Robotics System Toolbox™

Reference

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3 Apple Hill Drive
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Contents

Classes — Alphabetical List

BagSelection

Create rosbag selection

Description

The `BagSelection` object is an index of the messages within a rosbag. You can use it to extract message data from a rosbag, select messages based on specific criteria, or create a `timeseries` of the message properties.

Creation

Syntax

```
bag = rosbag(filename)
```

```
bagsel = select(bag)
```

Description

`bag = rosbag(filename)` creates an indexable `BagSelection` object, `bag`, that contains all the message indexes from the rosbag at the input path, `filename`. To access the data, you can call `readMessages` or `timeseries` to extract relevant data.

See `rosbag` for other syntaxes.

`bagsel = select(bag)` returns an object, `bagsel`, that contains all the messages in the `BagSelection` object, `bag`.

This function does not change the contents of the original `BagSelection` object. The return object, `bagsel`, a new object that contains the specified message selection.

See `select` for other syntaxes. You can specify parameters to filter by criteria such as time and topic.

Properties

`FilePath` — Absolute path to rosbag file
character vector

This property is read-only.

Absolute path to the rosbag file, specified as a character vector.

Data Types: `char`

`StartTime` — Timestamp of first message in selection
scalar

This property is read-only.

Timestamp of the first message in the selection, specified as a scalar in seconds.

Data Types: `double`

`EndTime` — Timestamp of last message in selection
scalar

This property is read-only.

Timestamp of the last message in the selection, specified as a scalar in seconds.

Data Types: `double`

`NumMessages` — Number of messages in selection
scalar

This property is read-only.

Number of messages in the selection, specified as a scalar. When you first load a rosbag, this property contains the number of messages in the rosbag. Once you select a subset of messages with `select`, the property shows the number of messages in this subset.

Data Types: `double`

`AvailableTopics` — Table of topics in selection
table

This property is read-only.

Table of topics in the selection, specified as a table. Each row in the table lists one topic, the number of messages for this topic, the message type, and the definition of the type. For example:

```
          NumMessages        MessageType                          MessageDefinit:
          _____        _____        _____

   /odom  99                 nav_msgs/Odometry       '# This represents an estimate of a po
```

Data Types: `table`

AvailableFrames — List of available coordinate frames
cell array of character vectors

This property is read-only.

List of available coordinate frames, returned as a cell array of character vectors. Use `canTransform` to check whether specific transformations between frames are available, or `getTransform` to query a transformation.

Data Types: `cell array`

MessageList — List of messages in selection
table

This property is read-only.

List of messages in the selection, specified as a table. Each row in the table lists one message.

Data Types: `table`

Object Functions

canTransform	Verify if transformation is available
getTransform	Retrieve transformation between two coordinate frames
readMessages	Read messages from rosbag
select	Select subset of messages in rosbag
timeseries	Creates a time series object for selected message properties

Examples

Create rosbag Selection Using BagSelection Object

Create a `BagSelection` object from a rosbag log file and parse out specific messages based on the selected criteria.

Create a `BagSelection` object of all the messages in the rosbag log file.

```
bagMsgs = robotics.ros.Bag.parse('ex_multiple_topics.bag');
```

Select a subset of the messages based on their timestamp and topic.

```
bagMsgs2 = select(bagMsgs,'Time',...
            [bagMsgs.StartTime bagMsgs.StartTime + 1],'Topic','/odom');
```

Retrieve the messages in the selection as a cell array.

```
msgs = readMessages(bagMsgs2);
```

Return certain message properties as a time series.

```
ts = timeseries(bagMsgs2,'Pose.Pose.Position.X', ...
            'Twist.Twist.Angular.Y');
```

Retrieve Information from rosbag

Retrieve information from the rosbag. Specify the full path to the rosbag if it is not already available on the MATLAB® path.

```
bagselect = rosbag('ex_multiple_topics.bag');
```

Select a subset of the messages, filtered by time and topic.

```
bagselect2 = select(bagselect,'Time',...
    [bagselect.StartTime bagselect.StartTime + 1],'Topic','/odom');
```

Display rosbag Information from File

To view information about a rosbag log file, use `rosbag info` *filename*, where *filename* is a rosbag (`.bag`) file.

```
rosbag info 'ex_multiple_topics.bag'

Path:     C:\TEMP\Bdoc18a_815039_17936\ib0BF173\13\tp528964cd\robotics-ex61825935\ex_mu
Version:  2.0
Duration: 2:00s (120s)
Start:    Dec 31 1969 19:03:21.34 (201.34)
End:      Dec 31 1969 19:05:21.34 (321.34)
Size:     23.6 MB
Messages: 36963
Types:    gazebo_msgs/LinkStates [48c080191eb15c41858319b4d8a609c2]
          nav_msgs/Odometry      [cd5e73d190d741a2f92e81eda573aca7]
          rosgraph_msgs/Clock    [a9c97c1d230cfc112e270351a944ee47]
          sensor_msgs/LaserScan  [90c7ef2dc6895d81024acba2ac42f369]
Topics:   /clock              12001 msgs  : rosgraph_msgs/Clock
          /gazebo/link_states 11999 msgs  : gazebo_msgs/LinkStates
          /odom               11998 msgs  : nav_msgs/Odometry
          /scan                 965 msgs  : sensor_msgs/LaserScan
```

Get Transformations from rosbag File

Get transformations from rosbag (`.bag`) files by loading the rosbag and checking the available frames. From these frames, use `getTransform` to query the transformation between two coordinate frames.

Load the rosbag.

```
bag = rosbag('ros_turtlesim.bag');
```

Get a list of available frames.

```
frames = bag.AvailableFrames;
```

Get the latest transformation between two coordinate frames.

```
tf = getTransform(bag,'world',frames{1});
```

Check for a transformation available at a specific time and retrieve the transformation. Use `canTransform` to check if the transformation is available. Specify the time using `rostime`.

```
tfTime = rostime(bag.StartTime + 1);
if (canTransform(bag,'world',frames{1},tfTime))
    tf2 = getTransform(bag,'world',frames{1},tfTime);
end
```

Read Messages from a rosbag as a Structure

Load the rosbag.

```
bag = rosbag('ros_turtlesim.bag');
```

Select a specific topic.

```
bSel = select(bag,'Topic','/turtle1/pose');
```

Read messages as a structure. Specify the `DataFormat` name-value pair when reading the messages. Inspect the first structure in the returned cell array of structures.

```
msgStructs = readMessages(bSel,'DataFormat','struct');
msgStructs{1}

ans = struct with fields:
        MessageType: 'turtlesim/Pose'
                  X: 5.5016
                  Y: 6.3965
              Theta: 4.5377
     LinearVelocity: 1
    AngularVelocity: 0
```

Extract the *xy* points from the messages and plot the robot trajectory.

Use `cellfun` to extract all the X and Y fields from the structure. These fields represent the *xy* positions of the robot during the rosbag recording.

```
xPoints = cellfun(@(m) double(m.X),msgStructs);
yPoints = cellfun(@(m) double(m.Y),msgStructs);
plot(xPoints,yPoints)
```

- "Work with rosbag Logfiles"

See Also

`canTransform` | `getTransform` | `readMessages` | `select` | `timeseries`

Topics

"Work with rosbag Logfiles"
"ROS Log Files (rosbags)"

Introduced in R2015a

Core

Create ROS Core

Description

The ROS Core encompasses many key components and nodes that are essential for the ROS network. You must have exactly one ROS core running in the ROS network for nodes to communicate. Using this class allows the creation of a ROS core in MATLAB®. Once the core is created, you can connect to it by calling `rosinit` or `robotics.ros.Node`.

Creation

Syntax

```
core = robotics.ros.Core
core = robotics.ros.Core(port)
```

Description

`core = robotics.ros.Core` returns a `Core` object and starts a ROS core in MATLAB. This ROS core has a default port of `11311`. MATLAB only allows the creation of one core on any given port and displays an error if another core is detected on the same port.

`core = robotics.ros.Core(port)` starts a ROS core at the specified port, `port`.

Properties

Port — Network port at which the ROS master is listening
11311 (default) | scalar

This property is read-only.

Network port at which the ROS master is listening, returned as a scalar.

MasterURI — The URI on which the ROS master can be reached
'http://<HOSTNAME>:11311' (default) | character vector

This property is read-only.

The URI on which the ROS master can be reached, returned as a character vector. The MasterURI is constructed based on the host name of your computer. If your host name is not valid, the IP address of your first network interface is used.

Examples

Create ROS Core

Create ROS core on localhost and default port 11311.

```
core = robotics.ros.Core;
```

Clear the ROS core to shut down the ROS network.

```
clear('core')
```

Create ROS Core On Specific Port

Create ROS core on localhost and port 12000.

```
core = robotics.ros.Core(12000);
```

Clear the ROS core to shut down the ROS network.

```
clear('core')
```

•   "Connect to a ROS Network"

See Also
Node | rosinit

Topics
"Connect to a ROS Network"
"ROS Network Setup"

External Websites
ROS Core

Introduced in R2015a

CompressedImage

Create compressed image message

Description

The `CompressedImage` object is an implementation of the `sensor_msgs/CompressedImage` message type in ROS. The object contains the compressed image and meta-information about the message. You can create blank `CompressedImage` messages and populate them with data, or subscribe to image messages over the ROS network. To convert the image to a MATLAB image, use the `readImage` function.

Only images that are sent through the ROS Image Transport package are supported for conversion to MATLAB images.

Creation

Syntax

`msg = rosmessage('sensor_msgs/CompressedImage')`

Description

`msg = rosmessage('sensor_msgs/CompressedImage')` creates an empty `CompressedImage` object. To specify image data, use the `msg.Data` property. You can also get these image messages off the ROS network using `rossubscriber`.

Properties

MessageType — Message type of ROS message
character vector

This property is read-only.

Message type of ROS message, returned as a character vector.

Data Types: `char`

Header — ROS Header message
`Header` object

This property is read-only.

ROS Header message, returned as a `Header` object. This header message contains the `MessageType`, sequence (`Seq`), timestamp (`Stamp`), and `FrameId`.

Format — Image format
character vector

Image format, specified as a character vector.

Example: `'bgr8; jpeg compressed bgr8'`

Data — Image data
`uint8` array

Image data, specified as a `uint8` array.

Object Functions

readImage   Convert ROS image data into MATLAB image

Examples

Read and Write `CompressedImage` Messages

Read and write a sample ROS `CompressedImage` message by converting it

Load sample ROS messages and inspect the image message. `imgcomp` is a sample ROS `CompressedImage` message object.

```
exampleHelperROSLoadMessages
imgcomp

imgcomp =
  ROS CompressedImage message with properties:
```

```
   MessageType: 'sensor_msgs/CompressedImage'
        Header: [1x1 Header]
        Format: 'bgr8; jpeg compressed bgr8'
          Data: [30376x1 uint8]

  Use showdetails to show the contents of the message
```

Create a MATLAB image from the `CompressedImage` message using `readImage` and display it.

```
I = readImage(imgcomp);
imshow(I)
```

Create Blank Compressed Image Message

```
compImg = rosmessage('sensor_msgs/CompressedImage')

compImg =
  ROS CompressedImage message with properties:

    MessageType: 'sensor_msgs/CompressedImage'
         Header: [1x1 Header]
         Format: ''
           Data: [0x1 uint8]
```

```
Use showdetails to show the contents of the message
```

- "Work with Specialized ROS Messages"

See Also

readImage | rosmessage | rossubscriber

Topics
"Work with Specialized ROS Messages"

Introduced in R2015a

Image

Create image message

Description

The `Image` object is an implementation of the `sensor_msgs/Image` message type in ROS. The object contains the image and meta-information about the message. You can create blank `Image` messages and populate them with data, or subscribe to image messages over the ROS network. To convert the image to a MATLAB image, use the `readImage` function.

Creation

Syntax

```
msg = rosmessage('sensor_msgs/Image')
```

Description

`msg = rosmessage('sensor_msgs/Image')` creates an empty `Image` object. To specify image data, use the `msg.Data` property. You can also get these image messages off the ROS network using `rossubscriber`.

Properties

MessageType — Message type of ROS message
character vector

This property is read-only.

Message type of ROS message, returned as a character vector.

Data Types: `char`

Header — ROS Header message
Header object

This property is read-only.

ROS Header message, returned as a Header object. This header message contains the MessageType, sequence (Seq), timestamp (Stamp), and FrameId.

Height — Image height in pixels
scalar

Image height in pixels, specified as a scalar.

Width — Image width in pixels
scalar

Image width in pixels, specified as a scalar.

Encoding — Image encoding
character vector

Image encoding, specified as a character vector.

Example: 'rgb8'

IsBigendian — Image byte sequence
true | false

Image byte sequence, specified as a true or false.

- true —Big endian sequence. Stores the most significant byte in the smallest address.
- false —Little endian sequence. Stores the least significant byte in the smallest address.

The Big endian sequence stores the most significant byte in the smallest address. The Little endian sequence stores the least significant byte in the smallest address.

Step — Full row length in bytes
integer

Full row length in bytes, specified as an integer. This length depends on the color depth and the pixel width of the image. For example, an RGB image has 3 bytes per pixel, so an image with width 640 has a step of 1920.

Data — Image data
uint8 array

Image data, specified as a `uint8` array.

Object Functions

readImage   Convert ROS image data into MATLAB image
writeImage   Write MATLAB image to ROS image message

Examples

Read and Write Image Messages

Read and write a sample ROS `Image` message by converting it to a MATLAB image. Then, convert a MATLAB® image to ROS message.

Load sample ROS messages and inspect the image message data. `img` is a sample ROS `Image` message object.

```
exampleHelperROSLoadMessages
img

img =
  ROS Image message with properties:

    MessageType: 'sensor_msgs/Image'
         Header: [1x1 Header]
         Height: 480
          Width: 640
       Encoding: 'rgb8'
    IsBigendian: 0
           Step: 1920
           Data: [921600x1 uint8]

  Use showdetails to show the contents of the message
```

Create a MATLAB image from the `Image` message using `readImage` and display it.

```
I = readImage(img);
imshow(I)
```
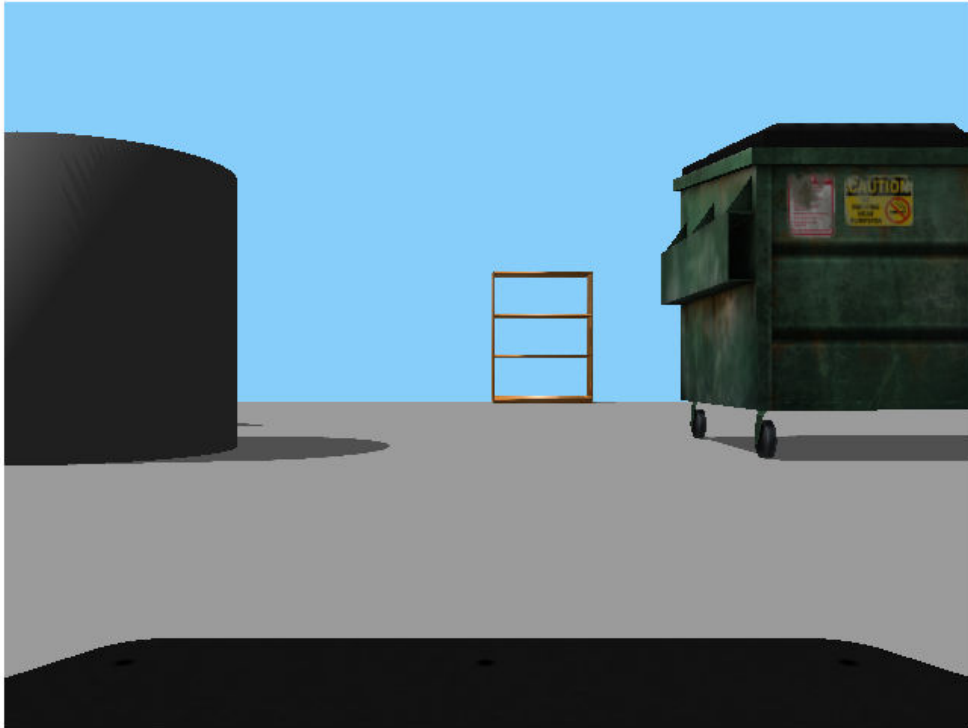

Create a ROS `Image` message from a MATLAB image.

```
imgMsg = rosmessage('sensor_msgs/Image');
imgMsg.Encoding = 'rgb8'; % Specifies Image Encoding Type
writeImage(imgMsg,I)
imgMsg
```

```
imgMsg =
  ROS Image message with properties:

    MessageType: 'sensor_msgs/Image'
```

```
       Header: [1x1 Header]
       Height: 480
        Width: 640
     Encoding: 'rgb8'
  IsBigendian: 0
         Step: 1920
         Data: [921600x1 uint8]

Use showdetails to show the contents of the message
```

Create Blank Image Message

```
msg = rosmessage('sensor_msgs/Image')

msg =
  ROS Image message with properties:

    MessageType: 'sensor_msgs/Image'
         Header: [1x1 Header]
         Height: 0
          Width: 0
       Encoding: ''
    IsBigendian: 0
           Step: 0
           Data: [0x1 uint8]

Use showdetails to show the contents of the message
```

• "Work with Specialized ROS Messages"

See Also
readImage | rosmessage | rossubscriber | writeImage

Topics
"Work with Specialized ROS Messages"

Introduced in R2015a

LaserScan

Create laser scan message

Description

The `LaserScan` object is an implementation of the `sensor_msgs/LaserScan` message type in ROS. The object contains meta-information about the message and the laser scan data. You can extract the ranges and angles using the `Ranges` property and the `readScanAngles` function. To access points in Cartesian coordinates, use `readCartesian`.

You can also convert this to a `lidarScan` object to use with other robotics algorithms such as `matchScans`, `robotics.VectorFieldHistogram`, or `robotics.MonteCarloLocalization`.

Creation

Syntax

scan = rosmessage('sensor_msgs/LaserScan')

Description

scan = rosmessage('sensor_msgs/LaserScan') creates an empty `LaserScan` object. You can specify scan info and data using the properties, or you can get these messages off a ROS network using `rossubscriber`.

Properties

MessageType — Message type of ROS message
character vector

This property is read-only.

Message type of ROS message, returned as a character vector.

Data Types: char

Header — ROS Header message
Header object

This property is read-only.

ROS Header message, returned as a Header object. This header message contains the MessageType, sequence (Seq), timestamp (Stamp), and FrameId. Timestamp relates to the acquisition time of the first ray in the scan.

AngleMin — Minimum angle of range data
scalar

Minimum angle of range data, specified as a scalar in radians. Positive angles are measured from the forward direction of the robot.

AngleMax — Maximum angle of range data
scalar

Maximum angle of range data, specified as a scalar in radians. Positive angles are measured from the forward direction of the robot.

AngleIncrement — Angle increment of range data
scalar

Angle increment of range data, specified as a scalar in radians.

TimeIncrement — Time between individual range data points in seconds
scalar

Time between individual range data points in seconds, specified as a scalar.

ScanTime — Time to complete a full scan in seconds
scalar

Time to complete a full scan in seconds, specified as a scalar.

RangeMin — Minimum valid range value
scalar

Minimum valid range value, specified as a scalar.

RangeMax — Maximum valid range value
scalar

Maximum valid range value, specified as a scalar.

Ranges — Range readings from laser scan
vector

Range readings from laser scan, specified as a vector. To get the corresponding angles, use `readScanAngles`.

Intensities — Intensity values from range readings
vector

Intensity values from range readings, specified as a vector. If no valid intensity readings are found, this property is empty.

Object Functions

lidarScan	Create object for storing 2-D lidar scan
plot	Display laser or lidar scan readings
readCartesian	Read laser scan ranges in Cartesian coordinates
readScanAngles	Return scan angles for laser scan range readings

Examples

Inspect Sample Laser Scan Message

Load, inspect, and display a sample laser scan message.

Create sample messages and inspect the laser scan message data. `scan` is a sample ROS `LaserScan` message object.

```
exampleHelperROSLoadMessages
scan

scan =
  ROS LaserScan message with properties:

        MessageType: 'sensor_msgs/LaserScan'
```

```
        Header: [1x1 Header]
      AngleMin: -0.5467
      AngleMax: 0.5467
AngleIncrement: 0.0017
 TimeIncrement: 0
      ScanTime: 0.0330
      RangeMin: 0.4500
      RangeMax: 10
        Ranges: [640x1 single]
   Intensities: [0x1 single]

Use showdetails to show the contents of the message
```

Get ranges and angles from the object properties. Check that the ranges and angles are the same size.

```
ranges = scan.Ranges;
angles = scan.readScanAngles;
size(ranges)
```

ans = *1×2*

```
   640      1
```

```
size(angles)
```

ans = *1×2*

```
   640      1
```

Display laser scan data in a figure using `plot`.

```
plot(scan)
```
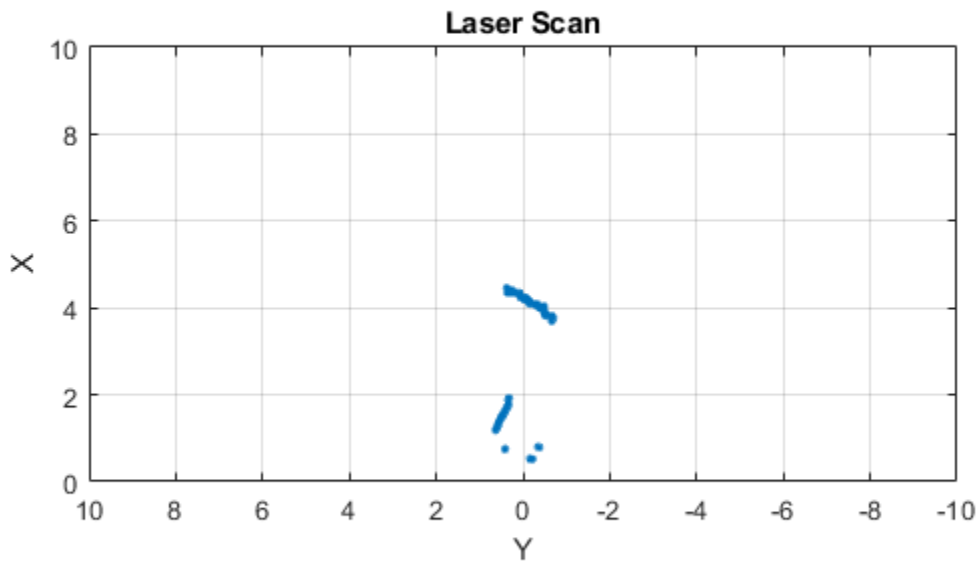
Create Empty LaserScan Message

```
scan = rosmessage('sensor_msgs/LaserScan')

scan =
  ROS LaserScan message with properties:

        MessageType: 'sensor_msgs/LaserScan'
             Header: [1x1 Header]
           AngleMin: 0
           AngleMax: 0
     AngleIncrement: 0
```

```
    TimeIncrement: 0
         ScanTime: 0
         RangeMin: 0
         RangeMax: 0
           Ranges: [0x1 single]
      Intensities: [0x1 single]

Use showdetails to show the contents of the message
```

- "Work with Specialized ROS Messages"

See Also

lidarScan | plot | readCartesian | readScanAngles | rosmessage | rossubscriber | showdetails

Topics

"Work with Specialized ROS Messages"

Introduced in R2016a

Node

Start ROS node and connect to ROS master

Description

The `robotics.ros.Node` object represents a ROS node in the ROS network. The object enables you to communicate with the rest of the ROS network. You must create a node before you can use other ROS functionality, such as publishers, subscribers, and services.

You can create a ROS node using the `rosinit` function, or by calling `robotics.ros.Node`:

- `rosinit` — Creates a single ROS node in MATLAB. You can specify an existing ROS master, or the function creates one for you. The `Node` object is not visible.

- `robotics.ros.Node`— Creates multiple ROS nodes for use on the same ROS network in MATLAB.

Creation

Syntax

```
N = robotics.ros.Node(Name)
N = robotics.ros.Node(Name,Host)
N = robotics.ros.Node(Name,Host,Port)
N = robotics.ros.Node(Name,MasterURI,Port)
N = robotics.ros.Node( ___ ,'NodeHost',HostName)
```

Description

`N = robotics.ros.Node(Name)` initializes the ROS node with `Name` and tries to connect to the ROS master at default URI, `http://localhost:11311`.

`N = robotics.ros.Node(Name,Host)` tries to connect to the ROS master at the specified IP address or host name, `Host` using the default port number, `11311`.

`N = robotics.ros.Node(Name,Host,Port)`tries to connect to the ROS master with port number, `Port`.

`N = robotics.ros.Node(Name,MasterURI,Port)` tries to connect to the ROS master at the specified IP address, `MasterURI`.

`N = robotics.ros.Node( ___ ,'NodeHost',HostName)` specifies the IP address or host name that the node uses to advertise itself to the ROS network. Examples include `'192.168.1.1'` or `'comp-home'`. You can use any of the arguments from the previous syntaxes.

Properties

Name — Name of the node
character vector

Name of the node, specified as a character vector. The node name must be a valid ROS graph name. See ROS Names.

MasterURI — URI of the ROS master
character vector

URI of the ROS master, specified as a character vector. The node is connected to the ROS master with the given URI.

NodeURI — URI for the node
character vector

URI for the node, specified as a character vector. The node uses this URI to advertise itself on the ROS network for others to connect to it.

CurrentTime — Current ROS network time
Time object

Current ROS network time, specified as a `Time` object. For more information, see `rostime`.

Examples

Create Multiple ROS Nodes

Create multiple ROS nodes. Use the `Node` object with publishers, subscribers, and other ROS functionality to specify with which node you are connecting to.

Create a ROS master.

```
master = robotics.ros.Core;
```

Initialize multiple nodes.

```
node1 = robotics.ros.Node('/test_node_1');
node2 = robotics.ros.Node('/test_node_2');
```

Use these nodes to perform separate operations and send separate messages. A message published by `node1` can be accessed by a subscriber running in `node2`.

```
pub = robotics.ros.Publisher(node1,'/chatter','std_msgs/String');
sub = robotics.ros.Subscriber(node2,'/chatter','std_msgs/String');

msg = rosmessage('std_msgs/String');
msg.Data = 'Message from Node 1';
```

Send a message from `node1`. The subscriber attached to `node2` will receive the message.

```
send(pub,msg) % Sent from node 1
pause(1) % Wait for message to update
sub.LatestMessage

ans =
  ROS String message with properties:

    MessageType: 'std_msgs/String'
           Data: 'Message from Node 1'

  Use showdetails to show the contents of the message
```

Clear the ROS network of publisher, subscriber, and nodes. Delete the `Core` object to shut down the ROS master.

```
clear('pub','sub','node1','node2')
clear('master')
```

Connect to Multiple ROS Masters

Connecting to multiple ROS masters is possible using MATLAB®. These separate ROS masters do not share information and must have different port numbers. Connect ROS nodes to each master based on how you want to separate information across the network.

Create two ROS masters on different ports.

```
m1 = robotics.ros.Core; % Default port of 11311
m2 = robotics.ros.Core(12000);
```

Connect separate ROS nodes to each ROS master.

```
node1 = robotics.ros.Node('/test_node_1','localhost');
node2 = robotics.ros.Node('/test_node_2','localhost',12000);
```

Clear the ROS nodes. Shut down the ROS masters.

```
clear('node1','node2')
clear('m1','m2')
```

See Also
rosinit | rosshutdown

Topics
"ROS Network Setup"

External Websites
ROS Nodes

Introduced in R2015a

OccupancyGrid

Create occupancy grid message

Description

The `OccupancyGrid` object is an implementation of the `nav_msgs/OccupancyGrid` message type in ROS. The object contains meta-information about the message and the occupancy grid data. To create a `robotics.BinaryOccupancyGrid` object from a ROS message, use `readBinaryOccupancyGrid`.

Note See `robotics.OccupancyGrid` for the MATLAB representation of occupancy grids independent of ROS.

Creation

Syntax

```
msg = rosmessage('nav_msgs/OccupancyGrid');
```

Description

`msg = rosmessage('nav_msgs/OccupancyGrid');` creates an empty `OccupancyGrid` object. To specify map information and data, use the `map.Info` and `msg.Data` properties. You can also get the occupancy grid messages off the ROS network using `rossubscriber`.

Properties

MessageType — Message type of ROS message
character vector

This property is read-only.

Message type of ROS message, returned as a character vector.

Data Types: char

Header — ROS Header message
Header object

This property is read-only.

ROS Header message, returned as a Header object. This header message contains the MessageType, sequence (Seq), timestamp (Stamp), and FrameId.

Info — Information about the map
MapMetaData object

Information about the map, specified as a MapMetaData object. It contains the width, height, resolution, and origin of the map.

Data — Map data
vector

Map data, specified as a vector. The vector is all the occupancy data from each grid location in a single 1-D array.

Object Functions

readBinaryOccupancyGrid   Read binary occupancy grid
writeBinaryOccupancyGrid   Write values from grid to ROS message

Examples

Create Occupancy Grid from 2-D Map

Load two maps, simpleMap and complexMap, as logical matrices. Use whos to show the map.

```
filePath = fullfile(fileparts(which('PathPlanningExample')),'data','exampleMaps.mat');
load(filePath)
whos *Map*
```

```
Name               Size               Bytes  Class       Attributes

complexMap        41x52                2132  logical
simpleMap         26x27                 702  logical
ternaryMap       501x501            2008008  double
```

Create a ROS message from `simpleMap` using a `BinaryOccupancyGrid` object. Write
the `OccupancyGrid` message using `writeBinaryOccupancyGrid`.

```
bogMap = robotics.BinaryOccupancyGrid(double(simpleMap));
mapMsg = rosmessage('nav_msgs/OccupancyGrid');
writeBinaryOccupancyGrid(mapMsg,bogMap)
mapMsg

mapMsg =
  ROS OccupancyGrid message with properties:

    MessageType: 'nav_msgs/OccupancyGrid'
         Header: [1x1 Header]
           Info: [1x1 MapMetaData]
           Data: [702x1 int8]

  Use showdetails to show the contents of the message
```

Use `readBinaryOccupancyGrid` to convert the ROS message to a
`BinaryOccupancyGrid` object. Use the object function `show` to display the map.

```
bogMap2 = readBinaryOccupancyGrid(mapMsg);
show(bogMap2);
```

Binary Occupancy Grid
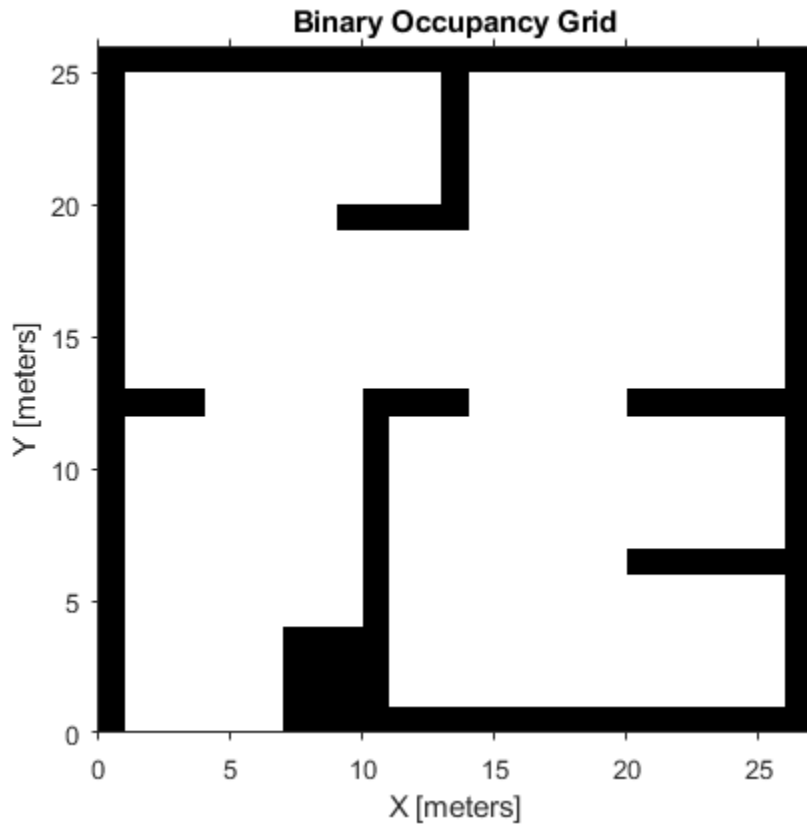
See Also
readBinaryOccupancyGrid | robotics.BinaryOccupancyGrid | rosmessage |
rossubscriber | writeBinaryOccupancyGrid

Topics
"Occupancy Grids"

Introduced in R2015a

PointCloud2

Access point cloud messages

Description

The `PointCloud2` object is an implementation of the `sensor_msgs/PointCloud2` message type in ROS. The object contains meta-information about the message and the point cloud data. To access the actual data, use `readXYZ` to get the point coordinates and `readRGB` to get the color information, if available.

Creation

Syntax

```
ptcloud = rosmessage('sensor_msgs/PointCloud2')
```

Description

`ptcloud = rosmessage('sensor_msgs/PointCloud2')` creates an empty `PointCloud2` object. To specify point cloud data, use the `ptcloud.Data` property. You can also get point cloud data messages off the ROS network using `rossubscriber`.

Properties

`PreserveStructureOnRead` — Preserve the shape of point cloud matrix
`false` (default) | true

This property is read-only.

Preserve the shape of point cloud matrix, specified as `false` or `true`. When the property is `true`, the output data from `readXYZ` and `readRGB` are returned as matrices instead of vectors.

MessageType — Message type of ROS message
character vector

This property is read-only.

Message type of ROS message, returned as a character vector.

Data Types: `char`

Header — ROS Header message
`Header` object

This property is read-only.

ROS Header message, returned as a `Header` object. This header message contains the `MessageType`, sequence (`Seq`), timestamp (`Stamp`), and `FrameId`.

Height — Point cloud height in pixels
integer

Point cloud height in pixels, specified as an integer.

Width — Point cloud width in pixels
integer

Point cloud width in pixels, specified as an integer.

IsBigendian — Image byte sequence
true | false

Image byte sequence, specified as a `true` or `false`.

- `true` —Big endian sequence. Stores the most significant byte in the smallest address.
- `false` —Little endian sequence. Stores the least significant byte in the smallest address.

The Big endian sequence stores the most significant byte in the smallest address. The Little endian sequence stores the least significant byte in the smallest address.

PointStep — Length of a point in bytes
integer

Length of a point in bytes, specified as an integer.

RowStep — Full row length in bytes
integer

Full row length in bytes, specified as an integer. The row length equals the `PointStep` property multiplied by the `Width` property.

Data — Point cloud data
uint8 array

Point cloud data, specified as a `uint8` array. To access the data, use the "Object Functions" on page 1-40.

Object Functions

readAllFieldNames	Get all available field names from ROS point cloud
readField	Read point cloud data based on field name
readRGB	Extract RGB values from point cloud data
readXYZ	Extract XYZ coordinates from point cloud data
scatter3	Display point cloud in scatter plot
showdetails	Display all ROS message contents

Examples

Inspect Point Cloud Image

Access and visualize the data inside a point cloud message.

Create sample ROS messages and inspect a point cloud image. `ptcloud` is a sample ROS `PointCloud2` message object.

```
exampleHelperROSLoadMessages
ptcloud

ptcloud =
  ROS PointCloud2 message with properties:

    PreserveStructureOnRead: 0
                MessageType: 'sensor_msgs/PointCloud2'
                     Header: [1x1 Header]
                     Height: 480
```

```
                  Width: 640
            IsBigendian: 0
              PointStep: 32
                RowStep: 20480
                IsDense: 0
                 Fields: [4x1 PointField]
                   Data: [9830400x1 uint8]

  Use showdetails to show the contents of the message
```

Get RGB info and *xyz*-coordinates from the point cloud using `readXYZ` and `readRGB`.

```
xyz = readXYZ(ptcloud);
rgb = readRGB(ptcloud);
```

Display the point cloud in a figure using `scatter3`.

```
scatter3(ptcloud)
```
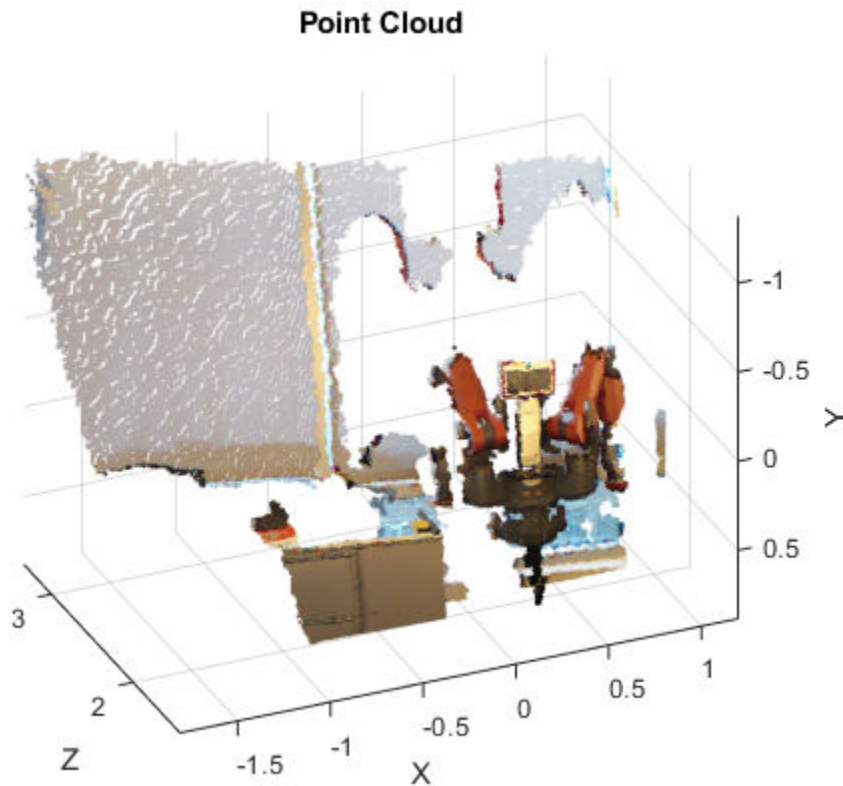
Point Cloud

Create `pointCloud` Object Using Point Cloud Message

Convert a Robotics System Toolbox™ point cloud message into a Computer Vision System Toolbox™ `pointCloud` object.

Load sample messages.

```
exampleHelperROSLoadMessages
```

Convert a `ptcloud` message to the `pointCloud` object.

```
pcobj = pointCloud(readXYZ(ptcloud),'Color',uint8(255*readRGB(ptcloud)))
```

```
pcobj =
  pointCloud with properties:

     Location: [307200x3 single]
        Color: [307200x3 uint8]
       Normal: []
    Intensity: []
        Count: 307200
       XLimits: [-1.8147 1.1945]
       YLimits: [-1.3714 0.8812]
       ZLimits: [1.4190 3.3410]
```

*   "Work with Specialized ROS Messages"

See Also

readAllFieldNames | readField | readRGB | readXYZ | rosmessage | rossubscriber | scatter3 | showdetails

Topics
"Work with Specialized ROS Messages"

Introduced in R2015a

rosdevice

Connect to remote ROS device

Description

The `rosdevice` object is used to create a connection with a ROS device. The object contains the necessary login information and other parameters of the ROS distribution. Once a connection is made using `rosdevice`, you can run and stop a ROS core or ROS nodes and check the status of the ROS network. Before running ROS nodes, you must connect MATLAB to the ROS network using `rosinit`.

You can deploy ROS nodes to a ROS device using Simulink® models. For an example, see "Generate a Standalone ROS Node from Simulink®".

Note To connect to a ROS device, an SSH server must be installed on the device.

Creation

Syntax

```
device = rosdevice(deviceAddress,username,password)
device = rosdevice
```

Description

`device = rosdevice(deviceAddress,username,password)` creates a `rosdevice` object connected to the ROS device at the specified address and with the specified user name and password.

`device = rosdevice` creates a `rosdevice` object connected to a ROS device using the saved values for `deviceAddress`, `username`, and `password`.

Properties

DeviceAddress — Hostname or IP address of the ROS device
character vector

This property is read-only.

Hostname or IP address of the ROS device, specified as a character vector.

Example: `'192.168.1.10'`

Example: `'samplehost.foo.com'`

UserName — User name used to connect to the ROS device
character vector

This property is read-only.

User name used to connect to the ROS device, specified as a character vector.

Example: `'user'`

ROSFolder — Location of ROS installation
character vector

Location of ROS installation, specified as a character vector. If a folder is not specified, MATLAB tries to determine the correct folder for you. When you deploy a ROS node, set this value from Simulink in the **Configuration Parameters** dialog box, under **Hardware Implementation**.

Example: `'/opt/ros/hydro'`

CatkinWorkspace — Catkin folder where models are deployed on device
character vector

Catkin folder where models are deployed on device, specified as a character vector. When you deploy a ROS node, set this value from Simulink in the **Configuration Parameters** dialog box, under **Hardware Implementation**.

Example: `'~/catkin_ws_test'`

AvailableNodes — Nodes available to run on ROS device
cell array of character vectors

This property is read-only.

Nodes available to run on ROS device, returned as a cell array of character vectors. Nodes are only listed if they are part of the `CatkinWorkspace` and have been deployed to the device using Simulink.

Example: `{'robotcontroller','publishernode'}`

Object Functions

runNode	Start ROS node
stopNode	Stop ROS node
isNodeRunning	Determine if ROS node is running
runCore	Start ROS core
stopCore	Stop ROS core
isCoreRunning	Determine if ROS core is running
system	Execute system command on device
putFile	Copy file to device
getFile	Get file from device
deleteFile	Delete file from device
dir	List folder contents on device
openShell	Open interactive command shell to device

Examples

Run ROS Core on ROS Device

Connect to a remote ROS device and start a ROS core. The ROS core is needed to run ROS nodes to communicate via a ROS network. You can run and stop a ROS core or node and check their status using a `rosdevice` object.

Create a connection to a ROS device. Specify the address, user name, and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using `runNode`.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password')
```

```
d =
```

```
rosdevice with properties:

    DeviceAddress: '192.168.154.131'
         Username: 'user'
        ROSFolder: '/opt/ros/hydro'
  CatkinWorkspace: '~/catkin_ws_test'
   AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core and check if it is running.

```
runCore(d)
running = isCoreRunning(d)


running =

  logical

   1
```

Stop the ROS core and confirm that it is no longer running.

```
stopCore(d)
running = isCoreRunning(d)


running =

  logical

   0
```

Run ROS Node on ROS Device

Connect to a remote ROS device and start a ROS node. First, run a ROS core so that ROS nodes can communicate via a ROS network. You can run and stop a ROS core or node and check their status using a rosdevice object.

Create a connection to a ROS device. Specify the address, user name and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using `runNode`.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password');
d.ROSFolder = '/opt/ros/hydro';
d.CatkinWorkspace = '~/catkin_ws_test'
```

```
d =

  rosdevice with properties:

      DeviceAddress: '192.168.154.131'
           Username: 'user'
          ROSFolder: '/opt/ros/hydro'
    CatkinWorkspace: '~/catkin_ws_test'
     AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core. Connect MATLAB® to the ROS master using `rosinit`. This core enables you to run ROS nodes on your ROS device.

```
runCore(d)
rosinit(d.DeviceAddress)
```

```
Another roscore / ROS master is already running on the ROS device. Use the 'stopCore'
Initializing global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:56
```

Check the available ROS nodes on the connected ROS device. These nodes were generated from Simulink® models following the process in the Generate a standalone ROS node from Simulink® example.

```
d.AvailableNodes
```

```
ans =

  1×2 cell array

    'robotcontroller'    'robotcontroller2'
```

Run a ROS node. specifying the node name. Check if the node is running.

```
runNode(d,'robotcontroller')
running = isNodeRunning(d,'robotcontroller')


running =

  logical

   1
```

Stop the ROS node. Disconnect from the ROS network. Stop the ROS core.

```
stopNode(d,'robotcontroller')
rosshutdown
stopCore(d)
```

```
Shutting down global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:5
```

Run Multiple ROS Nodes

Run multiple ROS nodes on a connected ROS device. ROS nodes can be generated using Simulink® models to perform different tasks on the ROS network. These nodes are then deployed on a ROS device and can be run independently of Simulink.

This example uses two different Simulink models that have been deployed as ROS nodes. See Generate a standalone ROS node from Simulink®). and follow the instructions to generate and deploy a ROS node. The 'robotcontroller' node sends velocity commands to a robot to navigate it to a given point. The 'robotcontroller2' node uses the same model, but doubles the linear velocity to drive the robot faster.

Create a connection to a ROS device. Specify the address, user name, and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using runNode.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password')


d =

  rosdevice with properties:
```

```
      DeviceAddress: '192.168.154.131'
           Username: 'user'
          ROSFolder: '/opt/ros/hydro'
    CatkinWorkspace: '~/catkin_ws_test'
     AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core. Connect MATLAB® to the ROS master using `rosinit`. This ROS core enables you to run ROS nodes on your ROS device.

```
runCore(d)
rosinit(d.DeviceAddress)
```

Initializing global node /matlab_global_node_68749 with NodeURI http://192.168.154.1:64

Check the available ROS nodes on the connected ROS device. These nodes were generated from Simulink® models following the process in the Generate a standalone ROS node from Simulink® example.

```
d.AvailableNodes
```

```
ans =

  1×2 cell array

    'robotcontroller'    'robotcontroller2'
```

Start up the Robot Simulator using `ExampleHelperSimulinkRobotROS`. This simulator automatically connects to the ROS master on the ROS device. You will use this simulator to run a ROS node and control the robot.

```
sim = ExampleHelperSimulinkRobotROS;
```

Run a ROS node, specifying the node name. The `'robotcontroller'` node commands the robot to a specific location (`[-10 10]`). Wait to see the robot drive.

```
runNode(d,'robotcontroller')
pause(10)
```

Reset the Robot Simulator to reset the robot position. Alternatively, click **Reset Simulation**. Because the node is still running, the robot continues back to the specific location. To stop sending commands, stop the node.

```
resetSimulation(sim.Simulator)
pause(5)
stopNode(d,'robotcontroller')
```

Run the `'robotcontroller2'` node. This model drives the robot with twice the linear velocity. Reset the robot position. Wait to see the robot drive.

```
runNode(d,'robotcontroller2')
resetSimulation(sim.Simulator)
pause(10)
```

Close the simulator. Stop the ROS node. Disconnect from the ROS network and stop the ROS core.

```
close
stopNode(d,'robotcontroller2')
rosshutdown
stopCore(d)
```

Shutting down global node /matlab_global_node_68749 with NodeURI http://192.168.154.1:6

- "Generate a Standalone ROS Node from Simulink®"

See Also

isNodeRunning | runCore | runNode | stopNode

Topics

"Generate a Standalone ROS Node from Simulink®"

Introduced in R2016b

TransformStamped

Create transformation message

Description

The `TransformStamped` object is an implementation of the `geometry_msgs/TransformStamped` message type in ROS. The object contains meta-information about the message itself and the transformation. The transformation has a translational and rotational component.

Creation

Syntax

`tform = getTransform(tftree,targetframe,sourceframe)`

Description

`tform = getTransform(tftree,targetframe,sourceframe)` returns the latest known transformation between two coordinate frames. Transformations are structured as a 3-D translation (3-element vector) and a 3-D rotation (quaternion).

Properties

MessageType — Message type of ROS message
character vector

This property is read-only.

Message type of ROS message, returned as a character vector.

Data Types: `char`

Header — ROS Header message
Header object

This property is read-only.

ROS Header message, returned as a Header object. This header message contains the MessageType, sequence (Seq), timestamp (Stamp), and FrameId.

ChildFrameID — Second coordinate frame to transform point into
character vector

Second coordinate frame to transform point into, specified as a character vector.

Transform — Transformation message
Transform object

This property is read-only.

Transformation message, specified as a Transform object. The object contains the MessageType with a Translation vector and Rotation quaternion.

Object Functions

apply   Transform message entities into target frame

Examples

Inspect Sample TransformStamped Object

This example looks at the TransformStamped object to show the underlying structure of a TransformStamped ROS message. After setting up a network and transformations, you can create a transformation tree and get transformations between specific coordinate systems. Using showdetails lets you inspect the information in the transformation. It contains the ChildFrameId, Header, and Transform.

Start ROS network and setup transformations.

```
rosinit
```

```
Initializing ROS master on http://ah-sradford:11311/.
Initializing global node /matlab_global_node_28474 with NodeURI http://ah-sradford:6500
```

exampleHelperROSStartTfPublisher

Create transformation tree and wait for tree to update. Get the transform between the robot base and its camera center.

```
tftree = rostf;
waitForTransform(tftree,'camera_center','robot_base');
tform = getTransform(tftree,'camera_center','robot_base');
```

Inspect the `TransformStamped` object.

```
showdetails(tform)

  ChildFrameId :  robot_base
  Header
    Seq     :  20
    FrameId :  camera_center
    Stamp
      Sec  :  1512065171
      Nsec :  111000064
  Transform
    Translation
      X :  0.4999999999999998
      Y :  0
      Z :  -1
    Rotation
      X :  0
      Y :  -0.7071067811865475
      Z :  0
      W :  0.7071067811865476
```

Access the `Translation` vector inside the `Transform` property.

```
trans = tform.Transform.Translation

trans =
  ROS Vector3 message with properties:

    MessageType: 'geometry_msgs/Vector3'
            X: 0.5000
            Y: 0
            Z: -1
```

Use showdetails to show the contents of the message

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_28474 with NodeURI http://ah-sradford:65(
Shutting down ROS master on http://ah-sradford:11311/.
```

Apply Transformation using `TransformStamped` Object

Apply a transformation from a `TransformStamped` object to a `PointStamped` message.

Start ROS network and setup transformations.

```
rosinit
```

```
Initializing ROS master on http://ah-sradford:11311/.
Initializing global node /matlab_global_node_71764 with NodeURI http://ah-sradford:625!
```

```
exampleHelperROSStartTfPublisher
```

Create transformation tree and wait for tree to update. Get the transform between the robot base and its camera center. Inspect the transformation.

```
tftree = rostf;
waitForTransform(tftree,'camera_center','robot_base');
tform = getTransform(tftree,'camera_center','robot_base');
showdetails(tform)
```

```
  ChildFrameId :   robot_base
  Header
    Seq    :   15
    FrameId :   camera_center
    Stamp
      Sec  :   1512064258
      Nsec :   68999936
  Transform
    Translation
      X :   0.499999999999998
      Y :   0
```

```
        Z :  -1
      Rotation
        X :  0
        Y :  -0.7071067811865475
        Z :  0
        W :  0.7071067811865476
```

Create point to transform. You could also get this point message off the ROS network.

```
pt = rosmessage('geometry_msgs/PointStamped');
pt.Header.FrameId = 'camera_center';
pt.Point.X = 3;
pt.Point.Y = 1.5;
pt.Point.Z = 0.2;
```

Apply the transformation to the point.

```
tfpt = apply(tform,pt);
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_71764 with NodeURI http://ah-sradford:625
Shutting down ROS master on http://ah-sradford:11311/.
```

- "Access the tf Transformation Tree in ROS"

See Also

Functions
apply | getTransform | rostf | transform | waitForTransform

Topics
"Access the tf Transformation Tree in ROS"

Introduced in R2015a

robotics.AimingConstraint class

Package: robotics

Create aiming constraint for pointing at a target location

Description

The `AimingConstraint` object describes a constraint that requires the *z*-axis of one body (the end effector) to aim at a target point on another body (the reference body). This constraint is satisfied if the *z*-axis of the end-effector frame is within an angular tolerance in any direction of the line connecting the end-effector origin and the target point. The position of the target point is defined relative to the reference body.

Constraint objects are used in `GeneralizedInverseKinematics` objects to specify multiple kinematic constraints on a robot.

For an example that uses multiple constraint objects, see "Plan a Reaching Trajectory With Multiple Kinematic Constraints".

Construction

`aimConst = robotics.AimingConstraint(endeffector)` returns an aiming constraint object that represents a constraint on a body specified by `endeffector`.

`aimConst = robotics.AimingConstraint(endeffector,Name,Value)` returns an aiming constraint object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

`Name` is any property name and must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Input Arguments

endeffector — End-effector name
character vector

End-effector name, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

Properties

`EndEffector` — Name of the end effector
character vector

Name of the end effector, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

`ReferenceBody` — Name of the reference body frame
`''` (default) | character vector

Name of the reference body frame, specified as a character vector. The default `''` indicates that the constraint is relative to the base of the robot model. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

`TargetPoint` — Position of the target relative to the reference body
`[0 0 0]` (default) | `[x y z]` vector

Position of the target relative to the reference body, specified as an `[x y z]` vector. The constraint uses the line between the origin of the `EndEffector` body frame and this target point for maintaining the specified `AngularTolerance`.

`AngularTolerance` — Maximum allowed angle
`0` (default) | numeric scalar

Maximum allowed angle between the z-axis of the end-effector frame and the line connecting the end-effector origin to the target point, specified as a numeric scalar in radians.

`Weights` — Weight of the constraint
`1` (default) | numeric scalar

Weight of the constraint, specified as a numeric scalar. This weight is used with the `Weights` property of all the constraints specified in `GeneralizedInverseKinematics` to properly balance each constraint.

Extended Capabilities

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

See Also

Classes
`robotics.GeneralizedInverseKinematics` | `robotics.OrientationTarget` | `robotics.PoseTarget` | `robotics.PositionTarget`

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

robotics.BinaryOccupancyGrid class

Package: robotics

Create occupancy grid with binary values

Description

`BinaryOccupancyGrid` creates a 2-D occupancy grid object, which you can use to represent and visualize a robot workspace, including obstacles. The integration of sensor data and position estimates create a spatial representation of the approximate locations of the obstacles.

Occupancy grids are used in robotics algorithms such as path planning. They are also used in mapping applications, such as for finding collision-free paths, performing collision avoidance, and calculating localization. You can modify your occupancy grid to fit your specific application.

Each cell in the occupancy grid has a value representing the occupancy status of that cell. An occupied location is represented as `true (1)` and a free location is represented as `false (0)`.

The two coordinate systems supported are world and grid coordinates. The world coordinates origin is defined by `GridLocationInWorld`, which defines the bottom-left corner of the map. The number and size of grid locations are defined by the `Resolution`. Also, the first grid location with index `(1,1)` begins in the top-left corner of the grid.

Construction

`map = robotics.BinaryOccupancyGrid(width,height)` creates a 2-D binary occupancy grid representing a work space of `width` and `height` in meters. The default grid resolution is one cell per meter.

`map = robotics.BinaryOccupancyGrid(width,height,resolution)` creates a grid with `resolution` specified in cells per meter. The map is in world coordinates by default. You can use any of the arguments from previous syntaxes.

`map = robotics.BinaryOccupancyGrid(rows,cols,resolution,'grid')` creates a 2-D binary occupancy grid of size (`rows`,`cols`).

`map = robotics.BinaryOccupancyGrid(p)` creates a grid from the values in matrix `p`. The size of the grid matches the size of the matrix, with each cell value interpreted from its location in the matrix. `p` contains any numeric or logical type with zeros (`0`) and ones (`1`).

`map = robotics.BinaryOccupancyGrid(p,resolution)` creates a `BinaryOccupancyGrid` object with `resolution` specified in cells per meter.

Input Arguments

`width` — Map width
double in meters

Map width, specified as a double in meters.

Data Types: `double`

`height` — Map height
double in meters

Map width, specified as a double in meters.

Data Types: `double`

`resolution` — Grid resolution
1 (default) | double in cells per meter

Grid resolution, specified as a double in cells per meter.

Data Types: `double`

`p` — Input occupancy grid
matrix of ones and zeros

Input occupancy grid, specified as a matrix of ones and zeros. The size of the grid matches the size of the matrix. Each matrix element corresponds to an occupied location (`1`) or free location (`0`).

Properties

GridSize — Number of rows and columns in grid
two-element horizontal vector

Number of rows and columns in grid, stored as a two-element horizontal vector of the form `[rows cols]`. This value is read only.

Resolution — Grid resolution
1 (default) | scalar in cells per meter

Grid resolution, stored as a scalar in cells per meter. This value is read only.

Data Types: `double`

XWorldLimits — Minimum and maximum values of *x*-coordinates
two-element vector

Minimum and maximum values of *x*-coordinates, stored as a two-element horizontal vector of the form `[min max]`. These values indicate the world range of the *x*-coordinates in the grid. This value is read only.

YWorldLimits — Minimum and maximum values of *y*-coordinates
two-element vector

Minimum and maximum values of *y*-coordinates, stored as a two-element vector of the form `[min max]`. These values indicate the world range of the *y*-coordinates in the grid. This value is read only.

GridLocationInWorld — [x,y] world coordinates of grid
[0 0] (default) | two-element vector

`[x,y]` world coordinates of the bottom-left corner of the grid, specified as a two-element vector.

Data Types: `double`

Methods

copy	Copy array of handle objects
getOccupancy	Get occupancy value for one or more positions
grid2world	Convert grid indices to world coordinates
inflate	Inflate each occupied grid location
setOccupancy	Set occupancy value for one or more positions
show	Show occupancy grid values
world2grid	Convert world coordinates to grid indices

Examples

Create and Modify Binary Occupancy Grid

Create a 10m x 10m empty map.

```
map = robotics.BinaryOccupancyGrid(10,10,10);
```

Set occupancy of world locations and show map.

```
map = robotics.BinaryOccupancyGrid(10,10,10);
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

setOccupancy(map, [x y], ones(5,1))
figure
show(map)
```
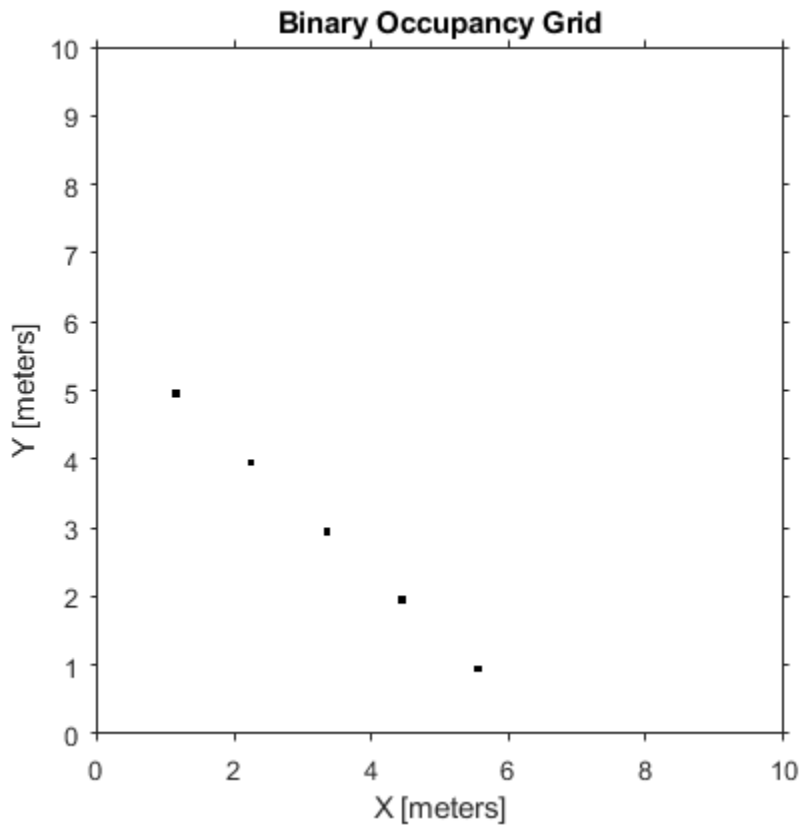
Inflate occupied locations by a given radius.

```
inflate(map, 0.5)
figure
show(map)
```

Binary Occupancy Grid

Get grid locations from world locations.

```
ij = world2grid(map, [x y]);
```
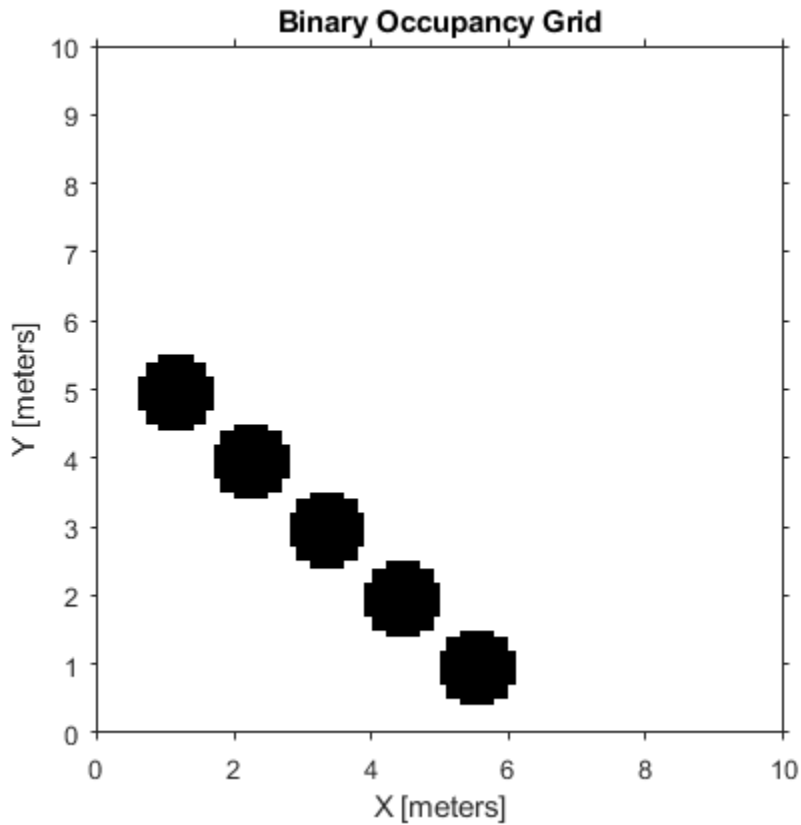
Set grid locations to free locations.

```
setOccupancy(map, ij, zeros(5,1), 'grid')
figure
show(map)
```
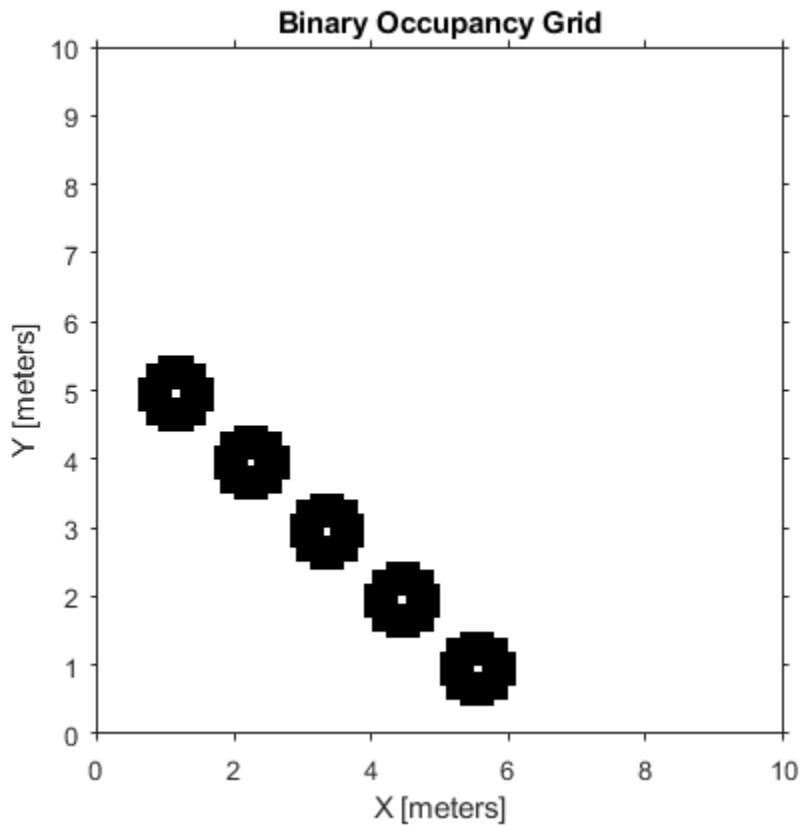
Image to Binary Occupancy Grid Example

This example shows how to convert an image to a binary occupancy grid for using with the Robotics System Toolbox®

```
% Import Image
filepath = fullfile(matlabroot,'examples','robotics','imageMap.png');
image = imread(filepath);

% Convert to grayscale and then black and white image based on arbitrary
% threshold.
```

```
grayimage = rgb2gray(image);
bwimage = grayimage < 0.5;

% Use black and white image as matrix input for binary occupancy grid
grid = robotics.BinaryOccupancyGrid(bwimage);

show(grid)
```

Binary Occupancy Grid
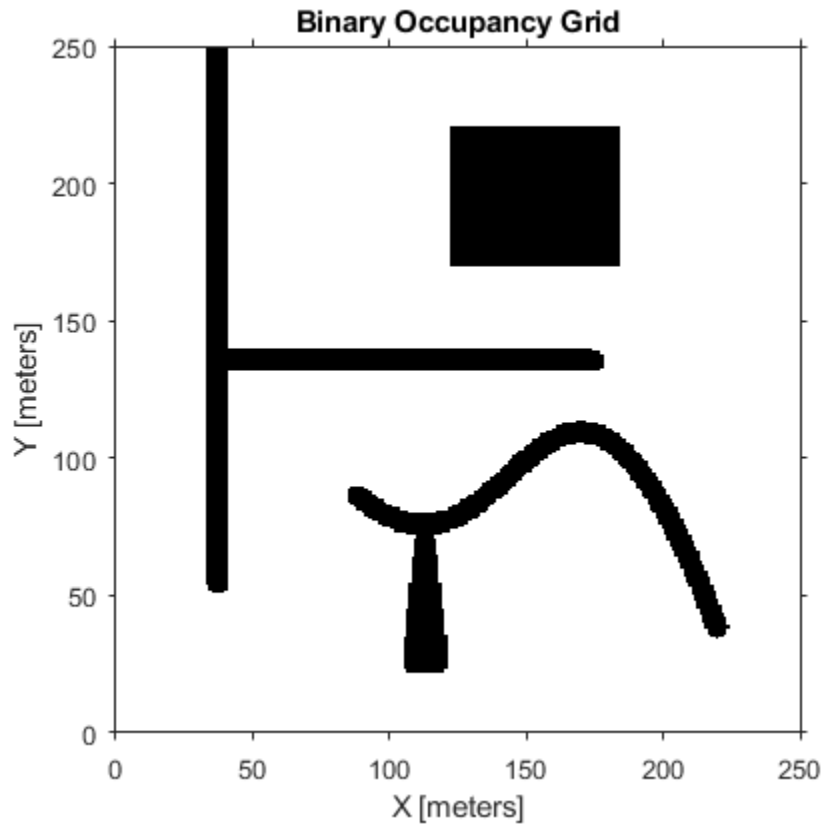
Convert PGM Image to Map

This example shows how to convert a `.pgm` file which contains a ROS map into a `BinaryOccupancyGrid` map for use in MATLAB.

Import image using `imread`. The image is quite large and should be cropped to the relevant area.

```
image = imread(fullfile(matlabroot,'examples','robotics','playpen_map.pgm'));
imageCropped = image(750:1250,750:1250);
imshow(imageCropped)
```
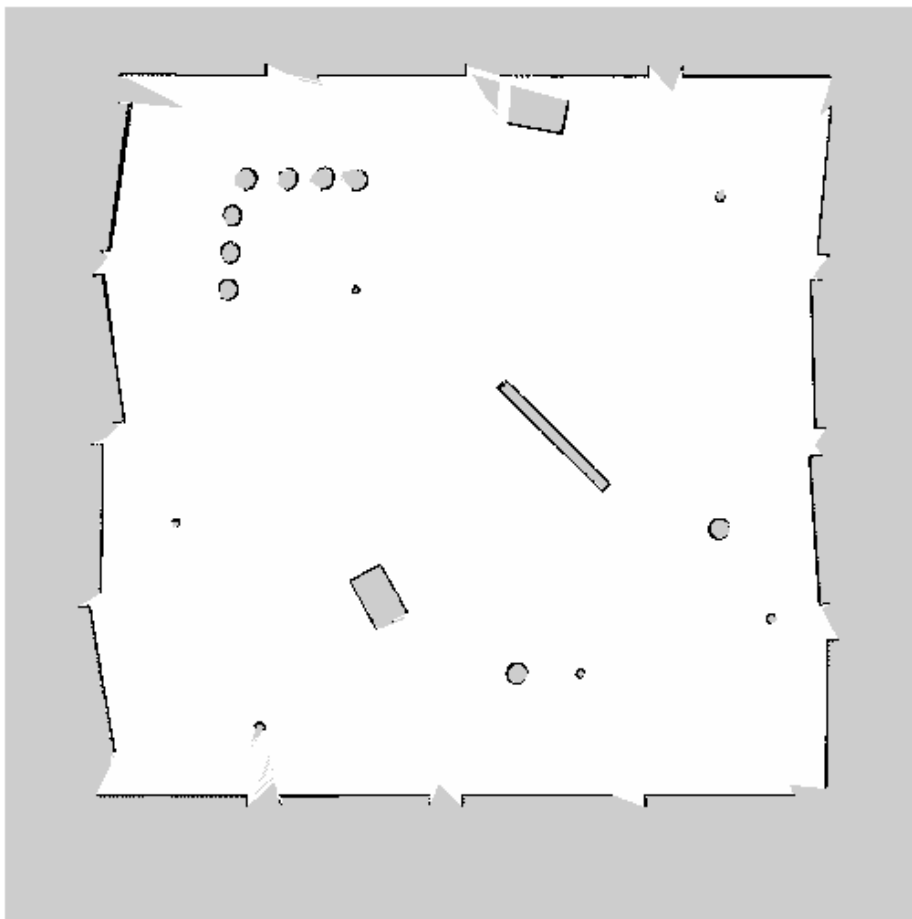
Unknown areas (gray) should be removed and treated as free space. Create a logical matrix based on a threshold. Depending on your image, this value could be different. Occupied space should be set as 1 (white in image).

```
imageBW = imageCropped < 100;
imshow(imageBW)
```
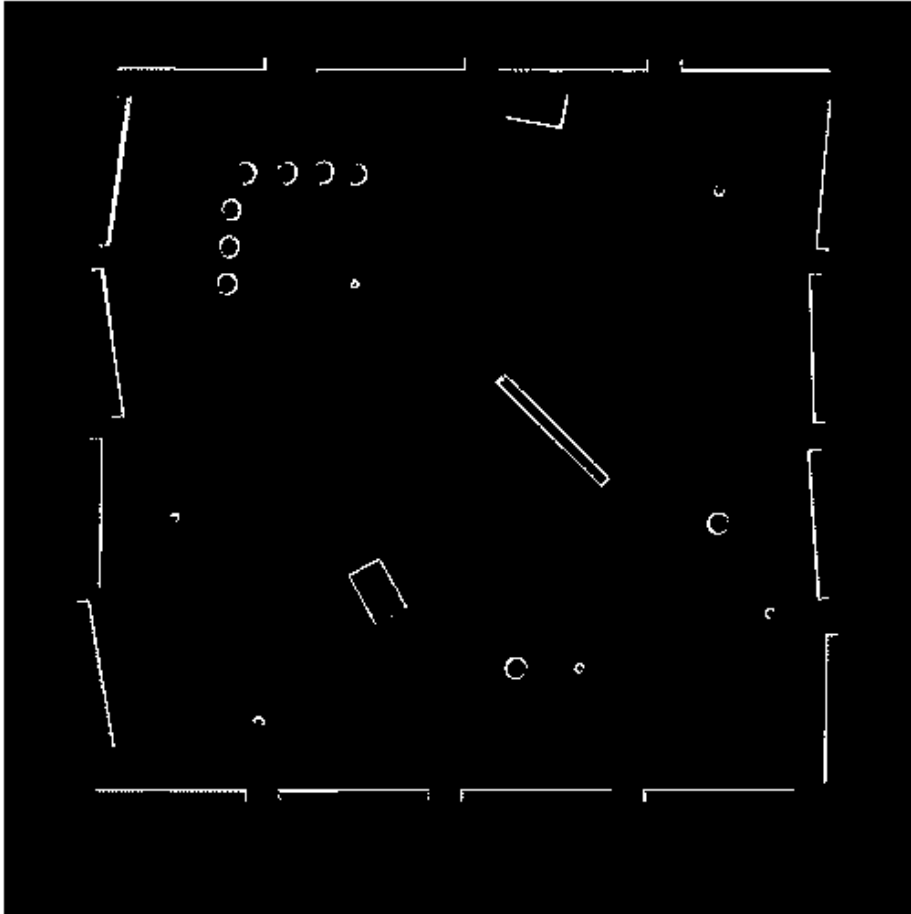

Create `BinaryOccupancyGrid` object using adjusted map image.

```
map = robotics.BinaryOccupancyGrid(imageBW);
show(map)
```
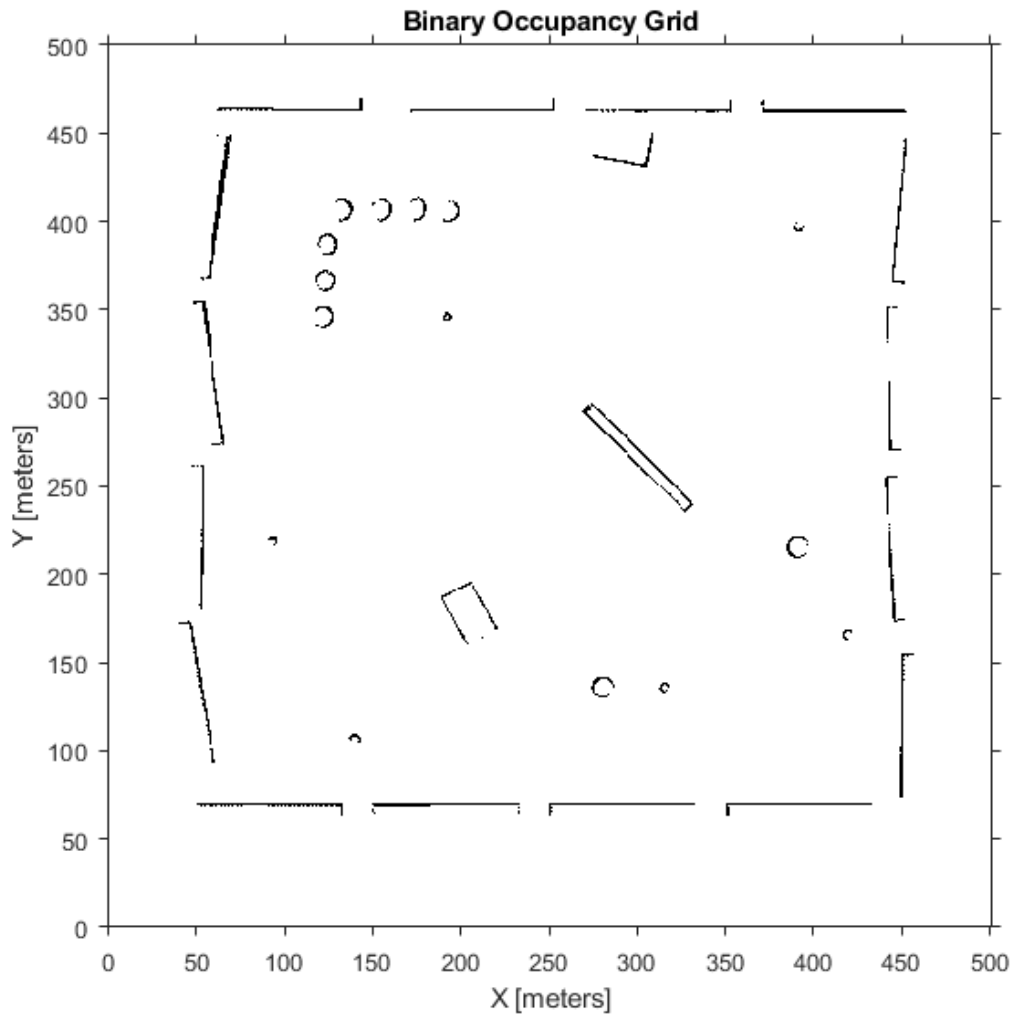
Binary Occupancy Grid

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

robotics.PRM | robotics.PurePursuit

Topics

"Occupancy Grids"

Introduced in R2015a

robotics.CartesianBounds class

Package: robotics

Create constraint to keep body origin inside Cartesian bounds

Description

The `CartesianBounds` object describes a constraint on the position of one body (the end effector) relative to a target frame fixed on another body (the reference body). This constraint is satisfied if the position of the end-effector origin relative to the target frame remains within the `Bounds` specified. The `TargetTransform` property is the homogeneous transform that converts points in the target frame to points in the `ReferenceBody` frame.

Constraint objects are used in `GeneralizedInverseKinematics` objects to specify multiple kinematic constraints on a robot.

For an example that uses multiple constraint objects, see "Plan a Reaching Trajectory With Multiple Kinematic Constraints".

Construction

`cartConst = robotics.CartesianBounds(endeffector)` returns a Cartesian bounds object that represents a constraint on the body of the robot model specified by `endeffector`.

`cartConst = robotics.CartesianBounds(endeffector,Name,Value)` returns a Cartesian bounds object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

`Name` is any property name and must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Input Arguments

endeffector — End-effector name
character vector

End-effector name, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

Properties

EndEffector — Name of the end effector
character vector

Name of the end effector, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

ReferenceBody — Name of the reference body frame
`''` (default) | character vector

Name of the reference body frame, specified as a character vector. The default `''` indicates that the constraint is relative to the base of the robot model. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

TargetTransform — Pose of the target frame relative to the reference body
`eye(4)` (default) | matrix

Pose of the target frame relative to the reference body, specified as a matrix. The matrix is a homogeneous transform that specifies the relative transformation to convert a point in the target frame to the reference body frame.

Example: `[1 0 0 1; 0 1 0 1; 0 0 1 1; 0 0 0 1]`

Bounds — Bounds on end-effector position relative to target frame
`zeros(3,2)` (default) | `[xMin xMax; yMin yMax; zMin zMax]` vector

Bounds on end-effector position relative to target frame, specified as a 3-by-2 vector, [xMin xMax; yMin yMax; zMin zMax]. Each row defines the minimum and maximum values for the *xyz*-coordinates respectively.

Weights — Weights of the constraint
[1 1 1] (default) | [x y z] vector

Weights of the constraint, specified as an [x y z] vector. Each element of the vector corresponds to the weight for the *xyz*-coordinates, respectively. These weights are used with the Weights property of all the constraints specified in GeneralizedInverseKinematics to properly balance each constraint.

Extended Capabilities

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

See Also

Classes
robotics.GeneralizedInverseKinematics | robotics.OrientationTarget | robotics.PoseTarget | robotics.PositionTarget

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

robotics.GeneralizedInverseKinematics System object

Package: robotics

Create multiconstraint inverse kinematics solver

Description

The `GeneralizedInverseKinematics` System object™ uses a set of kinematic constraints to compute a joint configuration for the rigid body tree model specified by a `RigidBodyTree` object. The `GeneralizedInverseKinematics` object uses a nonlinear solver to satisfy the constraints or reach the best approximation.

Specify the constraint types, `ConstraintInputs`, before calling the object. To change constraint inputs after calling the object, call `release(gik)`.

Specify the constraint inputs as constraint objects and call `GeneralizedInverseKinematics` with these objects passed into it. To create constraint objects, use these classes:

- `AimingConstraint`
- `CartesianBounds`
- `JointPositionBounds`
- `OrientationTarget`
- `PoseTarget`
- `PositionTarget`

If your only constraint is the end-effector position and orientation, consider using `InverseKinematics` as your solver instead.

To solve the generalized inverse kinematics constraints:

1   Create the robotics.GeneralizedInverseKinematics 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

```
gik = robotics.GeneralizedInverseKinematics
gik = robotics.GeneralizedInverseKinematics('
RigidBodyTree',rigidbodytree,'ConstraintInputs',inputTypes)
gik = robotics.GeneralizedInverseKinematics(Name,Value)
```

Description

`gik = robotics.GeneralizedInverseKinematics` returns a generalized inverse kinematics solver with no rigid body tree model specified. Specify a `RigidBodyTree` model and the `ConstraintInputs` property before using this solver.

`gik = robotics.GeneralizedInverseKinematics('
RigidBodyTree',rigidbodytree,'ConstraintInputs',inputTypes)` returns a generalized inverse kinematics solver with the rigid body tree model and the expected constraint inputs specified.

`gik = robotics.GeneralizedInverseKinematics(Name,Value)` returns a generalized inverse kinematics solver with each specified property name set to the specified value by one or more `Name,Value` pair arguments. `Name` must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

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).

`NumConstraints` — Number of constraint inputs
scalar

This property is read-only.

Number of constraint inputs, specified as a scalar. The value of this property is the number of constraint types specified in the `ConstraintInputs` property.

`ConstraintInputs` — Constraint input types
cell array of character vectors

Constraint input types, specified as a cell array of character vectors. The possible constraint input types with their associated constraint objects are:

- `'orientation'` — `OrientationTarget`
- `'position'` — `PositionTarget`
- `'pose'` — `PoseTarget`
- `'aiming'` — `AimingConstraint`
- `'cartesian'` — `CartesianBounds`
- `'joint'` — `JointPositionBounds`

Use the constraint objects to specify the required parameters and pass those object types into the object when you call it. For example:

Create the generalized inverse kinematics solver object. Specify the `RigidBodyTree` and `ConstraintInputs` properties.

