold values must satisfy: C_1 <= C_2 <= C_3.

If the cost of an assignment is `C = costmatrix(i,j)`, the following hypotheses are created based on comparing the cost to the values of the assignment thresholds. Below each comparison, there is a list of the possible hypotheses.
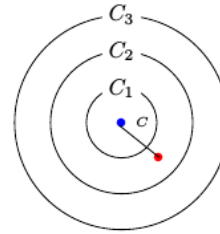
- ● Track
- ● Detection

C_3
C_2
C_1
C

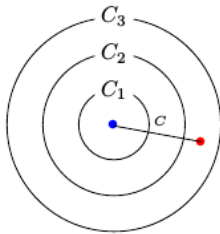$C \leq C_1$

Single Hypothesis

(1) Detection is assigned to track. A branch is created updating the track with this detection.

C_3
C_2
C_1
C

$C_1 < C \leq C_2$

Two Hypotheses

(1) Detection is assigned to track. A branch is created updating the track with this detection.
(2) Track is not assigned to detection and is coasted.

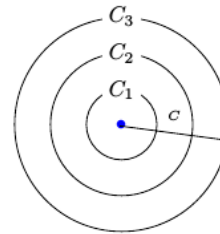C_3
C_2
C_1
C

$C_2 < C \leq C_3$

Three Hypotheses

(1) Detection is assigned to track. A branch is created updating the track with this detection.
(2) Track is not assigned to detection and is coasted.
(3) Detection is not assigned and creates a new track (branch).

C_3
C_2
C_1
C

$C_3 < C$

Single Hypothesis

(1) Detection is not assigned and creates a new track (branch).

Tips:

- Increase the value of C_3 if there are detections that should be assigned to tracks but are not. Decrease the value if there are detections that are assigned to tracks they should not be assigned to (too far away).

3-401

- Increasing the values C_1 and C_2 helps control the number of track branches that are created. However, doing so reduces the number of branches (hypotheses) each track has.
- To allow each track to be unassigned, set $C_1 = 0$.
- To allow each detection to be unassigned, set $C_2 = 0$.

Data Precision

All numeric inputs can be single or double precision, but they all must have the same precision.

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).
- All the detections used with a multi-object tracker must have properties with the same sizes and types.
- If you use the `ObjectAttributes` field within an `objectDetection` object, you must specify this field as a cell containing a structure. The structure for all detections must have the same fields and the values in these fields must always have the same size and type. The form of the structure cannot change during simulation.
- If `ObjectAttributes` are contained in the detection, the `SensorIndex` value of the detection cannot be greater than 10.
- The first update to the multi-object tracker must contain at least one detection.

See Also

Functions
getTrackPositions | getTrackVelocities

Classes
objectDetection | trackingAB | trackingCKF | trackingEKF | trackingGSF |
trackingIMM | trackingKF | trackingMSCEKF | trackingPF | trackingUKF

System Objects
irSensor | monostaticRadarSensor | radarSensor | sonarSensor | trackerGNN

Introduced in R2018b

getTrackFilterProperties

Obtain track filter properties

Syntax

```
filtervalues = getTrackFilterProperties(tracker,branchID,properties)
filtervalues = getTrackFilterProperties(tracker,trackID,properties)
```

Description

`filtervalues = getTrackFilterProperties(tracker,branchID,properties)` returns the values, `filtervalues`, of tracking filter properties, `properties`, for the specified branch, `branchID`.

This syntax applies when you create the tracker using `trackerTOMHT`.

`filtervalues = getTrackFilterProperties(tracker,trackID,properties)` returns the values, `filtervalues`, of tracking filter properties, `properties`, for the specified track, `trackID`.

This syntax applies when you create the tracker using `trackerGNN`.

Examples

Get Multi-Hypothesis Track Filter Properties

Create a track filter with default properties from one detection. Obtain the values of the `MeasurementNoise` and `ProcessNoise` track filter properties.

```
tracker = trackerTOMHT;
detection = objectDetection(0,[0;0;0]);
tracker(detection,0);
branches = getBranches(tracker);
branchID = branches(1).BranchID;
```

```
values = getTrackFilterProperties(tracker, branchID, ...
    'MeasurementNoise', 'ProcessNoise')
disp(values{1})


values =

  2×1 cell array

    {3×3 double}
    {3×3 double}

     1     0     0
     0     1     0
     0     0     1
```

Get Global Nearest-Neighbor Track Filter Properties

Create a track filter from one detection. Assume default properties. Obtain the values of the MeasurementNoise and ProcessNoise track filter properties.

```
tracker = trackerGNN;
detection = objectDetection(0,[0;0;0]);
[~,tracks] = tracker(detection,0);
values = getTrackFilterProperties(tracker,tracks.TrackID, ...
    'MeasurementNoise','ProcessNoise')
disp(values{1})


values =

  2×1 cell array

    {3×3 double}
    {3×3 double}

     1     0     0
     0     1     0
```

```
        0       0       1
```

Input Arguments

`tracker` — Target tracker
`trackerTOMHT` object | `trackerGNN` object

Target tracker, specified as a `trackerTOMHT` or `trackerGNN` object.

`branchID` — Branch identifier
positive integer

Branch identifier, specified as a positive integer. The identifier must be a valid `BranchID` reported in the list of branches returned by the `getBranches` object function.

Example: 21

Dependencies

Data Types: `uint32`

`trackID` — Track identifier
positive integer

Track identifier, specified as a positive integer. `trackID` must be a valid track identifier as reported from the previous track update.

Example: 21

Data Types: `uint32`

`properties` — Filter properties
comma-delimited list of properties

Filter properties, specified as a comma-delimited list of valid tracker properties to obtain. Enclose each property in single quotes.

Example: `'MeasurementNoise','ProcessNoise'`

Data Types: `char`

Output Arguments

`filtervalues` — Filter property values
cell array

Filter property values, returned as a cell array. Filter values are returned in the same order as the list of properties.

Introduced in R2018b

setTrackFilterProperties

Set track filter properties

Syntax

```
setTrackFilterProperties(tracker,branchID,'Name',Value)
setTrackFilterProperties(tracker,trackID,'Name',Value)
```

Description

setTrackFilterProperties(tracker,branchID,'Name',Value) sets the values of tracking filter properties of the tracker, `tracker`, for the branch specified by, `branchID`. Use valid Name-Value pairs to set properties for the branch. You can specify as many Name-Value pairs as you wish. Property names must match the names of public filter properties. This syntax applies when you create the tracker using `trackerTOMHT`.

setTrackFilterProperties(tracker,trackID,'Name',Value) sets the values of tracking filter properties of the tracker, `tracker`, for the track, `trackID`. Use Name-Value pairs to set properties for the track. You can specify as many Name-Value pairs as you wish. Property names must match the names of public filter properties. This syntax applies when you create the tracker using `trackerGNN`.

Examples

Set Multi-Hypothesis Tracking Filter Properties

Create a tracker using `trackerTOMHT`. Assign values to the `MeasurementNoise` and `ProcessNoise` properties and verify the assignment.

```
tracker = trackerTOMHT;
detection = objectDetection(0,[0;0;0]);
tracker(detection,0);
branches = getBranches(tracker);
branchID = branches(1).BranchID;
```

```
setTrackFilterProperties(tracker,branchID,'MeasurementNoise',2,'ProcessNoise',5);
values = getTrackFilterProperties(tracker,branchID,'MeasurementNoise','ProcessNoise');
```

Show the measurement noise.

```
disp(values{1})
```

```
     2     0     0
     0     2     0
     0     0     2
```

Show the process noise.

```
disp(values{2})
```

```
     5     0     0
     0     5     0
     0     0     5
```

Set Global Nearest-Neighbor Track Filter Properties

Create a tracker using `trackerGNN`. Assign values to the `MeasurementNoise` and `ProcessNoise` properties and verify the assignment.

```
tracker = trackerGNN;
detection = objectDetection(0,[0;0;0]);
[~, tracks] = tracker(detection,0);
setTrackFilterProperties(tracker,1,'MeasurementNoise',2,'ProcessNoise',5);
values = getTrackFilterProperties(tracker,1,'MeasurementNoise','ProcessNoise');
```

Show the measurement noise.

```
disp(values{1})
```

```
     2     0     0
     0     2     0
     0     0     2
```

Show the process noise.

```
disp(values{2})
```

```
5      0      0
0      5      0
0      0      5
```

Input Arguments

`tracker` — Target tracker
`trackerTOMHT` object | `trackerGNN` object

Target tracker, specified as a `trackerTOMHT` or `trackerGNN` object.

`branchID` — Branch identifier
positive integer

Branch identifier, specified as a positive integer. The identifier must be a valid `BranchID` reported in the list of branches returned by the `getBranches` object function.

Example: 21

Data Types: `uint32`

`trackID` — Track identifier
positive integer

Track identifier, specified as a positive integer. `trackID` must be a valid track identifier as reported from the previous track update.

Example: 21

Data Types: `uint32`

Introduced in R2018b

getBranches

Lists track branches

Syntax

```
branches = getBranches(tracker)
```

Description

`branches = getBranches(tracker)` returns a list of track `branches` maintained by the `tracker`. The tracker must be updated at least once before calling this object function. Use `isLocked(tracker)` to test whether the tracker has been updated.

Examples

Get Multi-Hypothesis Tracker Branches

Create a multi-hypothesis tracker with one detection and obtain its branches.

```
tracker = trackerTOMHT;
detection = objectDetection(0,[0;0;0]);
tracker(detection,0);
branches = getBranches(tracker)


branches =

  struct with fields:

            TrackID: 1
           BranchID: 1
         UpdateTime: 0
                Age: 1
              State: [6×1 double]
     StateCovariance: [6×6 double]
```

```
        TrackLogic: 'Score'
   TrackLogicState: [13.7102 13.7102]
        IsConfirmed: 0
          IsCoasted: 0
      ObjectClassID: 0
   ObjectAttributes: {}
```

Input Arguments

`tracker` — Target tracker
`trackerTOMHT` object | `trackerGNN` object

Target tracker, specified as a `trackerTOMHT` or `trackerGNN` object.

Output Arguments

`branches` — List of track branches
structure | array of structures

List of track branches, returned as an array of track structure or array of track structures.

Field	Description
`TrackID`	Integer that identifies the track.
`BranchID`	Unique integer that identifies the track branch (hypothesis).
`UpdateTime`	Time to which the track is updated.
`Age`	Number of updates since track initialization.
`State`	Value of state vector at update time.
`StateCovariance`	Uncertainty covariance matrix.
`TrackLogic`	The track logic used. Values are either `'History'` or `'Score'`.

TrackLogicState	The current state of the track logic.
	• For `'History'` track logic, a 1-by-*Q* logical array, where *Q* is the greater of *N* or *R* from the confirmation and deletion thresholds.
	• For `'Score'` track logic, a 1-by-2 numerical array in the form: `[currentScore, maxScore]`.
IsConfirmed	True if the track is assumed to be of a real target.
IsCoasted	True if the track has been updated without a detection (predicted).
ObjectClassID	An integer value representing the object classification. Zero is reserved for `'unknown'`.
ObjectAttributes	A cell array of cells. Each cell captures the object attributes reported by the corresponding sensor.

Data Types: `struct`

Introduced in R2018b

predictTracksToTime

Predict track state

Syntax

```
predictedtracks = predictTracksToTime(tracker,type,id,time)
predictedtracks = predictTracksToTime(tracker,type,category,time)
predictedtracks = predictTracksToTime(tracker,trackid,time)
predictedtracks = predictTracksToTime(tracker,category,time)
```

Description

predictedtracks = predictTracksToTime(tracker,type,id,time) returns the predicted tracks or branches, predictedtracks, of the tracker, tracker, at the specified time, time. Specify the type, type, of tracked object and the object ID, id. The tracker must be updated at least once before calling this object function. Use isLocked(tracker) to test whether the tracker has been updated.

This syntax applies when you create the tracker using trackerTOMHT.

predictedtracks = predictTracksToTime(tracker,type,category,time) returns all predicted tracks or branches for a specified category, category, of track objects.

This syntax applies when you create the tracker using trackerTOMHT.

predictedtracks = predictTracksToTime(tracker,trackid,time) returns the predicted tracks, predictedtracks, of the tracker, tracker, at the specified time, time. Specify the track identifier, trackid. The tracker must be updated at least once before calling this object function. Use isLocked(tracker) to test whether the tracker has been updated.

This syntax applies when you create the tracker using trackerGNN.

predictedtracks = predictTracksToTime(tracker,category,time) returns all predicted tracks for a specified category, category, of track objects.

This syntax applies when you create the tracker using `trackerGNN`.

Examples

Predict Track State

Create a track from a detection and predict its state later on.

```
tracker = trackerTOMHT;
detection = objectDetection(0,[0;0;0]);
tracker(detection,0);
branches = getBranches(tracker);
predictedtracks = predictTracksToTime(tracker,'branch',1,1)
```

```
predictedtracks =

  struct with fields:

             TrackID: 1
            BranchID: 1
          UpdateTime: 1
                 Age: 1
               State: [6×1 double]
      StateCovariance: [6×6 double]
           TrackLogic: 'Score'
      TrackLogicState: [13.7102 13.7102]
          IsConfirmed: 0
            IsCoasted: 0
         ObjectClassID: 0
       ObjectAttributes: {}
```

Input Arguments

`tracker` — Target tracker
`trackerTOMHT` object | `trackerGNN` object

Target tracker, specified as a `trackerTOMHT` or `trackerGNN` object.

type — Tracked object type
`'track'` | `'branch'`

Tracked object type, specified as `'track'` or `'branch'`.

id — Track or branch identifier
positive integer

Track or branch identifier, specified as a positive integer.

Example: 21

Data Types: `single` | `double`

trackid — Track identifier
positive integer

Track, specified as a positive integer.

Example: 15

Data Types: `single` | `double`

time — Prediction time
scalar

Prediction time, specified as a scalar. Tracks states are predicted to this time. The time must be greater than the time input to the tracker in the previous track update. Units are in seconds.

Example: 1.0

Data Types: `single` | `double`

category — Track categories
`'all'` | `'confirmed'` | `'tentative'`

Track categories, specified as `'all'`, `'confirmed'`, or `'tentative'`. You can choose to predict all tracks, only confirmed tracks, or only tentative tracks.

Data Types: `char`

Output Arguments

`predictedtracks` — List of predicted track or branch states
structures | array of structures

List of tracks or branches, returned as an array of track structures.

Field	Description
TrackID	Integer that identifies the track.
BranchID	Unique integer that identifies the track branch (hypothesis).
UpdateTime	Time to which the track is updated.
Age	Number of updates since track initialization.
State	Value of state vector at update time.
StateCovariance	Uncertainty covariance matrix.
TrackLogic	The track logic used. Values are either `'History'` or `'Score'`.
TrackLogicState	The current state of the track logic. • For `'History'` track logic, a 1-by-Q logical array, where Q is the greater of N or R from the confirmation and deletion thresholds. • For `'Score'` track logic, a 1-by-2 numerical array in the form: `[currentScore, maxScore]`.
IsConfirmed	True if the track is assumed to be of a real target.
IsCoasted	True if the track has been updated without a detection (predicted).
ObjectClassID	An integer value representing the object classification. Zero is reserved for `'unknown'`.

ObjectAttributes	A cell array of cells. Each cell captures the object attributes reported by the corresponding sensor.

Data Types: `struct`

Introduced in R2018b

trackerGNN System object

Multi-sensor, multi-object tracker using GNN assignment

Description

The `trackerGNN` System object is a tracker capable of processing detections of many targets from multiple sensors. The tracker uses a global nearest-neighbor (GNN) assignment algorithm. The tracker initializes, confirms, predicts, corrects, and deletes tracks. Inputs to the tracker are detection reports generated by `objectDetection`, `radarSensor`, `monostaticRadarSensor`, `irSensor`, or `sonarSensor` objects. The tracker estimates the state vector and state vector covariance matrix for each track. Each detection is assigned to at least one track. If the detection cannot be assigned to any track, the tracker creates a track.

Any new track starts in a *tentative* state. If enough detections are assigned to a tentative track, its status changes to *confirmed*. If the detection already has a known classification (the `ObjectClassID` field of the returned track is nonzero), that track is confirmed immediately. When a track is confirmed, the tracker considers the track to represent a physical object. If detections are not assign to the track within a specifiable number of updates, the track is deleted. For an overview of how the tracker functions, see "Algorithms" on page 3-399.