```
gik = robotics.GeneralizedInverseKinematics(...
                    'RigidBodyTree',rigidbodytree,
                    'ConstraintInputs',{'position','aiming'});
```

Create the corresponding constraint objects.

```
positionTgt = robotics.PositionTarget('left_palm');
aimConst = robotics.AimingConstraint('right_palm');
```

Pass the constraint objects into the solver object with an initial guess.

```
configSol = gik(initialGuess,positionTgt,aimConst);
```

RigidBodyTree — Rigid body tree model
RigidBodyTree object

Rigid body tree model, specified as a `RigidBodyTree` object. Define this property before using the solver. If you modify your rigid body tree model, reassign the rigid body tree to this property. For example:

Create IK solver and specify the rigid body tree.

```
gik = robotics.GeneralizedInverseKinematics(...
                    'RigidBodyTree',rigidbodytree,
                    'ConstraintInputs',{'position','aiming'});
```

Modify the rigid body tree model.

```
addBody(rigidbodytree,robotics.RigidBody('body1'), 'base')
```

Reassign the rigid body tree to the IK solver. If the solver or the `step` function is called before modifying the rigid body tree model, use `release` to allow the property to be changed.

```
gik.RigidBodyTree = rigidbodytree;
```

SolverAlgorithm — Algorithm for solving inverse kinematics
'BFGSGradientProjection' (default) | 'LevenbergMarquardt'

Algorithm for solving inverse kinematics, specified as either `'BFGSGradientProjection'` or `'LevenbergMarquardt'`. For details of each algorithm, see "Inverse Kinematics Algorithms".

SolverParameters — Parameters associated with algorithm
structure

Parameters associated with the specified algorithm, specified as a structure. The fields in the structure are specific to the algorithm. See "Solver Parameters".

Usage

Syntax

```
[configSol,solInfo] = gik(initialguess,
constraintObj,...,constraintObjN)
```

Description

[configSol,solInfo] = gik(initialguess,
constraintObj,...,constraintObjN) finds a joint configuration, `configSol`, based on the initial guess and a comma-separated list of constraint description objects. The number of constraint descriptions depends on the `ConstraintInputs` property.

Input Arguments

initialguess — Initial guess of robot configuration
structure array | vector

Initial guess of robot configuration, specified as a structure array or vector. The value of `initialguess` depends on the `DataFormat` property of the object specified in the `RigidBodyTree` property specified in `gik`.

Use this initial guess to guide the solver to the target robot configuration. However, the solution is not guaranteed to be close to this initial guess.

constraintObj,...,constraintObjN — Constraint descriptions
constraint objects

Constraint descriptions defined by the `ConstraintInputs` property of `gik`, specified as one or more of these constraint objects:

- `AimingConstraint`
- `CartesianBounds`
- `JointPositionBounds`
- `OrientationTarget`
- `PoseTarget`

• PositionTarget

Output Arguments

configSol — Robot configuration solution
structure array | vector

Robot configuration solution, returned as a structure array or vector.depends on the `DataFormat` property of the object specified in the `RigidBodyTree` property specified in `gik`.

The structure array contains these fields:

• `JointName` — Character vector for the name of the joint specified in the `RigidBodyTree` robot model
• `JointPosition` — Position of the corresponding joint

The vector output is an array of the joint positions that would be given in `JointPosition` for a structure output.

This joint configuration is the computed solution that achieves the target end-effector pose within the solution tolerance.

solInfo — Solution information
structure

Solution information, returned as a structure containing these fields:

• `Iterations` — Number of iterations run by the solver.
• `NumRandomRestarts` — Number of random restarts because the solver got stuck in a local minimum.
• `ConstraintViolation` — Information about the constraint, returned as a structure array. Each structure in the array has these fields:

  • `Type`: Type of the corresponding constraint input, as specified in the `ConstraintInputs` property.
  • `Violation`: Vector of constraint violations for the corresponding constraint type. `0` indicates that the constraint is satisfied.
• `ExitFlag` — Code that gives more details on the solver execution and what caused it to return. For the exit flags of each solver type, see "Exit Flags".

- `Status` — Character vector describing whether the solution is within the tolerances defined by each constraint (`'success'`). If the solution is outside the tolerance, the best possible solution that the solver could find is given (`'best available'`).

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

Solve Generalized Inverse Kinematics for a Set of Constraints

Create a generalized inverse kinematics solver that holds a robotic arm at a specific location and points toward the robot base. Create the constraint objects to pass the necessary constraint parameters into the solver.

Load predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Create the System object™ for solving generalized inverse kinematics.

```
gik = robotics.GeneralizedInverseKinematics;
```

Configure the System object to use the KUKA LBR robot.

```
gik.RigidBodyTree = lbr;
```

Tell the solver to expect a `PositionTarget` object and an `AimingConstraint` object as the constraint inputs.

```
gik.ConstraintInputs = {'position','aiming'};
```

Create the two constraint objects.

1 The origin of the body named `tool0` is located at `[0.0 0.5 0.5]` relative to the robot's base frame.

2 The *z*-axis of the body named `tool0` points toward the origin of the robot's base frame.

```
posTgt = robotics.PositionTarget('tool0');
posTgt.TargetPosition = [0.0 0.5 0.5];

aimCon = robotics.AimingConstraint('tool0');
aimCon.TargetPoint = [0.0 0.0 0.0];
```

Find a configuration that satisfies the constraints. You must pass the constraint objects into the System object in the order in which they were specified in the `ConstraintInputs` property. Specify an initial guess at the robot configuration.

```
q0 = homeConfiguration(lbr); % Initial guess for solver
[q,solutionInfo] = gik(q0,posTgt,aimCon);
```

Visualize the configuration returned by the solver.

```
show(lbr,q);
title(['Solver status: ' solutionInfo.Status])
axis([-0.75 0.75 -0.75 0.75 -0.5 1])
```
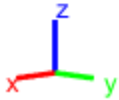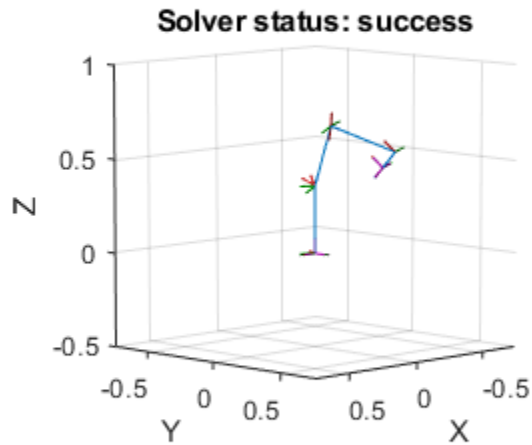
Plot a line segment from the target position to the origin of the base. The origin of the `tool0` frame coincides with one end of the segment, and its `z`-axis is aligned with the segment.

```
hold on
plot3([0.0 0.0],[0.5 0.0],[0.5 0.0],'--o')
hold off
```
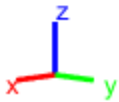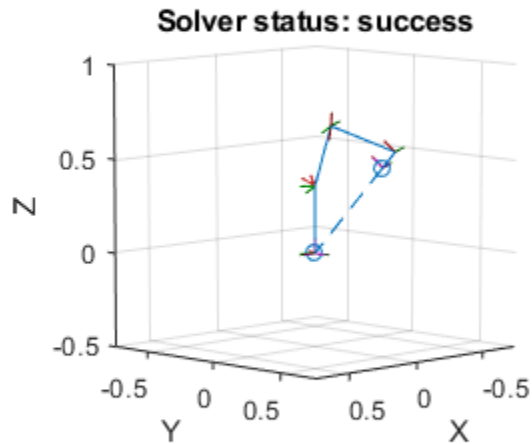
- "Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics"
- "Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Extended Capabilities

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

When using code generation, you must specify the `ConstraintInputs` and `RigidBodyTree` properties on construction of the object. For example:

```
gik = robotics.GeneralizedInverseKinematics(...
    'ConstraintInputs',{'pose','position'},...
    'RigidBodyTree',rigidbodytree);
```

You also cannot change the `SolverAlgorithm` property after creation. To specify the solver algorithm on creation, use:

```
gik = robotics.GeneralizedInverseKinematics(...
    'ConstraintInputs',{'pose','position'},...
    'RigidBodyTree',rigidbodytree,...
    'SolverAlgorithm','LevenbergMarquardt');
```

See Also

Classes
robotics.AimingConstraint | robotics.CartesianBounds |
robotics.InverseKinematics | robotics.JointPositionBounds |
robotics.OrientationTarget | robotics.PoseTarget |
robotics.PositionTarget

Topics
"Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics"
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

robotics.InverseKinematics System object

Package: robotics

Create inverse kinematic solver

Description

The `robotics.InverseKinematics` System object creates an inverse kinematic (IK) solver to calculate joint configurations for a desired end-effector pose based on a specified rigid body tree model. You must create a rigid body tree model for your robot using the `robotics.RigidBodyTree` class. This model defines all the joint constraints that the solver enforces. If a solution is possible, the joint limits specified in the robot model are obeyed.

To specify more constraints besides the end-effector pose, including aiming constraints, position bounds, or orientation targets, consider using `robotics.GeneralizedInverseKinematics`. This allows you to compute multiconstraint IK solutions.

To compute joint configurations for a desired end-effector pose:

1   Create the robotics.InverseKinematics 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

```
ik = robotics.InverseKinematics
ik = robotics.InverseKinematics(Name,Value)
```

Description

`ik = robotics.InverseKinematics` creates an inverse kinematic solver. To use the solver, specify a rigid body tree model in the `RigidBodyTree` property.

`ik = robotics.InverseKinematics(Name,Value)` creates an inverse kinematic solver with additional options specified by one or more `Name,Value` pair arguments. `Name` is a property name and `Value` is the corresponding value. `Name` must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

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).

RigidBodyTree — Rigid body tree model
RigidBodyTree object

Rigid body tree model, specified as a `RigidBodyTree` object. If you modify your rigid body tree model, reassign the rigid body tree to this property. For example:

Create IK solver and specify the rigid body tree.

```
ik = robotics.InverseKinematics('RigidBodyTree',rigidbodytree)
```

Modify the rigid body tree model.

```
addBody(rigidbodytree,robotics.RigidBody('body1'), 'base')
```

Reassign the rigid body tree to the IK solver. If the solver or the `step` function is called prior to modifying the rigid body tree model, use `release` to allow the property to be changed.

```
ik.RigidBodyTree = rigidbodytree;
```

SolverAlgorithm — Algorithm for solving inverse kinematics
`'BFGSGradientProjection'` (default) | `'LevenbergMarquardt'`

Algorithm for solving inverse kinematics, specified as either
`'BFGSGradientProjection'` or `'LevenbergMarquardt'`. For details of each
algorithm, see "Inverse Kinematics Algorithms".

SolverParameters — Parameters associated with algorithm
structure

Parameters associated with the specified algorithm, specified as a structure. The fields in
the structure are specific to the algorithm. See "Solver Parameters".

Usage

Syntax

`[configSol,solInfo] = ik(endeffector,pose,weights,initialguess)`

Description

`[configSol,solInfo] = ik(endeffector,pose,weights,initialguess)` finds a
joint configuration that achieves the specified end-effector pose. Specify an initial guess
for the configuration and your desired weights on the tolerances for the six components
of `pose`. Solution information related to execution of the algorithm, `solInfo`, is returned
with the joint configuration solution, `configSol`.

Input Arguments

endeffector — End-effector name
character vector

End-effector name, specified as a character vector. The end effector must be a body on
the `RigidBodyTree` object specified in the `robotics.InverseKinematics` System
object.

pose — End-effector pose
4-by-4 homogeneous transform

End-effector pose, specified as a 4-by-4 homogeneous transform. This transform defines the desired position and orientation of the rigid body specified in the `endeffector` property.

`weights` — Weight for pose tolerances
6-element vector

Weight for pose tolerances, specified as a 6-element vector. The first three elements correspond to the weights on the error in orientation for the desired pose. The last three elements correspond to the weights on the error in *xyz* position for the desired pose.

`initialguess` — Initial guess of robot configuration
structure array

Initial guess of robot configuration, specified as a structure array. Use this initial guess to help guide the solver to a desired robot configuration. However, the solution is not guaranteed to be close to this initial guess.

Output Arguments

`configSol` — Robot configuration solution
structure array

Robot configuration, returned as a structure array. The structure array contains these fields:

- `JointName` — Character vector for the name of the joint specified in the `RigidBodyTree` robot model
- `JointPosition` — Position of the corresponding joint

This joint configuration is the computed solution that achieves the desired end-effector pose within the solution tolerance.

`solInfo` — Solution information
structure

Solution information, returned as a structure. The solution information structure contains these fields:

- `Iterations` — Number of iterations run by the algorithm.

- NumRandomRestarts — Number of random restarts because algorithm got stuck in a local minimum.
- PoseErrorNorm — The magnitude of the pose error for the solution compared to the desired end-effector pose.
- ExitFlag — Code that gives more details on the algorithm execution and what caused it to return. For the exit flags of each algorithm type, see "Exit Flags".
- Status — Character vector describing whether the solution is within the tolerance ('success') or the best possible solution the algorithm could find ('best available').

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 Joint Positions to Achieve End-Effector Position

Generate joint positions for a robot model to achieve a desired end-effector position. The InverseKinematics system object uses inverse kinematic algorithms to solve for valid joint positions.

Load example robots. The puma1 robot is a RigidBodyTree model of a six-axis robot arm with six revolute joints.

```
load exampleRobots.mat
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)    L2(2)
   2            L2         jnt2     revolute              L1(1)     L3(3)
   3            L3         jnt3     revolute              L2(2)     L4(4)
   4            L4         jnt4     revolute              L3(3)     L5(5)
   5            L5         jnt5     revolute              L4(4)     L6(6)
   6            L6         jnt6     revolute              L5(5)
--------------------
```

Generate a random configuration. Get the transformation from the end effector (L6) to the base for that random configuration. Use this transform as a goal pose of the end effector. Show this configuration.

```
randConfig = puma1.randomConfiguration;
tform = getTransform(puma1,randConfig,'L6','base');

show(puma1,randConfig);
```
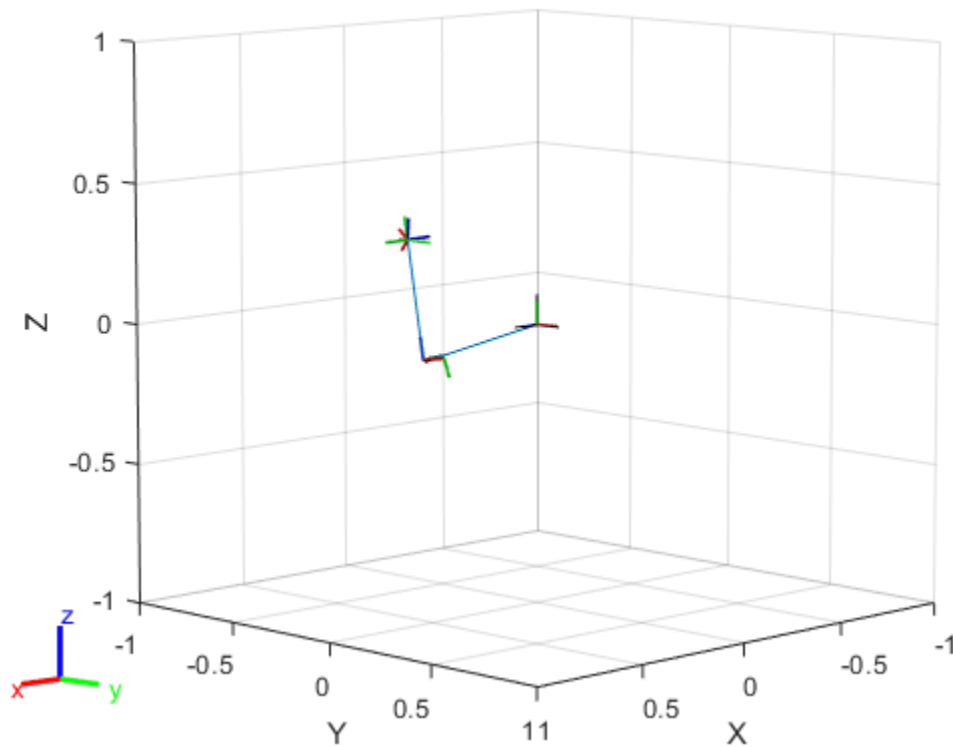
Create an `InverseKinematics` object for the `puma1` model. Specify weights for the different components of the pose. Use a lower magnitude weight for the orientation angles than the position components. Use the home configuration of the robot as an initial guess.

```
ik = robotics.InverseKinematics('RigidBodyTree',puma1);
weights = [0.25 0.25 0.25 1 1 1];
initialguess = puma1.homeConfiguration;
```

Calculate the joint positions using the `ik` object.

```
[configSoln,solnInfo] = ik('L6',tform,weights,initialguess);
```

Show the newly generated solution configuration. The solution is a slightly different joint configuration that achieves the same end-effector position. Multiple calls to the `ik` object can give similar or very different joint configurations.

```
show(puma1,configSoln);
```
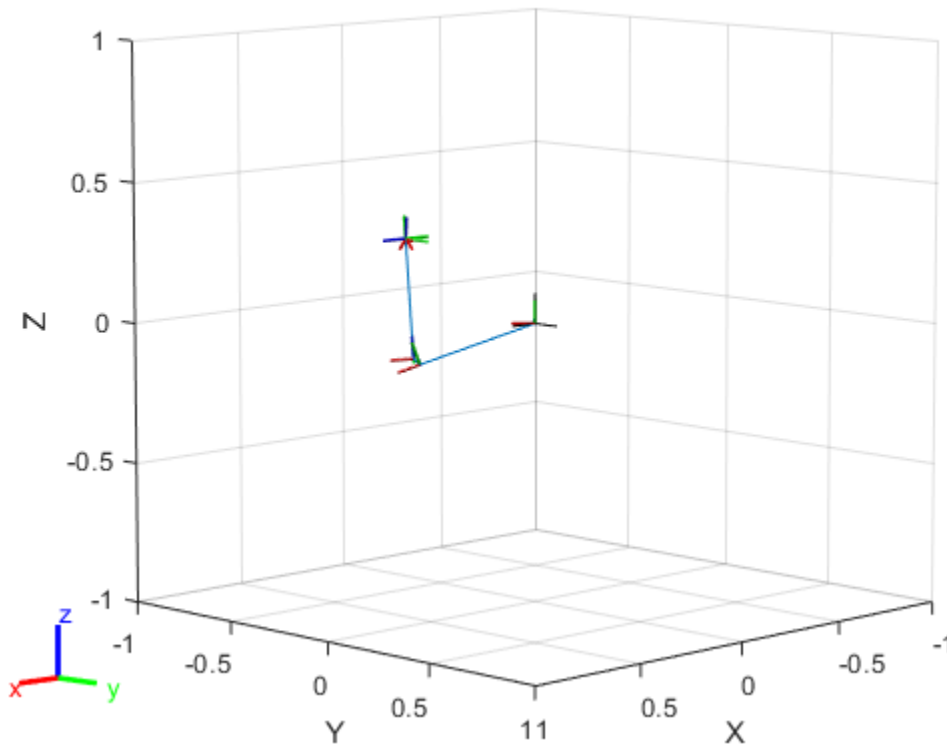

- "Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics"

References

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Turbulent Flow." *Journal of Computational Physics*. 256 (2014): 1–16. doi:10.1016/j.jcp.2013.08.044.

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[5] Sugihara, Tomomichi. "Solvability-Unconcerned Inverse Kinematics by the Levenberg–Marquardt Method." *IEEE Transactions on Robotics* Vol. 27, No. 5 (2011): 984–91. doi:10.1109/tro.2011.2148230.

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Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

When using code generation, you must specify the `RigidBodyTree` property to define the robot on construction of the object. For example:

```
ik = robotics.InverseKinematics('RigidBodyTree',robotModel);
```

You also cannot change the `SolverAlgorithm` property after creation. To specify the solver algorithm on creation, use:

```
ik = robotics.InverseKinematics('RigidBodyTree',robotModel,...
        'SolverAlgorithm','LevenbergMarquardt');
```

See Also

robotics.GeneralizedInverseKinematics | robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree

Topics

"Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics"
"Inverse Kinematics Algorithms"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016b

robotics.Joint class

Package: robotics

Create a joint

Description

The `Joint` class creates a joint object that defines how a rigid body moves relative to an attachment point. In a tree-structured robot, a joint always belongs to a specific rigid body, and each rigid body has one joint.

The `Joint` object can describe joints of various types. When building a rigid body tree structure with `robotics.RigidBodyTree`, you must assign the `Joint` object to a rigid body using the `robotics.RigidBody` class.

The different joint types supported are:

- `'fixed'` — Fixed joint that prevents relative motion between two bodies.
- `'revolute'` — Single degree of freedom (DOF) joint that rotates around a given axis. Also called a pin or hinge joint.
- `'prismatic'` — Single DOF joint that slides along a given axis. Also called a sliding joint.

Each joint type has different properties with different dimensions, depending on its defined geometry.

Construction

`jointObj = robotics.Joint(jname)` creates a fixed joint with the specified name.

`jointObj = robotics.Joint(jname,jtype)` creates a joint of the specified type with the specified name.

Input Arguments

jname — Joint name
character vector

Joint name, specified as a character vector. The joint name must be unique to access it off the rigid body tree.

Example: `'elbow_right'`

jtype — Joint type
`'fixed'` (default) | character vector

Joint type, specified as a character vector. The joint type predefines certain properties when creating the joint.

The different joint types supported are:

- `'fixed'` — Fixed joint that prevents relative motion between two bodies.
- `'revolute'` — Single degree of freedom (DOF) joint that rotates around a given axis. Also called a pin or hinge joint.
- `'prismatic'` — Single DOF joint that slides along a given axis. Also called a sliding joint.

Properties

Type — Joint type
`'fixed'` (default) | character vector

This property is read-only.

Joint type, returned as a character vector. The joint type predefines certain properties when creating the joint.

The different joint types supported are:

- `'fixed'` — Fixed joint that prevents relative motion between two bodies.
- `'revolute'` — Single degree of freedom (DOF) joint that rotates around a given axis. Also called a pin or hinge joint.

- `'prismatic'` — Single DOF joint that slides along a given axis. Also called a sliding joint.

If the rigid body that contains this joint is added to a robot model, the joint type must be changed by replacing the joint using `robotics.RigidBodyTree.replaceJoint`.

Name — Joint name
character vector

Joint name, returned as a character vector. The joint name must be unique to access it off the rigid body tree. If the rigid body that contains this joint is added to a robot model, the joint name must be changed by replacing the joint using `robotics.RigidBodyTree.replaceJoint`.

Example: `'elbow_right'`

PositionLimits — Position limits of joint
vector

Position limits of the joint, specified as a vector of `[min max]` values. Depending on the type of joint, these values have different definitions.

- `'fixed'` — `[NaN NaN]` (default). A fixed joint has no joint limits. Bodies remain fixed between each other.
- `'revolute'` — `[-pi pi]` (default). The limits define the angle of rotation around the axis in radians.
- `'prismatic'` — `[0 0.5]` (default). The limits define the linear motion along the axis in meters.

HomePosition — Home position of joint
scalar

Home position of joint, specified as a scalar that depends on your joint type. The home position must fall in the range set by `PositionLimits`. This property is used by `robotics.RigidBodyTree.homeConfiguration` to generate the predefined home configuration for an entire rigid body tree.

Depending on the joint type, the home position has a different definition.

- `'fixed'` — `0` (default). A fixed joint has no relevant home position.
- `'revolute'` — `0` (default). A revolute joint has a home position defined by the angle of rotation around the joint axis in radians.

- `'prismatic'` — `0` (default). A prismatic joint has a home position defined by the linear motion along the joint axis in meters.

JointAxis — Axis of motion for joint
[NaN NaN NaN] (default) | three-element unit vector

Axis of motion for joint, specified as a three-element unit vector. The vector can be any direction in 3-D space in local coordinates.

Depending on the joint type, the joint axis has a different definition.

- `'fixed'` — A fixed joint has no relevant axis of motion.
- `'revolute'` — A revolute joint rotates the body in the plane perpendicular to the joint axis.
- `'prismatic'` — A prismatic joint moves the body in a linear motion along the joint axis direction.

JointToParentTransform — Fixed transform from joint to parent frame
eye(4) (default) | 4-by-4 homogeneous transform matrix

This property is read-only.

Fixed transform from joint to parent frame, returned as a 4-by-4 homogeneous transform matrix. The transform converts the coordinates of points in the joint predecessor frame to the parent body frame.

ChildToJointTransform — Fixed transform from child body to joint frame
eye(4) (default) | 4-by-4 homogeneous transform matrix

This property is read-only.

Fixed transform from child body to joint frame, returned as a 4-by-4 homogeneous transform matrix. The transform converts the coordinates of points in the child body frame to the joint successor frame.

Methods

copy	Create copy of joint
setFixedTransform	Set fixed transform properties of joint

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `RigidBody` object contains a `Joint` object and must be added to the `RigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = robotics.RigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = robotics.RigidBody('b1');
```

Create a revolute joint. By default, the `RigidBody` object comes with a fixed joint. Replace the joint by assigning a new `Joint` object to the `body1.Joint` property.

```
jnt1 = robotics.Joint('jnt1','revolute');
body1.Joint = jnt1;
```

Add the rigid body to the tree. Specify the body name that you are attaching the rigid body to. Because this is the first body, use the base name of the tree.

```
basename = rbtree.BaseName;
addBody(rbtree,body1,basename)
```

Use `showdetails` on the tree to confirm the rigid body and joint were added properly.

```
showdetails(rbtree)

--------------------
Robot: (1 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1           b1         jnt1     revolute             base(0)
--------------------
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix. The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0        pi/2    0        0;
            0.4318   0       0        0
            0.0203   -pi/2   0.15005  0;
            0        pi/2    0.4318   0;
            0        -pi/2   0        0;
            0        0       0        0];
```

Create a rigid body tree object to build the robot.

```
robot = robotics.RigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1 Create a `RigidBody` object and give it a unique name.
2 Create a `Joint` object and give it a unique name.
3 Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4 Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = robotics.RigidBody('body1');
jnt1 = robotics.Joint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

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```
body2 = robotics.RigidBody('body2');
jnt2 = robotics.Joint('jnt2','revolute');
body3 = robotics.RigidBody('body3');
jnt3 = robotics.Joint('jnt3','revolute');
body4 = robotics.RigidBody('body4');
jnt4 = robotics.Joint('jnt4','revolute');
body5 = robotics.RigidBody('body5');
jnt5 = robotics.Joint('jnt5','revolute');
body6 = robotics.RigidBody('body6');
jnt6 = robotics.Joint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

Verify that your robot was built properly by using the `showdetails` or `show` function. `showdetails` lists all the bodies in the MATLAB® command window. `show` displays the robot with a given configuration (home by default). Calls to `axis` modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------   ----------------   ----------------
   1        body1         jnt1     revolute            base(0)   body2(2)
   2        body2         jnt2     revolute           body1(1)   body3(3)
   3        body3         jnt3     revolute           body2(2)   body4(4)
   4        body4         jnt4     revolute           body3(3)   body5(5)
```

```
   5          body5          jnt5      revolute                body4(4)   body6(6)
   6          body6          jnt6      revolute                body5(5)
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute             L1(1)     L3(3)
   3            L3         jnt3     revolute             L2(2)     L4(4)
   4            L4         jnt4     revolute             L3(3)     L5(5)
   5            L5         jnt5     revolute             L4(4)     L6(6)
   6            L6         jnt6     revolute             L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

           Name: 'L4'
          Joint: [1x1 robotics.Joint]
           Mass: 1
   CenterOfMass: [0 0 0]
        Inertia: [1 1 1 0 0 0]
         Parent: [1x1 robotics.RigidBody]
       Children: {[1x1 robotics.RigidBody]}
        Visuals: {}


body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx      Body Name      Joint Name      Joint Type      Parent Name(Idx)    Children Name
 ---      ---------      ----------      ----------      ----------------    -------------
   1            L1            jnt1         revolute                base(0)    L2(2)
   2            L2            jnt2         revolute                  L1(1)    L3(3)
   3            L3       prismatic            fixed                  L2(2)    L4(4)
   4            L4            jnt4         revolute                  L3(3)    L5(5)
   5            L5            jnt5         revolute                  L4(4)    L6(6)
   6            L6            jnt6         revolute                  L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')

subtree =
  RigidBodyTree with properties:

     NumBodies: 3
        Bodies: {1x3 cell}
          Base: [1x1 robotics.RigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

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```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1          L1         jnt1     revolute              base(0)   L2(2)
   2          L2         jnt2     revolute                L1(1)   L3(3)
   3          L3         jnt3     revolute                L2(2)   L4(4)
   4          L4         jnt4     revolute                L3(3)   L5(5)
   5          L5         jnt5     revolute                L4(4)   L6(6)
   6          L6         jnt6     revolute                L5(5)
--------------------
```

- "Build a Robot Step by Step"
- "Rigid Body Tree Robot Model"

References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control*. Reading, MA: Addison-Wesley, 1989.

[2] Siciliano, Bruno. *Robotics: Modelling, Planning and Control.* London: Springer, 2009.

Extended Capabilities

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

See Also

robotics.RigidBody | robotics.RigidBodyTree

Topics

"Build a Robot Step by Step"
"Rigid Body Tree Robot Model"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016b

robotics.JointPositionBounds class

Package: robotics

Create constraint on joint positions of robot model

Description

The `JointPositionBounds` object describes a constraint on the joint positions of a rigid body tree. This constraint is satisfied if the robot configuration vector maintains all joint positions within the `Bounds` specified. The configuration vector contains positions for all nonfixed joints in a `RigidBodyTree` object.

Constraint objects are used in `GeneralizedInverseKinematics` objects to specify multiple kinematic constraints on a robot.

For an example that uses multiple constraint objects, see "Plan a Reaching Trajectory With Multiple Kinematic Constraints".

Construction

`jointConst = robotics.JointPositionBounds(robot)` returns a joint position bounds object that represents a constraint on the configuration vector of the robot model specified by `robot`.

`jointConst = robotics.JointPositionBounds(robot,Name,Value)` returns a joint position bounds object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

`Name` is any property name and must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Input Arguments

robot — Rigid body tree model
RigidBodyTree object

Rigid body tree model, specified as a `RigidBodyTree` object.

Properties

Bounds — Bounds on the configuration vector
n-by-2 matrix

Bounds on the configuration vector, specified as an *n*-by-2 matrix. Each row of the array corresponds to a nonfixed joint on the robot model and gives the minimum and maximum position for that joint. By default, the bounds are set based on the `PositionLimits` property of each `robotics.Joint` object within the input rigid body tree model, `robot`.

Weights — Weights of the constraint
`ones(1,n)` (default) | *n*-element vector

Weights of the constraint, specified as an *n*-element vector, where each element corresponds to a row in `Bounds` and gives relative weights for each bound. The default is a vector of ones to give equal weight to all joint positions. These weights are used with the `Weights` property of all the constraints specified in `GeneralizedInverseKinematics` to properly balance each constraint

Extended Capabilities

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

See Also

Classes
`robotics.GeneralizedInverseKinematics` | `robotics.OrientationTarget` | `robotics.PoseTarget` | `robotics.PositionTarget`

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

lidarScan

Create object for storing 2-D lidar scan

Description

A `lidarScan` object contains data for a single 2-D lidar (light detection and ranging) scan. The lidar scan is a laser scan for a 2-D plane with distances (`Ranges`) measured from the sensor to obstacles in the environment at specific angles (`Angles`). Use this laser scan object as an input to other robotics algorithms such as `matchScans`, `robotics.VectorFieldHistogram`, or `robotics.MonteCarloLocalization`.

Creation

Syntax

```
scan = lidarScan(ranges,angles)
scan = lidarScan(cart)
```

Description

`scan = lidarScan(ranges,angles)` creates a `lidarScan` object from the `ranges` and `angles`, that represent the data collected from a lidar sensor. The `ranges` and `angles` inputs are vectors of the same length and are set directly to the `Ranges` and `Angles` properties.

`scan = lidarScan(cart)` creates a `lidarScan` object using the input Cartesian coordinates as an *n*-by-2 matrix. The `Cartesian` property is set directly from this input.

`scan = lidarScan(scanMsg)` creates a `lidarScan` object from a `LaserScan` ROS message object.

Properties

Ranges — Range readings from lidar
vector

Range readings from lidar, specified as a vector. This vector is the same length as `Angles`, and the vector elements are measured in meters.

Data Types: `single` | `double`

Angles — Angle of readings from lidar
vector

Angle of range readings from lidar, specified as a vector. This vector is the same length as `Ranges`, and the vector elements are measured in radians. Angles are measured counter-clockwise around the positive z-axis.

Data Types: `single` | `double`

Cartesian — Cartesian coordinates of lidar readings
`[x y]` matrix

Cartesian coordinates of lidar readings, returned as an `[x y]` matrix. In the lidar coordinate frame, positive x is forward and positive y is to the left.

Data Types: `single` | `double`

Count — Number of lidar readings
scalar

Number of lidar readings, returned as a scalar. This scalar is also equal to the length of the `Ranges` and `Angles` vectors or the number of rows in `Cartesian`.

Data Types: `double`

Object Functions

plot	Display laser or lidar scan readings
removeInvalidData	Remove invalid range and angle data
transformScan	Transform laser scan based on relative pose

Examples

Plot Lidar Scan and Remove Invalid Points

Specify lidar data as vectors of ranges and angles. These values include readings outside of the sensors range.

```
x = linspace(-2,2);
ranges = abs((1.5).*x.^2 + 5);
ranges(45:55) = 3.5;
angles = linspace(-pi/2,pi/2,numel(ranges));
```

Create a lidar scan by specifying the ranges and angles. Plot all points of the lidar scan.

```
scan = lidarScan(ranges,angles);
plot(scan)
```

Remove invalid points based on a specified minimum and maximum range.

```
minRange = 0.1;
maxRange = 7;
scan2 = removeInvalidData(scan,'RangeLimits',[minRange maxRange]);
hold on
plot(scan2)
legend('All Points','Valid Points')
```

LiDAR Scan

Match Lidar Scans

Create a reference lidar scan using `lidarScan`. Specify ranges and angles as vectors.

```
refRanges = 5*ones(1,300);
refAngles = linspace(-pi/2,pi/2,300);
refScan = lidarScan(refRanges,refAngles);
```

Using the `transformScan` function, generate a second lidar scan at an `x,y` offset of (0.5,0.2).

```
currScan = transformScan(refScan,[0.5 0.2 0]);
```

Match the reference scan and the second scan to estimate the pose difference between them.

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```
pose = matchScans(currScan,refScan);
```

Use the `transformScan` function to align the scans by transforming the second scan into the frame of the first scan using the relative pose difference. Plot both the original scans and the aligned scans.

```
currScan2 = transformScan(currScan,pose);
```

```
subplot(2,1,1);
hold on
plot(currScan)
plot(refScan)
title('Original Scans')
hold off

subplot(2,1,2);
hold on
plot(currScan2)
plot(refScan)
title('Aligned Scans')
xlim([0 5])
hold off
```

Extended Capabilities

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

Usage notes and limitations:

Lidar scans require a limited size in code generation. The lidar scans are limited to 4000 points (range and angles) as a maximum.

See Also

LaserScan | matchScans | robotics.MonteCarloLocalization | robotics.VectorFieldHistogram | transformScan

Introduced in R2017b

robotics.LidarSLAM class

Package: robotics

Perform localization and mapping using lidar scans

Description

The `LidarSLAM` class performs simultaneous localization and mapping (SLAM) for lidar scan sensor inputs. The SLAM algorithm takes in lidar scans and attaches them to a node in an underlying pose graph. The algorithm then correlates the scans using scan matching. It also searches for loop closures, where scans overlap previously mapped regions, and optimizes the node poses in the pose graph.

Construction

`slamObj = LidarSLAM` creates a lidar SLAM object. The default occupancy map size is 20 cells per meter. The maximum range for each lidar scan is 8 meters.

`slamObj = LidarSLAM(mapResolution,maxLidarRange)` creates a lidar SLAM object and sets the `MapResolution` and `MaxLidarRange` properties based on the inputs.

Examples

Perform SLAM Using Lidar Scans

Use a `LidarSLAM` object to iteratively add and compare lidar scans and build an optimized pose graph of the robot trajectory. To get an occupancy map from the associated poses and scans, use the `buildMap` function.

Load Data and Set Up SLAM Algorithm

Load a cell array of `lidarScan` objects. The lidar scans were collected in a parking garage on a Husky® robot from ClearPath Robotics®. Typically, lidar scans are taken at a

high frequency and each scan is not needed for SLAM. Therefore, down sample the scans by selecting only every 40th scan.

```
load garage_fl1_southend.mat scans
scans = scans(1:40:end);
```

To set up the SLAM algorithm, specify the lidar range, map resolution, loop closure threshold, and search radius. Tune these parameters for your specific robot and environment. Create the LidarSLAM object with these parameters.

```
maxRange = 19.2; % meters
resolution = 10; % cells per meter

slamObj = robotics.LidarSLAM(resolution,maxRange);
slamObj.LoopClosureThreshold = 360;
slamObj.LoopClosureSearchRadius = 8;
```

Add Scans Iteratively

Using a for loop, add scans to the SLAM object. The object uses scan matching to compare each added scan to previously added ones. To improve the map, the object optimizes the pose graph whenever it detects a loop closure. Every 10 scans, display the stored poses and scans.

```
for i = 1:numel(scans)

    addScan(slamObj,scans{i});

    if rem(i,10) == 0
        show(slamObj);
    end
end
```

View Occupancy Map

After adding all the scans to the SLAM object, build an `robotics.OccupancyGrid` map by calling `buildMap` with the scans and poses. Use the same map resolution and max range you used with the SLAM object.

```
[scansSLAM,poses] = scansAndPoses(slamObj);
occGrid = buildMap(scansSLAM,poses,resolution,maxRange);
figure
show(occGrid)
title('Occupancy Map of Garage')
```

- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Properties

PoseGraph — Underlying pose graph that connects scans
PoseGraph object

Underlying pose graph that connects scans, specified as a PoseGraph object. Adding scans to LidarSLAM updates this pose graph. When loop closures are found, the pose graph is optimized using OptimizationFcn.

`MapResolution` — Resolution of occupancy grid map
20 cells per meter (default) | positive integer

Resolution of the occupancy grid map, specified as a positive integer in cells per meter. Specify the map resolution on construction.

`MaxLidarRange` — Maximum range of lidar sensor
8 meters (default) | positive scalar

Maximum range of the lidar sensor, specified as a positive scalar in meters. Specify the maximum range on construction.

`OptimizationFcn` — Pose graph optimization function
optimizePoseGraph (default) | function handle

Pose graph optimization function, specified as a function handle. By default, the algorithm calls the `optimizePoseGraph` function. To specify your own optimization method, the class requires the function signature to be:

```
[updatedPose,stat] = myOptimizationFcn(poseGraph)
```

`poseGraph` is a `PoseGraph` object. `updatedPose` is an *n*-by-3 vector of [x y theta] poses listed in sequential node ID order. `stat` is a structure containing a `ResidualError` field as a positive scalar. Use the `stat` structure to include other information relevant to your optimization.

`LoopClosureThreshold` — Threshold for accepting loop closures
100 (default) | positive scalar

Threshold on the score from the scan matching algorithm for accepting loop closures, specified as a positive scalar. Higher thresholds correspond to a better match, but scores vary based on sensor data.

`LoopClosureSearchRadius` — Search radius for loop closure detection
8 meters (default) | positive scalar

Search radius for loop closure detection, specified as a positive scalar. Increasing this radius affects performance by increasing search time. Tune this distance based on your environment and the expected robot trajectory.

`LoopClosureMaxAttempts` — Number of attempts at finding loop closures
1 (default) | positive integer

Number of attempts at finding looping closures, specified as a positive integer. Increasing the number of attempts affects performance by increasing search time.

LoopClosureAutoRollback — Allow automatic rollback of added loop closures
`true` (default) | `false`

Allow automatic rollback of added loop closures, specified as `true` or `false`. The SLAM object tracks the residual error returned by the `OptimizationFcn`. If it detects a sudden change in the residual error and this property is `true`, it rejects (rolls back) the loop closure.

OptimzationInterval — Number of loop closures accepted to trigger optimization
`1` (default) | positive integer

Number of loop closures accepted to trigger optimization, specified as a positive integer. By default, the `PoseGraph` is optimized every time `LidarSLAM` adds a loop closure.

MovementThreshold — Minimum change in pose required to process scans
`[0 0]` (default) | `[translation rotation]`

Minimum change in pose required to process scans, specified as a `[translation rotation]` vector. A relative pose change for a newly added scan is calculated as `[x y theta]`. If the translation in *xy*-position or rotation of `theta` exceeds these thresholds, the `LidarSLAM` object accepts the scan and adds a pose is added to the `PoseGraph`.

Methods

addScan	Add scan to lidar SLAM map
copy	Copy lidar SLAM object
removeLoopClosures	Remove loop closures from pose graph
scansAndPoses	Extract scans and corresponding poses
show	Plot scans and robot poses

Definitions

SLAM

Simultaneous localization and mapping (SLAM) is a general concept for algorithms correlating different sensor readings to build a map of a robot environment and track pose estimates. Different algorithms use different types of sensors and methods for correlating data.

The `LidarSLAM` algorithm uses lidar scans and odometry information as sensor inputs. The lidar scans map the environment and are correlated between each other to build an underlying pose graph of the robot trajectory. Odometry information is an optional input that gives an initial pose estimate for the scans to aid in the correlation. Scan matching algorithms correlate scans to previously added scans to estimate the relative pose between them and add them to an underlying pose graph.

The pose graph contains nodes connected by edges that represent the relative poses of the robot. Edges specify constraints on the node as an information matrix. To correct for drifting pose estimates, the algorithm optimizes over the whole pose graph whenever it detects loop closures.

The algorithm assumes that data comes from a robot navigating an environment and incrementally getting laser scans along its path. Therefore, scans are first compared to the most recent scan to identify relative poses and are added to the pose graph incrementally. However, the algorithm also searches for loop closures, which identify when the robot scans an area that was previously visited.

When working with SLAM algorithms, the environment and robot sensors affect the performance and data correlation quality. Tune your parameters properly for your expected environment or dataset.

References

[1] Hess, Wolfgang, Damon Kohler, Holger Rapp, and Daniel Andor. "Real-Time Loop Closure in 2D LIDAR SLAM." *2016 IEEE International Conference on Robotics and Automation (ICRA)*. 2016.

See Also

`optimizePoseGraph` | `robotics.PoseGraph`

Topics

"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

robotics.LikelihoodFieldSensorModel class

Package: robotics

Create a likelihood field range sensor model

Description

`LikelihoodFieldSensorModel` creates a likelihood field sensor model object for range sensors. This object contains specific sensor model parameters. You can use this object to specify the model parameters in a `robotics.MonteCarloLocalization` object.

Construction

`lf = robotics.LikelihoodFieldSensorModel` creates a likelihood field sensor model object for range sensors.

Properties

Map — Occupancy grid representing the map
`BinaryOccupancyGrid` object (default)

Occupancy grid representing the map, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot as a grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

SensorPose — Pose of the range sensor relative to the robot
[0 0 0] (default) | three-element vector

Pose of the range sensor relative to the coordinate frame of the robot, specified as a three-element vector, `[x y theta]`.

SensorLimits — Minimum and maximum range of sensor
[0 12] (default) | two-element vector

Minimum and maximum range of sensor, specified as a two-element vector in meters.

NumBeams — Number of beams used for likelihood computation
60 (default) | scalar

Number of beams used for likelihood computation, specified as a scalar. The computation efficiency can be improved by specifying a smaller number of beams than the actual number available from the sensor.

MeasurementNoise — Standard deviation for measurement noise
0.2 (default) | scalar

Standard deviation for measurement noise, specified as a scalar.

RandomMeasurementWeight — Weight for probability of random measurement
0.05 (default) | scalar

Weight for probability of random measurement, specified as a scalar. This scalar is the probability that the measurement is not accurate due to random interference.

ExpectedMeasurementWeight — Weight for probability of expected measurement
0.95 (default) | scalar

Weight for probability of expected measurement, specified as a scalar. The weight is the probability of getting a correct range measurement within the noise limits specified in `MeasurementNoise` property.

MaxLikelihoodDistance — Maximum distance to find nearest obstacles
2.0 (default) | scalar

Maximum distance to find nearest obstacles, specified as a scalar in meters.

Limitations

If you change your sensor model after using it with the `MonteCarloLocalization` object, call `release` on that object beforehand. For example:

```
mcl = robotics.MonteCarloLocalization(...);
[isUpdated,pose,covariance] = mcl(...);
release(mcl)
mcl.SensorModel.PropName = value;
```

See Also

robotics.MonteCarloLocalization | robotics.OdometryMotionModel

Topics

"Localize TurtleBot Using Monte Carlo Localization"
"Monte Carlo Localization Algorithm"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016a

robotics.MonteCarloLocalization System object

Package: robotics

Localize robot using range sensor data and map

Description

The `robotics.MonteCarloLocalization` creates a Monte Carlo localization (MCL) object. The MCL algorithm is used to estimate the position and orientation of a robot in its environment using a known map of the environment, lidar scan data, and odometry sensor data.

To localize the robot, the MCL algorithm uses a particle filter to estimate the robot's position. The particles represent the distribution of likely states for the robot, where each particle represents a possible robot state. The particles converge around a single location as the robot moves in the environment and senses different parts of the environment using a range sensor. An odometry sensor measures the robot's motion.

A `robotics.MonteCarloLocalization` object takes the pose and lidar scan data as inputs. The input lidar scan sensor data is given in its own coordinate frame, and the algorithm transforms the data according to the `SensorModel.SensorPose` property that you must specify. The input pose is computed by integrating the odometry sensor data over time. If the change in pose is greater than any of the specified update thresholds, `UpdateThresholds`, then the particles are updated and the algorithm computes a new state estimate from the particle filter. The particles are updated using this process:

1 The particles are propagated based on the change in the pose and the specified motion model, `MotionModel`.

2 The particles are assigned weights based on the likelihood of receiving the range sensor reading for each particle. These likelihood weights are based on the sensor model you specify in `SensorModel`.

3 Based on the `ResamplingInterval` property, the particles are resampled from the posterior distribution, and the particles of low weight are eliminated. For example, a

resampling interval of 2 means that the particles are resampled after every other update.

The outputs of the object are the estimated pose and covariance, and the value of `isUpdated`. This estimated state is the mean and covariance of the highest weighted cluster of particles. The output pose is given in the map's coordinate frame that is specified in the `SensorModel.Map` property. If the change in pose is greater than any of the update thresholds, then the state estimate has been updated and `isUpdated` is `true`. Otherwise, `isUpdated` is `false` and the estimate remains the same. For continuous tracking the best estimate of a robot's state, repeat this process of propagating particles, evaluating their likelihood, and resampling.

To estimate robot pose and covariance using lidar scan data:

1   Create the robotics.MonteCarloLocalization 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

```
mcl = robotics.MonteCarloLocalization
mcl = robotics.MonteCarloLocalization(Name,Value)
```

Description

`mcl = robotics.MonteCarloLocalization` returns an MCL object that estimates the pose of a robot using a map, a range sensor, and odometry data. By default, an empty map is assigned, so a valid map assignment is required before using the object.

`mcl = robotics.MonteCarloLocalization(Name,Value)` creates an MCL object with additional options specified by one or more `Name,Value` pair arguments.

`Name` is a property name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Properties

`InitialPose` — **Initial pose of robot**
[0 0 0] (default) | three-element vector

Initial pose of the robot used to start localization, specified as a three-element vector, `[x y theta]`, that indicates the position and heading of the robot. Initializing the MCL object with an initial pose estimate enables you to use a smaller value for the maximum number of particles and still converge on a location.

`InitialCovariance` — **Covariance of initial pose**
`diag([1 1 1])` (default) | diagonal matrix | three-element vector | scalar

Covariance of the Gaussian distribution for the initial pose, specified as a diagonal matrix. Three-element vector and scalar inputs are converted to a diagonal matrix. This matrix gives an estimate of the uncertainty of the `InitialPose`.

`GlobalLocalization` — **Flag to start global localization**
`false` (default) | `true`

Flag indicating whether to perform global localization, specified as `false` or `true`. The default value, `false`, initializes particles using the `InitialPose` and `InitialCovariance` properties. A `true` value initializes uniformly distributed particles in the entire map and ignores the `InitialPose` and `InitialCovariance` properties. Global localization requires a large number of particles to cover the entire workspace. Use global localization only when the initial estimate of robot location and orientation is not available.

`ParticleLimits` — **Minimum and maximum number of particles**
[500 5000] (default) | two-element vector

Minimum and maximum number of particles, specified as a two-element vector, `[min max]`.

`SensorModel` — **Likelihood field sensor model**
`LikelihoodFieldSensorModel` object

Likelihood field sensor model, specified as a `LikelihoodFieldSensorModel` object. The default value uses the default `robotics.LikelihoodFieldSensorModel` object. After using the object to get output, call `release` on the object to make changes to `SensorModel`. For example:

```
mcl = robotics.MonteCarloLocalization(_);
[isUpdated,pose,covariance] = mcl(_);
release(mcl)
mcl.SensorModel.PropName = value;
```

MotionModel — Odometry motion model for differential drive
OdometryMotionModel object

Odometry motion model for differential drive, specified as an OdometryMotionModel object. The default value uses the default robotics.OdometryMotionModel object. After using the object to get output, call release on the object to make changes to MotionModel. For example:

```
mcl = robotics.MonteCarloLocalization(_);
[isUpdated,pose,covariance] = mcl(_);
release(mcl)
mcl.MotionModel.PropName = value;
```

UpdateThresholds — Minimum change in states required to trigger update
[0.2 0.2 0.2] (default) | three-element vector

Minimum change in states required to trigger update, specified as a three-element vector. The localization updates the particles if the minimum change in any of the [x y theta] states is met. The pose estimate updates only if the particle filter is updated.

ResamplingInterval — Number of filter updates between resampling of particles
1 (default) | positive integer

Number of filter updates between resampling of particles, specified as a positive integer.

UseLidarScan — Use lidarScan object as scan input
false (default) | true

Use a lidarScan object as scan input, specified as either false or true.

Usage

Note For versions earlier than R2016b, use the step function to run the System object™ algorithm. The arguments to step are the object you created, followed by the arguments shown in this section.

For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Syntax

`[isUpdated,pose,covariance] = mcl(odomPose,scan)`

`[isUpdated,pose,covariance] = mcl(odomPose,ranges,angles)`

Description

`[isUpdated,pose,covariance] = mcl(odomPose,scan)` estimates the pose and covariance of a robot using the MCL algorithm. The estimates are based on the pose calculated from the specified robot odometry, `odomPose`, and the specified lidar scan sensor data, `scan`. `mcl` is the `robotics.MonteCarloLocalization` object. `isUpdated` indicates whether the estimate is updated based on the `UpdateThreshold` property.

To enable this syntax, you must set the `UseLidarScan` property to `true`. For example:

```
mcl = robotics.MonteCarloLocalization('UseLidarScan','true');
...
[isUpdated,pose,covariance] = mcl(odomPose,scan);
```

`[isUpdated,pose,covariance] = mcl(odomPose,ranges,angles)` specifies the lidar scan data as `ranges` and `angles`.

Input Arguments

odomPose — Pose based on odometry
three-element vector

Pose based on odometry, specified as a three-element vector, `[x y theta]`. This pose is calculated by integrating the odometry over time.

scan — Lidar scan readings
`lidarScan` object

Lidar scan readings, specified as a `lidarScan` object.

Dependencies

To use this argument, you must set the UseLidarScan property to true.

```
mcl.UseLidarScan = true;
```

ranges — Range values from scan data
vector

Range values from scan data, specified as a vector with elements measured in meters. These range values are distances from a laser scan sensor at the specified angles. The ranges vector must have the same number of elements as the corresponding angles vector.

angles — Angle values from scan data
vector

Angle values from scan data, specified as a vector with elements measured in radians. These angle values are the angles at which the specified ranges were measured. The angles vector must be the same length as the corresponding ranges vector.

Output Arguments

isUpdated — Flag for pose update
logical

Flag for pose update, returned as a logical. If the change in pose is more than any of the update thresholds, then the output is true. Otherwise, it is false. A true output means that updated pose and covariance are returned. A false output means that pose and covariance are not updated and are the same as at the last update.

pose — Current pose estimate
three-element vector

Current pose estimate, returned as a three-element vector, [x y theta]. The pose is computed as the mean of the highest-weighted cluster of particles.

covariance — Covariance estimate for current pose
matrix

Covariance estimate for current pose, returned as a matrix. This matrix gives an estimate of the uncertainty of the current pose. The covariance is computed as the covariance of the highest-weighted cluster of particles.

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 robotics.MonteCarloLocalization
getParticles   Get particles from localization algorithm

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 Robot Pose from Range Sensor Data

Create a `MonteCarloLocalization` object, assign a sensor model, and calculate a pose estimate using the `step` method.

Note: Starting in R2016b, instead of using the step method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

Create an MCL object.

```
mcl = robotics.MonteCarloLocalization;
```

Assign a sensor model with an occupancy grid map to the object.

```
sm = robotics.LikelihoodFieldSensorModel;
p = zeros(200,200);
sm.Map = robotics.OccupancyGrid(p,20);
mcl.SensorModel = sm;
```

Create sample laser scan data input.

```
ranges = 10*ones(1,300);
ranges(1,130:170) = 1.0;
angles = linspace(-pi/2,pi/2,300);
odometryPose = [0 0 0];
```

Estimate robot pose and covariance.

```
[isUpdated,estimatedPose,covariance] = mcl(odometryPose,ranges,angles)

isUpdated = logical
   1


estimatedPose = 1×3

    0.0343    0.0193    0.0331


covariance = 3×3

    0.9467    0.0048         0
    0.0048    0.9025         0
         0         0    1.0011
```

- "Localize TurtleBot Using Monte Carlo Localization"

References

[1] Thrun, Sebatian, Wolfram Burgard, and Dieter Fox. *Probabilistic Robotics*. MIT Press, 2005.

[2] Dellaert, F., D. Fox, W. Burgard, and S. Thrun. "Monte Carlo Localization for Mobile Robots." *Proceedings 1999 IEEE International Conference on Robotics and Automation.*

See Also

`lidarScan` | `robotics.LikelihoodFieldSensorModel` | `robotics.OdometryMotionModel`

Topics

"Localize TurtleBot Using Monte Carlo Localization"
"Monte Carlo Localization Algorithm"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016a

robotics.OccupancyGrid class

Package: robotics

Create occupancy grid with probabilistic values

Description

`OccupancyGrid` creates a 2-D occupancy grid map. Each cell in the occupancy grid has a value representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

Occupancy grids are used in robotics algorithms such as path planning (see `robotics.PRM`). They are also used in mapping applications for finding collision-free paths, performing collision avoidance, and calculating localization (see `robotics.MonteCarloLocalization`). You can modify your occupancy grid to fit your specific application.

The `OccupancyGrid` objects support world and grid coordinates. The world coordinates origin is defined by the `GridLocationInWorld` property of the object, which defines the bottom-left corner of the grid. The number and size of grid locations are defined by the `Resolution` property. The first grid location with index `(1,1)` begins in the top-left corner of the grid.

Use the `OccupancyGrid` class to create 2-D maps of an environment with probability values representing different obstacles in your world. You can specify exact probability values of cells or include observations from sensors such as laser scanners.

Probability values are stored using a binary Bayes filter to estimate the occupancy of each grid cell. A log-odds representation is used, with values stored as `int16` to reduce the map storage size and allow for real-time applications.

If memory size is a limitation, consider using `robotics.BinaryOccupancyGrid` instead. The binary occupancy grid uses less memory with binary values, but still works with Robotics System Toolbox algorithms and other applications.

Construction

`map = robotics.OccupancyGrid(width,height)` creates a 2-D occupancy grid object representing a world space of `width` and `height` in meters. The default grid resolution is 1 cell per meter.

`map = robotics.OccupancyGrid(width,height,resolution)` creates an occupancy grid with a specified grid resolution in cells per meter.

`map = robotics.OccupancyGrid(rows,cols,resolution,'grid')` creates an occupancy grid with the specified number of rows and columns and with the resolution in cells per meter.

`map = robotics.OccupancyGrid(p)` creates an occupancy grid from the values in matrix `p`. The grid size matches the size of the matrix, with each cell probability value interpreted from the matrix location.

`map = robotics.OccupancyGrid(p,resolution)` creates an occupancy grid from the specified matrix and resolution in cells per meter.

Input Arguments

`width` — Map width
scalar in meters

Map width, specified as a scalar in meters.

Data Types: `double`

`height` — Map height
scalar in meters

Map height, specified as a scalar in meters.

Data Types: `double`

`resolution` — Grid resolution
1 (default) | scalar in cells per meter

Grid resolution, specified as a scalar in cells per meter.

Data Types: `double`

p — Input occupancy grid
matrix of probability values from 0 to 1

Input occupancy grid, specified as a matrix of probability values from 0 to 1. The size of the grid matches the size of the matrix. Each matrix element corresponds to the probability of the grid cell location being occupied. Values close to 0 represent a high certainty that the cell contains an obstacle. Values close to 1 represent certainty that the cell is not occupied and obstacle free.

Data Types: `double`

Properties

FreeThreshold — Threshold to consider cells as obstacle-free
scalar

Threshold to consider cells as obstacle-free, specified as a scalar. Probability values below this threshold are considered obstacle free. This property also defines the free locations for path planning when using `robotics.PRM`.

OccupiedThreshold — Threshold to consider cells as occupied
scalar

Threshold to consider cells as occupied, specified as a scalar. Probability values above this threshold are considered occupied.

ProbabilitySaturation — Saturation limits for probability
[0.001 0.999] (default) | [min max] vector

Saturation limits for probability, specified as a [min max] vector. Values above or below these saturation values are set to the min and max values. This property reduces oversaturating of cells when incorporating multiple observations.

GridSize — Number of rows and columns in grid
[rows cols] vector

This property is read-only.

Number of rows and columns in grid, stored as a [rows cols] vector.

Resolution — Grid resolution
1 (default) | scalar in cells per meter

Grid resolution, stored as a scalar in cells per meter. This value is read only.

XWorldLimits — Minimum and maximum world range values of *x*-coordinates
[min max] vector

Minimum and maximum world range values of *x*-coordinates, stored as a [min max] vector. This value is read only.

YWorldLimits — Minimum and maximum world range values of *y*-coordinates
[min max] vector

Minimum and maximum world range values of *y*-coordinates, stored as a [min max] vector. This value is read only.

GridLocationInWorld — [x,y] world coordinates of grid
[0 0] (default) | two-element vector

[x,y] world coordinates of the bottom-left corner of the grid, specified as a two-element vector.

Methods

checkOccupancy	Check locations for free, occupied, or unknown values
copy	Create copy of occupancy grid
getOccupancy	Get occupancy of a location
grid2world	Convert grid indices to world coordinates
inflate	Inflate each occupied grid location
insertRay	Insert ray from laser scan observation
occupancyMatrix	Convert occupancy grid to double matrix
raycast	Compute cell indices along a ray
rayIntersection	Compute map intersection points of rays
setOccupancy	Set occupancy of a location
show	Show grid values in a figure
updateOccupancy	Integrate probability observation at a location
world2grid	Convert world coordinates to grid indices

Examples

Insert Laser Scans Into Occupancy Grid

Take range and angle readings from a laser scan and insert these readings into an occupancy grid.

Create an empty occupancy grid map.

```
map = robotics.OccupancyGrid(10,10,20);
```

Insert a laser scan into the occupancy grid. Specify the pose of the robot ranges and angles and the max range of the laser scan.

```
pose = [5,5,0];
ranges = 3*ones(100, 1);
angles = linspace(-pi/2, pi/2, 100);
maxrange = 20;

insertRay(map,pose,ranges,angles,maxrange);
```

Show the map to see the results of inserting the laser scan. Check the occupancy of the spot directly in front of the robot.

```
show(map)
getOccupancy(map,[8 5])


ans =

    0.7000
```

Occupancy Grid

Add a second reading and view the update to the occupancy values. The additional reading increases the confidence in the readings. The free and occupied values become more distinct.

```
insertRay(map,pose,ranges,angles,maxrange);
show(map)
getOccupancy(map,[8 5])
```

```
ans =

    0.8448
```

Occupancy Grid

Convert PGM Image to Map

Convert a portable graymap (`.pgm`) file containing a ROS map into an `OccupancyGrid` map for use in MATLAB.

Import the image using `imread`. Crop the image to the relevant area.

```
image = imread(fullfile(matlabroot,'examples','robotics','playpen_map.pgm'));
imageCropped = image(750:1250,750:1250);
imshow(imageCropped)
```

PGM values are expressed from 0 to 255 as `uint8`. Normalize these values by converting the cropped image to `double` and dividing each cell by 255. This image shows obstacles as values close to 0. Subtract the normalized image from 1 to get occupancy values with 1 representing occupied space.

```
imageNorm = double(imageCropped)/255;
imageOccupancy = 1 - imageNorm;
```

Create the `OccupancyGrid` object using an adjusted map image. The imported map resolution is 20 cells per meter.

```
map = robotics.OccupancyGrid(imageOccupancy,20);
show(map)
```

- "Mapping With Known Poses"

Limitations

Occupancy values have a limited resolution of ±0.001. The values are stored as `int16` using a log-odds representation. This data type limits resolution, but saves you memory when storing large maps in MATLAB. When calling `set` and then `get`, the value returned might not equal the value you set. For more information, see the log-odds representations section in "Occupancy Grids".

Extended Capabilities

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

See Also
readOccupancyGrid | robotics.BinaryOccupancyGrid | robotics.PRM | robotics.PurePursuit | writeOccupancyGrid

Topics
"Mapping With Known Poses"
"Occupancy Grids"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016b

robotics.OccupancyMap3D class

Package: robotics

Create 3-D occupancy map

Description

The `OccupancyMap3D` class stores a 3-D map and map information. The map is stored as probabilistic values in an octree data structure on page 1-161. The class handles arbitrary environments and expands its size dynamically based on observation inputs. You can add observations as point clouds or as specific *xyz* locations. These observations update the probability values. Probabilistic values represent the occupancy of locations. The octree data structure trims data appropriately to remain efficient both in memory and on disk.

Construction

`omap = robotics.OccupancyMap3D` creates an empty 3-D occupancy map with no observations and default property values.

`omap = robotics.OccupancyMap3D(res)` specifies a map resolution in cells/meter and sets the `Resolution` property.

`omap = robotics.OccupancyMap3D(res,Name,Value)` creates an object with additional options specified by one or more `Name,Value` pair arguments. For example, `'FreeThreshold',0.25` sets the threshold to consider cells obstacle-free as a probability value of 0.25. Enclose each property name in quotes.

Properties

Resolution — Grid resolution
1 (default) | positive scalar

Grid resolution in cells per meter, specified as a scalar. Specify resolution on construction. Inserting observations with precisions higher than this value are rounded down and applied at this resolution.

FreeThreshold — Threshold to consider cells as obstacle-free
`0.2` (default) | positive scalar

Threshold to consider cells as obstacle-free, specified as a positive scalar. Probability values below this threshold are considered obstacle-free.

OccupiedThreshold — Threshold to consider cells as occupied
`0.65` (default) | positive scalar

Threshold to consider cells as occupied, specified as a positive scalar. Probability values above this threshold are considered occupied.

ProbabilitySaturation — Saturation limits on probability values
`[0.001 0.999]` (default) | `[min max]` vector

Saturation limits on probability values, specified as a `[min max]` vector. Values above or below these saturation values are set to the `min` or `max` values. This property reduces oversaturating of cells when incorporating multiple observations.

Methods

checkOccupancy	Check if locations are free or occupied
getOccupancy	Get occupancy probability of locations
inflate	Inflate map
insertPointCloud	Insert 3-D points or point cloud observation into map
setOccupancy	Set occupancy probability of locations
show	Show occupancy map
updateOccupancy	Update occupancy probability at locations

Examples

Create 3-D Occupancy Map and Inflate Points

The `OccupancyMap3D` object stores obstacles in 3-D space, using sensor observations to map an environment. Create a map and add points from a point cloud to identify

obstacles. Then inflate the obstacles in the map to ensure safe operating space around obstacles.

Create an `OccupancyMap3D` object with a map resolution of 10 cells/meter.

```
map3D = robotics.OccupancyMap3D(10);
```

Define a set of 3-D points as an observation from a pose `[x y z qw qx qy qz]`. This pose is for the sensor that observes these points and is centered on the origin. Define two sets of points to insert multiple observations.

```
pose = [ 0 0 0 1 0 0 0];

points = repmat([0:0.25:2]', 1, 3);
points2 = [(0:0.25:2)' (2:-0.25:0)' (0:0.25:2)'];
maxRange = 5;
```

Insert the first set of points using `insertPointCloud`. The function uses the sensor pose and the given points to insert observations into the map. The colors displayed correlate to the height of the point only for illustrative purposes.

```
insertPointCloud(map3D,pose,points,maxRange)
show(map3D)
```
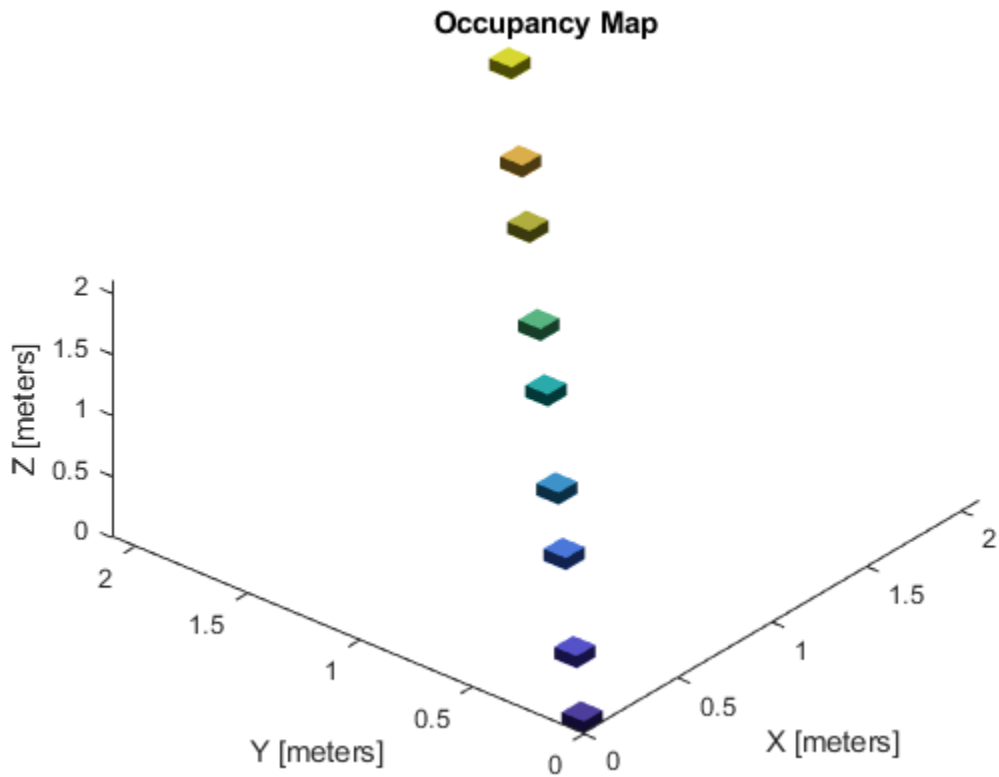
Insert the second set of points. The ray between the sensor pose (origin) and these points overlap points from the previous insertion. Therefore, the free space between the sensor and the new points are updated and marked as free space.

```
insertPointCloud(map3D,pose,points2,maxRange)
show(map3D)
```
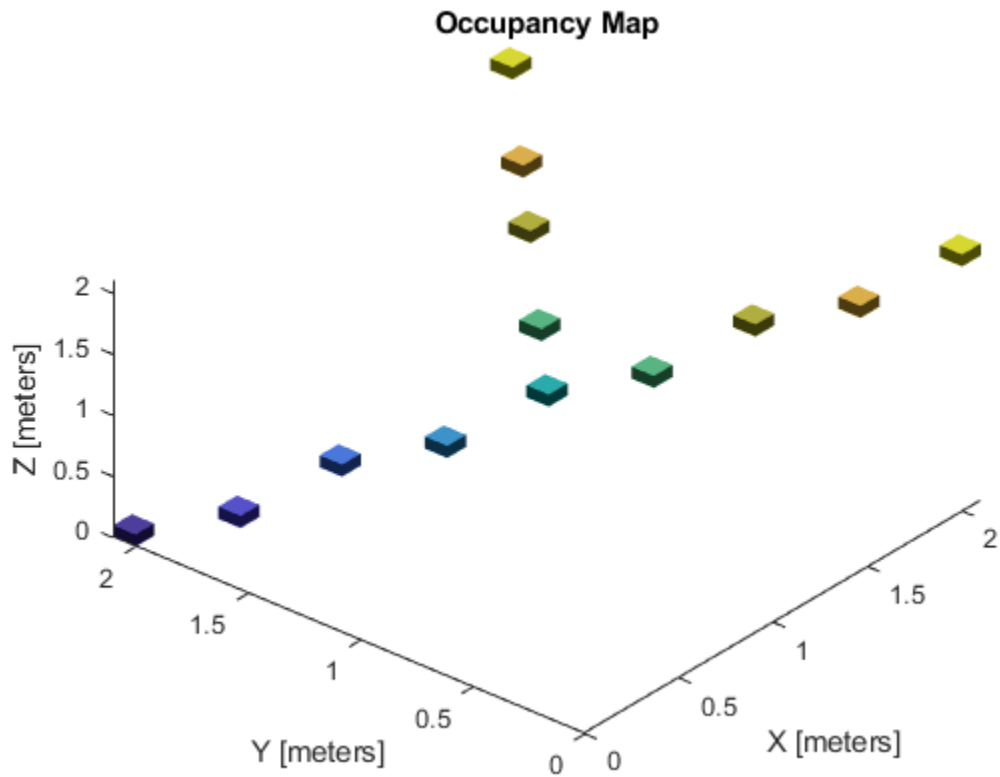
Inflate the map to add a buffer zone for safe operation around obstacles. Define the robot radius and safety distance and use the sum of these values to define the inflation radius for the map.

```
robotRadius = 0.2;
safetyRadius = 0.3;
inflationRadius = robotRadius + safetyRadius;
inflate(map3D, inflationRadius);

show(map3D)
```

Occupancy Map
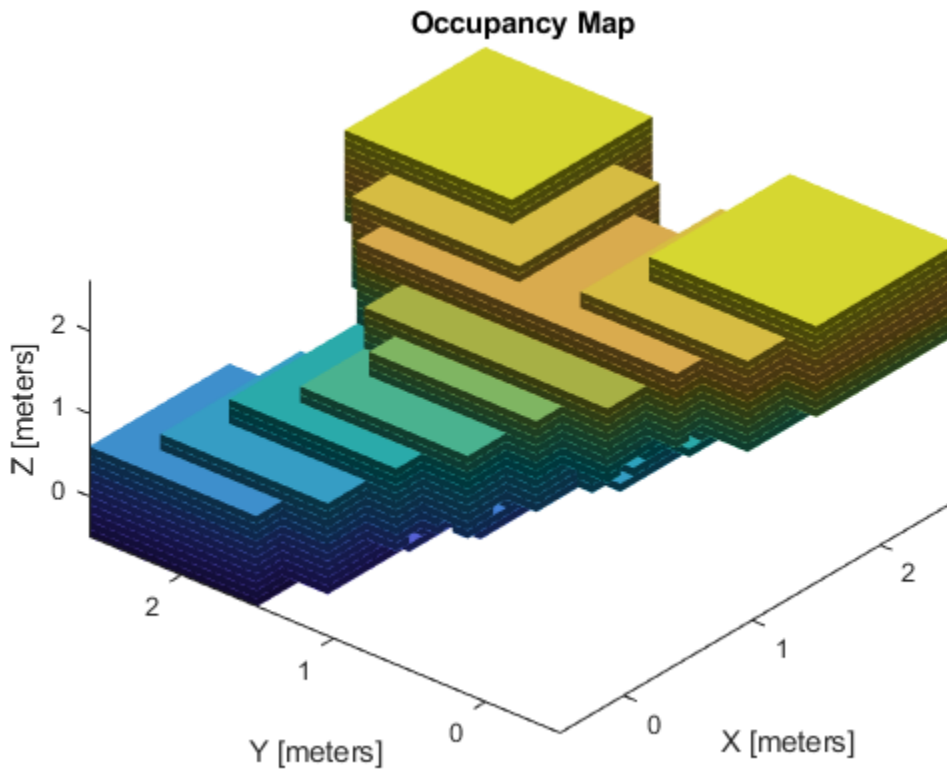
Algorithms

Octree Data Structure

The octree data structure is a hierarchical structure used for subdivision of an environment into cubic volumes called voxels. For a given map volume, the space is recursively subdivided into eight voxels until achieving a desired map resolution (voxel size) is achieved. This subdivision can be represented as a tree, which stores probability values for locations in the map.
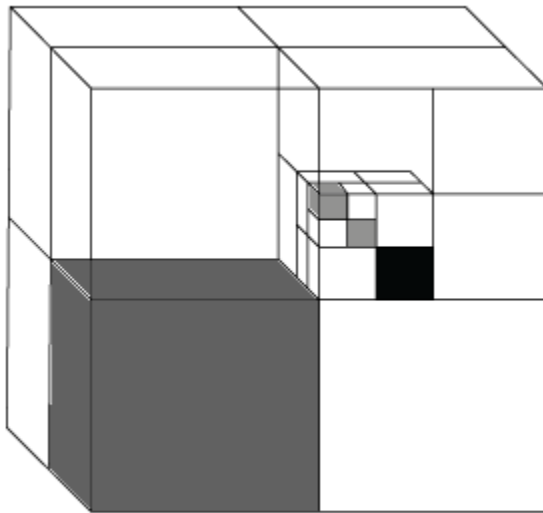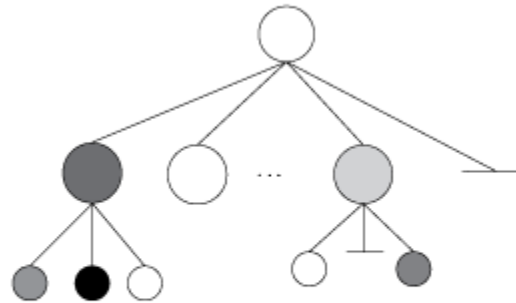
3-D Voxels   Octree Branching Structure

The probability values in the tree have a log-odds representation. Using this representation, locations easily recover from dynamic observations and numerical errors due to small probabilities are reduced. To remain efficient in memory, lower branches of the tree are pruned in the structure if they share the same occupancy values using this log-odds representation.
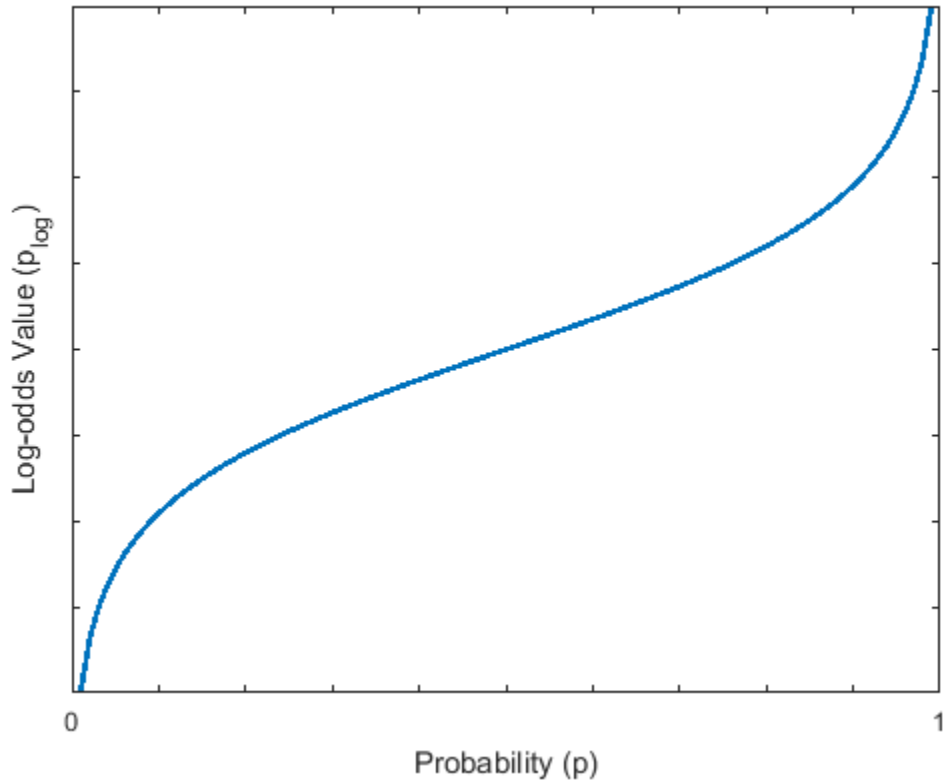
The class internally handles the organization of this data structure, including the pruning of branches. Specify all observations as spatial coordinates when using functions such as `setOccupancy`, `getOccupancy`, or `insertPointCloud`. Insertions into the tree, and navigation through the tree, is determined based on the spatial coordinates and the resolution of the map.

References

–

[1] Hornung, Armin, Kai M. Wurm, Maren Bennewitz, Cyrill Stachniss, and Wolfram Burgard. "OctoMap: an efficient probabilistic 3D mapping framework based on

octrees." *Autonomous Robots*, Vol. 34, No. 3, 2013, pp. 189–206.. doi:10.1007/s10514-012-9321-0.

See Also

Classes
BinaryOccupancyGrid | OccupancyGrid

Functions
inflate | insertPointCloud | readOccupancyMap3D | setOccupancy | show

Introduced in R2018a

robotics.OdometryMotionModel class

Package: robotics

Create an odometry motion model

Description

`OdometryMotionModel` creates an odometry motion model object for differential drive robots. This object contains specific motion model parameters. You can use this object to specify the motion model parameters in the `robotics.MonteCarloLocalization` object.

This motion model assumes that the robot makes pure rotation and translation motions to travel from one location to the other. The model propagates points for either forward or backwards motion based on these motion patterns. The elements of the `Noise` property refer to the variance in the motion. To see the effect of changing the noise parameters, use `robotics.OdometryMotionModel.showNoiseDistribution`.

Construction

`omm = robotics.OdometryMotionModel` creates an odometry motion model object for differential drive robots.

Properties

Noise — Gaussian noise for robot motion
[0.2 0.2 0.2 0.2] (default) | 4-element vector

Gaussian noise for robot motion, specified as a 4-element vector. This property represents the variance parameters for Gaussian noise applied to robot motion. The elements of the vector correspond to the following errors in order:

- Rotational error due to rotational motion
- Rotational error due to translational motion

- Translational error due to translation motion
- Translational error due to rotational motion

Type — Type of the odometry motion model
'DifferentialDrive' (default) | character vector

This property is read-only.

Type of the odometry motion model, returned as a character vector. This read-only property indicates the type of odometry motion model being used by the object.

Examples

Predict Poses Based On An Odometry Motion Model

This example shows how to use the robotics.OdometryMotionModel class to predict the pose of a robot. An OdometryMotionModel object contains the motion model parameters for a differential drive robot. Use the object to predict the pose of a robot based on its current and previous poses and the motion model parameters.

Create odometry motion model object.

```
motionModel = robotics.OdometryMotionModel;
```

Define previous poses and the current odometry reading. Each pose prediction corresponds to a row in previousPoses vector.

```
previousPoses =  rand(10,3);
currentOdom = [0.1 0.1 0.1];
```

The first call to the object initializes values and returns the previous poses as the current poses.

```
currentPoses = motionModel(previousPoses, currentOdom);
```

Subsequent calls to the object with updated odometry poses returns the predicted poses based on the motion model.

```
currentOdom = currentOdom + [0.1 0.1 0.05];
predPoses = motionModel(previousPoses, currentOdom);
```

Show Noise Distribution Effects for Odometry Motion Model

This example shows how to visualize the effect of different noise parameters on the `robotics.OdometryMotionModel` class. An `OdometryMotionModel` object contains the motion model noise parameters for a differential drive robot. Use `showNoiseDistribution` to visualize how changing these values affect the distribution of predicted poses.

Create a motion model object.

```
motionModel = robotics.OdometryMotionModel;
```

Show the distribution of particles with the existing noise parameters. Each particle is a hypothesis for the predicted pose.

```
showNoiseDistribution(motionModel);
```

Show the distribution with a specified odometry pose change and number of samples. The change in odometry is used as the final pose with hypotheses distributed around based on the `Noise` parameters.

```
showNoiseDistribution(motionModel, ...
          'OdometryPoseChange', [0.5 0.1 0.25], ...
          'NumSamples', 1000);
```

Change the `Noise` parameters and visualize the effects. Use the same odometry pose change and number of samples.

```
motionModel.Noise = [0.2 1 0.2 1];

showNoiseDistribution(motionModel, ...
          'OdometryPoseChange', [0.5 0.1 0.25], ...
          'NumSamples', 1000);
```

- "Localize TurtleBot Using Monte Carlo Localization"

Methods

showNoiseDistribution	Display noise parameter effects
step	Computer next pose from previous pose

Limitations

If you make changes to your motion model after using it with the `MonteCarloLocalization` object, call `release` on that object beforehand. For example:

```
mcl = robotics.MonteCarloLocalization(...);
[isUpdated,pose,covariance] = mcl(...);
release(mcl)
mcl.MotionModel.PropName = value;
```

References

[1] Thrun, Sebatian, Wolfram Burgard, and Dieter Fox. *Probabilistic Robotics*. MIT Press, 2005.

Extended Capabilities

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

See Also
robotics.LikelihoodFieldSensorModel | robotics.MonteCarloLocalization

Topics
"Localize TurtleBot Using Monte Carlo Localization"

Introduced in R2016a

robotics.OrientationTarget class

Package: robotics

Create constraint on relative orientation of body

Description

The `OrientationTarget` object describes a constraint that requires the orientation of one body (the end effector) to match a target orientation within an angular tolerance in any direction. The target orientation is specified relative to the body frame of the reference body.

Constraint objects are used in `GeneralizedInverseKinematics` objects to specify multiple kinematic constraints on a robot.

For an example that uses multiple constraint objects, see "Plan a Reaching Trajectory With Multiple Kinematic Constraints".

Construction

`orientationConst = robotics.OrientationTarget(endeffector)` returns an orientation target object that represents a constraint on a body of the robot model specified by `endeffector`.

`orientationConst = robotics.OrientationTarget(endeffector, Name,Value)` returns an orientation target object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

`Name` is any property name and must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Input Arguments

endeffector — End-effector name
character vector

End-effector name, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

Properties

EndEffector — Name of the end effector
character vector

Name of the end effector, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

ReferenceBody — Name of the reference body frame
`''` (default) | character vector

Name of the reference body frame, specified as a character vector. The default `''` indicates that the constraint is relative to the base of the robot model. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

TargetOrientation — Target orientation of the end effector relative to the reference body
`[1 0 0 0]` (default) | four-element vector

Target orientation of the end effector relative to the reference body, specified as four-element vector that represents a unit quaternion. The orientation of the end effector relative to the reference body frame is the orientation that converts a direction specified in the end-effector frame to the same direction specified in the reference body frame.

OrientationTolerance — Maximum allowed rotation angle
`0` (default) | numeric scalar

Maximum allowed rotation angle in radians, specified as a numeric scalar. This value is the upper bound on the magnitude of the rotation required to make the end-effector orientation match the target orientation.

Weights — Weight of the constraint
1 (default) | numeric scalar

Weight of the constraint, specified as a numeric scalar. This weight is used with the `Weights` property of all the constraints specified in `GeneralizedInverseKinematics` to properly balance each constraint.

Extended Capabilities

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

See Also

Classes
robotics.GeneralizedInverseKinematics | robotics.JointPositionBounds | robotics.PoseTarget | robotics.PositionTarget

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

ParameterTree

Access ROS parameter server

Description

A `ParameterTree` object communicates with the ROS parameter server. The ROS parameter server can store strings, integers, doubles, Booleans, and cell arrays. The parameters are accessible globally over the ROS network. You can use these parameters to store static data such as configuration parameters.

To directly set, get, or access ROS parameters without creating a `ParameterTree` object, see `rosparam`.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed.

ROS Data Type	MATLAB Data Type
32-bit integer	`int32`
boolean	`logical`
double	`double`
string	character vector (`char`)
list	cell array (`cell`)
dictionary	structure (`struct`)

Creation

Syntax

```
ptree = rosparam
```

```
ptree = robotics.ros.ParameterTree(node)
```

Description

`ptree = rosparam` creates a parameter tree object, `ptree`. After `ptree` is created, the connection to the parameter server remains persistent until the object is deleted or the ROS master becomes unavailable.

`ptree = robotics.ros.ParameterTree(node)` returns a `ParameterTree` object to communicate with the ROS parameter server. The parameter tree attaches to the ROS node, `node`. To connect to the global node, specify `node` as `[]`.

Properties

`AvailableParameters` — List of parameter names on the server
cell array

This property is read-only.

List of parameter names on the server, specified as a cell array.

Example: `{'/myParam';'/robotSize';'/hostname'}`

Data Types: `cell`

Object Functions

get   Get ROS parameter value
has   Check if ROS parameter name exists
search   Search ROS network for parameter names
set   Set value of ROS parameter or add new parameter
del   Delete a ROS parameter

Examples

Create ROS ParameterTree Object and Modify Parameters

Start the ROS master and create a ROS node.

```
master = robotics.ros.Core;
node = robotics.ros.Node('/test1');
```

Create the parameter tree object.

```
ptree = robotics.ros.ParameterTree(node);
```

Set multiple parameters.

```
set(ptree,'DoubleParam',1.0)
set(ptree,'CharParam','test')
set(ptree,'CellParam',{{'test'},{1,2}});
```

View the available parameters.

```
parameters = ptree.AvailableParameters

parameters = 3x1 cell array
    {'/CellParam'  }
    {'/CharParam'  }
    {'/DoubleParam'}
```

Get a parameter value.

```
data = get(ptree,'CellParam')

data = 1x2 cell array
    {1x1 cell}    {1x2 cell}
```

Search for a parameter name.

```
search(ptree,'char')

ans = 1x1 cell array
    {'/CharParam'}
```

Delete the parameter tree and ROS node. Shut down the ROS master.

```
clear('ptree','node')
clear('master')
```

Set A Dictionary Of Parameter Values

Use structures to specify a dictionary of ROS parameters under a specific namespace.

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_08339 with NodeURI http://bat5811win64:570
```

Create a dictionary of parameters values. This dictionary contains the information relevant to an image. Display the structure to verify values.

```
image = imread('peppers.png');

pval.ImageWidth = size(image,1);
pval.ImageHeight = size(image,2);
pval.ImageTitle = 'peppers.png';
disp(pval)

     ImageWidth: 384
    ImageHeight: 512
     ImageTitle: 'peppers.png'
```

Set the dictionary of values using the desired namespace.

```
rosparam('set','ImageParam',pval)
```

Get the parameters using the namespace. Verify the values.

```
pval2 = rosparam('get','ImageParam')

pval2 = struct with fields:
    ImageHeight: 512
     ImageTitle: 'peppers.png'
     ImageWidth: 384
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_08339 with NodeURI http://bat5811win64:57
Shutting down ROS master on http://bat5811win64:11311/.
```

• "Access the ROS Parameter Server"

See Also

del | get | has | rosparam | search | set

Topics

"Access the ROS Parameter Server"

Introduced in R2015a

robotics.ParticleFilter class

Package: robotics

Create particle filter state estimator

Description

The particle filter is a recursive, Bayesian state estimator that uses discrete particles to approximate the posterior distribution of the estimated state.

The particle filter algorithm computes the state estimate recursively and involves two steps: prediction and correction. The prediction step uses the previous state to predict the current state based on a given system model. The correction step uses the current sensor measurement to correct the state estimate. The algorithm periodically redistributes, or resamples, the particles in the state space to match the posterior distribution of the estimated state.

The estimated state consists of state variables. Each particle represents a discrete state hypothesis of these state variables. The set of all particles is used to help determine the final state estimate.

You can apply the particle filter to arbitrary nonlinear system models. Process and measurement noise can follow arbitrary non-Gaussian distributions.

For more information on the particle filter workflow and setting specific parameters, see:

- "Particle Filter Workflow"
- "Particle Filter Parameters"

Construction

`pf = robotics.ParticleFilter` creates a `ParticleFilter` object that enables the state estimation for a simple system with three state variables. Use the `initialize` method to initialize the particles with a known mean and covariance or uniformly distributed particles within defined bounds. To customize the particle filter's system and

measurement models, modify the `StateTransitionFcn` and `MeasurementLikelihoodFcn` properties.

After you create the `ParticleFilter` object, use `robotics.ParticleFilter.initialize` to initialize the `NumStateVariables` and `NumParticles` properties. The `initialize` function sets these two properties based on your inputs.

Properties

NumStateVariables — Number of state variables
3 (default) | scalar

This property is read-only.

Number of state variables, specified as a scalar. This property is set based on the inputs to the `initialize` method. The number of states is implicit based on the specified matrices for initial state and covariance.

NumParticles — Number of particles used in the filter
1000 (default) | scalar

This property is read-only.

Number of particles using in the filter, specified as a scalar. You can specify this property only by calling the `initialize` method.

StateTransitionFcn — Callback function for determining the state transition between particle filter steps
function handle

Callback function for determining the state transition between particle filter steps, specified as a function handle. The state transition function evolves the system state for each particle. The function signature is:

```
function predictParticles = stateTransitionFcn(pf,prevParticles,varargin)
```

The callback function accepts at least two input arguments: the `ParticleFilter` object, `pf`, and the particles at the previous time step, `prevParticles`. These specified particles are the `predictParticles` returned from the previous `step` call of the

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ParticleFilter object. `predictParticles` and `prevParticles` are the same size: NumParticles-by-NumStateVariables.

You can also use `varargin` to pass in a variable number of arguments from the `predict` function. When you call:

predict(pf,arg1,arg2)

MATLAB essentially calls `stateTranstionFcn` as:

stateTransitionFcn(pf,prevParticles,arg1,arg2)

MeasurementLikelihoodFcn — Callback function calculating the likelihood of sensor measurements
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. You must implement this function based on your measurement model. The function signature is:

function likelihood = measurementLikelihoodFcn(PF,predictParticles,measurement,varargin

The callback function accepts at least three input arguments:

1   `pf` – The associated `ParticleFilter` object
2   `predictParticles` – The particles that represent the predicted system state at the current time step as an array of size NumParticles-by-NumStateVariables
3   `measurement` – The state measurement at the current time step

You can also use `varargin` to pass in a variable number of arguments. These arguments are passed by the `correct` function. When you call:

correct(pf,measurement,arg1,arg2)

MATLAB essentially calls `measurementLikelihoodFcn` as:

measurementLikelihoodFcn(pf,predictParticles,measurement,arg1,arg2)

The callback needs to return exactly one output, `likelihood`, which is the likelihood of the given `measurement` for each particle state hypothesis.

IsStateVariableCircular — Indicator if state variables have a circular distribution

[0 0 0] (default) | logical array

Indicator if state variables have a circular distribution, specified as a logical array. Circular (or angular) distributions use a probability density function with a range of [-pi,pi]. If the `ParticleFilter` object has multiple state variables, then `IsStateVariableCircular` is a row vector. Each vector element indicates if the associated state variable is circular. If the object has only one state variable, then `IsStateVariableCircular` is a scalar.

ResamplingPolicy — Policy settings that determine when to trigger resampling

object

Policy settings that determine when to trigger resampling, specified as an object. You can trigger resampling either at fixed intervals, or you can trigger it dynamically, based on the number of effective particles. See `robotics.ResamplingPolicy` for more information.

ResamplingMethod — Method used for particle resampling

`'multinomial'` (default) | `'residual'` | `'stratified'` | `'systematic'`

Method used for particle resampling, specified as `'multinomial'`, `'residual'`, `'stratified'`, and `'systematic'`.

StateEstimationMethod — Method used for state estimation

`'mean'` (default) | `'maxweight'`

Method used for state estimation, specified as `'mean'` and `'maxweight'`.

Particles — Array of particle values

NumParticles-by-NumStateVariables matrix

Array of particle values, specified as a NumParticles-by-NumStateVariables matrix. Each row corresponds to the state hypothesis of a single particle.

Weights — Particle weights

NumParticles-by-1 vector

Particle weights, specified as a NumParticles-by-1 vector. Each weight is associated with the particle in the same row in the `Particles` property.

State — Best state estimate

vector

This property is read-only.

Best state estimate, returned as a vector with length `NumStateVariables`. The estimate is extracted based on the `StateEstimationMethod` property.

State Covariance — Corrected system covariance
N-by-N matrix | [ ]

This property is read-only.

Corrected system variance, returned as an *N-by-N* matrix, where *N* is equal to the `NumStateVariables` property. The corrected state is calculated based on the `StateEstimationMethod` property and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the property is set to [ ].

Methods

copy	Create copy of particle filter
correct	Adjust state estimate based on sensor measurement
getStateEstimate	Extract best state estimate and covariance from particles
initialize	Initialize the state of the particle filter
predict	Predict state of robot in next time step

Examples

Particle Filter Prediction and Correction

Create a `ParticleFilter` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = robotics.ParticleFilter
```

```
pf =
  ParticleFilter with properties:

           NumStateVariables: 3
                NumParticles: 1000
           StateTransitionFcn: @robotics.algs.gaussianMotion
    MeasurementLikelihoodFcn: @robotics.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
            ResamplingPolicy: [1x1 robotics.ResamplingPolicy]
            ResamplingMethod: 'multinomial'
       StateEstimationMethod: 'mean'
             StateOrientation: 'row'
                   Particles: [1000x3 double]
                     Weights: [1000x1 double]
                       State: 'Use the getStateEstimate function to see the value.'
             StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (eye(3)). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the StateEstimationMethod algorithm.

```
stateEst = getStateEstimate(pf)
```

stateEst = *1×3*

    4.1562   0.9185   9.0202

Estimate Robot Position in a Loop Using Particle Filter

Use the `ParticleFilter` object to track a robot as it moves in a 2-D space. The measured position has random noise added. Using `predict` and `correct`, track the robot based on the measurement and on an assumed motion model.

Initialize the particle filter and specify the default state transition function, the measurement likelihood function, and the resampling policy.

```
pf = robotics.ParticleFilter;
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Sample 1000 particles with an initial position of [0 0] and unit covariance.

```
initialize(pf,1000,[0 0],eye(2));
```

Prior to estimation, define a sine wave path for the dot to follow. Create an array to store the predicted and estimated position. Define the amplitude of noise.

```
t = 0:0.1:4*pi;
dot = [t; sin(t)]';
robotPred = zeros(length(t),2);
robotCorrected = zeros(length(t),2);
noise = 0.1;
```

Begin the loop for predicting and correcting the estimated position based on measurements. The resampling of particles occurs based on the `ResamplingPolicy` property. The robot moves based on a sine wave function with random noise added to the measurement.

```
for i = 1:length(t)
    % Predict next position. Resample particles if necessary.
    [robotPred(i,:),robotCov] = predict(pf);
    % Generate dot measurement with random noise. This is
    % equivalent to the observation step.
    measurement(i,:) = dot(i,:) + noise*(rand([1 2])-noise/2);
    % Correct position based on the given measurement to get best estimation.
    % Actual dot position is not used. Store corrected position in data array.
    [robotCorrected(i,:),robotCov] = correct(pf,measurement(i,:));
end
```

Plot the actual path versus the estimated position. Actual results may vary due to the randomness of particle distributions.

```
plot(dot(:,1),dot(:,2),robotCorrected(:,1),robotCorrected(:,2),'or')
xlim([0 t(end)])
ylim([-1 1])
legend('Actual position','Estimated position')
grid on
```
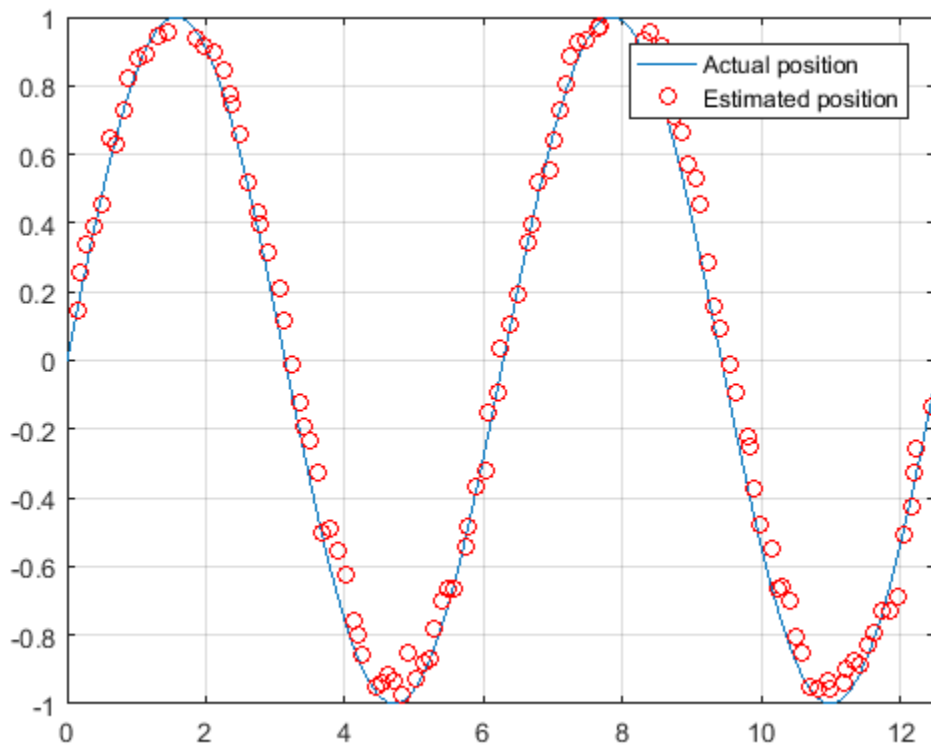

The figure shows how close the estimate state matches the actual position of the robot. Try tuning the number of particles or specifying a different initial position and covariance to see how it affects tracking over time.

- "Track a Car-Like Robot Using Particle Filter"

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
robotics.ParticleFilter.correct | robotics.ParticleFilter.predict | robotics.ResamplingPolicy

Topics
"Track a Car-Like Robot Using Particle Filter"
"Particle Filter Parameters"
"Particle Filter Workflow"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016a

robotics.PoseGraph

Create 2-D pose graph

Description

A `PoseGraph` object stores information for a 2-D pose graph representation. A pose graph contains `nodes` connected by `edges`, with edge constraints that define the relative pose between nodes and the uncertainty on that measurement. The `optimizePoseGraph` function modifies the nodes to account for the uncertainty and improve the overall graph.

For 3-D pose graphs, see `PoseGraph3D`.

To construct a pose graph iteratively, use `addRelativePose` to add a node and connect it to an existing node with specified edge constraints. Specify the uncertainty of the measurement using an information matrix. Adding an edge between two existing nodes creates a loop closure in the graph.

`LidarSLAM` (lidar-based simultaneous localization and mapping) is built around the optimization of a 2-D pose graph.

Creation

Syntax

poseGraph = robotics.PoseGraph

Description

poseGraph = robotics.PoseGraph creates a 2-D pose graph object. Add poses using `addRelativePose` to construct a pose graph iteratively.

Properties

NumNodes — Number of nodes in pose graph
1 (default) | positive integer

This property is read-only.

Number of nodes in pose graph, specified as a positive integer. Each node represents a pose in the pose graph as an [x y theta] vector with an *xy*-position and orientation angle, theta. To specify relative poses between nodes, use addRelativePose. To get a list of all nodes, use nodes.

NumEdges — Number of edges in pose graph
0 (default) | nonnegative integer

This property is read-only.

Number of edges in pose graph, specified as a nonnegative integer. Each edge connects two nodes in the pose graph. Loop closure edges are included.

NumLoopClosures — Number of loop closures
0 (default) | nonnegative integer

This property is read-only.

Number of loop closures in pose graph, specified as a nonnegative integer. To get the edge IDs of the loop closures, use the LoopClosureEdgeIDs property.

LoopClosureEdgeIDs — Loop closure edge IDs
vector

This property is read-only.

Loop closure edges IDs, specified as a vector of edge IDs.

Object Functions

addRelativePose	Add relative pose to pose graph
edges	Edges in pose graph
edgeConstraints	Edge constraints in pose graph
findEdgeID	Find edge ID of edge

nodes	Poses of nodes in pose graph
optimizePoseGraph	Optimize nodes in pose graph
removeEdges	Remove loop closure edges from graph
show	Plot pose graph

Examples

Optimize a 2-D Pose Graph

Optimize a pose graph based on the nodes and edge constraints. The pose graph used in this example is from the Intel Research Lab Dataset and was generated from collecting wheel odometry and a laser range finder sensor information in an indoor lab.

Load the Intel data set that contains a 2-D pose graph. Inspect the `robotics.PoseGraph` object to view the number of nodes and loop closures.

```
load intel-2d-posegraph.mat pg
disp(pg)

  PoseGraph with properties:

             NumNodes: 1228
             NumEdges: 1483
    NumLoopClosureEdges: 256
     LoopClosureEdgeIDs: [1x256 double]
```

Plot the pose graph with IDs off. Red lines indicate loop closures identified in the dataset.

```
title('Original Pose Graph')
show(pg,'IDs','off');
```

Optimize the pose graph. Nodes are adjusted based on the edge constraints and loop closures. Plot the optimized pose graph to see the adjustment of the nodes with loop closures.

```
updatedPG = optimizePoseGraph(pg);
figure
title('Updated Pose Graph')
show(updatedPG,'IDs','off');
```

- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

References

[1] Grisetti, G., R. Kummerle, C. Stachniss, and W. Burgard. "A Tutorial on Graph-Based SLAM." *IEEE Intelligent Transportation Systems Magazine*. Vol. 2, No. 4, 2010, pp. 31–43. doi:10.1109/mits.2010.939925.

See Also

Functions
addRelativePose | optimizePoseGraph | show

Objects
robotics.LidarSLAM | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

robotics.PoseGraph3D

Create 3-D pose graph

Description

A `PoseGraph3D` object stores information for a 3-D pose graph representation. A pose graph contains `nodes` connected by `edges`, with edge constraints that define the relative pose between nodes and the uncertainty on that measurement. The `optimizePoseGraph` function modifies the nodes to account for the uncertainty and improve the overall graph.

For 2-D pose graphs, see `PoseGraph`.

To construct a pose graph iteratively, use `addRelativePose` to add poses and connect them to the existing graph. Specify the uncertainty associated using an information matrix. Specify loop closures by add extra edge constraints between existing nodes.

Creation

Syntax

`poseGraph = robotics.PoseGraph3D`

Description

`poseGraph = robotics.PoseGraph3D` creates a 3-D pose graph object. Add poses using `addRelativePose` to construct a pose graph iteratively.

Properties

NumNodes — Number of nodes in pose graph
1 (default) | positive integer

This property is read-only.

Number of nodes in pose graph, specified as a positive integer. Each node represents a pose in the pose graph as an `[x y z qw qx qy qz]` vector with an *xyz*-position and quaternion orientation, `[qw qx qy qz]`. To specify relative poses between nodes, use `addRelativePose`. To get a list of all nodes, use `nodes`.

Note The order of the quaternion `[qw qx qy qz]` uses the standard convention. Some robot coordinate systems instead specify the order as `[qx qy qz qw]`. Check the source of your pose graph data before adding nodes to your `PoseGraph3D` object.

NumEdges — Number of edges in pose graph
`0` (default) | nonnegative integer

This property is read-only.

Number of edges in pose graph, specified as a nonnegative integer. Each edge connects two nodes in the pose graph. Loop closure edges are included.

NumLoopClosures — Number of loop closures
`0` (default) | nonnegative integer

This property is read-only.

Number of loop closures in pose graph, specified as a nonnegative integer. To get the edge IDs of the loop closures, use the `LoopClosureEdgeIDs` property.

LoopClosureEdgeIDs — Loop closure edge IDs
vector

This property is read-only.

Loop closure edges IDs, specified as a vector of edge IDs.

Object Functions

addRelativePose	Add relative pose to pose graph
edges	Edges in pose graph
edgeConstraints	Edge constraints in pose graph

findEdgeID	Find edge ID of edge
nodes	Poses of nodes in pose graph
optimizePoseGraph	Optimize nodes in pose graph
removeEdges	Remove loop closure edges from graph
show	Plot pose graph

Examples

Optimize a 3-D Pose Graph

Optimize a pose graph based on the nodes and edge constraints. The pose graph used in this example is from the MIT Dataset and was generated using information extracted from a parking garage.

Load the pose graph from the MIT dataset. Inspect the `robotics.PoseGraph3D` object to view the number of nodes and loop closures.

```
load parking-garage-posegraph.mat pg
disp(pg);

  PoseGraph3D with properties:

              NumNodes: 1661
              NumEdges: 6275
    NumLoopClosureEdges: 4615
     LoopClosureEdgeIDs: [1x4615 double]
```

Plot the pose graph with IDs off. Red lines indicate loop closures identified in the dataset.

```
title('Original Pose Graph')
show(pg,'IDs','off');
view(-30,45)
```

Optimize the pose graph. Nodes are adjusted based on the edge constraints and loop closures. Plot the optimized pose graph to see the adjustment of the nodes with loop closures.

```
updatedPG = optimizePoseGraph(pg);
figure
title('Updated Pose Graph')
show(updatedPG,'IDs','off');
view(-30,45)
```

References

[1] Carlone, Luca, Roberto Tron, Kostas Daniilidis, and Frank Dellaert. "Initialization Techniques for 3D SLAM: a Survey on Rotation Estimation and its Use in Pose Graph Optimization." *2015 IEEE International Conference on Robotics and Automation (ICRA)*. 2015, pp. 4597–4604.

See Also

Functions
addRelativePose | optimizePoseGraph

Objects
`robotics.LidarSLAM` | `robotics.PoseGraph`

Introduced in R2018a

robotics.PoseTarget class

Package: robotics

Create constraint on relative pose of body

Description

The `PoseTarget` object describes a constraint that requires the pose of one body (the end effector) to match a target pose within a distance and angular tolerance in any direction. The target pose is specified relative to the body frame of the reference body.

Constraint objects are used in `GeneralizedInverseKinematics` objects to specify multiple kinematic constraints on a robot.

For an example that uses multiple constraint objects, see "Plan a Reaching Trajectory With Multiple Kinematic Constraints".

Construction

`poseConst = robotics.PoseTarget(endeffector)` returns a pose target object that represents a constraint on the body of the robot model specified by `endeffector`.

`poseConst = robotics.PoseTarget(endeffector,Name,Value)` returns a pose target object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

`Name` is any property name and must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Input Arguments

endeffector — End-effector name
character vector

End-effector name, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

Properties

`EndEffector` — Name of the end effector
character vector

Name of the end effector, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

`ReferenceBody` — Name of the reference body frame
`''` (default) | character vector

Name of the reference body frame, specified as a character vector. The default `''` indicates that the constraint is relative to the base of the robot model. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

`TargetTransform` — Pose of the target frame relative to the reference body
`eye(4)` (default) | matrix

Pose of the target frame relative to the reference body, specified as a matrix. The matrix is a homogeneous transform that specifies the relative transformation to convert a point in the target frame to the reference body frame.

Example: `[1 0 0 1; 0 1 0 1; 0 0 1 1; 0 0 0 1]`

`OrientationTolerance` — Maximum allowed rotation angle
`0` (default) | numeric scalar

Maximum allowed rotation angle in radians, specified as a numeric scalar. This value is the upper bound on the magnitude of the rotation required to make the end-effector orientation match the target orientation.

PositionTolerance — Maximum allowed distance from target
0 (default) | numeric scalar in meters

Maximum allowed distance from target, specified as a numeric scalar in meters. This value is the upper bound on the distance between the end-effector origin and the target position.

Weights — Weights of the constraint
[1 1] (default) | two-element vector

Weights of the constraint, specified as a two-element vector. Each element of the vector corresponds to the weight for the `PositionTolerance` and `OrientationTolerance` respectively. These weights are used with the `Weights` of all the constraints specified in `GeneralizedInverseKinematics` to properly balance each constraint.

Extended Capabilities

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

See Also

Classes
robotics.CartesianBounds | robotics.GeneralizedInverseKinematics | robotics.OrientationTarget | robotics.PositionTarget

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

robotics.PositionTarget class

Package: robotics

Create constraint on relative position of body

Description

The `PositionTarget` object describes a constraint that requires the position of one body (the end effector) to match a target position within a distance tolerance in any direction. The target position is specified relative to the body frame of the reference body.

Constraint objects are used in `GeneralizedInverseKinematics` objects to specify multiple kinematic constraints on a robot.

For an example that uses multiple constraint objects, see "Plan a Reaching Trajectory With Multiple Kinematic Constraints".

Construction

`positionConst = robotics.PositionTarget(endeffector)` returns a position target object that represents a constraint on the body of the robot model specified by `endeffector`.

`positionConst = robotics.PositionTarget(endeffector,Name,Value)` returns a position target object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

`Name` is any property name and must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Input Arguments

endeffector — End-effector name
character vector

End-effector name, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

Properties

EndEffector — Name of the end effector
character vector

Name of the end effector, specified as a character vector. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

Example: `'left_palm'`

ReferenceBody — Name of the reference body frame
`''` (default) | character vector

Name of the reference body frame, specified as a character vector. The default `''` indicates that the constraint is relative to the base of the robot model. When using this constraint with `GeneralizedInverseKinematics`, the name must match a body specified in the robot model (`RigidBodyTree`).

TargetPosition — Position of the target relative to the reference body
`[0 0 0]` (default) | `[x y z]` vector

Position of the target relative to the reference body, specified as an `[x y z]` vector. The target position is a point specified in the reference body frame.

PositionTolerance — Maximum allowed distance from target
`0` (default) | numeric scalar

Maximum allowed distance from target in meters, specified as a numeric scalar. This value is the upper bound on the distance between the end-effector origin and the target position.

Weights — Weight of the constraint
`1` (default) | numeric scalar

Weight of the constraint, specified as a numeric scalar. This weight is used with the `Weights` property of all the constraints specified in `GeneralizedInverseKinematics` to properly balance each constraint.

Extended Capabilities

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

See Also

Classes
`robotics.CartesianBounds` | `robotics.GeneralizedInverseKinematics` | `robotics.OrientationTarget` | `robotics.PoseTarget`

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

robotics.PRM class

Package: robotics

Create probabilistic roadmap path planner

Description

PRM creates a roadmap path planner object for the environment map specified in the `Map` property. The object uses the map to generate a roadmap, which is a network graph of possible paths in the map based on free and occupied spaces. You can customize the number of nodes, `NumNodes`, and the connection distance, `ConnectionDistance`, to fit the complexity of the map and find an obstacle-free path from a start to an end location.

After the map is defined, the PRM path planner generates the specified number of nodes throughout the free spaces in the map. A connection between nodes is made when a line between two nodes contains no obstacles and is within the specified connection distance.

After defining a start and end location, to find an obstacle-free path using this network of connections, use the `findpath` method. If `findpath` does not find a connected path, it returns an empty array. By increasing the number of nodes or the connection distance, you can improve the likelihood of finding a connected path, but tuning these properties is necessary. To see the roadmap and the generated path , use the visualization options in `show`. If you change any of the PRM properties, call `update`, `show`, or `findpath` to recreate the roadmap.

Construction

`planner = robotics.PRM` creates an empty roadmap with default properties. Before you can use the roadmap, you must specify a `robotics.BinaryOccupancyGrid` object in the `Map` property.

`planner = robotics.PRM(map)` creates a roadmap with `map` set as the `Map` property, where `map` is an object of the `robotics.BinaryOccupancyGrid` class.

`planner = robotics.PRM(map,numnodes)` sets the maximum number of nodes, `numnodes`, to the `NumNodes` property.

Input Arguments

`map` — Map representation
BinaryOccupancyGrid object

Map representation, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object is a matrix grid with binary values indicating obstacles as `true`(1) and free locations as `false`(0).

`numnodes` — Maximum number of nodes in roadmap
50 (default) | scalar

Maximum number of nodes in roadmap, specified as a scalar. By increasing this value, the complexity and computation time for the path planner increases.

Properties

`'ConnectionDistance'` — Maximum distance between two connected nodes
inf (default) | scalar in meters

Maximum distance between two connected nodes, specified as the comma-separated pair consisting of `'ConnectionDistance'` and a scalar in meters. This property controls whether nodes are connected based on their distance apart. Nodes are connected only if no obstacles are directly in the path. By decreasing this value, the number of connections is lowered, but the complexity and computation time decreases as well.

`'Map'` — Map representation
BinaryOccupancyGrid object

Map representation, specified as the comma-separated pair consisting of 'Map' and a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object is a matrix grid with binary values indicating obstacles as `true`(1) and free locations as `false`(0).

`'NumNodes'` — Number of nodes in the map
50 (default) | scalar

Number of nodes in the map, specified as the comma-separated pair consisting of `'NumNodes'` and a scalar. By increasing this value, the complexity and computation time for the path planner increases.

Methods

findpath	Find path between start and goal points on roadmap
show	Show map, roadmap, and path
update	Create or update roadmap

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

The `map` input must be specified on creation of the `PRM` object.

See Also

`robotics.BinaryOccupancyGrid` | `robotics.PurePursuit`

Topics
"Path Planning in Environments of Different Complexity"
"Probabilistic Roadmaps (PRM)"

Introduced in R2015a

robotics.PurePursuit System object

Package: robotics

Create controller to follow set of waypoints

Description

The `robotics.PurePursuit` creates a controller object used to make a differential drive robot follow a set of waypoints. The object computes the linear and angular velocities for the robot given the current pose of the robot. Successive calls to the object with updated poses provide updated velocity commands for the robot. Use the `MaxAngularVelocity` and `DesiredLinearVelocity` properties to update the velocities based on the robot's performance.

The `LookaheadDistance` property computes a look-ahead point on the path, which is a local goal for the robot. The angular velocity command is computed based on this point. Changing `LookaheadDistance` has a significant impact on the performance of the algorithm. A higher look-ahead distance results in a smoother trajectory for the robot, but can cause the robot to cut corners along the path. A low look-ahead distance can result in oscillations in tracking the path, causing unstable behavior. For more information on the pure pursuit algorithm, see "Pure Pursuit Controller".

Note Starting in R2016b, instead of using the `step` method to perform the operation defined by the System object, you can call the object with arguments, as if it were a function. For example, `y = step(obj,x)` and `y = obj(x)` perform equivalent operations.

To compute linear and angular velocity control commands:

1 Create the robotics.PurePursuit 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

`controller = robotics.PurePursuit`

`controller = robotics.PurePursuit(Name,Value)`

Description

`controller = robotics.PurePursuit` creates a pure pursuit object that uses the pure pursuit algorithm to compute the linear and angular velocity inputs for a differential drive robot.

`controller = robotics.PurePursuit(Name,Value)` creates a pure pursuit object with additional options specified by one or more `Name,Value` pairs. Name is the 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 not specified retain their default values.

Example: `controller = robotics.PurePursuit('DesiredLinearVelocity', 0.5)`

Properties

`DesiredLinearVelocity` — Desired constant linear velocity
`0.1` (default) | scalar in meters per second

Desired constant linear velocity, specified as a scalar in meters per second. The controller assumes that the robot drives at a constant linear velocity and that the computed angular velocity is independent of the linear velocity.

Data Types: `double`

`LookaheadDistance` — Look-ahead distance
`1.0` (default) | scalar in meters

Look-ahead distance, specified as a scalar in meters. The look-ahead distance changes the response of the controller. A robot with a higher look-ahead distance produces smooth

paths but takes larger turns at corners. A robot with a smaller look-ahead distance follows the path closely and takes sharp turns, but potentially creating oscillations in the path.

Data Types: `double`

MaxAngularVelocity — Maximum angular velocity
`1.0` (default) | scalar in radians per second

Maximum angular velocity, specified a scalar in radians per second. The controller saturates the absolute angular velocity output at the given value.

Data Types: `double`

Waypoints — Waypoints
[ ] (default) | *n*-by-2 array

Waypoints, specified as an *n*-by-2 array of [x y] pairs, where *n* is the number of waypoints. You can generate the waypoints from the PRM class or from another source.

Data Types: `double`

Usage

Syntax

```
[vel,angvel] = controller(pose)
[vel,angvel,lookaheadpoint] = controller(pose)
```

Description

`[vel,angvel] = controller(pose)` processes the robot's position and orientation, `pose`, and outputs the linear velocity, `vel`, and angular velocity, `angvel`.

`[vel,angvel,lookaheadpoint] = controller(pose)` returns the look-ahead point, which is a location on the path used to compute the velocity commands. This location on the path is computed using the `LookaheadDistance` property on the `controller` object.

Input Arguments

pose — Position and orientation of robot
3-by-1 vector in the form [x y theta]

Position and orientation of robot, specified as a 3-by-1 vector in the form [x y theta]. The robot's pose is an *x* and *y* position with angular orientation θ (in radians) measured from the *x*-axis.

Output Arguments

vel — Linear velocity
scalar in meters per second

Linear velocity, specified as a scalar in meters per second.

Data Types: double

angvel — Angular velocity
scalar in radians per second

Angular velocity, specified as a scalar in radians per second.

Data Types: double

lookaheadpoint — Look-ahead point on path
[x y] vector

Look-ahead point on the path, returned as an [x y] vector. This value is calculated based on the LookaheadDistance property.

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 torobotics.PurePursuit
info   Characteristic information about PurePursuit object

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

Get Additional PurePursuit Object Information

Use the `info` method to get more information about a `PurePursuit` object. `info` returns two fields, `RobotPose` and `LookaheadPoint`, which correspond to the current position and orientation of the robot and the point on the path used to compute outputs from the last call of the object.

Create a `PurePursuit` object.

```
pp = robotics.PurePursuit;
```

Assign waypoints.

```
pp.Waypoints = [0 0;1 1];
```

Compute control commands using the `pp` object with the initial pose `[x y theta]` given as the input.

```
[v,w] = pp([0 0 0]);
```

Get additional information.

```
s = info(pp)
```

```
s = struct with fields:
        RobotPose: [0 0 0]
    LookaheadPoint: [0.7071 0.7071]
```

- "Path Following for a Differential Drive Robot"

Extended Capabilities

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

Usage notes and limitations:

Use in a MATLAB Function block is not supported.

For additional information about code generation for System objects, see "System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also
robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | robotics.PRM

Topics
"Path Following for a Differential Drive Robot"
"Pure Pursuit Controller"

Introduced in R2015a

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.
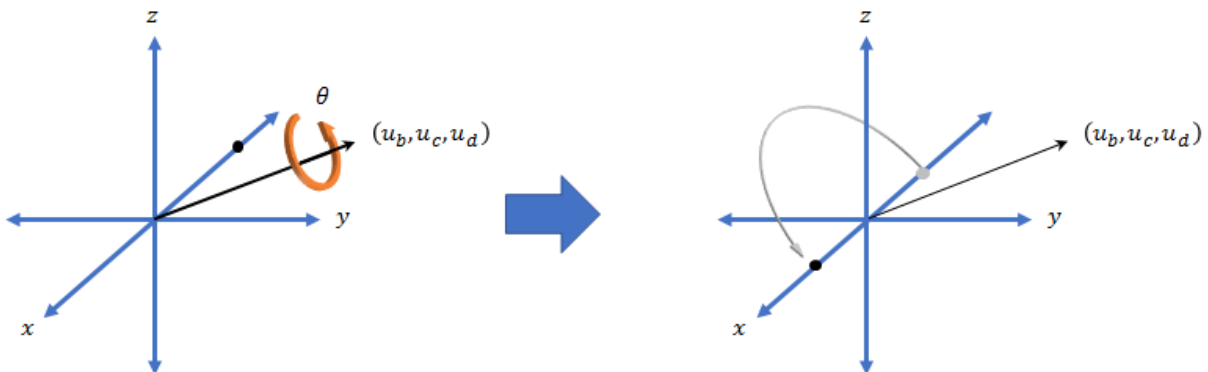
The quaternion representation of the rotation may be expressed as

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

, where θ is the angle of rotation and $[u_b, u_c,$ 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(RM,'rotmat',PF)
quat = quaternion(E,'euler',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.

`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.

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 + 5k` 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.

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.

To use this syntax, specify the first argument as a matrix of rotation vectors and the second argument as the character vector `'rotvec'` or string `"rotvec"`.

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(RM,'rotmat','point')`

Example: `quat = quaternion(RM,'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(RM,'rotmat','point')`

Example: `quat = quaternion(RM,'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.

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'`

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- `'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(deg2rad([45,45,0]),'Euler','ZYX','frame');
  newPointCoordinate = rotateframe(quatRotator,point);
  ```

  ```
  newPointCoordinate =

      0.7071   -0.0000    0.7071
  ```
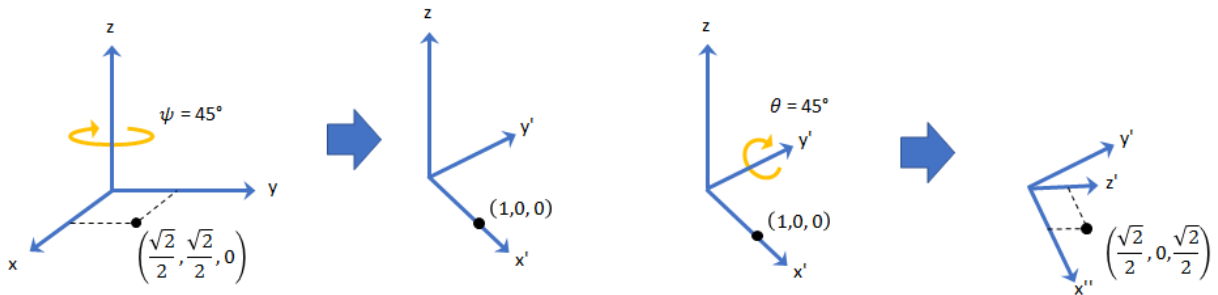

- If you create a quaternion rotator and specify the 'YZX' sequence, the frame is first rotated 45° around the *y*-axis, then 45° around the new *z*-axis.

  ```
  quatRotator = quaternion(deg2rad([45,45,0]),'Euler','YZX','frame');
  newPointCoordinate = rotateframe(quatRotator,point);
  ```

  ```
  newPointCoordinate =

      0.8536    0.1464    0.5000
  ```
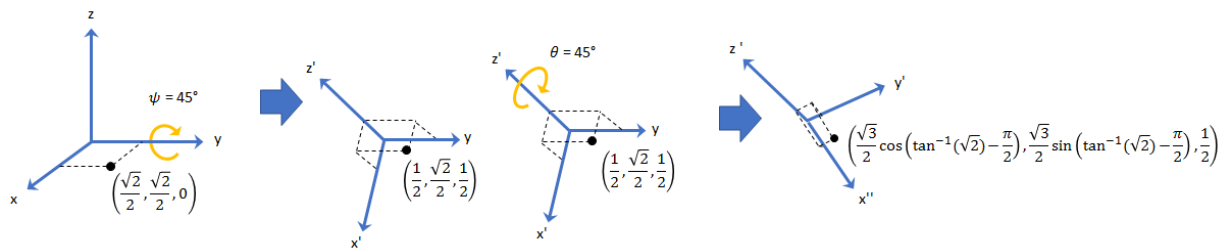
Data Types: char | string

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
dist	Angular distance in radians
euler	Convert quaternion to Euler angles
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
times, .*	Element-wise quaternion multiplication
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 =

    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 =

    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. 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 = [0.3635,0.6296,0.3635];
quat = quaternion(rotationVector,'rotvec')
norm(quat)
```

```
quat =

  quaternion


    0.91855 + 0.17679i + 0.30621j + 0.17679k


ans =

    1
```

You can convert from quaternions to rotation vectors using the `rotvec` function. Recover the `rotationVector` from the quaternion, `quat`.

```
rotvec(quat)
```

```
ans =

    0.3635    0.6296    0.3635
```

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 =

    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.

Create a scalar quaternion using a 1-by-3 vector of Euler angles. 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 =

    1.5708         0    0.7854
```

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)
```

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```
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)
```

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```
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
```

See Also

Introduced in R2018a

robotics.Rate

Execute loop at fixed frequency

Description

The `Rate` object enables you to run a loop at a fixed frequency. It also collects statistics about the timing of the loop iterations. Use `waitfor` in the loop to pause code execution until the next time step. The loop operates every `DesiredPeriod` seconds, unless the enclosed code takes longer to operate. The object uses the `OverrunAction` property to determine how it handles longer loop operation times. The default setting, `'slip'`, immediately executes the loop if `LastPeriod` is greater than `DesiredPeriod`. Using `'drop'` causes the `waitfor` method to wait until the next multiple of `DesiredPeriod` is reached to execute the next loop.

Tip The scheduling resolution of your operating system and the level of other system activity can affect rate execution accuracy. As a result, accurate rate timing is limited to 100 Hz for execution of MATLAB code. To improve performance and execution speeds, use code generation.

Creation

Syntax

```
rateObj = robotics.Rate(desiredRate)
```

Description

`rateObj = robotics.Rate(desiredRate)` creates a `Rate` object that operates loops at a fixed-rate based on your system time and directly sets the `DesireRate` property.

Properties

DesiredRate — Desired execution rate
scalar

Desired execution rate of loop, specified as a scalar in Hz. When using `waitfor`, the loop operates every `DesiredRate` seconds, unless the loop takes longer. It then begins the next loop based on the specified `OverrunAction`.

DesiredPeriod — Desired time period between executions
scalar

Desired time period between executions, specified as a scalar in seconds. This property is equal to the inverse of `DesiredRate`.

TotalElapsedTime — Elapsed time since construction or reset
scalar

Elapsed time since construction or reset, specified as a scalar in seconds.

LastPeriod — Elapsed time between last two calls to `waitfor`
NaN (default) | scalar

Elapsed time between last two calls to `waitfor`, specified as a scalar. By default, `LastPeriod` is set to NaN until `waitfor` is called for the first time. After the first call, `LastPeriod` equals `TotalElapsedTime`.

OverrunAction — Method for handling overruns
'slip' (default) | 'drop'

Method for handling overruns, specified as one of these character vectors:

- `'drop'` — waits until the next time interval equal to a multiple of `DesiredPeriod`
- `'slip'` — immediately executes the loop again

Each code section calls `waitfor` at the end of execution.

Object Functions

waitfor	Pause code execution to achieve desired execution rate
statistics	Statistics of past execution periods
reset	Reset Rate object

Examples

Run Loop at Fixed Rate

Create a rate object that runs at 1 Hz.

```
r = robotics.Rate(1);
```

Start a loop using the `Rate` object inside to control the loop execution. Reset the object prior to the loop execution to reset timer. Print the iteration and time elapsed.

```
reset(r)
for i = 1:10
    time = r.TotalElapsedTime;
    fprintf('Iteration: %d - Time Elapsed: %f\n',i,time)
    waitfor(r);
end
```

```
Iteration: 1 - Time Elapsed: 0.007008
Iteration: 2 - Time Elapsed: 1.003965
Iteration: 3 - Time Elapsed: 2.004261
Iteration: 4 - Time Elapsed: 3.005156
Iteration: 5 - Time Elapsed: 4.004166
Iteration: 6 - Time Elapsed: 5.003940
Iteration: 7 - Time Elapsed: 6.004566
Iteration: 8 - Time Elapsed: 7.003711
Iteration: 9 - Time Elapsed: 8.003916
Iteration: 10 - Time Elapsed: 9.005005
```

Each iteration executes at a 1-second interval.

Get Statistics From Rate Object Execution

Create a `Rate` object for running at 20 Hz.

```
r = robotics.Rate(2);
```

Start a loop and control operation using the `Rate` object.

```
for i = 1:30
    % Your code goes here
    waitfor(r);
end
```

Get `Rate` object statistics after loop operation.

```
stats = statistics(r)
```

```
stats = struct with fields:
               Periods: [1x30 double]
            NumPeriods: 30
         AveragePeriod: 0.5000
     StandardDeviation: 6.5567e-04
            NumOverruns: 0
```

Run Loop At Fixed Rate and Reset Rate Object

Create a `Rate` object for running at 20 Hz.

```
r = robotics.Rate(2);
```

Start a loop and control operation using the `Rate` object.

```
for i = 1:30
    % Your code goes here
    waitfor(r);
end
```

Display the `Rate` object properties after loop operation.

```
disp(r)

  Rate with properties:

          DesiredRate: 2
        DesiredPeriod: 0.5000
         OverrunAction: 'slip'
     TotalElapsedTime: 15.0140
            LastPeriod: 0.4992
```

Reset the object to restart the time statistics.

```
reset(r);
disp(r)

  Rate with properties:

          DesiredRate: 2
        DesiredPeriod: 0.5000
         OverrunAction: 'slip'
     TotalElapsedTime: 0.0091
            LastPeriod: NaN
```

- "Execute Code at a Fixed-Rate"

See Also

rosrate | waitfor

Topics

"Execute Code at a Fixed-Rate"

Introduced in R2016a

robotics.ResamplingPolicy class

Package: robotics

Create resampling policy object with resampling settings

Description

`ResamplingPolicy` creates an object encapsulating settings for when resampling should occur when using a particle filter for state estimation. The object contains the method that triggers resampling and the relevant threshold for this resampling. Use this object as the `ResamplingPolicy` property of the `ParticleFilter` class.

Construction

`policy = robotics.ResamplingPolicy` creates a `ResamplingPolicy` object which contains properties to be modified to control when resampling should be triggered. Use this object as the `ResamplingPolicy` property of the `ParticleFilter` class.

Properties

`TriggerMethod` — Method for determining if resampling should occur
`'ratio'` (default) | character vector

Method for determining if resampling should occur, specified as a character vector. Possible choices are `'ratio'` and `'interval'`. The `'interval'` method triggers resampling at regular intervals of operating the particle filter. The `'ratio'` method triggers resampling based on the ratio of effective total particles.

`SamplingInterval` — Fixed interval between resampling
1 (default) | scalar

Fixed interval between resampling, specified as a scalar. This interval determines during which correction steps the resampling is executed. For example, a value of 2 means the resampling is executed every second correction step. A value of `inf` means that resampling is never executed.

This property only applies with the `TriggerMethod` is set to `'interval'`.

`MinEffectiveParticleRatio` — Minimum desired ratio of effective to total particles
0.5 (default) | scalar

Minimum desired ratio of effective to total particles, specified as a scalar. The effective number of particles is a measure of how well the current set of particles approximates the posterior distribution. A lower effective particle ratio means less particles are contributing to the estimation and resampling might be required. If the ratio of effective particles to total particles falls below the `MinEffectiveParticleRatio`, a resampling step is triggered.

See Also
`robotics.ParticleFilter` | `robotics.ParticleFilter.correct`

Topics
"Track a Car-Like Robot Using Particle Filter"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016a

robotics.RigidBody class

Package: robotics

Create a rigid body

Description

The `RigidBody` class represents a rigid body. A rigid body is the building block for any tree-structured robot manipulator. Each `RigidBody` has a `robotics.Joint` object attached to it that defines how the rigid body can move. Rigid bodies are assembled into a tree-structured robot model using `robotics.RigidBodyTree`.

Set a joint object to the `Joint` property before calling `robotics.RigidBodyTree.addBody` to add the rigid body to the robot model. When a rigid body is in a rigid body tree, you cannot directly modify its properties because it corrupts the relationships between bodies. Use `robotics.RigidBodyTree.replaceJoint` to modify the entire tree structure.

Construction

`body = robotics.RigidBody(name)` creates a rigid body with the specified name. By default, the body comes with a fixed joint.

Input Arguments

name — Name of rigid body
character vector

Name of the rigid body, specified as a character vector. This name must be unique to the body so that it can be accessed in a `RigidBodyTree` object.

Properties

Name — Name of rigid body
character vector

Name of the rigid body, specified as a character vector. This name must be unique to the body so that it can be found in a `RigidBodyTree` object.

Joint — Joint object
handle

`Joint` object, specified as a handle. By default, the joint is `'fixed'` type. Create the joint using `robotics.Joint` and specify the joint type on creation.

Mass — Mass of rigid body
1 kg (default) | numeric scalar

Mass of rigid body, specified as a numeric scalar in kilograms.

CenterOfMass — Center of mass position of rigid body
[0 0 0] m (default) | [x y z] vector

Center of mass position of rigid body, specified as an [x y z] vector. The vector describes the location of the center of mass relative to the body frame in meters.

Inertia — Inertia of rigid body
[1 1 1 0 0 0] kg•m^2 (default) | [Ixx Iyy Izz Iyz Ixz Ixy] vector

Inertia of rigid body, specified as a [Ixx Iyy Izz Iyz Ixz Ixy] vector relative to the body frame in kilogram square meters. The first three elements of the vector are the diagonal elements of the inertia tensor. The last three elements are the off-diagonal elements of the inertia tensor. The inertia tensor is a positive definite symmetric matrix:

$$\begin{pmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{pmatrix}$$

Parent — Rigid body parent
`RigidBody` object handle

Rigid body parent, specified as a `RigidBody` object handle. The rigid body joint defines how this body can move relative to the parent. This property is empty until the rigid body is added to a `RigidBodyTree` robot model.

Children — Rigid body children
cell array of `RigidBody` object handles

Rigid body children, specified as a cell array of `RigidBody` object handles. These rigid body children are all attached to this rigid body object. This property is empty until the rigid body is added to a `RigidBodyTree` robot model, and at least one other body is added to the tree with this body as its parent.

Visuals — Visual geometries
cell array of character vectors

Visual geomteries, specified as a cell array of character vectors. Each character vector describes a type and source of a visual geometry. For example, if a mesh file, `link_0.stl`, is attached to the rigid body, the character vector would be `'Mesh:link_0.stl'`. Visual geometries are added to the rigid body using `robotics.RigidBody.addVisual`.

Methods

addVisual	Add visual geometry data to rigid body
clearVisual	Clear all visual geometries
copy	Create a deep copy of rigid body

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `RigidBody` object contains a `Joint` object and must be added to the `RigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = robotics.RigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = robotics.RigidBody('b1');
```

Create a revolute joint. By default, the `RigidBody` object comes with a fixed joint. Replace the joint by assigning a new `Joint` object to the `body1.Joint` property.

```
jnt1 = robotics.Joint('jnt1','revolute');
body1.Joint = jnt1;
```

Add the rigid body to the tree. Specify the body name that you are attaching the rigid body to. Because this is the first body, use the base name of the tree.

```
basename = rbtree.BaseName;
addBody(rbtree,body1,basename)
```

Use `showdetails` on the tree to confirm the rigid body and joint were added properly.

```
showdetails(rbtree)

--------------------
Robot: (1 bodies)

 Idx     Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------   ----------------   ----------------
   1            b1         jnt1      revolute            base(0)
--------------------
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix. The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0        pi/2    0        0;
            0.4318   0       0        0
            0.0203   -pi/2   0.15005  0;
```

```
        0       pi/2    0.4318   0;
        0       -pi/2   0        0;
        0       0       0        0];
```

Create a rigid body tree object to build the robot.

```
robot = robotics.RigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1   Create a `RigidBody` object and give it a unique name.
2   Create a `Joint` object and give it a unique name.
3   Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4   Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = robotics.RigidBody('body1');
jnt1 = robotics.Joint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = robotics.RigidBody('body2');
jnt2 = robotics.Joint('jnt2','revolute');
body3 = robotics.RigidBody('body3');
jnt3 = robotics.Joint('jnt3','revolute');
body4 = robotics.RigidBody('body4');
jnt4 = robotics.Joint('jnt4','revolute');
body5 = robotics.RigidBody('body5');
jnt5 = robotics.Joint('jnt5','revolute');
body6 = robotics.RigidBody('body6');
jnt6 = robotics.Joint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
```

```
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

Verify that your robot was built properly by using the showdetails or show function.
showdetails lists all the bodies in the MATLAB® command window. show displays the
robot with a given configuration (home by default). Calls to axis modify the axis limits
and hide the axis labels.

```
showdetails(robot)

--------------------
Robot: (6 bodies)

 Idx      Body Name    Joint Name    Joint Type    Parent Name(Idx)    Children Name(s)
 ---      ---------    ----------    ----------    ----------------    ----------------
   1          body1          jnt1      revolute              base(0)    body2(2)
   2          body2          jnt2      revolute            body1(1)    body3(3)
   3          body3          jnt3      revolute            body2(2)    body4(4)
   4          body4          jnt4      revolute            body3(3)    body5(5)
   5          body5          jnt5      revolute            body4(4)    body6(6)
   6          body6          jnt6      revolute            body5(5)
--------------------


show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```

- "Build a Robot Step by Step"
- "Rigid Body Tree Robot Model"

References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control.* Reading, MA: Addison-Wesley, 1989.

[2] Siciliano, Bruno. Robotics: Modelling, Planning and Control. London: Springer, 2009.

Extended Capabilities

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

See Also
robotics.Joint | robotics.RigidBodyTree |
robotics.RigidBodyTree.addBody | robotics.RigidBodyTree.replaceJoint

Topics
"Build a Robot Step by Step"
"Rigid Body Tree Robot Model"
Class Attributes (MATLAB)
Property Attributes (MATLAB)

Introduced in R2016b

robotics.RigidBodyTree class

Package: robotics

Create tree-structured robot

Description

The `RigidBodyTree` is a representation of the connectivity of rigid bodies with joints. Use this class to build robot manipulator models in MATLAB. If you have a robot model specified using the Unified Robot Description Format (URDF), use `importrobot` to import your robot model.

A rigid body tree model is made up of rigid bodies as `RigidBody` objects. Each rigid body has a `Joint` object associated with it that defines how it can move relative to its parent body. Use `setFixedTransform` to define the fixed transformation between the frame of a joint and the frame of one of the adjacent bodies. You can add, replace, or remove rigid bodies from the model using the methods of the `RigidBodyTree` class.

Robot dynamics calculations are also possible. Specify the `Mass`, `CenterOfMass`, and `Inertia` properties for each `RigidBody` in the robot model. You can calculate forward and inverse dynamics with or without external forces and compute dynamics quantities given robot joint motions and joint inputs. To use the dynamics-related functions, set the `DataFormat` property to `'row'` or `'column'`.

For a given rigid body tree model, you can also use the robot model to calculate joint angles for desired end-effector positions using the robotics inverse kinematics algorithms. Specify your rigid body tree model when using `InverseKinematics` or `GeneralizedInverseKinematics`.

The `show` method supports visualization of body meshes. Meshes are specified as `.stl` files and can be added to individual rigid bodies using `addVisual`. Also, by default, the `importrobot` function loads all the accessible `.stl` files specified in your URDF robot model.

Construction

`robot = robotics.RigidBodyTree` creates a tree-structured robot object. Add rigid bodies to it using `addBody`.

`robot = robotics.RigidBodyTree('MaxNumBodies',N,'DataFormat',dataFormat)` specifies an upper bound on the number of bodies allowed in the robot when generating code. You must also specify the `DataFormat` property as a name-value pair.

Properties

NumBodies — Number of bodies
integer

This property is read-only.

Number of bodies in the robot model (not including the base), returned as an integer.

Bodies — List of rigid bodies
cell array of handles

This property is read-only.

List of rigid bodies in the robot model, returned as a cell array of handles. Use this list to access specific `RigidBody` objects in the model. You can also call `robotics.RigidBodyTree.getBody` to get a body by its name.

BodyNames — Names of rigid bodies
cell array of character vectors

This property is read-only.

Names of rigid bodies, returned as a cell array of character vectors.

BaseName — Name of robot base
`'base'` (default) | character vector

Name of robot base, returned as a character vector.

`Gravity` — Gravitational acceleration experienced by robot
`[0 0 0]` m/s² (default) | `[x y z]` vector

Gravitational acceleration experienced by robot, specified as an `[x y z]` vector in meters per second squared. Each element corresponds to the acceleration of the base robot frame in that direction.

`DataFormat` — Input/output data format for kinematics and dynamics functions
`'struct'` (default) | `'row'` | `'column'`

Input/output data format for kinematics and dynamics functions, specified as `'struct'`, `'row'`, or `'column'`. To use dynamics functions, you must use either `'row'` or `'column'`.

Methods

addBody	Add a body to robot
addSubtree	Add subtree to robot
centerOfMass	Center of mass position and Jacobian
copy	Copy robot model
externalForce	Compose external force matrix relative to base
forwardDynamics	Joint accelerations given joint torques and states
geometricJacobian	Geometric Jacobian for robot configuration
gravityTorque	Joint torques that compensate gravity
getBody	Get robot body handle by name
getTransform	Get transform between body frames
homeConfiguration	Get home configuration of robot
inverseDynamics	Required joint torques for given motion
massMatrix	Joint-space mass matrix
randomConfiguration	Generate random configuration of robot
removeBody	Remove body from robot
replaceBody	Replace body on robot
replaceJoint	Replace joint on body
show	Show robot model in a figure
showdetails	Show details of robot model
subtree	Create subtree from robot model
velocityProduct	Joint torques that cancel velocity-induced forces

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `RigidBody` object contains a `Joint` object and must be added to the `RigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = robotics.RigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = robotics.RigidBody('b1');
```

Create a revolute joint. By default, the `RigidBody` object comes with a fixed joint. Replace the joint by assigning a new `Joint` object to the `body1.Joint` property.

```
jnt1 = robotics.Joint('jnt1','revolute');
body1.Joint = jnt1;
```

Add the rigid body to the tree. Specify the body name that you are attaching the rigid body to. Because this is the first body, use the base name of the tree.

```
basename = rbtree.BaseName;
addBody(rbtree,body1,basename)
```

Use `showdetails` on the tree to confirm the rigid body and joint were added properly.

```
showdetails(rbtree)

--------------------
Robot: (1 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1          b1         jnt1      revolute             base(0)
--------------------
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix. The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0          pi/2    0        0;
            0.4318    0        0        0
            0.0203    -pi/2    0.15005  0;
            0          pi/2    0.4318   0;
            0          -pi/2   0        0;
            0          0       0        0];
```

Create a rigid body tree object to build the robot.

```
robot = robotics.RigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1 Create a `RigidBody` object and give it a unique name.

2 Create a `Joint` object and give it a unique name.

3 Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.

4 Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = robotics.RigidBody('body1');
jnt1 = robotics.Joint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = robotics.RigidBody('body2');
jnt2 = robotics.Joint('jnt2','revolute');
body3 = robotics.RigidBody('body3');
jnt3 = robotics.Joint('jnt3','revolute');
body4 = robotics.RigidBody('body4');
jnt4 = robotics.Joint('jnt4','revolute');
body5 = robotics.RigidBody('body5');
jnt5 = robotics.Joint('jnt5','revolute');
body6 = robotics.RigidBody('body6');
jnt6 = robotics.Joint('jnt6','revolute');
```

```
setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

Verify that your robot was built properly by using the `showdetails` or `show` function.
`showdetails` lists all the bodies in the MATLAB® command window. `show` displays the
robot with a given configuration (home by default). Calls to `axis` modify the axis limits
and hide the axis labels.

```
showdetails(robot)

--------------------
Robot: (6 bodies)

 Idx      Body Name   Joint Name   Joint Type     Parent Name(Idx)   Children Name(s)
 ---      ---------   ----------   ----------     ----------------   ----------------
   1          body1         jnt1     revolute              base(0)   body2(2)
   2          body2         jnt2     revolute             body1(1)   body3(3)
   3          body3         jnt3     revolute             body2(2)   body4(4)
   4          body4         jnt4     revolute             body3(3)   body5(5)
   5          body5         jnt5     revolute             body4(4)   body6(6)
   6          body6         jnt6     revolute             body5(5)
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

`load exampleRobots.mat`

View the details of the Puma robot using `showdetails`.

`showdetails(puma1)`

```
--------------------
Robot: (6 bodies)

 Idx     Body Name    Joint Name   Joint Type     Parent Name(Idx)   Children Name(s)
 ---     ---------    ----------   ----------     ----------------   ----------------
   1            L1          jnt1     revolute               base(0)   L2(2)
   2            L2          jnt2     revolute                L1(1)    L3(3)
   3            L3          jnt3     revolute                L2(2)    L4(4)
   4            L4          jnt4     revolute                L3(3)    L5(5)
   5            L5          jnt5     revolute                L4(4)    L6(6)
   6            L6          jnt6     revolute                L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

            Name: 'L4'
           Joint: [1x1 robotics.Joint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 robotics.RigidBody]
        Children: {[1x1 robotics.RigidBody]}
          Visuals: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new Joint object and use replaceJoint to ensure the downstream body geometry is unaffected. Call setFixedTransform if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);
```

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)
```

```
Idx     Body Name        Joint Name        Joint Type     Parent Name(Idx)    Children Name
---     ---------        ----------        ----------     ----------------    ------------
  1           L1              jnt1          revolute               base(0)    L2(2)
  2           L2              jnt2          revolute                 L1(1)    L3(3)
  3           L3         prismatic             fixed                 L2(2)    L4(4)
  4           L4              jnt4          revolute                 L3(3)    L5(5)
  5           L5              jnt5          revolute                 L4(4)    L6(6)
  6           L6              jnt6          revolute                 L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')

subtree =
  RigidBodyTree with properties:

     NumBodies: 3
        Bodies: {1x3 cell}
          Base: [1x1 robotics.RigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name    Joint Name    Joint Type      Parent Name(Idx)    Children Name(s)
 ---     ---------    ----------    ----------      ----------------    ----------------
   1           L1          jnt1      revolute                base(0)    L2(2)
   2           L2          jnt2      revolute                  L1(1)    L3(3)
```

```
3              L3          jnt3     revolute                      L2(2)    L4(4)
4              L4          jnt4     revolute                      L3(3)    L5(5)
5              L5          jnt5     revolute                      L4(4)    L6(6)
6              L6          jnt6     revolute                      L5(5)
--------------------
```

Specify Dynamics Properties to Rigid Body Tree

To use dynamics functions to calculate joint torques and accelerations, specify the dynamics properties for the `robotics.RigidBodyTree` object and `robotics.RigidBody`.

Create a rigid body tree model. Create two rigid bodies to attach to it.

```
robot = robotics.RigidBodyTree('DataFormat','row');
body1 = robotics.RigidBody('body1');
body2 = robotics.RigidBody('body2');
```

Specify joints to attach to the bodies. Set the fixed transformation of `body2` to `body1`. This transform is 1m in the *x*-direction.

```
joint1 = robotics.Joint('joint1','revolute');
joint2 = robotics.Joint('joint2');
setFixedTransform(joint2,trvec2tform([1 0 0]))
body1.Joint = joint1;
body2.Joint = joint2;
```

Specify dynamics properties for the two bodies. Add the bodies to the robot model. For this example, basic values for a rod (`body1`) with an attached spherical mass (`body2`) are given.

```
body1.Mass = 2;
body1.CenterOfMass = [0.5 0 0];
body1.Inertia = [0.167 0.001 0.167 0 0 0];

body2.Mass = 1;
body2.CenterOfMass = [0 0 0];
body2.Inertia = 0.0001*[4 4 4 0 0 0];

addBody(robot,body1,'base');
addBody(robot,body2,'body1');
```

Compute the center of mass position of the whole robot. Plot the position on the robot. Move the view to the *xy* plane.

```
comPos = centerOfMass(robot);

show(robot);
hold on
plot(comPos(1),comPos(2),'or')
view(2)
```
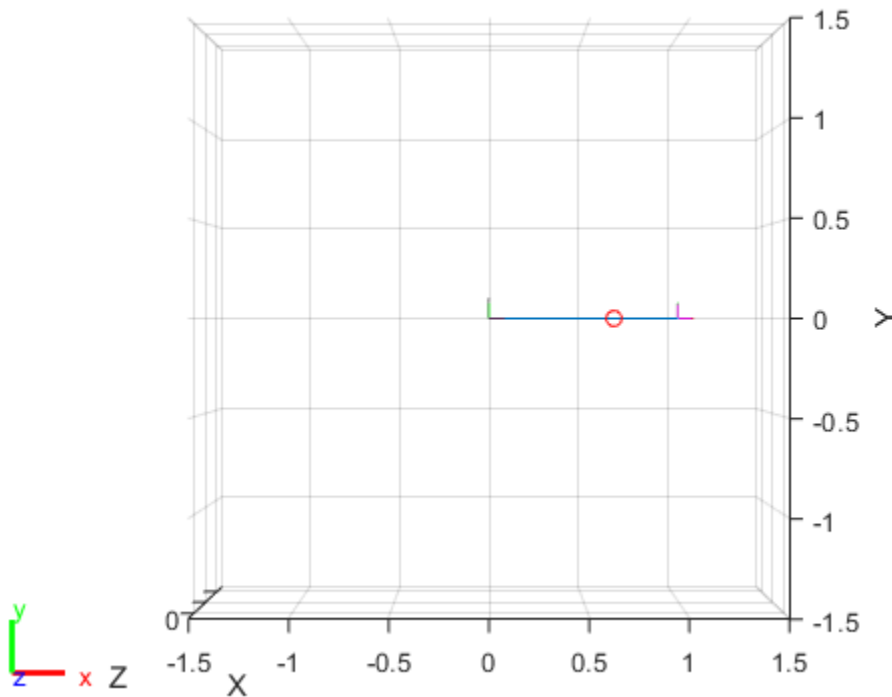

Change the mass of the second body. Notice the change in center of mass.

```
body2.Mass = 20;
replaceBody(robot,'body2',body2)
```

```
comPos2 = centerOfMass(robot);
plot(comPos2(1),comPos2(2),'*g')
hold off
```


Compute Forward Dynamics Due to External Forces on Rigid Body Tree Model

Calculate the resultant joint accelerations for a given robot configuration with applied external forces and forces due to gravity. A wrench is applied to a specific body with the gravity being specified for the whole robot.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the gravity. By default, gravity is assumed to be zero.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for the `lbr` robot.

```
q = homeConfiguration(lbr);
```

Specify the wrench vector that represents the external forces experienced by the robot. Use the `externalForce` function to generate the external force matrix. Specify the robot model, the end effector that experiences the wrench, the wrench vector, and the current robot configuration. `wrench` is given relative to the `'tool0'` body frame, which requires you to specify the robot configuration, `q`.

```
wrench = [0 0 0.5 0 0 0.3];
fext = externalForce(lbr,'tool0',wrench,q);
```

Compute the resultant joint accelerations due to gravity, with the external force applied to the end-effector `'tool0'` when `lbr` is at its home configuration. The joint velocities and joint torques are assumed to be zero (input as an empty vector `[]`).

```
qddot = forwardDynamics(lbr,q,[],[],fext);
```

Compute Inverse Dynamics from Static Joint Configuration

Use the `inverseDynamics` function to calculate the required joint torques to statically hold a specific robot configuration. You can also specify the joint velocities, joint accelerations, and external forces using other syntaxes.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

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```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Generate a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Compute the required joint torques for `lbr` to statically hold that configuration.

```
tau = inverseDynamics(lbr,q);
```

Compute Joint Torque to Counter External Forces

Use the `externalForce` function to generate force matrices to apply to a rigid body tree model. The force matrix is an *m*-by-6 vector that has a row for each joint on the robot to apply a six-element wrench. Use the `externalForce` function and specify the end effector to properly assign the wrench to the correct row of the matrix. You can add multiple force matrices together to apply multiple forces to one robot.

To calculate the joint torques that counter these external forces, use the `inverseDynamics` function.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for `lbr`.

```
q = homeConfiguration(lbr);
```

Set external force on `link1`. The input wrench vector is expressed in the base frame.

```
fext1 = externalForce(lbr,'link_1',[0 0 0.0 0.1 0 0]);
```

Set external force on the end effector, `tool0`. The input wrench vector is expressed in the `tool0` frame.

```
fext2 = externalForce(lbr,'tool0',[0 0 0.0 0.1 0 0],q);
```

Compute the joint torques required to balance the external forces. To combine the forces, add the force matrices together. Joint velocities and accelerations are assumed to be zero (input as `[]`).

```
tau = inverseDynamics(lbr,q,[],[],fext1+fext2);
```

Display a Robot Model with Visual Geometries

You can import robots that have `.stl` files associated with the Unified Robot Description format (URDF) file to describe the visual geometries of the robot. Each rigid body has an individual visual geometry specified. The `importrobot` function parses to URDF file to get the robot model and visual geometries. Use the `show` function to visualize the robot model in a figure. You can then interact with the model by clicking components to inspect them and right-clicking to toggle visibility.

Import a robot model as a URDF file. The `.stl` file locations must be properly specified in this URDF. To add other `.stl` files to individual rigid bodies, see `addVisual`.

```
robot = importrobot('iiwa14.urdf');
```

Visualize the robot with the associated visual model. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each visual geometry.

```
show(robot);
```

- "Build a Robot Step by Step"
- "Rigid Body Tree Robot Model"
- "Solve Inverse Kinematics for a Four-Bar Linkage"
- "Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics"
- "Plan a Reaching Trajectory With Multiple Kinematic Constraints"
- "Control LBR Manipulator Motion Through Joint Torque Commands"

References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control.* Reading, MA: Addison-Wesley, 1989.

[2] Siciliano, Bruno, Lorenzo Sciavicco, Luigi Villani, and Giuseppe Oriolo. *Robotics: Modelling, Planning and Control.* London: Springer, 2009.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

Use the syntax that specifies the `'MaxNumBodies'` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = robotics.RigidBodyTree('MaxNumBodies',15,'DataFormat','row')
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `'row'` or `'column'`.

Also, the `show` and `showdetails` functions do not support code generation.

See Also

importrobot | robotics.GeneralizedInverseKinematics | robotics.InverseKinematics | robotics.Joint | robotics.RigidBody

Topics
"Build a Robot Step by Step"
"Rigid Body Tree Robot Model"
"Solve Inverse Kinematics for a Four-Bar Linkage"

"Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics"
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"
"Control LBR Manipulator Motion Through Joint Torque Commands"

Introduced in R2016b

rosactionclient

Create ROS action client

Description

Use the `rosactionclient` to connect to an action server using a `SimpleActionClient` object and request the execution of action goals. You can get feedback on the execution process and cancel the goal at anytime. The `SimpleActionClient` object encapsulates a simple action client and enables you to track a single goal at a time.

Creation

Syntax

```
client = rosactionclient(actionname)
client = rosactionclient(actionname,actiontype)
[client,goalMsg] = rosactionclient( ___ )

client = robotics.ros.SimpleActionClient(node,actionname)
client = robotics.ros.SimpleActionClient(node,actionname,actiontype)
```

Description

`client = rosactionclient(actionname)` creates a client for the specified ROS `ActionName`. The client determines the action type automatically. If the action is not available, this function displays an error.

Use `rosactionclient` to connect to an action server and request the execution of action goals. You can get feedback on the execution progress and cancel the goal at any time.

`client = rosactionclient(actionname,actiontype)` creates an action client with the specified name and type (`ActionType`). If the action is not available, or the name and type do no match, the function displays an error.

`[client,goalMsg] = rosactionclient( ___ )` returns a goal message to send the action client created using any of the arguments from the previous syntaxes. The `Goal` message is initialized with default values for that message.

If the `ActionFcn`, `FeedbackFcn`, and `ResultFcn` callbacks are defined, they are called when the goal is processing on the action server. All callbacks associated with a previously sent goal are disabled, but the previous goal is not canceled.

`client = robotics.ros.SimpleActionClient(node,actionname)` creates a client for the specified ROS action name. `node` is the `Node` object that is connected to the ROS network. The client determines the action type automatically. If the action is not available, the function displays an error.

`client = robotics.ros.SimpleActionClient(node,actionname,actiontype)` creates an action client with the specified name and type. You can get the type of an action using `rosaction type actionname`.

Properties

ActionName — ROS action name
character vector

ROS action name, returned as a character vector. The action name must match one of the topics that `rosaction('list')` outputs.

ActionType — Action type for a ROS action
character vector

Action type for a ROS action, returned as a character vector. You can get the action type of an action using `rosaction type <action_name>`. For more details, see `rosaction`.

IsServerConnected — Indicates if client is connected to ROS action server
`false` (default) | `true`

Indicator of whether the client is connected to a ROS action server, returned as `false` or `true`. Use `waitForServer` to wait until the server is connected when setting up an action client.

Goal — Tracked goal
ROS message

Tracked goal, returned as a ROS message. This message is the last goal message this client sent. The goal message depends on the action type.

GoalState — Goal state
character vector

Goal state, returned as one of the following:

- `'pending'` — Goal was received, but has not yet been accepted or rejected.
- `'active'` — Goal was accepted and is running on the server.
- `'succeeded'` — Goal executed successfully.
- `'preempted'` — An action client canceled the goal before it finished executing.
- `'aborted'` — The goal was aborted before it finished executing. The action server typically aborts a goal.
- `'rejected'` — The goal was not accepted after being in the `'pending'` state. The action server typically triggers this status.
- `'recalled'` — A client canceled the goal while it was in the `'pending'` state.
- `'lost'` — An internal error occurred in the action client.

ActivationFcn — Activation function
`@(~) disp('Goal is active.')` (default) | function handle

Activation function, returned as a function handle. This function executes when `GoalState` is set to `'active'`. By default, the function displays `'Goal is active.'`. You can set the function to `[]` to have the action client do nothing upon activation.

FeedbackFcn — Feedback function
`@(~,msg) disp(['Feedback: ', showdetails(msg)])` (default) | function handle

Feedback function, returned as a function handle. This function executes when a new feedback message is received from the action server. By default, the function displays the details of the message. You can set the function to `[]` to have the action client not give any feedback.

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ResultFcn — Result function
@(~,msg,s,~) disp(['Result with state ' s ': ', showdetails(msg)])
(default) | function handle

Result function, returned as a function handle. This function executes when the server finishes executing the goal and returns a result state and message. By default, the function displays the state and details of the message. You can set the function to [] to have the action client do nothing once the goal is completed.

Object Functions

cancelGoal	Cancel last goal sent by client
cancelAllGoals	Cancel all goals on action server
rosmessage	Create ROS messages
sendGoal	Send goal message to action server
sendGoalAndWait	Send goal message and wait for result
waitForServer	Wait for action server to start

Examples

Setup a ROS Action Client and Execute an Action

This example shows how to create a ROS action client and execute the action. Action types must be setup beforehand with an action server running.

You must have the '/fibonacci' action type setup. To run this action server use the following command on the ROS system:

```
rosrun actionlib_tutorials fibonacci_server
```

Connect to a ROS network. You must be connected to a ROS network to gather information about what actions are available. Replace ipaddress with your network address.

```
ipaddress = '192.168.154.131';
rosinit(ipaddress)
```

Initializing global node /matlab_global_node_68978 with NodeURI http://192.168.154.1:5

List actions available on the network. The only action setup on this network is the `'/fibonacci'` action.

```
rosaction list
```

```
/fibonacci
```

Create an action client. Specify the action name.

```
[actClient,goalMsg] = rosactionclient('/fibonacci');
```

Wait for action client to connect to server.

```
waitForServer(actClient);
```

The fibonacci action will calculate the fibonacci sequence for a given order specified in the goal message. The goal message was returned when creating the action client and can be modified to send goals to the ROS action server.

```
goalMsg.Order = 8
```

```
goalMsg =

  ROS FibonacciGoal message with properties:

    MessageType: 'actionlib_tutorials/FibonacciGoal'
          Order: 8

  Use showdetails to show the contents of the message
```

Send goal and wait for its completion. Specify a timeout of 10 seconds to complete the action.

```
[resultMsg,resultState] = sendGoalAndWait(actClient,goalMsg,10)
```

```
Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
```

```
  Sequence :  [0, 1, 1, 2, 3, 5]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13, 21]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13, 21, 34]
Final state succeeded with result:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13, 21, 34]

resultMsg =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [10×1 int32]

  Use showdetails to show the contents of the message


resultState =

  1×9 char array

succeeded
```

Disconnect from the ROS network.

`rosshutdown`

```
Shutting down global node /matlab_global_node_68978 with NodeURI http://192.168.154.1:5
```

Send and Cancel ROS Action Goals

Send and cancel goals for ROS actions. First, setup a ROS action client. Then send a goal message with modified parameters. Finally, cancel your goal and all goals on the action server.

Connect to a ROS network with a specified IP address. Create a ROS action client connected using `rosactionclient`. Specify the action name. Wait for the client to be connected to the server.

```
rosinit('192.168.154.131')
[actClient,goalMsg] = rosactionclient('/fibonacci');
waitForServer(actClient);
```

```
Initializing global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5
```

Send a goal message with modified parameters. Wait for the goal to finish executing.

```
goalMsg.Order = 4;
sendGoalAndWait(actClient,goalMsg)
```

```
Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5]

ans =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [6×1 int32]

  Use showdetails to show the contents of the message
```

Send a new goal message without waiting.

```
goalMsg.Order = 5;
sendGoal(actClient,goalMsg)
```

Cancel the goal on the ROS action client, `actClient`.

```
cancelGoal(actClient)
```

Cancel all the goals on the action server that `actClient` is connected to.

```
cancelAllGoals(actClient)
```

Delete the action client.

```
delete(actClient)
```

Disconnect from the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5

See Also
cancelGoal | rosaction | rosmessage | sendGoal | waitForServer

Topics
"ROS Actions Overview"
"Move a Turtlebot Robot Using ROS Actions"

External Websites
ROS Actions

Introduced in R2016b

rospublisher

Publish message on a topic

Description

Use `rospublisher` to create a ROS publisher for sending messages via a ROS network. To create ROS messages, use `rosmessage`. Send these messages via the ROS publisher with the `send` function.