To track objects using a this object:

1 Create the `trackerGNN` 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

```
tracker = trackerGNN
```

```
tracker = trackerGNN(Name,Value)
```

Description

`tracker = trackerGNN` creates a `trackerGNN` System object with default property values.

`tracker = trackerGNN(Name,Value)` sets properties for the tracker using one or more name-value pairs. For example,
`trackerGNN('FilterInitializationFcn',@initcvukf,'MaxNumTracks',100)` creates a multi-object tracker that uses a constant-velocity, unscented Kalman filter and allows a maximum of 100 tracks. Enclose each property name in quotes.

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).

FilterInitializationFcn — Filter initialization function
@initcvekf (default) | function handle | character vector

Filter initialization function, specified as a function handle or as a character vector containing the name of a valid filter initialization function. The tracker uses a filter initialization function when creating new tracks.

Sensor Fusion and Tracking Toolbox supplies many initialization functions that you can use to specify `FilterInitializationFcn`.

Initialization Function	Function Definition
initcvabf	Initialize constant-velocity alpha-beta filter
initcaabf	Initialize constant-acceleration alpha-beta filter

Initialization Function	Function Definition
initcvekf	Initialize constant-velocity extended Kalman filter.
initcackf	Initialize constant-acceleration cubature filter.
initctckf	Initialize constant-turn-rate cubature filter.
initcvckf	Initialize constant-velocity cubature filter.
initcapf	Initialize constant-acceleration particle filter.
initctpf	Initialize constant-turn-rate particle filter.
initcvpf	Initialize constant-velocity particle filter.
initcvkf	Initialize constant-velocity linear Kalman filter.
initcvukf	Initialize constant-velocity unscented Kalman filter.
initcaekf	Initialize constant-acceleration extended Kalman filter.
initcakf	Initialize constant-acceleration linear Kalman filter.
initcaukf	Initialize constant-acceleration unscented Kalman filter.
initctekf	Initialize constant-turn-rate extended Kalman filter.
initctukf	Initialize constant-turn-rate unscented Kalman filter.
initcvmscekf	Initialize constant-velocity modified spherical coordinates extended Kalman filter.
initrpekf	Initialize constant-velocity range-parametrized extended Kalman filter.
initapekf	Initialize constant-velocity angle-parametrized extended Kalman filter.
initekfimm	Initialize tracking IMM filter.

You can also write your own initialization function. The function must have the following syntax:

```
filter = filterInitializationFcn(detection)
```

The input to this function is a detection report like those created by `objectDetection`. The output of this function must be an object belonging to one of the filter classes: `trackingKF`, `trackingEKF`, `trackingUKF`, `trackingCKF`, `trackingPF`, `trackingMSCEKF`, `trackingGSF`, `trackingIMM`, or `trackingAB`.

To guide you in writing this function, you can examine the details of the supplied functions from within MATLAB. For example:

```
type initcvekf
```

Data Types: `function_handle` | `char`

Assignment — Assignment algorithm
`'Munkres'` (default) | `'Jonker-Volgenant'` | `'Auction'` | `'Custom'`

Assignment algorithm, specified as `'Munkres'`, `'Jonker-Volgenant'`, `'Auction'`, or `'Custom'`. Munkres is the only assignment algorithm that guarantees an optimal solution, but it is also the slowest, especially for large numbers of detections and tracks. The other algorithms do not guarantee an optimal solution but can be faster for problems with 20 or more tracks and detections. Use `'Custom'` to define your own assignment function and specify its name in the `CustomAssignmentFcn` property.

Example: `'Custom'`

Data Types: `char`

CustomAssignmentFcn — Custom assignment function
character vector

Custom assignment function name, specified as a character string. An assignment function must have the following syntax:

```
 [assignment,unTrs,unDets] = f(cost,costNonAssignment)
```

For an example of an assignment function and a description of its arguments, see `assignmunkres`.

Dependencies

To enable this property, set the `Assignment` property to `'Custom'`.

Data Types: `char`

AssignmentThreshold — Detection assignment threshold
30 (default) | positive scalar

Detection assignment threshold, specified as a positive scalar. The threshold controls the assignment of a detection to a track. Detections can only be assigned to a track if their normalized distance from the track is less than the assignment threshold. Look at the `distance` method of a tracking filter for a discussion of the distance calculation. Increase the threshold if there are detections that should be assigned to tracks but are not. Decrease the value if there are detections that are assigned to tracks that they should not be assigned to.

Data Types: `single` | `double`

TrackLogic — Confirmation and deletion logic type
`'History'` (default) | `'Score'`

Confirmation and deletion logic type, specified as `'History'` or `'Score'`.

- `'History'` – Track confirmation and deletion is based on the number of times the track has been assigned to a detection in the latest tracker updates.

- `'Score'` – Track confirmation and deletion is based on a log-likelihood track score. A high score means that the track is more likely to be valid. A low score means that the track is more likely to be a false alarm.

ConfirmationThreshold — Threshold for track confirmation
scalar | 1-by-2 vector

Threshold for track confirmation, specified as a scalar or a 1-by-2 vector. The threshold depends on the type of track confirmation and deletion logic you set using the `TrackLogic` property.

- History – Specify the confirmation threshold as 1-by-2 vector `[M N]`. A track is confirmed if it receives at least `M` detections in the last `N` updates. The default value is `[2,3]`.

- Score – Specify the confirmation threshold as a scalar. A track is confirmed if its score is at least as high as the confirmation threshold. The default value is `20`.

Data Types: `single` | `double`

DeletionThreshold — Minimum score required to delete track
[5 5] or -7 (default) | scalar | real-valued 1-by-2 vector of positive values

Minimum score required to delete track, specified as a scalar or a real-valued 1-by-2 vector. The threshold depends on the type of track confirmation and deletion logic you set using the TrackLogic property:

- History – Specify the confirmation threshold as [P R]. A track is deleted if, in the last R updates, it was assigned less than P detections.
- Score – A track is deleted if its score decreases by at least the threshold from the maximum track score.

Example: 3

Data Types: single | double

DetectionProbability — Probability of detection used for track score
0.9 (default) | positive scalar between 0 and 1

Probability of detection, specified as a positive scalar between 0 and 1. This property is used to compute track score.

Example: 0.5

Data Types: single | double

FalseAlarmRate — Probability of false alarm used for track score
1e-6 (default) | scalar

The probability of false alarm, specified as a scalar. This property is used to compute track score.

Example: 1e-5

Data Types: single | double

Beta — Rate of new tracks per unit volume
1 (default) | positive scalar

The rate of new tracks per unit volume, specified as a positive scalar. The rate of new tracks is used in calculating the track score during track initialization.

Example: 2.5

Data Types: single | double

Volume — Volume of sensor measurement bin
1 (default) | positive scalar

The volume of a sensor measurement bin, specified as a positive scalar. For example, if a radar produces a 4-D measurement, which includes azimuth, elevation, range, and range rate, the 4-D volume is defined by the radar angular beam width, the range bin width and the range-rate bin width. Volume is used in calculating the track score when initializing and updating a track.

Example: 1.5

Data Types: `single` | `double`

MaxNumTracks — Maximum number of tracks
100 (default) | positive integer

Maximum number of tracks that the tracker can maintain, specified as a positive integer.

Data Types: `single` | `double`

MaxNumSensors — Maximum number of sensors
20 (default) | positive integer

Maximum number of sensors that can be connected to the tracker, specified as a positive integer. `MaxNumSensors` must be greater than or equal to the largest value of `SensorIndex` found in all the detections used to update the tracker. `SensorIndex` is a property of an `objectDetection` object. The `MaxNumSensors` property determines how many sets of `ObjectAttributes` fields each output track can have.

Data Types: `single` | `double`

HasDetectableTrackIDsInput — Enable input of detectable track IDs
false (default) | true

Enable the input of detectable track IDs at each object update, specified as `false` or `true`. Set this property to `true` if you want to provide a list of detectable track IDs. This list tells the tracker of all tracks that the sensors are expected to detect and, optionally, the probability of detection for each track.

Data Types: `logical`

HasCostMatrixInput — Enable cost matrix input
false (default) | true

Enable a cost matrix, specified as `false` or `true`. If `true`, you can provide an assignment cost matrix as an input argument at object update time.

Data Types: `logical`

`NumTracks` — Number of tracks maintained by tracker
nonnegative integer

This property is read-only.

Number of tracks maintained by the tracker, returned as a nonnegative integer.

Data Types: `double`

`NumConfirmedTracks` — Number of confirmed tracks
nonnegative integer

This property is read-only.

Number of confirmed tracks, returned as a nonnegative integer. If the `IsConfirmed` field of an output track structure is `true`, the track is confirmed.

Data Types: `double`

Usage

To process detections and update tracks, call the tracker with arguments, as if it were a function (described here).

Syntax

```
confirmedTracks = tracker(detections,time)
confirmedTracks = tracker(detections,time,costMatrix)
confirmedTracks = tracker(___,detectableTrackIDs)
[confirmedTracks,tentativeTracks,allTracks] = tracker(___)
[___,analysisInformation] = tracker(___)
```

Description

confirmedTracks = tracker(detections,time) returns a list of confirmed tracks that are updated from a list of detections, detections, at the update time, time. Confirmed tracks are corrected and predicted to the update time.

confirmedTracks = tracker(detections,time,costMatrix) also specifies a cost matrix, costMatrix.

To enable this syntax, set the HasCostMatrixInput property to true.

confirmedTracks = tracker(___ ,detectableTrackIDs) also specifies a list of expected detectable tracks, detectableTrackIDs.

To enable this syntax, set the HasDetectableTrackIDsInput property to true.

[confirmedTracks,tentativeTracks,allTracks] = tracker(___) also returns a list of tentative tracks, tentativeTracks, and a list of all tracks, allTracks.

[___ ,analysisInformation] = tracker(___) also returns information, analysisInformation, which can be used for track analysis.

Input Arguments

detections — Detection list
cell array of objectDetection objects

Detection list, specified as a cell array of objectDetection objects. The Time property value of each objectDetection object must be less than or equal to the current update time, time, and greater than the previous time value used to update the tracker.

time — Time of update
scalar

Time of update, specified as a scalar. The tracker updates all tracks to this time. Units are in seconds.

time must be greater than or equal to the largest Time property value of the objectDetection objects in the input detections list. time must increase in value with each update to the tracker.

Data Types: single | double

costMatrix — Cost matrix
real-valued *N*-by-*M* matrix

Cost matrix, specified as a real-valued *N*-by-*M* matrix, where *N* is the number of existing tracks, and *M* is the number of current detections. The cost matrix rows must be in the same order as the list of tracks. The columns must be in the same order as the list of detections. Obtain the correct order of the list of tracks from the third output argument, `allTracks`, when is the tracker is updated.

At the first update of the object or when the tracker has no previous tracks, specify the cost matrix to have a size of `[0,numDetections]`. Note that the cost must be calculated so that lower costs indicate a higher likelihood of assigning a detection to a track. To prevent certain detections from being assigned to certain tracks, set the appropriate cost matrix entry to `Inf`.

Dependencies

To enable this argument, set the `HasCostMatrixInput` property to `true`.

Data Types: `double` | `single`

detectableTrackIDs — Detectable track IDs
real-valued *M*-by-1 vector | real-valued *M*-by-2 matrix

Detectable branch IDs, specified as a real-valued *M*-by-1 vector or *M*-by-2 matrix. Detectable tracks are tracks that the sensors expect to detect. The first column of the matrix contains a list of track IDs that the sensors report as detectable. The second column contains the detection probability for the track. The detection probability is either reported by a sensor or, if not reported, obtained from the `DetectionProbability` property.

Tracks whose identifiers are not included in `detectableTrackIDs` are considered as undetectable. The track deletion logic does not count the lack of detection as a 'missed detection' for track deletion purposes.

Dependencies

To enable this input argument, set the `detectableTrackIDs` property to `true`.

Data Types: `single` | `double`

Output Arguments

`confirmedTracks` — Confirmed tracks
structure | array of structures

Confirmed tracks, returned as a structure or array of structures. Each structure corresponds to a track. A track is confirmed if its score is greater than the confirmation threshold specified in the `ConfirmationThreshold` property. In that case, the `IsConfirmed` field of the structure is `true`. The fields of the structure are defined in "Track Structure" on page 3-432.

Data Types: `struct`

`tentativeTracks` — Tentative tracks
structure | array of structures

Tentative tracks, returned as a structure or array of structures. Each structure corresponds to a track. A track is tentative if its score is less than or equal to the confirmation threshold specified in the `ConfirmationThreshold` property. In that case, the `IsConfirmed` field of the structure is `false`. The fields of the structure are defined in "Track Structure" on page 3-432.

Data Types: `struct`

`allTracks` — All tracks
structure

All tracks, returned as a structure or array of structures. Each structure corresponds to a track. The set of all tracks consists of confirmed and tentative tracks. The fields of the structure are defined in "Track Structure" on page 3-432.

Data Types: `struct`

`analysisInformation` — Additional information for analyzing track updates
structure

Additional information for analyzing track updates, returned as a structure. The fields of this structure are:

Field	Description
`TrackIDsAtStepBeginning`	Track IDs when step began

CostMatrix	Cost of assignment matrix
Assignments	Assignments returned from `assignTOMHT`
UnassignedTracks	IDs of unassigned tracks returned from the tracker
UnassignedDetections	IDs of unassigned detections returned from `trackerGNN`
InitiatedTrackIDs	IDs of tracks initiated during the step
DeletedTrackIDs	IDs of tracks deleted during the step
TrackIDsAtStepEnd	Track IDs when the step ended

Data Types: `struct`

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 `trackerGNN`

getTrackFilterProperties   Obtain track filter properties
setTrackFilterProperties   Set track filter properties
predictTrackToTime   Predict track state

Common to All System Objects

release   Release resources and allow changes to System object property values and input characteristics
reset   Reset internal states of System object
isLocked   Determine if System object is in use
clone   Create duplicate System object

Examples

Track Two Objects Using trackerGNN

Construct a `trackerGNN` object with the default 2-D constant-velocity Kalman filter initialization function, `initcvkf`.

```
tracker = trackerGNN('FilterInitializationFcn', @initcvkf, ...
    'ConfirmationThreshold', [4 5], ...
    'DeletionThreshold', 10);
```

Update the tracker with two detections both having nonzero `ObjectClassID`. These detections immediately create confirmed tracks.

```
detections = {objectDetection(1,[10;0],'SensorIndex',1, ...
    'ObjectClassID',5,'ObjectAttributes',{struct('ID',1)}); ...
    objectDetection(1,[0;10],'SensorIndex',1, ...
    'ObjectClassID',2,'ObjectAttributes',{struct('ID',2)})};
time = 2;
tracks = tracker(detections,time);
```

Find the positions and velocities.

```
positionSelector = [1 0 0 0; 0 0 1 0];
velocitySelector = [0 1 0 0; 0 0 0 1];

positions = getTrackPositions(tracks,positionSelector)
velocities = getTrackVelocities(tracks,velocitySelector)


positions =

    10     0
     0    10


velocities =

     0     0
```

```
     0     0
```

Definitions

Track Structure

Track information is returned as an array of structures having the following fields:

Field	Description
TrackID	Integer that identifies the track.
BranchID	Unique integer that identifies the track branch (hypothesis).
UpdateTime	Time to which the track is updated.
Age	Number of updates since track initialization.
State	Value of state vector at update time.
StateCovariance	Uncertainty covariance matrix.
TrackLogic	The track logic used. Values are either 'History' or 'Score'.
TrackLogicState	The current state of the track logic. • For 'History' track logic, a 1-by-Q logical array, where Q is the greater of N or R from the confirmation and deletion thresholds. • For 'Score' track logic, a 1-by-2 numerical array in the form: [currentScore, maxScore].
IsConfirmed	True if the track is assumed to be of a real target.
IsCoasted	True if the track has been updated without a detection (predicted).

ObjectClassID	An integer value representing the object classification. Zero is reserved for `'unknown'`.
ObjectAttributes	A cell array of cells. Each cell captures the object attributes reported by the corresponding sensor.

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).

- All the detections used with a multi-object tracker must have properties with the same sizes and types.

- If you use the `ObjectAttributes` field within an `objectDetection` object, you must specify this field as a cell containing a structure. The structure for all detections must have the same fields, and the values in these fields must always have the same size and type. The form of the structure cannot change during simulation.

- If `ObjectAttributes` are contained in the detection, the `SensorIndex` value of the detection cannot be greater than 10.

- The first update to the multi-object tracker must contain at least one detection.

See Also

Functions
assignTOMHT | assignauction | assignjv | assignkbest | assignkbestsd | assignmunkres | assignsd | clusterTrackBranches | compatibleTrackBranches | fusecovint | fusecovunion | fusexcov | getTrackPositions | getTrackVelocities | pruneTrackBranches | triangulateLOS

Classes
objectDetection | trackHistoryLogic | trackScoreLogic | trackingABF |
trackingCKF | trackingEKF | trackingGSF | trackingIMM | trackingKF |
trackingMSCEKF | trackingPF | trackingUKF

System Objects
monostaticRadarSensor | staticDetectionFuser | trackBranchHistory |
trackerTOMHT

Introduced in R2018b

poseTrajectory System object

Pose trajectory generator

Description

`poseTrajectory` System object creates a trajectory starting from an initial pose. Execute the object to obtain the pose at each time step.

The object supports single and double data types for property values. If the value for a name-value pair is a single, then all of the properties and outputs from the object are converted to the single data type. Otherwise, the double data type is used. Data types cannot be changed after the object has been created.

To obtain trajectory points:

1   Create the `poseTrajectory` 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

```
trajectory = poseTrajectory()
trajectory = poseTrajectory(Name,Value)
```

Description

`trajectory = poseTrajectory()` creates a pose trajectory object with default property values.

`trajectory = poseTrajectory(Name,Value)` sets properties using one or more name-value pairs. For example, `traj = poseTrajectory('SampleRate',`

2,'Position',[100 500 2000]) creates a pose trajectory that reports trajectory values every ½ second and has an initial position of (100,500,2000) meters in the scenario coordinate system. Enclose each property name in quotes.

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).

SampleRate — Sampling frequency of trajectory
100 (default) | positive scalar

Sample rate of trajectory, specified as a positive scalar. This property is tunable. Units are in hertz.

Example: 250

Data Types: single | double

Position — Initial position of platform in scenario frame
[0 0 0] (default) | 1-by-3 real-valued vector

Initial position of platform in the scenario frame, specified as a 1-by-3 real-valued vector. This property is tunable. Units are in meters.

Example: [100 500 2000]

Data Types: single | double

Velocity — Initial velocity of platform in scenario frame
[0 0 0] (default) | 1-by-3 real-valued vector

Initial velocity of platform in the scenario frame, specified as a 1-by-3 real-valued vector. This property is tunable. Units are in meters per second.

Example: [100 500 2000]

Data Types: `single` | `double`

Acceleration — Acceleration of platform in body frame
[0 0 0] (default) | 1-by-3 real-valued vector

Acceleration of platform in the body frame, specified as a 1-by-3 real-valued vector. This property is tunable. Units are in meters per second squared.

Example: [1 0.50 0.12]

Data Types: `single` | `double`

AngularVelocity — Angular velocity of platform in body frame
[0 0 0] (default) | 1-by-3 real-valued vector

Angular velocity of platform in the body frame, specified as a 1-by-3 real-valued vector. This property is tunable. Units are in radians per second.

Data Types: `single` | `double`

Usage

Syntax

```
[pos,orient,vel,acc,angvel] = trajectory()
```

Description

`[pos,orient,vel,acc,angvel] = trajectory()` returns the pose of a platform at its current trajectory point.

- `pos` – current position
- `orient` – orientation
- `vel` – velocity
- `acc` – acceleration
- `angvel` – angular velocity

3-437

Output Arguments

pos — position of platform in scenario frame
1-by-3 real-valued vector

Position of platform in scenario coordinates, returned as a 1-by-3 real-valued vector. Units are in meters.

Data Types: `single` | `double`

orient — Orientation of platform in scenario coordinates
quaternion | 3-by-3 real-valued orthogonal matrix

Orientation of body frame, returned as a quaternion or 3-by-3 real-valued orthogonal matrix. The orientation rotates the scenario frame into the body frame. Units are dimensionless.

Data Types: `single` | `double`

vel — Velocity of platform in scenario frame
1-by-3 real-valued vector

Velocity of platform in scenario frame, returned as a 1-by-3 real-valued vector. Units are in meters per second.

Data Types: `single` | `double`

acc — Acceleration of platform in body frame
1-by-3 real-valued vector

Acceleration of platform in body frame, returned as a 1-by-3 real-valued vector. Units are in meters per second squared.

Data Types: `single` | `double`

angvel — Angular velocity in body frame
[0 0 0] (default) | 1-by-3 real-valued vector

Angular velocity of body frame, returned as a 1-by-3 real-valued vector. Units are in radians per second.

Data Types: `single` | `double`

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)
```

Examples

Create Circular Trajectory

Create a trajectory that follows a circle. Set the number of trajectory points to 500. To follow a circular trajectory, the platform must accelerate.

```
N = 500;
fs = 1;
```

Set the initial conditions for the object motion. Place the object on the x-axis 100 meters from the origin in scenario coordinates. Set the velocity of the body to 2.5 m/s along the y-axis.

```
r = 100;
speed = 2.5;
initPos = [r,0,0];
velBody = [0,speed,0];
```

Orient the body along the direction of motion. Apply an acceleration orthogonal to the body in the xy-plane. Acceleration is always in the body frame. Rotate the body as it moves by an angular rotation rate equal to the rotation rate around the origin.
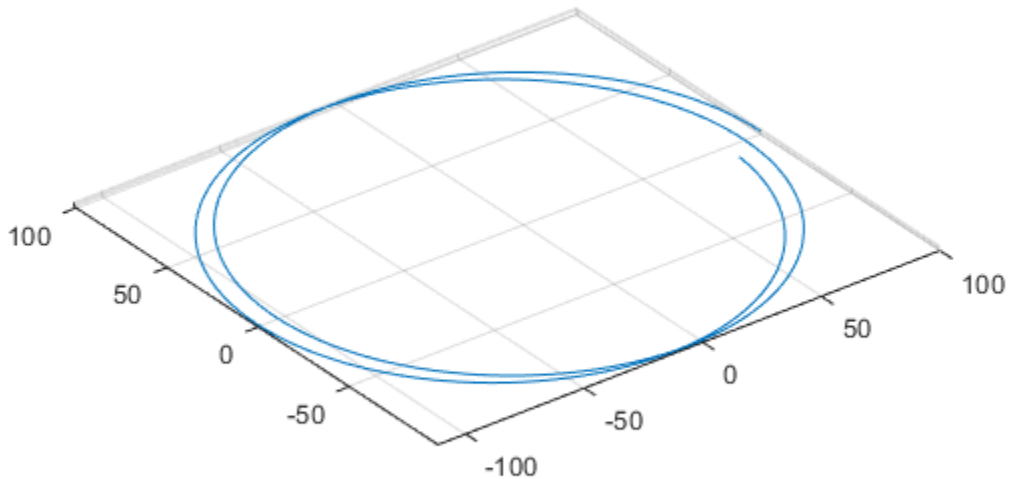
```
accmag = speed^2/r;
initialYaw = deg2rad(90);
initPos = [r,0,0];
velBody = [0,speed,0];
accBody = [0,accmag,0];
initAtt = quaternion([initialYaw, 0, 0],'euler','ZYX', 'frame');
traj = kinematicTrajectory('SampleRate',fs,'Position',initPos, ...
    'Velocity',velBody,'Orientation',initAtt);

pos = zeros(N, 3);
for i = 1:N
```

```
        pos(i,:) = traj(accBody,[0 0 speed/r]);
end
```

Plot the trajectory.

```
plot3(pos(:,1), pos(:,2), pos(:,3))
grid
axis equal
```


See Also

Classes
trackingScenario

System Objects
kinematicTrajectory | waypointTrajectory

Introduced in R2018b

imuSensor System object

IMU simulation model

Description

The `imuSensor` System object models receiving data from an inertial measurement unit (IMU).

To model an IMU:

1 Create the `imuSensor` 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

```
IMU = imuSensor
IMU = imuSensor('accel-gyro')
IMU = imuSensor('accel-mag')
IMU = imuSensor('accel-gyro-mag')
IMU = imuSensor( ___ ,Name,Value)
```

Description

`IMU = imuSensor` returns a System object, `IMU`, that computes an inertial measurement unit reading based on an inertial input signal. `IMU` has an ideal accelerometer and gyroscope.

IMU = imuSensor('accel-gyro') returns an imuSensor System object with an ideal accelerator and gyroscope. imuSensor and imuSensor('accel-gyro') are equivalent creation syntaxes.

IMU = imuSensor('accel-mag') returns an imuSensor System object with an ideal accelerator and magnetometer.

IMU = imuSensor('accel-gyro-mag') returns an imuSensor System object with an ideal accelerator, gyroscope, and magnetometer.

IMU = imuSensor(___ ,Name,Value) sets each property Name to the specified Value. Unspecified properties have default values. This syntax can be used in combination with any of the previous input arguments.

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).

IMUType — Type of inertial measurement unit
'accel-gyro' (default) | 'accel-mag' | 'accel-gyro-mag'

Type of inertial measurement unit, specified as a 'accel-gyro', 'accel-mag', or 'accel-gyro-mag'.

The type of inertial measurement unit specifies which sensor readings to model:

- 'accel-gyro' –– Accelerometer and gyroscope
- 'accel-mag' –– Accelerometer and magnetometer
- 'accel-gyro-mag' –– Accelerometer, gyroscope, and magnetometer

You can specify IMUType as a value-only argument during creation or as a Name,Value pair.

Data Types: char | string

SampleRate — Sample rate of sensor (Hz)
100 (default) | positive scalar

Sample rate of the sensor model in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Temperature — Temperature of IMU (ºC)
25 (default) | real scalar

Operating temperature of the IMU in degrees Celsius, specified as a real scalar.

Tunable: Yes

Data Types: `single` | `double`

MagneticField — Magnetic field vector in local NED coordinate system (µT)
`[27.5550 -2.4169 -16.0849]` (default) | real scalar

Magnetic field vector in microtesla, specified as a three-element row vector in the local NED coordinate system.

The default magnetic field corresponds to the magnetic field at latitude zero, longitude zero, and altitude zero.

Tunable: Yes

Data Types: `single` | `double`

Accelerometer — Accelerometer sensor parameters
`accelparams` object (default)

Accelerometer sensor parameters, specified by an `accelparams` object.

Tunable: Yes

Gyroscope — Gyroscope sensor parameters
`gyroparams` object (default)

Gyroscope sensor parameters, specified by a `gyroparams` object.

Tunable: Yes

Magnetometer — Magnetometer sensor parameters
`magparams` object (default)

Magnetometer sensor parameters, specified by a `magparams` object.

Tunable: Yes

RandomStream — Random number source
`'Global stream'` (default) | `'mt19937ar with seed'`

Random number source, specified as a character vector or string:

- `'Global stream'` –– Random numbers are generated using the current global random number stream.
- `'mt19937ar with seed'` –– Random numbers are generated using the mt19937ar algorithm with the seed specified by the `Seed` property.

Data Types: `char` | `string`

Seed — Initial seed
67 (default) | nonnegative integer scalar

Initial seed of an mt19937ar random number generator algorithm, specified as a real, nonnegative integer scalar.

Dependencies

To enable this property, set `RandomStream` to `'mt19937ar with seed'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Usage

Syntax

```
[accelReadings,gyroReadings] = IMU(acc,angVel)
[accelReadings,gyroReadings] = IMU(acc,angVel,orientation)

[accelReadings,magReadings] = IMU(acc,angVel)
[accelReadings,magReadings] = IMU(acc,angVel,orientation)

[accelReadings,gyroReadings,magReadings] = IMU(acc,angVel)
```

```
[accelReadings,gyroReadings,magReadings] = IMU(acc,angVel,
orientation)
```

Description

`[accelReadings,gyroReadings] = IMU(acc,angVel)` generates accelerometer and gyroscope readings from the acceleration and angular velocity inputs.

This syntax is only valid if `IMUType` is set to `'accel-gyro'` or `'accel-gyro-mag'`.

`[accelReadings,gyroReadings] = IMU(acc,angVel,orientation)` generates accelerometer and gyroscope readings from the acceleration, angular velocity, and orientation inputs.

This syntax is only valid if `IMUType` is set to `'accel-gyro'` or `'accel-gyro-mag'`.

`[accelReadings,magReadings] = IMU(acc,angVel)` generates accelerometer and magnetometer readings from the acceleration and angular velocity inputs.

This syntax is only valid if `IMUType` is set to `'accel-mag'`.

`[accelReadings,magReadings] = IMU(acc,angVel,orientation)` generates accelerometer and magnetometer readings from the acceleration, angular velocity, and orientation inputs.

This syntax is only valid if `IMUType` is set to `'accel-mag'`.

`[accelReadings,gyroReadings,magReadings] = IMU(acc,angVel)` generates accelerometer, gyroscope, and magnetometer readings from the acceleration and angular velocity inputs.

This syntax is only valid if `IMUType` is set to `'accel-gyro-mag'`.

`[accelReadings,gyroReadings,magReadings] = IMU(acc,angVel,orientation)` generates accelerometer, gyroscope, and magnetometer readings from the acceleration, angular velocity, and orientation inputs.

This syntax is only valid if `IMUType` is set to `'accel-gyro-mag'`.

Input Arguments

acc — Acceleration of IMU in local NED coordinate system (m/s²)
N-by-3 matrix

Acceleration of the IMU in the local NED coordinate system, specified as a real, finite *N*-by-3 array in meters per second squared. *N* is the number of samples in the current frame.

Data Types: `single` | `double`

angVel — Angular velocity of IMU in local NED coordinate system (rad/s)
N-by-3 matrix

Angular velocity of the IMU in the local NED coordinate system, specified as a real, finite *N*-by-3 array in radians per second. *N* is the number of samples in the current frame.

Data Types: `single` | `double`

orientation — Orientation of IMU in local NED coordinate system
N-element quaternion column vector | 3-by-3-by-*N*-element rotation matrix

Orientation of the IMU with respect to the local NED coordinate system, specified as a `quaternion` *N*-element column vector or a 3-by-3-by-*N* rotation matrix. Each `quaternion` or rotation matrix represents a frame rotation from the local NED coordinate system to the current IMU sensor body coordinate system. *N* is the number of samples in the current frame.

Data Types: `single` | `double` | `quaternion`

Output Arguments

accelReadings — Accelerometer measurement of IMU in sensor body coordinate system (m/s²)
N-by-3 matrix

Accelerator measurement of the IMU in the sensor body coordinate system, specified as a real, finite *N*-by-3 array in meters per second squared. *N* is the number of samples in the current frame.

Data Types: `single` | `double`

gyroReadings — Gyroscope measurement of IMU in sensor body coordinate system (rad/s)
N-by-3 matrix

Gyroscope measurement of the IMU in the sensor body coordinate system, specified as a real, finite *N*-by-3 array in radians per second. *N* is the number of samples in the current frame.

Data Types: `single` | `double`

magReadings — Magnetometer measurement of IMU in sensor body coordinate system (μT)
N-by-3 matrix (default)

Magnetometer measurement of the IMU in the sensor body coordinate system, specified as a real, finite *N*-by-3 array in microtelsa. *N* is the number of samples in the current frame.

Data Types: `single` | `double`

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

Create Default `imuSensor` System object

The `imuSensor` System object™ enables you to model the data received from an inertial measurement unit consisting of a combination of gyroscope, accelerometer, and magnetometer.

Create a default `imuSensor` object.

```
IMU = imuSensor
```

```
IMU =

  imuSensor with properties:

          IMUType: 'accel-gyro'
       SampleRate: 100
      Temperature: 25
    Accelerometer: [1x1 accelparams]
         Gyroscope: [1x1 gyroparams]
     RandomStream: 'Global stream'
```

The `imuSensor` object, `IMU`, contains an idealized gyroscope and accelerometer. Use dot notation to view properties of the gyroscope.