The `Publisher` object created by the function represents a publisher on the ROS network. The object publishes a specific message type on a given topic. When the `Publisher` object publishes a message to the topic, all subscribers to the topic receive this message. The same topic can have multiple publishers and subscribers.

The publisher gets the topic message type from the topic list on the ROS master. When the MATLAB global node publishes messages on that topic, ROS nodes that subscribe to that topic receive those messages. If the topic is not on the ROS master topic list, this function displays an error message. If the ROS master topic list already contains a matching topic, the ROS master adds the MATLAB global node to the list of publishers for that topic. To see a list of available topic names, at the MATLAB command prompt, type `rostopic list`.

You can create a `Publisher` object using the `rospublisher` function, or by calling `robotics.ros.Publisher`:

- `rospublisher` only works with the global node using `rosinit`. It does not require a node object handle as an argument.
- `robotics.ros.Publisher` works with additional nodes that are created using `robotics.ros.Node`. It requires a node object handle as the first argument.

Creation

Syntax

```
pub = rospublisher(topicname)
pub = rospublisher(topicname,msgtype)
pub = rospublisher( ___ ,Name,Value)
[pub,msg] = rospublisher( ___ )

pub = robotics.ros.Publisher(node,topicname)
pub = robotics.ros.Publisher(node,topicname,type)
pub = robotics.ros.Publisher( ___ , 'IsLatching',value)
```

Description

`pub = rospublisher(topicname)` creates a publisher for a topic specified as a character vector and sets the `TopicName`. The topic must already exist on the ROS master topic list with an established `MessageType`.

`pub = rospublisher(topicname,msgtype)` creates a publisher for a topic and adds that topic to the ROS master topic list. The inputs are set to the `TopicName` and `MessageType` properties of the publisher. If the topic already exists and `msgtype` differs from the topic type on the ROS master topic list, the function displays an error message.

`pub = rospublisher( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments using any of the arguments from previous syntaxes. `Name` is the 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 not specified retain their default values.

`[pub,msg] = rospublisher( ___ )` returns a message, `msg`, that you can send with the publisher, `pub`. The message is initialized with default values. You can also get the ROS message using the `rosmessage` function.

`pub = robotics.ros.Publisher(node,topicname)` creates a publisher for a topic with name, `topicname`. `node` is the `robotics.ros.Node` object handle that this publisher attaches to. If `node` is specified as `[]`, the publisher tries to attach to the global node.

`pub = robotics.ros.Publisher(node,topicname,type)` creates a publisher with specified message type, `type`. If the topic already exists, MATLAB checks the message type and displays an error if the input type differs. If the ROS master topic list already contains a matching topic, the ROS master adds the MATLAB global node to the list of publishers for that topic.

`pub = robotics.ros.Publisher( ___ , 'IsLatching',value)` specifies if the publisher is latching with a Boolean, `value`. If a publisher is latching, it saves the last sent message and sends it to any new subscribers. By default, `IsLatching` is enabled.

Properties

`TopicName` — Name of the published topic
character vector

This property is read-only.

Name of the published topic, specified as a character vector. If the topic does not exist, the object creates the topic using its associated message type.

Example: `'/chatter'`

Data Types: `char`

`MessageType` — Message type of published messages
character vector

This property is read-only.

Message type of published messages, specified as a character vector. This message type remains associated with the topic and must be used for new messages published.

Example: `'std_msgs/String'`

Data Types: `char`

`IsLatching` — Indicator of whether publisher is latching
`true` (default) | `false`

This property is read-only.

Indicator of whether publisher is latching, specified as `true` or `false`. A publisher that is latching saves the last sent message and resends it to any new subscribers.

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Data Types: `logical`

NumSubscribers — Number of subscribers
integer

This property is read-only.

Number of subscribers to the published topic, specified as an integer.

Data Types: `double`

Object Functions

send   Publish ROS message to topic
rosmessage   Create ROS messages

Examples

Create a ROS Publisher and Send Data

Connect to a ROS network.

`rosinit`

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_81707 with NodeURI http://bat5811win64:570
```

Create publisher for the `'/chatter'` topic with the `'std_msgs/String'` message type.

```
chatpub = rospublisher('/chatter','std_msgs/String');
```

Create a message to send. Specify the `Data` property.

```
msg = rosmessage(chatpub);
msg.Data = 'test phrase';
```

Send message via the publisher.

```
send(chatpub,msg);
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_81707 with NodeURI http://bat5811win64:5
Shutting down ROS master on http://bat5811win64:11311/.
```

Create ROS Publisher with `rospublisher` and View Properties

Create a ROS publisher and view the associated properties for the `robotics.ros.Publisher` object. Add a subscriber to view the updated properties.

Start ROS master.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_74080 with NodeURI http://bat5811win64:574
```

Create a publisher and view its properties.

```
pub = rospublisher('/chatter','std_msgs/String');
```

```
topic = pub.TopicName
```

```
topic =
'/chatter'
```

```
subCount = pub.NumSubscribers
```

```
subCount = 0
```

Subscriber to the publisher topic and view the changes in the `NumSubscribers` property.

```
sub = rossubscriber('/chatter');
pause(1)
```

```
subCount = pub.NumSubscribers
```

```
subCount = 1
```

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_74080 with NodeURI http://bat5811win64:5
Shutting down ROS master on http://bat5811win64:11311/.
```

Publish Data Without A ROS Publisher

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_58792 with NodeURI http://bat5811win64:57
```

Create a message to send. Specify the `Data` property.

```
msg = rosmessage('std_msgs/String');
msg.Data = 'test phrase';
```

Send message via the '`/chatter`' topic.

```
rospublisher('/chatter',msg)
```

```
ans =

    []
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_58792 with NodeURI http://bat5811win64:57
Shutting down ROS master on http://bat5811win64:11311/.
```

Use ROS Publisher Object

Create a `Publisher` object using the class constructor.

Start the ROS master.

```
master = robotics.ros.Core;
```

Create a ROS node, which connects to the master.

```
node = robotics.ros.Node('/test1');
```

Create a publisher and send string data. The publisher attaches to the node object in the first argument.

```
pub = robotics.ros.Publisher(node, '/robotname', 'std_msgs/String');
msg = rosmessage('std_msgs/String');
msg.Data = 'robot1';
send(pub,msg);
```

Clear the publisher and ROS node. Shut down the ROS master.

```
clear('pub','node')
clear('master')
```

- "Exchange Data with ROS Publishers and Subscribers"

See Also

Functions
rosmessage | send

Topics
"Exchange Data with ROS Publishers and Subscribers"

Introduced in R2015a

rosrate

Execute loop at fixed frequency

Description

The `robotics.ros.Rate` object uses the `robotics.Rate` superclass to inherit most of its properties and methods. The main difference is that `robotics.ros.Rate` uses the ROS node as a source for time information. Therefore, it can use the ROS simulation or wall clock time (see the `IsSimulationTime` property).

If `rosinit` creates a ROS master in MATLAB, the global node uses wall clock time.

The performance of the `ros.Rate` object and the ability to maintain the `DesiredRate` value depends on the publishing of the clock information in ROS.

Tip The scheduling resolution of your operating system and the level of other system activity can affect rate execution accuracy. As a result, accurate rate timing is limited to 100 Hz for execution of MATLAB code. To improve performance and execution speeds, use code generation.

Creation

Syntax

```
rate = rosrate(desiredRate)
rate = robotics.ros.Rate(node,desiredRate)
```

Description

`rate = rosrate(desiredRate)` creates a `robotics.ros.Rate` object, which enables you to execute a loop at a fixed frequency, `DesiredRate`. The time source is linked to the time source of the global ROS node, which requires you to connect MATLAB to a ROS network using `rosinit`.

`rate = robotics.ros.Rate(node,desiredRate)` creates a `Rate` object that operates loops at a fixed rate based on the time source linked to the specified ROS node, `node`.

Properties

DesiredRate — Desired execution rate
scalar

Desired execution rate of loop, specified as a scalar in Hz. When using `waitfor`, the loop operates every `DesiredRate` seconds, unless the loop takes longer. It then begins the next loop based on the specified `OverRunAction`.

DesiredPeriod — Desired time period between executions
scalar

Desired time period between executions, specified as a scalar in seconds. This property is equal to the inverse of `DesiredRate`.

TotalElapsedTime — Elapsed time since construction or reset
scalar

Elapsed time since construction or reset, specified as a scalar in seconds.

LastPeriod — Elapsed time between last two calls to `waitfor`
NaN (default) | scalar

Elapsed time between last two calls to `waitfor`, specified as a scalar. By default, `LastPeriod` is set to `NaN` until `waitfor` is called for the first time. After the first call, `LastPeriod` equals `TotalElapsedTime`.

OverrunAction — Method for handling overruns
'slip' (default) | 'drop'

Method for handling overruns, specified as one of these character vectors:

- `'drop'` — waits until the next time interval equal to a multiple of `DesiredPeriod`
- `'slip'` — immediately executes the loop again

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Each code section calls `waitfor` at the end of execution.

IsSimulationTime — Indicator if simulation or wall clock time is used
`true` | `false`

Indicator if simulation or wall clock time is used, returned as `true` or `false`. If `true`, the `Rate` object is using the ROS simulation time to regulate the rate of loop execution.

Object Functions
waitfor   Pause code execution to achieve desired execution rate
statistics   Statistics of past execution periods
reset   Reset Rate object

Examples

Run Loop At Fixed Rate Using `rosrate`

Initialize the ROS master and node.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_34952 with NodeURI http://bat5811win64:568
```

Create a rate object that runs at 1 Hz.

```
r = rosrate(1);
```

Start loop that prints iteration and time elapsed. Use `waitfor` to pause the loop until the next time interval. Reset r prior to the loop execution. Notice that each iteration executes at a 1-second interval.

```
reset(r)
for i = 1:10
    time = r.TotalElapsedTime;
    fprintf('Iteration: %d - Time Elapsed: %f\n',i,time)
    waitfor(r);
end
```

```
Iteration: 1 - Time Elapsed: 0.006860
Iteration: 2 - Time Elapsed: 1.007595
Iteration: 3 - Time Elapsed: 2.006221
Iteration: 4 - Time Elapsed: 3.008911
Iteration: 5 - Time Elapsed: 4.008776
Iteration: 6 - Time Elapsed: 5.011740
Iteration: 7 - Time Elapsed: 6.003548
Iteration: 8 - Time Elapsed: 7.003356
Iteration: 9 - Time Elapsed: 8.003361
Iteration: 10 - Time Elapsed: 9.003661
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_34952 with NodeURI http://bat5811win64:56
Shutting down ROS master on http://bat5811win64:11311/.
```

Run Loop At Fixed Rate Using ROS Time

Initialize the ROS master and node.

```
rosinit
```

Initializing global node /matlab_global_node_11337 with NodeURI http://bat5811win64:569

```
node = robotics.ros.Node('/testTime');
```

Using Master URI http://localhost:11311 from the global node to connect to the ROS mast

Create a `ros.Rate` object running at 20 Hz.

```
r = robotics.ros.Rate(node,20);
```

Reset the object to restart the timer and run the loop for 30 iterations. Insert code you want to run in the loop before calling `waitfor`.

```
reset(r)
for i = 1:30
    % User code goes here.
    waitfor(r);
end
```

Shutdown ROS node.

```
rosshutdown
```

Shutting down global node /matlab_global_node_11337 with NodeURI http://bat5811win64:56

- "Execute Code at a Fixed-Rate"

See Also
`robotics.Rate` | `waitfor`

Topics
"Execute Code at a Fixed-Rate"

Introduced in R2016a

rossubscriber

Subscribe to messages on a topic

Description

Use `rossubscriber` to create a ROS subscriber for receiving messages on the ROS network. To send messages, use `rospublisher`. To wait for a new ROS message, use the `receive` function with your created subscriber.

The `Subscriber` object created by the `rossubscriber` function represents a subscriber on the ROS network. The `Subscriber` object subscribes to an available topic or to a topic that it creates. This topic has an associated message type. Publishers can send messages over the network that the `Subscriber` object receives.

You can create a `Subscriber` object by using the `rossubscriber` function, or by calling `robotics.ros.Subscriber`:

- `rossubscriber` only works with the global node using `rosinit`. It does not require a node object handle as an argument.
- `robotics.ros.Subscriber` works with additional nodes that are created using `robotics.ros.Node`. It requires a node object handle as the first argument.

Creation

Syntax

```
sub = rossubscriber(topicname)
sub = rossubscriber(topicname,msgtype)
sub = rossubscriber(topicname,callback)
sub = rossubscriber(topicname, msgtype,callback)
sub = rossubscriber( ___ ,Name,Value)

sub = robotics.ros.Subscriber(node,topicname)
sub = robotics.ros.Subscriber(node,topicname,msgtype)
```

```
sub = robotics.ros.Subscriber(node,topicname,callback)
sub = robotics.ros.Subscriber(node,topicname,type,callback)
sub = robotics.ros.Subscriber( ___ ,'BufferSize',value)
```

Description

`sub = rossubscriber(topicname)` subscribes to a topic with the given `TopicName` specified as a character vector.The topic must already exist on the ROS master topic list with an established message type. When ROS nodes publish messages on that topic, MATLAB receives those messages through this subscriber.

`sub = rossubscriber(topicname,msgtype)` subscribes to a topic that has the specified name, `TopicName`, and type, `MessageType`. If the topic list on the ROS master does not include a topic with that specified name and type, it is added to the topic list. Use this syntax to avoid errors when subscribing to a topic before a publisher has added the topic to the topic list on the ROS master.

`sub = rossubscriber(topicname,callback)` specifies a callback function, `callback` that runs when the subscriber object handle receives a topic message. Use this syntax to avoid the blocking receive function. `callback` can be a single function handle or a cell array. The first element of the cell array must be a function handle or a character vector containing the name of a function. The remaining elements of the cell array can be arbitrary user data that is passed to the callback function.

`sub = rossubscriber(topicname, msgtype,callback)` specifies a callback function and subscribes to a topic that has the specified name, `TopicName`, and type, `MessageType`.

`sub = rossubscriber( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments using any of the arguments from previous syntaxes. `Name` is the 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 not specified retain their default values.

`sub = robotics.ros.Subscriber(node,topicname)` subscribes to a topic with name, `TopicName`. `node` is the `robotics.ros.Node` object handle that this publisher attaches to.

`sub = robotics.ros.Subscriber(node,topicname,msgtype)` specifies the message type, `MessageType`, of the topic. If a topic with the same name exists with a different message type, MATLAB creates a new topic with the given message type.

`sub = robotics.ros.Subscriber(node,topicname,callback)` specifies a callback function, and optional data, to run when the subscriber object receives a topic message. See `NewMessageFcn` for more information about the callback function.

`sub = robotics.ros.Subscriber(node,topicname,type,callback)` specifies the topic name, message type, and callback function for the subscriber.

`sub = robotics.ros.Subscriber( ___ ,'BufferSize',value)` specifies the queue size in `BufferSize` for incoming messages. You can use any combination of previous inputs with this syntax.

Properties

TopicName — Name of the subscribed topic
character vector

This property is read-only.

Name of the subscribed topic, specified as a character vector. If the topic does not exist, the object creates the topic using its associated message type.

Example: `'/chatter'`

Data Types: `char`

MessageType — Message type of subscribed messages
character vector

This property is read-only.

Message type of subscribed messages, specified as a character vector. This message type remains associated with the topic.

Example: `'std_msgs/String'`

Data Types: `char`

LatestMessage — Latest message sent to the topic
Message object

Latest message sent to the topic, specified as a `Message` object. The `Message` object is specific to the given `MessageType`. If the subscriber has not received a message, then the `Message` object is empty.

BufferSize — Buffer size
1 (default) | scalar

Buffer size of the incoming message queue, specified as the comma-separated pair consisting of `'BufferSize'` and a scalar. If messages arrive faster and than your callback can process them, they are deleted once the incoming queue is full.

NewMessageFcn — Callback property
function handle | cell array

Callback property, specified as a function handle or cell array. In the first element of the cell array, specify either a function handle or a character vector representing a function name. In subsequent elements, specify user data.

The subscriber callback function requires at least two input arguments. The first argument, `src`, is the associated subscriber object. The second argument, `msg`, is the received message object. The function header for the callback is:

```
function subCallback(src,msg)
```

Specify the `NewMessageFcn` property as:

```
sub.NewMessageFcn = @subCallback;
```

When setting the callback, you pass additional parameters to the callback function by including both the callback function and the parameters as elements of a cell array. The function header for the callback is:

```
function subCallback(src,msg,userData)
```

Specify the `NewMessageFcn` property as:

```
sub.NewMessageFcn = {@subCallback,userData};
```

Object Functions

receive	Wait for new ROS message
rosmessage	Create ROS messages

Examples

Create A Subscriber and Get Data From ROS

Connect to a ROS network. Set up a sample ROS network. The `'/scan'` topic is being published on the network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_54632 with NodeURI http://bat5811win64:568
```

```
exampleHelperROSCreateSampleNetwork
```

Create a subscriber for the `'/scan'` topic. Wait for the subscriber to register with the master.

```
sub = rossubscriber('/scan');
pause(1);
```

Receive data from the subscriber as a ROS message. Specify a 10 second timeout.

```
msg2 = receive(sub,10)
```

```
msg2 =
  ROS LaserScan message with properties:

        MessageType: 'sensor_msgs/LaserScan'
             Header: [1x1 Header]
           AngleMin: -0.5216
           AngleMax: 0.5243
     AngleIncrement: 0.0016
      TimeIncrement: 0
           ScanTime: 0.0330
           RangeMin: 0.4500
           RangeMax: 10
             Ranges: [640x1 single]
        Intensities: [0x1 single]

  Use showdetails to show the contents of the message
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_54632 with NodeURI http://bat5811win64:56
Shutting down ROS master on http://bat5811win64:11311/.
```

Create A Subscriber That Uses A Callback Function

You can trigger callback functions when subscribers receive messages. Specify the callback when you create it or use the `NewMessageFcn` property.

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_70371 with NodeURI http://bat5811win64:568
```

Setup a publisher to publish a message to the `'/chatter'` topic. This topic is used to trigger the subscriber callback. Specify the `Data` property of the message. Wait 1 second to allow the publisher to register with the network.

```
pub = rospublisher('/chatter','std_msgs/String');
msg = rosmessage(pub);
msg.Data = 'hello world';
pause(1)
```

Setup a subscriber with a specified callback function. The `exampleHelperROSChatterCallback` function displays the `Data` inside the received message.

```
sub = rossubscriber('/chatter',@exampleHelperROSChatterCallback);
pause(1)
```

Send message via the publisher. The subscriber should execute the callback to display the new message. Wait for the message to be received.

```
send(pub,msg);
pause(1)
```

```
ans =
'hello world'
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_70371 with NodeURI http://bat5811win64:56
Shutting down ROS master on http://bat5811win64:11311/.
```

Use ROS Subscriber Object

Use a ROS `Subscriber` object to receive messages over the ROS network.

Start the ROS master and node.

```
master = robotics.ros.Core;
node = robotics.ros.Node('/test');
```

Create a publisher and subscriber to send and receive a message over the ROS network.

```
pub = robotics.ros.Publisher(node,'/chatter','std_msgs/String');
pause(1)
sub = robotics.ros.Subscriber(node,'/chatter','std_msgs/String');
```

Send a message over the network.

```
msg = rosmessage('std_msgs/String');
msg.Data = 'hello world';
send(pub,msg)
```

View the message data using the `LatestMessage` property of the `Subscriber` object.

```
pause(1)
sub.LatestMessage
```

```
ans =
  ROS String message with properties:

    MessageType: 'std_msgs/String'
           Data: 'hello world'

  Use showdetails to show the contents of the message
```

Clear the publisher, subscriber, and ROS node. Shut down the ROS master.

```
clear('pub','sub','node')
clear('master')
```

- "Exchange Data with ROS Publishers and Subscribers"

See Also

`receive` | `rosmessage` | `rospublisher`

Topics

"Exchange Data with ROS Publishers and Subscribers"

Introduced in R2015a

rossvcclient

Connect to ROS service server

Description

Use `rossvcclient` or `robotics.ros.ServiceClient` to create a ROS service client object. This service client uses a persistent connection to send requests to, and receive responses from, a ROS service server. The connection persists until the service client is deleted or the service server becomes unavailable.

Use the `robotics.ros.ServiceClient` syntax when connecting to a specific ROS node.

Creation

Syntax

```
client = rossvcclient(servicename)
client = rossvcclient(servicename,Name,Value)

[client,reqmsg] = rossvcclient( ___ )

client = robotics.ros.ServiceClient(node, name)
client = robotics.ros.ServiceClient(node, name,'Timeout',timeout)
```

Description

`client = rossvcclient(servicename)` creates a service client with the given `ServiceName` that connects to, and gets its `ServiceType` from, a service server. This command syntax blocks the current MATLAB program from running until it can connect to the service server.

`client = rossvcclient(servicename,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments. Name must appear inside single

quotes (''). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`. Properties not specified retain their default values.

`[client,reqmsg] = rossvcclient( ___ )` returns a new service request message in `reqmsg`, using any of the arguments from previous syntaxes. The message type of `reqmsg` is determined by the service that `client` is connected to. The message is initialized with default values. You can also create the request message using `rosmessage` wutg.

`client = robotics.ros.ServiceClient(node, name)` creates a service client that connects to a service server. The client gets its service type from the server. The service client attaches to the `robotics.ros.Node` object handle, `node`.

`client = robotics.ros.ServiceClient(node, name,'Timeout',timeout)` specifies a timeout period in seconds for the client to connect the service server.

Properties

ServiceName — Name of the service
character vector

This property is read-only.

Name of the service, specified as a character vector.

Example: `'/gazebo/get_model_state'`

ServiceType — Type of service
character vector

This property is read-only.

Type of service, specified as a character vector.

Example: `'gazebo_msgs/GetModelState'`

Object Functions

rosmessage   Create ROS messages
call   Call the ROS service server and receive a response

Examples

Call Service Client with Default Message

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://ah-sradford:11311/.
Initializing global node /matlab_global_node_03934 with NodeURI http://ah-sradford:613(
```

Set up a service server and client.

```
server = rossvcserver('/test', 'std_srvs/Empty', @exampleHelperROSEmptyCallback);
client = rossvcclient('/test');
```

Call service server with default message.

```
response = call(client)
```

```
A service client is calling
```

```
response =

  ROS EmptyResponse message with properties:

    MessageType: 'std_srvs/EmptyResponse'

  Use showdetails to show the contents of the message
```

Shut down ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_03934 with NodeURI http://ah-sradford:613
Shutting down ROS master on http://ah-sradford:11311/.
```

Use ROS Service Server with ServiceServer and ServiceClient Objects

Create a ROS service serve by creating a `ServiceServer` object and use `ServiceClient` objects to request information over the network. The callback function used by the server takes a string, reverses it, and returns the reversed string.

Start the ROS master and node.

```
master = robotics.ros.Core;
node = robotics.ros.Node('/test');
```

Create a service server. This server expects a string as a request and responds with a string based on the callback.

```
server = robotics.ros.ServiceServer(node,'/data/string',...
                                    'roseus/StringString');
```

Create a callback function. This function takes an input string as the `Str` property of `req` and returns it as the `Str` property of `resp`. You must create and save this function separately. `req` is a ROS message you create using `rosmessage`.

```
% Copyright 2015 The MathWorks, Inc.

function [resp] = flipString(~,req,resp)
% FLIPSTRING Reverses the order of a string in REQ and returns it in RESP.
resp.Str = fliplr(req.Str);
end
```

Save this code as a file named `flipString.m` to a folder on your MATLAB® path.

Assign the callback function for incoming service calls.

```
server.NewRequestFcn = @flipString;
```

Create a service client and connect to the service server. Create a request message based on the client.

```
client = robotics.ros.ServiceClient(node,'/data/string');
request = rosmessage(client);
request.Str = 'hello world';
```

1-301

Send a service request and wait for a response. Specify that the service waits 3 seconds for a response.

```
response = call(client,request,'Timeout',3)
```

```
response =

  ROS StringStringResponse message with properties:

    MessageType: 'roseus/StringStringResponse'
            Str: 'dlrow olleh'

  Use showdetails to show the contents of the message
```

The response is a flipped string from the request message.

Clear the service client, service server, and ROS node. Shut down the ROS master.

```
clear('client', 'server', 'node')
clear('master')
```

•   "Call and Provide ROS Services"

See Also
call | rosmessage | rosservice | rossvcserver

Topics
"Call and Provide ROS Services"

Introduced in R2015a

rossvcserver

Create ROS service server

Description

Use `rossvcserver` or `robotics.ros.ServiceServer` to create a ROS service server that can receive requests from, and send responses to, a ROS service client. You must create the service server before creating the service client (see ROSSVCCLIENT).

When you create the service client, it establishes a connection to the server. The connection persists while both client and server exist and can reach each other. When you create the service server, it registers itself with the ROS master. To get a list of services, or to get information about a particular service that is available on the current ROS network, use the `rosservice` function.

The service has an associated message type and contains a pair of messages: one for the request and one for the response. The service server receives a request, constructs an appropriate response based on a call function, and returns it to the client. The behavior of the service server is inherently asynchronous, because it becomes active only when a service client connects to the ROS network and issues a call.

Use the `robotics.ros.ServiceServer` syntax when connecting to a specific ROS node.

Creation

Syntax

```
server = rossvcserver(servicename,svctype)
server = rossvcserver(servicename,svctype,callback)

server = robotics.ros.ServiceServer(node, name,type)
server = robotics.ros.ServiceServer(node, name,type,callback)
```

Description

`server = rossvcserver(servicename,svctype)` creates a service server object with the specified `ServiceType` available in the ROS network under the name `ServiceName`. The service object cannot respond to service requests until you specify a function handle callback, `NewMessageFcn`.

`server = rossvcserver(servicename,svctype,callback)` specifies the callback function that constructs a response when the server receives a request. `callback` specifies the `NewMessageFcn` property.

`server = robotics.ros.ServiceServer(node, name,type)` creates a service server that attaches to the ROS node, `node`. The server becomes available through the specified service name and type once a callback function handle is specified in `NewMessageFcn`.

`server = robotics.ros.ServiceServer(node, name,type,callback)` specifies the callback function which is set to the `NewMessageFcn` property.

Properties

ServiceName — Name of the service
character vector

This property is read-only.

Name of the service, specified as a character vector.

Example: `'/gazebo/get_model_state'`

ServiceType — Type of service
character vector

This property is read-only.

Type of service, specified as a character vector.

Example: `'gazebo_msgs/GetModelState'`

NewMessageFcn — Callback property
function handle | cell array

Callback property, specified as a function handle or cell array. In the first element of the cell array, specify either a function handle or a character vector representing a function name. In subsequent elements, specify user data.

The subscriber callback function requires at least two input arguments. The first argument, `src`, is the associated subscriber object. The second argument, `msg`, is the received message object. The function header for the callback is:

```
function subCallback(src,msg)
```

Specify the `NewMessageFcn` property as:

```
sub.NewMessageFcn = @subCallback;
```

When setting the callback, you pass additional parameters to the callback function by including both the callback function and the parameters as elements of a cell array. The function header for the callback is:

```
function subCallback(src,msg,userData)
```

Specify the `NewMessageFcn` property as:

```
sub.NewMessageFcn = {@subCallback,userData};
```

Object Functions

rosmessage   Create ROS messages

Examples

Call Service Client with Default Message

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://ah-sradford:11311/.
Initializing global node /matlab_global_node_03934 with NodeURI http://ah-sradford:613(
```

Set up a service server and client.

```
server = rossvcserver('/test', 'std_srvs/Empty', @exampleHelperROSEmptyCallback);
client = rossvcclient('/test');
```

Call service server with default message.

```
response = call(client)
```

```
A service client is calling
```

```
response =

  ROS EmptyResponse message with properties:

    MessageType: 'std_srvs/EmptyResponse'

  Use showdetails to show the contents of the message
```

Shut down ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_03934 with NodeURI http://ah-sradford:61:
Shutting down ROS master on http://ah-sradford:11311/.
```

- "Call and Provide ROS Services"

See Also
call | rosmessage | rossvcclient

Topics
"Call and Provide ROS Services"

Introduced in R2015a

rostf

Receive, send, and apply ROS transformations

Description

Calling `rostf` creates a ROS `TransformationTree` object, which allows you to access the tf coordinate transformations that are shared on the ROS network. You can receive transformations and apply them to different entities. You can also send transformations and share them with the rest of the ROS network.

ROS uses the tf transform library to keep track of the relationship between multiple coordinate frames. The relative transformations between these coordinate frames is maintained in a tree structure. Querying this tree lets you transform entities like poses and points between any two coordinate frames. To access available frames use the syntax:

`tfTree.AvailableFrames`

Use the `robotics.ros.TransformationTree` syntax when connecting to a specific ROS node, otherwise use `rostf` to create the transformation tree.

Creation

Syntax

`tfTree = rostf`

`trtree = robotics.ros.TransformationTree(node)`

Description

`tfTree = rostf` creates a ROS `TransformationTree` object.

`trtree = robotics.ros.TransformationTree(node)` creates a ROS transformation tree object handle that the transformation tree is attached to. `node` is the node connected to the ROS network that publishes transformations.

Properties

AvailableFrames — List of all available coordinate frames
cell array

This property is read-only.

List of all available coordinate frames, specified as a cell array. This list of available frames updates if new transformations are received by the transformation tree object.

Example: {'camera_center';'mounting_point';'robot_base'}

Data Types: cell

LastUpdateTime — Time when the last transform was received
ROS Time object

This property is read-only.

Time when the last transform was received, specified as a ROS Time object.

BufferTime — Length of time transformations are buffered
10 (default) | scalar

This property is read-only.

Length of time transformations are buffered, specified as a scalar in seconds. If you change the buffer time from the current value, the transformation tree and all transformations are reinitialized. You must wait the entire buffer time to get a fully buffered transformation tree.

Object Functions

waitForTransform	Wait until a transformation is available
getTransform	Retrieve transformation between two coordinate frames
transform	Transform message entities into target coordinate frame
sendTransform	Send transformation to ROS network

Examples

Create a ROS Transformation Tree

Connect to a ROS network and create a transformation tree.

Connect to a ROS network. Specify the IP address.

```
rosinit('192.168.203.129')
```

Initializing global node /matlab_global_node_92595 with NodeURI http://192.168.203.1:64

Create a transformation tree. Use the `AvailableFrames` property to see the transformation frames available. These transformations were specified separately prior to connecting to the network.

```
tree = rostf;
pause(1);
tree.AvailableFrames
```

```
ans =

  36×1 cell array

    {'base_footprint'            }
    {'base_link'                 }
    {'camera_depth_frame'        }
    {'camera_depth_optical_frame'}
    {'camera_link'               }
    {'camera_rgb_frame'          }
    {'camera_rgb_optical_frame'  }
    {'caster_back_link'          }
    {'caster_front_link'         }
    {'cliff_sensor_front_link'   }
    {'cliff_sensor_left_link'    }
    {'cliff_sensor_right_link'   }
    {'gyro_link'                 }
    {'mount_asus_xtion_pro_link' }
    {'odom'                      }
    {'plate_bottom_link'         }
    {'plate_middle_link'         }
    {'plate_top_link'            }
    {'pole_bottom_0_link'        }
    {'pole_bottom_1_link'        }
    {'pole_bottom_2_link'        }
    {'pole_bottom_3_link'        }
```

```
{'pole_bottom_4_link'        }
{'pole_bottom_5_link'        }
{'pole_kinect_0_link'        }
{'pole_kinect_1_link'        }
{'pole_middle_0_link'        }
{'pole_middle_1_link'        }
{'pole_middle_2_link'        }
{'pole_middle_3_link'        }
{'pole_top_0_link'           }
{'pole_top_1_link'           }
{'pole_top_2_link'           }
{'pole_top_3_link'           }
{'wheel_left_link'           }
{'wheel_right_link'          }
```

Disconnect from the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_92595 with NodeURI http://192.168.203.1:6

Use TransformationTree Object

Create a ROS transformation tree. You can then view or use transformation information
for different coordinate frames setup in the ROS network.

Start ROS network and broadcast sample transformation data.

```
rosinit
```

Initializing ROS master on http://ah-sradford:11311/.
Initializing global node /matlab_global_node_75001 with NodeURI http://ah-sradford:5225

```
node = robotics.ros.Node('/testTf');
```

Using Master URI http://localhost:11311 from the global node to connect to the ROS mas

```
exampleHelperROSStartTfPublisher
```

Retrieve the `TransformationTree` object. Pause to wait for tftree to update.

```
tftree = robotics.ros.TransformationTree(node);
pause(1)
```

View available coordinate frames and the time when they were last received.

```
frames = tftree.AvailableFrames
```

```
frames = 3×1 cell array
    {'camera_center' }
    {'mounting_point'}
    {'robot_base'    }
```

```
updateTime = tftree.LastUpdateTime
```

```
updateTime =
  ROS Time with properties:

     Sec: 1.5121e+09
    Nsec: 262000000
```

Wait for the transform between two frames, `'camera_center'` and `'robot_base'`. This will wait until the transformation is valid and block all other operations. A time out of 5 seconds is also given.

```
waitForTransform(tftree,'robot_base','camera_center',5)
```

Define a point in the camera's coordinate frame.

```
pt = rosmessage('geometry_msgs/PointStamped');
pt.Header.FrameId = 'camera_center';
pt.Point.X = 3;
pt.Point.Y = 1.5;
pt.Point.Z = 0.2;
```

Transform the point into the `'base_link'` frame.

```
tfpt = transform(tftree, 'robot_base', pt)
```

```
tfpt =
  ROS PointStamped message with properties:

    MessageType: 'geometry_msgs/PointStamped'
         Header: [1×1 Header]
          Point: [1×1 Point]

  Use showdetails to show the contents of the message
```

Display the transformed point coordinates.

```
tfpt.Point
```

```
ans =
  ROS Point message with properties:

    MessageType: 'geometry_msgs/Point'
              X: 1.2000
              Y: 1.5000
              Z: -2.5000

  Use showdetails to show the contents of the message
```

Clear ROS node. Shut down ROS master.

```
clear('node')
rosshutdown
```

```
Shutting down global node /matlab_global_node_75001 with NodeURI http://ah-sradford:522
Shutting down ROS master on http://ah-sradford:11311/.
```

• "Access the tf Transformation Tree in ROS"

See Also

getTransform | sendTransform | transform | waitForTransform

Topics

"Access the tf Transformation Tree in ROS"

Introduced in R2015a

rostime

Access ROS time functionality

Description

A ROS `Time` object representing and instance of time in seconds and nanoseconds. This time can be based off your system time, the ROS simulation time, or an arbitrary time.

Creation

Syntax

```
time = rostime(totalSecs)
time = rostime(secs,nsecs)

time = rostime('now')
[time,issimtime] = rostime('now')
time = rostime('now','system')
```

Description

`time = rostime(totalSecs)` initializes the time values for seconds and nanoseconds based on `totalSecs`, which represents the time in seconds as a floating-point number.

`time = rostime(secs,nsecs)` initializes the time values for seconds and nanoseconds individually. Both inputs must be integers. Large values for `nsecs` are wrapped automatically with the remainder added to `secs`.

`time = rostime('now')` returns the current ROS time. If the `use_sim_time` ROS parameter is set to `true`, the `rostime` returns the simulation time published on the `clock` topic. Otherwise, the function returns the system time of your machine. `time` is a ROS `Time` object. If no output argument is given, the current time (in seconds) is printed to the screen.

`rostime` can be used to timestamp messages or to measure time in the ROS network.

`[time,issimtime] = rostime('now')` also returns a Boolean that indicates if `time` is in simulation time (`true`) or system time (`false`).

`time = rostime('now','system')` always returns the system time of your machine, even if ROS publishes simulation time on the `clock` topic. If no output argument is given, the system time (in seconds) is printed to the screen.

The system time in ROS follows the Unix or POSIX time standard. POSIX time is defined as the time that has elapsed since 00:00:00 Coordinated Universal Time (UTC), 1 January 1970, not counting leap seconds.

Properties

`totalSecs` — Total time
0 (default) | scalar

Total time, specified as a floating-point scalar. The integer portion is set to the `Sec` property with the remainder applied to `Nsec` property of the `Time` object.

Sec — Whole seconds
0 (default) | positive integer

Whole seconds, specified as a positive integer.

Note The maximum and minimum values for `secs` are `[0, 4294967294]`.

Nsec — Nanoseconds
0 (default) | positive integer

Nanoseconds, specified as a positive integer. It this value is greater than or equal to 10^9, then the value is then wrapped and the remainders are added to the value of `Sec`.

Examples

Get Current ROS Time

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://AH-SRADFORD:11311/.
Initializing global node /matlab_global_node_00466 with NodeURI http://AH-SRADFORD:6439
```

Get current ROS Time. You can also check whether is it system time by getting the `issim` output.

```
[t,issim] = rostime('now')
```

```
t =

  ROS Time with properties:

     Sec: 1.4734e+09
    Nsec: 408000000


issim =

  logical

   0
```

Timestamp ROS Message Data

Create a stamped ROS message. Specify the `Header.Stamp` property with the current system time.

```
point = rosmessage('geometry_msgs/PointStamped');
point.Header.Stamp = rostime('now','system');
```

ROS Time to MATLAB Time Example

This example shows how to convert current ROS time into a MATLAB® standard time. The ROS Time object is first converted to a double in seconds, then to the specified MATLAB time.

1-315

```
% Sets up ROS network and stores ROS time
rosinit

Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_02774 with NodeURI http://bat5811win64:572

t = rostime('now');

% Converts ROS time to a double in seconds
secondtime = double(t.Sec)+double(t.Nsec)*10^-9;

% Sets time to a specified MATLAB format
time = datetime(secondtime, 'ConvertFrom','posixtime')

time = datetime
   27-Feb-2018 01:45:53


% Shuts down ROS network
rosshutdown

Shutting down global node /matlab_global_node_02774 with NodeURI http://bat5811win64:57
Shutting down ROS master on http://bat5811win64:11311/.
```

Get Seconds From A Time Object

Use the `seconds` function to get the total seconds of a `Time` object from its `Secs` and `Nsecs` properties.

Create a `Time` object.

```
time = rostime(1,860000000)

time =
  ROS Time with properties:

     Sec: 1
    Nsec: 860000000
```

Get the total seconds from the time object.

```
secs = seconds(time)
```

```
secs = 1.8600
```

See Also

rosduration | rosmessage | seconds

Introduced in R2015a

robotics.VectorFieldHistogram System object

Package: robotics

Avoid obstacles using vector field histogram

Description

The `robotics.VectorFieldHistogram` System objectenables your robot to avoid obstacles based on range sensor data using vector field histograms (VFH) . Given laser scan readings and a target direction to drive toward, the object computes an obstacle-free steering direction.

`VectorFieldHistogram` specifically uses the VFH+ algorithm to compute an obstacle-free direction. First, the algorithm takes the ranges and angles from laser scan data and builds a polar histogram for obstacle locations. Then, the input histogram thresholds are used to calculate a binary histogram that indicates occupied and free directions. Finally, the algorithm computes a masked histogram, which is computed from the binary histogram based on the minimum turning radius of the robot.

The algorithm selects multiple steering directions based on the open space and possible driving directions. A cost function, with weights corresponding to the previous, current, and target directions, calculates the cost of different possible directions. The object then returns an obstacle-free direction with minimal cost. Using the obstacle-free direction, you can input commands to move your robot in that direction.

To use this object for your own application and environment, you must tune the properties of the algorithm. Property values depend on the type of robot, the range sensor, and the hardware you use.

To find an obstacle-free steering direction:

1   Create the robotics.VectorFieldHistogram 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

```
VFH = robotics.VectorFieldHistogram
VFH = robotics.VectorFieldHistogram(Name,Value)
```

Description

`VFH = robotics.VectorFieldHistogram` returns a vector field histogram object that computes the obstacle-free steering direction using the `VFH+` algorithm.

`VFH = robotics.VectorFieldHistogram(Name,Value)` returns a vector field histogram object with additional options specified by one or more `Name,Value` pairs. Name is the 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 not specified retain their default values.

Properties

`NumAngularSectors` — Number of angular sectors in histogram
180 (default) | positive integer

Number of angular sectors in the vector field histogram, specified as a scalar. This property defines the number of bins used to create the histograms. This property is non-tunable. You can only set this when the object is initialized.

`DistanceLimits` — Limits for range readings
`[0.05 2]` (default) | 2-element vector

Limits for range readings, specified as a 2-element vector with elements measured in meters. The range readings specified when calling the object are considered only if they fall within the distance limits. Use the lower distance limit to ignore false positives from poor sensor performance at lower ranges. Use the upper limit to ignore obstacles that are too far from the robot.

RobotRadius — Radius of robot
`0.1` (default) | scalar

Radius of the robot in meters, specified as a scalar. This dimension defines the smallest circle that can circumscribe your robot. The robot radius is used to account for robot size when computing the obstacle-free direction.

SafetyDistance — Safety distance around robot
`0.1` (default) | scalar

Safety distance around the robot, specified as a scalar in meters. This is a safety distance to leave around the robot position in addition to the value of the `RobotRadius` parameter. The sum of the robot radius and the safety distance is used to compute the obstacle-free direction.

MinTurningRadius — Minimum turning radius at current speed
`0.1` (default) | scalar

Minimum turning radius in meters for the robot moving at its current speed, specified as a scalar.

TargetDirectionWeight — Cost function weight for target direction
5 (default) | scalar

Cost function weight for moving toward the target direction, specified as a scalar. To follow a target direction, set this weight to be higher than the sum of the `CurrentDirectionWeight` and `PreviousDirectionWeight` properties. To ignore the target direction cost, set this weight to zero.

CurrentDirectionWeight — Cost function weight for current direction
2 (default) | scalar

Cost function weight for moving the robot in the current heading direction, specified as a scalar. Higher values of this weight produce efficient paths. To ignore the current direction cost, set this weight to zero.

PreviousDirectionWeight — Cost function weight for previous direction
2 (default) | scalar

Cost function weight for moving in the previously selected steering direction, specified as a scalar. Higher values of this weight produces smoother paths. To ignore the previous direction cost, set this weight to zero.

HistogramThresholds — Thresholds for binary histogram computation
[3 10] (default) | 2-element vector

Thresholds for binary histogram computation, specified as a 2-element vector. The algorithm uses these thresholds to compute the binary histogram from the polar obstacle density. Polar obstacle density values higher than the upper threshold are represented as occupied space (1) in the binary histogram. Values smaller than the lower threshold are represented as free space (0). Values that fall between the limits are set to the values in the previous binary histogram, with the default being free space (0).

UseLidarScan — Use lidarScan object as scan input
false (default) | true

Use lidarScan object as scan input, specified as either true or false.

Usage

Syntax

```
steeringDir = vfh(scan,targetDir)
steeringDir = vfh(ranges,angles,targetDir)
```

Description

steeringDir = vfh(scan,targetDir) finds an obstacle-free steering direction using the VFH+ algorithm for the input lidarScan object, scan. A target direction is given based on the target location.

To enable this syntax, you must set the UseLidarScan property to true. For example:

```
mcl = robotics.MonteCarloLocalization('UseLidarScan','true');
...
[isUpdated,pose,covariance] = mcl(odomPose,scan);
```

steeringDir = vfh(ranges,angles,targetDir) defines the lidar scan with two vectors: ranges and angles.

Input Arguments

scan — Lidar scan readings
lidarScan object

Lidar scan readings, specified as a `lidarScan` object.

Dependencies

To use this argument, you must set the `UseLidarScan` property to `true`.

```
mcl.UseLidarScan = true;
```

ranges — Range values from scan data
vector

Range values from scan data, specified as a vector in meters. These range values are distances from a sensor at given `angles`. The vector must be the same length as the corresponding `angles` vector.

angles — Angle values from scan data
vector

Angle values from scan data, specified as a vector in radians. These angle values are the specific angles of the given `ranges`. The vector must be the same length as the corresponding `ranges` vector.

targetDir — Target direction for robot
scalar

Target direction for the robot, specified as a scalar in radians. The forward direction of the robot is considered zero radians, with positive angles measured counterclockwise.

Output Arguments

steeringDir — Steering direction for robot
scalar

Steering direction for the robot, specified as a scalar in radians. This obstacle-free direction is calculated based on the VFH+ algorithm. The forward direction of the robot is considered zero radians, with positive angles measured counterclockwise.

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 robotics.VectorFieldHistogram

show   Display VectorFieldHistogram information in figure window

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 a Vector Field Histogram Object and Visualize Data

This example shows how to calculate a steering direction based on input laser scan data.

Create a `VectorFieldHistogram` object.

```
 vfh = robotics.VectorFieldHistogram;
```

Input laser scan data and target direction.

```
ranges = 10*ones(1,500);
ranges(1,225:275) = 1.0;
angles = linspace(-pi,pi,500);
targetDir = 0;
```

Compute an obstacle-free steering direction.

```
steeringDir = vfh(ranges,angles,targetDir)
```

```
steeringDir = -0.8014
```

Visualize the `VectorFieldHistogram` computation.

```
h = figure;
set(h,'Position',[50 50 800 400])
show(vfh)
```


- "Obstacle Avoidance Using TurtleBot"

References

[1] Borenstein, J., and Y. Koren. "The Vector Field Histogram - Fast Obstacle Avoidance for Mobile Robots." IEEE Journal of Robotics and Automation. Vol. 7, Number 3, 1991, pp.278–88.

[2] Ulrich, I., and J. Borenstein. "VFH : Reliable Obstacle Avoidance for Fast Mobile Robots." *Proceedings. 1998 IEEE International Conference on Robotics and Automation*. (1998): 1572–1577.

Extended Capabilities

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

Usage notes and limitations:

Use in a MATLAB Function block is not supported.

Lidar scans require a limited size in code generation. The lidar scans, `scan`, are limited to 4000 points (range and angles) as a maximum.

For additional information about code generation for System objects, see "System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also
`lidarScan` | `show`

Topics
"Obstacle Avoidance Using TurtleBot"
"Vector Field Histogram"

Introduced in R2015b

Functions — Alphabetical List

addRelativePose

Package: robotics

Add relative pose to pose graph

Syntax

```
addRelativePose(poseGraph,relPose)
addRelativePose(poseGraph,relPose,infoMatrix)
addRelativePose(poseGraph,relPose,infoMatrix,fromNodeID)
addRelativePose(poseGraph,relPose,infoMatrix,fromNodeID,toNodeID)
[edge,edgeID] = addRelativePose( ___ )
```

Description

`addRelativePose(poseGraph,relPose)` creates a pose node and uses an edge specified by `relPose` to connect it to the last node in the pose graph.

`addRelativePose(poseGraph,relPose,infoMatrix)` also specifies the information matrix as part of the edge constraint, which represents the uncertainty of the pose measurement.

`addRelativePose(poseGraph,relPose,infoMatrix,fromNodeID)` creates a new pose node and connects it to the specific node specified by `fromNodeID`.

`addRelativePose(poseGraph,relPose,infoMatrix,fromNodeID,toNodeID)` creates an edge by specifying a relative pose between existing nodes specified by `fromNodeID` and `toNodeID`. This edge is called a loop closure.

`[edge,edgeID] = addRelativePose( ___ )` returns the newly added edge and edge ID using any of the previous syntaxes.

Input Arguments

poseGraph — Pose graph
PoseGraph object | PoseGraph3D object

Pose graph, specified as a PoseGraph or PoseGraph3D object.

relPose — Relative pose between nodes
[x y theta] vector | [x y z qw qx qy qz] vector

Relative pose between nodes, specified as one of the following:

For PoseGraph (2-D), the pose is a [x y theta] vector, which defines a *xy*-position and orientation angle, theta.

For PoseGraph3D, the pose is a [x y z qw qx qy qz] vector, which defines by an *xyz*-position and quaternion orientation, [qw qx qy qz]

Note Many other sources for 3-D pose graphs, including .g2o formats, specify the quaternion orientation in a different order, for example, [qx qy qz qw]. Check the source of your pose graph data before adding nodes to your PoseGraph3D object.

---

infoMatrix — Information matrix
6-element vector | 21-element vector

Information matrix, specified as a 6-element or 21-element vector. This vector contains the elements of the upper triangle of the square information matrix (compact form). The information matrix is the inverse of the covariance of the pose and represents the uncertainty of the measurement. If the pose vector is [x y theta], the covariance is a 3-by-3 matrix of pairwise covariance calculations. Typically, the uncertainty is determined by the sensor model.

For PoseGraph (2-D), the information matrix is a six-element vector. The default is [1 0 0 1 0 1].

For PoseGraph3D, the information matrix is a 21-element vector. The default is [1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 1 0 1].

fromNodeID — Node to attach from
positive integer

Node to attach from, specified as a positive integer. This integer corresponds to the node ID of a node in `poseGraph`. When specified without `toNodeID`, `addRelativePose` creates a new node and adds an edge between the new node and the `fromNodeID` node.

toNodeID — Node to attach to
positive integer

Node to attach to, specified as a positive integer. This integer corresponds to the node ID of a node in `poseGraph`. `addRelativePose` adds an edge between this node and the `fromNodeID` node.

Output Arguments

edge — Added edge
two-element vector

Added edge, returned as a two-element vector. An edge is defined by the IDs of the two nodes that it connects with a relative pose.

edgeID — ID of added edge
positive integer

ID of added edge, returned as a positive integer.

See Also

Functions
edgeConstraints | edges | findEdgeID | nodes | optimizePoseGraph | removeEdges

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

angdiff

Difference between two angles

Syntax

```
delta = angdiff(alpha,beta)
```

```
delta = angdiff(alpha)
```

Description

`delta = angdiff(alpha,beta)` calculates the difference between the angles `alpha` and `beta`. This function subtracts `alpha` from `beta` with the result wrapped on the interval `[-pi,pi]`. You can specify the input angles as single values or as arrays of angles that have the same number of values.

`delta = angdiff(alpha)` returns the angular difference between adjacent elements of `alpha` along the first dimension whose size does not equal 1. If `alpha` is a vector of length *n*, the first entry is subtracted from the second, the second from the third, etc. The output, `delta`, is a vector of length *n-1*. If `alpha` is an *m*-by-*n* matrix with *m* greater than 1, the output, `delta`, will be a matrix of size *m-1*-by-*n*.

Examples

Calculate Difference Between Two Angles

```
d = angdiff(pi,2*pi)
```

```
d = 3.1416
```

Calculate Difference Between Two Angle Arrays

```
d = angdiff([pi/2 3*pi/4 0],[pi pi/2 -pi])

d = 1×3

    1.5708   -0.7854   -3.1416
```

Calculate Angle Differences of Adjacent Elements

```
angles = [pi pi/2 pi/4 pi/2];
d = angdiff(angles)

d = 1×3

   -1.5708   -0.7854    0.7854
```

Input Arguments

alpha — Angle in radians
scalar | vector | matrix | multidimensional array

Angle in radians, specified as a scalar, vector, matrix, or multidimensional array. This is the angle that is subtracted from `beta` when specified.

Example: `pi/2`

beta — Angle in radians
scalar | vector | matrix | multidimensional array

Angle in radians, specified as a scalar, vector, matrix, or multidimensional array of the same size as `alpha`. This is the angle that `alpha` is subtracted from when specified.

Example: `pi/2`

Output Arguments

`delta` — Difference between two angles
scalar | vector | matrix | multidimensional array

Angular difference between two angles, returned as a scalar, vector, or array. `delta` is wrapped to the interval `[-pi,pi]`.

Extended Capabilities

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

Introduced in R2015a

apply

Transform message entities into target frame

Syntax

```
tfentity = apply(tfmsg,entity)
```

Description

`tfentity = apply(tfmsg,entity)` applies the transformation represented by the `'TransformStamped'` ROS message to the input message object `entity`.

This function determines the message type of `entity` and apples the appropriate transformation method to it. If the object cannot handle a particular message type, then MATLAB displays an error message.

If you only want to use the most current transformation, call `transform` instead. If you want to store a transformation message for later use, call`getTransform` and then call `apply`.

Examples

Apply A Transformation To A Point

Connect to a ROS network to get a `TransformStamped` ROS message. Specify the IP address to connect. Create a transformation tree and get the transformation between desired frames.

```
rosinit('192.168.203.129')
tftree = rostf;
pause(1);
tform = getTransform(tftree,'base_link','camera_link',...
                     rostime('now'),'Timeout',5);
```

Initializing global node /matlab_global_node_77541 with NodeURI http://192.168.203.1:58

Create a ROS Point message and apply the transformation. You could also get point messages off the ROS network.

```
pt = rosmessage('geometry_msgs/PointStamped');
pt.Header.FrameId = 'camera_link';
pt.Point.X = 3;
pt.Point.Y = 1.5;
pt.Point.Z = 0.2;

tfpt = apply(tform,pt);
```

Shut down ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_77541 with NodeURI http://192.168.203.1:5
```

Input Arguments

`tfmsg` — Transformation message
TransformStamped ROS message handle

Transformation message, specified as a `TransformStamped` ROS message handle. The `tfmsg` is a ROS message of type: `geometry_msgs/TransformStamped`.

`entity` — ROS message
Message object handle

ROS message, specified as a `Message` object handle.

Supported messages are:

- `geometry_msgs/PointStamped`
- `geometry_msgs/PoseStamped`
- `geometry_msgs/PointCloud2Stamped`
- `geometry_msgs/QuaternionStamped`
- `geometry_msgs/Vector3Stamped`

Output Arguments

`tfentity` — Transformed ROS message
Message object handle

Transformed ROS message, returned as a Message object handle.

See Also

getTransform | transform

Introduced in R2015a

axang2quat

Convert axis-angle rotation to quaternion

Syntax

```
quat = axang2quat(axang)
```

Description

`quat = axang2quat(axang)` converts a rotation given in axis-angle form, `axang`, to quaternion, `quat`.

Examples

Convert Axis-Angle Rotation to Quaternion

```
axang = [1 0 0 pi/2];
quat = axang2quat(axang)
```

```
quat = 1×4

    0.7071    0.7071         0         0
```

Input Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: [1 0 0 pi/2]

Output Arguments

quat — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: [0.7071 0.7071 0 0]

Extended Capabilities

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

See Also
quat2axang

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

axang2rotm

Convert axis-angle rotation to rotation matrix

Syntax

```
rotm = axang2rotm(axang)
```

Description

`rotm = axang2rotm(axang)` converts a rotation given in axis-angle form, `axang`, to an orthonormal rotation matrix, `rotm`. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Examples

Convert Axis-Angle Rotation to Rotation Matrix

```
axang = [0 1 0 pi/2];
rotm = axang2rotm(axang)

rotm = 3×3

    0.0000         0    1.0000
         0    1.0000         0
   -1.0000         0    0.0000
```

Input Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1; 0 1 0; -1 0 0]`

Extended Capabilities

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

See Also
`rotm2axang`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

axang2tform

Convert axis-angle rotation to homogeneous transformation

Syntax

```
tform = axang2tform(axang)
```

Description

`tform = axang2tform(axang)` converts a rotation given in axis-angle form, `axang`, to a homogeneous transformation matrix, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Axis-Angle Rotation to Homogeneous Transformation

```
axang = [1 0 0 pi/2];
tform = axang2tform(axang)

tform = 4×4

    1.0000         0         0         0
         0    0.0000   -1.0000         0
         0    1.0000    0.0000         0
         0         0         0    1.0000
```

Input Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the transformation matrix, premultiply it with the coordinates to be formed (as opposed to postmultiplying).

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Extended Capabilities

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

See Also
`tform2axang`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

buildMap

Build occupancy grid from lidar scans

Syntax

```
map = buildMap(scans,poses,mapResolution,maxRange)
```

Description

`map = buildMap(scans,poses,mapResolution,maxRange)` creates a `robotics.OccupancyGrid` map by inserting lidar `scans` at the given `poses`. Specify the resolution of the resulting map, `mapResolution`, and the maximum range of the lidar sensor, `maxRange`.

Examples

Build Occupancy Map from Lidar Scans and Poses

The `buildMap` function takes in lidar scan readings and associated poses to build an occupancy grid. as `lidarScan` objects and associated `[x y theta]` poses to build an `robotics.OccupancyGrid`.

Load scan and pose estimates collected from sensors on a robot in a parking garage. The data collected is correlated using a `robotics.LidarSLAM` algorithm, which performs scan matching to associate scans and adjust poses over the full robot trajectory. Check to make sure scans and poses are the same length.

```
load scansAndPoses.mat
length(scans) == length(poses)

ans = logical
   1
```

Build the map. Specify the scans and poses in the buildMap function and include the desired map resolution (10 cells per meter) and the max range of the lidar (19.2 meters). Each scan is added at the associated poses and probability values in the occupancy grid are updated.

```
occGrid = buildMap(scans,poses,10,19.2);
figure
show(occGrid)
title('Occupancy Map of Garage')
```


Occupancy Map of Garage

Perform SLAM Using Lidar Scans

Use a `LidarSLAM` object to iteratively add and compare lidar scans and build an optimized pose graph of the robot trajectory. To get an occupancy map from the associated poses and scans, use the `buildMap` function.

Load Data and Set Up SLAM Algorithm

Load a cell array of `lidarScan` objects. The lidar scans were collected in a parking garage on a Husky® robot from ClearPath Robotics®. Typically, lidar scans are taken at a high frequency and each scan is not needed for SLAM. Therefore, down sample the scans by selecting only every 40th scan.

```
load garage_fl1_southend.mat scans
scans = scans(1:40:end);
```

To set up the SLAM algorithm, specify the lidar range, map resolution, loop closure threshold, and search radius. Tune these parameters for your specific robot and environment. Create the `LidarSLAM` object with these parameters.

```
maxRange = 19.2; % meters
resolution = 10; % cells per meter

slamObj = robotics.LidarSLAM(resolution,maxRange);
slamObj.LoopClosureThreshold = 360;
slamObj.LoopClosureSearchRadius = 8;
```

Add Scans Iteratively

Using a `for` loop, add scans to the SLAM object. The object uses scan matching to compare each added scan to previously added ones. To improve the map, the object optimizes the pose graph whenever it detects a loop closure. Every 10 scans, display the stored poses and scans.

```
for i = 1:numel(scans)

    addScan(slamObj,scans{i});

    if rem(i,10) == 0
        show(slamObj);
    end
end
```

View Occupancy Map

After adding all the scans to the SLAM object, build an `robotics.OccupancyGrid` map by calling `buildMap` with the scans and poses. Use the same map resolution and max range you used with the SLAM object.

```
[scansSLAM,poses] = scansAndPoses(slamObj);
occGrid = buildMap(scansSLAM,poses,resolution,maxRange);
figure
show(occGrid)
title('Occupancy Map of Garage')
```

2-21

- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Input Arguments

scans — Lidar scans
cell array of `lidarScan` objects

Lidar scans used to build the map, specified as a cell array of `lidarScan` objects.

poses — Poses of lidar scans
n-by-3 matrix

Poses of lidar scans, specified as an *n*-by-3 matrix. Each row is an `[x y theta]` vector representing the *xy*-position and orientation angle of a scan.

mapResolution — Resolution of occupancy grid
positive integer

Resolution of the output `robotics.OccupancyGrid` map, specified as a positive integer in cells per meter.

maxRange — Maximum range of lidar sensor
positive scalar

Maximum range of lidar sensor, specified as a positive scalar in meters. Points in the `scans` outside this range are ignored.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`'  '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `['MapWidth',10]`

MapWidth — Width of occupancy grid
positive scalar

Width of the occupancy grid, specified as the comma-separated pair consisting of `'MapWidth'` and a positive scalar. If this value is not specified, the map is automatically scaled to fit all laser scans.

MapHeight — Height of occupancy grid
positive scalar

Height of occupancy grid, specified as the comma-separated pair consisting of `'MapHeight'` and a positive scalar. If this value is not specified, the map is automatically scaled to fit all laser scans.

Output Arguments

map — Occupancy grid
`robotics.OccupancyGrid` object

Occupancy grid, returned as a `robotics.OccupancyGrid` object.

See Also

Functions
`lidarScan` | `matchScans` | `matchScansGrid` | `transformScan`

Classes
`robotics.LidarSLAM` | `robotics.OccupancyGrid`

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

call

Call the ROS service server and receive a response

Syntax

```
response = call(serviceclient)
response = call(serviceclient,requestmsg)
response = call( ___ ,Name,Value)
```

Description

`response = call(serviceclient)` sends a default service request message and waits for a service `response`. The default service request message is an empty message of type `serviceclient.ServiceType`.

`response = call(serviceclient,requestmsg)` specifies a service request message, `requestmsg`, to be sent to the service.

`response = call( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments, using any of the arguments from the previous syntaxes. `Name` must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Examples

Call Service Client with Default Message

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://ah-sradford:11311/.
Initializing global node /matlab_global_node_03934 with NodeURI http://ah-sradford:613(
```

Set up a service server and client.

```
server = rossvcserver('/test', 'std_srvs/Empty', @exampleHelperROSEmptyCallback);
client = rossvcclient('/test');
```

Call service server with default message.

```
response = call(client)
```

A service client is calling

```
response =

  ROS EmptyResponse message with properties:

    MessageType: 'std_srvs/EmptyResponse'

  Use showdetails to show the contents of the message
```

Shut down ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_03934 with NodeURI http://ah-sradford:61
Shutting down ROS master on http://ah-sradford:11311/.
```

Call for Response Using Specific Request Message

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://ah-sradford:11311/.
Initializing global node /matlab_global_node_18061 with NodeURI http://ah-sradford:6181
```

Set up a service server and client. This server calculates the sum of two integers and is based on a ROS service tutorial.

```
sumserver = rossvcserver('/sum','roscpp_tutorials/TwoInts',@exampleHelperROSSumCallback
sumclient = rossvcclient('/sum');
```

Get the request message for the client and modify the parameters.

```
reqMsg = rosmessage(sumclient);
reqMsg.A = 2;
reqMsg.B = 1;
```

Call service and get response. The response should be the sum of the two integers given in the request message. Wait 5 seconds for the service to timeout.

```
response = call(sumclient,reqMsg,'Timeout',5)
```

```
response =

  ROS TwoIntsResponse message with properties:

    MessageType: 'roscpp_tutorials/TwoIntsResponse'
            Sum: 3

  Use showdetails to show the contents of the message
```

Shut down ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_18061 with NodeURI http://ah-sradford:618
Shutting down ROS master on http://ah-sradford:11311/.
```

Input Arguments

serviceclient — Service client
ServiceClient object handle

Service client, specified as a ServiceClient object handle.

requestmsg — Request message
Message object handle

Request message, specified as a Message object handle. The default message type is serviceclient.ServiceType.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'TimeOut',5`

`TimeOut` — Timeout for service response in seconds
inf (default) | scalar

Timeout for service response in seconds, specified as a comma-separated pair consisting of `'Timeout'` and a scalar. If the service client does not receive a service response and the timeout period elapses, `call` displays an error message and lets MATLAB continue running the current program. The default value of `inf` blocks MATLAB from running the current program until the service client receives a service response.

Output Arguments

`response` — Response message
`Message` object handle

llResponse message sent by the service server, returned as a `Message` object handle.

See Also
`rossvcclient`

Introduced in R2015a

cancelAllGoals

Cancel all goals on action server

Syntax

```
cancelAllGoals(client)
```

Description

cancelAllGoals(client) sends a request from the specified client to the ROS action server to cancel all currently pending or active goals, including goals from other clients.

Examples

Send and Cancel ROS Action Goals

Send and cancel goals for ROS actions. First, setup a ROS action client. Then send a goal message with modified parameters. Finally, cancel your goal and all goals on the action server.

Connect to a ROS network with a specified IP address. Create a ROS action client connected using rosactionclient. Specify the action name. Wait for the client to be connected to the server.

```
rosinit('192.168.154.131')
[actClient,goalMsg] = rosactionclient('/fibonacci');
waitForServer(actClient);
```

Initializing global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5

Send a goal message with modified parameters. Wait for the goal to finish executing.

```
goalMsg.Order = 4;
sendGoalAndWait(actClient,goalMsg)
```

```
Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5]

ans =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [6×1 int32]

  Use showdetails to show the contents of the message
```

Send a new goal message without waiting.

```
goalMsg.Order = 5;
sendGoal(actClient,goalMsg)
```

Cancel the goal on the ROS action client, `actClient`.

```
cancelGoal(actClient)
```

Cancel all the goals on the action server that `actClient` is connected to.

```
cancelAllGoals(actClient)
```

Delete the action client.

```
delete(actClient)
```

Disconnect from the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5

Input Arguments

client — ROS action client
SimpleActionClient object handle

ROS action client, specified as a SimpleActionClient object handle. This simple action
client enables you to track a single goal at a time.

See Also

cancelGoal | rosaction | sendGoal | sendGoalAndWait

Topics

"ROS Actions Overview"
"Move a Turtlebot Robot Using ROS Actions"

Introduced in R2016b

cancelGoal

Cancel last goal sent by client

Syntax

```
cancelGoal(client)
```

Description

`cancelGoal(client)` sends a cancel request for the tracked goal, which is the last one sent to the action server. The specified client sends the request.

If the goal is in the `'active'` state, the server preempts the execution of the goal. If the goal is `'pending'`, it is recalled. If this client has not sent a goal, or if the previous goal was achieved, this function returns immediately.

Examples

Send and Cancel ROS Action Goals

Send and cancel goals for ROS actions. First, setup a ROS action client. Then send a goal message with modified parameters. Finally, cancel your goal and all goals on the action server.

Connect to a ROS network with a specified IP address. Create a ROS action client connected using `rosactionclient`. Specify the action name. Wait for the client to be connected to the server.

```
rosinit('192.168.154.131')
[actClient,goalMsg] = rosactionclient('/fibonacci');
waitForServer(actClient);
```

Initializing global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5

Send a goal message with modified parameters. Wait for the goal to finish executing.

```
goalMsg.Order = 4;
sendGoalAndWait(actClient,goalMsg)

Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5]

ans =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [6×1 int32]

  Use showdetails to show the contents of the message
```

Send a new goal message without waiting.

```
goalMsg.Order = 5;
sendGoal(actClient,goalMsg)
```

Cancel the goal on the ROS action client, `actClient`.

```
cancelGoal(actClient)
```

Cancel all the goals on the action server that `actClient` is connected to.

```
cancelAllGoals(actClient)
```

Delete the action client.

```
delete(actClient)
```

Disconnect from the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5

Input Arguments

client — ROS action client
SimpleActionClient object handle

ROS action client, specified as a SimpleActionClient object handle. This simple action client enables you to track a single goal at a time.

See Also

cancelAllGoals | rosaction | sendGoal | sendGoalAndWait

Topics
"ROS Actions Overview"
"Move a Turtlebot Robot Using ROS Actions"

Introduced in R2016b

canTransform

Verify if transformation is available

Syntax

```
isAvailable = canTransform(tftree,targetframe,sourceframe)
isAvailable = canTransform(tftree,targetframe,sourceframe,
sourcetime)

isAvailable = canTransform(bagSel,targetframe,sourceframe)
isAvailable = canTransform(bagSel,targetframe,sourceframe,
sourcetime)
```

Description

`isAvailable = canTransform(tftree,targetframe,sourceframe)` verifies if a transformation between the source frame and target frame is available at the current time in `tftree`. Create the `tftree` object using `rostf`, which requires a connection to a ROS network.

`isAvailable = canTransform(tftree,targetframe,sourceframe, sourcetime)` verifies if a transformation is available for the source time. If `sourcetime` is outside the buffer window, the function returns `false`.

`isAvailable = canTransform(bagSel,targetframe,sourceframe)` verifies if a transformation is available in a rosbag in `bagSel`. To get the `bagSel` input, load a rosbag using `rosbag`.

`isAvailable = canTransform(bagSel,targetframe,sourceframe, sourcetime)` verifies if a transformation is available in a rosbag for the source time. If `sourcetime` is outside the buffer window, the function returns `false`.

Examples

Send a Transformation to ROS Network

This example shows how to create a transformation and send it over the ROS network.

Create a ROS transformation tree. Use `rosinit` to connect a ROS network. Replace `ipaddress` with your ROS network address.

```
ipaddress = '192.168.203.129';
rosinit(ipaddress)
tftree = rostf;
pause(2)
```

Initializing global node /matlab_global_node_69912 with NodeURI http://192.168.203.1:55

Verify the transformation you want to send over the network does not already exist. `canTransform` returns false if the transformation is not immediately available.

```
canTransform(tftree,'new_frame','base_link')
```

```
ans =

  logical

   0
```

Create a `TransformStamped` message. Populate the message fields with the transformation information.

```
tform = rosmessage('geometry_msgs/TransformStamped');
tform.ChildFrameId = 'new_frame';
tform.Header.FrameId = 'base_link';
tform.Transform.Translation.X = 0.5;
tform.Transform.Rotation.Z = 0.75;
```

Send the transformation over the ROS network.

```
sendTransform(tftree,tform)
```

Verify the transformation is now on the ROS network

```
canTransform(tftree,'new_frame','base_link')
```

```
ans =
```

```
logical

 1
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_69912 with NodeURI http://192.168.203.1:5
```

Get ROS Transformations and Apply to ROS Messages

This example shows how to set up a ROS transformation tree and transform frames based on this information. It uses time-buffered transformations to access transformations at different times.

Create a ROS transformation tree. Use `rosinit` to connect to a ROS network. Replace `ipaddress` with your ROS network address.

```
ipaddress = '192.168.203.129';
rosinit(ipaddress)
tftree = rostf;
pause(1)
```

```
Initializing global node /matlab_global_node_60416 with NodeURI http://192.168.203.1:53
```

Look at the available frames on the transformation tree.

```
tftree.AvailableFrames
```

```
ans =

  36×1 cell array

    {'base_footprint'          }
    {'base_link'               }
    {'camera_depth_frame'       }
    {'camera_depth_optical_frame'}
    {'camera_link'             }
    {'camera_rgb_frame'         }
```

```
{'camera_rgb_optical_frame'  }
{'caster_back_link'          }
{'caster_front_link'         }
{'cliff_sensor_front_link'   }
{'cliff_sensor_left_link'    }
{'cliff_sensor_right_link'   }
{'gyro_link'                 }
{'mount_asus_xtion_pro_link' }
{'odom'                      }
{'plate_bottom_link'         }
{'plate_middle_link'         }
{'plate_top_link'            }
{'pole_bottom_0_link'        }
{'pole_bottom_1_link'        }
{'pole_bottom_2_link'        }
{'pole_bottom_3_link'        }
{'pole_bottom_4_link'        }
{'pole_bottom_5_link'        }
{'pole_kinect_0_link'        }
{'pole_kinect_1_link'        }
{'pole_middle_0_link'        }
{'pole_middle_1_link'        }
{'pole_middle_2_link'        }
{'pole_middle_3_link'        }
{'pole_top_0_link'           }
{'pole_top_1_link'           }
{'pole_top_2_link'           }
{'pole_top_3_link'           }
{'wheel_left_link'           }
{'wheel_right_link'          }
```

Check if the desired transformation is available now. For this example, check for the transformation from `'camera_link'` to `'base_link'`.

```
canTransform(tftree,'base_link','camera_link')
```

```
ans =

  logical

   1
```

Get the transformation for 3 seconds from now. `getTransform` will wait until the transformation becomes available with the specified timeout.

```
desiredTime = rostime('now') + 3;
tform = getTransform(tftree,'base_link','camera_link',...
                     desiredTime,'Timeout',5);
```

Create a ROS message to transform. Messages could also be retrieved off the ROS network.

```
pt = rosmessage('geometry_msgs/PointStamped');
pt.Header.FrameId = 'camera_link';
pt.Point.X = 3;
pt.Point.Y = 1.5;
pt.Point.Z = 0.2;
```

Transform the ROS message to the `'base_link'` frame using the desired time saved from before.

```
tfpt = transform(tftree,'base_link',pt,desiredTime);
```

Optional: You can also use `apply` with the stored `tform` to apply this transformation to the `pt` message.

```
tfpt2 = apply(tform,pt);
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_60416 with NodeURI http://192.168.203.1:5
```

Get Transformations from rosbag File

Get transformations from rosbag (`.bag`) files by loading the rosbag and checking the available frames. From these frames, use `getTransform` to query the transformation between two coordinate frames.

Load the rosbag.

```
bag = rosbag('ros_turtlesim.bag');
```

Get a list of available frames.

```
frames = bag.AvailableFrames;
```

Get the latest transformation between two coordinate frames.

```
tf = getTransform(bag,'world',frames{1});
```

Check for a transformation available at a specific time and retrieve the transformation. Use `canTransform` to check if the transformation is available. Specify the time using `rostime`.

```
tfTime = rostime(bag.StartTime + 1);
if (canTransform(bag,'world',frames{1},tfTime))
    tf2 = getTransform(bag,'world',frames{1},tfTime);
end
```

Input Arguments

tftree — ROS transformation tree
TransformationTree object handle

ROS transformation tree, specified as a `TransformationTree` object handle. Create a transformation tree by calling the `rostf` function.

bagSel — Selection of rosbag messages
BagSelection object handle

Selection of rosbag messages, specified as a `BagSelection` object handle. To create a selection of rosbag messages, use `rosbag`.

targetframe — Target coordinate frame
character vector

Target coordinate frame, specified as a character vector. You can view the available frames for transformation calling `tftree.AvailableFrames` or `bagSel.AvailableFrames`.

sourceframe — Initial coordinate frame
character vector

Initial coordinate frame, specified as a character vector. You can view the available frames for transformation by calling `tftree.AvailableFrames` or `bagSel.AvailableFrames`.

`sourcetime` — ROS or system time
scalar | `Time` object handle

ROS or system time, specified as a scalar or `Time` object handle. The scalar input is converted to a `Time` object using `rostime`.

Output Arguments

`isAvailable` — Indicator if transform exists
boolean

Indicator if transform exists, returned as a boolean. The function returns false if:

- `sourcetime` is outside the buffer window for a `tftree` object.
- `sourcetime` is outside the time of the `bagSel` object.
- `sourcetime` is in the future.
- The transformation is not published yet.

See Also

getTransform | rosbag | rostf | transform | waitForTransform

Introduced in R2016b

cart2hom

Convert Cartesian coordinates to homogeneous coordinates

Syntax

```
hom = cart2hom(cart)
```

Description

`hom = cart2hom(cart)` converts a set of points in Cartesian coordinates to homogeneous coordinates.

Examples

Convert 3-D Cartesian Points to Homogeneous Coordinates

```
c = [0.8147 0.1270 0.6324; 0.9058 0.9134 0.0975];
h = cart2hom(c)
```

h = *2×4*

```
    0.8147    0.1270    0.6324    1.0000
    0.9058    0.9134    0.0975    1.0000
```

Input Arguments

cart — Cartesian coordinates
n-by-(*k*–1) matrix

Cartesian coordinates, specified as an *n*-by-(*k*–1) matrix, containing *n* points. Each row of `cart` represents a point in (*k*–1)-dimensional space. *k* must be greater than or equal to 2.

Example: [0.8147 0.1270 0.6324; 0.9058 0.9134 0.0975]

Output Arguments

hom — Homogeneous points
n-by-*k* matrix

Homogeneous points, returned as an *n*-by-*k* matrix, containing *n* points. *k* must be greater than or equal to 2.

Example: [0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5]

Extended Capabilities

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

See Also
hom2cart

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

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]))
classUnderlying(qSingle)

qSingle =

  quaternion

    1 + 2i + 3j + 4k
```

```
ans =

    'single'


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

qDouble =

  quaternion


    1 + 2i + 3j + 4k


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

aS =

  single

      1


bS =

  single

      2


cS =
```

```
  single

     3


dS =

  single

     4


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`

See Also

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

Quaternions are four-part hyper-complex numbers. The `quaternion` class encapsulates the four parts into a single representation. You can use the `compact` function to convert an array of quaternions to an *N*-by-4 matrix of quaternion parts. The number of rows, *N*, is the total number of quaternions, and the four columns correspond to the four quaternion parts.

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

```
randomParts = randn(1,4)
quat = quaternion(randomParts)
quatParts = compact(quat)
```

```
randomParts =

    0.5377    1.8339   -2.2588    0.8622
```

```
quat =

  quaternion

     0.53767 +  1.8339i -  2.2588j + 0.86217k


quatParts =

    0.5377    1.8339   -2.2588    0.8622
```

The `compact` function always outputs an *N*-by-4 matrix, where *N* is the total number of quaternions in the input argument. 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])]
quatArrayParts = compact(quatArray)


quatArray =

  2x2 quaternion array


      1 +  2i +  3j +  4k       9 + 10i + 11j + 12k
      5 +  6i +  7j +  8k      13 + 14i + 15j + 16k


quatArrayParts =

      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`

See Also

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

```
q =

  quaternion

    0.87727 + 0.29242i + 0.29242j + 0.24369k

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`

See Also

Introduced in R2018a

ctranspose, '

Complex conjugate transpose of quaternion

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))
quatTransposed = quat'
```

```
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 =
```

```
    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))]
quatTransposed = quat'


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 =

  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`

See Also

Introduced in R2018a

definition

Retrieve definition of ROS message type

Syntax

```
def = definition(msg)
```

Description

`def = definition(msg)` returns the ROS definition of the message type associated with the message object, `msg`. The details of the message definition include the structure, property data types, and comments from the authors of that specific message.

Examples

Access ROS Message Definition for Message

Create a `Point` Message.

```
point = rosmessage('geometry_msgs/Point');
```

Access the definition.

```
def = definition(point)

def =
    '% This contains the position of a point in free space
     double X
     double Y
     double Z
     '
```

Input Arguments

`msg` — ROS message
Message object handle

ROS message, specified as a Message object handle. This message can be created using the rosmessage function.

Output Arguments

`def` — Details of message definition
character vector

Details of the information inside the ROS message definition, returned as a character vector.

See Also

rosmessage | rosmsg

Introduced in R2015a

del

Delete a ROS parameter

Syntax

```
del(ptree,paramname)
del(ptree,namespace)
```

Description

del(ptree,paramname) deletes a parameter with name paramname from the parameter tree, ptree. The parameter is also deleted from the ROS parameter server. If the specified paramname does not exist, the function displays an error.

del(ptree,namespace) deletes from the parameter tree all parameter values under the specified namespace.

Examples

Delete Parameter on ROS Master

Connect to the ROS network. Create a parameter tree and a 'MyParam' parameter. Check that the parameter exists.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_16209 with NodeURI http://bat5811win64:572
```

```
ptree = rosparam;
set(ptree,'MyParam','test')
has(ptree,'MyParam')
```

```
ans = logical
   1
```

Delete the parameter. Verify it was deleted. Shut down the ROS network.

```
del(ptree,'MyParam')
has(ptree,'MyParam')

ans = logical
   0
```

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_16209 with NodeURI http://bat5811win64:5
Shutting down ROS master on http://bat5811win64:11311/.
```

Input Arguments

ptree — Parameter tree
ParameterTree object handle

Parameter tree, specified as a `ParameterTree` object handle. Create this object using the `rosparam` function.

paramname — ROS parameter name
character vector

ROS parameter name, specified as a character vector. This character vector must match the parameter name exactly.

namespace — ROS parameter namespace
character vector

ROS parameter namespace, specified as a character vector. All parameter names starting with this character vector are listed when calling `rosparam('list',namespace)`.

See Also
has | rosparam | set

Introduced in R2015a

deleteFile

Delete file from device

Syntax

```
deleteFile(device,filename)
```

Description

deleteFile(device,filename) deletes the specified file from the ROS device.

Examples

Put, Get, and Delete Files on ROS Device

Put a file from your host computer onto a ROS device, get it back, and then delete it.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.154.131','user','password');
```

Put a new text file that is in the MATLAB® current folder onto the ROS device. The destination folder must exist.

```
putFile(d,'test_file.txt','/home/user/test_folder')
```

Get a text file from the ROS device. You can get any file, not just ones added from MATLAB®. By default, the file is added to the MATLAB current folder.

```
getFile(d,'/home/user/test_folder/test_file.txt')
```

Delete the text file on the ROS device.

```
deleteFile(d,'/home/user/test_folder/test_file.txt')
```

Put, Get, and Delete Files on ROS Device Using Wildcards

Put a file from your host computer onto a ROS device, get it back, and then delete it. Use wildcards to search for all matching files.

Note: You must have a valid ROS device to connect to at the IP address specified in the example.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.203.129','user','password');
```

Put all text files at the specified path onto the ROS device. The destination folder must exist.

```
putFile(d,'C:/MATLAB/*.txt','/home/user/test_folder')
```

Get all text files from the ROS device. You can get any files, not just ones added from MATLAB®. By default, the files are added to the MATLAB current folder.

```
getFile(d,'/home/user/test_folder/*.txt')
```

Delete all text files on the ROS device at the specified folder.

```
deleteFile(d,'/home/user/test_folder/*.txt')
```

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a `rosdevice` object.

filename — File to delete
character vector

File to delete, specified as a character vector. When you specify the file name, you can use path information and wildcards.

Example: '/home/user/image.jpg'

Example: '/home/user/*.jpg'

Data Types: cell

See Also

dir | getFile | openShell | putFile | rosdevice | system

Introduced in R2016b

dir

List folder contents on device

Syntax

```
dir(device,folder)
clist = dir(device,folder)
```

Description

dir(device,folder) lists the files in a folder on the ROS device. Wildcards are supported.

clist = dir(device,folder) stores the list of files as a structure

Examples

View Folder Contents on ROS Device

Connect to a ROS device and list the contents of a folder.

Connect to a ROS device. Specify the device address, username, and password of your ROS device.

```
d = rosdevice('192.168.154.131','user','password');
```

Get the folder list of a Catkin workspace on your ROS device. View the folder as a table.

```
flist = dir(d,'/home/user/catkin_ws_test/');
ftable = struct2table(flist)
```

```
ftable =
```

name	folder	isdir	bytes

`'.'`	`'/home/user/catkin_ws_test'`	true	0
`'..'`	`'/home/user/catkin_ws_test'`	true	0
`'.catkin_workspace'`	`'/home/user/catkin_ws_test'`	false	98
`'build'`	`'/home/user/catkin_ws_test'`	true	0
`'devel'`	`'/home/user/catkin_ws_test'`	true	0
`'robotcontroller2_node.log'`	`'/home/user/catkin_ws_test'`	false	75
`'robotcontroller_node.log'`	`'/home/user/catkin_ws_test'`	false	75
`'src'`	`'/home/user/catkin_ws_test'`	true	0

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a `rosdevice` object.

folder — Folder name
character vector

Name of the folder to list the contents of, specified as a character vector.

Output Arguments

clist — Contents list
structure

Contents list, returned as a structure. The structure contains these fields:

- `name` — File name (`char`)
- `folder` — Absolute path (`char`)
- `bytes` — Size of the file in bytes (`double`)
- `isdir` — Indicator of whether `name` is a folder (`logical`)

See Also
deleteFile | getFile | openShell | putFile | rosdevice | system

Introduced in R2016b

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

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

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

```
q = quaternion(deg2rad([0,0,0]),'euler','zyx','frame')
qArray = quaternion(deg2rad([0,45,0;0,90,0;0,180,0;0,-90,0;0,-45,0]),'euler','zyx','fr

quaternionDistance = rad2deg(dist(q,qArray))


q =

  quaternion

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

```
qArray =

  5x1 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 =

    45.0000
    90.0000
   180.0000
    90.0000
    45.0000
```

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(deg2rad(angles1),'euler','zyx','frame');
qVector2 = quaternion(deg2rad(angles2),'euler','zyx','frame');

rad2deg(dist(qVector1,qVector2))


ans =

    6.0000
    6.0827
    6.0827
```

```
6.0287
```

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:

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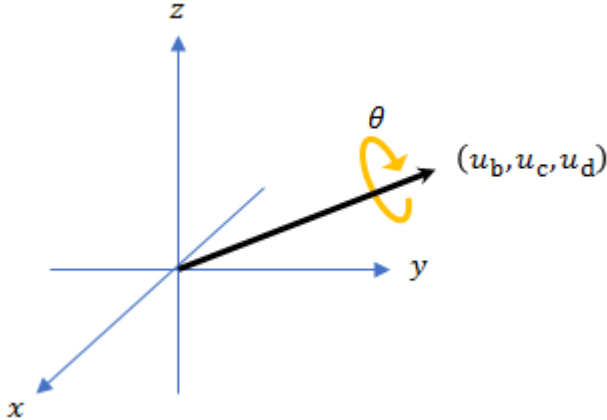
Given a quaternion in the form, $q \; = \; a \; + \; b\mathrm{i} \; + \; c\mathrm{j} \; + \; d\mathrm{k}$, where a is the real part, you can solve for θ_q: $\theta_q \; = \; 2 \cos^{-1}(a)$.

Consider two quaternions, p and q, and the product $z \; = \; p \; {}^\star \; \mathrm{conjugate}(q)$. 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

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

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

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

See Also

Introduced in R2018a

edgeConstraints

Package: robotics

Edge constraints in pose graph

Syntax

```
relPoses = edgeConstraints(poseGraph)
[relPoses,infoMatrices] = edgeConstraints(poseGraph)
[relPoses,infoMatrices] = edgeConstraints(poseGraph,edgeIDs)
```

Description

`relPoses = edgeConstraints(poseGraph)` lists all edge constraints in the specified pose graph as a relative pose.

`[relPoses,infoMatrices] = edgeConstraints(poseGraph)` also returns the information matrices for each edge. The information matrix is the inverse of the covariance of the pose measurement.

`[relPoses,infoMatrices] = edgeConstraints(poseGraph,edgeIDs)` returns edge constraints for the specified edge IDs.

Input Arguments

poseGraph — Pose graph
PoseGraph object | PoseGraph3D object

Pose graph, specified as a `PoseGraph` or `PoseGraph3D` object.

edgeIDs — Edge IDs
vector of positive integers

Edge IDs, specified as a vector of positive integers.

Output Arguments

`relPoses` — Relative poses measured between nodes
n-by-3 matrix | *n*-by-7 matrix

Relative poses measured between nodes, returned as an *n*-by-3 matrix or *n*-by-7 matrix.

For `PoseGraph` (2-D), each row is an `[x y theta]` vector, which defines the relative *xy*-position and orientation angle, `theta`, of a pose in the graph.

For `PoseGraph3D`, each row is an `[x y z qw qx qy qz]` vector, which defines the relative *xyz*-position and quaternion orientation, `[qw qx qy qz]`, of a pose in the graph.

Note Many other sources for 3-D pose graphs, including `.g2o` formats, specify the quaternion orientation in a different order, for example, `[qx qy qz qw]`. Check the source of your pose graph data before adding nodes to your `PoseGraph3D` object.

`infoMatrices` — Information matrices
n-by-6 matrix | *n*-by-21 matrix

Information matrices, specified in compact form as a *n*-by-6 or *n*-by-21 matrix, where *n* is the number of poses in the pose graph.

Each row is a vector that contains the elements of the upper triangle of the square information matrix. The information matrix is the inverse of the covariance of the pose and represents the uncertainty of the measurement. If the pose vector is `[x y theta]`, the covariance is a 3-by-3 matrix of pairwise covariance calculations. Typically, the uncertainty is determined by the sensor model.

For `PoseGraph` (2-D), each information matrix is a six-element vector. The default is `[1 0 0 1 0 1]`.

For `PoseGraph3D`, each information matrix is a 21-element vector. The default is `[1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 1 0 1]`.

See Also

Functions
addRelativePose | edges | findEdgeID | nodes | optimizePoseGraph | removeEdges

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

edges

Package: robotics

Edges in pose graph

Syntax

```
edges = edges(poseGraph)
edges = edges(poseGraph,edgeIDs)
```

Description

`edges = edges(poseGraph)` returns all edges in the specified pose graph as a list of node ID pairs.

`edges = edges(poseGraph,edgeIDs)` returns edges corresponding to the specified edge IDs.

Input Arguments

poseGraph — Pose graph
PoseGraph object | PoseGraph3D object

Pose graph, specified as a `PoseGraph` or `PoseGraph3D` object.

edgeIDs — Edge IDs
vector of positive integers

Edge IDs, specified as a vector of positive integers.

Output Arguments

edges — Edges in pose graph
n-by-2 matrix

Edges in pose graph, returned as *n*-by-2 matrix that lists the IDs of the two nodes that each edge connects.

See Also

Functions
addRelativePose | edgeConstraints | findEdgeID | nodes | optimizePoseGraph
| removeEdges

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

eul2quat

Convert Euler angles to quaternion

Syntax

```
quat = eul2quat(eul)
quat = eul2quat(eul,sequence)
```

Description

`quat = eul2quat(eul)` converts a given set of Euler angles, `eul`, to the corresponding quaternion, `quat`. The default order for Euler angle rotations is `'ZYX'`.

`quat = eul2quat(eul,sequence)` converts a set of Euler angles into a quaternion. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `'ZYX'`.

Examples

Convert Euler Angles to Quaternion

```
eul = [0 pi/2 0];
qZYX = eul2quat(eul)

qZYX = 1×4

    0.7071         0    0.7071         0
```

Convert Euler Angles to Quaternion Using Default ZYZ Axis Order

```
eul = [pi/2 0 0];
qZYZ = eul2quat(eul,'ZYZ')
```

```
qZYZ = 1×4

    0.7071         0         0    0.7071
```

Input Arguments

eul — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, specified as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

sequence — Axis rotation sequence
`'ZYX'` (default) | `'ZYZ'` | `'XYZ'`

Axis rotation sequence for the Euler angles, specified as one of these character vectors:

- `'ZYX'` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `'ZYZ'` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `'XYZ'` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Output Arguments

quat — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Extended Capabilities

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

See Also
quat2eul | quaternion

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

eul2rotm

Convert Euler angles to rotation matrix

Syntax

```
rotm = eul2rotm(eul)
rotm = eul2rotm(eul,sequence)
```

Description

`rotm = eul2rotm(eul)` converts a set of Euler angles, `eul`, to the corresponding rotation matrix, `rotm`. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying). The default order for Euler angle rotations is `'ZYX'`.

`rotm = eul2rotm(eul,sequence)` converts Euler angles to a rotation matrix, `rotm`. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `'ZYX'`.

Examples

Convert Euler Angles to Rotation Matrix

```
eul = [0 pi/2 0];
rotmZYX = eul2rotm(eul)

rotmZYX = 3×3

    0.0000         0    1.0000
         0    1.0000         0
   -1.0000         0    0.0000
```

Convert Euler Angles to Rotation Matrix Using ZYZ Axis Order

```
eul = [0 pi/2 pi/2];
rotmZYZ = eul2rotm(eul,'ZYZ')

rotmZYZ = 3×3

    0.0000   -0.0000    1.0000
    1.0000    0.0000         0
   -0.0000    1.0000    0.0000
```

Input Arguments

eul — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, specified as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

sequence — Axis rotation sequence
`'ZYX'` (default) | `'ZYZ'` | `'XYZ'`

Axis rotation sequence for the Euler angles, specified as one of these character vectors:

- `'ZYX'` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `'ZYZ'` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `'XYZ'` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Output Arguments

rotm — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1; 0 1 0; -1 0 0]`

Extended Capabilities

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

See Also
`rotm2eul`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

eul2tform

Convert Euler angles to homogeneous transformation

Syntax

```
eul = eul2tform(eul)
tform = eul2tform(eul,sequence)
```

Description

`eul = eul2tform(eul)` converts a set of Euler angles, `eul`, into a homogeneous transformation matrix, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying). The default order for Euler angle rotations is `'ZYX'`.

`tform = eul2tform(eul,sequence)` converts Euler angles to a homogeneous transformation. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `'ZYX'`.

Examples

Convert Euler Angles to Homogeneous Transformation Matrix

```
eul = [0 pi/2 0];
tformZYX = eul2tform(eul)

tformZYX = 4×4

    0.0000         0    1.0000         0
         0    1.0000         0         0
   -1.0000         0    0.0000         0
         0         0         0    1.0000
```

Convert Euler Angles to Homogeneous Transformation Matrix Using ZYZ Axis Order

```
eul = [0 pi/2 pi/2];
tformZYZ = eul2tform(eul,'ZYZ')

tformZYZ = 4×4

    0.0000   -0.0000    1.0000         0
    1.0000    0.0000         0         0
   -0.0000    1.0000    0.0000         0
         0         0         0    1.0000
```

Input Arguments

eul — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, specified as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: [0 0 1.5708]

sequence — Axis rotation sequence
'ZYX' (default) | 'ZYZ' | 'XYZ'

Axis rotation sequence for the Euler angles, specified as one of these character vectors:

- 'ZYX' (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- 'ZYZ' – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- 'XYZ' – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Output Arguments

tform — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Extended Capabilities

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

See Also
`tform2eul`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

euler

Convert quaternion to Euler angles

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

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

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

```
eul =

        0        0    1.5708
```

Euler angles are returned in radians. Convert the Euler angle to degrees.

```
rad2deg(eul)
```

```
ans =
```

```
       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 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.

Point Rotation
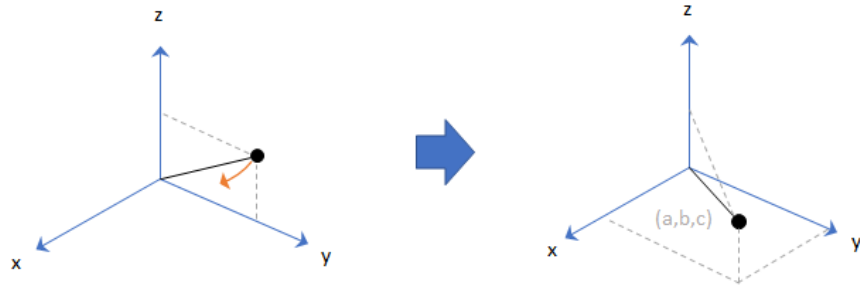
Frame Rotation
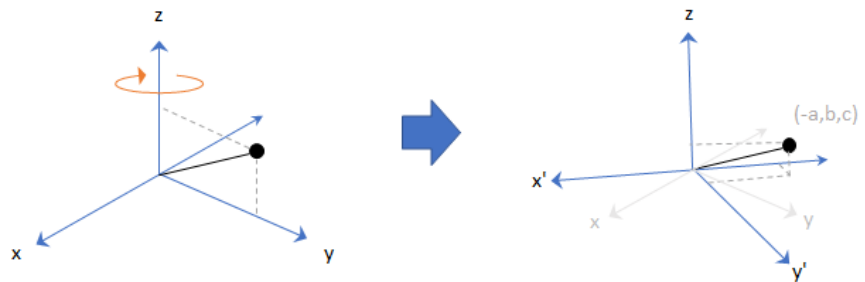
Data Types: char | string

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

See Also

Introduced in R2018a

findEdgeID

Package: robotics

Find edge ID of edge

Syntax

```
edgeID = findEdgeID(poseGraph,edge)
```

Description

`edgeID = findEdgeID(poseGraph,edge)` finds the edge ID for a specified edge. Edges are defined by the IDs of the two nodes that connect them.

Input Arguments

poseGraph — Pose graph
PoseGraph object | PoseGraph3D object

Pose graph, specified as a `PoseGraph` or `PoseGraph3D` object.

edge — Edge in pose graph
two-element vector

Edge in pose graph, specified as a two-element vector that lists the IDs of the two nodes that the edge connects.

Output Arguments

edgeID — Edge ID
positive integer

Edge IDs, returned as a positive integer.

See Also

Functions
addRelativePose | edgeConstraints | edges | nodes | optimizePoseGraph | removeEdges

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

get

Get ROS parameter value

Syntax

```
pvalue = get(ptree)
pvalue = get(ptree,paramname)
pvalue = get(ptree,namespace)
```

Description

`pvalue = get(ptree)` returns a dictionary of parameter values under the root namespace: `/`. The dictionary is stored in a structure.

`pvalue = get(ptree,paramname)` gets the value of the parameter with the name `paramname` from the parameter tree object `ptree`.

`pvalue = get(ptree,namespace)` returns a dictionary of parameter values under the specified namespace.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed.

- 32-bit integer — `int32`
- boolean — `logical`
- double — `double`
- string — character vector (`char`)
- list — cell array (`cell`)
- dictionary — structure (`struct`)

Examples

Set and Get Parameter Value

Create the parameter tree. A ROS network must be available using `rosinit`.

```
rosinit
ptree = rosparam;
```

```
Initializing ROS master on http://bat5811win64:55470/.
Initializing global node /matlab_global_node_22457 with NodeURI http://bat5811win64:554
```

Set a parameter value. You can also use the simplified version without a parameter tree:

```
rosparam set 'DoubleParam' 1.0
```

```
set(ptree,'DoubleParam',1.0)
```

Get the parameter value.

```
get(ptree,'DoubleParam')
```

```
ans =

     1
```

Alternatively, use the simplified versions without using the parameter tree.

```
rosparam set 'DoubleParam' 2.0
rosparam get 'DoubleParam'
```

```
2
```

Disconnect from ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_22457 with NodeURI http://bat5811win64:55
Shutting down ROS master on http://bat5811win64:55470/.
```

Input Arguments

`ptree` — Parameter tree
`ParameterTree` object handle

Parameter tree, specified as a `ParameterTree` object handle. Create this object using the `rosparam` function.

paramname — ROS parameter name
character vector

ROS parameter name, specified as a character vector. This character vector must match the parameter name exactly.

namespace — ROS parameter namespace
character vector

ROS parameter namespace, specified as a character vector. All parameter names starting with this character vector are listed when calling `rosparam('list',namespace)`.

Output Arguments

pvalue — ROS parameter value or dictionary of values
int32 | logical | double | character vector | cell array | structure

ROS parameter value, returned as a supported MATLAB data type. When specifying the `namespace` input argument, `pvalue` is returned as a dictionary of parameter values under the specified namespace. The dictionary is represented in MATLAB as a structure.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed.

- 32-bit integer — `int32`
- boolean — `logical`
- double — `double`
- string — character vector (`char`)
- list — cell array (`cell`)
- dictionary — structure (`struct`)

Limitations

Base64-encoded binary data and iso8601 data from ROS are not supported.

See Also

`rosparam` | `set`

Introduced in R2015a

getParticlesrobotics.MonteCarloLocalization.getParticles

Package: robotics

Get particles from localization algorithm

Syntax

```
[particles,weights] = getParticles(mcl)
```

Description

`[particles,weights] = getParticles(mcl)` returns the current particles used by the `MonteCarloLocalization` object. `particles` is an *n*-by-3 matrix that contains the location and orientation of each particle. Each row has a corresponding weight value specified in `weights`. The number of rows can change with each iteration of the MCL algorithm. Use this method to extract the particles and analyze them separately from the algorithm.

Examples

Get Particles from Monte Carlo Localization Algorithm

Get particles from the particle filter used in the Monte Carlo Localization object.

Create a map and a Monte Carlo localization object.

```
map = robotics.BinaryOccupancyGrid(10,10,20);
mcl = robotics.MonteCarloLocalization(map);
```

Create robot data for the range sensor and pose.

```
ranges = 10*ones(1,300);
ranges(1,130:170) = 1.0;
```

```
angles = linspace(-pi/2,pi/2,300);
odometryPose = [0 0 0];
```

Initialize particles using `step`.

```
[isUpdated,estimatedPose,covariance] = step(mcl,odometryPose,ranges,angles);
```

Get particles from the updated object.

```
[particles,weights] = getParticles(mcl);
```

Input Arguments

`mcl` — `MonteCarloLocalization object`
handle

`robotics.MonteCarloLocalization` object, specified as an object handle.

Output Arguments

`particles` — **Estimation particles**
n-by-3 vector

Estimation particles, returned as an *n*-by-3 vector, `[x y theta]`. Each row corresponds to the position and orientation of a single particle. The length can change with each iteration of the algorithm.

`weights` — **Weights of particles**
n-by-1 vector

Weights of particles, returned as a *n*-by-1 vector. Each row corresponds to the weight of the particle in the matching row of `particles`. These weights are used in the final estimate of the pose of the robot. The length can change with each iteration of the algorithm.

See Also
`robotics.MonteCarloLocalization`

Topics
"Monte Carlo Localization Algorithm"

Introduced in R2016a

getFile

Get file from device

Syntax

```
getFile(device,remoteSource)
getFile(device,remoteSource,localDestination)
```

Description

`getFile(device,remoteSource)` copies the specified file from the ROS device to the MATLAB current folder. Wildcards are supported.

`getFile(device,remoteSource,localDestination)` copies the remote file to a destination path. Specify a file name at the end of the destination path to copy with a custom file name.

Examples

Put, Get, and Delete Files on ROS Device

Put a file from your host computer onto a ROS device, get it back, and then delete it.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.154.131','user','password');
```

Put a new text file that is in the MATLAB® current folder onto the ROS device. The destination folder must exist.

```
putFile(d,'test_file.txt','/home/user/test_folder')
```

Get a text file from the ROS device. You can get any file, not just ones added from MATLAB®. By default, the file is added to the MATLAB current folder.

```
getFile(d,'/home/user/test_folder/test_file.txt')
```

Delete the text file on the ROS device.

```
deleteFile(d,'/home/user/test_folder/test_file.txt')
```

Put, Get, and Delete Files on ROS Device Using Wildcards

Put a file from your host computer onto a ROS device, get it back, and then delete it. Use wildcards to search for all matching files.

Note: You must have a valid ROS device to connect to at the IP address specified in the example.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.203.129','user','password');
```

Put all text files at the specified path onto the ROS device. The destination folder must exist.

```
putFile(d,'C:/MATLAB/*.txt','/home/user/test_folder')
```

Get all text files from the ROS device. You can get any files, not just ones added from MATLAB®. By default, the files are added to the MATLAB current folder.

```
getFile(d,'/home/user/test_folder/*.txt')
```

Delete all text files on the ROS device at the specified folder.

```
deleteFile(d,'/home/user/test_folder/*.txt')
```

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a rosdevice object.

remoteSource — Path and name of file on ROS device
source path

Path and name of the file on the ROS device. Specify the path as a character vector. You can use an absolute path or a relative path from the MATLAB Current Folder. Use the path and file naming conventions of the operating system on your host computer.

Example: `'/home/user/test_folder/test_file.txt'`

Data Types: `char`

localDestination — Destination folder path and optional file name
character vector

Destination folder path and optional file name, specified as a character vector. Specify a file name at the end of the destination path to copy with a custom file name. Use the host computer path and file naming conventions.

Example: `'C:/User/username/test_folder'`

Data Types: `char`

See Also
`deleteFile` | `dir` | `openShell` | `putFile` | `rosdevice` | `system`

Introduced in R2016b

getTransform

Retrieve transformation between two coordinate frames

Note The behavior of `getTransform` changed in R2018a. When using the `tftree` input argument, the function no longer returns an empty transform when the transform is unavailable and no `sourcetime` is specified. If `getTransform` waits for the specified timeout period and the transform is still not available, the function returns an error. The timeout period is 0 by default.

Syntax

```
tf = getTransform(tftree,targetframe,sourceframe)
tf = getTransform(tftree,targetframe,sourceframe,sourcetime)
tf = getTransform( ___ ,'Timeout',timeout)

tf = getTransform(bagSel,targetFrame,sourceframe)
tf = getTransform(bagSel,targetFrame,sourceframe,sourcetime)
```

Description

`tf = getTransform(tftree,targetframe,sourceframe)` returns the latest known transformation between two coordinate frames in `tftree`. Create the `tftree` object using `rostf`, which requires a connection to a ROS network.

Transformations are structured as a 3-D translation (three-element vector) and a 3-D rotation (quaternion).

`tf = getTransform(tftree,targetframe,sourceframe,sourcetime)` returns the transformation from the `tftree` at the given source time. If the transformation is not available at that time, an error is displayed.

`tf = getTransform( ___ ,'Timeout',timeout)` also specifies a timeout period, in seconds, to wait for the transformation to be available. Otherwise, if the transformation doesn't become available in the timeout period, the function returns an error. This option can be combined with the previous syntaxes.

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`tf = getTransform(bagSel,targetFrame,sourceframe)` returns the latest transformation between two frames in the rosbag in `bagSel`. To get the `bagSel` input, load a rosbag using `rosbag`.

`tf = getTransform(bagSel,targetFrame,sourceframe,sourcetime)` returns the transformation at the specified `sourcetime` in the rosbag in `bagSel`.

Examples

Get ROS Transformations and Apply to ROS Messages

This example shows how to set up a ROS transformation tree and transform frames based on this information. It uses time-buffered transformations to access transformations at different times.

Create a ROS transformation tree. Use `rosinit` to connect to a ROS network. Replace `ipaddress` with your ROS network address.

```
ipaddress = '192.168.203.129';
rosinit(ipaddress)
tftree = rostf;
pause(1)
```

```
Initializing global node /matlab_global_node_60416 with NodeURI http://192.168.203.1:53
```

Look at the available frames on the transformation tree.

```
tftree.AvailableFrames
```

```
ans =

  36×1 cell array

    {'base_footprint'          }
    {'base_link'               }
    {'camera_depth_frame'      }
    {'camera_depth_optical_frame'}
    {'camera_link'             }
    {'camera_rgb_frame'        }
    {'camera_rgb_optical_frame' }
```

```
{'caster_back_link'          }
{'caster_front_link'         }
{'cliff_sensor_front_link'   }
{'cliff_sensor_left_link'    }
{'cliff_sensor_right_link'   }
{'gyro_link'                 }
{'mount_asus_xtion_pro_link' }
{'odom'                      }
{'plate_bottom_link'         }
{'plate_middle_link'         }
{'plate_top_link'            }
{'pole_bottom_0_link'        }
{'pole_bottom_1_link'        }
{'pole_bottom_2_link'        }
{'pole_bottom_3_link'        }
{'pole_bottom_4_link'        }
{'pole_bottom_5_link'        }
{'pole_kinect_0_link'        }
{'pole_kinect_1_link'        }
{'pole_middle_0_link'        }
{'pole_middle_1_link'        }
{'pole_middle_2_link'        }
{'pole_middle_3_link'        }
{'pole_top_0_link'           }
{'pole_top_1_link'           }
{'pole_top_2_link'           }
{'pole_top_3_link'           }
{'wheel_left_link'           }
{'wheel_right_link'          }
```

Check if the desired transformation is available now. For this example, check for the transformation from 'camera_link' to 'base_link'.

```
canTransform(tftree,'base_link','camera_link')
```

```
ans =

  logical

   1
```

Get the transformation for 3 seconds from now. `getTransform` will wait until the transformation becomes available with the specified timeout.

```
desiredTime = rostime('now') + 3;
tform = getTransform(tftree,'base_link','camera_link',...
                     desiredTime,'Timeout',5);
```

Create a ROS message to transform. Messages could also be retrieved off the ROS network.

```
pt = rosmessage('geometry_msgs/PointStamped');
pt.Header.FrameId = 'camera_link';
pt.Point.X = 3;
pt.Point.Y = 1.5;
pt.Point.Z = 0.2;
```

Transform the ROS message to the `'base_link'` frame using the desired time saved from before.

```
tfpt = transform(tftree,'base_link',pt,desiredTime);
```

Optional: You can also use `apply` with the stored `tform` to apply this transformation to the `pt` message.

```
tfpt2 = apply(tform,pt);
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_60416 with NodeURI http://192.168.203.1:5
```

Get Buffered Transformations from ROS Network

This example shows how to access time-buffered transformations on the ROS network. Access transformations for specific times and modify the `BufferTime` property based on your desired times.

Create a ROS transformation tree. Use `rosinit` to connect to a ROS network. Replace `ipaddress` with your ROS network address.

```
ipaddress = '192.168.203.129';
rosinit(ipaddress)
```

```
tftree = rostf;
pause(2);
```

Initializing global node /matlab_global_node_29163 with NodeURI http://192.168.203.1:53

Get the transformation from 1 second ago.

```
desiredTime = rostime('now') - 1;
tform = getTransform(tftree,'base_link','camera_link',desiredTime);
```

The transformation buffer time is 10 seconds by default. Modify the BufferTime property of the transformation tree to increase the buffer time and wait for that buffer to fill.

```
tftree.BufferTime = 15;
pause(15);
```

Get the transformation from 12 seconds ago.

```
desiredTime = rostime('now') - 12;
tform = getTransform(tftree,'base_link','camera_link',desiredTime);
```

You can also get transformations at a time in the future. getTransform will wait until the transformation is available. You can also specify a timeout to error out if no transformation is found. This example waits 5 seconds for the transformation at 3 seconds from now to be available.

```
desiredTime = rostime('now') + 3;
tform = getTransform(tftree,'base_link','camera_link',desiredTime,'Timeout',5);
```

Shut down the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_29163 with NodeURI http://192.168.203.1:5

Get Transformations from rosbag File

Get transformations from rosbag (.bag) files by loading the rosbag and checking the available frames. From these frames, use getTransform to query the transformation between two coordinate frames.

Load the rosbag.

```
bag = rosbag('ros_turtlesim.bag');
```

Get a list of available frames.

```
frames = bag.AvailableFrames;
```

Get the latest transformation between two coordinate frames.

```
tf = getTransform(bag,'world',frames{1});
```

Check for a transformation available at a specific time and retrieve the transformation. Use `canTransform` to check if the transformation is available. Specify the time using `rostime`.

```
tfTime = rostime(bag.StartTime + 1);
if (canTransform(bag,'world',frames{1},tfTime))
    tf2 = getTransform(bag,'world',frames{1},tfTime);
end
```

Input Arguments

`tftree` — ROS transformation tree
`TransformationTree` object handle

ROS transformation tree, specified as a `TransformationTree` object handle. You can create a transformation tree by calling the `rostf` function.

`bagSel` — Selection of rosbag messages
`BagSelection` object handle

Selection of rosbag messages, specified as a `BagSelection` object handle. To create a selection of rosbag messages, use `rosbag`.

`targetframe` — Target coordinate frame
character vector

Target coordinate frame, specified as a character vector. You can view the available frames for transformation by calling `tftree.AvailableFrames`.

`sourceframe` — Initial coordinate frame
character vector

Initial coordinate frame, specified as a character vector. You can view the available frames for transformation by calling `tftree.AvailableFrames`.

`sourcetime` — ROS or system time
`Time` object handle

ROS or system time, specified as a `Time` object handle. By default, `sourcetime` is the ROS simulation time published on the `clock` topic. If the `use_sim_time` ROS parameter is set to `true`, `sourcetime` returns the system time. You can create a `Time` object using `rostime`.

`timeout` — Timeout for receiving transform
`0` (default) | scalar in seconds

Timeout for receiving transform, specified as a scalar in seconds. The function returns an error if the timeout is reached and no transform becomes available.

Output Arguments

`tf` — Transformation between coordinate frames
`TransformStamped` object handle

Transformation between coordinate frames, returned as a `TransformStamped` object handle. Transformations are structured as a 3-D translation (three-element vector) and a 3-D rotation (quaternion).

See Also
`canTransform` | `rosbag` | `rostf` | `transform` | `waitForTransform`

Introduced in R2015a

has

Check if ROS parameter name exists

Syntax

```
exists = has(ptree,paramname)
```

Description

`exists = has(ptree,paramname)` checks if the parameter with name `paramname` exists in the parameter tree, `ptree`.

Examples

Check If ROS Parameter Exists

Connect to a ROS network. Create a parameter tree and check for the `'MyParam'` parameter.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_78472 with NodeURI http://bat5811win64:57:
```

```
ptree = rosparam;
has(ptree,'MyParam')
```

```
ans = logical
   0
```

Set the `'MyParam'` parameter and verify it exists. Disconnect from ROS network.

```
set(ptree,'MyParam','test')
has(ptree,'MyParam')
```

```
ans = logical
   1
```

```
rosshutdown
```

Shutting down global node /matlab_global_node_78472 with NodeURI http://bat5811win64:51
Shutting down ROS master on http://bat5811win64:11311/.

Input Arguments

ptree — Parameter tree
ParameterTree object handle

Parameter tree, specified as a `ParameterTree` object handle. Create this object using the `rosparam` function.

paramname — ROS parameter name
character vector

ROS parameter name, specified as a character vector. This character vector must match the parameter name exactly.

Output Arguments

exists — Flag indicating whether the parameter exists
true | false

Flag indicating whether the parameter exists, returned as `true` or `false`.

See Also

get | rosparam | search | set

Introduced in R2015a

hom2cart

Convert homogeneous coordinates to Cartesian coordinates

Syntax

```
cart = hom2cart(hom)
```

Description

`cart = hom2cart(hom)` converts a set of homogeneous points to Cartesian coordinates.

Examples

Convert Homogeneous Points to 3-D Cartesian Points

```
h = [0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5];
c = hom2cart(h)
```

c = *2×3*

```
    0.5570    1.9150    0.3152
    1.0938    1.9298    1.9412
```

Input Arguments

hom — Homogeneous points
n-by-*k* matrix

Homogeneous points, specified as an *n*-by-*k* matrix, containing *n* points. *k* must be greater than or equal to 2.

Example: [0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5]

Output Arguments

`cart` — Cartesian coordinates
n-by-(*k*–1) matrix

Cartesian coordinates, returned as an *n*-by-(*k*–1) matrix, containing *n* points. Each row of `cart` represents a point in (*k*–1)-dimensional space. *k* must be greater than or equal to 2.

Example: `[0.8147 0.1270 0.6324; 0.9058 0.9134 0.0975]`

Extended Capabilities

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

See Also
`cart2hom`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

inforobotics.PurePursuit.info

Package: robotics

Characteristic information about `PurePursuit` object

Syntax

```
controllerInfo = info(controller)
```

Description

`controllerInfo = info(controller)` returns a structure, `controllerInfo`, with additional information about the status of the `PurePursuit` object, `controller`. The structure contains the fields, `RobotPose` and `LookaheadPoint`.

Examples

Get Additional PurePursuit Object Information

Use the `info` method to get more information about a `PurePursuit` object. `info` returns two fields, `RobotPose` and `LookaheadPoint`, which correspond to the current position and orientation of the robot and the point on the path used to compute outputs from the last call of the object.

Create a `PurePursuit` object.

```
pp = robotics.PurePursuit;
```

Assign waypoints.

```
pp.Waypoints = [0 0;1 1];
```

Compute control commands using the `pp` object with the initial pose `[x y theta]` given as the input.

```
[v,w] = pp([0 0 0]);
```

Get additional information.

```
s = info(pp)
```

```
s = struct with fields:
        RobotPose: [0 0 0]
    LookaheadPoint: [0.7071 0.7071]
```

Input Arguments

controller — Pure pursuit controller
PurePursuit object

Pure pursuit controller, specified as a `PurePursuit` object.

Output Arguments

controllerInfo — Information on the PurePursuit object
structure

Information on the `PurePursuit` object, returned as a structure. The structure contains two fields:

- `RobotPose` – A three-element vector in the form `[x y theta]` that corresponds to the *x-y* position and orientation of the robot. The angle, `theta`, is measured in radians with positive angles measured counterclockwise from the *x*-axis.
- `LookaheadPoint`– A two-element vector in the form `[x y]`. The location is a point on the path that was used to compute outputs of the last call to the object.

See Also
robotics.PurePursuit

Topics
"Pure Pursuit Controller"

Introduced in R2015a

importrobot

Import rigid body tree model from URDF file or text

Syntax

```
robot = importrobot(filename)
robot = importrobot(URDFtext)
robot = importrobot(filename,format)
robot = importrobot( ___ ,Name,Value)
```

Description

`robot = importrobot(filename)` returns a `robotics.RigidBodyTree` object by parsing the Unified Robot Description Format (URDF) file specified by `filename`.

`robot = importrobot(URDFtext)` parses the URDF text. Specify `URDFtext` as a character vector.

`robot = importrobot(filename,format)` specifies the type of robot description file for validation. The only supported format is `'urdf'`.

`robot = importrobot( ___ ,Name,Value)` provides additional options specified by `Name,Value` pair arguments.

Examples

Import Robot from URDF File

Import the URDF file as a `robotics.RigidBodyTree` object.

```
robot = importrobot('iiwa14.urdf')

robot =
  RigidBodyTree with properties:
```

```
        NumBodies: 10
           Bodies: {1x10 cell}
             Base: [1x1 robotics.RigidBody]
        BodyNames: {1x10 cell}
         BaseName: 'world'
          Gravity: [0 0 0]
       DataFormat: 'struct'
```

Import Robot from URDF Character Vector

Specify the URDF character vector. This character vector is a minimalist description for creating a valid robot model.

```
URDFtext = '<?xml version="1.0" ?><robot name="min"><link name="L0"/></robot>';
```

Import the robot model. The description creates a `RigidBodyTree` object that has only a robot base link named `'L0'`.

```
robot = importrobot(URDFtext)

robot =
  RigidBodyTree with properties:

        NumBodies: 0
           Bodies: {1x0 cell}
             Base: [1x1 robotics.RigidBody]
        BodyNames: {1x0 cell}
         BaseName: 'L0'
          Gravity: [0 0 0]
       DataFormat: 'struct'
```

Display a Robot Model with Visual Geometries

You can import robots that have `.stl` files associated with the Unified Robot Description format (URDF) file to describe the visual geometries of the robot. Each rigid body has an individual visual geometry specified. The `importrobot` function parses to URDF file to get the robot model and visual geometries. Use the `show` function to visualize the robot

model in a figure. You can then interact with the model by clicking components to inspect them and right-clicking to toggle visibility.

Import a robot model as a URDF file. The `.stl` file locations must be properly specified in this URDF. To add other `.stl` files to individual rigid bodies, see `addVisual`.

```
robot = importrobot('iiwa14.urdf');
```

Visualize the robot with the associated visual model. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each visual geometry.

```
show(robot);
```

Input Arguments

`filename` — Name of URDF file
character vector

Name of URDF file, specified as a character vector. This file must be a valid URDF robot description.

Example: `'robot_file.urdf'`

`URDFtext` — URDF text
character vector

URDF robot text, specified as a character vector.

Example: `<?xml version="1.0" ?><robot name="min"><link name="L0"/></robot>`

`format` — File format of robot description
`'urdf'` | character vector

File format of robot description, specified as a character vector. The only supported file format is `'urdf'`. Use this input to validate the file type.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MeshPath',{'../arm_meshes','../body_meshes'}`

`MeshPath` — Relative search paths for mesh files
character vector | cell array of character vectors

Relative search paths for mesh files, specified as a character vector or cell array of character vectors. Mesh files must still be specified inside the URDF file, but `MeshPath` defines the relative paths for these specified files. When using this function, the URDF importer searches for the mesh files specified in the URDF using all the specified relative paths.

Output Arguments

robot — Robot model
RigidBodyTree object

Robot model, returned as a `robotics.RigidBodyTree` object.

Note If the gravity is not specified in the URDF file, the default `Gravity` property is set to [0 0 0]. Simscape™ Multibody™ uses a default of [0 0 -9.80665]m/s^2 when using `smimport` to import a URDF.

Tips

When importing a robot model with visual meshes, the `importrobot` function searches for the `.stl` files to assign to each rigid body using these rules:

- The function searches the raw mesh path for a specified rigid body from the URDF file. References to ROS packages have the `package:\\<pkg_name>` removed.
- Absolute paths are checked directly with no modification.
- Relative paths are checked using the following directories in order:
  - User-specified `MeshPath`
  - Current directory
  - MATLAB path
  - The folder containing the URDF file
  - One level above the folder containing the URDF file
- The file name from the mesh path in the URDF file is appended to the `MeshPath` input argument.

If the mesh file is still not found, the parser ignores the mesh file and returns a `robotics.RigidBodyTree` object without visual.

See Also
robotics.RigidBodyTree

Topics

"Rigid Body Tree Robot Model"

Introduced in R2017a

isCoreRunning

Determine if ROS core is running

Syntax

```
running = isCoreRunning(device)
```

Description

`running = isCoreRunning(device)` determines if the ROS core is running on the connected device.

Examples

Run ROS Core on ROS Device

Connect to a remote ROS device and start a ROS core. The ROS core is needed to run ROS nodes to communicate via a ROS network. You can run and stop a ROS core or node and check their status using a `rosdevice` object.

Create a connection to a ROS device. Specify the address, user name, and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using `runNode`.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password')


d =

  rosdevice with properties:

      DeviceAddress: '192.168.154.131'
           Username: 'user'
```

```
        ROSFolder: '/opt/ros/hydro'
   CatkinWorkspace: '~/catkin_ws_test'
    AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core and check if it is running.

```
runCore(d)
running = isCoreRunning(d)
```

```
running =

  logical

   1
```

Stop the ROS core and confirm that it is no longer running.

```
stopCore(d)
running = isCoreRunning(d)
```

```
running =

  logical

   0
```

• "Generate a Standalone ROS Node from Simulink®"

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a `rosdevice` object.

Output Arguments

running — Status of whether ROS core is running
true | false

Status of whether ROS core is running, returned as `true` or `false`.

See Also

rosdevice | runCore | stopCore

Topics

"Generate a Standalone ROS Node from Simulink®"

Introduced in R2016b

isNodeRunning

Determine if ROS node is running

Syntax

```
running = isNodeRunning(device,modelName)
```

Description

`running = isNodeRunning(device,modelName)` determines if the ROS node associated with the specified Simulink model is running on the specified `rosdevice`, `device`.

Examples

Run ROS Node on ROS Device

Connect to a remote ROS device and start a ROS node. First, run a ROS core so that ROS nodes can communicate via a ROS network. You can run and stop a ROS core or node and check their status using a `rosdevice` object.

Create a connection to a ROS device. Specify the address, user name and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using `runNode`.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password');
d.ROSFolder = '/opt/ros/hydro';
d.CatkinWorkspace = '~/catkin_ws_test'


d =

  rosdevice with properties:
```

```
     DeviceAddress: '192.168.154.131'
          Username: 'user'
         ROSFolder: '/opt/ros/hydro'
   CatkinWorkspace: '~/catkin_ws_test'
    AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core. Connect MATLAB® to the ROS master using `rosinit`. This core enables you to run ROS nodes on your ROS device.

```
runCore(d)
rosinit(d.DeviceAddress)
```

```
Another roscore / ROS master is already running on the ROS device. Use the 'stopCore'
Initializing global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:56
```

Check the available ROS nodes on the connected ROS device. These nodes were generated from Simulink® models following the process in the Generate a standalone ROS node from Simulink® example.

```
d.AvailableNodes
```

```
ans =

  1×2 cell array

    'robotcontroller'    'robotcontroller2'
```

Run a ROS node. specifying the node name. Check if the node is running.

```
runNode(d,'robotcontroller')
running = isNodeRunning(d,'robotcontroller')
```

```
running =

  logical

   1
```

Stop the ROS node. Disconnect from the ROS network. Stop the ROS core.

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```
stopNode(d,'robotcontroller')
rosshutdown
stopCore(d)
```

Shutting down global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:5

- "Generate a Standalone ROS Node from Simulink®"

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a rosdevice object.

modelName — Name of the deployed Simulink model
character vector

Name of the deployed Simulink model, specified as a character vector. If the model name is not valid, the function returns false.

Output Arguments

running — Status of whether ROS node is running
true | false

Status of whether ROS node is running, returned as true or false.

See Also
rosdevice | runNode | stopNode

Topics
"Generate a Standalone ROS Node from Simulink®"

Introduced in R2016b

matchScans

Estimate pose between two laser scans

Syntax

```
pose = matchScans(currScan,refScan)
pose = matchScans(currRanges,currAngles,refRanges,refAngles)
[pose,stats] = matchScans( ___ )
[ ___ ] = matchScans( ___ ,Name,Value)
```

Description

`pose = matchScans(currScan,refScan)` finds the relative pose between a reference `lidarScan` and a current `lidarScan` object using the normal distributions transform (NDT).

`pose = matchScans(currRanges,currAngles,refRanges,refAngles)` finds the relative pose between two laser scans specified as ranges and angles.

`[pose,stats] = matchScans( ___ )` returns additional statistics about the scan match result using the previous input arguments.

`[ ___ ] = matchScans( ___ ,Name,Value)` specifies additional options specified by one or more `Name,Value` pair arguments.

Examples

Match Lidar Scans

Create a reference lidar scan using `lidarScan`. Specify ranges and angles as vectors.

```
refRanges = 5*ones(1,300);
refAngles = linspace(-pi/2,pi/2,300);
refScan = lidarScan(refRanges,refAngles);
```

Using the `transformScan` function, generate a second lidar scan at an `x,y` offset of (0.5,0.2).

```
currScan = transformScan(refScan,[0.5 0.2 0]);
```

Match the reference scan and the second scan to estimate the pose difference between them.

```
pose = matchScans(currScan,refScan);
```

Use the `transformScan` function to align the scans by transforming the second scan into the frame of the first scan using the relative pose difference. Plot both the original scans and the aligned scans.

```
currScan2 = transformScan(currScan,pose);

subplot(2,1,1);
hold on
plot(currScan)
plot(refScan)
title('Original Scans')
hold off

subplot(2,1,2);
hold on
plot(currScan2)
plot(refScan)
title('Aligned Scans')
xlim([0 5])
hold off
```

Match Laser Scans

This example uses the `'fminunc'` solver algorithm to perform scan matching. This solver algorithm requires an Optimization Toolbox™ license.

Specify a reference laser scan as ranges and angles.

```
refRanges = 5*ones(1,300);
refAngles = linspace(-pi/2,pi/2,300);
```

Using the `transformScan` function, generate a second laser scan at an `x,y` offset of (`0.5,0.2`).

```
[currRanges,currAngles] = transformScan(refRanges,refAngles,[0.5 0.2 0]);
```

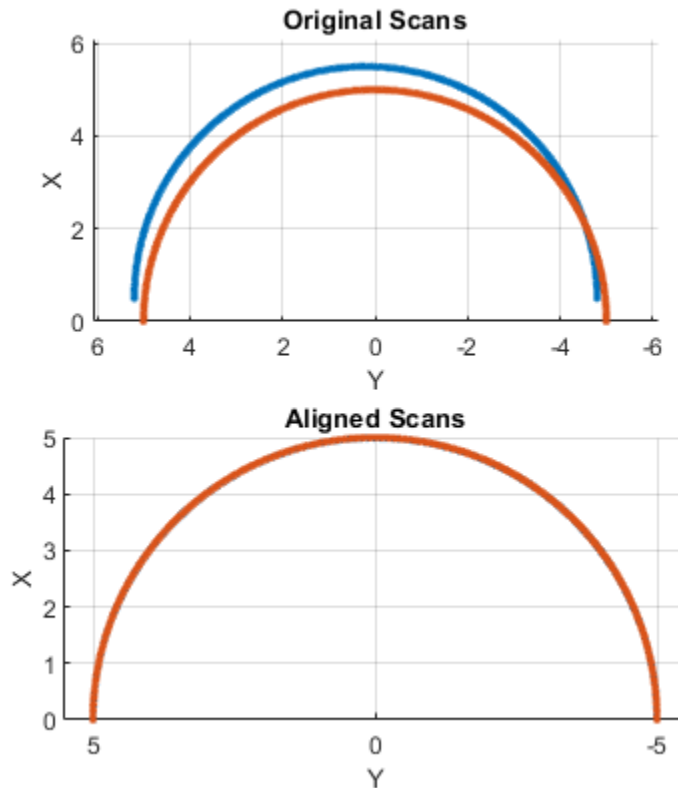Match the reference scan and the second scan to estimate the pose difference between them.

```
pose = matchScans(currRanges,currAngles,refRanges,refAngles,'SolverAlgorithm','fminunc
```

Improve the estimate by giving an initial pose estimate.

```
pose = matchScans(currRanges,currAngles,refRanges,refAngles,...
                  'SolverAlgorithm','fminunc','InitialPose',[-0.4 -0.1 0]);
```

Use the `transformScan` function to align the scans by transforming the second scan into the frame of the first scan using the relative pose difference. Plot both the original scans and the aligned scans.

```
[currRanges2,currAngles2] = transformScan(currRanges,currAngles,pose);

[x1 y1] = pol2cart(refAngles,refRanges);
[x2 y2] = pol2cart(currAngles,currRanges);
[x3 y3] = pol2cart(currAngles2,currRanges2);

subplot(1,2,1)
plot(x1,y1,'o',x2,y2,'*r')
title('Original Scans')
subplot(1,2,2)
plot(x1,y1,'o',x3,y3,'*r')
title('Aligned Scans')
```
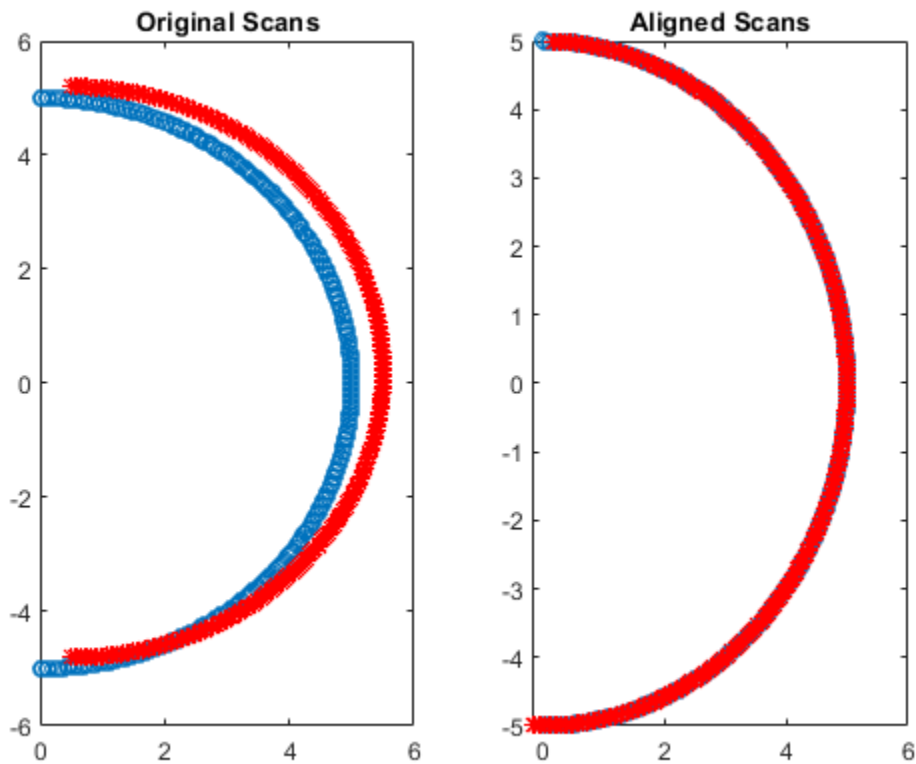
- "Estimate Robot Pose with Scan Matching"
- "Compose a Series of Laser Scans with Pose Changes"

Input Arguments

currScan — Current lidar scan readings
lidarScan object

Current lidar scan readings, specified as a lidarScan object.

Your lidar scan can contain Inf and NaN values, but the algorithm ignores them.

refScan — Reference lidar scan readings
lidarScan object

Reference lidar scan readings, specified as a lidarScan object.

Your lidar scan can contain Inf and NaN values, but the algorithm ignores them.

currRanges — Current laser scan ranges
vector in meters

Current laser scan ranges, specified as a vector. Ranges are given as distances to objects measured from the laser sensor.

Your laser scan ranges can contain Inf and NaN values, but the algorithm ignores them.

currAngles — Current laser scan angles
vector in radians

Current laser scan angles, specified as a vector in radians. Angles are given as the orientations of the corresponding range measurements.

refRanges — Reference laser scan ranges
vector in meters

Reference laser scan ranges, specified as a vector in meters. Ranges are given as distances to objects measured from the laser sensor.

Your laser scan ranges can contain Inf and NaN values, but the algorithm ignores them.

refAngles — Reference laser scan angles
vector in radians

Reference laser scan angles, specified as a vector in radians. Angles are given as the orientations of the corresponding range measurements.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'InitialPose',[1 1 pi/2]

SolverAlgorithm — Optimization algoerithm
`'trust-region'` (default) | `'fminunc'`

Optimization algorithm, specified as either `'trust-region'` or `'fminunc'`. Using `'fminunc'` requires an Optimization Toolbox™ license.

InitialPose — Initial guess of current pose
`[0 0 0]` (default) | `[x y theta]`

Initial guess of the current pose relative to the reference laser scan, specified as the comma-separated pair consisting of `'InitialPose'` and an `[x y theta]` vector. `[x y]` is the translation in meters and `theta` is the rotation in radians.

CellSize — Length of cell side
`1` (default) | numeric scalar

Length of a cell side in meters, specified as the comma-separated pair consisting of `'CellSize'` and a numeric scalar. `matchScans` uses the cell size to discretize the space for the NDT algorithm.

Tuning the cell size is important for proper use of the NDT algorithm. The optimal cell size depends on the input scans and the environment of your robot. Larger cell sizes can lead to less accurate matching with poorly sampled areas. Smaller cell sizes require more memory and less variation between subsequent scans. Sensor noise influences the algorithm with smaller cell sizes as well. Choosing a proper cell size depends on the scale of your environment and the input data.

MaxIterations — Maximum number of iterations
`400` (default) | scalar integer

Maximum number of iterations, specified as the comma-separated pair consisting of `'MaxIterations'` and a scalar integer. A larger number of iterations results in more accurate pose estimates, but at the expense of longer execution time.

ScoreTolerance — Lower bounds on the change in NDT score
`1e-6` (default) | numeric scalar

Lower bound on the change in NDT score, specified as the comma-separated pair consisting of `'ScoreTolerance'` and a numeric scalar. The NDT score is stored in the `Score` field of the output `stats` structure. Between iterations, if the score changes by less than this tolerance, the algorithm converges to a solution. A smaller tolerance results in more accurate pose estimates, but requires a longer execution time.

Output Arguments

pose — Pose of current scan
[x y theta]

Pose of current scan relative to the reference scan, returned as [x y theta], where [x y] is the translation in meters and theta is the rotation in radians.

stats — Scan matching statistics
structure

Scan matching statistics, returned as a structure with the following fields:

- Score — Numeric scalar representing the NDT score while performing scan matching. This score is an estimate of the likelihood that the transformed current scan matches the reference scan. Score is always nonnegative. Larger scores indicate a better match.

- Hessian — 3-by-3 matrix representing the Hessian of the NDT cost function at the given pose solution. The Hessian is used as an indicator of the uncertainty associated with the pose estimate.

References

[1] Biber, P., and W. Strasser. "The Normal Distributions Transform: A New Approach to Laser Scan Matching." *Intelligent Robots and Systems Proceedings*. 2003.

[2] Magnusson, Martin. "The Three-Dimensional Normal-Distributions Transform -- an Efficient Representation for Registration, Surface Analysis, and Loop Detection." PhD Dissertation. Örebro University, School of Science and Technology, 2009.

Extended Capabilities

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

Code generation is supported for the default SolverAlgorithm, 'trust-region'. You cannot use the 'fminunc' algorithm in code generation.

See Also

Functions
lidarScan | readCartesian | readScanAngles | transformScan

Classes
MonteCarloLocalization | OccupancyGrid

Topics
"Estimate Robot Pose with Scan Matching"
"Compose a Series of Laser Scans with Pose Changes"

Introduced in R2017a

matchScansGrid

Estimate pose between two lidar scans using grid-based search

Syntax

```
pose = matchScansGrid(currScan,refScan)
[pose,stats] = matchScansGrid( ___ )
[ ___ ] = matchScansGrid( ___ ,Name,Value)
```

Description

`pose = matchScansGrid(currScan,refScan)` finds the relative pose between a reference `lidarScan` and a current `lidarScan` object using a grid-based search. `matchScansGrid` converts lidar scan pairs into probabilistic grids and finds the pose between the two scans by correlating their grids. The function uses a branch-and-bound strategy to speed up computation over large discretized search windows.

`[pose,stats] = matchScansGrid( ___ )` returns additional statistics about the scan match result using the previous input arguments.

`[ ___ ] = matchScansGrid( ___ ,Name,Value)` specifies options using one or more `Name,Value` pair arguments. For example, `'InitialPose',[1 1 pi/2]` specifies an initial pose estimate for scan matching.

Examples

Match Scans Using Grid-Based Search

Perform scan matching using a grid-based search to estimate the pose between two laser scans. Generate a probabilistic grid from the scans and estimate the pose difference from those grids.

Specify the laser scan data. The current laser scan is just the reference scan transformed using `transformScan`.

```
refRanges = [6*ones(1,100),7*ones(1,100),3*ones(1,100),5*ones(1,100),4*ones(1,100)];
refAngles = linspace(-pi/2,pi/2,500);
refScan = lidarScan(refRanges,refAngles);

currentScan = transformScan(refScan,[0.5,0.5,1.1]);
```

Use `matchScansGrid` to estimate the pose between the two scans.

```
relPose = matchScansGrid(currentScan,refScan);
```

Using the estimated pose, transform the current scan back to the reference scan. The scans overlap closely when you plot them together.

```
currentScanTformed = transformScan(currentScan,relPose);

plot(refScan)
hold on
plot(currentScanTformed)
hold off
```
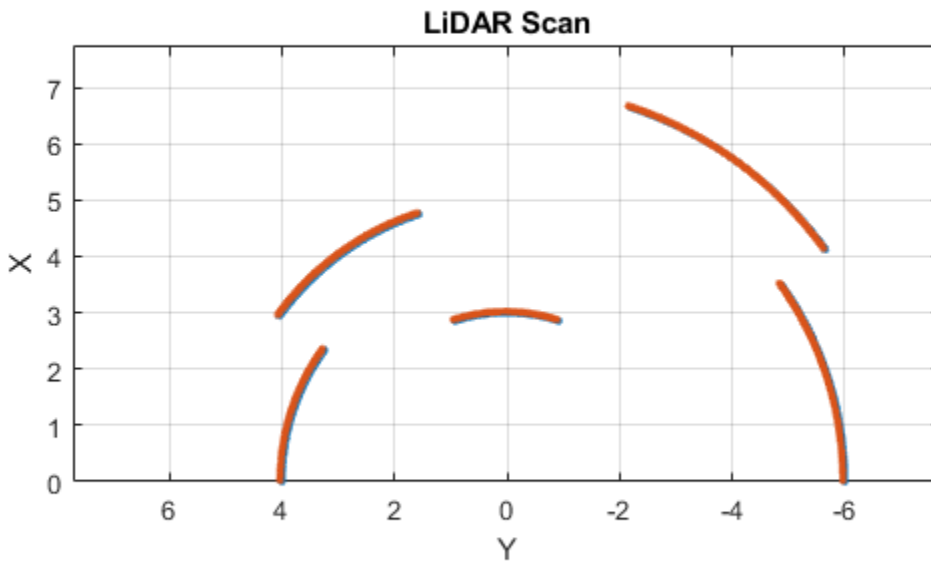
- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Input Arguments

currScan — Current lidar scan readings
lidarScan object

Current lidar scan readings, specified as a lidarScan object.

Your lidar scan can contain `Inf` and `NaN` values, but the algorithm ignores them.

refScan — Reference lidar scan readings
`lidarScan` object

Reference lidar scan readings, specified as a `lidarScan` object.

Your lidar scan can contain `Inf` and `NaN` values, but the algorithm ignores them.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'InitialPose',[1 1 pi/2]`

InitialPose — Initial guess of current pose
`[0 0 0]` (default) | `[x y theta]`

Initial guess of the current pose relative to the reference laser scan, specified as the comma-separated pair consisting of `'InitialPose'` and an `[x y theta]` vector. `[x y]` is the translation in meters and `theta` is the rotation in radians.

Resolution — Grid cells per meter
20 (default) | positive integer

Grid cells per meter, specified as the comma-separated pair consisting of `'Resolution'` and a positive integer. The accuracy of the scan matching result is accurate up to the grid cell size.

MaxRange — Maximum range of lidar sensor
8 (default) | positive scalar

Maximum range of lidar sensor, specified as the comma-separated pair consisting of `'MaxRange'` and a positive scalar.

TranslationSearchRange — Search range for translation
`[4 4]` (default) | `[x y]` vector

Search range for translation, specified as the comma-separated pair consisting of `'TranslationSearchRange'` and an `[x y]` vector. These values define the search

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window in meters around the initial translation estimate given in `InitialPose`. If the `InitialPose` is given as `[x0 y0]`, then the search window coordinates are `[x0-x x0+x]` and `[y0-y y0+y]`. This parameter is used only when `InitialPose` is specified.

`RotationSearchRange` — Search range for rotation
`pi/4` (default) | positive scalar

Search range for rotation, specified as the comma-separated pair consisting of `'RotationSearchRange'` and a positive scalar. This value defines the search window in radians around the initial rotation estimate given in `InitialPose`. If the `InitialPose` rotation is given as `th0`, then the search window is `[th0-a th0+a]`, where `a` is the rotation search range. This parameter is used only when `InitialPose` is specified.

`MaxLevel` — Maximum resolution level used for scan matching
5 (default) | positive integer

Maximum resolution level used for scan matching, specified as the comma-separated pair consisting of `'MaxLevel'` and a positive integer. A level below 6 is recommended. Decreasing the level speeds up performance, but can result in a coarser resolution of the matching solution.

Output Arguments

`pose` — Pose of current scan
`[x y theta]` vector

Pose of current scan relative to the reference scan, returned as an `[x y theta]` vector, where `[x y]` is the translation in meters and `theta` is the rotation in radians.

`stats` — Scan matching statistics
structure

Scan matching statistics, returned as a structure with the following field:

* `Score` — Numeric scalar representing the score while performing scan matching. This score is an estimate of the likelihood that the transformed current scan matches the reference scan. `Score` is always nonnegative. Larger scores indicate a better match, but values vary depending on the lidar data used.

References

[1] Hess, Wolfgang, Damon Kohler, Holger Rapp, and Daniel Andor. "Real-Time Loop Closure in 2D LIDAR SLAM." *2016 IEEE International Conference on Robotics and Automation (ICRA)*. 2016.

Extended Capabilities

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

See Also

Functions
lidarScan | matchScans | readCartesian | readScanAngles | transformScan

Classes
robotics.LidarSLAM

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

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`

See Also

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))
b = quaternion(randn(1,4))
C = A*b


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


    -0.12414 +  1.4897i +   1.409j +  1.4172k


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:

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

You can simplify the equation using the quaternion multiplication table:

$$
\begin{aligned}
z = pq &= a_p a_q + a_p b_q i + a_p c_q j + a_p d_q k \\
&\quad + b_p a_q i - b_p b_q + b_p c_q k - b_p d_q j \\
&\quad + c_p a_q j - c_p b_q k - c_p c_q + c_p d_q i \\
&\quad + d_p a_q k + d_p b_q j - d_p c_q i - d_p d_q
\end{aligned}
$$

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.

See Also

Introduced in R2018a

nodes

Package: robotics

Poses of nodes in pose graph

Syntax

```
nodes = nodes(poseGraph)
nodes = nodes(poseGraph,nodeIDs)
```

Description

`nodes = nodes(poseGraph)` lists all poses in the specified pose graph.

`nodes = nodes(poseGraph,nodeIDs)` lists the poses with the specified node IDs.

Input Arguments

poseGraph — Pose graph
PoseGraph object | PoseGraph3D object

Pose graph, specified as a `PoseGraph` or `PoseGraph3D` object.

nodeIDs — Node IDs
positive integer | vector of positive integers

Node IDs, specified as a positive integer or vector of positive integers. Each node added gets an ID sequentially in the graph.

Output Arguments

nodes — Pose of each node
n-by-3 matrix | *n*-by-7 matrix

Pose of each node, specified as an *n*-by-3 or *n*-by-7 matrix. These poses are given in global coordinates for the whole pose graph.

For `PoseGraph` (2-D), each row is an `[x y theta]` vector, which defines the relative *xy*-position and orientation angle, `theta`, of a pose in the graph.

For `PoseGraph3D`, each row is an `[x y z qw qx qy qz]` vector, which defines the relative *xyz*-position and quaternion orientation, `[qw qx qy qz]`, of a pose in the graph.

Note Many other sources for 3-D pose graphs, including `.g2o` formats, specify the quaternion orientation in a different order, for example, `[qx qy qz qw]`. Check the source of your pose graph data before adding nodes to your `PoseGraph3D` object.

See Also

Functions
addRelativePose | edgeConstraints | edges | findEdgeID | optimizePoseGraph | removeEdges

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

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 $\mathrm{norm}(Q) = \sqrt{a^2 + b^2 + c^2 + d^2}$.

Examples

Get the Quaternion Norm

To return the norm of a quaternion, use `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 `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`

See Also

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 $Q/\sqrt{a^2 + b^2 + c^2 + d^2}$.

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

See Also

Introduced in R2018a

openShell

Open interactive command shell to device

Syntax

```
openShell(device)
```

Description

`openShell(device)` opens an SSH terminal on your host computer that provides encrypted access to the Linux® command shell on the ROS device. When prompted, enter a user name and password.

Examples

Open Command Shell on ROS Device
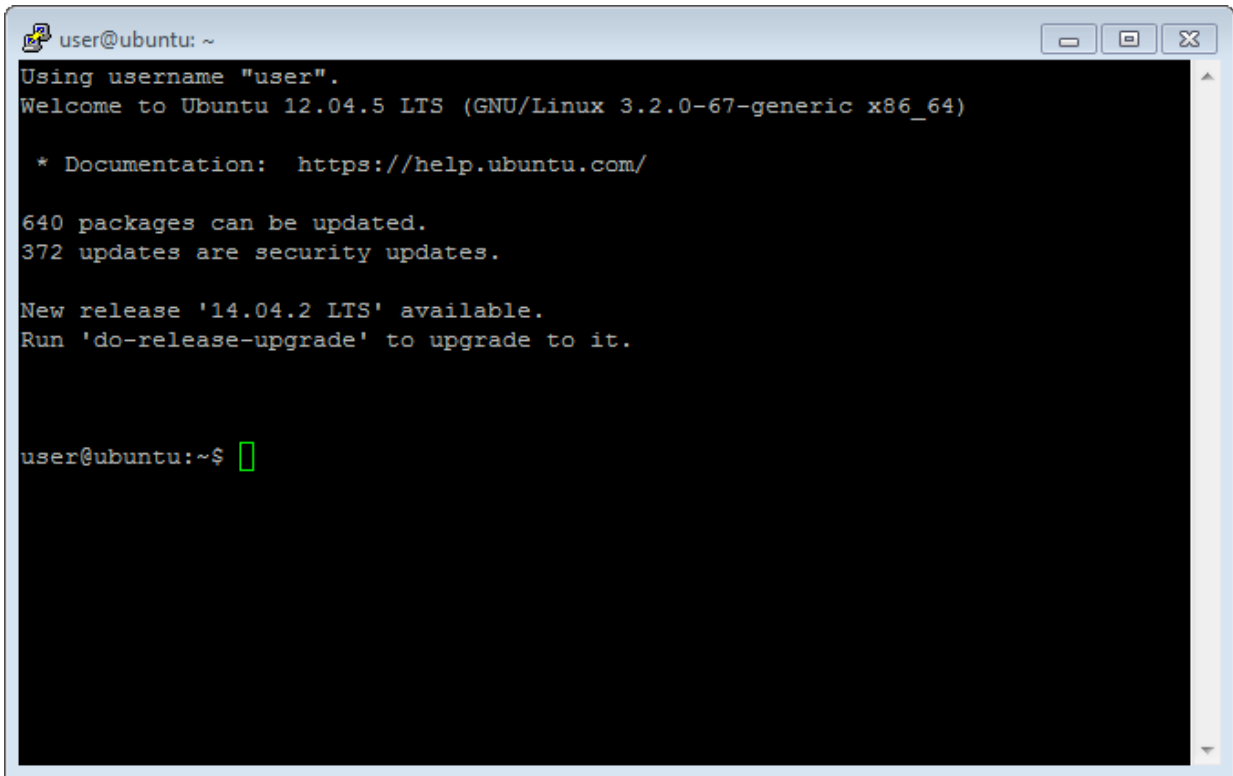
Connect to a ROS device and open the command shell on your host computer.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.154.131','user','password');
```

Open the command shell.

```
openShell(d);
```

```
user@ubuntu: ~

Using username "user".
Welcome to Ubuntu 12.04.5 LTS (GNU/Linux 3.2.0-67-generic x86_64)

 * Documentation:  https://help.ubuntu.com/

640 packages can be updated.
372 updates are security updates.

New release '14.04.2 LTS' available.
Run 'do-release-upgrade' to upgrade to it.


user@ubuntu:~$ 
```

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a rosdevice object.

See Also
deleteFile | dir | getFile | putFile | rosdevice | system

Introduced in R2016b

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')

qOnes = 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.

`qOnes = 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')
```

```
  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

`qOnes` — 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 $Q = a + bi + cj + dk$, a quaternion one is defined as $Q = 1 + 0i + 0j + 0k$.

Data Types: `quaternion`

See Also

Introduced in R2018a

optimizePoseGraph

Optimize nodes in pose graph

Syntax

```
updatedGraph = optimizePoseGraph(poseGraph)
[updatedGraph,solutionInfo] = optimizePoseGraph(poseGraph)
[ ___ ] = optimizePoseGraph(poseGraph,Name,Value)
```

Description

`updatedGraph = optimizePoseGraph(poseGraph)` adjusts the poses based on their edge constraints defined in the specified graph to improve the overall graph. You optimize either a 2-D or 3-D pose graph. The returned pose graph has the same topology with updated nodes.

`[updatedGraph,solutionInfo] = optimizePoseGraph(poseGraph)` returns additional statistics about the optimization process in `solutionInfo`.

`[ ___ ] = optimizePoseGraph(poseGraph,Name,Value)` specifies options using one or more `Name,Value` pairs. For example, `'MaxIterations',1000` increases the maximum number of iterations to 1000.

Examples

Optimize a 3-D Pose Graph

Optimize a pose graph based on the nodes and edge constraints. The pose graph used in this example is from the MIT Dataset and was generated using information extracted from a parking garage.

Load the pose graph from the MIT dataset. Inspect the `robotics.PoseGraph3D` object to view the number of nodes and loop closures.

```
load parking-garage-posegraph.mat pg
disp(pg);
```

```
  PoseGraph3D with properties:

               NumNodes: 1661
               NumEdges: 6275
    NumLoopClosureEdges: 4615
     LoopClosureEdgeIDs: [1x4615 double]
```

Plot the pose graph with IDs off. Red lines indicate loop closures identified in the dataset.

```
title('Original Pose Graph')
show(pg,'IDs','off');
view(-30,45)
```

Optimize the pose graph. Nodes are adjusted based on the edge constraints and loop closures. Plot the optimized pose graph to see the adjustment of the nodes with loop closures.

```
updatedPG = optimizePoseGraph(pg);
figure
title('Updated Pose Graph')
show(updatedPG,'IDs','off');
view(-30,45)
```


- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Input Arguments

poseGraph — 2-D or 3-D pose graph
PoseGraph object | PoseGraph3D object

2-D or 3-D pose graph, specified as a PoseGraph or PoseGraph3D object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'MaxIterations', 1000

MaxIterations — Maximum number of iterations
300 (default) | positive integer

Maximum number of iterations, specified as the comma-separated pair consisting of 'MaxIterations' and a positive integer. The optimizer exits after it exceeds this number of iterations.

GradientTolerance — Lower bound on norm of gradient
0.5e-8 (default) | scalar

Lower bound on the norm of the gradient, specified as the comma-separated pair consisting of 'GradientTolerance' and a scalar. The norm of the gradient is calculated based on the cost function of the optimization. If the norm falls below this value, the optimizer exits.

FunctionTolerance — Lower bound on change in cost function
1e-8 (default) | scalar

Lower bound on the change in the cost function, specified as the comma-separated pair consisting of 'FunctionTolerance' and a scalar. If the cost function change falls below this value between optimization steps, the optimizer exits.

FirstNodePose — Pose of first node
[0 0 0] or [0 0 0 1 0 0 0] (default) | [x y theta] | [x y z qw qx qy qz]

Pose of the first node in `poseGraph`, specified as the comma-separated pair consisting of `'FirstNodePose'` and a pose vector.

For `PoseGraph` (2-D), the pose is an `[x y theta]` vector, which defines the relative *xy*-position and orientation angle, `theta`.

For `PoseGraph3D`, the pose is an `[x y z qw qx qy qz]` vector, which defines the relative *xyz*-position and quaternion orientation, `[qw qx qy qz]`.

Note Many other sources for 3-D pose graphs, including `.g2o` formats, specify the quaternion orientation in a different order, for example, `[qx qy qz qw]`. Check the source of your pose graph data before adding nodes to your `PoseGraph3D` object.

`LoopClosuresToIgnore` — IDs of loop closure edges in pose graph
vector

IDs of loop closure edges in `poseGraph`, specified as the comma-separated pair consisting of `'LoopClosuresToIgnore'` and a vector. To get edge IDs from the pose graph, use `findEdgeID`.

`VerboseOutput` — Display intermediate iteration information
`'off'` (default) | `'on'`

Display intermediate iteration information on the MATLAB command line, specified as the comma-separated pair consisting of `'VerboseOutput'` and either `'off'` or `'on'`.

`InitialTrustRegionRadius` — Initial trust region radius
100 (default) | scalar

Initial trust region radius, specified as a scalar.

`StepTolerance` — Lower bound on step size
1e-12 (default) | scalar

Lower bound on the step size, specified as the comma-separated pair consisting of `'StepTolerance'` and a scalar. If the norm of the optimization step falls below this value, the optimizer exits.

Output Arguments

`updatedGraph` — Optimized 2-D or 3-D pose graph
`PoseGraph` object | `PoseGraph3D` object

Optimized 2-D or 3-D pose graph, returned as a `PoseGraph` or `PoseGraph3D` object.

`solutionInfo` — Statistics of optimization process
structure

Statistics of optimization process, returned as a structure with these fields:

- `Iterations` — Number of iterations used in optimization.

- `ResidualError` — Value of cost function when optimizer exits.

- `Exit Flag` — Exit condition for optimizer:

  - `1` — Local minimum found.

  - `2` — Maximum number of iterations reached. See `MaxIterations` name-value pair argument.

  - `3` — Algorithm timed out during operation.

  - `4` — Minimum step size. The step size is below the `StepTolerance` name-value pair argument.

  - `5` — The change in error is below the minimum.

  - `8` — Trust region radius is below the minimum set in `InitialTrustRegionRadius`.

References

[1] Grisetti, G., R. Kummerle, C. Stachniss, and W. Burgard. "A Tutorial on Graph-Based SLAM." *IEEE Intelligent Transportation Systems Magazine*. Vol. 2, No. 4, 2010, pp. 31–43. doi:10.1109/mits.2010.939925.

[2] Carlone, Luca, Roberto Tron, Kostas Daniilidis, and Frank Dellaert. "Initialization Techniques for 3D SLAM: a Survey on Rotation Estimation and its Use in Pose Graph Optimization." *2015 IEEE International Conference on Robotics and Automation (ICRA)*. 2015, pp. 4597–4604.

See Also

Functions
addRelativePose | edgeConstraints | edges | findEdgeID | nodes | removeEdges

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

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

A quaternion is a four-part hyper-complex number. You can create quaternions by specifying the individual parts. You can convert 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 =

  2x1 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 and the input 2-by-1 column vector of quaternions.

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


qA =

     1
     5


qB =

     2
     6


qC =

     3
     7


qD =

     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`

See Also

Introduced in R2018a

plot

Display laser or lidar scan readings

Syntax

```
plot(scanMsg)
plot(scanObj)
plot( ___ ,Name,Value)
linehandle = plot( ___ )
```

Description

`plot(scanMsg)` plots the laser scan readings specified in the input `LaserScan` object message. Axes are automatically scaled to the maximum range that the laser scanner supports.

`plot(scanObj)` plots the lidar scan readings specified in `scanObj`.

`plot( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments. Name must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`. You can use either a laser scan

`linehandle = plot( ___ )` returns a column vector of line series handles, using any of the arguments from previous syntaxes. Use `linehandle` to modify properties of the line series after it is created.

When plotting ROS laser scan messages, MATLAB follows the standard ROS convention for axis orientation. This convention states that **positive x is forward, positive y is left, and positive z is up**. For more information, see Axis Orientation on the ROS Wiki.

Examples

Plot Laser Scan Message

Connect to ROS network. Subscribe to a laser scan topic, and receive a message.

```
rosinit('192.168.154.131')
sub = rossubscriber('/scan');
scan = receive(sub);
```

Initializing global node /matlab_global_node_06485 with NodeURI http://192.168.154.1:60

Plot the laser scan.

```
plot(scan)
```
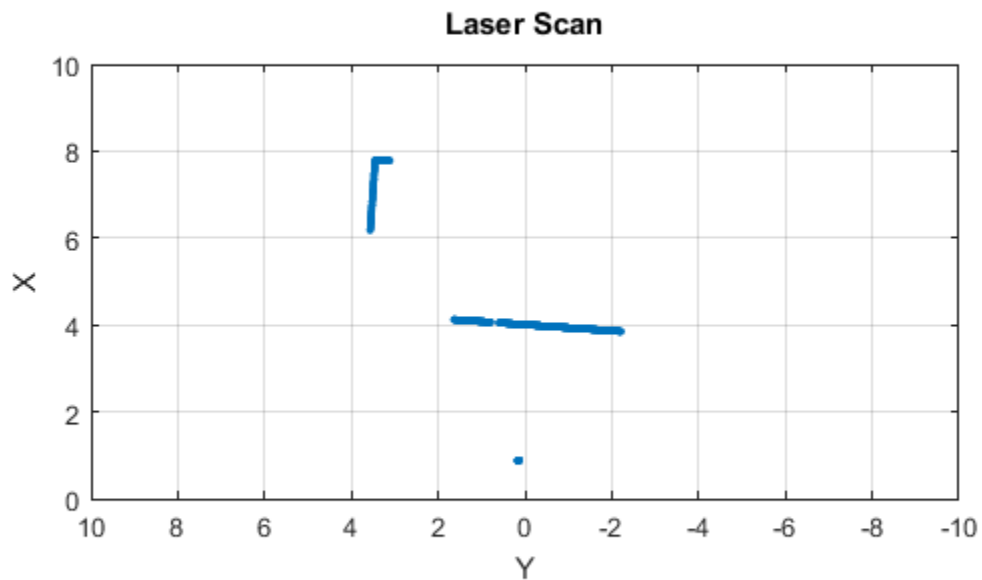

Shutdown ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_06485 with NodeURI http://192.168.154.1:6

Plot Laser Scan Message With Maximum Range

Connect to ROS network. Subscribe to a laser scan topic, and receive a message.

```
rosinit('192.168.154.131')
sub = rossubscriber('/scan');
scan = receive(sub);
```

Initializing global node /matlab_global_node_29862 with NodeURI http://192.168.154.1:60

Plot the laser scan specifying the maximum range.

```
plot(scan,'MaximumRange',6)
```

Shutdown ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_29862 with NodeURI http://192.168.154.1:6

Plot Lidar Scan and Remove Invalid Points

Specify lidar data as vectors of ranges and angles. These values include readings outside of the sensors range.

```
x = linspace(-2,2);
ranges = abs((1.5).*x.^2 + 5);
```

```
ranges(45:55) = 3.5;
angles = linspace(-pi/2,pi/2,numel(ranges));
```

Create a lidar scan by specifying the ranges and angles. Plot all points of the lidar scan.

```
scan = lidarScan(ranges,angles);
plot(scan)
```


Remove invalid points based on a specified minimum and maximum range.

```
minRange = 0.1;
maxRange = 7;
scan2 = removeInvalidData(scan,'RangeLimits',[minRange maxRange]);
hold on
```

```
plot(scan2)
legend('All Points','Valid Points')
```


Input Arguments

scanMsg — Laser scan message
LaserScan object handle

'sensor_msgs/LaserScan' ROS message, specified as a LaserScan object handle.

scanObj — Lidar scan readings
lidarScan object

Lidar scan readings, specified as a `lidarScan` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MaximumRange',5`

Parent — Parent of axes
axes object

Parent of axes, specified as the comma-separated pair consisting of `'Parent'` and an axes object in which the laser scan is drawn. By default, the laser scan is plotted in the currently active axes.

MaximumRange — Range of laser scan
`scan.RangeMax` (default) | scalar

Range of laser scan, specified as the comma-separated pair consisting of `'MaximumRange'` and a scalar. When you specify this name-value pair argument, the minimum and maximum *x*-axis and the maximum *y*-axis limits are set based on specified value. The minimum *y*-axis limit is automatically determined by the opening angle of the laser scanner.

This name-value pair only works when you input `scanMsg` as the laser scan.

Outputs

`linehandle` — One or more chart line objects
scalar | vector

One or more chart line objects, returned as a scalar or a vector. These are unique identifiers, which you can use to query and modify properties of a specific chart line.

See Also
readCartesian

Introduced in R2015a

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 -  1.22
```

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

See Also

Introduced in R2018a

putFile

Copy file to device

Syntax

```
putFile(device,localSource)
putFile(device,localSource,remoteDestination)
```

Description

putFile(device,localSource) copies the specified source file from the MATLAB current folder to the print working directory (pwd) on the ROS device. Wildcards are supported.

putFile(device,localSource,remoteDestination) copies the file to a destination path. Specify a file name at the end of the destination path to copy with a custom file name.

Examples

Put, Get, and Delete Files on ROS Device

Put a file from your host computer onto a ROS device, get it back, and then delete it.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.154.131','user','password');
```

Put a new text file that is in the MATLAB® current folder onto the ROS device. The destination folder must exist.

```
putFile(d,'test_file.txt','/home/user/test_folder')
```

Get a text file from the ROS device. You can get any file, not just ones added from MATLAB®. By default, the file is added to the MATLAB current folder.

```
getFile(d,'/home/user/test_folder/test_file.txt')
```

Delete the text file on the ROS device.