```
IMU.Gyroscope
```

```
ans =

  gyroparams with properties:

    MeasurementRange: Inf        rad/s
          Resolution: 0          (rad/s)/LSB
        ConstantBias: [0 0 0]    rad/s
    AxesMisalignment: [0 0 0]    %

        NoiseDensity: [0 0 0]    (rad/s)/√Hz
    BiasInstability: [0 0 0]    rad/s
          RandomWalk: [0 0 0]    (rad/s)*√Hz

            TemperatureBias: [0 0 0]    (rad/s)/°C
    TemperatureScaleFactor: [0 0 0]    %/°C
```

3-449

```
        AccelerationBias: [0 0 0]    (rad/s)/(m/s²)
```

Sensor properties are defined by corresponding parameter objects. For example, the gyroscope model used by the `imuSensor` is defined by an instance of the `gyroparams` class. You can modify properties of the gyroscope model using dot notation. Set the gyroscope measurement range to 4.3 rad/s.

```
IMU.Gyroscope.MeasurementRange = 4.3;
```

You can also set sensor properties to preset parameter objects. Create an `accelparams` object to mimic specific hardware, and then set the IMU `Accelerometer` property to the `accelparams` object. Display the `Accelerometer` property to verify the properties are correctly set.

```
SpecSheet1 = accelparams( ...
    'MeasurementRange',19.62, ...
    'Resolution',0.00059875, ...
    'ConstantBias',0.4905, ...
    'AxesMisalignment',2, ...
    'NoiseDensity',0.003924, ...
    'BiasInstability',0, ...
    'TemperatureBias', [0.34335 0.34335 0.5886], ...
    'TemperatureScaleFactor', 0.02);

IMU.Accelerometer = SpecSheet1;

IMU.Accelerometer


ans =

  accelparams with properties:

    MeasurementRange: 19.62                          m/s²
          Resolution: 0.00059875                     (m/s²)/LSB
        ConstantBias: [0.4905 0.4905 0.4905]    m/s²
    AxesMisalignment: [2 2 2]                        %

        NoiseDensity: [0.003924 0.003924 0.003924]    (m/s²)/√Hz
     BiasInstability: [0 0 0]                         m/s²
          RandomWalk: [0 0 0]                         (m/s²)*√Hz

            TemperatureBias: [0.34335 0.34335 0.5886]    (m/s²)/°C
```

```
      TemperatureScaleFactor: [0.02 0.02 0.02]              %/°C
```

Generate Ideal IMU Data from Stationary Input

Use the `imuSensor` System object™ to model receiving data from a stationary ideal IMU containing an accelerometer, gyroscope, and magnetometer.

Create an ideal IMU sensor model that contains an accelerometer, gyroscope, and magnetometer.

```
IMU = imuSensor('accel-gyro-mag')
```

```
IMU =

  imuSensor with properties:

           IMUType: 'accel-gyro-mag'
        SampleRate: 100
       Temperature: 25
     MagneticField: [27.5550 -2.4169 -16.0849]
     Accelerometer: [1x1 accelparams]
         Gyroscope: [1x1 gyroparams]
       Magnetometer: [1x1 magparams]
      RandomStream: 'Global stream'
```

Define the ground-truth, underlying motion of the IMU you are modeling. The acceleration and angular velocity are defined relative to the local NED coordinate system.

```
numSamples = 1000;
acceleration = zeros(numSamples,3);
angularVelocity = zeros(numSamples,3);
```

Call `IMU` with the ground-truth acceleration and angular velocity. The object outputs accelerometer readings, gyroscope readings, and magnetometer readings, as modeled by the properties of the `imuSensor` System object. The accelerometer readings, gyroscope readings, and magnetometer readings are relative to the IMU sensor body coordinate system.

```
[accelReading,gyroReading,magReading] = IMU(acceleration,angularVelocity);
```

3-451

Plot the accelerometer readings, gyroscope readings, and magnetometer readings.

```
t = (0:(numSamples-1))/IMU.SampleRate;
subplot(3,1,1)
plot(t,accelReading)
legend('X-axis','Y-axis','Z-axis')
title('Accelerometer Readings')
ylabel('Acceleration (m/s^2)')

subplot(3,1,2)
plot(t,gyroReading)
legend('X-axis','Y-axis','Z-axis')
title('Gyroscope Readings')
ylabel('Angular Velocity (rad/s)')

subplot(3,1,3)
plot(t,magReading)
legend('X-axis','Y-axis','Z-axis')
title('Magnetometer Readings')
xlabel('Time (s)')
ylabel('Magnetic Field (uT)')
```
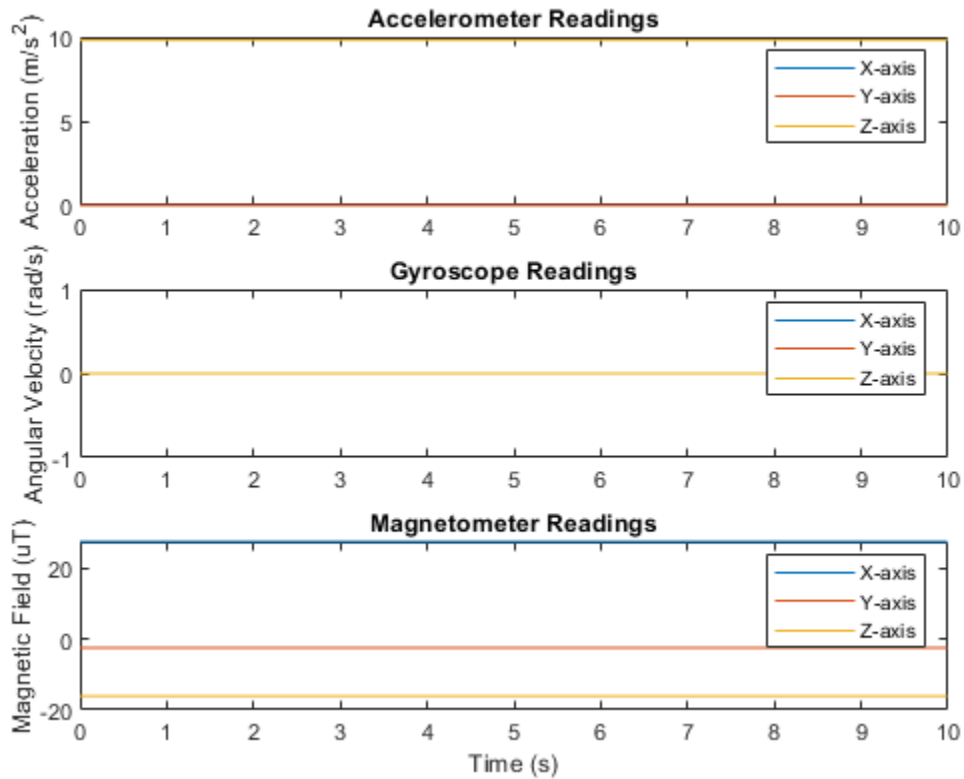
Orientation is not specified and the ground-truth motion is stationary, so the IMU sensor body coordinate system and the local NED coordinate system overlap for the entire simulation.

- Accelerometer readings: The *z*-axis of the sensor body corresponds to the Down-axis. The 9.8 m/s^2 acceleration along the *z*-axis is due to gravity.

- Gyroscope readings: The gyroscope readings are zero along each axis, as expected.

- Magnetometer readings: Because the sensor body coordinate system is aligned with the local NED coordinate system, the magnetometer readings correspond to the

MagneticField property of `imuSensor`. The MagneticField property is defined in the local NED coordinate system.

Model Rotating Six-Axis IMU Data

Use `imuSensor` to model data obtained from a rotating IMU containing an ideal accelerometer and an ideal magnetometer. Use `kinematicTrajectory` to define the ground-truth motion. Fuse the `imuSensor` model output using the `ecompass` function to determine orientation over time.

Define the ground-truth motion for a platform that rotates 360 degrees in four seconds, and then another 360 degrees in two seconds. Use `kinematicTrajectory` to output the orientation, acceleration, and angular velocity in the NED coordinate system.

```
fs = 100;
firstLoopNumSamples = fs*4;
secondLoopNumSamples = fs*2;
totalNumSamples = firstLoopNumSamples + secondLoopNumSamples;

traj = kinematicTrajectory('SampleRate',fs);

accBody = zeros(totalNumSamples,3);
angVelBody = zeros(totalNumSamples,3);
angVelBody(1:firstLoopNumSamples,3) = (2*pi)/4;
angVelBody(firstLoopNumSamples+1:end,3) = (2*pi)/2;

[~,orientationNED,~,accNED,angVelNED] = traj(accBody,angVelBody);
```

Create an `imuSensor` object with an ideal accelerometer and an ideal magnetometer. Call `IMU` with the ground-truth acceleration, angular velocity, and orientation to output accelerometer readings and magnetometer readings. Plot the results.

```
IMU = imuSensor('accel-mag','SampleRate',fs);

[accelReadings,magReadings] = IMU(accNED,angVelNED,orientationNED);

figure(1)
t = (0:(totalNumSamples-1))/fs;
subplot(2,1,1)
plot(t,accelReadings)
legend('X-axis','Y-axis','Z-axis')
ylabel('Acceleration (m/s^2)')
```
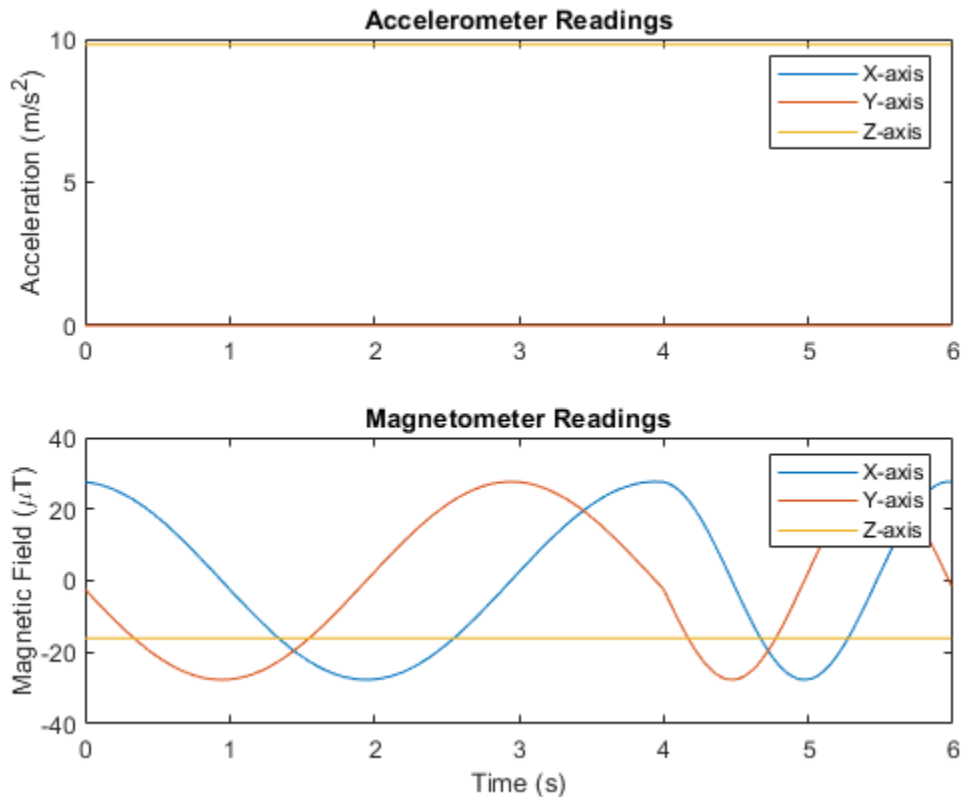
```
title('Accelerometer Readings')

subplot(2,1,2)
plot(t,magReadings)
legend('X-axis','Y-axis','Z-axis')
ylabel('Magnetic Field (\muT)')
xlabel('Time (s)')
title('Magnetometer Readings')
```
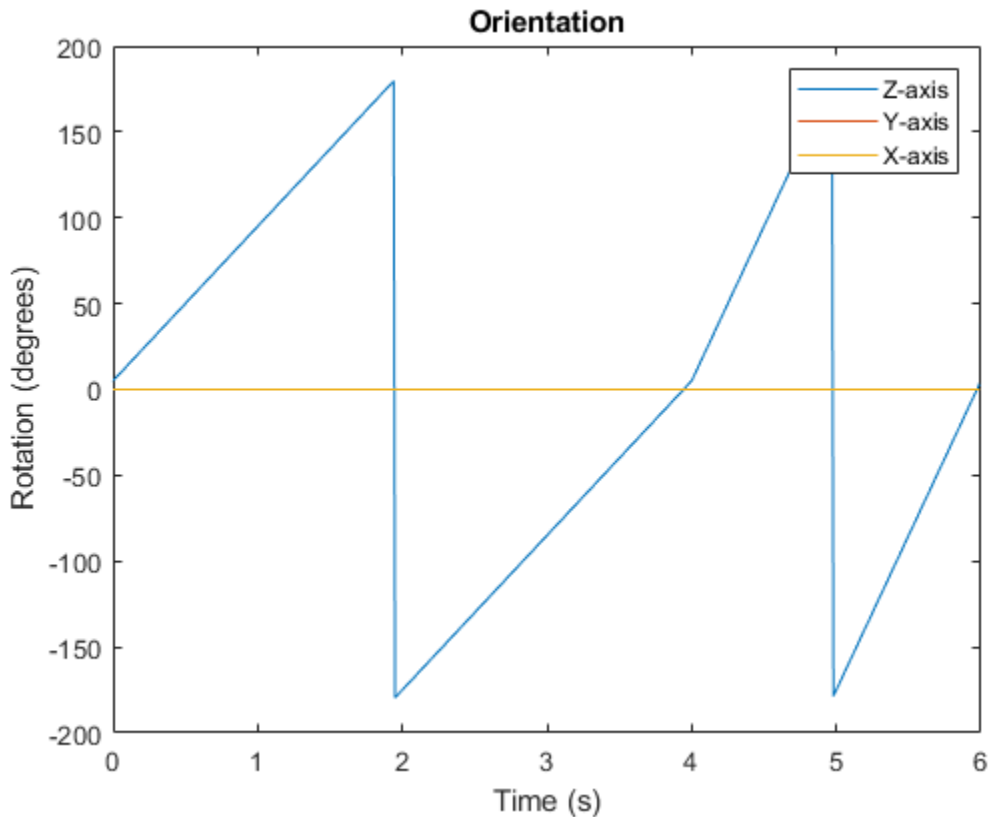

The accelerometer readings indicate that the platform has no translation. The magnetometer readings indicate that the platform is rotating around the *z*-axis.

Feed the accelerometer and magnetometer readings into the `ecompass` function to estimate the orientation over time. The `ecompass` function returns orientation in

quaternion format. Convert orientation to Euler angles and plot the results. The orientation plot indicates that the platform rotates about the *z*-axis only.

```
orientation = ecompass(accelReadings,magReadings);

orientationEuler = eulerd(orientation,'ZYX','frame');

figure(2)
plot(t,orientationEuler)
legend('Z-axis','Y-axis','X-axis')
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation')
```

Model Rotating Six-Axis IMU Data with Noise

Use `imuSensor` to model data obtained from a rotating IMU containing a realistic accelerometer and a realistic magnetometer. Use `kinematicTrajectory` to define the ground-truth motion. Fuse the `imuSensor` model output using the `ecompass` function to determine orientation over time.

Define the ground-truth motion for a platform that rotates 360 degrees in four seconds, and then another 360 degrees in two seconds. Use `kinematicTrajectory` to output the orientation, acceleration, and angular velocity in the NED coordinate system.

```
fs = 100;
firstLoopNumSamples = fs*4;
secondLoopNumSamples = fs*2;
totalNumSamples = firstLoopNumSamples + secondLoopNumSamples;

traj = kinematicTrajectory('SampleRate',fs);

accBody = zeros(totalNumSamples,3);
angVelBody = zeros(totalNumSamples,3);
angVelBody(1:firstLoopNumSamples,3) = (2*pi)/4;
angVelBody(firstLoopNumSamples+1:end,3) = (2*pi)/2;

[~,orientationNED,~,accNED,angVelNED] = traj(accBody,angVelBody);
```

Create an `imuSensor` object with a realistic accelerometer and a realistic magnetometer.
Call `IMU` with the ground-truth acceleration, angular velocity, and orientation to output
accelerometer readings and magnetometer readings. Plot the results.