```
deleteFile(d,'/home/user/test_folder/test_file.txt')
```

Put, Get, and Delete Files on ROS Device Using Wildcards

Put a file from your host computer onto a ROS device, get it back, and then delete it. Use wildcards to search for all matching files.

Note: You must have a valid ROS device to connect to at the IP address specified in the example.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.203.129','user','password');
```

Put all text files at the specified path onto the ROS device. The destination folder must exist.

```
putFile(d,'C:/MATLAB/*.txt','/home/user/test_folder')
```

Get all text files from the ROS device. You can get any files, not just ones added from MATLAB®. By default, the files are added to the MATLAB current folder.

```
getFile(d,'/home/user/test_folder/*.txt')
```

Delete all text files on the ROS device at the specified folder.

```
deleteFile(d,'/home/user/test_folder/*.txt')
```

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a `rosdevice` object.

`localSource` — Path and name of file on host computer
character vector

Path and name of the file on the host computer, specified as a character vector. You can use an absolute path or a path relative from the MATLAB current folder. Use the path and file naming conventions of the operating system on your host computer.

Example: `'C:\Work\.profile'`

Data Types: `char`

`remoteDestination` — Destination folder path and optional file name
character vector

Destination folder path and optional file name, specified as a character vector. Specify a file name at the end of the destination path to copy with a custom file name. Use the Linux path and file naming conventions.

Example: `'/home/user/.profile'`

Data Types: `char`

See Also

`deleteFile` | `dir` | `getFile` | `openShell` | `rosdevice` | `system`

Introduced in R2016b

quat2axang

Convert quaternion to axis-angle rotation

Syntax

```
axang = quat2axang(quat)
```

Description

`axang = quat2axang(quat)` converts a quaternion, `quat`, to the equivalent axis-angle rotation, `axang`.

Examples

Convert Quaternion to Axis-Angle Rotation

```
quat = [0.7071 0.7071 0 0];
axang = quat2axang(quat)
```

```
axang = 1×4

    1.0000         0         0    1.5708
```

Input Arguments

quat — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an n-by-4 matrix or n-element vector of `quaternion` objects containing n quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with w as the scalar number.

Example: [0.7071 0.7071 0 0]

Output Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, returned as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: [1 0 0 pi/2]

Extended Capabilities

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

See Also
axang2quat | quaternion

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

quat2eul

Convert quaternion to Euler angles

Syntax

```
eul = quat2eul(quat)
eul = quat2eul(quat,sequence)
```

Description

`eul = quat2eul(quat)` converts a quaternion rotation, `quat`, to the corresponding Euler angles, `eul`. The default order for Euler angle rotations is `'ZYX'`.

`eul = quat2eul(quat,sequence)` converts a quaternion into Euler angles. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `'ZYX'`.

Examples

Convert Quaternion to Euler Angles

```
quat = [0.7071 0.7071 0 0];
eulZYX = quat2eul(quat)
```

```
eulZYX = 1×3

        0        0    1.5708
```

Convert Quaternion to Euler Angles Using ZYZ Axis Order

```
quat = [0.7071 0.7071 0 0];
eulZYZ = quat2eul(quat,'ZYZ')
```

eulZYZ = *1×3*

```
    1.5708   -1.5708   -1.5708
```

Input Arguments

quat — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

sequence — Axis rotation sequence
`'ZYX'` (default) | `'ZYZ'` | `'XYZ'`

Axis rotation sequence for the Euler angles, specified as one of these character vectors:

- `'ZYX'` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `'ZYZ'` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `'XYZ'` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Output Arguments

eul — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, returned as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

Extended Capabilities

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

See Also
eul2quat | quaternion

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

quat2rotm

Convert quaternion to rotation matrix

Syntax

```
rotm = quat2rotm(quat)
```

Description

`rotm = quat2rotm(quat)` converts a quaternion `quat` to an orthonormal rotation matrix, `rotm`. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Examples

Convert Quaternion to Rotation Matrix

```
quat = [0.7071 0.7071 0 0];
rotm = quat2rotm(quat)
```

rotm = *3×3*

```
    1.0000         0         0
         0   -0.0000   -1.0000
         0    1.0000   -0.0000
```

Input Arguments

quat — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form *q* = [*w x y z*], with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1; 0 1 0; -1 0 0]`

Extended Capabilities

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

See Also
quaternion | rotm2quat

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

quat2tform

Convert quaternion to homogeneous transformation

Syntax

```
tform = quat2tform(quat)
```

Description

`tform = quat2tform(quat)` converts a quaternion, `quat`, to a homogeneous transformation matrix, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Quaternion to Homogeneous Transformation

```
quat = [0.7071 0.7071 0 0];
tform = quat2tform(quat)
```

tform = *4×4*

```
    1.0000         0         0         0
         0   -0.0000   -1.0000         0
         0    1.0000   -0.0000         0
         0         0         0    1.0000
```

Input Arguments

quat — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

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Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, returned as a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Extended Capabilities

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

See Also
`quaternion` | `tform2quat`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

readAllFieldNames

Get all available field names from ROS point cloud

Syntax

```
fieldnames = readAllFieldNames(pcloud)
```

Description

`fieldnames = readAllFieldNames(pcloud)` gets the names of all point fields that are stored in the `PointCloud2` object message, `pcloud`, and returns them in `fieldnames`.

Examples

Read All Fields From Point Cloud Message

Load sample ROS messages including a ROS point cloud message, `ptcloud`.

```
exampleHelperROSLoadMessages
```

Read all the field names available on the point cloud message.

```
fieldnames = readAllFieldNames(ptcloud)
```

```
fieldnames =

  1×4 cell array
```

```
'x'    'y'    'z'    'rgb'
```

Input Arguments

pcloud — Point cloud
PointCloud2 object handle

Point cloud, specified as a PointCloud2 object handle for a 'sensor_msgs/
PointCloud2' ROS message.

Output Arguments

fieldnames — List of field names in PointCloud2 object
cell array of character vectors

List of field names in PointCloud2 object, returned as a cell array of character vectors.
If no fields exist in the object, fieldname returns an empty cell array.

See Also
PointCloud2 | readField

Introduced in R2015a

readBinaryOccupancyGrid

Read binary occupancy grid

Syntax

```
map = readBinaryOccupancyGrid(msg)
map = readBinaryOccupancyGrid(msg,thresh)
map = readBinaryOccupancyGrid(msg,thresh,val)
```

Description

`map = readBinaryOccupancyGrid(msg)` returns a
`robotics.BinaryOccupancyGrid` object by reading the data inside a ROS message,
`msg`, which must be a `'nav_msgs/OccupancyGrid'` message. All message data values
greater than or equal to the occupancy threshold are set to occupied, `1`, in the map. All
other values, including unknown values (`-1`) are set to unoccupied, `0`, in the map.

`map = readBinaryOccupancyGrid(msg,thresh)` specifies a threshold, `thresh`, for
occupied values. All values greater than or equal to the threshold are set to occupied, `1`.
All other values are set to unoccupied, `0`.

`map = readBinaryOccupancyGrid(msg,thresh,val)` specifies a value to set for
unknown values (`-1`). By default, all unknown values are set to unoccupied, `0`.

Examples

Read Binary Occupancy Data from ROS Message

Create a occupancy grid message and populate it with data.

```
msg = rosmessage('nav_msgs/OccupancyGrid');
msg.Info.Height = 10;
msg.Info.Width = 10;
```

```
msg.Info.Resolution = 0.1;
msg.Data = 100*rand(100,1);
```

Read data from message. Show the map.

```
map = readBinaryOccupancyGrid(msg);
show(map)
```


Binary Occupancy Grid

Read Binary Occupancy Data from ROS Message Using Threshold and Unknown Value Replacement
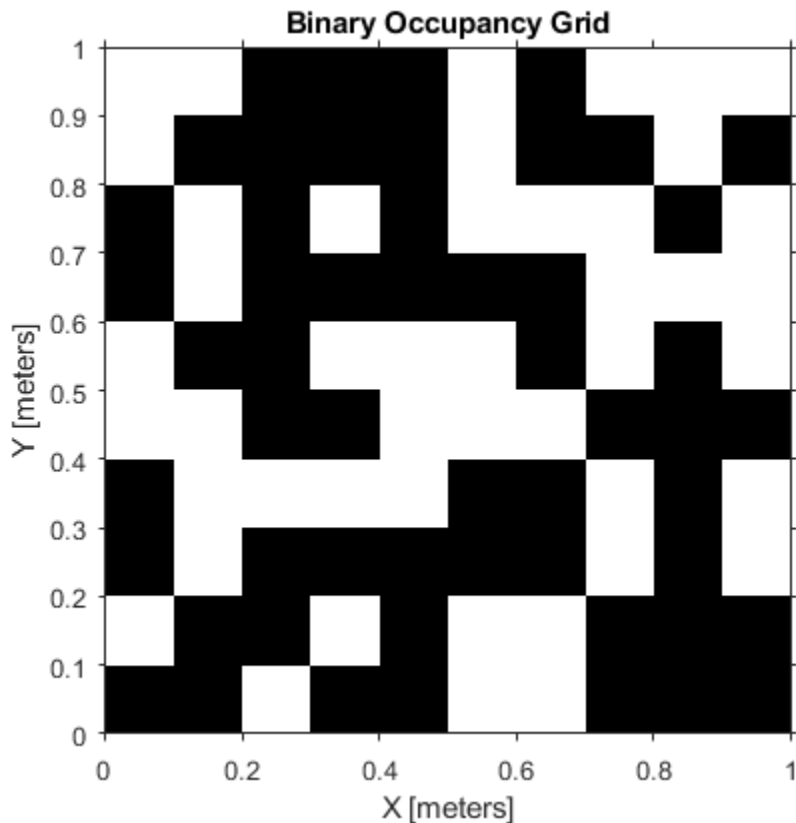
Create a occupancy grid message and populate it with data.

```
msg = rosmessage('nav_msgs/OccupancyGrid');
msg.Info.Height = 10;
msg.Info.Width = 10;
msg.Info.Resolution = 0.1;
msg.Data = 100*rand(100,1);
```

Read data from message. Specify the threshold value and what unknown values should be set as. Show the map.

```
map = readBinaryOccupancyGrid(msg,65,1);
show(map)
```
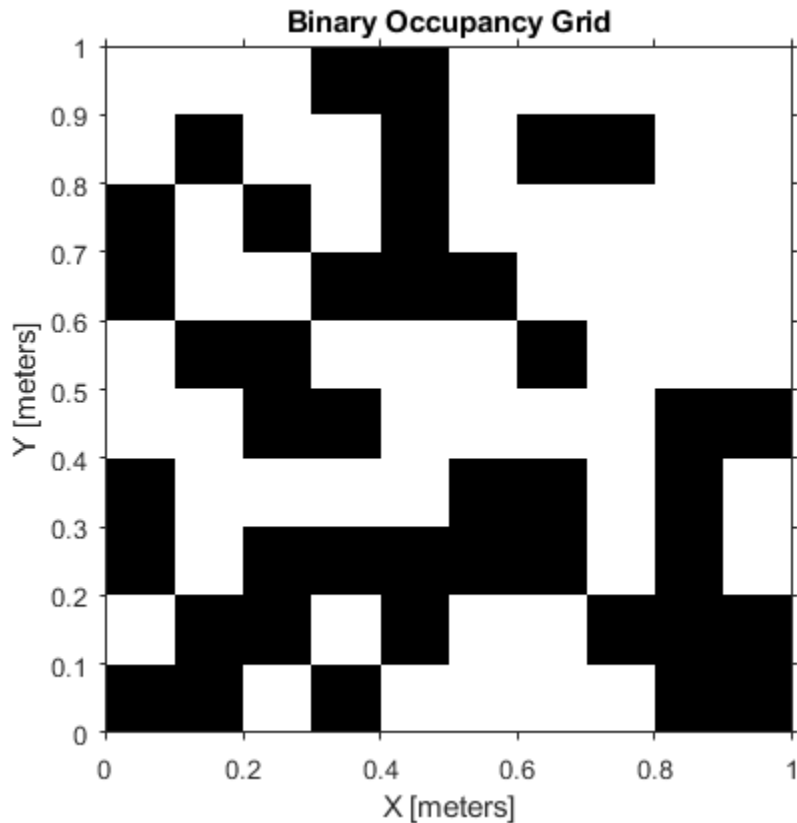
Input Arguments

msg — 'nav_msgs/OccupancyGrid' ROS message
OccupancyGrid object handle

'nav_msgs/OccupancyGrid' ROS message, specified as a OccupancyGrid object handle.

thresh — Threshold for occupied values
50 (default) | scalar

Threshold for occupied values, specified as a scalar. Any value greater than or equal to the threshold is set to occupied, 1. All other values are set to unoccupied, 0.

Data Types: double

val — Value to replace unknown values
0 (default) | 1

Value to replace unknown values, specified as either 0 or 1. Unknown message values (-1) are set to the given value.

Data Types: double | logical

Output Arguments

map — Binary occupancy grid
BinaryOccupancyGrid object handle

Binary occupancy grid, returned as a BinaryOccupancyGrid object handle. map is converted from a 'nav_msgs/OccupancyGrid' message on the ROS network. It is an object with a grid of binary values, where 1 indicates an occupied location and 0 indications an unoccupied location.

See Also
readOccupancyGrid | robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | writeBinaryOccupancyGrid | writeOccupancyGrid

Introduced in R2015a

readCartesian

Read laser scan ranges in Cartesian coordinates

Syntax

```
cart = readCartesian(scan)
cart = readCartesian( ___ ,Name,Value)
[angles,cart] = readCartesian( ___ )
```

Description

`cart = readCartesian(scan)` converts the polar measurements of the laser scan object, `scan`, into Cartesian coordinates, `cart`. This function uses the metadata in the message, such as angular resolution and opening angle of the laser scanner, to perform the conversion. Invalid range readings, usually represented as `NaN`, are ignored in this conversion.

`cart = readCartesian( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments. Name must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

`[angles,cart] = readCartesian( ___ )` returns the scan angles, `angles` that are associated with each Cartesian coordinate. Angles are measured counter-clockwise around the positive *z*-axis, with the zero angle along the *x*-axis. `angles` is returned in radians and wrapped to the [`-pi`, `pi`] interval.

Examples

Get Cartesian Coordinates from Laser Scan

Connect to ROS network. Subscribe to a laser scan topic, and receive a message.

```
rosinit('192.168.154.131')
sub = rossubscriber('/scan');
scan = receive(sub);
```

```
Initializing global node /matlab_global_node_60179 with NodeURI http://192.168.154.1:60
```

Read the Cartesian points from the laser scan. Plot the laser scan.

```
cart = readCartesian(scan);
plot(cart(:,1),cart(:,2))
```
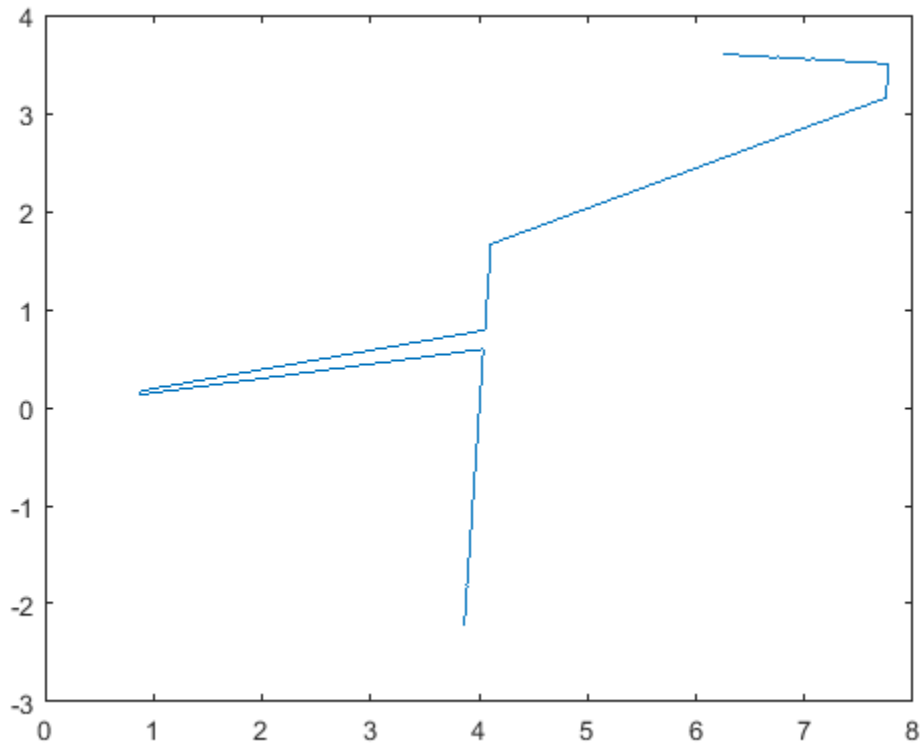

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_60179 with NodeURI http://192.168.154.1:6
```

Get Cartesian Coordinates from Laser Scan With Scan Range

Connect to ROS network. Subscribe to a laser scan topic, and receive a message.

```
rosinit('192.168.154.131')
sub = rossubscriber('/scan');
scan = receive(sub);
```

```
Initializing global node /matlab_global_node_98143 with NodeURI http://192.168.154.1:60
```

Read the Cartesian points from the laser scan with specified range limits. Plot the laser scan.

```
cart = readCartesian(scan,'RangeLimit',[0.5 6]);
plot(cart(:,1),cart(:,2))
```
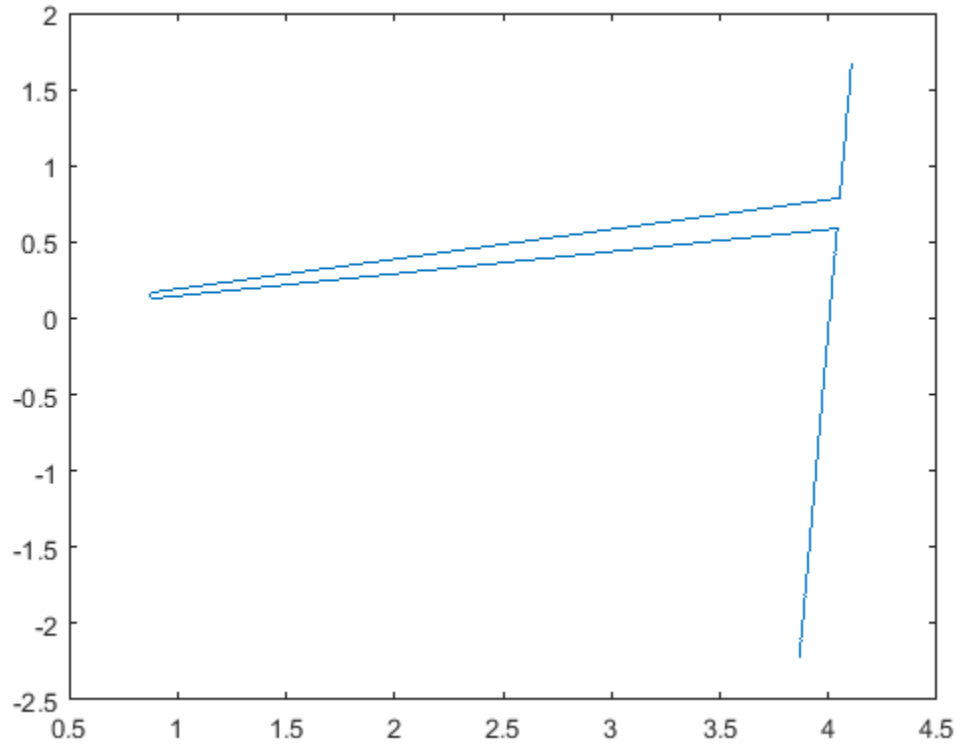
Shutdown ROS network.

rosshutdown

Shutting down global node /matlab_global_node_98143 with NodeURI http://192.168.154.1:6

Input Arguments

scan — Laser scan message
LaserScan object handle

'sensor_msgs/LaserScan' ROS message, specified as a LaserScan object handle.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'RangeLimits',[-2 2]`

RangeLimits — Minimum and maximum range for scan in meters
`[scan.RangeMin scan.RangeMax]` (default) | 2-element `[min max]` vector

Minimum and maximum range for scan in meters, specified as a 2-element `[min max]` vector. All ranges smaller than `min` or larger than `max` are ignored during the conversion to Cartesian coordinates.

Output Arguments

`cart` — Cartesian coordinates of laser scan
n–by–2 matrix in meters

Cartesian coordinates of laser scan, returned as an *n*-by-2 matrix in meters.

`angles` — Scan angles for laser scan data
n–by–1 matrix in radians

Scan angles for laser scan data, returned as an *n*-by-1 matrix in radians. Angles are measured counter-clockwise around the positive *z*-axis, with the zero angle along the *x*-axis. `angles` is returned in radians and wrapped to the [–pi, pi] interval.

See Also
`plot` | `readScanAngles`

Introduced in R2015a

readField

Read point cloud data based on field name

Syntax

```
fielddata = readField(pcloud,fieldname)
```

Description

`fielddata = readField(pcloud,fieldname)` reads the point field from the `PointCloud2` object, `pcloud`, specified by `fieldname` and returns it in `fielddata`. If `fieldname` does not exist, the function displays an error. To preserve the structure of the point cloud data, see "Preserving Point Cloud Structure" on page 2-212.

Examples

Read Specific Field From Point Cloud Message

Load sample ROS messages including a ROS point cloud message, `ptcloud`.

```
exampleHelperROSLoadMessages
```

Read the `'x'` field name available on the point cloud message.

```
x = readField(ptcloud,'x');
```

Input Arguments

pcloud — Point cloud
PointCloud2 object handle

Point cloud, specified as a `PointCloud2` object handle for a `'sensor_msgs/PointCloud2'` ROS message.

`fieldname` — Field name of point cloud data
character vector

Field name of point cloud data, specified as a character vector. This character vector must match the field name exactly. If `fieldname` does not exist, the function displays an error.

Output Arguments

`fielddata` — List of field values from point cloud
matrix

List of field values from point cloud, returned as a matrix. Each row of is a point cloud reading, where *n* is the number of points and *c* is the number of values for each point. If the point cloud object being read has the `PreserveStructureOnRead` property set to true, the points are returned as an *h*-by-*w*-by-*c* matrix. For more information, see "Preserving Point Cloud Structure" on page 2-212.

Preserving Point Cloud Structure

Point cloud data can be organized in either 1-D lists or in 2-D image styles. 2-D image styles usually come from depth sensors or stereo cameras. The input `PointCloud2` object contains a `PreserveStructureOnRead` property that is either `true` or `false` (default). Suppose you set the property to `true`.

```
pcloud.PreserveStructureOnRead = true;
```

Now calling any read functions (`readXYZ`,`readRGB`, or `readField`) preserves the organizational structure of the point cloud. When you preserve the structure, the output matrices are of size *m*-by-*n*-by-*d*, where *m* is the height, *n* is the width, and *d* is the number of return values for each point. Otherwise, all points are returned as a *x*-by-*d* list. This structure can only be preserved if the point cloud is organized.

See Also
`PointCloud2` | `readAllFieldNames`

Introduced in R2015a

readImage

Convert ROS image data into MATLAB image

Syntax

```
img = readImage(msg)
[img,alpha] = readImage(msg)
```

Description

`img = readImage(msg)` converts the raw image data in the message object, `msg`, into an image matrix, `img`. You can call `readImage` using either `'sensor_msgs/Image'` or `'sensor_msgs/CompressedImage'` messages.

ROS image message data is stored in a format that is not compatible with further image processing in MATLAB. Based on the specified encoding, this function converts the data into an appropriate MATLAB image and returns it in `img`.

`[img,alpha] = readImage(msg)` returns the alpha channel of the image in `alpha`. If the image does not have an alpha channel, then `alpha` is empty.

Examples

Read ROS Image Data

Load sample ROS messages including a ROS image message, `img`.
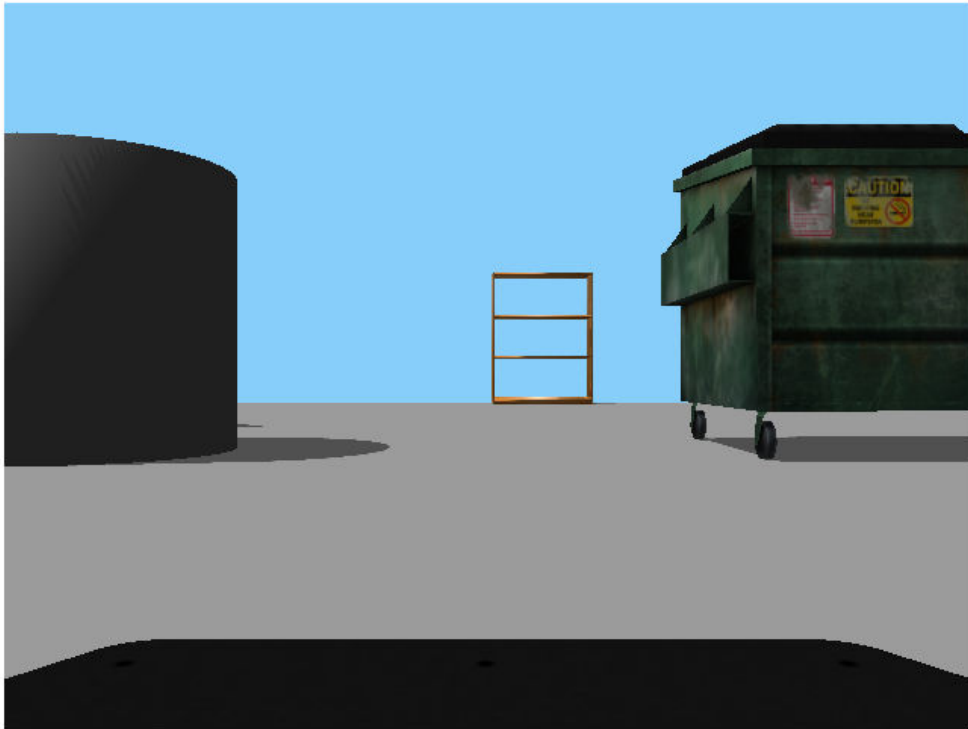
```
exampleHelperROSLoadMessages
```

Read the ROS image message as a MATLAB® image.

```
image = readImage(img);
```

Display the image.

```
imshow(image)
```


Input Arguments

msg — ROS image message
Image object handle | CompressedImage object handle

'sensor_msgs/Image' or 'sensor_msgs/CompressedImage' ROS image message,
specified as an Image or Compressed Image object handle.

Output Arguments

`img` — Image
grayscale image matrix | RGB image matrix | *m*-by-*n*-by-3 array

Image, returned as a matrix representing a grayscale or RGB image or as a *m*-by-*n*-by-3 array, depending on the sensor image.

`alpha` — Alpha channel
`uint8` grayscale image

Alpha channel, returned as a `uint8` grayscale image. If no alpha channel exists, `alpha` is empty.

Note For `CompressedImage` messages, you cannot output an Alpha channel.

Supported Image Encodings

ROS image messages can have different encodings. The encodings supported for images are different for `'sensor_msgs/Image'` and `'sensor_msgs/CompressedImage'` message types. Less compressed images are supported. The following encodings for raw images of size *M*x*N* are supported using the `'sensor_msgs/Image'` message type (**`'sensor_msgs/CompressedImage'` support is in bold**):

- **`rgb8, rgba8, bgr8, bgra8`**: `img` is an `rgb` image of size *M*x*N*x3. The alpha channel is returned in `alpha`. Each value in the outputs is represented as a `uint8`.

- `rgb16, rgba16, bgr16, bgra16`: `img` is an RGB image of size *M*x*N*x3. The alpha channel is returned in `alpha`. Each value in the outputs is represented as a `uint16`.

- **`mono8`** images are returned as grayscale images of size *M*x*N*x1. Each pixel value is represented as a `uint8`.

- `mono16` images are returned as grayscale images of size *M*x*N*x1. Each pixel value is represented as a `uint16`.

- `32fcX` images are returned as floating-point images of size *M*x*N*x*D*, where *D* is 1, 2, 3, or 4. Each pixel value is represented as a `single`.

- `64fcX` images are returned as floating-point images of size *M*x*N*x*D*, where *D* is 1, 2, 3, or 4. Each pixel value is represented as a `double`.

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- `8ucX` images are returned as matrices of size *MxNxD*, where *D* is 1, 2, 3, or 4. Each pixel value is represented as a `uint8`.

- `8scX` images are returned as matrices of size *MxNxD*, where *D* is 1, 2, 3, or 4. Each pixel value is represented as a `int8`.

- `16ucX` images are returned as matrices of size *MxNxD*, where *D* is 1, 2, 3, or 4. Each pixel value is represented as a `int16`.

- `16scX` images are returned as matrices of size *MxNxD*, where *D* is 1, 2, 3, or 4. Each pixel value is represented as a `int16`.

- `32scX` images are returned as matrices of size *MxNxD*, where *D* is 1, 2, 3, or 4. Each pixel value is represented as a `int32`.

- `bayer_X` images are returned as either Bayer matrices of size *MxN*x1, or as a converted image of size *MxN*x3 (Image Processing Toolbox™ is required).

The following encoding for raw images of size *MxN* is supported using the `'sensor_msgs/CompressedImage'` message type:

- `rgb8, rgba8, bgr8, bgra8`: `img` is an `rgb` image of size *MxN*x3. The alpha channel is returned in `alpha`. Each output value is represented as a `uint8`.

See Also

`writeImage`

Introduced in R2015a

readMessages

Read messages from rosbag

Syntax

```
msgs = readMessages(bag)
msgs = readMessages(bag,rows)
msgs = readMessages( ___ ,'DataFormat','struct')
```

Description

`msgs = readMessages(bag)` returns data from all the messages in the `BagSelection` object, `bag`. The messages are returned in a cell array of messages.

To get a `BagSelection` object, use `rosbag`.

`msgs = readMessages(bag,rows)` returns data from messages in the rows specified by `rows`. The range of the rows is [1, `bag.NumMessages`].

`msgs = readMessages( ___ ,'DataFormat','struct')` returns data as a cell array of structures using either set of the previous input arguments. Using structures can be significantly faster than using message objects, and custom message data can be read directly without loading message definitions using `rosgenmsg`.

Examples

Return ROS Messages as a Cell Array

Read rosbag and filter by topic and time.

```
bagselect = rosbag('ex_multiple_topics.bag');
bagselect2 = select(bagselect,'Time',...
[bagselect.StartTime bagselect.StartTime + 1],'Topic','/odom');
```

Return all messages as a cell array.

```
allMsgs = readMessages(bagselect2);
```

Return the first ten messages as a cell array.

```
firstMsgs = readMessages(bagselect2,1:10);
```

Read Messages from a rosbag as a Structure

Load the rosbag.

```
bag = rosbag('ros_turtlesim.bag');
```

Select a specific topic.

```
bSel = select(bag,'Topic','/turtle1/pose');
```

Read messages as a structure. Specify the `DataFormat` name-value pair when reading the messages. Inspect the first structure in the returned cell array of structures.

```
msgStructs = readMessages(bSel,'DataFormat','struct');
msgStructs{1}

ans = struct with fields:
        MessageType: 'turtlesim/Pose'
                  X: 5.5016
                  Y: 6.3965
              Theta: 4.5377
     LinearVelocity: 1
    AngularVelocity: 0
```

Extract the *xy* points from the messages and plot the robot trajectory.

Use `cellfun` to extract all the X and Y fields from the structure. These fields represent the *xy* positions of the robot during the rosbag recording.

```
xPoints = cellfun(@(m) double(m.X),msgStructs);
yPoints = cellfun(@(m) double(m.Y),msgStructs);
plot(xPoints,yPoints)
```

Input Arguments

bag — Message of rosbag
BagSelection object

All the messages contained within a rosbag, specified as a BagSelection object.

rows — Rows of BagSelection object
n-element vector

Rows of `BagSelection` object, specified as *n*-element vector, where *n* is the number of rows to retrieve messages from. Each entry in the vector corresponds to a numbered message in the bag. The range of the rows is [1, `bag.NumMessage`].

Output Arguments

`msgs` — ROS message data
object | cell array of message objects | cell array of structures

ROS message data, returned as an object, cell array of message objects, or cell array of structures. Data comes from the `BagSelection` object created using `rosbag`. You must specify `'DataFormat','struct'` in the function to get messages as a cell array of structures. Using structures can be significantly faster than using message objects, and custom message data can be read directly without loading message definitions using `rosgenmsg`.

See Also

rosbag | select | timeseries

Introduced in R2015a

readOccupancyGrid

Read occupancy grid message

Syntax

```
map = readOccupancyGrid(msg)
```

Description

`map = readOccupancyGrid(msg)` returns an `OccupancyGrid` object by reading the data inside a ROS message, `msg`, which must be a `'nav_msgs/OccupancyGrid'` message. All message data values are converted to probabilities from 0 to 1. The unknown values (-1) in the message are set as 0.5 in the map.

Examples

Read An OccupancyGrid Message from ROS

Create a `nav_msgs/OccupancyGrid` ROS message.

```
msg = rosmessage('nav_msgs/OccupancyGrid');
```

Populate the ROS occupancy grid message with data.

```
msg.Info.Height = 10;
msg.Info.Width = 10;
msg.Info.Resolution = 0.1;
msg.Data = 100*rand(100,1);
```

Read the msg data and convert to an `OccupancyGrid` object.

```
map = readOccupancyGrid(msg);
```

Input Arguments

msg — 'nav_msgs/OccupancyGrid' ROS message
OccupancyGrid object handle

'nav_msgs/OccupancyGrid' ROS message, specified as an OccupancyGrid ROS message object handle.

Output Arguments

map — Occupancy grid
robotics.OccupancyGrid object handle

Occupancy grid, returned as an robotics.OccupancyGrid object handle.

See Also

OccupancyGrid | readBinaryOccupancyGrid | robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | writeBinaryOccupancyGrid

Introduced in R2016b

readOccupancyMap3D

Read 3-D map from Octomap ROS message

Syntax

```
map = readOccupancyMap3D(msg)
```

Description

`map = readOccupancyMap3D(msg)` reads the data inside a ROS `'octomap_msgs/Octomap'` message to return an `OccupancyMap3D` object. All message data values are converted to probabilities from 0 to 1.

Examples

Read Octomap ROS Messages

Load Octomap ROS messages and read them into MATLAB® as an `OccupancyMap3D` object.

Load the Octomap ROS messages. The Octomap map messages were previously recorded in a rosbag and read into MATLAB® as ROS message objects. You could also get these ROS messages live on a network.

```
load octomap_msgs
disp(octomapMsgs{1})
```

```
  ROS Octomap message with properties:

    MessageType: 'octomap_msgs/Octomap'
         Header: [1×1 Header]
         Binary: 0
             Id: 'OcTree'
     Resolution: 0.0500
```

```
            Data: [1175340×1 int8]

    Use showdetails to show the contents of the message
```

Read the data from the ROS messages into an `occupancyMap3D` object. Display each map.

```
for i = 1:length(octomapMsgs)
    msg = octomapMsgs{i};
    map{i} = readOccupancyMap3D(msg);
    figure
    show(map{i});
end
```
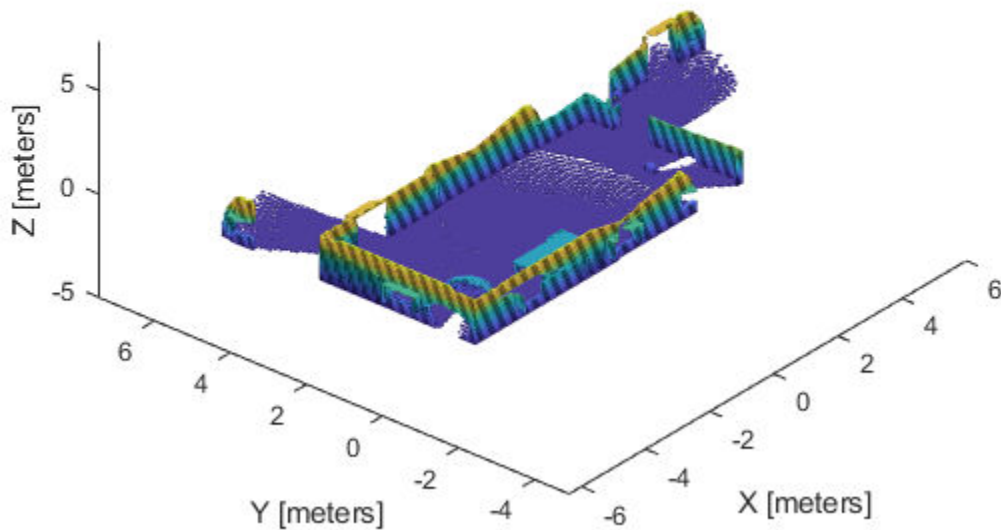

Occupancy Map

Occupancy Map
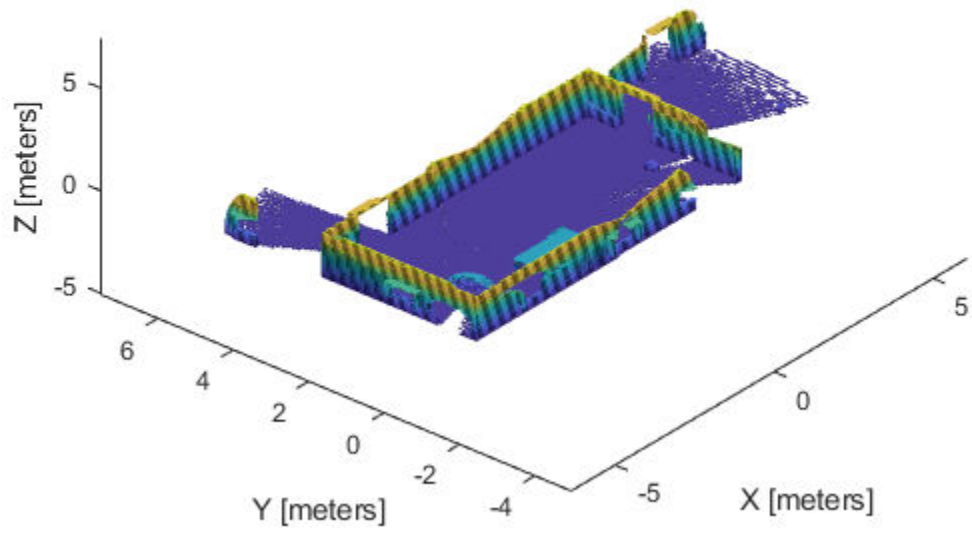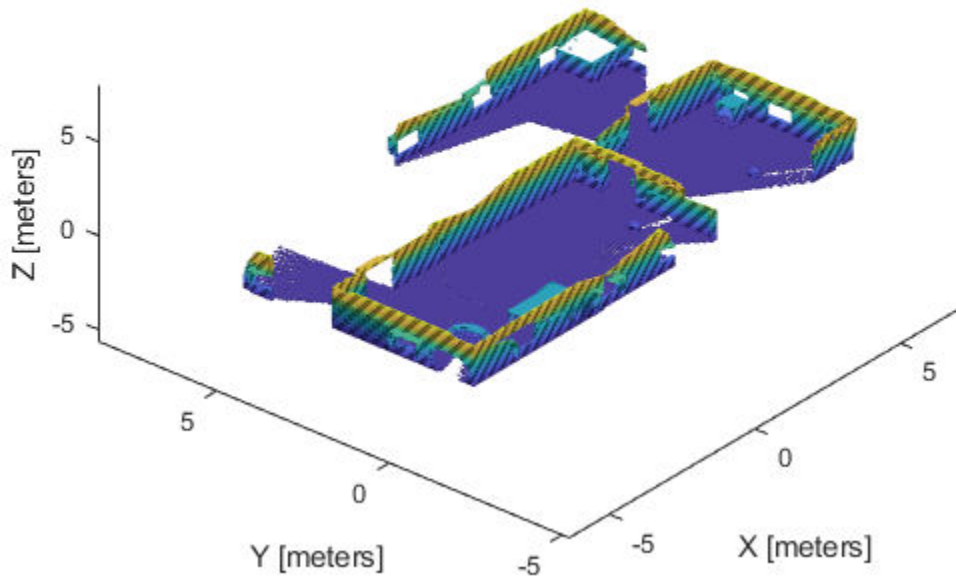
Input Arguments

msg — 'octomap_msgs/Octomap' ROS message
Octomap object handle

'octomap_msgs/Octomap' ROS message, specified as an Octomap object handle. Get this message by subscribing to an 'octomap_msgs/Octomap' topic using rossubscriber on a live ROS network or by creating your own message using rosmessage.

Output Arguments

map — 3-D occupancy map
OccupancyMap3D object handle

3-D occupancy map, returned as an OccupancyMap3D object handle.

See Also

OccupancyMap3D | rosmessage | rossubscriber

Introduced in R2018a

readRGB

Extract RGB values from point cloud data

Syntax

```
rgb = readRGB(pcloud)
```

Description

`rgb = readRGB(pcloud)` extracts the `[r g b]` values from all points in the `PointCloud2` object, `pcloud`, and returns them as an *n*-by-3 of *n* 3-D point coordinates. If the point cloud does not contain the RGB field, this function displays an error. To preserve the structure of the point cloud data, see "Preserving Point Cloud Structure" on page 2-229.

Examples

Read RGB Values from ROS Point Cloud Message

Load sample ROS messages including a ROS point cloud message, `ptcloud`.

```
exampleHelperROSLoadMessages
```

Read the RGB values from the point cloud.

```
rgb = readRGB(ptcloud);
```

Input Arguments

`pcloud` — Point cloud
`PointCloud2` object handle

Point cloud, specified as a `PointCloud2` object handle for a `'sensor_msgs/PointCloud2'` ROS message.

Output Arguments

`rgb` — List of RGB values from point cloud
matrix

List of RGB values from point cloud, returned as a matrix. By default, this is an *n*-by-3 matrix. If the point cloud object being read has the `PreserveStructureOnRead` property set to true, the points are returned as an *h*-by-*w*-by-3 matrix. For more information, see "Preserving Point Cloud Structure" on page 2-229.

Preserving Point Cloud Structure

Point cloud data can be organized in either 1-D lists or in 2-D image styles. 2-D image styles usually come from depth sensors or stereo cameras. The input `PointCloud2` object contains a `PreserveStructureOnRead` property that is either `true` or `false` (default). Suppose that you set the property to `true`.

```
pcloud.PreserveStructureOnRead = true;
```

Now calling any read functions (`readXYZ`,`readRGB`, or `readField`) preserves the organizational structure of the point cloud. When you preserve the structure, the output matrices are of size *m*-by-*n*-by-*d*, where *m* is the height, *n* is the width, and *d* is the number of return values for each point. Otherwise, all points are returned as an *x*-by-*d* list. This structure can only be preserved if the point cloud is organized.

See Also
`PointCloud2` | `readField` | `readXYZ`

Introduced in R2015a

readScanAngles

Return scan angles for laser scan range readings

Syntax

```
angles = readScanAngles(scan)
```

Description

`angles = readScanAngles(scan)` calculates the scan angles, `angles`, corresponding to the range readings in the laser scan message, `scan`. Angles are measured counter-clockwise around the positive *z*-axis, with the zero angle along the *x*-axis. `angles` is returned in radians and wrapped to the [–`pi`, `pi`] interval.

Examples

Read Scan Angles from ROS Laser Scan Message

Load sample ROS messages including a ROS laser scan message, `scan`.

```
exampleHelperROSLoadMessages
```

Read the scan angles from the laser scan.

```
angles = readScanAngles(scan);
```

Input Arguments

scan — Laser scan message
LaserScan object handle

`'sensor_msgs/LaserScan'` ROS message, specified as a `LaserScan` object handle.

Output Arguments

angles — Scan angles for laser scan data
n–by–1 matrix in radians

Scan angles for laser scan data, returned as an *n*-by-1 matrix in radians. Angles are measured counter-clockwise around the positive *z*-axis, with the zero angle along the *x*-axis. `angles` is returned in radians and wrapped to the [–`pi`, `pi`] interval.

See Also
`plot` | `readCartesian`

Introduced in R2015a

readXYZ

Extract XYZ coordinates from point cloud data

Syntax

```
xyz = readXYZ(pcloud)
```

Description

`xyz = readXYZ(pcloud)` extracts the `[x y z]` coordinates from all points in the `PointCloud2` object, `pcloud`, and returns them as an *n*-by-3 matrix of *n* 3-D point coordinates. If the point cloud does not contain the *x*, *y*, and *z* fields, this function returns an error. Points that contain `NaN` are preserved in the output. To preserve the structure of the point cloud data, see "Preserving Point Cloud Structure" on page 2-233.

Examples

Read XYZ Values from ROS Point Cloud Message

Load sample ROS messages including a ROS point cloud message, `ptcloud`.

```
exampleHelperROSLoadMessages
```

Read the XYZ values from the point cloud.

```
xyz = readXYZ(ptcloud);
```

Input Arguments

pcloud — Point cloud
`PointCloud2` object handle

Point cloud, specified as a `PointCloud2` object handle for a `'sensor_msgs/PointCloud2'` ROS message.

Output Arguments

xyz — List of XYZ values from point cloud
matrix

List of XYZ values from point cloud, returned as a matrix. By default, this is a *n*-by-3 matrix. If the point cloud object being read has the `PreserveStructureOnRead` property set to true, the points are returned as an *h*-by-*w*-by-3 matrix. For more information, see "Preserving Point Cloud Structure" on page 2-233.

Preserving Point Cloud Structure

Point cloud data can be organized in either 1-D lists or in 2-D image styles. 2-D image styles usually come from depth sensors or stereo cameras. The input `PointCloud2` object contains a `PreserveStructureOnRead` property that is either `true` or `false` (default). Suppose you set the property to `true`.

`pcloud.PreserveStructureOnRead = true;`

Now calling any read functions (`readXYZ`, `readRGB`, or `readField`) preserves the organizational structure of the point cloud. When you preserve the structure, the output matrices are of size *m*-by-*n*-by-*d*, where *m* is the height, *n* is the width, and *d* is the number of return values for each point. Otherwise, all points are returned as a *x*-by-*d* list. This structure can only be preserved if the point cloud is organized.

See Also
PointCloud2 | readField | readRGB

Introduced in R2015a

receive

Wait for new ROS message

Syntax

```
msg = receive(sub)
msg = receive(sub,timeout)
```

Description

`msg = receive(sub)` waits for MATLAB to receive a topic message from the specified subscriber, `sub`, and returns it as `msg`.

`msg = receive(sub,timeout)` specifies in `timeout` the number of seconds to wait for a message. If a message is not received within the timeout limit, the software throws an error.

Examples

Create A Subscriber and Get Data From ROS

Connect to a ROS network. Set up a sample ROS network. The `'/scan'` topic is being published on the network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_54632 with NodeURI http://bat5811win64:568
```

```
exampleHelperROSCreateSampleNetwork
```

Create a subscriber for the `'/scan'` topic. Wait for the subscriber to register with the master.

```
sub = rossubscriber('/scan');
pause(1);
```

Receive data from the subscriber as a ROS message. Specify a 10 second timeout.

```
msg2 = receive(sub,10)

msg2 =
  ROS LaserScan message with properties:

        MessageType: 'sensor_msgs/LaserScan'
             Header: [1x1 Header]
           AngleMin: -0.5216
           AngleMax: 0.5243
     AngleIncrement: 0.0016
      TimeIncrement: 0
           ScanTime: 0.0330
           RangeMin: 0.4500
           RangeMax: 10
             Ranges: [640x1 single]
        Intensities: [0x1 single]

  Use showdetails to show the contents of the message
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_54632 with NodeURI http://bat5811win64:56
Shutting down ROS master on http://bat5811win64:11311/.
```

Create, Send, And Receive ROS Messages

Set up a publisher and subscriber to send and receive a message on a ROS network.

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://AH-SRADFORD:11311/.
Initializing global node /matlab_global_node_10876 with NodeURI http://AH-SRADFORD:651
```

Create a publisher with a specific topic and message type. You can also return a default message to send using this publisher.

```
[pub,msg] = rospublisher('position','geometry_msgs/Point');
```

Modify the message before sending over the network.

```
msg.X = 1;
msg.Y = 2;
send(pub,msg);
```

Create a subscriber and wait for the latest message. Verify the message is the one you sent.

```
sub = rossubscriber('position')
pause(1);
sub.LatestMessage
```

```
sub =

  Subscriber with properties:

        TopicName: '/position'
      MessageType: 'geometry_msgs/Point'
    LatestMessage: [0×1 Point]
       BufferSize: 1
     NewMessageFcn: []


ans =

  ROS Point message with properties:

    MessageType: 'geometry_msgs/Point'
              X: 1
              Y: 2
              Z: 0

  Use showdetails to show the contents of the message
```

Shut down ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_10876 with NodeURI http://AH-SRADFORD:651
Shutting down ROS master on http://AH-SRADFORD:11311/.

Read Specific Field From Point Cloud Message

Load sample ROS messages including a ROS point cloud message, `ptcloud`.

`exampleHelperROSLoadMessages`

Read the `'x'` field name available on the point cloud message.

`x = readField(ptcloud,'x');`

• "Exchange Data with ROS Publishers and Subscribers"

Input Arguments

sub — ROS subscriber
Subscriber object handle

ROS subscriber, specified as a `Subscriber` object handle. You can create the subscriber using `rossubscriber`.

timeout — Timeout for receiving a message
scalar in seconds

Timeout for receiving a message, specified as a scalar in seconds.

Output Arguments

msg — ROS message
Message object handle

ROS message, returned as a `Message` object handle.

See Also
rosmessage | rospublisher | rossubscriber | rostopic | send

Topics

"Exchange Data with ROS Publishers and Subscribers"

Introduced in R2015a

removeEdges

Package: robotics

Remove loop closure edges from graph

Syntax

```
removeEdges(poseGraph,edgeIDs)
```

Description

removeEdges(poseGraph,edgeIDs) removes loop closure edges from the pose graph. Edges that are not loop closures cannot be removed.

Input Arguments

poseGraph — Pose graph
PoseGraph object | PoseGraph3D object

Pose graph, specified as a PoseGraph or PoseGraph3D object.

edgeIDs — Edge IDs
vector of positive integers

Edge IDs, specified as a vector of positive integers.

See Also

Functions
addRelativePose | edgeConstraints | edges | findEdgeID | nodes | optimizePoseGraph

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

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Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

removeInvalidData

Remove invalid range and angle data

Syntax

```
validScan = removeInvalidData(scan)
validScan = removeInvalidData(scan,Name,Value)
```

Description

`validScan = removeInvalidData(scan)`returns a new `lidarScan` object with all `Inf` and `NaN` values from the input `scan` removed. The corresponding angle readings are also removed.

`validScan = removeInvalidData(scan,Name,Value)`provides additional options specified by one or more `Name,Value` pairs.

Examples

Plot Lidar Scan and Remove Invalid Points

Specify lidar data as vectors of ranges and angles. These values include readings outside of the sensors range.

```
x = linspace(-2,2);
ranges = abs((1.5).*x.^2 + 5);
ranges(45:55) = 3.5;
angles = linspace(-pi/2,pi/2,numel(ranges));
```

Create a lidar scan by specifying the ranges and angles. Plot all points of the lidar scan.

```
scan = lidarScan(ranges,angles);
plot(scan)
```

LiDAR Scan

Remove invalid points based on a specified minimum and maximum range.

```
minRange = 0.1;
maxRange = 7;
scan2 = removeInvalidData(scan,'RangeLimits',[minRange maxRange]);
hold on
plot(scan2)
legend('All Points','Valid Points')
```

Input Arguments

scan — Lidar scan readings
lidarScan object

Lidar scan readings, specified as a lidarScan object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single

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

Example: `['RangeLimits',[0.05 2]`

RangeLimits — Range reading limits
two-element vector

Range reading limits, specified as a two-element vector, `[minRange maxRange]`, in meters. All range readings and corresponding angles outside these range limits are removed

Data Types: `single` | `double`

AngleLimits — Angle limits
two-element vector

Angle limits, specified as a two-element vector, `[minAngle maxAngle]` in radians. All angles and corresponding range readings outside these angle limitslimits are removed.

Angles are measured counter-clockwise around the positive z-axis.

Data Types: `single` | `double`

Output Arguments

validScan — Lidar scan readings
`lidarScan` object

Lidar scan readings, specified as a `lidarScan` object. All invalid lidar scan readings are removed.

See Also
`lidarScan` | `matchScans` | `transformScan`

Introduced in R2017b

reset

Reset `Rate` object

Syntax

```
reset(rate)
```

Description

`reset(rate)` resets the state of the `Rate` object, including the elapsed time and all statistics about previous periods. `reset` is useful if you want to run multiple successive loops at the same rate, or if the object is created before the loop is executed.

Input Arguments

rate — Rate object
handle

`Rate` object, specified as a handle. This object contains the information for the desired rate and other information about the execution. See `robotics.Rate` for more information.

Examples

Run Loop At Fixed Rate and Reset Rate Object

Create a `Rate` object for running at 20 Hz.

```
r = robotics.Rate(2);
```

Start a loop and control operation using the `Rate` object.

```matlab
for i = 1:30
    % Your code goes here
    waitfor(r);
end
```

Display the `Rate` object properties after loop operation.

```matlab
disp(r)
```

```
  Rate with properties:

         DesiredRate: 2
       DesiredPeriod: 0.5000
        OverrunAction: 'slip'
    TotalElapsedTime: 15.0140
          LastPeriod: 0.4992
```

Reset the object to restart the time statistics.

```matlab
reset(r);
disp(r)
```

```
  Rate with properties:

         DesiredRate: 2
       DesiredPeriod: 0.5000
        OverrunAction: 'slip'
    TotalElapsedTime: 0.0091
          LastPeriod: NaN
```

- "Execute Code at a Fixed-Rate"

See Also

`robotics.Rate` | `rosrate` | `waitfor`

Topics
"Execute Code at a Fixed-Rate"

Introduced in R2016a

roboticsAddons

Install add-ons for robotics

Syntax

```
roboticsAddons
```

Description

`roboticsAddons` allows you to download and install add-ons for Robotics System Toolbox. Use this function to open the Add-ons Explorer to browse the available add-ons.

Examples

Install Add-ons for Robotics System Toolbox™

```
roboticsAddons
```

- "Install Robotics System Toolbox Add-ons"
- "ROS Custom Message Support"
- "Get Add-Ons" (MATLAB)
- "Manage Your Add-Ons" (MATLAB)

See Also

Topics
"Install Robotics System Toolbox Add-ons"
"ROS Custom Message Support"
"Get Add-Ons" (MATLAB)

"Manage Your Add-Ons" (MATLAB)

Introduced in R2016a

roboticsSupportPackages

Download and install support packages for Robotics System Toolbox

Note `roboticsSupportPackages` has been removed. Use `roboticsAddons` instead.

Syntax

roboticsSupportPackages

Description

`roboticsSupportPackages` opens the Support Package Installer to download and install support packages for Robotics System Toolbox. For more details, see "Install Robotics System Toolbox Add-ons"

Examples

Open Robotics System Toolbox Support Package Installer

roboticsSupportPackages

Introduced in R2015a

rosaction

Retrieve information about ROS actions

Syntax

```
rosaction list
rosaction info actionname
rosaction type actionname

actionlist = rosaction('list')
actioninfo = rosaction('info',actionname)
actiontype = rosaction('type',actionname)
```

Description

`rosaction list` returns a list of available ROS actions from the ROS network.

`rosaction info actionname` returns the action type, message types, action server, and action clients for the specified action name.

`rosaction type actionname` returns the action type for the specified action name.

`actionlist = rosaction('list')` returns a list of available ROS actions from the ROS network.

`actioninfo = rosaction('info',actionname)` returns a structure containing the action type, message types, action server, and action clients for the specified action name.

`actiontype = rosaction('type',actionname)` returns the action type for the specified action name.

Examples

Get Information About ROS Actions

Get information about ROS actions that are available from the ROS network. You must be connected to a ROS network using `rosinit`.

Connect to a ROS network. You must be connected to a ROS network to gather information about what actions are available. Action types must be set up beforehand with a ROS action server running on the network. Replace `ipaddress` with your network address.

```
ipaddress = '192.168.154.131';
rosinit(ipaddress)
```

Initializing global node /matlab_global_node_87036 with NodeURI http://192.168.154.1:62

List the actions available on the network. The only action setup on this network is the `'/fibonacci'` action.

```
rosaction list
```

/fibonacci

Get information about a specific ROS action type. The action type, message types, action server, and clients are displayed.

```
rosaction info /fibonacci
```

Action Type: actionlib_tutorials/Fibonacci

Goal Message Type: actionlib_tutorials/FibonacciGoal
Feedback Message Type: actionlib_tutorials/FibonacciFeedback
Result Message Type: actionlib_tutorials/FibonacciResult

Action Server:
* /fibonacci (http://192.168.154.131:38213/)

Action Clients: None

Disconnect from the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_87036 with NodeURI http://192.168.154.1:6

Input Arguments

actionname — ROS action name
character vector

ROS action name, specified as a character vector. The action name must match one of the topics that `rosaction('list')` outputs.

Output Arguments

actionlist — List of actions available
cell array of character vectors

List of actions available on the ROS network, returned as a cell array of character vectors.

actioninfo — Information about a ROS action
structure

Information about a ROS action, returned as a structure. `actioninfo` contains the following fields:

- `ActionType`
- `GoalMessageType`
- `FeedbackMessageType`
- `ResultMessageType`
- `ActionServer`
- `ActionClients`

For more information about ROS actions, see "ROS Actions Overview".

actiontype — Type of ROS action
character vector

Type of ROS action, returned as a character vector.

See Also

cancelGoal | rosmessage | rostopic | sendGoal | waitForServer

Topics

"ROS Actions Overview"
"Move a Turtlebot Robot Using ROS Actions"

Introduced in R2016b

rosbag

Open and parse rosbag log file

Syntax

```
bag = rosbag(filename)
```

```
bagInfo = rosbag('info',filename)
rosbag info filename
```

Description

`bag = rosbag(filename)` creates an indexable `BagSelection` object, `bag`, that contains all the message indexes from the rosbag at path `filename`. To get a `BagSelection` object, use `rosbag`. To access the data, call `readMessages` or `timeseries` to extract relevant data.

A rosbag, or bag, is a file format for storing ROS message data. They are used primarily to log messages within the ROS network. You can use these bags for offline analysis, visualization, and storage. See the ROS Wiki page for more information about rosbags.

`bagInfo = rosbag('info',filename)` returns information as a structure, `bagInfo`, about the contents of the rosbag at `filename`.

`rosbag info filename` displays information in the MATLAB command window about the contents of the rosbag at `filename`. The information includes the number of messages, start and end times, topics, and message types.

Examples

Retrieve Information from rosbag

Retrieve information from the rosbag. Specify the full path to the rosbag if it is not already available on the MATLAB® path.

```
bagselect = rosbag('ex_multiple_topics.bag');
```

Select a subset of the messages, filtered by time and topic.

```
bagselect2 = select(bagselect,'Time',...
    [bagselect.StartTime bagselect.StartTime + 1],'Topic','/odom');
```

Display rosbag Information from File

To view information about a rosbag log file, use rosbag info *filename,* where *filename* is a rosbag (.bag) file.

```
rosbag info 'ex_multiple_topics.bag'

Path:     C:\TEMP\Bdoc18a_815039_17936\ib0BF173\13\tp528964cd\robotics-ex61825935\ex_mu
Version:  2.0
Duration: 2:00s (120s)
Start:    Dec 31 1969 19:03:21.34 (201.34)
End:      Dec 31 1969 19:05:21.34 (321.34)
Size:     23.6 MB
Messages: 36963
Types:    gazebo_msgs/LinkStates [48c080191eb15c41858319b4d8a609c2]
          nav_msgs/Odometry      [cd5e73d190d741a2f92e81eda573aca7]
          rosgraph_msgs/Clock    [a9c97c1d230cfc112e270351a944ee47]
          sensor_msgs/LaserScan  [90c7ef2dc6895d81024acba2ac42f369]
Topics:   /clock             12001 msgs  : rosgraph_msgs/Clock
          /gazebo/link_states 11999 msgs  : gazebo_msgs/LinkStates
          /odom              11998 msgs  : nav_msgs/Odometry
          /scan                965 msgs  : sensor_msgs/LaserScan
```

Get Transformations from rosbag File

Get transformations from rosbag (.bag) files by loading the rosbag and checking the available frames. From these frames, use getTransform to query the transformation between two coordinate frames.

Load the rosbag.

```
bag = rosbag('ros_turtlesim.bag');
```

Get a list of available frames.

```
frames = bag.AvailableFrames;
```

Get the latest transformation between two coordinate frames.

```
tf = getTransform(bag,'world',frames{1});
```

Check for a transformation available at a specific time and retrieve the transformation. Use `canTransform` to check if the transformation is available. Specify the time using `rostime`.

```
tfTime = rostime(bag.StartTime + 1);
if (canTransform(bag,'world',frames{1},tfTime))
    tf2 = getTransform(bag,'world',frames{1},tfTime);
end
```

Read Messages from a rosbag as a Structure

Load the rosbag.

```
bag = rosbag('ros_turtlesim.bag');
```

Select a specific topic.

```
bSel = select(bag,'Topic','/turtle1/pose');
```

Read messages as a structure. Specify the `DataFormat` name-value pair when reading the messages. Inspect the first structure in the returned cell array of structures.

```
msgStructs = readMessages(bSel,'DataFormat','struct');
msgStructs{1}
```

```
ans = struct with fields:
        MessageType: 'turtlesim/Pose'
                  X: 5.5016
                  Y: 6.3965
              Theta: 4.5377
     LinearVelocity: 1
    AngularVelocity: 0
```

Extract the xy points from the messages and plot the robot trajectory.

Use `cellfun` to extract all the X and Y fields from the structure. These fields represent the xy positions of the robot during the rosbag recording.

```
xPoints = cellfun(@(m) double(m.X),msgStructs);
yPoints = cellfun(@(m) double(m.Y),msgStructs);
plot(xPoints,yPoints)
```


Input Arguments

`filename` — Name of rosbag file and path
character vector

Name of file and path for the rosbag you want to access, specified as a character vector. This path can be relative or absolute.

Output Arguments

bag — Selection of rosbag messages
BagSelection object handle

Selection of rosbag messages, returned as a `BagSelection` object handle.

bagInfo — Information about contents of rosbag
structure

Information about the contents of the rosbag, returned as a structure. This structure contains fields related to the rosbag file and its contents. A sample output for a rosbag as a structure is:

```
Path:      \ros\data\ex_multiple_topics.bag
Version:   2.0
Duration:  2:00s (120s)
Start:     Dec 31 1969 19:03:21.34 (201.34)
End:       Dec 31 1969 19:05:21.34 (321.34)
Size:      23.6 MB
Messages:  36963
Types:     gazebo_msgs/LinkStates [48c080191eb15c41858319b4d8a609c2]
           nav_msgs/Odometry      [cd5e73d190d741a2f92e81eda573aca7]
           rosgraph_msgs/Clock    [a9c97c1d230cfc112e270351a944ee47]
           sensor_msgs/LaserScan  [90c7ef2dc6895d81024acba2ac42f369]
Topics:    /clock             12001 msgs  : rosgraph_msgs/Clock
           /gazebo/link_states 11999 msgs  : gazebo_msgs/LinkStates
           /odom              11998 msgs  : nav_msgs/Odometry
           /scan                965 msgs  : sensor_msgs/LaserScan
```

See Also
BagSelection | canTransform | getTransform | readMessages | select | timeseries

Introduced in R2015a

rosduration

Create a ROS duration object

Syntax

```
dur = rosduration
dur = rosduration(totalSecs)
dur = rosduration(secs,nsecs)
```

Description

`dur = rosduration` returns a default ROS duration object. The properties for seconds and nanoseconds are set to 0.

`dur = rosduration(totalSecs)` initializes the time values for seconds and nanoseconds based on `totalSecs`, which represents the time in seconds as a floating-point number.

`dur = rosduration(secs,nsecs)` initializes the time values for seconds and nanoseconds individually. Both inputs must be integers. Large values for `nsecs` are wrapped automatically with the remainder added to `secs`.

Examples

Work with ROS Duration Objects

Create ROS `Duration` objects, perform addition and subtraction, and compare duration objects. You can also add duration objects to ROS `Time` objects to get another `Time` object.

Create a duration using seconds and nanoseconds.

```
dur1 = rosduration(100,2000000)
```

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```
dur1 =
  ROS Duration with properties:

     Sec: 100
    Nsec: 2000000
```

Create a duration using a floating-point value. This sets the seconds using the integer portion and nanoseconds with the remainder.

```
dur2 = rosduration(20.5)
```

```
dur2 =
  ROS Duration with properties:

     Sec: 20
    Nsec: 500000000
```

Add the two durations together to get a single duration.

```
dur3 = dur1 + dur2
```

```
dur3 =
  ROS Duration with properties:

     Sec: 120
    Nsec: 502000000
```

Subtract durations and get a negative duration. You can initialize durations with negative values as well.

```
dur4 = dur2 - dur1
```

```
dur4 =
  ROS Duration with properties:

     Sec: -80
    Nsec: 498000000
```

```
dur5 = rosduration(-1,2000000)
```

```
dur5 =
  ROS Duration with properties:
```

```
     Sec: -1
    Nsec: 2000000
```

Compare durations.

```
dur1 > dur2

ans = logical
   1
```

Add a duration to a ROS `Time` object.

```
time = rostime('now','system')

time =
  ROS Time with properties:

     Sec: 1.5197e+09
    Nsec: 533000000
```

```
timeFuture = time + dur3

timeFuture =
  ROS Time with properties:

     Sec: 1.5197e+09
    Nsec: 35000000
```

Input Arguments

totalSecs — Total time
0 (default) | scalar

Total time, specified as a floating-point scalar. The integer portion is set to the `Sec` property with the remainder applied to `Nsec` property of the `Duration` object.

secs — Whole seconds
0 (default) | integer

Whole seconds, specified as an integer. This value is directly set to the `Sec` property of the `Duration` object.

Note The maximum and minimum values for `secs` are `[-2147483648, 2147483647]`.

---

nsecs — Nanoseconds
0 (default) | positive integer

Nanoseconds, specified as a positive integer. This value is directly set to the `NSec` property of the `Duration` object unless it is greater than or equal to 10^9. The value is then wrapped and the remainders are added to the value of `secs`.

Output Arguments

dur — Duration
ROS `Duration` object

Duration, returned as a ROS `Duration` object with `Sec` and `Nsec` properties.

See Also
`rosmessage` | `rostime` | `seconds`

Introduced in R2016b

rosgenmsg

Generate custom messages from ROS definitions

Syntax

```
rosgenmsg(folderpath)
```

Description

`rosgenmsg(folderpath)` generates ROS custom messages in MATLAB by reading ROS custom message and service definitions in the specified folder path. The function expects ROS package folders inside the folder path. These packages contain the message definitions in `.msg` files and the service definitions in `.srv` files. Also, the packages require a `package.xml` file to define its contents.

After calling this function, you can send and receive your custom messages in MATLAB like all other supported messages. You can create these messages using `rosmessage` or view the list of messages by calling `rosmsg list`.

Note You must install the Robotics System Toolbox Interface for ROS Custom Messages add-on using `roboticsAddons` to use this function.

Examples

Generate MATLAB Code for ROS Custom Messages

After you install the support package and prepare your custom message package folder, specify the folder path and call `rosgenmsg`.

```
folderpath = 'C:/Users/user1/Documents/robot_custom_msg/';
rosgenmsg(folderpath)
```

- "Create Custom Messages from ROS Package"

Input Arguments

folderpath — Path to ROS package folders
character vector

Path to package folders, specified as a character vector. These folders contain message definitions in `.msg` files and the service definitions in `.srv` files. Also, the packages require a `package.xml` file to define its contents.

Limitations

- You must install the Robotics System Toolbox Interface for ROS Custom Messages add-on using `roboticsAddons` to use this function.

See Also
`roboticsAddons`

Topics
"Create Custom Messages from ROS Package"
"ROS Custom Message Support"

External Websites
ROS Tutorials: Defining Custom Messages
ROS Tutorials: Creating a ROS msg and srv

Introduced in R2015a

rosinit

Connect to ROS network

Syntax

```
rosinit
rosinit(hostname)
rosinit(hostname,port)
rosinit(URI)
rosinit( ___ ,Name,Value)
```

Description

`rosinit` starts the global ROS node with a default MATLAB name and tries to connect to a ROS master running on `localhost` and port `11311`. If the global ROS node cannot connect to the ROS master, `rosinit` also starts a ROS core in MATLAB, which consists of a ROS master, a ROS parameter server, and a rosout logging node.

`rosinit(hostname)` tries to connect to the ROS master at the host name or IP address specified by `hostname`. This syntax uses `11311` as the default port number.

`rosinit(hostname,port)` tries to connect to the host name or IP address specified by `hostname` and the port number specified by `port`.

`rosinit(URI)` tries to connect to the ROS master at the given resource identifier, `URI`, for example, `'http://192.168.1.1:11311'`.

`rosinit( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments. `Name` must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Using `rosinit` is a prerequisite for most ROS-related tasks in MATLAB because:

- Communicating with a ROS network requires a ROS node connected to a ROS master.

- By default, ROS functions in MATLAB operate on the global ROS node, or they operate on objects that depend on the global ROS node.

For example, after creating a global ROS node with `rosinit`, you can subscribe to a topic on the global ROS node. When another node on the ROS network publishes messages on that topic, the global ROS node receives the messages.

If a global ROS node already exists, then `rosinit` restarts the global ROS node based on the new set of arguments.

For more advanced ROS networks, connecting to multiple ROS nodes or masters is possible using the `Node` object.

Examples

Start ROS Core and Global Node

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_25227 with NodeURI http://bat5811win64:56
```

When you are finished, shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_25227 with NodeURI http://bat5811win64:56
Shutting down ROS master on http://bat5811win64:11311/.
```

Start Node and Connect to ROS Master at Specified IP Address

```
rosinit('192.168.154.131')
```

```
Initializing global node /matlab_global_node_76850 with NodeURI http://192.168.154.1:50
```

Shut down the ROS network when you are finished.

```
rosshutdown
```

Shutting down global node /matlab_global_node_76850 with NodeURI http://192.168.154.1:5

Start Global Node at Given IP and NodeName

rosinit('192.168.154.131', 'NodeHost','192.168.1.1','NodeName','/test_node')

Initializing global node /test_node with NodeURI http://192.168.1.1:59577/

Shut down the ROS network when you are finished.

rosshutdown

Shutting down global node /test_node with NodeURI http://192.168.1.1:59577/

- "Connect to a ROS Network"

Input Arguments

hostname — Host name or IP address
character vector

Host name or IP address, specified as a character vector.

port — Port number
scalar

Port number used to connect to the ROS master, specified as a scalar.

URI — URI for ROS master
character vector

URI for ROS master, specified as a character vector. Standard format for URIs is either http://ipaddress:port or http://hostname:port

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'NodeHost','192.168.1.1'

NodeHost — Host name or IP address
character vector

Host name or IP address under which the node advertises itself to the ROS network, specified as the comma-separated pair consisting of' 'NodeHost' and a character vector.

Example: 'comp-home'

NodeName — Global node name
character vector

Global node name, specified as the comma-separated pair consisting of 'NodeName' and a character vector. The node that is created through `rosinit` is registered on the ROS network with this name.

Example: 'NodeName','/test_node'

See Also
Node | `rosshutdown`

Topics
"Connect to a ROS Network"

Introduced in R2015a

rosmessage

Create ROS messages

Syntax

```
msg = rosmessage(messagetype)

msg = rosmessage(pub)
msg = rosmessage(sub)
msg = rosmessage(client)
msg = rosmessage(server)
```

Description

`msg = rosmessage(messagetype)` creates an empty ROS message object with message type. The `messagetype` character vector is case-sensitive and no partial matches are allowed. It must match a message on the list given by calling `rosmsg('list')`.

`msg = rosmessage(pub)` creates an empty message determined by the topic published by `pub`.

`msg = rosmessage(sub)` creates an empty message determined by the subscribed topic of `sub`.

`msg = rosmessage(client)` creates an empty message determined by the service associated with `client`.

`msg = rosmessage(server)` creates an empty message determined by the service type of `server`.

Examples

Create Empty String Message

```
strMsg = rosmessage('std_msgs/String')

strMsg =
  ROS String message with properties:

    MessageType: 'std_msgs/String'
           Data: ''

  Use showdetails to show the contents of the message
```

Create a ROS Publisher and Send Data

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_81707 with NodeURI http://bat5811win64:570
```

Create publisher for the '/chatter' topic with the 'std_msgs/String' message type.

```
chatpub = rospublisher('/chatter','std_msgs/String');
```

Create a message to send. Specify the Data property.

```
msg = rosmessage(chatpub);
msg.Data = 'test phrase';
```

Send message via the publisher.

```
send(chatpub,msg);
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_81707 with NodeURI http://bat5811win64:57
Shutting down ROS master on http://bat5811win64:11311/.
```

Create and Access An Array Of ROS Messages

You can create an object array to store multiple messages. The array is indexable similar to any other array. You can modify properties of each object or access specific properties from each element using dot notation.

Create a two message object array.

```
msgArray = [rosmessage('std_msgs/String') rosmessage('std_msgs/String')]

msgArray =
  1x2 ROS String message array with properties:

    MessageType
    Data
```

Assign data to individual object elements of the array.

```
msgArray(1).Data = 'Some string';
msgArray(2).Data = 'Other string';
```

Read all the `Data` properties from the message objects into a cell array.

```
allData = {msgArray.Data}

allData = 1x2 cell array
    {'Some string'}    {'Other string'}
```

Preallocate A ROS Message Array

To preallocate an array using ROS messages, use the `arrayfun` or `cellfun` functions instead of `repmat`. These functions create object or cell arrays for handle classes properly.

Preallocate an object array of ROS messages.

```
msgArray = arrayfun(@(~) rosmessage('std_msgs/String'),zeros(1,50));
```

Preallocate a cell array of ROS messages.

```
msgCell = cellfun(@(~) rosmessage('std_msgs/String'),cell(1,50),'UniformOutput',false);
```

Input Arguments

`messagetype` — Message type
character vector

Message type, specified as a character vector. The character vector is case-sensitive and no partial matches are allowed. It must match a message on the list given by calling `rosmsg('list')`. To avoid errors in entering the message type, you can use `rostype` with tab completion to browse the list of all available types.

`pub` — ROS publisher
`Publisher` object handle

ROS publisher, specified as a `Publisher` object handle. You can create the object using `rospublisher`.

`sub` — ROS subscriber
`Subscriber` object handle

ROS subscriber, specified as a `Subscriber` object handle. You can create the object using `rossubscriber`.

`client` — ROS service client
`ServiceClient` object handle

ROS service client, specified as a `ServiceClient` object handle. You can create the object using `rossvcclient`.

`server` — ROS service server
`ServiceServer` object handle

ROS service server, specified as a `ServiceServer` object handle. You can create the object using `rossvcserver`.

Output Arguments

`msg` — ROS message
`Message` object handle

ROS message, returned as a `Message` object handle.

See Also

roboticsAddons | rosmsg | rostopic

Topics

"Work with Basic ROS Messages"
"Built-In Message Support"

Introduced in R2015a

rosmsg

Retrieve information about ROS messages and message types

Syntax

```
rosmsg show msgtype
rosmsg md5 msgtype
rosmsg list

msginfo = rosmsg('show', msgtype)
msgmd5 = rosmsg('md5', msgtype)
msglist = rosmsg('list')
```

Description

`rosmsg show msgtype` returns the definition of the `msgtype` message.

`rosmsg md5 msgtype` returns the MD5 checksum of the `msgtype` message.

`rosmsg list` returns all available message types that you can use in MATLAB.

`msginfo = rosmsg('show', msgtype)` returns the definition of the `msgtype` message as a character vector.

`msgmd5 = rosmsg('md5', msgtype)` returns the 'MD5' checksum of the `msgtype` message as a character vector.

`msglist = rosmsg('list')` returns a cell array containing all available message types that you can use in MATLAB.

Examples

Retrieve Message Type Definition

```
msgInfo = rosmsg('show','geometry_msgs/Point')

msgInfo =
    '% This contains the position of a point in free space
     double X
     double Y
     double Z
     '
```

Get the MD5 Checksum of Message Type

```
msgMd5 = rosmsg('md5','geometry_msgs/Point')

msgMd5 =
'4a842b65f413084dc2b10fb484ea7f17'
```

Input Arguments

`msgtype` — ROS message type
character vector

ROS message type, specified as a character vector. `msgType` must be a valid ROS message type from ROS that MATLAB supports.

Example: 'std_msgs/Int8'

Output Arguments

`msginfo` — Details of message definition
character vector

Details of the information inside the ROS message definition, returned as a character vector.

`msgmd5` — MD5 checksum hash value
character vector

MD5 checksum hash value, returned as a character vector. The MD5 output is a character vector representation of the 16-byte hash value that follows the MD5 standard.

`msglist` — List of all message types available in MATLAB
cell array of character vectors

List of all message types available in MATLAB, returned as a cell array of character vectors.

Introduced in R2015a

rosnode

Retrieve information about ROS network nodes

Syntax

```
rosnode list
rosnode info nodename
rosnode ping nodename

nodelist = rosnode('list')
nodeinfo = rosnode('info',nodename)
rosnode('ping',nodename)
```

Description

`rosnode list` returns a list of all nodes registered on the ROS network. Use these nodes to exchange data between MATLAB and the ROS network.

`rosnode info nodename` returns a structure containing the name, URI, publications, subscriptions, and services of a specific ROS node, `nodename`.

`rosnode ping nodename` pings a specific node, `nodename`, and displays the response time.

`nodelist = rosnode('list')` returns a cell array of character vectors containing the nodes registered on the ROS network.

`nodeinfo = rosnode('info',nodename)` returns a structure containing the name, URI, publications, subscriptions, and services of a specific ROS node, `nodename`.

`rosnode('ping',nodename)` pings a specific node, `nodename` and displays the response time.

Examples

Retrieve List of ROS Nodes

Note: This example requires a valid ROS network to be active with ROS nodes previously set up.

Connect to the ROS network. Specify the IP address for your specific network.

```
rosinit('192.168.203.129')
```

Initializing global node /matlab_global_node_90274 with NodeURI http://192.168.203.1:63

List the nodes available from the ROS master.

```
rosnode list
```

```
/bumper2pointcloud
/cmd_vel_mux
/depthimage_to_laserscan
/gazebo
/laserscan_nodelet_manager
/matlab_global_node_90274
/mobile_base_nodelet_manager
/robot_state_publisher
/rosout
```

Shut down the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_90274 with NodeURI http://192.168.203.1:6

Retrieve ROS Node Information

Connect to the ROS network. Specify the IP address for your specific network.

```
rosinit('192.168.154.131')
```

Initializing global node /matlab_global_node_40513 with NodeURI http://192.168.154.1:6

Get information on the '/robot_state_publisher' node. This node is available on the ROS master.

```
nodeinfo = rosnode('info','/robot_state_publisher')
```

```
nodeinfo =

  struct with fields:

         NodeName: '/robot_state_publisher'
              URI: 'http://192.168.154.131:40244/'
     Publications: [2×1 struct]
    Subscriptions: [2×1 struct]
         Services: [2×1 struct]
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_40513 with NodeURI http://192.168.154.1:6
```

Ping ROS Node

Connect to the ROS network. Specify the IP address for your specific network.

```
rosinit('192.168.154.131')
```

```
Initializing global node /matlab_global_node_88195 with NodeURI http://192.168.154.1:50
```

Ping the '/robot_state_publisher' node. This node is available on the ROS master.