```
IMU = imuSensor('accel-mag','SampleRate',fs);

IMU.Accelerometer = accelparams( ...
    'MeasurementRange',19.62, ...          % m/s^2
    'Resolution',0.0023936, ...            % m/s^2 / LSB
    'TemperatureScaleFactor',0.008, ...    % % / degree C
    'ConstantBias',0.1962, ...             % m/s^2
    'TemperatureBias',0.0014715, ...       % m/s^2 / degree C
    'NoiseDensity',0.0012361);             % m/s^2 / Hz^(1/2)

IMU.Magnetometer = magparams( ...
    'MeasurementRange',1200, ...           % uT
    'Resolution',0.1, ...                  % uT / LSB
    'TemperatureScaleFactor',0.1, ...      % % / degree C
    'ConstantBias',1, ...                  % uT
    'TemperatureBias',[0.8 0.8 2.4], ...   % uT / degree C
    'NoiseDensity',[0.6 0.6 0.9]/sqrt(100)); % uT / Hz^(1/2)

[accelReadings,magReadings] = IMU(accNED,angVelNED,orientationNED);

figure(1)
t = (0:(totalNumSamples-1))/fs;
subplot(2,1,1)
plot(t,accelReadings)
legend('X-axis','Y-axis','Z-axis')
ylabel('Acceleration (m/s^2)')
```
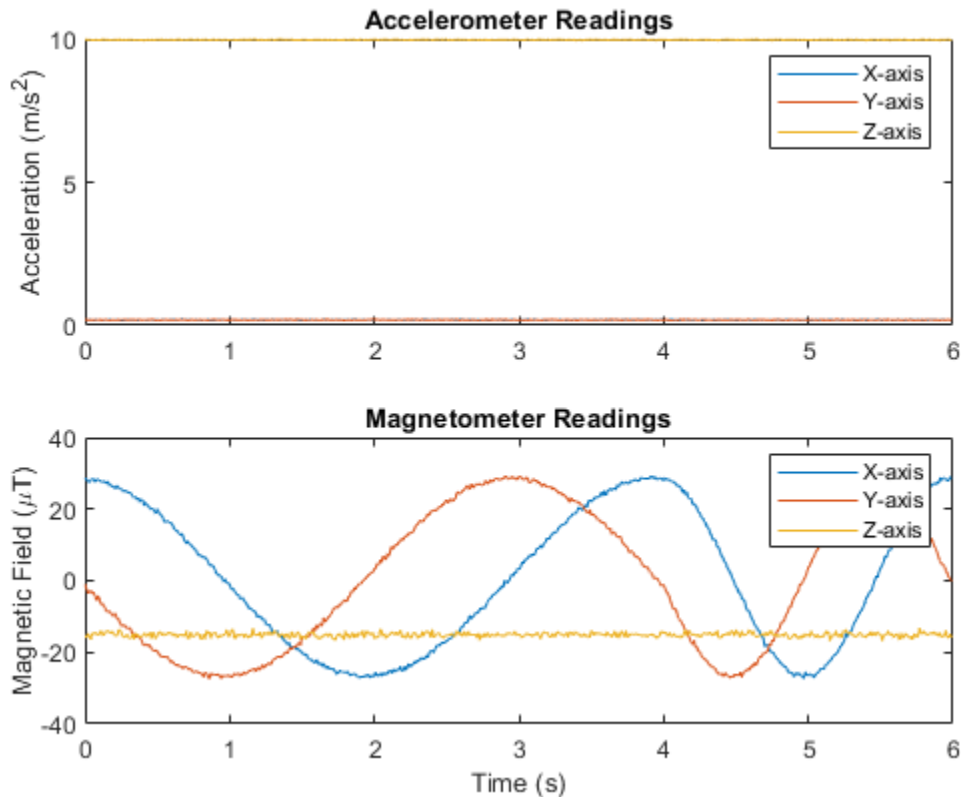
```
title('Accelerometer Readings')

subplot(2,1,2)
plot(t,magReadings)
legend('X-axis','Y-axis','Z-axis')
ylabel('Magnetic Field (\muT)')
xlabel('Time (s)')
title('Magnetometer Readings')
```
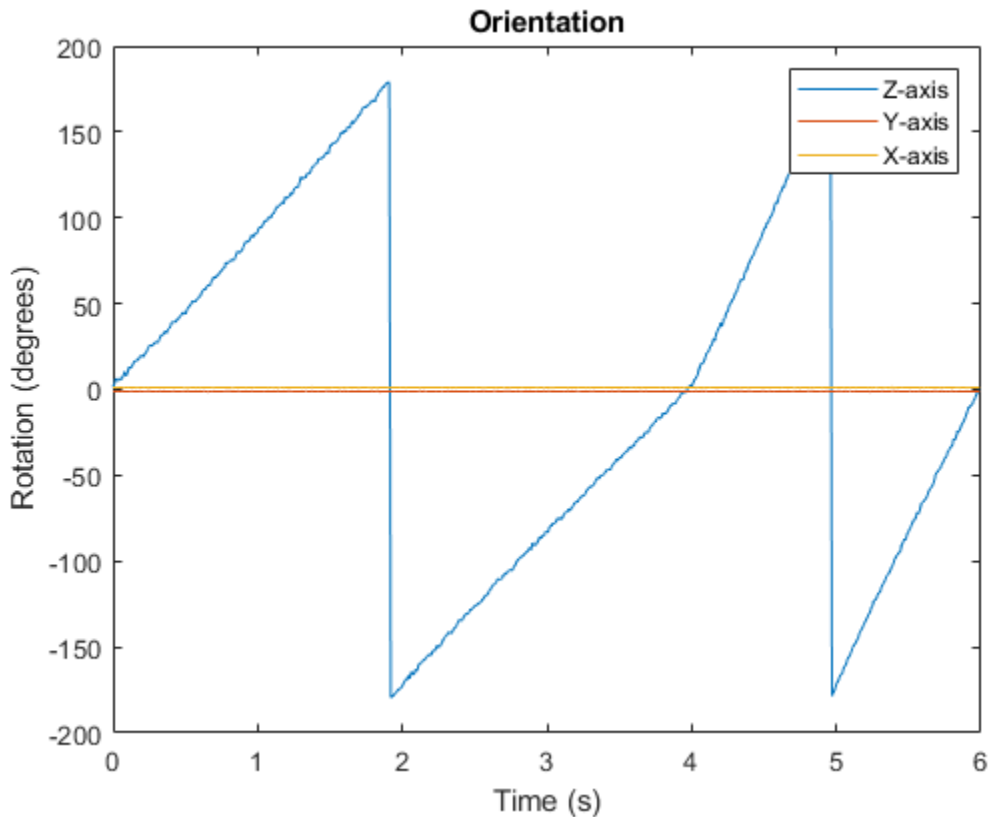

The accelerometer readings indicate that the platform has no translation. The magnetometer readings indicate that the platform is rotating around the z-axis.

Feed the accelerometer and magnetometer readings into the `ecompass` function to estimate the orientation over time. The `ecompass` function returns orientation in

quaternion format. Convert orientation to Euler angles and plot the results. The orientation plot indicates that the platform rotates about the *z*-axis only.

```
orientation = ecompass(accelReadings,magReadings);

orientationEuler = eulerd(orientation,'ZYX','frame');

figure(2)
plot(t,orientationEuler)
legend('Z-axis','Y-axis','X-axis')
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation')
%
```

Model Tilt Using Gyroscope and Accelerometer Readings

Model a tilting IMU that contains an accelerometer and gyroscope using the `imuSensor` System object™. Use ideal and realistic models to compare the results of orientation tracking using the `imufilter` System object.

Load a struct describing ground-truth motion and a sample rate. The motion struct describes sequential rotations:

1   yaw: 120 degrees over two seconds

2   pitch: 60 degrees over one second

3-461

> **3** roll: 30 degrees over one-half second
>
> **4** roll: -30 degrees over one-half second
>
> **5** pitch: -60 degrees over one second
>
> **6** yaw: -120 degrees over two seconds

In the last stage, the motion struct combines the 1st, 2nd, and 3rd rotations into a single-axis rotation. The acceleration, angular velocity, and orientation are defined in the local NED coordinate system.

```
load y120p60r30.mat motion fs
accNED = motion.Acceleration;
angVelNED = motion.AngularVelocity;
orientationNED = motion.Orientation;

numSamples = size(motion.Orientation,1);
t = (0:(numSamples-1)).'/fs;
```

Create an ideal IMU sensor object and a default IMU filter object.

```
IMU = imuSensor('accel-gyro','SampleRate',fs);

aFilter = imufilter('SampleRate',fs);
```

In a loop:

1 Simulate IMU output by feeding the ground-truth motion to the IMU sensor object.

2 Filter the IMU output using the default IMU filter object.

```
orientation = zeros(numSamples,1,'quaternion');
for i = 1:numSamples

    [accelBody,gyroBody] = IMU(accNED(i,:),angVelNED(i,:),orientationNED(i,:));

    orientation(i) = aFilter(accelBody,gyroBody);

end
release(aFilter)
```
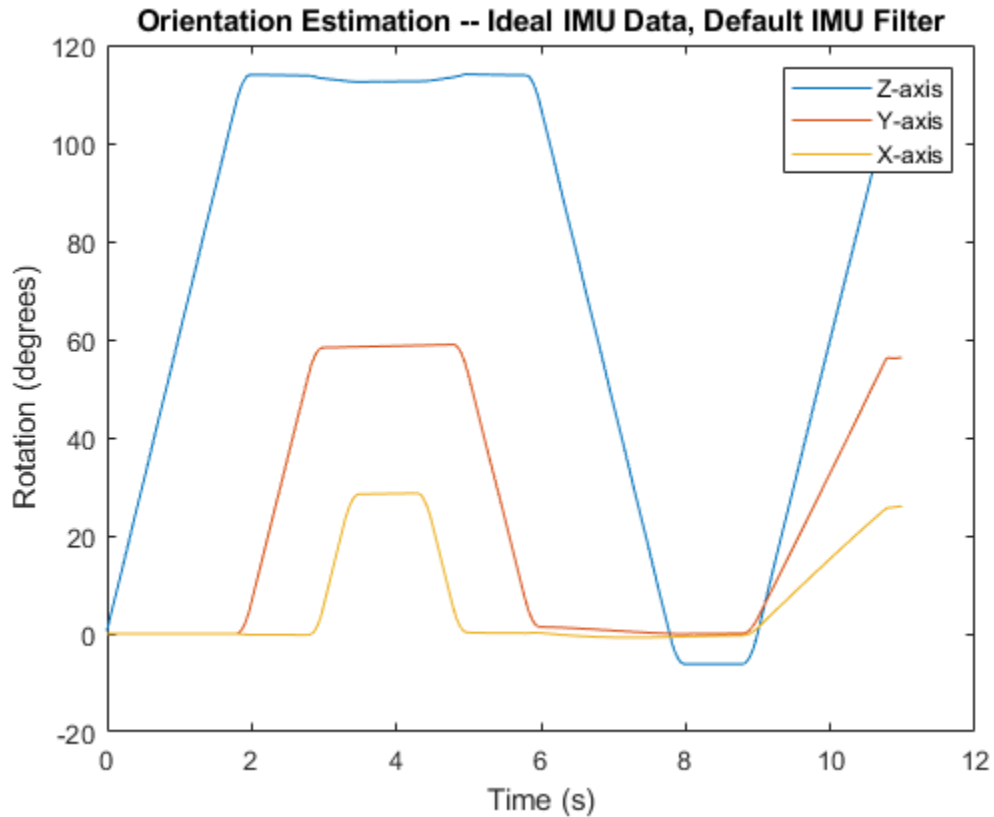
Plot the orientation over time.

```
figure(1)
plot(t,eulerd(orientation,'ZYX','frame'))
xlabel('Time (s)')
```

```
ylabel('Rotation (degrees)')
title('Orientation Estimation -- Ideal IMU Data, Default IMU Filter')
legend('Z-axis','Y-axis','X-axis')
```


Modify properties of your `imuSensor` to model real-world sensors. Run the loop again and plot the orientation estimate over time.

```
IMU.Accelerometer = accelparams( ...
    'MeasurementRange',19.62, ...
    'Resolution',0.00059875, ...
    'ConstantBias',0.4905, ...
    'AxesMisalignment',2, ...
    'NoiseDensity',0.003924, ...
    'BiasInstability',0, ...
```

```
    'TemperatureBias', [0.34335 0.34335 0.5886], ...
    'TemperatureScaleFactor',0.02);
IMU.Gyroscope = gyroparams( ...
    'MeasurementRange',4.3633, ...
    'Resolution',0.00013323, ...
    'AxesMisalignment',2, ...
    'NoiseDensity',8.7266e-05, ...
    'TemperatureBias',0.34907, ...
    'TemperatureScaleFactor',0.02, ...
    'AccelerationBias',0.00017809, ...
    'ConstantBias',[0.3491,0.5,0]);

orientationDefault = zeros(numSamples,1,'quaternion');
for i = 1:numSamples

    [accelBody,gyroBody] = IMU(accNED(i,:),angVelNED(i,:),orientationNED(i,:));

    orientationDefault(i) = aFilter(accelBody,gyroBody);

end
release(aFilter)

figure(2)
plot(t,eulerd(orientationDefault,'ZYX','frame'))
xlabel('Time (s)')
ylabel('Rotation (degrees)')
title('Orientation Estimation -- Realistic IMU Data, Default IMU Filter')
legend('Z-axis','Y-axis','X-axis')
```
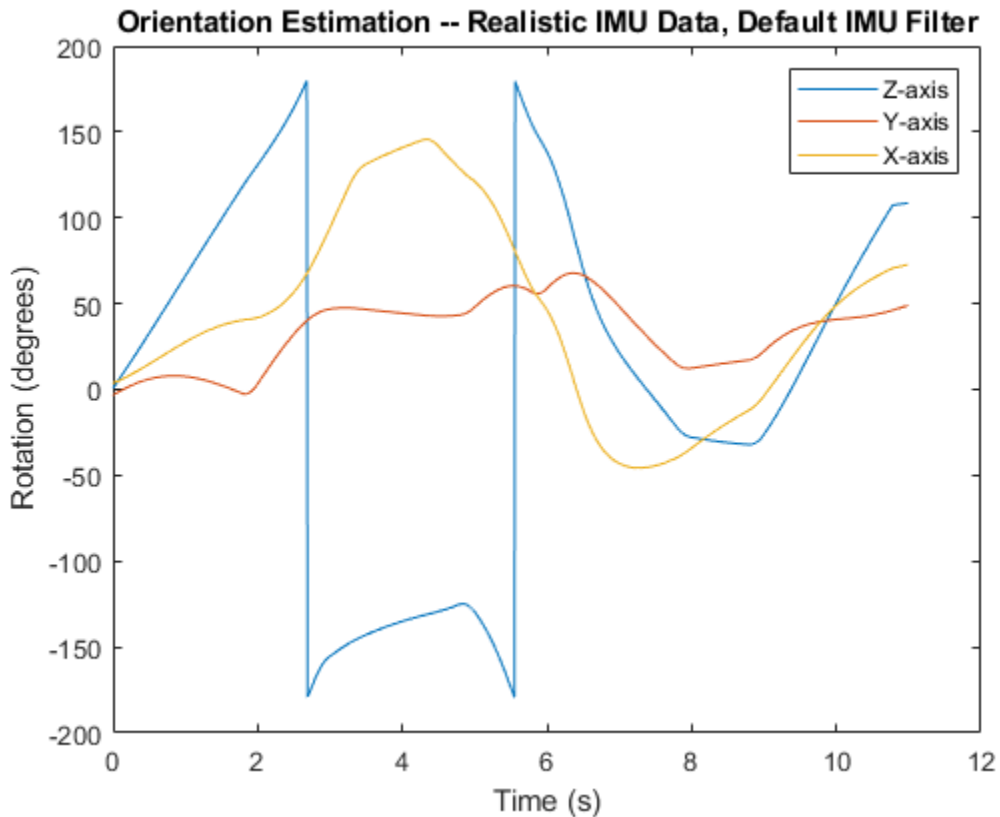
The ability of the `imufilter` to track the ground-truth data is significantly reduced when modeling a realistic IMU. To improve performance, modify properties of your `imufilter` object. These values were determined empirically. Run the loop again and plot the orientation estimate over time.

```
aFilter.GyroscopeNoise           = 7.6154e-7;
aFilter.AccelerometerNoise        = 0.0015398;
aFilter.GyroscopeDriftNoise        = 3.0462e-12;
aFilter.LinearAccelerationNoise   = 0.00096236;
aFilter.InitialProcessNoise        = aFilter.InitialProcessNoise*10;

orientationNondefault = zeros(numSamples,1,'quaternion');
for i = 1:numSamples
    [accelBody,gyroBody] = IMU(accNED(i,:),angVelNED(i,:),orientationNED(i,:));
```
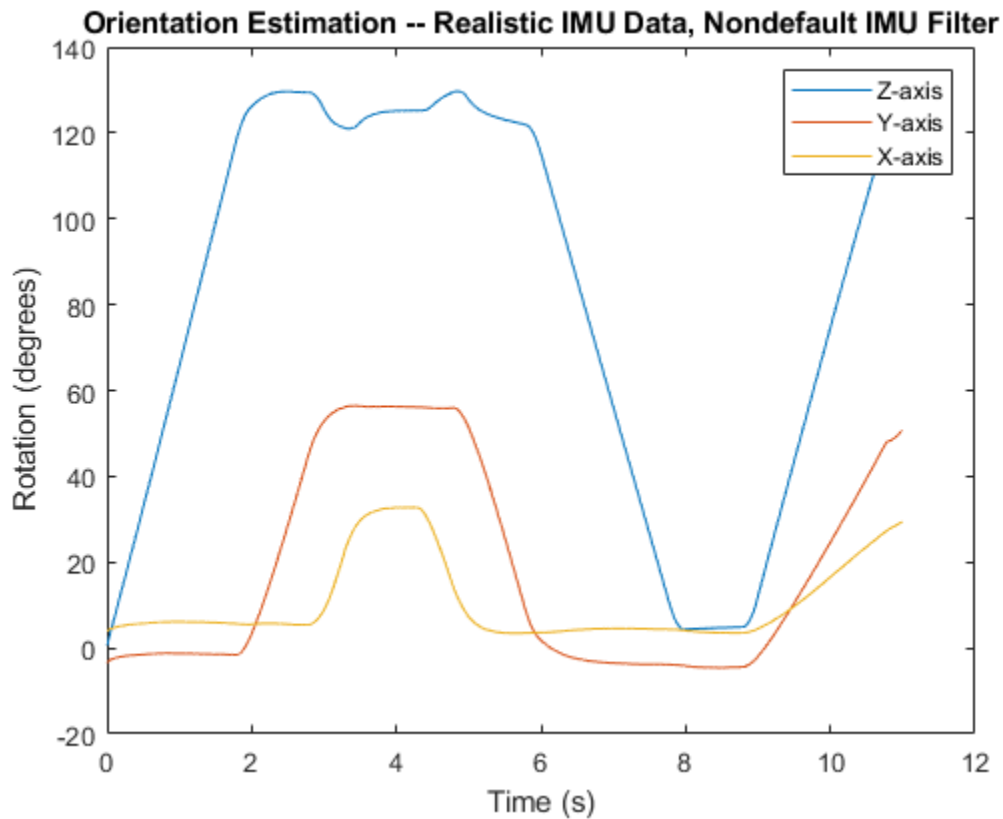
3-465

```
        orientationNondefault(i) = aFilter(accelBody,gyroBody);
    end
    release(aFilter)

    figure(3)
    plot(t,eulerd(orientationNondefault,'ZYX','frame'))
    xlabel('Time (s)')
    ylabel('Rotation (degrees)')
    title('Orientation Estimation -- Realistic IMU Data, Nondefault IMU Filter')
    legend('Z-axis','Y-axis','X-axis')
```

To quantify the improved performance of the modified `imufilter`, plot the quaternion distance between the ground-truth motion and the orientation as returned by the `imufilter` with default and nondefault properties.

```
qDistDefault = rad2deg(dist(orientationNED,orientationDefault));
qDistNondefault = rad2deg(dist(orientationNED,orientationNondefault));

figure(4)
plot(t,[qDistDefault,qDistNondefault])
title('Quaternion Distance from True Orientation')
legend('Realistic IMU Data, Default IMU Filter', ...
       'Realistic IMU Data, Nondefault IMU Filter')
xlabel('Time (s)')
ylabel('Quaternion Distance (degrees)')
```

Algorithms

Accelerometer

The accelerometer model uses the ground-truth orientation and acceleration inputs and the `imuSensor` and `accelparams` properties to model accelerometer readings.

The ground-truth acceleration is converted from the local frame to the sensor frame using the ground-truth orientation:

$$a = \left(orientation\right)\left(acceleration\right)^{T}$$

If the orientation is input in quaternion form, it is converted to a rotation matrix before processing.

The ground-truth acceleration in the sensor frame, a, passes through the bulk model, which adds axes misalignment and bias:

$$
b = \left(\begin{bmatrix} 1 & \dfrac{\alpha_2}{100} & \dfrac{\alpha_3}{100} \\[8pt] \dfrac{\alpha_1}{100} & 1 & \dfrac{\alpha_3}{100} \\[8pt] \dfrac{\alpha_1}{100} & \dfrac{\alpha_2}{100} & 1 \end{bmatrix} \left(a^T \right) \right)^T + \texttt{ConstantBias}
$$

where ConstantBias is a property of `accelparams`, and α_1, α_2, and α_3 are given by the first, second, and third elements of the AxesMisalignment property of `accelparams`.

The bias instability drift is modeled as white noise biased and then filtered:

$$
\beta_1 = h_1 * (w) \, (\texttt{BiasInstability})
$$

where BiasInstability is a property of `accelparams`, and h_1 is a filter defined by the SampleRate property:

$$
H_1(z) = \dfrac{1}{1 + \left(\dfrac{2}{\texttt{SampleRate}} - 1 \right) z^{-1}}
$$

White noise drift is modeled by multiplying elements of the white noise random stream by the standard deviation:

$$
\beta_2 = (w) \left(\sqrt{\dfrac{\texttt{SampleRate}}{2}} \right) (\texttt{NoiseDensity})
$$

where SampleRate is an `imuSensor` property, and NoiseDensity is an `accelparams` property. Elements of w are random numbers given by settings of the `imuSensor` random stream.

The random walk drift is modeled by biasing elements of the white noise random stream and then filtering:

$$\beta_3 \;=\; h_2 \;\star\; (w) \left(\frac{\mathtt{RandomWalk}}{\sqrt{\dfrac{\mathtt{SampleRate}}{2}}} \right)$$

where RandomWalk is a property of `accelparams`, SampleRate is a property of `imuSensor`, and h_2 is a filter defined as:

$$H_2\left(z\right) \;=\; \frac{1}{1 - z^{-1}}$$

The environmental drift noise is modeled by multiplying the temperature difference from a standard with the temperature bias:

$$\Delta_e \;=\; (\mathtt{Temperature} - 25)\,(\mathtt{TemperatureBias})$$

where Temperature is a property of `imuSensor`, and TemperatureBias is a property of `accelparams`. The constant 25 corresponds to a standard temperature.

The temperature scale factor error is modeled as:

$$scaleFactorError \;=\; 1 + \left(\frac{\mathtt{Temperature} - 25}{100} \right)(\mathtt{TemperatureScaleFacto}$$

where Temperature is a property of `imuSensor`, and TemperatureScaleFactor is a property of `accelparams`. The constant 25 corresponds to a standard temperature.

The quantization is modeled by first saturating the continuous signal model:

$$
e = \begin{cases} \texttt{MeasurementRange} & \text{if} \quad d > \texttt{MeasurementRange} \\ -\texttt{MeasurementRange} & \text{if} \quad -d > \texttt{MeasurementRange} \\ d & \text{else} \end{cases}
$$

and then setting the resolution:

$$
accelReadings = (\texttt{Resolution}) \left(\texttt{round} \left(\frac{e}{\texttt{Resolution}} \right) \right)
$$

where MeasurementRange is a property of `accelparams`.

Gyroscope

The gyroscope model uses the ground-truth orientation, acceleration, and angular velocity inputs, and the `imuSensor` and `gyroparams` properties to model accelerometer readings.
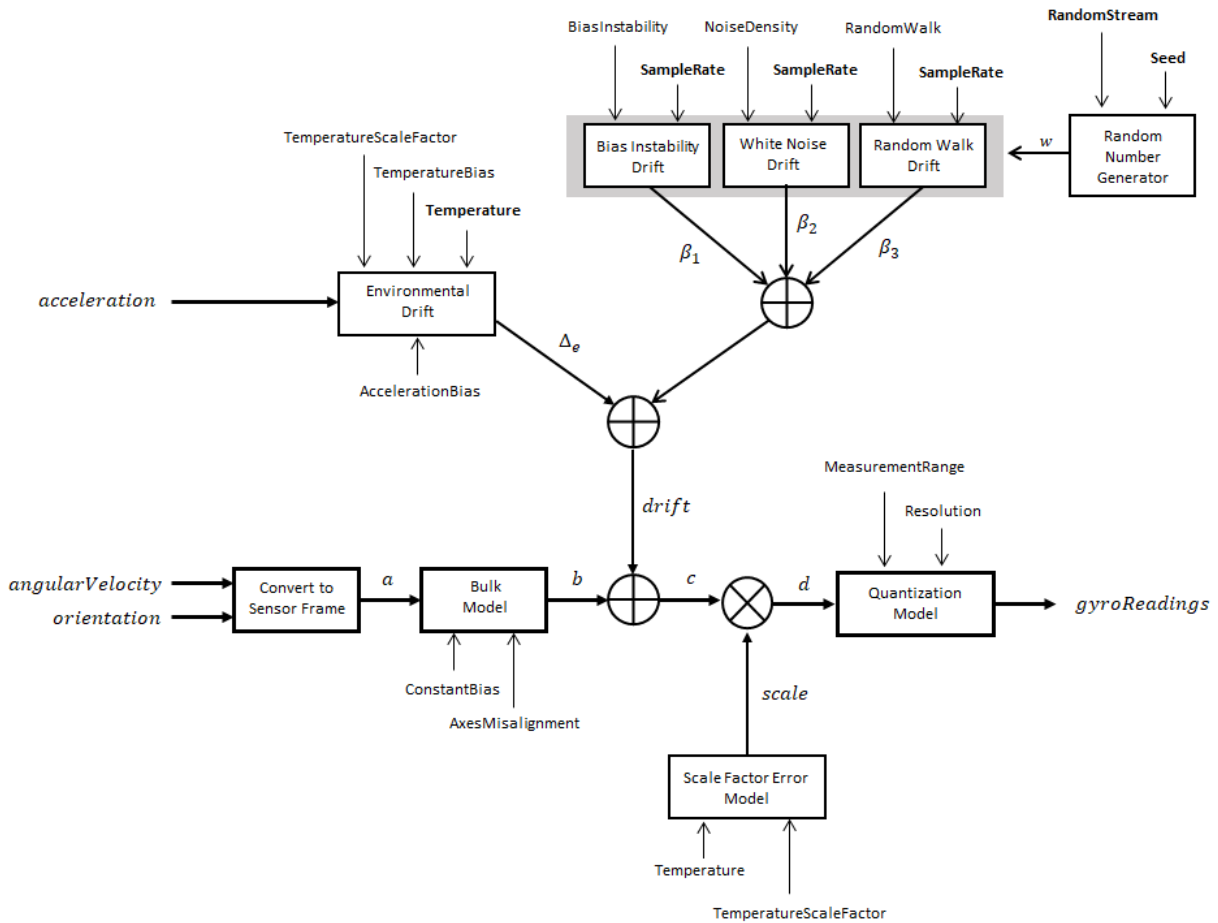
The ground-truth angular velocity is converted from the local frame to the sensor frame using the ground-truth orientation:

$$a = \left(orientation\right)\left(angularVelocity\right)^{T}$$

If the orientation is input in quaternion form, it is converted to a rotation matrix before processing.

The ground-truth angular velocity in the sensor frame, a, passes through the bulk model, which adds axes misalignment and bias:

$$
b = \left(\begin{bmatrix} 1 & \dfrac{\alpha_2}{100} & \dfrac{\alpha_3}{100} \\[2mm] \dfrac{\alpha_1}{100} & 1 & \dfrac{\alpha_3}{100} \\[2mm] \dfrac{\alpha_1}{100} & \dfrac{\alpha_2}{100} & 1 \end{bmatrix} \left(a^T \right) \right)^T + \texttt{ConstantBias}
$$

where ConstantBias is a property of $\texttt{gyroparams}$, and α_1, α_2, and α_3 are given by the first, second, and third elements of the AxesMisalignment property of $\texttt{gyroparams}$.

The bias instability drift is modeled as white noise biased and then filtered:

$$
\beta_1 = h_1 * (w) \, (\texttt{BiasInstability})
$$

where BiasInstability is a property of $\texttt{gyroparams}$ and h_1 is a filter defined by the SampleRate property:

$$
H_1\left(z \right) = \cfrac{1}{1 + \left(\cfrac{2}{\texttt{SampleRate}} - 1 \right) z^{-1}}
$$

White noise drift is modeled by multiplying elements of the white noise random stream by the standard deviation:

$$
\beta_2 = (w)\left(\sqrt{\dfrac{\texttt{SampleRate}}{2}} \right)(\texttt{NoiseDensity})
$$

where SampleRate is an $\texttt{imuSensor}$ property, and NoiseDensity is an $\texttt{gyroparams}$ property. The elements of w are random numbers given by settings of the $\texttt{imuSensor}$ random stream.

The random walk drift is modeled by biasing elements of the white noise random stream and then filtering:

$$\beta_3 = h_2 \star (w) \left(\frac{\text{RandomWalk}}{\sqrt{\dfrac{\text{SampleRate}}{2}}} \right)$$

where RandomWalk is a property of `gyroparams`, SampleRate is a property of `imuSensor`, and h_2 is a filter defined as:

$$H_2 (z) = \frac{1}{1 - z^{-1}}$$

The environmental drift noise is modeled by multiplying the temperature difference from a standard with the temperature bias:

$$\Delta_e = (\text{Temperature} - 25) \, (\text{TemperatureBias})$$

where Temperature is a property of `imuSensor`, and TemperatureBias is a property of `gyroparams`. The constant 25 corresponds to a standard temperature.

The temperature scale factor error is modeled as:

$$scaleFactorError = 1 + \left(\frac{\text{Temperature} - 25}{100} \right) (\text{TemperatureScaleFacto}$$

where Temperature is a property of `imuSensor`, and TemperatureScaleFactor is a property of `gyroparams`. The constant 25 corresponds to a standard temperature.

The quantization is modeled by first saturating the continuous signal model:

$$
e = \begin{cases} \text{MeasurementRange} & \text{if} \quad d > \text{MeasurementRange} \\ -\text{MeasurementRange} & \text{if} \quad -d > \text{MeasurementRange} \\ d & \text{else} \end{cases}
$$

and then setting the resolution:

$$
gyroReadings = (\text{Resolution})\left(\text{round}\left(\frac{e}{\text{Resolution}}\right)\right)
$$

where MeasurementRange is a property of `gyroparams`.

Magnetometer

The magnetometer model uses the ground-truth orientation and acceleration inputs, and the `imuSensor` and `magparams` properties to model magnetometer readings.

The ground-truth acceleration is converted from the local frame to the sensor frame using the ground-truth orientation:

$$a = \left(orientation\right)\left(acceleration\right)^{T}$$

If the orientation is input in quaternion form, it is converted to a rotation matrix before processing.

The ground-truth acceleration in the sensor frame, a, passes through the bulk model, which adds axes misalignment and bias:

$$b = \left(\begin{bmatrix} 1 & \dfrac{\alpha_2}{100} & \dfrac{\alpha_3}{100} \\[2ex] \dfrac{\alpha_1}{100} & 1 & \dfrac{\alpha_3}{100} \\[2ex] \dfrac{\alpha_1}{100} & \dfrac{\alpha_2}{100} & 1 \end{bmatrix} \left(a^T \right) \right)^T + \texttt{ConstantBias}$$

where ConstantBias is a property of `magparams`, and α_1, α_2, and α_3 are given by the first, second, and third elements of the AxesMisalignment property of `magparams`.

The bias instability drift is modeled as white noise biased and then filtered:

$$\beta_1 \;=\; h_1 \,*\, (w) \,(\texttt{BiasInstability})$$

where BiasInstability is a property of `magparams` and h_1 is a filter defined by the SampleRate property:

$$H_1\left(z \right) \;=\; \dfrac{1}{1 + \left(\dfrac{2}{\texttt{SampleRate}} - 1 \right) z^{-1}}$$

White noise drift is modeled by multiplying elements of the white noise random stream by the standard deviation:

$$\beta_2 \;=\; (w) \left(\sqrt{\dfrac{\texttt{SampleRate}}{2}} \right) (\texttt{NoiseDensity})$$

where SampleRate is an `imuSensor` property, and NoiseDensity is an `magparams` property. The elements of w are random numbers given by settings of the `imuSensor` random stream.

The random walk drift is modeled by biasing elements of the white noise random stream and then filtering:

$$\beta_3 = h_2 \ast (w) \left(\frac{\texttt{RandomWalk}}{\sqrt{\frac{\texttt{SampleRate}}{2}}} \right)$$

where RandomWalk is a property of `magparams`, SampleRate is a property of `imuSensor`, and h_2 is a filter defined as:

$$H_2(z) = \frac{1}{1 - z^{-1}}$$

The environmental drift noise is modeled by multiplying the temperature difference from a standard with the temperature bias:

$$\Delta_e = (\texttt{Temperature} - 25)\,(\texttt{TemperatureBias})$$

where Temperature is a property of `imuSensor`, and TemperatureBias is a property of `magparams`. The constant 25 corresponds to a standard temperature.

The temperature scale factor error is modeled as:

$$scaleFactorError = 1 + \left(\frac{\texttt{Temperature} - 25}{100} \right)(\texttt{TemperatureScaleFacto}$$

where Temperature is a property of `imuSensor`, and TemperatureScaleFactor is a property of `magparams`. The constant 25 corresponds to a standard temperature.

The quantization is modeled by first saturating the continuous signal model:

$$
e = \begin{cases} \texttt{MeasurementRange} & \texttt{if} \quad d > \texttt{MeasurementRange} \\ -\texttt{MeasurementRange} & \texttt{if} \quad -d > \texttt{MeasurementRange} \\ d & \texttt{else} \end{cases}
$$

and then setting the resolution:

$$
magReadings = (\texttt{Resolution})\left(\texttt{round}\left(\frac{e}{\texttt{Resolution}}\right)\right)
$$

where MeasurementRange is a property of `magparams`.

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

Classes
`accelparams` | `gyroparams` | `magparams`

System Objects
`gpsSensor` | `insSensor`

Topics
"Model IMU, GPS, and INS/GPS"

External Websites

National Centers For Environmental Information

Introduced in R2018b

trackBranchHistory System object

Track-oriented MHT branching and branch history

Description

The `trackBranchHistory` System object is a track-oriented, multi-hypothesis tracking (MHT) branch history manager. The object maintains a history of track branches (hypotheses) that are based on the results of an assignment algorithm, such as the algorithm used by the `assignTOMHT` function. Given the most recent scan of a set of sensors, the assignment algorithm results include:

- The assignments of sensor detections to specific track branches
- The unassigned track branches
- The unassigned detections

The `trackBranchHistory` object creates, updates, and deletes track branches as needed and maintains the track branch history for a specified number of scans. Each track and branch stored in the object has a unique ID. To view a table of track branches for the current history, use the `getHistory` function. To compute branch clusters and incompatible branches, specify the track branch history as an input to the `clusterTrackBranches` function.

To create a branch history manager and update the branch history:

1 Create the `trackBranchHistory` 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