```
nodeinfo = rosnode('info','/robot_state_publisher')
```

```
nodeinfo =

  struct with fields:

         NodeName: '/robot_state_publisher'
              URI: 'http://192.168.154.131:40244/'
     Publications: [2×1 struct]
    Subscriptions: [2×1 struct]
         Services: [2×1 struct]
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_88195 with NodeURI http://192.168.154.1:5
```

Input Arguments

nodename — Name of node
character vector

Name of node, specified as a character vector. The name of the node must match the name given in ROS.

Output Arguments

nodeinfo — Information about ROS node
structure

Information about ROS node, returned as a structure containing these properties: `'NodeName'`, `'URI'`, `'Publications'`, `'Subscriptions'`, and `'Services'`. Access these properties using dot syntax, for example, `nodeinfo.NodeName`.

nodelist — List of node names available
cell array of character vectors

List of node names available, returned as a cell array of character vectors.

See Also
`rosinit` | `rostopic`

Introduced in R2015a

rosparam

Access ROS parameter server values

Syntax

```
list = rosparam('list')
list = rosparam('list',namespace)
pvalOut = rosparam('get',pname)
pvalOut = rosparam('get',namespace)
rosparam('set',pname,pval)
rosparam('delete',pname)
rosparam('delete',namespace)

ptree = rosparam
```

Description

`list = rosparam('list')` returns the list of all ROS parameter names from the ROS master.

Simplified form: `rosparam list`

`list = rosparam('list',namespace)` returns the list of all parameter names under the specified ROS namespace.

Simplified form: `rosparam list namespace`

`pvalOut = rosparam('get',pname)` retrieves the value of the specified parameter.

Simplified form: `rosparam get pname`

`pvalOut = rosparam('get',namespace)` retrieves the values of all parameters under the specified namespace as a structure.

Simplified form: `rosparam get namespace`

`rosparam('set',pname,pval)` sets a value for a specified parameter name. If the parameter name does not exist, the function adds a new parameter in the parameter tree.

Simplified form: `rosparam set pname pval`

See "Limitations" on page 2-288 for limitations on `pval`.

`rosparam('delete',pname)` deletes a parameter from the parameter tree. If the parameter does not exist, the function displays an error.

Simplified form: `rosparam delete pname`

`rosparam('delete',namespace)` deletes all parameters under the given namespace from the parameter tree.

Simplified form: `rosparam delete namespace`

`ptree = rosparam` creates a parameter tree object, `ptree`. After `ptree` is created, the connection to the parameter server remains persistent until the object is deleted or the ROS master becomes unavailable.

A ROS parameter tree communicates with the ROS parameter server. The ROS parameter server can store strings, integers, doubles, booleans and cell arrays. The parameters are accessible by every node in the ROS network. Use the parameters to store static data such as configuration parameters. Use the `get`, `set`, `has`, `search`, and `del` functions to manipulate and view parameter values.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed.

- 32-bit integer — `int32`
- boolean — `logical`
- double — `double`
- string — character vector (`char`)
- list — cell array (`cell`)
- dictionary — structure (`struct`)

Examples

Get and Set Parameter Values

Connect to a ROS network to set and get ROS parameter values on the ROS parameter tree. You can get lists of parameters in their given namespaces as well. This example uses the simplified form that mimics the ROS command-line interface.

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_27078 with NodeURI http://bat5811win64:571
```

Set parameter values.

```
rosparam set /string_param 'param_value'
rosparam set /double_param 1.2
```

To set a list parameter, use the functional form.

```
rosparam('set', '/list_param', {int32(5), 124.1, -20, 'some_string'});
```

Get the list of parameters using the command-line form.

```
rosparam list
```

```
/double_param
/list_param
/string_param
```

List parameters in a specific namespace.

```
rosparam list /double
```

```
/double_param
```

Get the value of a parameter.

```
rosparam get /list_param
```

```
{5, 124.1, -20, some_string}
```

Delete a parameter. List the parameters to verify it was deleted.

```
rosparam delete /double_param
rosparam list
```

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```
/list_param
/string_param
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_27078 with NodeURI http://bat5811win64:5
Shutting down ROS master on http://bat5811win64:11311/.
```

Create Parameter Tree Object and View Parameters

Connect to the ROS network. ROS parameters should already be available on the ROS master.

```
rosinit('192.168.154.131')
```

```
Initializing global node /matlab_global_node_82870 with NodeURI http://192.168.154.1:58
```

Create a `ParameterTree` object using `rosparam`.

```
ptree = rosparam;
```

List the available parameters on the ROS master.

```
ptree.AvailableParameters
```

```
ans =

  33×1 cell array

    '/bumper2pointcloud/pointcloud_radius'
    '/camera/imager_rate'
    '/camera/rgb/image_raw/compressed/format'
    '/camera/rgb/image_raw/compressed/jpeg_quality'
    '/camera/rgb/image_raw/compressed/png_level'
    '/cmd_vel_mux/yaml_cfg_file'
    '/depthimage_to_laserscan/output_frame_id'
    '/depthimage_to_laserscan/range_max'
    '/depthimage_to_laserscan/range_min'
    '/depthimage_to_laserscan/scan_height'
    '/depthimage_to_laserscan/scan_time'
```

```
'/gazebo/auto_disable_bodies'
'/gazebo/cfm'
'/gazebo/contact_max_correcting_vel'
'/gazebo/contact_surface_layer'
'/gazebo/erp'
'/gazebo/gravity_x'
'/gazebo/gravity_y'
'/gazebo/gravity_z'
'/gazebo/max_contacts'
'/gazebo/max_update_rate'
'/gazebo/sor_pgs_iters'
'/gazebo/sor_pgs_precon_iters'
'/gazebo/sor_pgs_rms_error_tol'
'/gazebo/sor_pgs_w'
'/gazebo/time_step'
'/robot_description'
'/robot_state_publisher/publish_frequency'
'/rosdistro'
'/roslaunch/uris/host_192_168_154_131__41131'
'/rosversion'
'/run_id'
'/use_sim_time'
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_82870 with NodeURI http://192.168.154.1:5
```

Set A Dictionary Of Parameter Values

Use structures to specify a dictionary of ROS parameters under a specific namespace.

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_08339 with NodeURI http://bat5811win64:570
```

Create a dictionary of parameters values. This dictionary contains the information
relevant to an image. Display the structure to verify values.

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```
image = imread('peppers.png');

pval.ImageWidth = size(image,1);
pval.ImageHeight = size(image,2);
pval.ImageTitle = 'peppers.png';
disp(pval)

     ImageWidth: 384
    ImageHeight: 512
     ImageTitle: 'peppers.png'
```

Set the dictionary of values using the desired namespace.

```
rosparam('set','ImageParam',pval)
```

Get the parameters using the namespace. Verify the values.

```
pval2 = rosparam('get','ImageParam')

pval2 = struct with fields:
    ImageHeight: 512
     ImageTitle: 'peppers.png'
     ImageWidth: 384
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_08339 with NodeURI http://bat5811win64:5
Shutting down ROS master on http://bat5811win64:11311/.
```

Input Arguments

namespace — ROS parameter namespace
character vector

ROS parameter namespace, specified as a character vector. All parameter names starting with this character vector are listed when calling `rosparam('list',namespace)`.

pname — ROS parameter name
character vector

ROS parameter name, specified as a character vector.

pval — ROS parameter value or dictionary of values
int32 | logical | double | character vector | cell array | structure

ROS parameter value or dictionary of values, specified as a supported data type.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed:

- 32-bit integers — int32
- booleans — logical
- doubles — double
- strings — character vector char
- lists — cell array
- dictionaries — structure

Output Arguments

list — Parameter list
cell array of character vectors

Parameter list, returned as a cell array of character vectors. This is a list of all parameters available on the ROS master.

ptree — Parameter tree
ParameterTree object handle

Parameter tree, returned as a ParameterTree object handle. Use this object to reference parameter information, for example, ptree.AvailableFrames.

pvalOut — ROS parameter value or dictionary of values
int32 | logical | double | character vector | cell array | structure

ROS parameter value, specified as a supported MATLAB data type. When specifying the namespace input argument, pvalOut is returned as a structure of parameter value under the given namespace.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed.

ROS Data Type	MATLAB Data Type
32-bit integer	`int32`
boolean	`logical`
double	`double`
string	character vector (`char`)
list	cell array (`cell`)
dictionary	structure (`struct`)

Limitations

*   **Unsupported Data Types**: Base64-encoded binary data and iso8601 data from ROS are not supported.

*   **Simplified Commands**: When using the simplified command `rosparam set pname pval`, the parameter value is interpreted as:

    *   `logical` — If `pval` is `'true'` or `'false'`
    *   `int32` — If `pval` is an integer, for example, `5`
    *   `double` — If `pval` is a fractional number, for example, `1.256`
    *   character vector — If `pval` is any other value

See Also

Functions
del | get | has | search | set

Objects
ParameterTree

Introduced in R2015a

rosservice

Retrieve information about services in ROS network

Syntax

```
rosservice list
rosservice info svcname
rosservice type svcname
rosservice uri svcname

svclist = rosservice('list')
svcinfo = rosservice('info',svcname)
svctype = rosservice('type',svcname)
svcuri = rosservice('uri',svcname)
```

Description

`rosservice list` returns a list of service names for all of the active service servers on the ROS network.

`rosservice info svcname` returns information about the specified service, `svcname`.

`rosservice type svcname` returns the service type.

`rosservice uri svcname` returns the URI of the service.

`svclist = rosservice('list')` returns a list of service names for all of the active service servers on the ROS network. `svclist` contains a cell array of service names.

`svcinfo = rosservice('info',svcname)` returns a structure of information, `svcinfo`, about the service, `svcname`.

`svctype = rosservice('type',svcname)` returns the service type of the service as a character vector.

`svcuri = rosservice('uri',svcname)` returns the URI of the service as a character vector.

Examples

View List of ROS Services

Connect to the ROS network. Specify the IP address of your specific network.

```
rosinit('192.168.154.131')
```

Initializing global node /matlab_global_node_00003 with NodeURI http://192.168.154.1:56

List the services available on the ROS master.

```
rosservice list
```

```
/camera/rgb/image_raw/compressed/set_parameters
/camera/set_camera_info
/camera/set_parameters
/gazebo/apply_body_wrench
/gazebo/apply_joint_effort
/gazebo/clear_body_wrenches
/gazebo/clear_joint_forces
/gazebo/delete_model
/gazebo/get_joint_properties
/gazebo/get_link_properties
/gazebo/get_link_state
/gazebo/get_loggers
/gazebo/get_model_properties
/gazebo/get_model_state
/gazebo/get_physics_properties
/gazebo/get_world_properties
/gazebo/pause_physics
/gazebo/reset_simulation
/gazebo/reset_world
/gazebo/set_joint_properties
/gazebo/set_link_properties
/gazebo/set_link_state
/gazebo/set_logger_level
/gazebo/set_model_configuration
/gazebo/set_model_state
/gazebo/set_parameters
/gazebo/set_physics_properties
/gazebo/spawn_gazebo_model
/gazebo/spawn_sdf_model
```

```
/gazebo/spawn_urdf_model
/gazebo/unpause_physics
/laserscan_nodelet_manager/get_loggers
/laserscan_nodelet_manager/list
/laserscan_nodelet_manager/load_nodelet
/laserscan_nodelet_manager/set_logger_level
/laserscan_nodelet_manager/unload_nodelet
/mobile_base_nodelet_manager/get_loggers
/mobile_base_nodelet_manager/list
/mobile_base_nodelet_manager/load_nodelet
/mobile_base_nodelet_manager/set_logger_level
/mobile_base_nodelet_manager/unload_nodelet
/robot_state_publisher/get_loggers
/robot_state_publisher/set_logger_level
/rosout/get_loggers
/rosout/set_logger_level
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_00003 with NodeURI http://192.168.154.1:5
```

Get Information, Service Type, and URI for ROS Service

Connect to the ROS network. Specify the IP address of your specific network.

```
rosinit('192.168.154.131')
```

```
Initializing global node /matlab_global_node_76389 with NodeURI http://192.168.154.1:55
```

Get information on the gazebo/pause_physics service.

```
svcinfo = rosservice('info','gazebo/pause_physics')
```

```
svcinfo =

  struct with fields:

    Node: '/gazebo'
     URI: 'rosrpc://192.168.154.131:33260'
    Type: 'std_srvs/Empty'
```

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```
    Args: {}
```

Get the service type.

```
svctype = rosservice('type','gazebo/pause_physics')
```

```
svctype =

    'std_srvs/Empty'
```

Get the service URI.

```
svcuri = rosservice('uri','gazebo/pause_physics')
```

```
svcuri =

    'rosrpc://192.168.154.131:33260'
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_76389 with NodeURI http://192.168.154.1:5
```

Input Arguments

svcname — Name of service
character vector

Name of service, specified as a character vector. The service name must match its name in the ROS network.

Output Arguments

svcinfo — Information about a ROS service
character vector

Information about a ROS service, returned as a character vector.

svclist — List of available ROS services
cell array of character vectors

List of available ROS services, returned as a cell array of character vectors.

svctype — Type of ROS service
character vector

Type of ROS service, returned as a character vector.

svcuri — URI for accessing service
character vector

URI for accessing service, returned as a character vector.

See Also

`rosinit` | `rosparam`

Introduced in R2015a

rosshutdown

Shut down ROS system

Syntax

```
rosshutdown
```

Description

`rosshutdown` shuts down the global node and, if it is running, the ROS master. When you finish working with the ROS network, use `rosshutdown` to shut down the global ROS entities created by `rosinit`. If the global node and ROS master are not running, this function has no effect.

Note After calling `rosshutdown`, any ROS entities (objects) that depend on the global node like subscribers created with `rossubscriber`, are deleted and become unstable.

Prior to calling `rosshutdown`, call `clear` on these objects for a clean removal of ROS entities.

Examples

Start ROS Core and Global Node

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_25227 with NodeURI http://bat5811win64:56
```

When you are finished, shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_25227 with NodeURI http://bat5811win64:56
Shutting down ROS master on http://bat5811win64:11311/.
```

See Also

rosinit

Introduced in R2015a

rostopic

Retrieve information about ROS topics

Syntax

```
rostopic list
rostopic echo topicname
rostopic info topicname
rostopic type topicname

topiclist = rostopic('list')
msg = rostopic('echo', topicname)
topicinfo = rostopic('info', topicname)
msgtype = rostopic('type', topicname)
```

Description

`rostopic list` returns a list of ROS topics from the ROS master.

`rostopic echo topicname` returns the messages being sent from the ROS master about a specific topic, `topicname`. To stop returning messages, press **Ctrl+C**.

`rostopic info topicname` returns the message type, publishers, and subscribers for a specific topic, `topicname`.

`rostopic type topicname` returns the message type for a specific topic.

`topiclist = rostopic('list')` returns a cell array containing the ROS topics from the ROS master. If you do not define the output argument, the list is returned in the MATLAB Command Window.

`msg = rostopic('echo', topicname)` returns the messages being sent from the ROS master about a specific topic, `topicname`. To stop returning messages, press **Ctrl +C**. If the output argument is defined, then `rostopic` returns the first message that arrives on that topic.

`topicinfo = rostopic('info', topicname)` returns a structure containing the message type, publishers, and subscribers for a specific topic, `topicname`.

`msgtype = rostopic('type', topicname)` returns a character vector containing the message type for the specified topic, `topicname`.

Examples

Get List of ROS Topics

Connect to ROS network. Specify the IP address of the ROS device.

```
rosinit('192.168.154.131')
```

Initializing global node /matlab_global_node_23844 with NodeURI http://192.168.154.1:56

List the ROS topic available on the ROS master.

```
rostopic list
```

```
/camera/depth/camera_info
/camera/depth/image_raw
/camera/depth/points
/camera/parameter_descriptions
/camera/parameter_updates
/camera/rgb/camera_info
/camera/rgb/image_raw
/camera/rgb/image_raw/compressed
/camera/rgb/image_raw/compressed/parameter_descriptions
/camera/rgb/image_raw/compressed/parameter_updates
/clock
/cmd_vel_mux/active
/cmd_vel_mux/input/navi
/cmd_vel_mux/input/safety_controller
/cmd_vel_mux/input/teleop
/cmd_vel_mux/parameter_descriptions
/cmd_vel_mux/parameter_updates
/depthimage_to_laserscan/parameter_descriptions
/depthimage_to_laserscan/parameter_updates
/gazebo/link_states
/gazebo/model_states
/gazebo/parameter_descriptions
```

```
/gazebo/parameter_updates
/gazebo/set_link_state
/gazebo/set_model_state
/joint_states
/laserscan_nodelet_manager/bond
/mobile_base/commands/motor_power
/mobile_base/commands/reset_odometry
/mobile_base/commands/velocity
/mobile_base/events/bumper
/mobile_base/events/cliff
/mobile_base/sensors/bumper_pointcloud
/mobile_base/sensors/core
/mobile_base/sensors/imu_data
/mobile_base_nodelet_manager/bond
/odom
/rosout
/rosout_agg
/scan
/tf
```

Get ROS Topic Info

Connect to ROS network. Specify the IP address of the ROS device.

```
rosinit('192.168.154.131')
```

```
Initializing global node /matlab_global_node_28473 with NodeURI http://192.168.154.1:57
```

Show info on a specific ROS topic.

```
rostopic info camera/depth/points
```

```
Type: sensor_msgs/PointCloud2

Publishers:
* /gazebo  http://192.168.154.131:46957/

Subscribers:
```

Get ROS Topic Message Type

Connect to ROS network. Specify the IP address of the ROS device.

```
rosinit('192.168.154.131')
```

Initializing global node /matlab_global_node_70141 with NodeURI http://192.168.154.1:58

Get message type for a specific topic. Create a message from the message type to publish to the topic.

```
msgtype = rostopic('type','camera/depth/points');
msg = rosmessage(msgtype);
```

Input Arguments

topicname — ROS topic name
character vector

ROS topic name, specified as a character vector. The topic name must match one of the topics that rostopic('list') outputs.

Output Arguments

topiclist — List of topics from the ROS master
cell array of character vectors

List of topics from ROS master, returned as a cell array of character vectors.

msg — ROS message for a given topic
object handle

ROS message for a given topic, returned as an object handle.

topicinfo — Information about a given ROS topic
structure

Information about a ROS topic, returned as a structure. topicinfo included the message type, publishers, and subscribers associated with that topic.

msgtype — Message type for a ROS topic
character vector

Message type for a ROS topic, returned as a character vector.

Introduced in R2015a

rostype

Access available ROS message types

Syntax

```
rostype
```

Description

`rostype` creates a blank message of a certain type by browsing the list of available message types. You can use tab completion and do not have to rely on typing error-free message type character vectors. By typing `rostype.partialname`, and pressing **Tab**, a list of matching message types appears in a list. By setting the message type equal to a variable, you can create a character vector of that message type. Alternatively, you can create the message by supplying the message type directly into `rosmessage` as an input argument.

Examples

Create ROS Message Type and ROS Message

Create Message Type String

```
t = rostype.std_msgs_String
```

```
t =
'std_msgs/String'
```

Create ROS Message from ROS Type

```
msg = rosmessage(rostype.std_msgs_String)
```

```
msg =
  ROS String message with properties:
```

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```
   MessageType: 'std_msgs/String'
           Data: ''

  Use showdetails to show the contents of the message
```

- "Built-In Message Support"
- "Work with Basic ROS Messages"

See Also
rosmessage | rostopic

Topics
"Built-In Message Support"
"Work with Basic ROS Messages"

Introduced in R2015a

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.
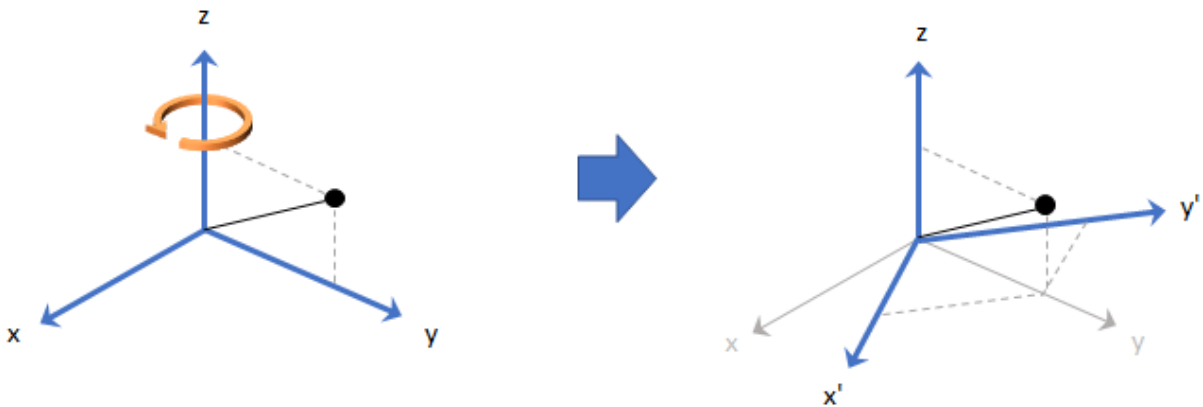
Examples

Rotate Frame Using Quaternion Vector

Define a point in three dimensions. When you specify a point, it is 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])
```
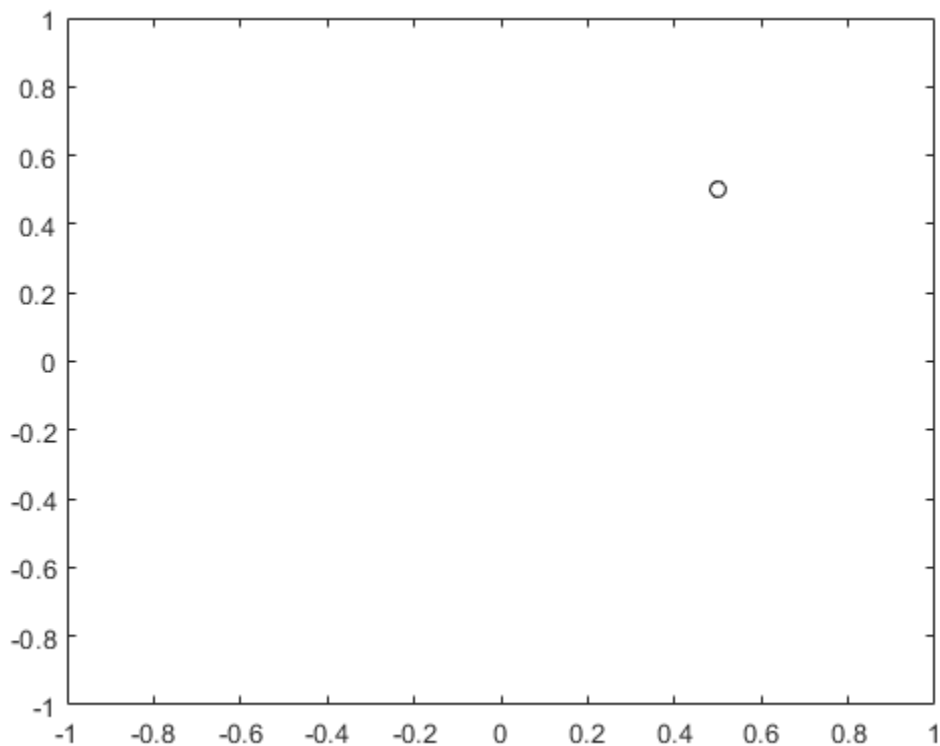

Create a quaternion vector specifying two separate rotations, one to rotate the frame 45 degrees and another to rotate the point -90 degrees about the Z axis. Use `rotateframe` to perform the rotation.

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

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

rereferencedPoint =

    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')
```
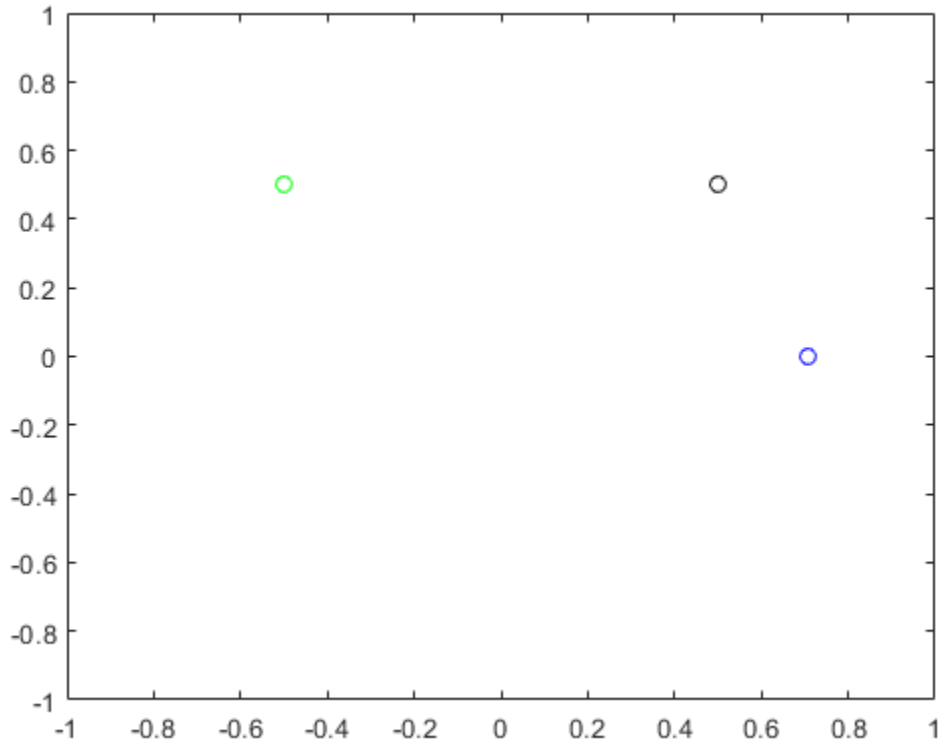
Rereference Group of Points using Quaternion

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(deg2rad([30,45,0]),'euler','ZYX','point');
```

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

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


rP =

    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')
```
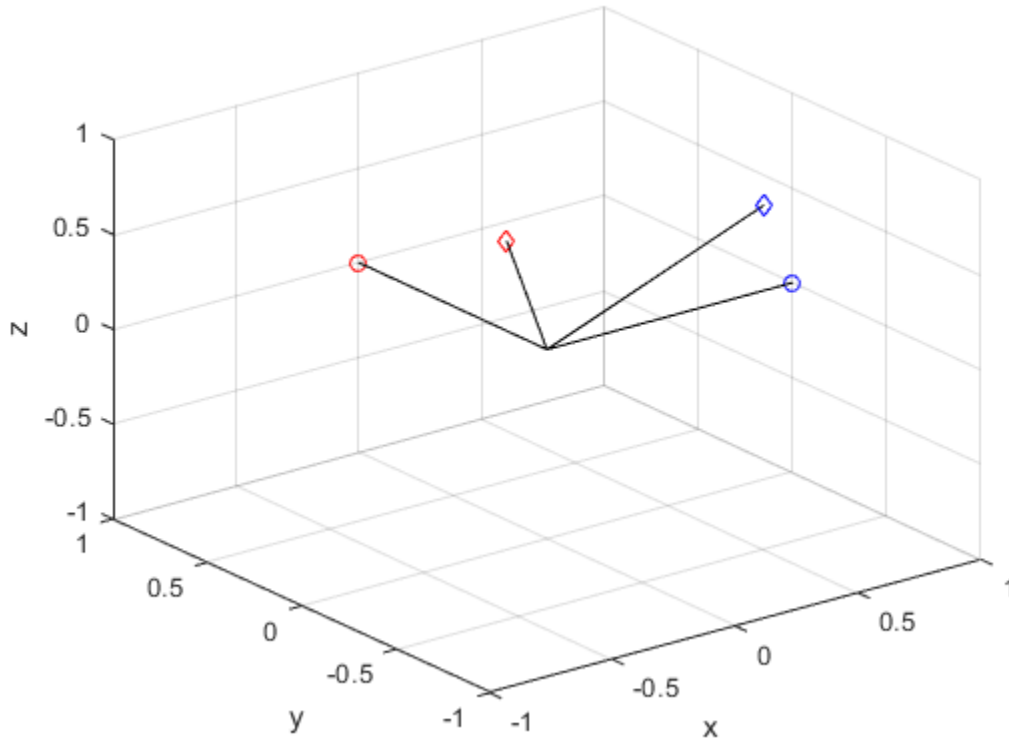
Input Arguments

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:

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

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

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

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 $\mathbf{R}^3$

See Also

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.
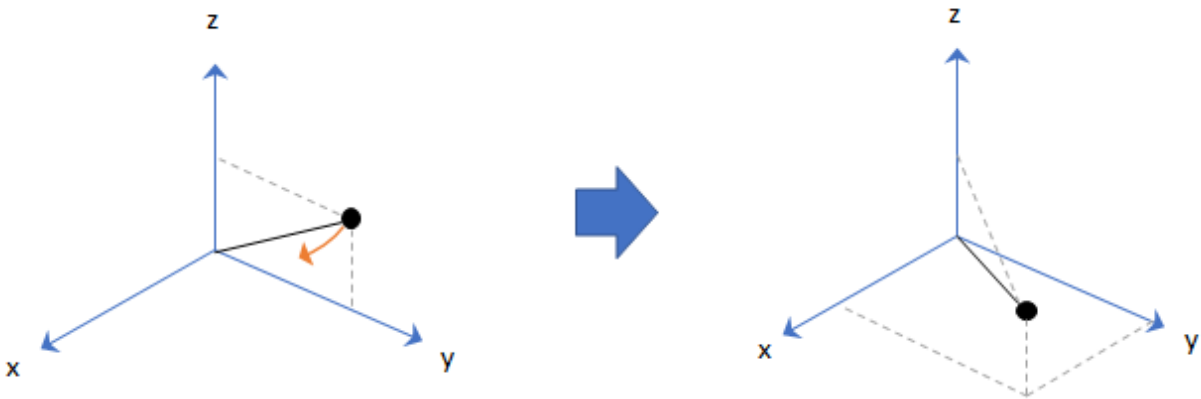
Examples

Rotate Point Using Quaternion Vector

Define a point in three dimensions. When you specify a point, it is 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])
```
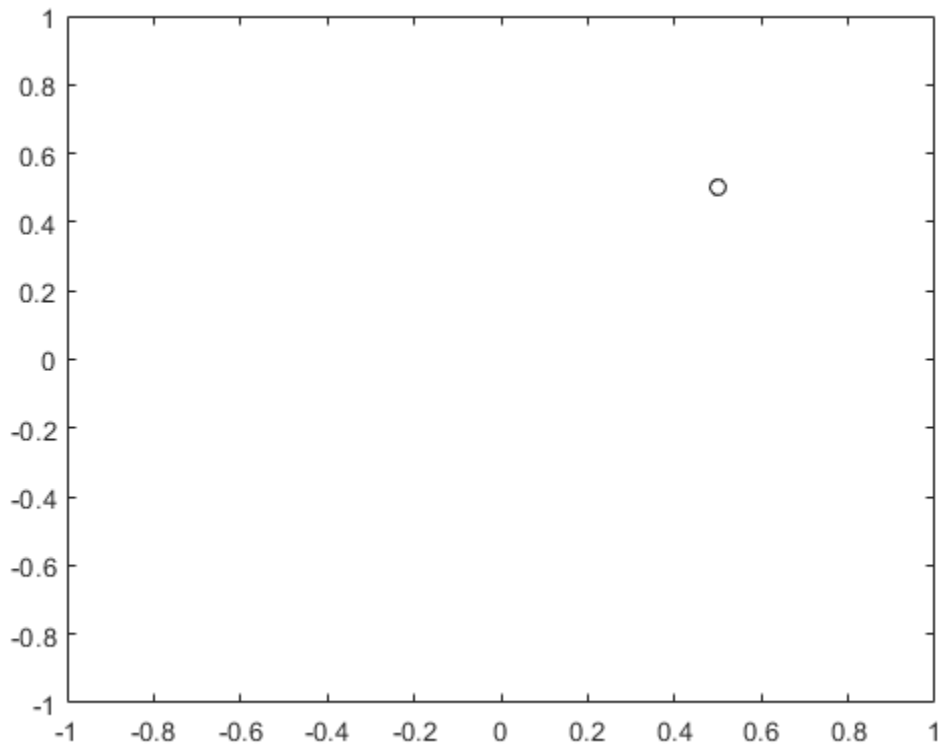

Create a quaternion vector specifying two separate rotations, one to rotate the point 45 and another to rotate the point -90 degrees about the Z axis. Use `rotatepoint` to perform the rotation.

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

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

```
rotatedPoint =

   -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')
```
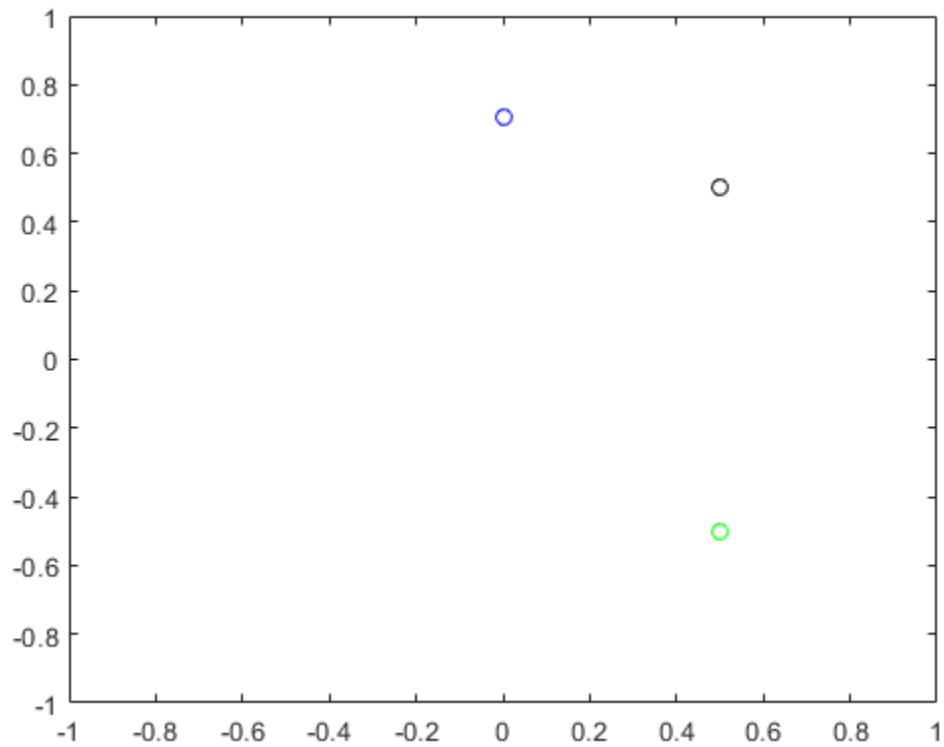
Rotate Group of Points using Quaternion

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(deg2rad([30,45,0]),'euler','ZYX','point');
```

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

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

```
rP =

    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')
```
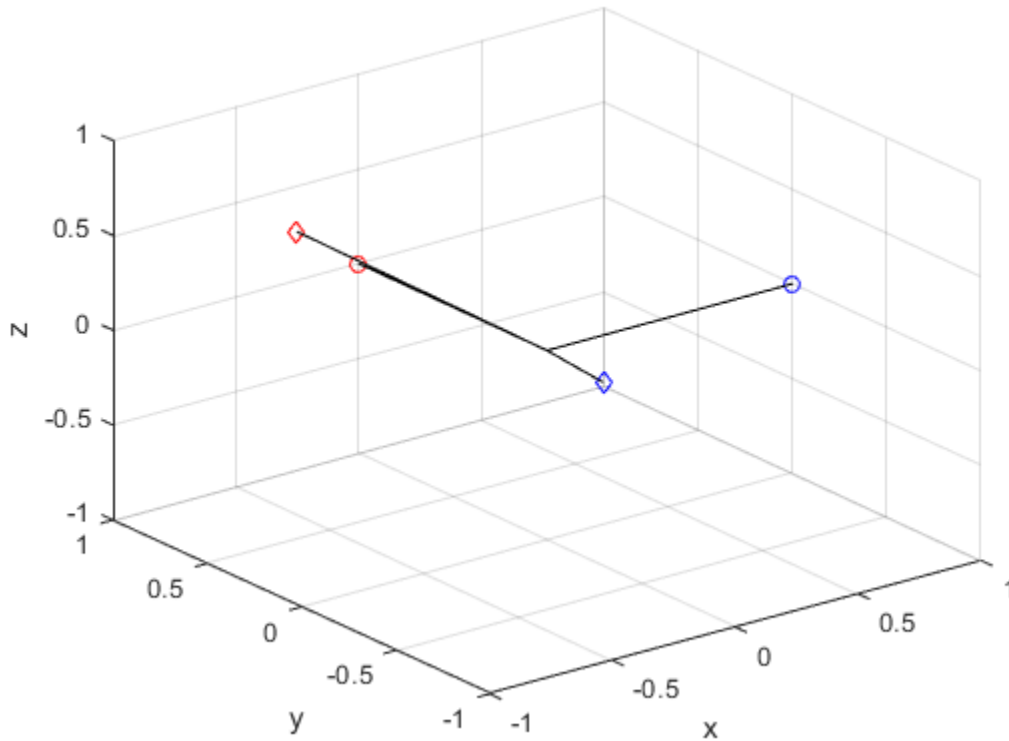
Input Arguments

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:

$$v_q \;=\; 0 \,+\, xi \,+\, yj \,+\, zk$$

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 $\mathbf{R}^3$

See Also

Introduced in R2018a

rotm2axang

Convert rotation matrix to axis-angle rotation

Syntax

```
axang = rotm2axang(rotm)
```

Description

`axang = rotm2axang(rotm)` converts a rotation given as an orthonormal rotation matrix, `rotm`, to the corresponding axis-angle representation, `axang`. The input rotation matrix must be in the premultiply form for rotations.

Examples

Convert Rotation Matrix to Axis-Angle Rotation

```
rotm = [1 0 0 ; 0 -1 0; 0 0 -1];
axang = rotm2axang(rotm)
```

```
axang = 1×4

    1.0000         0         0    3.1416
```

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and must be orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: `[0 0 1; 0 1 0; -1 0 0]`

Output Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, returned as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Extended Capabilities

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

See Also
`axang2rotm`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

rotm2eul

Convert rotation matrix to Euler angles

Syntax

```
eul = rotm2eul(rotm)
eul = rotm2eul(rotm,sequence)
```

Description

`eul = rotm2eul(rotm)` converts a rotation matrix, `rotm`, to the corresponding Euler angles, `eul`. The input rotation matrix must be in the premultiply form for rotations. The default order for Euler angle rotations is `'ZYX'`.

`eul = rotm2eul(rotm,sequence)` converts a rotation matrix to Euler angles. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `'ZYX'`.

Examples

Convert Rotation Matrix to Euler Angles

```
rotm = [0 0 1; 0 1 0; -1 0 0];
eulZYX = rotm2eul(rotm)

eulZYX = 1×3

       0    1.5708         0
```

Convert Rotation Matrix to Euler Angles Using ZYZ Axis Order

```
rotm = [0 0 1; 0 -1 0; -1 0 0];
eulZYZ = rotm2eul(rotm,'ZYZ')
```

eulZYZ = *1×3*

   -3.1416   -1.5708   -3.1416

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: [0 0 1; 0 1 0; -1 0 0]

sequence — Axis rotation sequence
'ZYX' (default) | 'ZYZ' | 'XYZ'

Axis rotation sequence for the Euler angles, specified as one of these character vectors:

- 'ZYX' (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- 'ZYZ' – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- 'XYZ' – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Output Arguments

eul — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, returned as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

Extended Capabilities

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

See Also
`eul2rotm`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

rotm2quat

Convert rotation matrix to quaternion

Syntax

```
quat = rotm2quat(rotm)
```

Description

quat = rotm2quat(rotm) converts a rotation matrix, rotm, to the corresponding unit quaternion representation, quat. The input rotation matrix must be in the premultiply form for rotations.

Examples

Convert Rotation Matrix to Quaternion

```
rotm = [0 0 1; 0 1 0; -1 0 0];
quat = rotm2quat(rotm)
```

quat = *1×4*

```
    0.7071         0    0.7071         0
```

Input Arguments

rotm — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: `[0 0 1; 0 1 0; -1 0 0]`

Output Arguments

quat — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with w as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Extended Capabilities

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

See Also
`quat2rotm`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

rotm2tform

Convert rotation matrix to homogeneous transformation

Syntax

```
tform = rotm2tform(rotm)
```

Description

`tform = rotm2tform(rotm)` converts the rotation matrix, `rotm`, into a homogeneous transformation matrix, `tform`. The input rotation matrix must be in the premultiply form for rotations. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Rotation Matrix to Homogeneous Transformation

```
rotm = [1 0 0 ; 0 -1 0; 0 0 -1];
tform = rotm2tform(rotm)

tform = 4×4

     1      0      0      0
     0     -1      0      0
     0      0     -1      0
     0      0      0      1
```

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: `[0 0 1; 0 1 0; -1 0 0]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Extended Capabilities

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

See Also
`tform2rotm`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

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

Define a quaternion for use in point rotation.

```
theta = 45;
gamma = 30;
quat = quaternion(deg2rad([0,theta,gamma]),'euler','ZYX','point')
```

```
quat =

  quaternion


      0.8924 +  0.23912i +  0.36964j + 0.099046k
```

Convert the quaternion to a rotation matrix.

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

```
rotationMatrix =

    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 =

    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 in 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 =

    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 resulted in the same orientation.

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

```
ans =

    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

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

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

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

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.

See Also

Introduced in R2018a

rotvec

Convert quaternion to rotation vector

Syntax

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

Description

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

Examples

Convert Quaternion to Rotation Vector

Convert a random quaternion scalar to a rotation vector.

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

```
ans =

    1.6866   -2.0774    0.7929
```

Input Arguments

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

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

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

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:

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

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

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

See Also

Introduced in R2018a

runCore

Start ROS core

Syntax

```
runCore(device)
```

Description

runCore(device) starts the ROS core on the connected device. The ROS master uses a default port number of 11311.

Examples

Run ROS Core on ROS Device

Connect to a remote ROS device and start a ROS core. The ROS core is needed to run ROS nodes to communicate via a ROS network. You can run and stop a ROS core or node and check their status using a rosdevice object.

Create a connection to a ROS device. Specify the address, user name, and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using runNode.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password')


d =

  rosdevice with properties:

      DeviceAddress: '192.168.154.131'
           Username: 'user'
```

```
        ROSFolder: '/opt/ros/hydro'
    CatkinWorkspace: '~/catkin_ws_test'
     AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core and check if it is running.

```
runCore(d)
running = isCoreRunning(d)


running =

  logical

   1
```

Stop the ROS core and confirm that it is no longer running.

```
stopCore(d)
running = isCoreRunning(d)


running =

  logical

   0
```

- "Generate a Standalone ROS Node from Simulink®"

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a rosdevice object.

See Also

isCoreRunning | rosdevice | stopCore

Topics
"Generate a Standalone ROS Node from Simulink®"

Introduced in R2016b

runNode

Start ROS node

Syntax

```
runNode(device,modelName)
runNode(device,modelName,masterURI)
runNode(device,modelName,masterURI,nodeHost)
```

Description

`runNode(device,modelName)` starts the ROS node associated with the deployed Simulink model named `modelName`. The ROS node must be deployed in the Catkin workspace specified by the `CatkinWorkspace` property of the input `rosdevice` object, `device`. By default, the node connects to the ROS master that MATLAB is connected to with the `device.DeviceAddress` property.

`runNode(device,modelName,masterURI)` connects to the specified master URI.

`runNode(device,modelName,masterURI,nodeHost)` connects to the specified master URI and node host. The node advertises its address as the hostname or IP address given in `nodeHost`.

Examples

Run ROS Node on ROS Device

Connect to a remote ROS device and start a ROS node. First, run a ROS core so that ROS nodes can communicate via a ROS network. You can run and stop a ROS core or node and check their status using a `rosdevice` object.

Create a connection to a ROS device. Specify the address, user name and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using `runNode`.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password');
d.ROSFolder = '/opt/ros/hydro';
d.CatkinWorkspace = '~/catkin_ws_test'


d =

  rosdevice with properties:

       DeviceAddress: '192.168.154.131'
            Username: 'user'
           ROSFolder: '/opt/ros/hydro'
    CatkinWorkspace: '~/catkin_ws_test'
     AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core. Connect MATLAB® to the ROS master using `rosinit`. This core
enables you to run ROS nodes on your ROS device.

```
runCore(d)
rosinit(d.DeviceAddress)
```

Another roscore / ROS master is already running on the ROS device. Use the 'stopCore'
Initializing global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:5

Check the available ROS nodes on the connected ROS device. These nodes were
generated from Simulink® models following the process in the Generate a standalone
ROS node from Simulink® example.

```
d.AvailableNodes
```

```
ans =

  1×2 cell array

    'robotcontroller'     'robotcontroller2'
```

Run a ROS node. specifying the node name. Check if the node is running.

```
runNode(d,'robotcontroller')
running = isNodeRunning(d,'robotcontroller')
```

```
running =

  logical

   1
```

Stop the ROS node. Disconnect from the ROS network. Stop the ROS core.

```
stopNode(d,'robotcontroller')
rosshutdown
stopCore(d)
```

```
Shutting down global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:5
```

Run Multiple ROS Nodes

Run multiple ROS nodes on a connected ROS device. ROS nodes can be generated using Simulink® models to perform different tasks on the ROS network. These nodes are then deployed on a ROS device and can be run independently of Simulink.

This example uses two different Simulink models that have been deployed as ROS nodes. See Generate a standalone ROS node from Simulink®). and follow the instructions to generate and deploy a ROS node. The 'robotcontroller' node sends velocity commands to a robot to navigate it to a given point. The 'robotcontroller2' node uses the same model, but doubles the linear velocity to drive the robot faster.

Create a connection to a ROS device. Specify the address, user name, and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using runNode.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password')
```

```
d =

  rosdevice with properties:

      DeviceAddress: '192.168.154.131'
           Username: 'user'
```

```
            ROSFolder: '/opt/ros/hydro'
     CatkinWorkspace: '~/catkin_ws_test'
      AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core. Connect MATLAB® to the ROS master using `rosinit`. This ROS core enables you to run ROS nodes on your ROS device.

```
runCore(d)
rosinit(d.DeviceAddress)
```

Initializing global node /matlab_global_node_68749 with NodeURI http://192.168.154.1:6₄

Check the available ROS nodes on the connected ROS device. These nodes were generated from Simulink® models following the process in the Generate a standalone ROS node from Simulink® example.

```
d.AvailableNodes
```

```
ans =

  1×2 cell array

    'robotcontroller'    'robotcontroller2'
```

Start up the Robot Simulator using `ExampleHelperSimulinkRobotROS`. This simulator automatically connects to the ROS master on the ROS device. You will use this simulator to run a ROS node and control the robot.

```
sim = ExampleHelperSimulinkRobotROS;
```

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Run a ROS node, specifying the node name. The `'robotcontroller'` node commands the robot to a specific location (`[-10 10]`). Wait to see the robot drive.

```
runNode(d,'robotcontroller')
pause(10)
```

Reset the Robot Simulator to reset the robot position. Alternatively, click **Reset Simulation**. Because the node is still running, the robot continues back to the specific location. To stop sending commands, stop the node.

```
resetSimulation(sim.Simulator)
pause(5)
stopNode(d,'robotcontroller')
```

Run the `'robotcontroller2'` node. This model drives the robot with twice the linear velocity. Reset the robot position. Wait to see the robot drive.

```
runNode(d,'robotcontroller2')
resetSimulation(sim.Simulator)
pause(10)
```

Close the simulator. Stop the ROS node. Disconnect from the ROS network and stop the ROS core.

```
close
stopNode(d,'robotcontroller2')
rosshutdown
stopCore(d)
```

Shutting down global node /matlab_global_node_68749 with NodeURI http://192.168.154.1:6

- "Connect to a ROS Network"
- "Generate a Standalone ROS Node from Simulink®"

Input Arguments

`device` — ROS device
`rosdevice` object

ROS device, specified as a `rosdevice` object.

`modelName` — Name of the deployed Simulink model
character vector

Name of the deployed Simulink model, specified as a character vector. If the model name is not valid, the function returns an error.

`masterURI` — URI of the ROS master
character vector

URI of the ROS master, specified as a character vector. On start up, the node connects to the ROS master with the given URI.

`nodeHost` — Host name for the node
character vector

Host name for the node, specified as a character vector. The node uses this host name to advertise itself on the ROS network for others to connect to it.

See Also
`isNodeRunning` | `rosdevice` | `stopNode`

Topics
"Connect to a ROS Network"
"Generate a Standalone ROS Node from Simulink®"

Introduced in R2016b

scatter3

Display point cloud in scatter plot

Syntax

```
scatter3(pcloud)
scatter3(pcloud,Name,Value)
h = scatter3( ___ )
```

Description

scatter3(pcloud) plots the input pcloud point cloud as a 3-D scatter plot in the current axes handle. If the data contains RGB information for each point, the scatter plot is colored accordingly.

scatter3(pcloud,Name,Value) provides additional options specified by one or more Name,Value pair arguments. Name must appear inside single quotes (''). You can specify several name-value pair arguments in any order as Name1,Value1,...,NameN,ValueN)

h = scatter3(___) returns the scatter series object, using any of the arguments from previous syntaxes. Use h to modify properties of the scatter series after it is created.

When plotting ROS point cloud messages, MATLAB follows the standard ROS convention for axis orientation. This convention states that **positive x is forward, positive y is left, and positive z is up**. However, if cameras are used, a second frame is defined with an "_optical" suffix which changes the orientation of the axis. In this case, positive z is forward, positive x is right, and positive y is down. MATLAB looks for the "_optical" suffix and will adjust the axis orientation of the scatter plot accordingly. For more information, see Axis Orientation on the ROS Wiki.

Examples

Get and Plot a 3-D Point Cloud

Connect to a ROS network. Subscribe to a point cloud message topic.

```
rosinit('192.168.154.131')
sub = rossubscriber('/camera/depth/points');
pause(1)
```

Initializing global node /matlab_global_node_47682 with NodeURI http://192.168.154.1:60

Get the latest point cloud message. Plot the point cloud.

```
pcloud = sub.LatestMessage;
scatter3(pcloud)
```
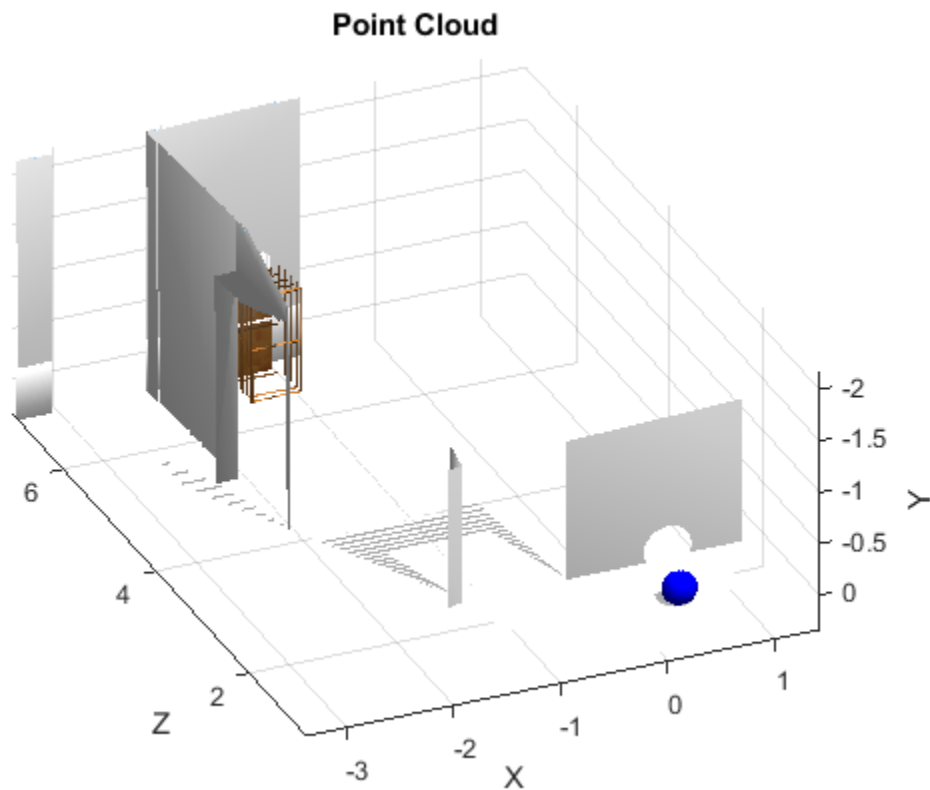

Point Cloud

Plot all points as black dots.

```
scatter3(sub.LatestMessage,'MarkerEdgeColor',[0 0 0]);
```
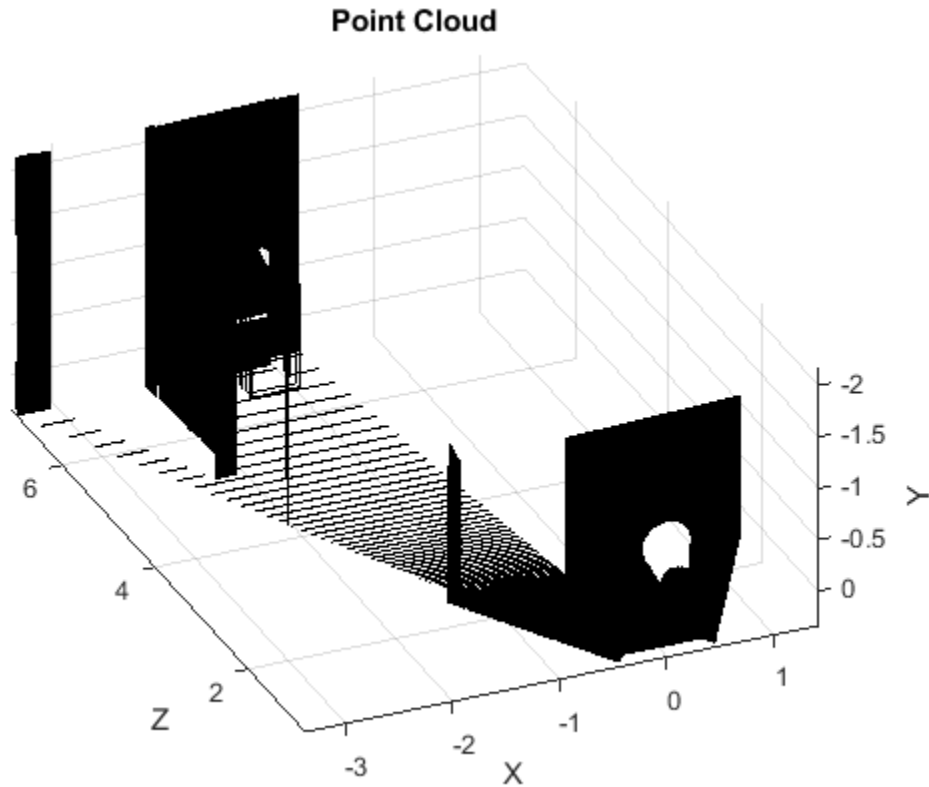

Point Cloud

Input Arguments

pcloud — Point cloud
PointCloud2 object handle

Point cloud, specified as a PointCloud2 object handle for a 'sensor_msgs/
PointCloud2' ROS message.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'MarkerEdgeColor',[1 0 0]`

MarkerEdgeColor — Marker outline color
`'flat'` (default) | `'none'` | RGB triplet | `'r'` | `'g'` | `'b'` | ...

Marker outline color, specified `'flat'`, an RGB triplet, or one of the color options listed in the table. The default value of `'flat'` uses colors from the `CData` property.

For a custom color, specify an RGB triplet. An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range `[0,1]`; for example, `[0.4 0.6 0.7]`. Alternatively, you can specify some common colors by name. This table lists the long and short color name options and the equivalent RGB triplet values.

Option	Description	Equivalent RGB Triplet
`'red'` or `'r'`	Red	`[1 0 0]`
`'green'` or `'g'`	Green	`[0 1 0]`
`'blue'` or `'b'`	Blue	`[0 0 1]`
`'yellow'` or `'y'`	Yellow	`[1 1 0]`
`'magenta'` or `'m'`	Magenta	`[1 0 1]`
`'cyan'` or `'c'`	Cyan	`[0 1 1]`
`'white'` or `'w'`	White	`[1 1 1]`
`'black'` or `'k'`	Black	`[0 0 0]`
`'none'`	No color	Not applicable

Example: `[0.5 0.5 0.5]`

Example: `'blue'`

Parent — Parent of axes
axes object

Parent of axes, specified as the comma-separated pair consisting of `'Parent` and an axes object in which to draw the point cloud. By default, the point cloud is plotted in the active axes.

Outputs

h — Scatter series object
scalar

Scatter series object, returned as a scalar. This value is a unique identifier, which you can use to query and modify the properties of the scatter object after it is created.

See Also

readRGB | readXYZ

Introduced in R2015a

search

Search ROS network for parameter names

Syntax

```
pnames = search(ptree,searchstr)
[pnames,pvalues] = search(ptree,searchstr)
```

Description

`pnames = search(ptree,searchstr)` searches within the parameter tree `ptree` and returns the parameter names that contain the character vector `searchstr`.

`[pnames,pvalues] = search(ptree,searchstr)` also returns the parameter values.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed:

- 32-bit integers — `int32`
- booleans — `logical`
- doubles — `double`
- strings — character vector `char`
- lists — cell array
- dictionaries — structure

Examples

Search for ROS Parameter Names

Connect to ROS network. Specify the IP address of the ROS master.

```
rosinit('192.168.154.131')
```

Initializing global node /matlab_global_node_11803 with NodeURI http://192.168.154.1:58

Create a parameter tree.

```
ptree = rosparam;
```

Search for parameter names that contain `'gravity'`.

```
[pnames,pvalues] = search(ptree,'gravity')
```

```
pnames =

  1×3 cell array

    '/gazebo/gravity_x'    '/gazebo/gravity_y'    '/gazebo/gravity_z'


pvalues =

  3×1 cell array

    [      0]
    [      0]
    [-9.8000]
```

Input Arguments

`ptree` — Parameter tree
ParameterTree object handle

Parameter tree, specified as a `ParameterTree` object handle. Create this object using the `rosparam` function.

`searchstr` — ROS parameter search string
character vector

ROS parameter search string specified as a character vector. `search` returns all parameters that contain this character vector.

Output Arguments

pnames — Parameter values
cell array of character vectors

Parameter names, returned as a cell array of character vectors. These character vectors match the parameter names in the ROS master that contain the search character vector.

pvalues — Parameter values
cell array

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed:

- 32-bit integers — `int32`
- booleans — `logical`
- doubles — `double`
- strings — character vector `char`
- lists — cell array
- dictionaries — structure

Base64–encoded binary data and iso8601 data from ROS are not supported.

Limitations

Base64–encoded binary data and iso8601 data from ROS are not supported.

See Also
`get` | `rosparam`

Introduced in R2015a

seconds

Returns seconds of a time or duration

Syntax

```
secs = seconds(time)
secs = seconds(duration)
```

Description

`secs = seconds(time)` returns the scalar number, `secs`, in seconds that represents the same value as the time object, `time`.

`secs = seconds(duration)` returns the scalar number, `secs`, in seconds that represents the same value as the duration object, `duration`.

Examples

Get Seconds From A Time Object

Use the `seconds` function to get the total seconds of a `Time` object from its `Secs` and `Nsecs` properties.

Create a `Time` object.

```
time = rostime(1,860000000)

time =
  ROS Time with properties:

     Sec: 1
    Nsec: 860000000
```

Get the total seconds from the time object.

```
secs = seconds(time)
```

```
secs = 1.8600
```

Input Arguments

`time` — Current ROS or system time
Time object handle

ROS or system time, specified as a `Time` object handle. Create a `Time` object using `rostime`.

`duration` — Duration
ROS `Duration` object

Duration, specified as a ROS `Duration` object with `Sec` and `Nsec` properties. Create a `Duration` object using `rosduration`

Output Arguments

`secs` — Total time
scalar in seconds

Total time of the `Time` or `Duration` object, returned as a scalar in seconds.

See Also
`rosduration` | `rostime`

Introduced in R2016a

select

Select subset of messages in rosbag

Syntax

```
bagsel = select(bag)
bagsel = select(bag,Name,Value)
```

Description

`bagsel = select(bag)` returns an object, `bagsel`, that contains all of the messages in the `BagSelection` object, `bag`

This function does not change the contents of the original `BagSelection` object. It returns a new object that contains the specified message selection.

`bagsel = select(bag,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments. `Name` must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Examples

Create Copy of rosbag

Retrieve the rosbag. Specify the file path.

```
filepath = fullfile(fileparts(which('ROSWorkingWithRosbagsExample')),...
                    'data','ex_multiple_topics.bag');
bag = rosbag(filepath);
```

Use `select` with no selection criteria to create a copy of the rosbag.

```
bagCopy = select(bag);
```

Select Subset of Messages In rosbag

Retrieve the rosbag. Specify the file path.

```
filepath = fullfile(fileparts(which('ROSWorkingWithRosbagsExample')),...
                    'data','ex_multiple_topics.bag');
bag = rosbag(filepath);
```

Select all messages within the first second of the rosbag.

```
bag = select(bag,'Time',[bag.StartTime,bag.StartTime + 1]);
```

Input Arguments

bag — Messages of a rosbag
BagSelection object

Messages contained within a rosbag, specified as a BagSelection object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

Example: 'MessageType','/geometry_msgs/Point'

MessageType — ROS message type
character vector | cell array

ROS message type, specified as a character vector or cell array. Multiple message types can be specified with a cell array of character vectors.

Time — Start and end times
n-by-2 matrix

Start and end times of the rosbag selection, specified as an *n*-by-2 vector.

Topic — ROS topic name
character vector | cell array

ROS topic name, specified as a character vector or cell array. Multiple topic names can be specified with a cell array of character vectors.

Output Arguments

bagsel — Copy or subset of rosbag messages
BagSelection object

Copy or subset of rosbag messages, returned as a BagSelection object

See Also

readMessages | rosbag | timeseries

Introduced in R2015a

send

Publish ROS message to topic

Syntax

```
send(pub,msg)
```

Description

`send(pub,msg)` publishes a message to the topic specified by the publisher, `pub`. This message can be received by all subscribers in the ROS network that are subscribed to the topic specified by `pub`

Examples

Create, Send, And Receive ROS Messages

Set up a publisher and subscriber to send and receive a message on a ROS network.

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://AH-SRADFORD:11311/.
Initializing global node /matlab_global_node_10876 with NodeURI http://AH-SRADFORD:6513
```

Create a publisher with a specific topic and message type. You can also return a default message to send using this publisher.

```
[pub,msg] = rospublisher('position','geometry_msgs/Point');
```

Modify the message before sending over the network.

```
msg.X = 1;
msg.Y = 2;
send(pub,msg);
```

Create a subscriber and wait for the latest message. Verify the message is the one you sent.

```
sub = rossubscriber('position')
pause(1);
sub.LatestMessage
```

```
sub =

  Subscriber with properties:

        TopicName: '/position'
      MessageType: 'geometry_msgs/Point'
    LatestMessage: [0×1 Point]
       BufferSize: 1
    NewMessageFcn: []
```

```
ans =

  ROS Point message with properties:

    MessageType: 'geometry_msgs/Point'
              X: 1
              Y: 2
              Z: 0

  Use showdetails to show the contents of the message
```

Shut down ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_10876 with NodeURI http://AH-SRADFORD:65
Shutting down ROS master on http://AH-SRADFORD:11311/.
```

• "Exchange Data with ROS Publishers and Subscribers"

Input Arguments

pub — ROS publisher
Publisher object handle

ROS publisher, specified as a Publisher object handle. You can create the object using rospublisher.

msg — ROS message
Message object handle

ROS message, specified as a Message object handle.

See Also

receive | rosmessage | rospublisher | rossubscriber | rostopic

Topics
"Exchange Data with ROS Publishers and Subscribers"

Introduced in R2015a

sendGoal

Send goal message to action server

Syntax

```
sendGoal(client,goalMsg)
```

Description

`sendGoal(client,goalMsg)` sends a goal message to the action server. The specified action client tracks this goal. The function does not wait for the goal to be executed and returns immediately.

If the `ActionFcn`, `FeedbackFcn`, and `ResultFcn` callbacks of the client are defined, they are called when the goal is processing on the action server. All callbacks associated with a previously sent goal are disabled, but the previous goal is not canceled.

Examples

Create And Send A ROS Action Goal Message

This example shows how to create goal messages and send to an already active ROS action server on a ROS network. You must create a ROS action client to connect to this server. To run the action server, this command is used on the ROS distribution:

```
roslaunch turtlebot_actions server_turtlebot_move.launch
```

Afterwards, connect to the ROS node using `rosinit` with the correct IP address.

Create a ROS action client and get a goal message. The `actClient` object connects to the already running ROS action server. `goalMsg` is a valid goal message. Update the message parameters with your specific goal.

```
[actClient, goalMsg] = rosactionclient('/turtlebot_move');
disp(goalMsg)

  ROS TurtlebotMoveGoal message with properties:

        MessageType: 'turtlebot_actions/TurtlebotMoveGoal'
       TurnDistance: 0
    ForwardDistance: 0

  Use showdetails to show the contents of the message
```

You can also create a message using `rosmessage` and the action client object. This message sends linear and angular velocity commands to a Turtlebot® robot.

```
goalMsg = rosmessage(actClient);
disp(goalMsg)

  ROS TurtlebotMoveGoal message with properties:

        MessageType: 'turtlebot_actions/TurtlebotMoveGoal'
       TurnDistance: 0
    ForwardDistance: 0

  Use showdetails to show the contents of the message
```

Modify the goal message parameters and send the goal to the action server.

```
goalMsg.ForwardDistance = 2;
sendGoal(actClient,goalMsg)
```

Send and Cancel ROS Action Goals

Send and cancel goals for ROS actions. First, setup a ROS action client. Then send a goal message with modified parameters. Finally, cancel your goal and all goals on the action server.

Connect to a ROS network with a specified IP address. Create a ROS action client connected using `rosactionclient`. Specify the action name. Wait for the client to be connected to the server.

```
rosinit('192.168.154.131')
[actClient,goalMsg] = rosactionclient('/fibonacci');
waitForServer(actClient);
```

```
Initializing global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5
```

Send a goal message with modified parameters. Wait for the goal to finish executing.

```
goalMsg.Order = 4;
sendGoalAndWait(actClient,goalMsg)
```

```
Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5]

ans =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [6×1 int32]

  Use showdetails to show the contents of the message
```

Send a new goal message without waiting.

```
goalMsg.Order = 5;
sendGoal(actClient,goalMsg)
```

Cancel the goal on the ROS action client, `actClient`.

```
cancelGoal(actClient)
```

Cancel all the goals on the action server that `actClient` is connected to.

```
cancelAllGoals(actClient)
```

Delete the action client.

```
delete(actClient)
```

Disconnect from the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5

Input Arguments

client — ROS action client
SimpleActionClient object handle

ROS action client, specified as a SimpleActionClient object handle. This simple action client enables you to track a single goal at a time.

goalMsg — ROS action goal message
Message object handle

ROS action goal message, specified as a Message object handle. Update this message with your goal details and send it to the ROS action client using sendGoal or sendGoalAndWait.

See Also
cancelGoal | rosaction | rosactionclient | sendGoalAndWait

Topics
"ROS Actions Overview"
"Move a Turtlebot Robot Using ROS Actions"

Introduced in R2016b

sendGoalAndWait

Send goal message and wait for result

Syntax

```
resultMsg = sendGoalAndWait(client,goalMsg)
resultMsg = sendGoalAndWait(client,goalMsg,timeout)
[resultMsg,state,status] = sendGoalAndWait( ___ )
```

Description

`resultMsg = sendGoalAndWait(client,goalMsg)` sends a goal message using the specified action client to the action server and waits until the action server returns a result message. Press **Ctrl+C** to abort the wait.

`resultMsg = sendGoalAndWait(client,goalMsg,timeout)` specifies a timeout period in seconds. If the server does not return the result in the timeout period, the function displays an error.

`[resultMsg,state,status] = sendGoalAndWait( ___ )` returns the final goal state and associated status text using any of the previous syntaxes. `state` contains information about where the goal execution succeeded or not.

Examples

Send and Cancel ROS Action Goals

Send and cancel goals for ROS actions. First, setup a ROS action client. Then send a goal message with modified parameters. Finally, cancel your goal and all goals on the action server.

Connect to a ROS network with a specified IP address. Create a ROS action client connected using `rosactionclient`. Specify the action name. Wait for the client to be connected to the server.

```
rosinit('192.168.154.131')
[actClient,goalMsg] = rosactionclient('/fibonacci');
waitForServer(actClient);
```

```
Initializing global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5
```

Send a goal message with modified parameters. Wait for the goal to finish executing.

```
goalMsg.Order = 4;
sendGoalAndWait(actClient,goalMsg)
```

```
Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5]

ans =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [6×1 int32]

  Use showdetails to show the contents of the message
```

Send a new goal message without waiting.

```
goalMsg.Order = 5;
sendGoal(actClient,goalMsg)
```

Cancel the goal on the ROS action client, `actClient`.

```
cancelGoal(actClient)
```

Cancel all the goals on the action server that `actClient` is connected to.

```
cancelAllGoals(actClient)
```

Delete the action client.

```
delete(actClient)
```

Disconnect from the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5
```

Input Arguments

client — ROS action client
SimpleActionClient object handle

ROS action client, specified as a SimpleActionClient object handle. This simple action client enables you to track a single goal at a time.

goalMsg — ROS action goal message
Message object handle

ROS action goal message, specified as a Message object handle. Update this message with your goal details and send it to the ROS action client using sendGoal or sendGoalAndWait.

timeout — Timeout period
scalar in seconds

Timeout period for receiving a result message, specified as a scalar in seconds. If the client does not receive a new result message in that time period, an error is displayed.

Output Arguments

resultMsg — Result message
ROS Message object

Result message, returned as a ROS Message object. The result message contains the result data sent by the action server. This data depends on the action type.

state — Final goal state
character vector

Final goal state, returned as one of the following:

- `'pending'` — Goal was received, but has not yet been accepted or rejected.
- `'active'` — Goal was accepted and is running on the server.
- `'succeeded'` — Goal executed successfully.
- `'preempted'` — An action client canceled the goal before it finished executing.
- `'aborted'` — The goal was aborted before it finished executing. The action server typically aborts a goal.
- `'rejected'` — The goal was not accepted after being in the `'pending'` state. The action server typically triggers this status.
- `'recalled'` — A client canceled the goal while it was in the `'pending'` state.
- `'lost'` — An internal error occurred in the action client.

status — Status text
character vector

Status text that the server associated with the final goal state, returned as a character vector.

See Also
cancelGoal | rosaction | rosactionclient | sendGoal

Topics
"ROS Actions Overview"
"Move a Turtlebot Robot Using ROS Actions"

Introduced in R2016b

sendTransform

Send transformation to ROS network

Syntax

```
sendTransform(tftree,tf)
```

Description

`sendTransform(tftree,tf)` broadcasts a transform or array of transforms, `tf`, to the ROS network as a `TransformationStamped` ROS message.

Examples

Send a Transformation to ROS Network

This example shows how to create a transformation and send it over the ROS network.

Create a ROS transformation tree. Use `rosinit` to connect a ROS network. Replace `ipaddress` with your ROS network address.

```
ipaddress = '192.168.203.129';
rosinit(ipaddress)
tftree = rostf;
pause(2)
```

Initializing global node /matlab_global_node_69912 with NodeURI http://192.168.203.1:55

Verify the transformation you want to send over the network does not already exist. `canTransform` returns false if the transformation is not immediately available.

```
canTransform(tftree,'new_frame','base_link')
```

ans =

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```
logical

  0
```

Create a `TransformStamped` message. Populate the message fields with the transformation information.

```
tform = rosmessage('geometry_msgs/TransformStamped');
tform.ChildFrameId = 'new_frame';
tform.Header.FrameId = 'base_link';
tform.Transform.Translation.X = 0.5;
tform.Transform.Rotation.Z = 0.75;
```

Send the transformation over the ROS network.

```
sendTransform(tftree,tform)
```

Verify the transformation is now on the ROS network

```
canTransform(tftree,'new_frame','base_link')
```

```
ans =

  logical

   1
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_69912 with NodeURI http://192.168.203.1:5
```

Input Arguments

`tftree` — ROS transformation tree
`TransformationTree` object handle

ROS transformation tree, specified as a `TransformationTree` object handle. You can create a transformation tree by calling the `rostf` function.

tf — Transformations between coordinate frames
TransformStamped object handle | array of object handles

Transformations between coordinate frames, returned as a TransformStamped object handle or as an array of object handles. Transformations are structured as a 3-D translation (3-element vector) and a 3-D rotation (quaternion).

See Also

getTransform | transform

Introduced in R2015a

set

Set value of ROS parameter or add new parameter

Syntax

```
set(ptree,paramname,pvalue)
set(ptree,namespace,pvalue)
```

Description

`set(ptree,paramname,pvalue)` assigns the value `pvalue` to the parameter with the name `paramname`. This parameter is sent to the parameter tree `ptree`.

`set(ptree,namespace,pvalue)` assigns multiple values as a dictionary in `pvalue` under the specified `namespace`.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed.

- 32-bit integer — `int32`
- boolean — `logical`
- double — `double`
- string — character vector (`char`)
- list — cell array (`cell`)
- dictionary — structure (`struct`)

Examples

Set and Get Parameter Value

Connect to ROS network.

```
rosinit
```

```
Initializing ROS master on http://AH-SRADFORD:11311/.
Initializing global node /matlab_global_node_68286 with NodeURI http://AH-SRADFORD:603:
```

Create ROS parameter tree. Set a double parameter. Get the parameter to verify it was set.

```
ptree = rosparam;
set(ptree,'DoubleParam',1.0)
get(ptree,'DoubleParam')
```

```
ans =

     1
```

Shut down ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_68286 with NodeURI http://AH-SRADFORD:603:
Shutting down ROS master on http://AH-SRADFORD:11311/.
```

Set A Dictionary Of Parameter Values

Use structures to specify a dictionary of ROS parameters under a specific namespace.

Connect to a ROS network.

```
rosinit
```

```
Initializing ROS master on http://bat5811win64:11311/.
Initializing global node /matlab_global_node_08339 with NodeURI http://bat5811win64:570
```

Create a dictionary of parameters values. This dictionary contains the information relevant to an image. Display the structure to verify values.

```
image = imread('peppers.png');

pval.ImageWidth = size(image,1);
pval.ImageHeight = size(image,2);
```

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```
pval.ImageTitle = 'peppers.png';
disp(pval)

    ImageWidth: 384
   ImageHeight: 512
    ImageTitle: 'peppers.png'
```

Set the dictionary of values using the desired namespace.

```
rosparam('set','ImageParam',pval)
```

Get the parameters using the namespace. Verify the values.

```
pval2 = rosparam('get','ImageParam')

pval2 = struct with fields:
   ImageHeight: 512
    ImageTitle: 'peppers.png'
    ImageWidth: 384
```

Shutdown ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_08339 with NodeURI http://bat5811win64:5
Shutting down ROS master on http://bat5811win64:11311/.
```

Input Arguments

ptree — Parameter tree
ParameterTree object handle

Parameter tree, specified as a ParameterTree object handle. Create this object using the rosparam function.

paramname — ROS parameter name
character vector

ROS parameter name, specified as a character vector. This character vector must match the parameter name exactly.

pvalue — ROS parameter value or dictionary of values
int32 | logical | double | character vector | cell array | structure

ROS parameter value or dictionary of values, specified as a supported MATLAB data type.

The following ROS data types are supported as values of parameters. For each ROS data type, the corresponding MATLAB data type is also listed.

ROS Data Type	MATLAB Data Type
32-bit integer	int32
boolean	logical
double	double
string	character vector (char)
list	cell array (cell)
dictionary	structure (struct)

namespace — ROS parameter namespace
character vector

ROS parameter namespace, specified as a character vector. All parameter names starting with this character vector are listed when calling rosparam('list',namespace).

Limitations

Base64-encoded binary data and iso8601 data from ROS are not supported.

See Also

get | rosparam

Introduced in R2015a

show

Package: robotics

Plot pose graph

Syntax

```
show(poseGraph)
show(poseGraph,Name,Value)
axes = show( ___ )
```

Description

show(poseGraph) plots the specified pose graph in a figure.

show(poseGraph,Name,Value) specifies options using Name,Value pair arguments. For example, 'IDs','on' plots all node and edge IDs of the pose graph.

axes = show(___) returns the axes handle that the pose graph is plotted to using any of previous syntaxes.

Examples

Optimize a 2-D Pose Graph

Optimize a pose graph based on the nodes and edge constraints. The pose graph used in this example is from the Intel Research Lab Dataset and was generated from collecting wheel odometry and a laser range finder sensor information in an indoor lab.

Load the Intel data set that contains a 2-D pose graph. Inspect the robotics.PoseGraph object to view the number of nodes and loop closures.

```
load intel-2d-posegraph.mat pg
disp(pg)
```

```
PoseGraph with properties:

            NumNodes: 1228
            NumEdges: 1483
  NumLoopClosureEdges: 256
   LoopClosureEdgeIDs: [1x256 double]
```

Plot the pose graph with IDs off. Red lines indicate loop closures identified in the dataset.

```
title('Original Pose Graph')
show(pg,'IDs','off');
```

Optimize the pose graph. Nodes are adjusted based on the edge constraints and loop closures. Plot the optimized pose graph to see the adjustment of the nodes with loop closures.

```
updatedPG = optimizePoseGraph(pg);
figure
title('Updated Pose Graph')
show(updatedPG,'IDs','off');
```

Optimize a 3-D Pose Graph

Optimize a pose graph based on the nodes and edge constraints. The pose graph used in this example is from the MIT Dataset and was generated using information extracted from a parking garage.

Load the pose graph from the MIT dataset. Inspect the `robotics.PoseGraph3D` object to view the number of nodes and loop closures.

```
load parking-garage-posegraph.mat pg
disp(pg);

  PoseGraph3D with properties:

             NumNodes: 1661
             NumEdges: 6275
   NumLoopClosureEdges: 4615
    LoopClosureEdgeIDs: [1x4615 double]
```

Plot the pose graph with IDs off. Red lines indicate loop closures identified in the dataset.

```
title('Original Pose Graph')
show(pg,'IDs','off');
view(-30,45)
```

Optimize the pose graph. Nodes are adjusted based on the edge constraints and loop closures. Plot the optimized pose graph to see the adjustment of the nodes with loop closures.

```
updatedPG = optimizePoseGraph(pg);
figure
title('Updated Pose Graph')
show(updatedPG,'IDs','off');
view(-30,45)
```

- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Input Arguments

poseGraph — Pose graph
PoseGraph object | PoseGraph3D object

Pose graph, specified as a PoseGraph or PoseGraph3D object.

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Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'IDs','off'`

Parent — Axes used to plot pose graph
Axes object | UIAxes object

Axes used to plot the pose graph, specified as the comma-separated pair consisting of `'Parent'` and either an `Axes` or `UIAxes`object. See `axes` or `uiaxes`.

IDs — Display of IDs on pose graph
`'loopclosures'` (default) | `'all'` | `'nodes'` | `'off'`

Display of IDs on pose graph, specified as the comma-separated pair consisting of `'IDs'` and one of the following:

- `'all'` — Plot node and edge IDs.
- `'nodes'` — Plot node IDs.
- `'loopclosures'` — Plot loop closure edge IDs.
- `'off'` — Do not plot any IDs.

Output Arguments

axes — Axes used to plot the map
Axes object | UIAxes object

Axes used to plot the map, returned as either an `Axes` or `UIAxes` object. See `axes` or `uiaxes`.

See Also

Functions
addRelativePose | optimizePoseGraph

Objects
robotics.LidarSLAM | robotics.PoseGraph | robotics.PoseGraph3D

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

showrobotics.VectorFieldHistogram.show

Package: robotics

Display `VectorFieldHistogram` information in figure window

Syntax

```
show(vfh)
```

```
show(vfh,'Parent',parent)
```

```
h = show( ___ )
```

Description

`show(vfh)` shows histograms calculated by the VFH+ algorithm in a figure window. The figure also includes the parameters of the `VectorFieldHistrogram` object and range values from the last object call.

`show(vfh,'Parent',parent)` sets the specified axes handle, `parent`, to the axes.

`h = show( ___ )` returns the figure object handle created by `show` using any of the arguments from the previous syntaxes.

Examples

Create a Vector Field Histogram Object and Visualize Data

This example shows how to calculate a steering direction based on input laser scan data.

Create a `VectorFieldHistogram` object.

```
 vfh = robotics.VectorFieldHistogram;
```

Input laser scan data and target direction.

```
ranges = 10*ones(1,500);
ranges(1,225:275) = 1.0;
angles = linspace(-pi,pi,500);
targetDir = 0;
```

Compute an obstacle-free steering direction.

```
steeringDir = vfh(ranges,angles,targetDir)
```

```
steeringDir = -0.8014
```

Visualize the `VectorFieldHistogram` computation.

```
h = figure;
set(h,'Position',[50 50 800 400])
show(vfh)
```

Input Arguments

vfh — Vector field histogram algorithm
VectorFieldHistogram object

Vector field histogram algorithm, specified as a VectorFieldHistogram object. This object contains all the parameters for tuning the VFH+ algorithm.

parent — Axes properties
handle

Axes properties, specified as a handle.

Output Arguments

h — Axes handles for VFH algorithm display
Axes array

Axes handles for VFH algorithm display, specified as an Axes array. The VFH histogram and HistogramThresholds are shown in the first axes. The binary histogram, range sensor readings, target direction, and steering directions are shown in the second axes.

See Also

robotics.VectorFieldHistogram

Introduced in R2015b

showdetails

Display all ROS message contents

Syntax

```
details = showdetails(msg)
```

Description

`details = showdetails(msg)` gets all data contents of message object `msg`. The details are stored in `details` or displayed on the command line.

Examples

Create Message and View Details

Create a message. Populate the message with data using the relevant properties.

```
msg = rosmessage('geometry_msgs/Point');
msg.X = 1;
msg.Y = 2;
msg.Z = 3;
```

View the message details.

```
showdetails(msg)

  X :   1
  Y :   2
  Z :   3
```

Input Arguments

`msg` — ROS message
Message object handle

ROS message, specified as a Message object handle.

Output Arguments

`details` — Details of ROS message
character vector

Details of ROS message, returned as a character vector.