```
branchHistoryMgr = trackBranchHistory
branchHistoryMgr = trackBranchHistory(Name,Value)
```

Description

`branchHistoryMgr = trackBranchHistory` creates a `trackBranchHistory` System object, `branchHistoryMgr`, with default property values.

`branchHistoryMgr = trackBranchHistory(Name,Value)` sets properties for the `trackBranchHistory` object by using one or more name-value pairs. For example, `branchHistoryMgr = trackBranchHistory('MaxNumTracks', 250,'MaxNumTrackBranches',5)` creates a `trackBranchHistory` object that can maintain a maximum of 250 tracks and 5 track branches per track. Enclose property names in quotes. Specified property values can be any numeric data type, but they must all be of the same data type.

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).

MaxNumSensors — Maximum number of sensors
20 (default) | positive integer

Maximum number of sensors, specified as a positive integer.

MaxNumHistoryScans — Maximum number of scans maintained in branch history
4 (default) | positive integer

Maximum number of scans maintained in the branch history, specified as a positive integer. Typical values are from 2 to 6. Higher values increase the computational load.

MaxNumTracks — Maximum number of tracks
200 (default) | positive integer

Maximum number of tracks that the branch history manager can maintain, specified as a positive integer.

MaxNumTrackBranches — Maximum number of branches per track
3 (default) | positive integer

Maximum number of branches per track that the branch history manager can maintain, specified as a positive integer.

Usage

Syntax

```
history = branchHistoryMgr(assignments,unassignedTracks,
unassignedDetections,originatingSensor)
```

Description

`history = branchHistoryMgr(assignments,unassignedTracks, unassignedDetections,originatingSensor)` returns the branch history based on the results of an assignment algorithm. Specify the assignments of detections to branches, the lists of unassigned tracks and unassigned detections, and the IDs of the sensors from which the detections originated. The inputs can be of any numeric data type.

The `assignTOMHT` function returns assignment results as `uint32` values, but the inputs to `branchHistoryMgr` can be of any numeric data type.

Input Arguments

assignments — Assignment of track branches to detections
P-by-2 matrix of integers

Assignment of track branches to detections, specified as a *P*-by-2 matrix of integers, where *P* is the number of assignments. The first column lists the track branch indices. The second column lists the detection indices. The same branch can be assigned to multiple detections. The same detection can be assigned to multiple branches.

For example, if `assignments = [1 1; 1 2; 2 1; 2 2]`, the rows of `assignments` specify these assignments:

- `[1 1]` — Branch 1 was assigned to detection 1.
- `[1 2]` — Branch 1 was assigned to detection 2.
- `[2 1]` — Branch 2 was assigned to detection 1.
- `[2 2]` — Branch 2 was assigned to detection 2.

unassignedTracks — Indices of unassigned track branches
Q-by-1 vector of integers

Indices of unassigned track branches, specified as a *Q*-by-1 vector of integers, where *Q* is the number of unassigned track branches. Each element of `unassignedTracks` must correspond to the indices of a track branch currently stored in the `trackBranchHistory` System object.

unassignedDetections — Indices of unassigned detections
R-by-1 vector of integers

Indices of unassigned detections, specified as an *R*-by-1 vector of integers, where *R* is the number of unassigned detections. Each unassigned detection results in a new track branch.

originatingSensor — Indices of sensors from which each detection originated
1-by-*L* vector of integers

Indices of sensors from which each detection originated, specified as a 1-by-*L* vector of integers, where *L* is the number of detections. The `i`th element of `originatingSensor` corresponds to the `SensorIndex` property value of `objectDetection` object `i`.

Output Arguments

history — Branch history
matrix of integers

Branch history, returned as a matrix of integers.

Each row of `history` represents a unique track branch. `history` has 3+($D\times S$) columns, where D is the number of maintained scans (the history depth) and S is the maximum number of maintained sensors. The first three columns represent the following information about each track branch:

- `TrackID` — ID of the track that is associated with the branch. Track branches that are assumed to have originated from the same target have the same track ID. If a branch originates from an unassigned detection, that branch gets a new track ID.

- `ParentID` — ID of the parent branch, that is, the branch from which the current branch originated. Branches that were created from the same parent have the same `ParentID`. A `ParentID` of 0 indicates a new track. These tracks are created from hypotheses corresponding to unassigned detections.

- `BranchID` — Unique ID of track branch. Every branch created from an unassigned detection or assignment gets a new branch ID.

The remaining $D\times S$ columns contain the IDs of the detections assigned to each branch. A branch can be assigned to at most one detection per scan and per sensor. The table shows the organization of these columns with sample detections. N is the number of scans. A value of 0 means that the sensor at that scan does not have a detection assigned to it.

Scan *N*				Scan *N* – 1				. . .	Scan *N* – *D*			
Sens or – 1	Sens or – 2	. . .	Sens or – *S*	Sens or – 1	Sens or – 2	. . .	Sens or – *S*	. . .	Sens or – 1	Sens or – 2	. . .	Sens or – *S*
1	0	…	0	1	2	…	0	…	0	0	…	0

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 `trackBranchHistory`
getHistory   Get branch history of maintained tracks

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

Branch Tracks Based on Assignment Results

Apply the results of an assignment algorithm to a track-oriented, multi-hypothesis tracking (MHT) branch history manager. View the resulting track branches (hypotheses).

Create the MHT branch history manager, which is a `trackBranchHistory` System object™. Set the object to maintain a history of four sensors and two scans.

```
branchHistoryMgr = trackBranchHistory('MaxNumSensors',4,'MaxNumHistoryScans',2)


branchHistoryMgr =

  trackBranchHistory with properties:

          MaxNumSensors: 4
     MaxNumHistoryScans: 2
           MaxNumTracks: 200
     MaxNumTrackBranches: 3
```

Update the branch history. Because the first update has no previous branches, the branch history manager contains only unassigned detections.

```
emptyAssignment = zeros(0,2,'uint32');
emptyUnassignment = zeros(0,1,'uint32');
unassignedDetections = uint32([1;2;3]);
originatingSensor = [1 1 2];
history = branchHistoryMgr(emptyAssignment,emptyUnassignment, ...
    unassignedDetections,originatingSensor);
```

View the current branch history by using the `getHistory` function. Each detection is assigned to a separate track.

```
getHistory(branchHistoryMgr)

ans =

  3x5 table

    TrackID    ParentID    BranchID                           Scan2
                                      Sensor1    Sensor2    Sensor3    Sensor4    Sens
    _____    _____    _____   _____

       1          0           1          1          0          0          0        (
       2          0           2          2          0          0          0        (
       3          0           3          0          3          0          0        (
```

Specify multiple branch assignments and multiple unassigned track branches and detections.

- Assign branch 1 to detections 1 and 2.
- Assign branch 2 to detections 1 and 2.
- Consider track branches 1 and 3 unassigned.
- Consider detections 1, 2, and 3 unassigned.

```
assignments = uint32([1 1; 1 2; 2 1; 2 2]);
unassignedTracks = uint32([1;3]);
unassignedDetections = uint32([1;2;3]);
```

Update the branch history manager with the assignments and unassigned tracks and detections.

```
history = branchHistoryMgr(assignments,unassignedTracks, ...
    unassignedDetections,originatingSensor);
```

View the updated branch history.

```
getHistory(branchHistoryMgr)

ans =

  9x5 table

    TrackID    ParentID    BranchID                           Scan2
```

			Sensor1	Sensor2	Sensor3	Sensor4	Sens
1	1	1	0	0	0	0	
3	3	3	0	0	0	0	0
4	0	4	1	0	0	0	0
5	0	5	2	0	0	0	0
6	0	6	0	3	0	0	0
1	1	7	1	0	0	0	
1	1	8	2	0	0	0	
2	2	9	1	0	0	0	2
2	2	10	2	0	0	0	2

Inspect the branch history.

- The most recent scan is Scan 2. The previous scan is Scan 1, which was Scan 2 in the previous assignment update. The history has shifted one scan to the right.

- Branches 1 and 3 are the branches for the unassigned tracks.

- Branch 2 is no longer in the history because it was not considered to be unassigned. Its assignment to detections 1 and 2 created branches 9 and 10.

- Branches 4–6 are branches created for the unassigned detections.

- Branches 7–10 are branches created for the track assignments.

References

[1] Werthmann, John R. "A Step-by-Step Description of a Computationally Efficient Version of Multiple Hypothesis Tracking." In *Proceedings of SPIE Vol. 1698, Signal and Processing of Small Targets*. 1992, pp. 288–300. doi: 10.1117/12.139379.

See Also

Functions
assignTOMHT | clusterTrackBranches

System Objects
trackerTOMHT

Introduced in R2018b

getHistory

Get branch history of maintained tracks

Syntax

```
history = getHistory(branchHistoryMgr)
history = getHistory(branchHistoryMgr,format)
```

Description

`history = getHistory(branchHistoryMgr)` returns a table containing the track branch history maintained by the input `trackBranchHistory` System object, `branchHistoryMgr`.

`history = getHistory(branchHistoryMgr,format)` returns the branch history in the specified format: `'table'` or `'matrix'`.

Examples

Branch Tracks Based on Assignment Results

Apply the results of an assignment algorithm to a track-oriented, multi-hypothesis tracking (MHT) branch history manager. View the resulting track branches (hypotheses).

Create the MHT branch history manager, which is a `trackBranchHistory` System object™. Set the object to maintain a history of four sensors and two scans.

```
branchHistoryMgr = trackBranchHistory('MaxNumSensors',4,'MaxNumHistoryScans',2)


branchHistoryMgr =

  trackBranchHistory with properties:
```

```
        MaxNumSensors: 4
   MaxNumHistoryScans: 2
         MaxNumTracks: 200
   MaxNumTrackBranches: 3
```

Update the branch history. Because the first update has no previous branches, the branch history manager contains only unassigned detections.

```
emptyAssignment = zeros(0,2,'uint32');
emptyUnassignment = zeros(0,1,'uint32');
unassignedDetections = uint32([1;2;3]);
originatingSensor = [1 1 2];
history = branchHistoryMgr(emptyAssignment,emptyUnassignment, ...
    unassignedDetections,originatingSensor);
```

View the current branch history by using the `getHistory` function. Each detection is assigned to a separate track.

```
getHistory(branchHistoryMgr)
```

```
ans =

  3x5 table
```

| TrackID | ParentID | BranchID | Scan2 | | | | |
			Sensor1	Sensor2	Sensor3	Sensor4	Sens
1	0	1	1	0	0	0	(
2	0	2	2	0	0	0	(
3	0	3	0	3	0	0	(

Specify multiple branch assignments and multiple unassigned track branches and detections.

- Assign branch 1 to detections 1 and 2.
- Assign branch 2 to detections 1 and 2.
- Consider track branches 1 and 3 unassigned.
- Consider detections 1, 2, and 3 unassigned.

```
assignments = uint32([1 1; 1 2; 2 1; 2 2]);
unassignedTracks = uint32([1;3]);
unassignedDetections = uint32([1;2;3]);
```

Update the branch history manager with the assignments and unassigned tracks and detections.

```
history = branchHistoryMgr(assignments,unassignedTracks, ...
    unassignedDetections,originatingSensor);
```

View the updated branch history.

```
getHistory(branchHistoryMgr)
```

```
ans =

  9x5 table
```

| TrackID | ParentID | BranchID | Scan2 | | | | |
			Sensor1	Sensor2	Sensor3	Sensor4	Sens
1	1	1	0	0	0	0	
3	3	3	0	0	0	0	
4	0	4	1	0	0	0	
5	0	5	2	0	0	0	
6	0	6	0	3	0	0	
1	1	7	1	0	0	0	
1	1	8	2	0	0	0	
2	2	9	1	0	0	0	
2	2	10	2	0	0	0	

Inspect the branch history.

- The most recent scan is Scan 2. The previous scan is Scan 1, which was Scan 2 in the previous assignment update. The history has shifted one scan to the right.

- Branches 1 and 3 are the branches for the unassigned tracks.

- Branch 2 is no longer in the history because it was not considered to be unassigned. Its assignment to detections 1 and 2 created branches 9 and 10.

- Branches 4–6 are branches created for the unassigned detections.

- Branches 7–10 are branches created for the track assignments.

Input Arguments

branchHistoryMgr — Input branch history manager
trackBranchHistory System object

Input branch history manager, specified as a `trackBranchHistory` System object.

format — Format of output branch history
'table' (default) | 'matrix'

Format of the output branch history, specified as one of the following:

- 'table' (default) — Return branch history in a table.
- 'matrix' — Return branch history in a matrix. This output is equivalent to the output returned when calling the `trackBranchHistory` System object.

Output Arguments

history — Branch history
table of integers | matrix of integers

Branch history, returned as a table of integers or as a matrix of integers.

Each row of `history` represents a unique track branch. `history` has 3+(D×S) columns, where D is the number of maintained scans (the history depth) and S is the maximum number of maintained sensors. The first three columns represent the following information about each track branch:

- `TrackID` — ID of the track that is associated with the branch. Track branches that are assumed to have originated from the same target have the same track ID. If a branch originates from an unassigned detection, that branch gets a new track ID.
- `ParentID` — ID of the parent branch, that is, the branch from which the current branch originated. Branches that were created from the same parent have the same `ParentID`. A `ParentID` of 0 indicates a new track. These tracks are created from hypotheses corresponding to unassigned detections.

- `BranchID` — Unique ID of track branch. Every branch created from an unassigned detection or assignment gets a new branch ID.

The remaining *D*×*S* columns contain the IDs of the detections assigned to each branch. A branch can be assigned to at most one detection per scan and per sensor. The table shows the organization of these columns with sample detections. *N* is the number of scans. A value of 0 means that the sensor at that scan does not have a detection assigned to it.

Scan *N*				Scan *N* – 1				. . .	Scan *N* – *D*			
Sens or – 1	Sens or – 2	. . .	Sens or – *S*	Sens or – 1	Sens or – 2	. . .	Sens or – *S*	. . .	Sens or – 1	Sens or – 2	. . .	Sens or – *S*
1	0	...	0	1	2	...	0	...	0	0	...	0

See Also
trackBranchHistory

Introduced in R2018b

staticDetectionFuser System object

Static fusion of synchronous sensor detections

Description

`staticDetectionFuser` System object creates a static detection fuser object to fuse angle-only sensor detections.

To obtain the fuser:

1 Create the `staticDetectionFuser` 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

```
fuser = staticDetectionFuser()
fuser = staticDetectionFuser(Name,Value)
```

Description

`fuser = staticDetectionFuser()` creates a default three-sensor static detection fuser object to fuse angle-only sensor detections.

`fuser = staticDetectionFuser(Name,Value)` sets properties using one or more name-value pairs. For example, `fuser = staticDetectionFuser('FalseAlarmRate',1e-6,'MaxNumSensors',12)` creates a fuser that has a maximum of 12 sensors and a false alarm rate of `1e-6`. Enclose each property name in quotes.

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).

FuserSensorIndex — Sensor index of composite detections
1 (default) | positive integer

Sensor index of the composite detections reported by the fuser, specified as a positive integer. This index becomes the `SensorIndex` of `objectDetection` objects returned by the fuser.

Example: 5

Data Types: `double`

MeasurementFusionFcn — Function for fusing multiple sensor detections
`'triangulateLOS'` (default) | char | string | function handle

Function for fusing multiple sensor detections, specified as a character vector, string, or function handle. The function fuses multiple detections into one and returns the fused measurement and measurement noise. Any fusing function combines at most one detection from each sensor. The syntax of the measurement fuser function is:

`[fusedMeasurement,fusedMeasurementNoise] = MeasurementFusionFcn(detections)`

where the input and output functions arguments are

- `detections` – cell array of `objectDetection` measurements.
- `fusedMeasurement` – an *N*-by-1 vector of fused measurements.
- `fusedMeasurementNoise` – an *N*-by-*N* matrix of fused measurements noise.

The value of *N* depends on the `MeasurementFormat` property.

MeasurementFormat Property	N

'Position'	1, 2, and 3
'Velocity	1, 2, and 3
'PositionAndVelocity	2, 4, and 6
'Custom'	Any

Data Types: `char` | `string` | `function_handle`

MeasurementFormat — Format of the fused measurement
`'Position'` (default) | `'Velocity'` | `'PositionAndVelocity'` | `'Custom'`

Format of the fused measurement, specified as `'Position'`, `'Velocity'`, `'PositionAndVelocity'`, or `'Custom'`. The formats are

- `'Position'` – the fused measurement is the position of the target in the global coordinate frame.
- `'Velocity'` – the fused measurement is the velocity of the target in the global coordinate frame.
- `'PositionAndVelocity'` – the fused measurement is the position and velocity of the target in the global coordinate frame defined according to the format `[x;vx;y;vy;z;vz]`.
- `'Custom'` – custom fused measurement. To enable this format, specify a function using the `MeasurementFcn`.

Example: `'PositionAndVelocity'`

MeasurementFcn — Custom measurement function
char | string | function handle

Custom measurement function, specified as a character vector, string, or function handle. Specify the function that transforms fused measurements into sensor measurements. The function must have the following signature:

`sensorMeas = MeasurementFcn(fusedMeas,measParameters)`

Dependencies

To enable this property, set the `MeasurementFormat` property to `'Custom'`.

Data Types: `char` | `string` | `function_handle`

MaxNumSensors — Maximum number of sensors in surveillance region
3 (default) | positive integer greater than one

Maximum number of sensors in surveillance region, specified as a positive integer greater than one.

Data Types: `double`

Volume — Volume of sensor detection bin
`1e-2` (default) | positive scalar | *N*-length vector of positive scalars

Volume of sensors detection bins, specified as a positive scalar or *N*-length vector of positive scalars. *N* is the number of sensors. If specified as a scalar, each sensor is assigned the same volume. If a sensor produces an angle-only measurement, for example, azimuth and elevation, the volume is defined as the solid angle subtended by one bin.

Data Types: `double`

DetectionProbability — Probabilities of a target detection
`0.9` (default) | positive scalar | *N*-length vector of positive scalars

Probability of detection of a target by each sensor, specified as a scalar or *N*-length vector of positive scalars in the range (0,1). *N* is the number of sensors. If specified as a scalar, each sensor is assigned the same detection probability. The probability of detection is used in calculating the cost of fusing a "one" (target was detected) or "zero" (target was not detected) detections from each sensor.

Example: `0.99`

Data Types: `double`

FalseAlarmRate — Rate of false positives generated by sensors
`1e-6` (default) | positive scalar | *N*-length vector of positive scalars

Rate at which false positives are reported by sensor in each bin, specified as a scalar or *N*-length vector of positive scalars. *N* is the number of sensors. If specified as a scalar, each sensor is assigned the same false alarm rate. The false alarm rate is used to calculate the likelihood of clutter in the detections reported by each sensor.

Example: `1e-5`

Data Types: `double`

UseParallel — Option to use parallel computing resources
`false` (default) | `true`

Option to use parallel computing resources, specified as `false` or `true`. The `staticDetectionFuser` calculates the cost of fusing detections from each sensor as an n-D assignment problem. The fuser spends most of the time in computing the cost matrix for the assignment problem. If Parallel Computing Toolbox™ is installed, this option lets the fuser use the parallel pool of workers to compute the cost matrix.

Data Types: `logical`

TimeTolerance — Absolute tolerance between timestamps of detections
`1e-6` (default) | nonnegative scalar

Absolute tolerance between timestamps of detections, specified as a nonnegative scalar. The `staticDetectionFuser` assumes that sensors are synchronous. This property defines the allowed tolerance value between detection time-stamps to still be considered synchronous.

Example: `1e-3`

Data Types: `double`

Usage

Syntax

```
compositeDets = fuser(dets)
[compositeDets,analysisInfo] = fuser(dets)
```

Description

`compositeDets = fuser(dets)` returns the fused detections, `compositeDets`, of input detections, `dets`.

`[compositeDets,analysisInfo] = fuser(dets)` also returns analysis information, `analysisInfo`.

Input Arguments

dets — Pre-fused detections
cell array of `objectDetection` objects

Pre-fused detections, specified as a cell array of `objectDetection` objects.

Output Arguments

compositeDets — Fused detections
cell array of `objectDetection` objects

Pre-fused detections, returned as a cell array of `objectDetection` objects.

analysisInfo — Analysis information
structure

Analysis information, returned as a structure. The fields of the structure are:

- `CostMatrix` – *N*-dimensional cost matrix providing the cost of association of detections, where *N* is the number of sensors. The cost is the negative log-likelihood of the association and can be interpreted as the negative score of the track that will be generated by the fused measurement.

- `Assignments` – A *P*-by-*N* list of assignments, where *P* is the number of composite detections.

- `FalseAlarms` – A *Q*-by-1 list of indices of detections declared as false alarms by association.

Data Types: `struct`

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

release   Release resources and allow changes to System object property values and input characteristics
reset   Reset internal states of System object
isLocked   Determine if System object is in use
clone   Create duplicate System object

Examples

Fuse Detections from ESM Sensors

Fuse angle-only detections from three ESM sensors.

Load stored detections from the sensors.

```
load('angleOnlyDetectionFusion.mat','detections');
```

Visualize angle-only detections for plotting the direction vector.

```
rPlot = 5000;
plotData = zeros(3,numel(detections)*3);
for i = 1:numel(detections)
    az = detections{i}.Measurement(1);
    el = detections{i}.Measurement(2);
    [xt,yt,zt] = sph2cart(deg2rad(az),deg2rad(el),rPlot);
    % The sensor is co-located at platform center, therefore use
    % the position from the second measurement parameter
    originPos = detections{i}.MeasurementParameters(2).OriginPosition;
    positionData(:,i) = originPos(:);
    plotData(:,3*i-2) = [xt;yt;zt] + originPos(:);
    plotData(:,3*i-1) = originPos(:);
    plotData(:,3*i) = [NaN;NaN;NaN];
end
plot3(plotData(1,:),plotData(2,:),plotData(3,:),'r-')
hold on
plot3(positionData(1,:),positionData(2,:),positionData(3,:),'o','MarkerSize',12,'Marker
```
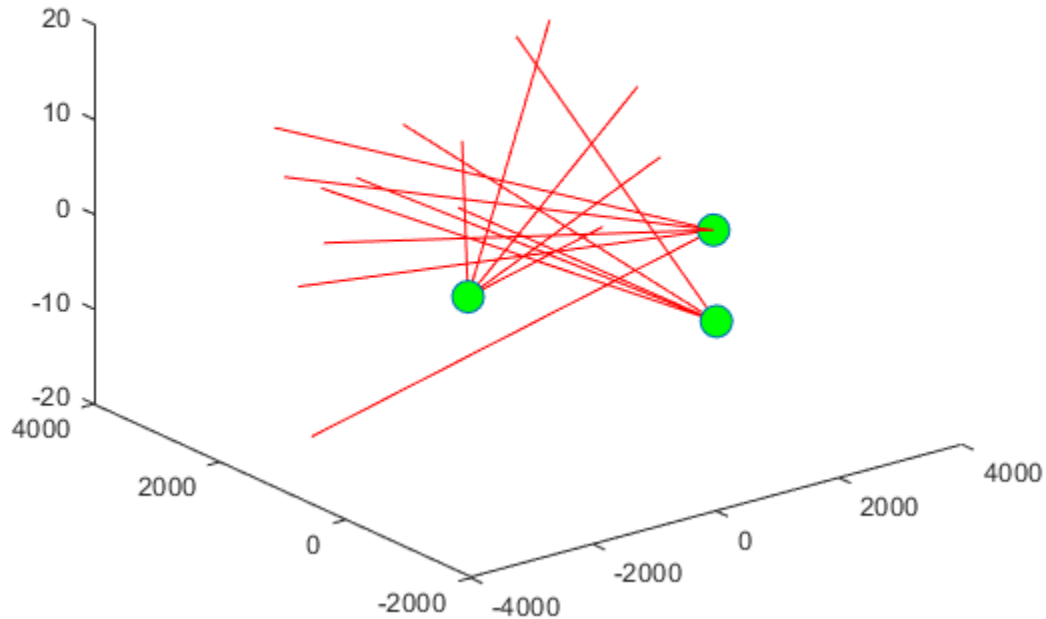
Create a `staticDetectionFuser` to fuse angle-only detections using the measurement fusion function `triangulateLOS`.

```
fuser = staticDetectionFuser('MeasurementFusionFcn','triangulateLOS','MaxNumSensors',3)
```

```
fuser =

  staticDetectionFuser with properties:

        FusedSensorIndex: 1
    MeasurementFusionFcn: 'triangulateLOS'
       MeasurementFormat: 'Position'
```

```
        MaxNumSensors: 3
              Volume: [3×1 double]
  DetectionProbability: [3×1 double]
       FalseAlarmRate: [3×1 double]

        TimeTolerance: 1.0000e-06
          UseParallel: false
```

Create the fused detections and obtain the analysis information.

```matlab
[fusedDetections, analysisInfo] = fuser(detections);
fusedPositions = zeros(3,numel(fusedDetections));
for i = 1:numel(fusedDetections)
    fusedPositions(:,i) = fusedDetections{i}.Measurement;
end
plot3(fusedPositions(1,:),fusedPositions(2,:),fusedPositions(3,:),'ko', ...
    'MarkerSize',12, 'MarkerFaceColor','k')
legend('Angle-only Detections','Sensor Positions','Fused Target Measurements')
title('Angle-only Detection Fusion')
xlabel('x [m]')
ylabel('y [m]')
view(2)
```
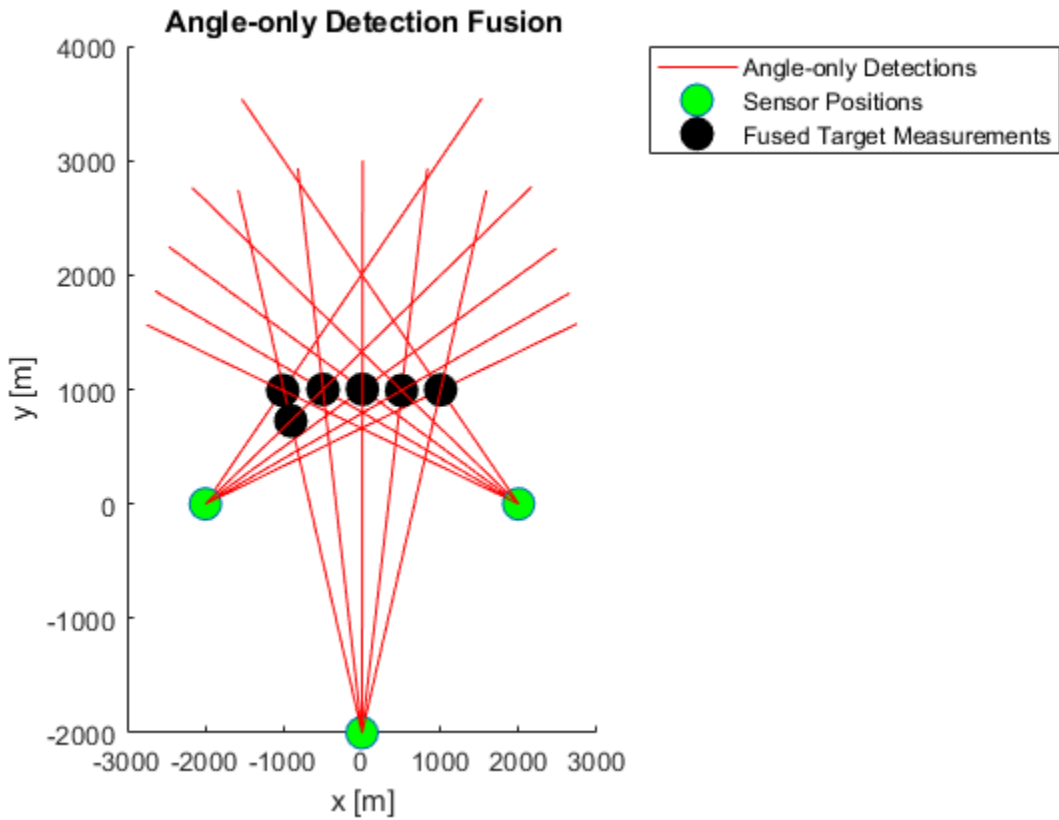
Use the analysisInfo output to check the assignments.

```
analysisInfo.Assignments
```

```
ans =

  6×3 uint32 matrix

     0   10   14
     1    6   11
     2    7   12
     3    8   13
     4    9    0
```

```
5     0    15
```

Algorithms

Detection Fusion Workflow

The static detection fuser:

- Calculates the cost of fusing or matching detections from each sensor to one another.
- Solves a 2-D or *S*-D assignment problem, where *S* is the number of sensors, to associate or match detections from one sensor to others.
- Fuses the measurement and measurement covariance of the associated detection n-tuples to generate a list of composite or fused detections.
- Declares unassigned detections from each sensor as false alarms.

The `staticDetectionFuser` assumes that all sensors are synchronous and generate detections simultaneously. The `staticDetectionFuser` also assumes that the sensors share a common surveillance region. Associating *n* detections from *m* sensors indicates *m* - *n* missed detections or false alarms.

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

Functions
`triangulateLOS`

Objects
objectDetection

System Objects
irSensor | monostaticRadarSensor | radarSensor | sonarSensor

Introduced in R2018b

Blocks in Sensor Fusion and Tracking Toolbox

Apps in Sensor Fusion and Tracking Toolbox