See Also
rosmessage

Introduced in R2015a

stopCore

Stop ROS core

Syntax

```
stopCore(device)
```

Description

`stopCore(device)` stops the ROS core on the specified `rosdevice`, `device`. If multiple ROS cores are running on the ROS device, the function stops all of them. If no core is running, the function returns immediately.

Examples

Run ROS Core on ROS Device

Connect to a remote ROS device and start a ROS core. The ROS core is needed to run ROS nodes to communicate via a ROS network. You can run and stop a ROS core or node and check their status using a `rosdevice` object.

Create a connection to a ROS device. Specify the address, user name, and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using `runNode`.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password')
```

```
d =

  rosdevice with properties:

      DeviceAddress: '192.168.154.131'
```

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```
          Username: 'user'
          ROSFolder: '/opt/ros/hydro'
    CatkinWorkspace: '~/catkin_ws_test'
     AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core and check if it is running.

```
runCore(d)
running = isCoreRunning(d)
```

```
running =

  logical

   1
```

Stop the ROS core and confirm that it is no longer running.

```
stopCore(d)
running = isCoreRunning(d)
```

```
running =

  logical

   0
```

- "Generate a Standalone ROS Node from Simulink®"

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a `rosdevice` object.

See Also

`isCoreRunning` | `rosdevice` | `runCore`

Topics

"Generate a Standalone ROS Node from Simulink®"

Introduced in R2016b

statistics

Statistics of past execution periods

Syntax

```
stats = statistics(rate)
```

Description

`stats = statistics(rate)` returns statistics of previous periods of code execution. `stats` is a struct with these fields: `Periods`, `NumPeriods`, `AveragePeriod`, `StandardDeviation`, and `NumOverruns`.

Here is a sample execution graphic using the default setting, `'slip'`, for the `OverrunAction` property in the `Rate` object. See `OverrunAction` for more information on overrun code execution.
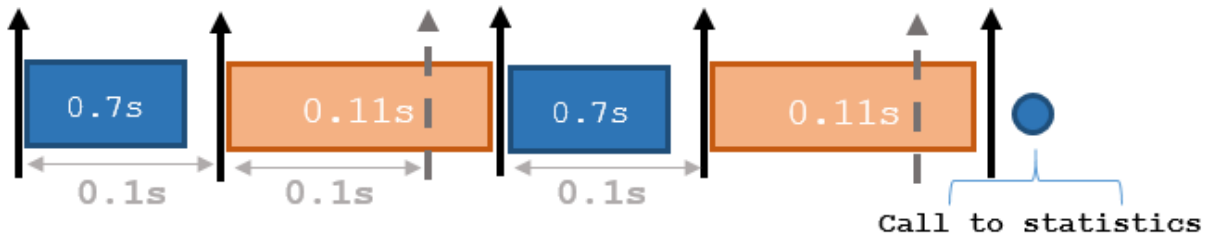
The output of `statistics` is:

```
stats =

              Periods: [0.7 0.11 0.7 0.11]
           NumPeriods: 4
        AveragePeriod: 0.09
    StandardDeviation: 0.0231
          NumOverruns: 2
```

Input Arguments

rate — Rate object
handle

`Rate` object, specified as an object handle. This object contains the information for the `DesiredRate` and other info about the execution. See `robotics.Rate` for more information.

Output Arguments

stats — Time execution statistics
structure

Time execution statistics, returned as a structure. This structure contains the following fields:

- `Period` — All time periods (returned in seconds) used to calculate statistics as an indexed array. `stats.Period(end)` is the most recent period.
- `NumPeriods` — Number of elements in `Periods`
- `AveragePeriod` — Average time in seconds
- `StandardDeviation` — Standard deviation of all periods in seconds, centered around the mean stored in `AveragePeriod`
- `NumOverruns` — Number of periods with overrun

Examples

Get Statistics From Rate Object Execution

Create a `Rate` object for running at 20 Hz.

```
r = robotics.Rate(2);
```

Start a loop and control operation using the `Rate` object.

```
for i = 1:30
    % Your code goes here
```

```
    waitfor(r);
end
```

Get `Rate` object statistics after loop operation.

```
stats = statistics(r)

stats = struct with fields:
              Periods: [1x30 double]
           NumPeriods: 30
        AveragePeriod: 0.5000
    StandardDeviation: 6.5567e-04
           NumOverruns: 0
```

*   "Execute Code at a Fixed-Rate"

See Also
`robotics.Rate` | `rosrate` | `waitfor`

Topics
"Execute Code at a Fixed-Rate"

Introduced in R2016a

stopNode

Stop ROS node

Syntax

```
stopNode(device,modelName)
```

Description

`stopNode(device,modelName)` stops a running ROS node running that was deployed from a Simulink model named `modelName`. The node is running on the specified `rosdevice` object, `device`. If the node is not running, the function immediately.

Examples

Run ROS Node on ROS Device

Connect to a remote ROS device and start a ROS node. First, run a ROS core so that ROS nodes can communicate via a ROS network. You can run and stop a ROS core or node and check their status using a `rosdevice` object.

Create a connection to a ROS device. Specify the address, user name and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using `runNode`.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password');
d.ROSFolder = '/opt/ros/hydro';
d.CatkinWorkspace = '~/catkin_ws_test'


d =

  rosdevice with properties:
```

```
       DeviceAddress: '192.168.154.131'
            Username: 'user'
           ROSFolder: '/opt/ros/hydro'
      CatkinWorkspace: '~/catkin_ws_test'
       AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core. Connect MATLAB® to the ROS master using `rosinit`. This core
enables you to run ROS nodes on your ROS device.

```
runCore(d)
rosinit(d.DeviceAddress)
```

```
Another roscore / ROS master is already running on the ROS device. Use the 'stopCore'
Initializing global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:56
```

Check the available ROS nodes on the connected ROS device. These nodes were
generated from Simulink® models following the process in the Generate a standalone
ROS node from Simulink® example.

```
d.AvailableNodes
```

```
ans =

  1×2 cell array

    'robotcontroller'    'robotcontroller2'
```

Run a ROS node. specifying the node name. Check if the node is running.

```
runNode(d,'robotcontroller')
running = isNodeRunning(d,'robotcontroller')
```

```
running =

  logical

   1
```

Stop the ROS node. Disconnect from the ROS network. Stop the ROS core.

```
stopNode(d,'robotcontroller')
rosshutdown
stopCore(d)
```

```
Shutting down global node /matlab_global_node_15046 with NodeURI http://192.168.154.1:5
```

Run Multiple ROS Nodes

Run multiple ROS nodes on a connected ROS device. ROS nodes can be generated using Simulink® models to perform different tasks on the ROS network. These nodes are then deployed on a ROS device and can be run independently of Simulink.

This example uses two different Simulink models that have been deployed as ROS nodes. See Generate a standalone ROS node from Simulink®). and follow the instructions to generate and deploy a ROS node. The 'robotcontroller' node sends velocity commands to a robot to navigate it to a given point. The 'robotcontroller2' node uses the same model, but doubles the linear velocity to drive the robot faster.

Create a connection to a ROS device. Specify the address, user name, and password of your specific ROS device. The device contains information about the ROS device, including the available ROS nodes that can be run using runNode.

```
ipaddress = '192.168.154.131';
d = rosdevice(ipaddress,'user','password')
```

```
d =

  rosdevice with properties:

      DeviceAddress: '192.168.154.131'
           Username: 'user'
          ROSFolder: '/opt/ros/hydro'
    CatkinWorkspace: '~/catkin_ws_test'
     AvailableNodes: {'robotcontroller'  'robotcontroller2'}
```

Run a ROS core. Connect MATLAB® to the ROS master using rosinit. This ROS core enables you to run ROS nodes on your ROS device.

```
runCore(d)
rosinit(d.DeviceAddress)
```

```
Initializing global node /matlab_global_node_68749 with NodeURI http://192.168.154.1:64
```

Check the available ROS nodes on the connected ROS device. These nodes were generated from Simulink® models following the process in the Generate a standalone ROS node from Simulink® example.

```
d.AvailableNodes
```

```
ans =

  1×2 cell array

    'robotcontroller'    'robotcontroller2'
```

Start up the Robot Simulator using `ExampleHelperSimulinkRobotROS`. This simulator automatically connects to the ROS master on the ROS device. You will use this simulator to run a ROS node and control the robot.

```
sim = ExampleHelperSimulinkRobotROS;
```

Run a ROS node, specifying the node name. The `'robotcontroller'` node commands the robot to a specific location (`[-10 10]`). Wait to see the robot drive.

```
runNode(d,'robotcontroller')
pause(10)
```

Reset the Robot Simulator to reset the robot position. Alternatively, click **Reset Simulation**. Because the node is still running, the robot continues back to the specific location. To stop sending commands, stop the node.

```
resetSimulation(sim.Simulator)
pause(5)
stopNode(d,'robotcontroller')
```

Run the `'robotcontroller2'` node. This model drives the robot with twice the linear velocity. Reset the robot position. Wait to see the robot drive.

```
runNode(d,'robotcontroller2')
resetSimulation(sim.Simulator)
pause(10)
```

Close the simulator. Stop the ROS node. Disconnect from the ROS network and stop the ROS core.

```
close
stopNode(d,'robotcontroller2')
rosshutdown
stopCore(d)
```

Shutting down global node /matlab_global_node_68749 with NodeURI http://192.168.154.1:6

- "Generate a Standalone ROS Node from Simulink®"

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a rosdevice object.

modelName — Name of the deployed Simulink model
character vector

Name of the deployed Simulink model, specified as a character vector. If the model name is not valid, the function returns immediately.

See Also

isNodeRunning | rosdevice | runNode

Topics

"Generate a Standalone ROS Node from Simulink®"

Introduced in R2016b

system

Execute system command on device

Syntax

```
system(device,command)
system(device,command,'sudo')
response = system( ___ )
```

Description

`system(device,command)` runs a command in the Linux command shell on the ROS device. This function does not allow you to run interactive commands.

`system(device,command,'sudo')` runs a command with superuser privileges.

`response = system( ___ )` runs a command using any of the previous syntaxes with the command shell output returned in `response`.

Examples

Run Linux Commands on ROS Device

Connect to a ROS device and run commands on the Linux® command shell.

Connect to a ROS device. Specify the device address, user name, and password of your ROS device.

```
d = rosdevice('192.168.154.131','user','password');
```

Run a command that lists the contents of the Catkin workspace folder.

```
system(d,'ls /home/user/catkin_ws_test')
```

```
ans =

build
devel
robotcontroller2_node.log
robotcontroller_node.log
src
```

Input Arguments

device — ROS device
rosdevice object

ROS device, specified as a rosdevice object.

command — Linux command
character vector

Linux command, specified as a character vector.

Example: 'ls -al'

Output Arguments

response — Output from Linux shell
character vector

Output from Linux shell, returned as a character vector.

See Also

deleteFile | dir | getFile | openShell | putFile | rosdevice

Introduced in R2016b

tform2axang

Convert homogeneous transformation to axis-angle rotation

Syntax

```
axang = tform2axang(tform)
```

Description

`axang = tform2axang(tform)` converts the rotational component of a homogeneous transformation, `tform`, to an axis-angle rotation, `axang`. The translational components of `tform` are ignored. The input homogeneous transformation must be in the premultiply form for transformations.

Examples

Convert Homogeneous Transformation to Axis-Angle Rotation

```
tform = [1 0 0 0; 0 0 -1 0; 0 1 0 0; 0 0 0 1];
axang = tform2axang(tform)

axang = 1×4

    1.0000         0         0    1.5708
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axes, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Extended Capabilities

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

See Also
axang2tform

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

tform2eul

Extract Euler angles from homogeneous transformation

Syntax

```
eul = tform2eul(tform)
eul = tform2eul(tform, sequence)
```

Description

`eul = tform2eul(tform)` extracts the rotational component from a homogeneous transformation, `tform`, and returns it as Euler angles, `eul`. The translational components of `tform` are ignored. The input homogeneous transformation must be in the premultiply form for transformations. The default order for Euler angle rotations is `'ZYX'`.

`eul = tform2eul(tform, sequence)` extracts the Euler angles, `eul`, from a homogeneous transformation, `tform`, using the specified rotation sequence, `sequence`. The default order for Euler angle rotations is `'ZYX'`.

Examples

Extract Euler Angles from Homogeneous Transformation Matrix

```
tform = [1 0 0 0.5; 0 -1 0 5; 0 0 -1 -1.2; 0 0 0 1];
eulZYX = tform2eul(tform)
```

eulZYX = *1×3*

         0   0   3.1416

Extract Euler Angles from Homogeneous Transformation Matrix Using ZYZ Rotation

```
tform = [1 0 0 0.5; 0 -1 0 5; 0 0 -1 -1.2; 0 0 0 1];
eulZYZ = tform2eul(tform,'ZYZ')
```

eulZYZ = *1×3*

```
    0   -3.1416    3.1416
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

`sequence` — Axis rotation sequence
`'ZYX'` (default) | `'ZYZ'` | `'XYZ'`

Axis rotation sequence for the Euler angles, specified as one of these character vectors:

- `'ZYX'` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `'ZYZ'` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `'XYZ'` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Output Arguments

`eul` — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, returned as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

Extended Capabilities

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

See Also
`eul2tform`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

tform2quat

Extract quaternion from homogeneous transformation

Syntax

quat = tform2quat(tform)

Description

quat = tform2quat(tform) extracts the rotational component from a homogeneous transformation, tform, and returns it as a quaternion, quat. The translational components of tform are ignored. The input homogeneous transformation must be in the premultiply form for transformations.

Examples

Extract Quaternion from Homogeneous Transformation

```
tform = [1 0 0 0; 0 -1 0 0; 0 0 -1 0; 0 0 0 1];
quat = tform2quat(tform)
```

quat = *1×4*

    0   1   0   0

Input Arguments

tform — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

quat — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Extended Capabilities

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

See Also
`quat2tform`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

tform2rotm

Extract rotation matrix from homogeneous transformation

Syntax

```
rotm = tform2rotm(tform)
```

Description

`rotm = tform2rotm(tform)` extracts the rotational component from a homogeneous transformation, `tform`, and returns it as an orthonormal rotation matrix, `rotm`. The translational components of `tform` are ignored. The input homogeneous transformation must be in the pre-multiply form for transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Examples

Convert Homogeneous Transformation to Rotation Matrix

```
tform = [1 0 0 0; 0 -1 0 0; 0 0 -1 0; 0 0 0 1];
rotm = tform2rotm(tform)

rotm = 3×3

    1     0     0
    0    -1     0
    0     0    -1
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the pre-multiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1; 0 1 0; -1 0 0]`

Extended Capabilities

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

See Also
`rotm2tform`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

tform2trvec

Extract translation vector from homogeneous transformation

Syntax

```
trvec = tform2trvec(tform)
```

Description

`trvec = tform2trvec(tform)` extracts the Cartesian representation of translation vector, `trvec`, from a homogeneous transformation, `tform`. The rotational components of `tform` are ignored. The input homogeneous transformation must be in the premultiply form for transformations.

Examples

Extract Translation Vector from Homogeneous Transformation

```
tform = [1 0 0 0.5; 0 -1 0 5; 0 0 -1 -1.2; 0 0 0 1];
trvec = tform2trvec(tform)

trvec = 1×3

    0.5000    5.0000   -1.2000
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

`trvec` — Cartesian representation of a translation vector
n-by-3 matrix

Cartesian representation of a translation vector, returned as an *n*-by-3 matrix containing *n* translation vectors. Each vector is of the form $t = [x\ y\ z]$.

Example: `[0.5 6 100]`

Extended Capabilities

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

See Also
`trvec2tform`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

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
```

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```
      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))]
b = quaternion(randn(4,4))
a.*b


a =

  1x3 quaternion array

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


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


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,

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

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:

$$z = pq = \left(a_p + b_p\mathrm{i} + c_p\mathrm{j} + d_p\mathrm{k}\right)\left(a_q + b_q\mathrm{i} + c_q\mathrm{j} + d_q\mathrm{k}\right)$$

$$= a_p a_q + a_p b_q\mathrm{i} + a_p c_q\mathrm{j} + a_p d_q\mathrm{k}$$

$$+ b_p a_q\mathrm{i} + b_p b_q\mathrm{i}^2 + b_p c_q\mathrm{i}\,\mathrm{j} + b_p d_q\mathrm{i}\,\mathrm{k}$$

$$+ c_p a_q\mathrm{j} + c_p b_q\mathrm{j}\,\mathrm{i} + c_p c_q\mathrm{j}^2 + c_p d_q\mathrm{j}\,\mathrm{k}$$

$$+ d_p a_q\mathrm{k} + d_p b_q\mathrm{k}\,\mathrm{i} + d_p c_q\mathrm{k}\,\mathrm{j} + d_p d_q\mathrm{k}^2$$

You can simplify the equation using the quaternion multiplication table.

$$z = pq = a_p a_q + a_p b_q\mathrm{i} + a_p c_q\mathrm{j} + a_p d_q\mathrm{k}$$

$$+ b_p a_q\mathrm{i} - b_p b_q + b_p c_q\mathrm{k} - b_p d_q\mathrm{j}$$

$$+ c_p a_q\mathrm{j} - c_p b_q\mathrm{k} - c_p c_q + c_p d_q\mathrm{i}$$

$$+ d_p a_q\mathrm{k} + d_p b_q\mathrm{j} - d_p c_q\mathrm{i} - d_p d_q$$

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.

See Also

Introduced in R2018a

timeseries

Creates a time series object for selected message properties

Syntax

```
[ts,cols] = timeseries(bag)
[ts,cols] = timeseries(bag,property)
[ts,cols] = timeseries(bag,property,...,propertyN)
```

Description

`[ts,cols] = timeseries(bag)` creates a time series for all numeric and scalar message properties. The function evaluates each message in the current `BagSelection` object, `bag`, as `ts`. The `cols` output argument stores property names as a cell array of character vectors.

The returned time series object is memory-efficient because it stores only particular message properties instead of whole messages.

`[ts,cols] = timeseries(bag,property)` creates a time series for a specific message property, `property`. Property names can also be nested, for example, `'Pose.Pose.Position.X'` for the *x*-axis position of a robot.

`[ts,cols] = timeseries(bag,property,...,propertyN)` creates a time series for a range specific message properties. Each property is a different column in the time series object.

Examples

Create Time Series from Entire Bag Selection

Load rosbag. Specify the file path.

```
filepath = fullfile(fileparts(which('ROSWorkingWithRosbagsExample')), 'data', 'ex_mult:
bag = rosbag(filepath);
```

Select a specific topic. Time series only support single topics.

```
bagSelection = select(bag,'Topic','/odom');
```

Create time series for the '/odom' topic.

```
ts = timeseries(bagSelection);
```

Create Time Series from Single Property

Load rosbag. Specify the file path.

```
filepath = fullfile(fileparts(which('ROSWorkingWithRosbagsExample')), 'data', 'ex_mult:
bag = rosbag(filepath);
```

Select a specific topic. Time series only support single topics.

```
bagSelection = select(bag,'Topic','/odom');
```

Create time series for the 'Pose.Pose.Position.X' property on the '/odom' topic.

```
ts = timeseries(bagSelection,'Pose.Pose.Position.X');
```

Create Time Series from Multiple Properties

Load rosbag. Specify the file path.

```
filepath = fullfile(fileparts(which('ROSWorkingWithRosbagsExample')), 'data', 'ex_mult:
bag = rosbag(filepath);
```

Select a specific topic. Time series only support single topics.

```
bagSelection = select(bag,'Topic','/odom');
```

Create time series for all the angular 'Twist' properties on the '/odom' topic.

```
ts = timeseries(bagSelection,'Twist.Twist.Angular.X', ...
          'Twist.Twist.Angular.Y', 'Twist.Twist.Angular.Z');
```

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Input Arguments

bag — Bag selection
BagSelection object handle

Bag selection, specified as a BagSelection object handle. You can get a bag selection by calling rosbag.

property — Property names
character vector

Property names, specified as a character vector. Multiple properties can be specified. Each property name is a separate input and represents a different column in the time series object.

Output Arguments

ts — Time series
Time object handle

Time series, returned as a Time object handle.

cols — List of property names
cell array of character vectors

List of property names, returned as a cell array of character vectors.

See Also
readMessages | rosbag | select

Topics
"Time Series" (MATLAB)

Introduced in R2015a

transform

Transform message entities into target coordinate frame

Syntax

```
tfentity = transform(tftree,targetframe,entity)
tfentity = transform(tftree,targetframe,entity,'msgtime')
tfentity = transform(tftree,targetframe,entity,sourcetime)
```

Description

`tfentity = transform(tftree,targetframe,entity)` retrieves the latest transformation between `targetframe` and the coordinate frame of `entity` and applies it to `entity`, a ROS message of a specific type. `tftree` is the full transformation tree containing known transformations between entities. If the transformation from `entity` to `targetframe` does not exist, MATLAB throws an error.

`tfentity = transform(tftree,targetframe,entity,'msgtime')` uses the timestamp in the header of the message, `entity`, as the source time to retrieve and apply the transformation.

`tfentity = transform(tftree,targetframe,entity,sourcetime)` uses the given source time to retrieve and apply the transformation to the message, `entity`.

Examples

Get ROS Transformations and Apply to ROS Messages

This example shows how to set up a ROS transformation tree and transform frames based on this information. It uses time-buffered transformations to access transformations at different times.

Create a ROS transformation tree. Use `rosinit` to connect to a ROS network. Replace `ipaddress` with your ROS network address.

```
ipaddress = '192.168.203.129';
rosinit(ipaddress)
tftree = rostf;
pause(1)
```

```
Initializing global node /matlab_global_node_60416 with NodeURI http://192.168.203.1:53
```

Look at the available frames on the transformation tree.

```
tftree.AvailableFrames
```

```
ans =

  36×1 cell array

    {'base_footprint'            }
    {'base_link'                 }
    {'camera_depth_frame'        }
    {'camera_depth_optical_frame'}
    {'camera_link'               }
    {'camera_rgb_frame'          }
    {'camera_rgb_optical_frame'  }
    {'caster_back_link'          }
    {'caster_front_link'         }
    {'cliff_sensor_front_link'   }
    {'cliff_sensor_left_link'    }
    {'cliff_sensor_right_link'   }
    {'gyro_link'                 }
    {'mount_asus_xtion_pro_link' }
    {'odom'                      }
    {'plate_bottom_link'         }
    {'plate_middle_link'         }
    {'plate_top_link'            }
    {'pole_bottom_0_link'        }
    {'pole_bottom_1_link'        }
    {'pole_bottom_2_link'        }
    {'pole_bottom_3_link'        }
    {'pole_bottom_4_link'        }
    {'pole_bottom_5_link'        }
    {'pole_kinect_0_link'        }
    {'pole_kinect_1_link'        }
    {'pole_middle_0_link'        }
    {'pole_middle_1_link'        }
    {'pole_middle_2_link'        }
```

```
{'pole_middle_3_link'        }
{'pole_top_0_link'           }
{'pole_top_1_link'           }
{'pole_top_2_link'           }
{'pole_top_3_link'           }
{'wheel_left_link'           }
{'wheel_right_link'          }
```

Check if the desired transformation is available now. For this example, check for the transformation from 'camera_link' to 'base_link'.

```
canTransform(tftree,'base_link','camera_link')
```

```
ans =

  logical

   1
```

Get the transformation for 3 seconds from now. getTransform will wait until the transformation becomes available with the specified timeout.

```
desiredTime = rostime('now') + 3;
tform = getTransform(tftree,'base_link','camera_link',...
                     desiredTime,'Timeout',5);
```

Create a ROS message to transform. Messages could also be retrieved off the ROS network.

```
pt = rosmessage('geometry_msgs/PointStamped');
pt.Header.FrameId = 'camera_link';
pt.Point.X = 3;
pt.Point.Y = 1.5;
pt.Point.Z = 0.2;
```

Transform the ROS message to the 'base_link' frame using the desired time saved from before.

```
tfpt = transform(tftree,'base_link',pt,desiredTime);
```

Optional: You can also use apply with the stored tform to apply this transformation to the pt message.

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```
tfpt2 = apply(tform,pt);
```

Shut down the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_60416 with NodeURI http://192.168.203.1:5

Get Buffered Transformations from ROS Network

This example shows how to access time-buffered transformations on the ROS network. Access transformations for specific times and modify the `BufferTime` property based on your desired times.

Create a ROS transformation tree. Use `rosinit` to connect to a ROS network. Replace `ipaddress` with your ROS network address.

```
ipaddress = '192.168.203.129';
rosinit(ipaddress)
tftree = rostf;
pause(2);
```

Initializing global node /matlab_global_node_29163 with NodeURI http://192.168.203.1:53

Get the transformation from 1 second ago.

```
desiredTime = rostime('now') - 1;
tform = getTransform(tftree,'base_link','camera_link',desiredTime);
```

The transformation buffer time is 10 seconds by default. Modify the `BufferTime` property of the transformation tree to increase the buffer time and wait for that buffer to fill.

```
tftree.BufferTime = 15;
pause(15);
```

Get the transformation from 12 seconds ago.

```
desiredTime = rostime('now') - 12;
tform = getTransform(tftree,'base_link','camera_link',desiredTime);
```

You can also get transformations at a time in the future. `getTransform` will wait until the transformation is available. You can also specify a timeout to error out if no

transformation is found. This example waits 5 seconds for the transformation at 3 seconds from now to be available.

```
desiredTime = rostime('now') + 3;
tform = getTransform(tftree,'base_link','camera_link',desiredTime,'Timeout',5);
```

Shut down the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_29163 with NodeURI http://192.168.203.1:5
```

Input Arguments

tftree — ROS transformation tree
TransformationTree object handle

ROS transformation tree, specified as a TransformationTree object handle. You can create a transformation tree by calling the rostf function.

targetframe — Target coordinate frame
character vector

Target coordinate frame that entity transforms into, specified as a character vector. You can view the available frames for transformation calling tftree.AvailableFrames.

entity — Initial message entity
Message object handle

Initial message entity, specified as a Message object handle.

Supported messages are:

- geometry_msgs/PointStamped
- geometry_msgs/PoseStamped
- geometry_msgs/QuaternionStamped
- geometry_msgs/Vector3Stamped
- sensor_msgs/PointCloud2

sourcetime — ROS or system time
scalar | Time object handle

ROS or system time, specified as a scalar or `Time` object handle. The scalar is converted to a `Time` object using `rostime`.

Output Arguments

`tfentity` — Transformed entity
Message object handle

Transformed entity, returned as a `Message` object handle.

See Also

canTransform | getTransform

Introduced in R2015a

transformScan

Transform laser scan based on relative pose

Syntax

```
transScan = transformScan(scan,relPose)
```

```
[transRanges,transAngles] = transformScan(ranges,angles,relPose)
```

Description

`transScan = transformScan(scan,relPose)` transforms the laser scan specified in `scan` by using the specified relative pose, `relPose`.

`[transRanges,transAngles] = transformScan(ranges,angles,relPose)` transforms the laser scan specified in `ranges` and `angles` by using the specified relative pose, `relPose`.

Examples

Transform Laser Scans

Create a `lidarScan` object. Specify the ranges and angles as vectors.

```
refRanges = 5*ones(1,300);
refAngles = linspace(-pi/2,pi/2,300);
refScan = lidarScan(refRanges,refAngles);
```

Translate the laser scan by an `[x y]` offset of `(0.5,0.2)`.

```
transScan = transformScan(refScan,[0.5 0.2 0]);
```

Rotate the laser scan by 20 degrees.

```
rotScan = transformScan(refScan,[0,0,deg2rad(20)]);
```

Use Scan Matching to Transform Scans

Use the `matchScans` function to find the relative transformation between two laser scans. Then transform the second laser scan into the coordinate frame of the first laser scan.

This example requires an Optimization Toolbox™ license.

Specify a laser scan as ranges and angles. Create a second laser scan that is offset from the first using `transformScan`. This transformation simulates a second laser scan being collected from a new coordinate frame.

```
refRanges = 5*ones(1,300);
refRanges(51:150) = 3*ones(1,100);
refAngles = linspace(-pi/2,pi/2,300);
offset = [0.5 0.2 0];
[currRanges,currAngles] = transformScan(refRanges,refAngles,offset);
```

Use scan matching to find the relative pose between the two laser scans. This pose is close to the specified `offset`. You must have an Optimization Toolbox™ license to use the `matchScans` function.

```
pose = matchScans(currRanges,currAngles,refRanges,refAngles,'SolverAlgorithm','fminunc
```

```
pose = 1×3

   -0.5102   -0.1806   -0.0394
```

Transform the second scan to the coordinate frame of the first scan. Plot the two scans to see how they overlap.

```
[currRanges2,currAngles2] = transformScan(currRanges,currAngles,pose);
clf
polarplot(refAngles,refRanges,'or')
hold on
polarplot(currAngles2,currRanges2,'.b')
legend('First laser scan','Second laser scan')
hold off
```

- "Estimate Robot Pose with Scan Matching"
- "Compose a Series of Laser Scans with Pose Changes"

Input Arguments

scan — Lidar scan readings
lidarScan object

Lidar scan readings, specified as a lidarScan object.

ranges — Range values from scan data
vector

Range values from scan data, specified as a vector in meters. These range values are distances from a sensor at specified `angles`. The vector must be the same length as the corresponding `angles` vector.

angles — Angle values from scan data
vector

Angle values from scan data, specified as a vector in radians. These angle values are the specific angles of the specified `ranges`. The vector must be the same length as the corresponding `ranges` vector.

relPose — Relative pose of current scan
[x y theta]

Relative pose of current scan, specified as [x y theta], where [x y] is the translation in meters and `theta` is the rotation in radians.

Output Arguments

transScan — Transformed lidar scan readings
lidarScan object

Transformed lidar scan readings, specified as a `lidarScan` object.

transRanges — Range values of transformed scan
vector

Range values of transformed scan, returned as a vector in meters. These range values are distances from a sensor at specified `transAngles`. The vector is the same length as the corresponding `transAngles` vector.

transAngles — Angle values from scan data
vector

Angle values of transformed scan, returned as a vector in radians. These angle values are the specific angles of the specified `transRanges`. The vector is the same length as the corresponding `ranges` vector.

Extended Capabilities

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

See Also

Functions
LaserScan | lidarScan | matchScans | readCartesian | readScanAngles

Classes
MonteCarloLocalization | OccupancyGrid

Topics
"Estimate Robot Pose with Scan Matching"
"Compose a Series of Laser Scans with Pose Changes"

Introduced in R2017a

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))
quatTransposed = quat.'
```

```
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 =

  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))]
quatTransposed = quat.'
```

```
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 =

  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.

See Also

Introduced in R2018a

trvec2tform

Convert translation vector to homogeneous transformation

Syntax

```
tform = trvec2tform(trvec)
```

Description

`tform = trvec2tform(trvec)` converts the Cartesian representation of a translation vector, `trvec`, to the corresponding homogeneous transformation, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Translation Vector to Homogeneous Transformation

```
trvec = [0.5 6 100];
tform = trvec2tform(trvec)

tform = 4×4

    1.0000         0         0    0.5000
         0    1.0000         0    6.0000
         0         0    1.0000  100.0000
         0         0         0    1.0000
```

Input Arguments

`trvec` — Cartesian representation of a translation vector
n-by-3 matrix

Cartesian representation of a translation vector, specified as an *n*-by-3 matrix containing *n* translation vectors. Each vector is of the form $t = [x\ y\ z]$.

Example: `[0.5 6 100]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, returned as a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Extended Capabilities

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

See Also
`tform2trvec`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

waitfor

Package: robotics

Pause code execution to achieve desired execution rate

Syntax

```
waitfor(rate)
numMisses = waitfor(rate)
```

Description

`waitfor(rate)` pauses execution until the code reaches the desired execution rate. The function accounts for the time that is spent executing code between `waitfor` calls.

`numMisses = waitfor(rate)` returns the number of iterations missed while executing code between calls.

Examples

Run Loop at Fixed Rate

Create a rate object that runs at 1 Hz.

```
r = robotics.Rate(1);
```

Start a loop using the `Rate` object inside to control the loop execution. Reset the object prior to the loop execution to reset timer. Print the iteration and time elapsed.

```
reset(r)
for i = 1:10
    time = r.TotalElapsedTime;
    fprintf('Iteration: %d - Time Elapsed: %f\n',i,time)
    waitfor(r);
end
```

2-445

```
Iteration: 1 - Time Elapsed: 0.007008
Iteration: 2 - Time Elapsed: 1.003965
Iteration: 3 - Time Elapsed: 2.004261
Iteration: 4 - Time Elapsed: 3.005156
Iteration: 5 - Time Elapsed: 4.004166
Iteration: 6 - Time Elapsed: 5.003940
Iteration: 7 - Time Elapsed: 6.004566
Iteration: 8 - Time Elapsed: 7.003711
Iteration: 9 - Time Elapsed: 8.003916
Iteration: 10 - Time Elapsed: 9.005005
```

Each iteration executes at a 1-second interval.

- "Execute Code at a Fixed-Rate"

Input Arguments

`rate` — Rate object
handle

`Rate` object, specified as a handle. This object contains the information for the desired rate and other information about the execution. See `robotics.Rate` for more information.

Output Arguments

`numMisses` — Number of missed task executions
scalar

Number of missed task executions, returned as a scalar. `waitfor` returns the number of times the task was missed in the `Rate` object based on the `LastPeriod` time. For example, if the desired rate is 1 Hz and the last period was 3.2 seconds, `numMisses` returns 3.

See Also

`robotics.Rate` | `rosrate` | `waitfor`

Topics
"Execute Code at a Fixed-Rate"

Introduced in R2016a

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
```

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`

See Also

Introduced in R2018a

waitForServer

Wait for action server to start

Syntax

```
waitForServer(client)
waitForServer(client,timeout)
```

Description

waitForServer(client) waits until the action server is started up and available to send goals. The IsServerConnected property of the SimpleActionClient shows the status of the server connection. Press **Ctrl+C** to abort the wait.

waitForServer(client,timeout) specifies a timeout period in seconds. If the server does not start up in the timeout period, this function displays an error.

Examples

Setup a ROS Action Client and Execute an Action

This example shows how to create a ROS action client and execute the action. Action types must be setup beforehand with an action server running.

You must have the '/fibonacci' action type setup. To run this action server use the following command on the ROS system:

```
rosrun actionlib_tutorials fibonacci_server
```

Connect to a ROS network. You must be connected to a ROS network to gather information about what actions are available. Replace ipaddress with your network address.

```
ipaddress = '192.168.154.131';
rosinit(ipaddress)
```

```
Initializing global node /matlab_global_node_68978 with NodeURI http://192.168.154.1:51
```

List actions available on the network. The only action setup on this network is the '/fibonacci' action.

```
rosaction list
```

```
/fibonacci
```

Create an action client. Specify the action name.

```
[actClient,goalMsg] = rosactionclient('/fibonacci');
```

Wait for action client to connect to server.

```
waitForServer(actClient);
```

The fibonacci action will calculate the fibonacci sequence for a given order specified in the goal message. The goal message was returned when creating the action client and can be modified to send goals to the ROS action server.

```
goalMsg.Order = 8
```

```
goalMsg =

  ROS FibonacciGoal message with properties:

    MessageType: 'actionlib_tutorials/FibonacciGoal'
          Order: 8

  Use showdetails to show the contents of the message
```

Send goal and wait for its completion. Specify a timeout of 10 seconds to complete the action.

```
[resultMsg,resultState] = sendGoalAndWait(actClient,goalMsg,10)
```

```
Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
```

```
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13, 21]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13, 21, 34]
Final state succeeded with result:
  Sequence :  [0, 1, 1, 2, 3, 5, 8, 13, 21, 34]

resultMsg =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [10×1 int32]

  Use showdetails to show the contents of the message


resultState =

  1×9 char array

succeeded
```

Disconnect from the ROS network.

`rosshutdown`

```
Shutting down global node /matlab_global_node_68978 with NodeURI http://192.168.154.1:5
```

Send and Cancel ROS Action Goals

Send and cancel goals for ROS actions. First, setup a ROS action client. Then send a goal message with modified parameters. Finally, cancel your goal and all goals on the action server.

Connect to a ROS network with a specified IP address. Create a ROS action client connected using `rosactionclient`. Specify the action name. Wait for the client to be connected to the server.

```
rosinit('192.168.154.131')
[actClient,goalMsg] = rosactionclient('/fibonacci');
waitForServer(actClient);
```

```
Initializing global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5
```

Send a goal message with modified parameters. Wait for the goal to finish executing.

```
goalMsg.Order = 4;
sendGoalAndWait(actClient,goalMsg)
```

```
Goal active
Feedback:
  Sequence :  [0, 1, 1]
Feedback:
  Sequence :  [0, 1, 1, 2]
Feedback:
  Sequence :  [0, 1, 1, 2, 3]
Feedback:
  Sequence :  [0, 1, 1, 2, 3, 5]

ans =

  ROS FibonacciResult message with properties:

    MessageType: 'actionlib_tutorials/FibonacciResult'
       Sequence: [6×1 int32]

  Use showdetails to show the contents of the message
```

Send a new goal message without waiting.

```
goalMsg.Order = 5;
sendGoal(actClient,goalMsg)
```

Cancel the goal on the ROS action client, `actClient`.

```
cancelGoal(actClient)
```

Cancel all the goals on the action server that `actClient` is connected to.

```
cancelAllGoals(actClient)
```

Delete the action client.

```
delete(actClient)
```

Disconnect from the ROS network.

```
rosshutdown
```

Shutting down global node /matlab_global_node_40739 with NodeURI http://192.168.154.1:5

Input Arguments

`client` — ROS action client
SimpleActionClient object handle

ROS action client, specified as a `SimpleActionClient` object handle. This simple action client enables you to track a single goal at a time.

`timeout` — Timeout period
scalar in seconds

Timeout period for setting up ROS action server, specified as a scalar in seconds. If the client does not connect to the server in the specified time period, an error is displayed.

See Also
cancelGoal | rosaction | rosactionclient | sendGoalAndWait

Topics
"ROS Actions Overview"
"Move a Turtlebot Robot Using ROS Actions"

Introduced in R2016b

waitForTransform

Wait until a transformation is available

Note `waitForTransform` will be removed in a future release. Use `getTransform` with a specified `timeout` instead. Use `inf` to wait indefinitely.

Syntax

```
waitForTransform(tftree,targetframe,sourceframe)
waitForTransform(tftree,targetframe,sourceframe,timeout)
```

Description

`waitForTransform(tftree,targetframe,sourceframe)` waits until the transformation between `targetframe` and `sourceframe` is available in the transformation tree, `tftree`. This functions disables the command prompt until a transformation becomes available on the ROS network.

`waitForTransform(tftree,targetframe,sourceframe,timeout)` specifies a timeout period in seconds. If the transformation does not become available, MATLAB displays an error, but continues running the current program.

Examples

Wait for Transformation Between Robot Frames

Connect to the ROS network. Specify the IP address of your network.

```
rosinit('192.168.154.131')
```

Initializing global node /matlab_global_node_73613 with NodeURI http://192.168.154.1:59

Create a ROS transformation tree.

```
tftree = rostf;
```

Wait for the transformation between the target frame, /camera_depth_frame, and the source frame, /base_link, to be available. Specify a timeout of 5 seconds.

```
waitForTransform(tftree,'/camera_depth_frame','/base_link',5);
```

Get the transformation.

```
tform = getTransform(tftree,'/camera_depth_frame','/base_link');
```

When you are finished, disconnect from the ROS network.

```
rosshutdown
```

```
Shutting down global node /matlab_global_node_73613 with NodeURI http://192.168.154.1:5
```

Input Arguments

tftree — ROS transformation tree
TransformationTree object handle

ROS transformation tree, specified as a TransformationTree object handle. You can create a transformation tree by calling the rostf function.

targetframe — Target coordinate frame
character vector

Target coordinate frame, specified as a character vector. You can view the available frames for transformation by calling tftree.AvailableFrames.

sourceframe — Initial coordinate frame
character vector

Initial coordinate frame, specified as a character vector. You can view the available frames for transformation using tftree.AvailableFrames.

timeout — Timeout period
scalar in seconds

Timeout period, specified as a scalar in seconds. If the transformation does not become available, MATLAB displays an error, but continues running the current program.

See Also

getTransform | receive | transform

Introduced in R2015a

writeBinaryOccupancyGrid

Write values from grid to ROS message

Syntax

writeBinaryOccupancyGrid(msg,map)

Description

writeBinaryOccupancyGrid(msg,map) writes occupancy values and other information to the ROS message, msg, from the binary occupancy grid, map.

Examples

Write Binary Occupancy Grid Information to ROS Message

Create occupancy grid and message. Write the map onto the message.

```
map = robotics.BinaryOccupancyGrid(randi([0,1], 10));
msg = rosmessage('nav_msgs/OccupancyGrid');
writeBinaryOccupancyGrid(msg, map);
```

Input Arguments

map — Binary occupancy grid
BinaryOccupancyGrid object handle

Binary occupancy grid, specified as a BinaryOccupancyGrid object handle. map is converted to a 'nav_msgs/OccupancyGrid' message on the ROS network. map is an object with a grid of binary values, where 1 indicates an occupied location and 0 indications an unoccupied location.

msg — 'nav_msgs/OccupancyGrid' ROS message
OccupancyGrid object handle

'nav_msgs/OccupancyGrid' ROS message, specified as a OccupancyGrid object
handle.

See Also

readBinaryOccupancyGrid | readOccupancyGrid |
robotics.BinaryOccupancyGrid | robotics.OccupancyGrid |
writeOccupancyGrid

Introduced in R2015a

writeOccupancyGrid

Write values from grid to ROS message

Syntax

```
writeOccupancyGrid(msg,map)
```

Description

writeOccupancyGrid(msg,map) writes occupancy values and other information to the ROS message, msg, from the occupancy grid, map.

Examples

Create OccupancyGrid ROS Message From Grid

The 'nav_msgs/OccupancyGrid' ROS message contains data for a 2-D occupancy grid with probabilistic values for occupancy. Convert a MATLAB® OccupancyGrid object into a ROS message using writeOccupancyGrid.

Create an occupancy grid with random data and an empty ROS message to put data into.

```
map = robotics.OccupancyGrid(rand(10));
msg = rosmessage('nav_msgs/OccupancyGrid');
```

Write the data from the occupancy grid into the message.

```
writeOccupancyGrid(msg, map);
```

Input Arguments

msg — 'nav_msgs/OccupancyGrid' ROS message
OccupancyGrid object handle

'nav_msgs/OccupancyGrid' ROS message, specified as an OccupancyGrid ROS message object handle.

map — Occupancy grid
robotics.OccupancyGrid object handle

Occupancy grid, returned as an robotics.OccupancyGrid object handle.

See Also

OccupancyGrid | readBinaryOccupancyGrid | robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | writeBinaryOccupancyGrid

Introduced in R2016b

writeImage

Write MATLAB image to ROS image message

Syntax

```
writeImage(msg,img)
writeImage(msg,img,alpha)
```

Description

writeImage(msg,img) converts the MATLAB image, img, to a message object and stores the ROS compatible image data in the message object, msg. The message must be a 'sensor_msgs/Image' message. 'sensor_msgs/CompressedImage' messages are not supported. The function does not perform any color space conversion, so the img input needs to have the encoding that you specify in the Encoding property of the message.

writeImage(msg,img,alpha) converts the MATLAB image, img to a message object. If the image encoding supports an alpha channel (rgba or bgra family), specify this alpha channel in alpha. Alternatively, the input image can store the alpha channel as its fourth channel.

Examples

Write Image to Message

Read an image.

```
image = imread('imageMap.png');
```

Create a ROS image message. Specify the default encoding for the image. Write the image to the message.

```
msg = rosmessage('sensor_msgs/Image');
msg.Encoding = 'rgb8';
writeImage(msg,image);
```

Input Arguments

msg — ROS image message
Image object handle

'sensor_msgs/Image' ROS image message, specified as an Image object handle.
'sensor_msgs/Image' image messages are not supported.

img — Image
grayscale image matrix | RGB image matrix | *m*-by-*n*-by-3 array

Image, specified as a matrix representing a grayscale or RGB image or as a *m*-by-*n*-by-3
array, depending on the sensor image.

alpha — Alpha channel
uint8 grayscale image

Alpha channel, specified as a uint8 grayscale image. Alpha must be the same size and
data type as img.

ROS Image Encoding

You must specify the correct encoding of the input image in the Encoding property of the
image message. If you do not specify the image encoding before calling the function, the
default encoding, rgb8, is used (3-channel RGB image with uint8 values). The function
does not perform any color space conversion, so the img input needs to have the
encoding that you specify in the Encoding property of the message.

All encoding types supported for the readImage are also supported in this function. For
more information on supported encoding types and their representations in MATLAB, see
readImage.

Bayer-encoded images (bayer_rggb8, bayer_bggr8, bayer_gbrg8, bayer_grbg8 and
their 16-bit equivalents) must be given as 8-bit or 16-bit single-channel images or they do
not encode.

See Also

readImage

Introduced in R2015a

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')

  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`

See Also

Introduced in R2018a

Methods — Alphabetical List

copy

Class: robotics.BinaryOccupancyGrid
Package: robotics

Copy array of handle objects

Syntax

```
b = copy(a)
```

Description

`b = copy(a)` copies each element in the array of handles, `a`, to the new array of handles, `b`.

The `copy` method does not copy dependent properties. MATLAB does not call `copy` recursively on any handles contained in property values. MATLAB does not call the class constructor or property set methods during the copy operation.

`b` has the same number of elements and is the same size and class of `a`. `b` is the same class as `a`. If `a` is empty, `b` is also empty. If `a` is heterogeneous, `b` is also heterogeneous. If `a` contains deleted handles, then `copy` creates deleted handles of the same class in `b`. Dynamic properties and listeners associated with objects in `a` are not copied to objects in `a`.

`copy` is a sealed and public method in class `matlab.mixin.Copyable`.

Input Arguments

a — Object array
handle

Object array, specified as a handle.

Output Arguments

b — Object array containing copies of the objects in a
handle

Object array containing copies of the object in a, specified as a handle.

See Also
robotics.BinaryOccupancyGrid

Introduced in R2015a

getOccupancy

Class: robotics.BinaryOccupancyGrid
Package: robotics

Get occupancy value for one or more positions

Syntax

```
occval = getOccupancy(map,xy)
occval = getOccupancy(map,ij,'grid')
```

Description

`occval = getOccupancy(map,xy)` returns an array of occupancy values for an input array of world coordinates, `xy`. Each row of `xy` is a point in the world, represented as an `[x y]` coordinate pair. `occval` is the same length as `xy` and a single column array. An occupied location is represented as `true` (1), and a free location is represented as `false` (0).

`occval = getOccupancy(map,ij,'grid')` returns an array of occupancy values based on a `[rows cols]`input array of grid positions, `ij`.

Input Arguments

`map` — Map representation
BinaryOccupancyGrid object

Map representation, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

`xy` — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of [x y] pairs, where *n* is the number of world coordinates.

Data Types: `double`

ij — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 vertical array of [i j] pairs in [rows cols] format, where *n* is the number of grid positions.

Data Types: `double`

Output Arguments

occval — Occupancy values
n-by-1 vertical array

Occupancy values of the same length as either `xy` or `ij`, returned as an *n*-by-1 vertical array, where *n* is the same *n* in either `xy` or `ij`.

See Also
`robotics.BinaryOccupancyGrid` |
`robotics.BinaryOccupancyGrid.setOccupancy`

Introduced in R2015a

grid2world

Class: robotics.BinaryOccupancyGrid
Package: robotics

Convert grid indices to world coordinates

Syntax

```
xy = grid2world(map,ij)
```

Description

`xy = grid2world(map,ij)` converts a `[row col]` array of grid indices, `ij`, to an array of world coordinates, `xy`.

Input Arguments

map — Map representation
BinaryOccupancyGrid object

Map representation, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

ij — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 vertical array of `[i j]` pairs in `[rows cols]` format, where *n* is the number of grid positions.

Output Arguments

xy — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of [x y] pairs, where *n* is the number of world coordinates.

See Also

robotics.BinaryOccupancyGrid | robotics.BinaryOccupancyGrid.world2grid

Introduced in R2015a

inflate

Class: robotics.BinaryOccupancyGrid
Package: robotics

Inflate each occupied grid location

Syntax

```
inflate(map,radius)
inflate(map,gridradius,'grid')
```

Description

`inflate(map,radius)` inflates each occupied position of the `map` by the radius given in meters. `radius` is rounded up to the nearest cell equivalent based on the resolution of the map. Every cell within the radius is set to `true` (1).

`inflate(map,gridradius,'grid')` inflates each occupied position by the radius given in number of cells.

Input Arguments

map — Map representation
`BinaryOccupancyGrid` object

Map representation, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

radius — Dimension the defines how much to inflate occupied locations
scalar

Dimension that defines how much to inflate occupied locations, specified as a scalar. `radius` is rounded up to the nearest cell value.

Data Types: `double`

gridradius — Dimension the defines how much to inflate occupied locations
positive scalar

Dimension that defines how much to inflate occupied locations, specified as a positive scalar. `gridradius` is the number of cells to inflate the occupied locations.

Data Types: `double`

See Also
`robotics.BinaryOccupancyGrid` |
`robotics.BinaryOccupancyGrid.setOccupancy`

Introduced in R2015a

setOccupancy

Class: robotics.BinaryOccupancyGrid
Package: robotics

Set occupancy value for one or more positions

Syntax

```
setOccupancy(map,xy,occval)
setOccupancy(map,ij,occval,'grid')
```

Description

`setOccupancy(map,xy,occval)` assigns occupancy values, `occval`, to the input array of world coordinates, `xy` in the occupancy grid, `map`. Each row of the array, `xy`, is a point in the world and is represented as an `[x y]` coordinate pair. `occval` is either a scalar or a single column array of the same length as `xy` . An occupied location is represented as `true` (1), and a free location is represented as `false` (0).

`setOccupancy(map,ij,occval,'grid')` assigns occupancy values, `occval`, to the input array of grid indices, `ij`, as `[rows cols]`.

Input Arguments

`map` — Map representation
BinaryOccupancyGrid object

Map representation, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

`xy` — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of [x y] pairs, where *n* is the number of world coordinates.

Data Types: double

ij — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 vertical array of [i j] pairs in [rows cols] format, where *n* is the number of grid positions.

Data Types: double

occval — Occupancy values
n-by-1 vertical array

Occupancy values of the same length as either xy or ij, returned as an *n*-by-1 vertical array, where *n* is the same *n* in either xy or ij.

Examples

Set Occupancy Values

Set the occupancy of grid locations using setOccupancy.

Initialize an occupancy grid object using BinaryOccupancyGrid.

```
map = robotics.BinaryOccupancyGrid(10,10);
```

Set the occupancy of a specific location using setOccupancy.

```
setOccupancy(map,[8 8],1);
```

Set the occupancy of an array of locations.

```
[x,y] = meshgrid(2:5);
setOccupancy(map,[x(:) y(:)],1);
```

See Also

robotics.BinaryOccupancyGrid |
robotics.BinaryOccupancyGrid.getOccupancy

Introduced in R2015a

show

Class: robotics.BinaryOccupancyGrid
Package: robotics

Show occupancy grid values

Syntax

```
show(map)
show(map, 'grid')

show( ___ ,'Parent',parent)

h = show(map, ___ )
```

Description

show(map) displays the binary occupancy grid map in the current axes, with the axes labels representing the world coordinates.

show(map, 'grid') displays the binary occupancy grid map in the current axes, with the axes labels representing the grid coordinates.

show(___ ,'Parent',parent) sets the specified axes handle parent to the axes, using any of the arguments from previous syntaxes.

h = show(map, ___) returns the figure object handle created by show.

Input Arguments

map — Map representation
BinaryOccupancyGrid object

Map representation, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

parent — Axes to plot the map
Axes object | UIAxes object

Axes to plot the map specified as either an `Axes` or `UIAxes`object. See `axes` or `uiaxes`.

See Also
`robotics.BinaryOccupancyGrid`

Introduced in R2015a

world2grid

Class: robotics.BinaryOccupancyGrid
Package: robotics

Convert world coordinates to grid indices

Syntax

```
ij = world2grid(map,xy)
```

Description

`ij = world2grid(map,xy)` converts an array of world coordinates, `xy`, to a `[rows cols]` array of grid indices, `ij`.

Input Arguments

map — Map representation
BinaryOccupancyGrid object

Map representation, specified as a `robotics.BinaryOccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

xy — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of `[x y]` pairs, where *n* is the number of world coordinates.

Output Arguments

ij — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 vertical array of `[i j]` pairs in `[rows cols]` format, where *n* is the number of grid positions.

See Also

`robotics.BinaryOccupancyGrid` | `robotics.BinaryOccupancyGrid.grid2world`

Introduced in R2015a

copy

Class: robotics.Joint
Package: robotics

Create copy of joint

Syntax

```
jCopy = copy(jointObj)
```

Description

`jCopy = copy(jointObj)` creates a copy of the `Joint` object with the same properties.

Input Arguments

jointObj — Joint object
handle

`Joint` object, specified as a handle. Create a joint object using `robotics.Joint`.

Output Arguments

jCopy — Joint object
handle

`Joint` object, returned as a handle. Create a joint object using `robotics.Joint`. This copy has the same properties.

See Also
robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree

Introduced in R2016b

setFixedTransform

Class: robotics.Joint
Package: robotics

Set fixed transform properties of joint

Syntax

```
setFixedTransform(jointObj,tform)

setFixedTransform(jointObj,dhparams,'dh')
setFixedTransform(jointObj,mdhparams,'mdh')
```

Description

`setFixedTransform(jointObj,tform)` sets the `JointToParentTransform` property of the `Joint` object directly with the supplied homogenous transformation.

`setFixedTransform(jointObj,dhparams,'dh')` sets the `ChildToJointTransform` property using Denavit-Hartenberg (DH) parameters. The `JointToParentTransform` property is set to an identity matrix. DH parameters are given in the order `[a alpha d theta]`.

The `theta` input is ignored when specifying the fixed transformation between joints because that angle is dependent on the joint configuration. For more information, see "Rigid Body Tree Robot Model".

`setFixedTransform(jointObj,mdhparams,'mdh')` sets the `JointToParentTransform` property using modified DH parameters. The `ChildToJointTransform` property is set to an identity matrix. Modified DH parameters are given in the order `[a alpha d theta]`.

Input Arguments

`jointObj` — Joint object
handle

`Joint` object, specified as a handle. Create a joint object using `robotics.Joint`.

`tform` — Homogeneous transform
4-by-4 matrix

Homogeneous transform, specified as a 4-by-4 matrix. The transform is set to the `ChildToJointTransform` property. The `JointToParentTransform` property is set to an identity matrix.

`dhparams` — Denavit-Hartenberg (DH) parameters
four-element vector

Denavit-Hartenberg (DH) parameters, specified as a four-element vector, `[a alpha d theta]`. These parameters are used to set the `ChildToJointTransform` property. The `JointToParentTransform` property is set to an identity matrix.

The `theta` input is ignored when specifying the fixed transformation between joints because that angle is dependent on the joint configuration. For more information, see "Rigid Body Tree Robot Model".

`mdhparams` — Modified Denavit-Hartenberg (DH) parameters
four-element vector

Modified Denavit-Hartenberg (DH) parameters, specified as a four-element vector, `[a alpha d theta]`. These parameters are used to set the `JointToParentTransform` property. The `ChildToJointTransform` is set to an identity matrix.

The `theta` input is ignored when specifying the fixed transformation between joints because that angle is dependent on the joint configuration. For more information, see "Rigid Body Tree Robot Model".

Examples

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix. The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0        pi/2    0         0;
            0.4318   0       0         0
            0.0203   -pi/2   0.15005   0;
            0        pi/2    0.4318    0;
            0        -pi/2   0         0;
            0        0       0         0];
```

Create a rigid body tree object to build the robot.

```
robot = robotics.RigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1 Create a `RigidBody` object and give it a unique name.
2 Create a `Joint` object and give it a unique name.
3 Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4 Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = robotics.RigidBody('body1');
jnt1 = robotics.Joint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = robotics.RigidBody('body2');
jnt2 = robotics.Joint('jnt2','revolute');
body3 = robotics.RigidBody('body3');
jnt3 = robotics.Joint('jnt3','revolute');
body4 = robotics.RigidBody('body4');
jnt4 = robotics.Joint('jnt4','revolute');
body5 = robotics.RigidBody('body5');
jnt5 = robotics.Joint('jnt5','revolute');
body6 = robotics.RigidBody('body6');
jnt6 = robotics.Joint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

Verify that your robot was built properly by using the showdetails or show function. showdetails lists all the bodies in the MATLAB® command window. show displays the robot with a given configuration (home by default). Calls to axis modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name    Joint Name    Joint Type    Parent Name(Idx)    Children Name(s)
 ---    ---------    ----------    ----------    ----------------    ----------------
   1        body1         jnt1      revolute             base(0)     body2(2)
   2        body2         jnt2      revolute            body1(1)     body3(3)
   3        body3         jnt3      revolute            body2(2)     body4(4)
   4        body4         jnt4      revolute            body3(3)     body5(5)
```

```
    5        body5       jnt5    revolute              body4(4)  body6(6)
    6        body6       jnt6    revolute              body5(5)
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```

References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control.* Reading, MA: Addison-Wesley, 1989.

[2] Siciliano, Bruno. *Robotics: Modelling, Planning and Control.* London: Springer, 2009.

See Also

robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree

Introduced in R2016b

addScan

Class: robotics.LidarSLAM
Package: robotics

Add scan to lidar SLAM map

Syntax

```
addScan(slamObj,currScan)
addScan(slamObj,currScan,relPoseEst)
[isAccepted,loopClosureInfo,optimInfo] = addScan( ___ )
```

Description

`addScan(slamObj,currScan)` adds a lidar scan, `currScan`, to the lidar SLAM object, `slamObj`. The function uses scan matching to correlate this scan to the most recent one, then adds it to the pose graph defined in `slamObj`. If the scan is accepted, `addScan` detects loop closures and optimizes based on settings in `slamObj`.

`addScan(slamObj,currScan,relPoseEst)` also specifies a relative pose to the latest lidar scan pose in `slamObj`. This relative pose improves the scan matching.

`[isAccepted,loopClosureInfo,optimInfo] = addScan( ___ )` outputs detailed information about adding the scan to the SLAM object. `isAccepted` indicates if the scan is added or rejected. `loopClosureInfo` and `optimInfo` indicate if a loop closure is detected or the pose graph is optimized.

Examples

Perform SLAM Using Lidar Scans

Use a `LidarSLAM` object to iteratively add and compare lidar scans and build an optimized pose graph of the robot trajectory. To get an occupancy map from the associated poses and scans, use the `buildMap` function.

Load Data and Set Up SLAM Algorithm

Load a cell array of `lidarScan` objects. The lidar scans were collected in a parking garage on a Husky® robot from ClearPath Robotics®. Typically, lidar scans are taken at a high frequency and each scan is not needed for SLAM. Therefore, down sample the scans by selecting only every 40th scan.

```
load garage_fl1_southend.mat scans
scans = scans(1:40:end);
```

To set up the SLAM algorithm, specify the lidar range, map resolution, loop closure threshold, and search radius. Tune these parameters for your specific robot and environment. Create the `LidarSLAM` object with these parameters.

```
maxRange = 19.2; % meters
resolution = 10; % cells per meter

slamObj = robotics.LidarSLAM(resolution,maxRange);
slamObj.LoopClosureThreshold = 360;
slamObj.LoopClosureSearchRadius = 8;
```

Add Scans Iteratively

Using a `for` loop, add scans to the SLAM object. The object uses scan matching to compare each added scan to previously added ones. To improve the map, the object optimizes the pose graph whenever it detects a loop closure. Every 10 scans, display the stored poses and scans.

```
for i = 1:numel(scans)

    addScan(slamObj,scans{i});

    if rem(i,10) == 0
        show(slamObj);
    end
end
```

View Occupancy Map

After adding all the scans to the SLAM object, build an `robotics.OccupancyGrid` map by calling `buildMap` with the scans and poses. Use the same map resolution and max range you used with the SLAM object.

```
[scansSLAM,poses] = scansAndPoses(slamObj);
occGrid = buildMap(scansSLAM,poses,resolution,maxRange);
figure
show(occGrid)
title('Occupancy Map of Garage')
```

Occupancy Map of Garage

- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Input Arguments

slamObj — Lidar SLAM object
LidarSLAM object

Lidar SLAM object, specified as a LidarSLAM object. The object contains the SLAM algorithm parameters, sensor data, and underlying pose graph used to build the map.

currScan — Lidar scan reading
lidarScan object

Lidar scan reading, specified as a lidarScan object. This scan is correlated to the most recent scan in slamObj using scan matching.

relPoseEst — Relative pose estimate of scan
[x y theta] vector

Relative pose estimate of scan, specified as an [x y theta] vector. This relative pose improves scan matching.

Output Arguments

isAccepted — Indicates if scan is accepted
true | false

Indicates if scan is accepted, returned as true or false. If the relative pose between scans is below the MovementThreshold property of slamObj, the scan is rejected. By default, all scans are accepted.

loopClosureInfo — Loop closure details
structure

Loop closure details, returned as a structure with these fields:

- EdgeIDs –– IDs of newly connected edges in the pose graph, returned as a vector.
- Edges –– Newly added loop closure edges, returned as an *n*-by-2 matrix of node IDs that each edge connects.
- Scores –– Scores of newly connected edges in the pose graph returned from scan matching, returned as a vector.

Note If the LoopClosureAutoRollback property is set to true in slamObj, loop closure edges can be removed from the pose graph. This property rejects loops closures if the residual error changes drastically after optimization. Therefore, some of the edge IDs listed in this structure may not exist in the actual pose graph.

optimInfo — Pose graph optimization details
structure

Pose graph optimization details, returned as a structure with these fields:

- `IsPerformed` –– Boolean indicating if optimization is performed when adding this scan. Optimization performance depends on the `OptimizationInterval` property in `slamObj`.
- `IsAccepted` –– Boolean indicating if optimization was accepted based on `ResidualError`.
- `ResidualError` –– Error associated with optimization, returned as a scalar.
- `LoopClosureRemoved` –– List of IDs of loop closure edges removed during optimization, returned as a vector.

See Also

`optimizePoseGraph` | `robotics.PoseGraph`

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

copy

Class: robotics.LidarSLAM
Package: robotics

Copy lidar SLAM object

Syntax

```
newSlamObj = copy(slamObj)
```

Description

newSlamObj = copy(slamObj) creates a deep copy of slamObj with the same properties. Any changes made to newSlamObj are not reflected in slamObj.

Input Arguments

slamObj — Lidar SLAM object
LidarSLAM object

Lidar SLAM object, specified as a LidarSLAM object. The object contains the SLAM algorithm parameters, sensor data, and underlying pose graph used to build the map.

Output Arguments

newSlamObj — Lidar SLAM object
LidarSLAM object

Lidar SLAM object, returned as a LidarSLAM object.

See Also
optimizePoseGraph | robotics.PoseGraph

Topics

"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

removeLoopClosures

Class: robotics.LidarSLAM
Package: robotics

Remove loop closures from pose graph

Syntax

```
removeLoopClosures(slamObj)
removeLoopClosures(slamObj,lcEdgeIDs)
```

Description

removeLoopClosures(slamObj) removes all loop closures from the underlying pose graph in slamObj.

removeLoopClosures(slamObj,lcEdgeIDs) removes the loop closure edges with the specified IDs from the underlying pose graph in slamObj.

Input Arguments

slamObj — Lidar SLAM object
LidarSLAM object

Lidar SLAM object, specified as a LidarSLAM object. The object contains the SLAM algorithm parameters, sensor data, and underlying pose graph used to build the map

lcEdgeIDs — Loop closure edge IDs
vector of positive integers

Loop closure edge IDs, specified as a vector of positive integers. To find specific edge IDs, use findEdgeID on the underlying PoseGraph object defined in slamObj.

See Also

`optimizePoseGraph` | `robotics.PoseGraph`

Topics

"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

scansAndPoses

Class: robotics.LidarSLAM
Package: robotics

Extract scans and corresponding poses

Syntax

```
[scans,poses] = scansAndPoses(slamObj)
[scans,poses] = scansAndPoses(slamObj,nodeIDs)
```

Description

`[scans,poses] = scansAndPoses(slamObj)` returns the scans used by the `LidarSLAM` object as `lidarScan` objects, along with their associated `[x y theta]` poses from the underlying pose graph of `slamObj`.

`[scans,poses] = scansAndPoses(slamObj,nodeIDs)` returns the scans and poses for the specific node IDs. To get the node IDs, see the underlying `PoseGraph` object in `slamObj` for the node IDs.

Examples

Perform SLAM Using Lidar Scans

Use a `LidarSLAM` object to iteratively add and compare lidar scans and build an optimized pose graph of the robot trajectory. To get an occupancy map from the associated poses and scans, use the `buildMap` function.

Load Data and Set Up SLAM Algorithm

Load a cell array of `lidarScan` objects. The lidar scans were collected in a parking garage on a Husky® robot from ClearPath Robotics®. Typically, lidar scans are taken at a

high frequency and each scan is not needed for SLAM. Therefore, down sample the scans by selecting only every 40th scan.

```
load garage_fl1_southend.mat scans
scans = scans(1:40:end);
```

To set up the SLAM algorithm, specify the lidar range, map resolution, loop closure threshold, and search radius. Tune these parameters for your specific robot and environment. Create the LidarSLAM object with these parameters.

```
maxRange = 19.2; % meters
resolution = 10; % cells per meter

slamObj = robotics.LidarSLAM(resolution,maxRange);
slamObj.LoopClosureThreshold = 360;
slamObj.LoopClosureSearchRadius = 8;
```

Add Scans Iteratively

Using a for loop, add scans to the SLAM object. The object uses scan matching to compare each added scan to previously added ones. To improve the map, the object optimizes the pose graph whenever it detects a loop closure. Every 10 scans, display the stored poses and scans.

```
for i = 1:numel(scans)

    addScan(slamObj,scans{i});

    if rem(i,10) == 0
        show(slamObj);
    end
end
```

View Occupancy Map

After adding all the scans to the SLAM object, build an `robotics.OccupancyGrid` map by calling `buildMap` with the scans and poses. Use the same map resolution and max range you used with the SLAM object.

```
[scansSLAM,poses] = scansAndPoses(slamObj);
occGrid = buildMap(scansSLAM,poses,resolution,maxRange);
figure
show(occGrid)
title('Occupancy Map of Garage')
```

Occupancy Map of Garage

- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Input Arguments

slamObj — Lidar SLAM object
LidarSLAM object

Lidar SLAM object, specified as a LidarSLAM object. The object contains the SLAM algorithm parameters, sensor data, and underlying pose graph used to build the map.

nodeIDs — Node IDs from pose graph
positive integer

Node IDs from pose graph, specified as a positive integer. Nodes are added to the pose graph with sequential ID numbers. To get the node IDs, see the underlying `PoseGraph` object in `slamObj` for the node IDs.

Output Arguments

scans — Lidar scan readings
`lidarScan` object

Lidar scan readings, returned as a `lidarScan` object.

poses — Pose for each scan
n-by-3 matrix | `[x y theta]` vectors

Pose for each scan, returned as an *n*-by-3 matrix of `[x y theta]` vectors. Each row is a pose that corresponds to a scan in `scans`.

See Also
`optimizePoseGraph` | `robotics.PoseGraph`

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

show

Class: robotics.LidarSLAM
Package: robotics

Plot scans and robot poses

Syntax

```
show(slamObj)
show(slamObj,Name,Value)
axes = show( ___ )
```

Description

`show(slamObj)` plots all the scans added to the `input LidarSLAM` object overlaid with the lidar poses in its underlying pose graph.

`show(slamObj,Name,Value)` specifies options using `Name,Value` pair arguments. For example, `'Poses','off'` turns off display of the underlying pose graph in `slamObj`.

`axes = show( ___ )` returns the axes handle that the lidar SLAM data is plotted to using any of the previous syntaxes.

Examples

Perform SLAM Using Lidar Scans

Use a `LidarSLAM` object to iteratively add and compare lidar scans and build an optimized pose graph of the robot trajectory. To get an occupancy map from the associated poses and scans, use the `buildMap` function.

Load Data and Set Up SLAM Algorithm

Load a cell array of `lidarScan` objects. The lidar scans were collected in a parking garage on a Husky® robot from ClearPath Robotics®. Typically, lidar scans are taken at a

high frequency and each scan is not needed for SLAM. Therefore, down sample the scans by selecting only every 40th scan.

```
load garage_fl1_southend.mat scans
scans = scans(1:40:end);
```

To set up the SLAM algorithm, specify the lidar range, map resolution, loop closure threshold, and search radius. Tune these parameters for your specific robot and environment. Create the LidarSLAM object with these parameters.

```
maxRange = 19.2; % meters
resolution = 10; % cells per meter

slamObj = robotics.LidarSLAM(resolution,maxRange);
slamObj.LoopClosureThreshold = 360;
slamObj.LoopClosureSearchRadius = 8;
```

Add Scans Iteratively

Using a for loop, add scans to the SLAM object. The object uses scan matching to compare each added scan to previously added ones. To improve the map, the object optimizes the pose graph whenever it detects a loop closure. Every 10 scans, display the stored poses and scans.

```
for i = 1:numel(scans)

    addScan(slamObj,scans{i});

    if rem(i,10) == 0
        show(slamObj);
    end
end
```

View Occupancy Map

After adding all the scans to the SLAM object, build an `robotics.OccupancyGrid` map by calling `buildMap` with the scans and poses. Use the same map resolution and max range you used with the SLAM object.

```
[scansSLAM,poses] = scansAndPoses(slamObj);
occGrid = buildMap(scansSLAM,poses,resolution,maxRange);
figure
show(occGrid)
title('Occupancy Map of Garage')
```

Occupancy Map of Garage

- "Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
- "Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Input Arguments

slamObj — Lidar SLAM object
LidarSLAM object

Lidar SLAM object, specified as a LidarSLAM object. The object contains the SLAM algorithm parameters, sensor data, and underlying pose graph used to build the map.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Poses','off'`

`Parent` — Axes used to plot pose graph
`Axes` object | `UIAxes` object

Axes used to plot the pose graph, specified as the comma-separated pair consisting of `'Parent'` and either an `Axes` or `UIAxes` object. See `axes` or `uiaxes`.

Poses — Display lidar poses
`'on'` (default) | `'off'`

Display lidar poses, specified as the comma-separated pair consisting of `'Poses'` and `'on'` or `'off'`.

Output Arguments

axes — Axes used to plot the map
`Axes` object | `UIAxes` object

Axes used to plot the map, returned as either an `Axes` or `UIAxes` object. See `axes` or `uiaxes`.

See Also
`optimizePoseGraph` | `robotics.PoseGraph`

Topics
"Implement Simultaneous Localization And Mapping (SLAM) with Lidar Scans"
"Implement Online Simultaneous Localization And Mapping (SLAM) with Lidar Scans"

Introduced in R2018a

checkOccupancy

Class: robotics.OccupancyGrid
Package: robotics

Check locations for free, occupied, or unknown values

Syntax

```
iOccval = checkOccupancy(map,xy)
iOccval = checkOccupancy(map,ij,'grid')
```

Description

`iOccval = checkOccupancy(map,xy)` returns an array of occupancy values at the `xy` locations using the `OccupiedThreshold` and `FreeThreshold` properties of the `map` object. Each row is a separate `xy` location in the grid to check the occupancy of. Occupancy values can be obstacle free (0), occupied (1), or unknown (–1).

`iOccval = checkOccupancy(map,ij,'grid')` specifies `ij` grid cell indices instead of `xy` locations.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

xy — World coordinates
n-by-2 matrix

World coordinates, specified as an *n*-by-2 matrix of [x y] pairs, where *n* is the number of world coordinates.

Data Types: `double`

`ij` — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 matrix of [i j] pairs in [rows cols] format, where *n* is the number of grid positions.

Data Types: `double`

Output Arguments

`iOccval` — Interpreted occupancy values
n-by-1 column vector

Interpreted occupancy values, returned as an *n*-by-1 column vector equal in length to `xy` or `ij`.

Occupancy values can be obstacle free (0), occupied (1), or unknown (–1). These values are determined from the actual probability values and the `OccupiedThreshold` and `FreeThreshold` properties of the `map` object.

Examples

Get Occupancy Values and Check Occupancy Status

Access occupancy values and check their occupancy status based on the occupied and free thresholds of the `OccupancyGrid` object.

Create a matrix and populate it with values. Use this matrix to create an occupancy grid.

```
p = 0.5*ones(20,20);
p(11:20,11:20) = 0.75*ones(10,10);
map = robotics.OccupancyGrid(p,10);
```

Get the occupancy of different locations and check their occupancy statuses. The occupancy status returns 0 for free space and 1 for occupied space. Unknown values return -1.

```
pocc = getOccupancy(map,[1.5 1])

pocc = 0.7500

occupied = checkOccupancy(map,[1.5 1])

occupied = 1


pocc2 = getOccupancy(map,[5 5],'grid')

pocc2 = 0.5000

occupied2 = checkOccupancy(map,[5 5],'grid')

occupied2 = -1
```

See Also

robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | robotics.OccupancyGrid.getOccupancy

Introduced in R2016b

copy

Class: robotics.OccupancyGrid
Package: robotics

Create copy of occupancy grid

Syntax

```
copyMap = copy(map)
```

Description

`copyMap = copy(map)` creates a deep copy of the `OccupancyGrid` object with the same properties.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

Output Arguments

copyMap — Copied map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. The properties are the same as the input object, `map`, but they have a different object handle.

Examples

Copy Occupancy Grid Map

Copy an occupancy grid object. Once copied, the original object can be modified without affecting the copied map.

Create an occupancy grid with zeros for an empty map.

```
p = zeros(10);
map = robotics.OccupancyGrid(p);
```

Copy the occupancy grid map. Modify the original map. The copied map is not modified. Plot the two maps side by side.

```
mapCopy = copy(map);
setOccupancy(map,[1:3;1:3]',ones(3,1));
subplot(1,2,1)
show(map)
title('Original map')
subplot(1,2,2)
show(mapCopy)
title('Copied map')
```
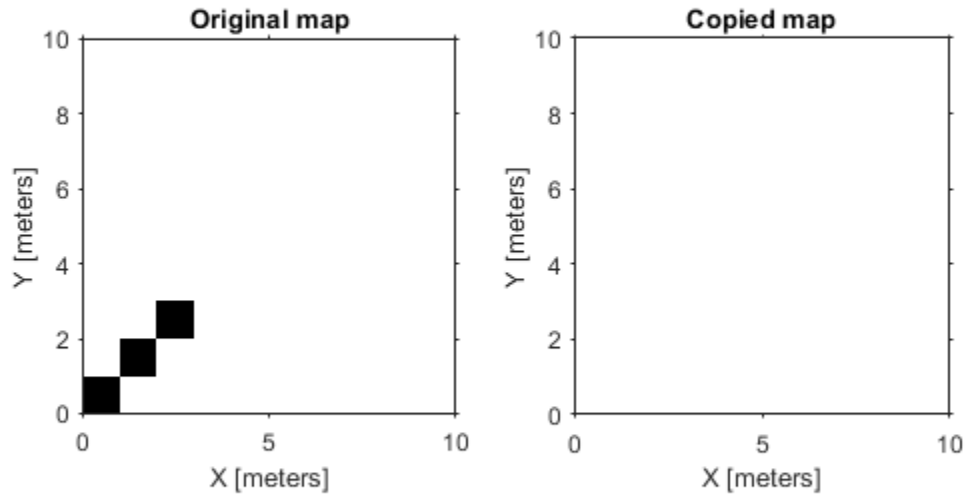
See Also

`robotics.BinaryOccupancyGrid` | `robotics.OccupancyGrid` |
`robotics.OccupancyGrid.getOccupancy` |
`robotics.OccupancyGrid.occupancyMatrix`

Topics

"Occupancy Grids"

Introduced in R2016b

getOccupancy

Class: robotics.OccupancyGrid
Package: robotics

Get occupancy of a location

Syntax

```
occval = getOccupancy(map,xy)
occval = getOccupancy(map,ij,'grid')
```

Description

`occval = getOccupancy(map,xy)` returns an array of probability occupancy values at the `xy` locations. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

`occval = getOccupancy(map,ij,'grid')` specifies `ij` grid cell indices instead of `xy` locations.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

xy — World coordinates
n-by-2 matrix

World coordinates, specified as an *n*-by-2 matrix of [x y] pairs, where *n* is the number of world coordinates.

Data Types: `double`

ij — Grid positions
n-by-2 matrix

Grid positions, specified as an *n*-by-2 matrix of [i j] pairs in [`rows cols`] format, where *n* is the number of grid positions.

Data Types: `double`

Output Arguments

`occval` — Probability occupancy values
column vector

Probability occupancy values, returned as a column vector the same length as either `xy` or `ij`.

Values close to 0 represent certainty that the cell is not occupied and obstacle free.

Examples

Get Occupancy Values and Check Occupancy Status

Access occupancy values and check their occupancy status based on the occupied and free thresholds of the `OccupancyGrid` object.

Create a matrix and populate it with values. Use this matrix to create an occupancy grid.

```
p = 0.5*ones(20,20);
p(11:20,11:20) = 0.75*ones(10,10);
map = robotics.OccupancyGrid(p,10);
```

Get the occupancy of different locations and check their occupancy statuses. The occupancy status returns 0 for free space and 1 for occupied space. Unknown values return -1.

```
pocc = getOccupancy(map,[1.5 1])

pocc = 0.7500

occupied = checkOccupancy(map,[1.5 1])

occupied = 1


pocc2 = getOccupancy(map,[5 5],'grid')

pocc2 = 0.5000

occupied2 = checkOccupancy(map,[5 5],'grid')

occupied2 = -1
```

Insert Laser Scans Into Occupancy Grid

Take range and angle readings from a laser scan and insert these readings into an occupancy grid.

Create an empty occupancy grid map.

```
map = robotics.OccupancyGrid(10,10,20);
```

Insert a laser scan into the occupancy grid. Specify the pose of the robot ranges and angles and the max range of the laser scan.

```
pose = [5,5,0];
ranges = 3*ones(100, 1);
angles = linspace(-pi/2, pi/2, 100);
maxrange = 20;

insertRay(map,pose,ranges,angles,maxrange);
```

Show the map to see the results of inserting the laser scan. Check the occupancy of the spot directly in front of the robot.

```
show(map)
getOccupancy(map,[8 5])


ans =
```

```
0.7000
```


Add a second reading and view the update to the occupancy values. The additional reading increases the confidence in the readings. The free and occupied values become more distinct.

```
insertRay(map,pose,ranges,angles,maxrange);
show(map)
getOccupancy(map,[8 5])
```

```
ans =
```

```
0.8448
```


Limitations

Occupancy values have a limited resolution of ±0.001. The values are stored as `int16` using a log-odds representation. This data type limits resolution, but saves you memory when storing large maps in MATLAB. When calling `set` and then `get`, the value returned might not equal the value you set. For more information, see the log-odds representations section in "Occupancy Grids".

See Also

robotics.BinaryOccupancyGrid | robotics.OccupancyGrid |
robotics.OccupancyGrid.checkOccupancy

Topics

"Occupancy Grids"

Introduced in R2016b

grid2world

Class: robotics.OccupancyGrid
Package: robotics

Convert grid indices to world coordinates

Syntax

```
xy = grid2world(map,ij)
```

Description

`xy = grid2world(map,ij)` converts a `[row col]` array of grid indices, `ij`, to an array of world coordinates, `xy`.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

ij — Grid positions
n-by-2 matrix

Grid positions, specified as an *n*-by-2 matrix of `[i j]` pairs in `[rows cols]` format, where *n* is the number of grid positions. The grid cell locations are counted from the top left corner of the grid.

Data Types: `double`

Output Arguments

xy — World coordinates
n-by-2 matrix

World coordinates, returned as an *n*-by-2 matrix of [x y] pairs, where *n* is the number of world coordinates.

Data Types: double

See Also

robotics.BinaryOccupancyGrid | robotics.OccupancyGrid |
robotics.OccupancyGrid.world2grid

Topics
"Occupancy Grids"

Introduced in R2016b

inflate

Class: robotics.OccupancyGrid
Package: robotics

Inflate each occupied grid location

Syntax

```
inflate(map,radius)
inflate(map,gridradius,'grid')
```

Description

`inflate(map,radius)` inflates each occupied position of the specified `map` by the `radius` specified in meters. `radius` is rounded up to the nearest equivalent cell based on the resolution of the map. Values are modified using *grayscale inflation* to inflate higher probability values across the grid. This inflation increases the size of the occupied locations in the map.

`inflate(map,gridradius,'grid')` inflates each occupied position by the `gridradius` in number of cells.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

radius — Dimension that defines by how much to inflate occupied locations
scalar

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Dimension that defines by how much to inflate occupied locations, specified as a scalar. `radius` is rounded up to the nearest cell value.

Data Types: `double`

`gridradius` — Number of cells by which to inflate the occupied locations
positive scalar

Number of cells by which to inflate the occupied locations, specified as a positive scalar.

Data Types: `double`

Examples

Create and Modify Occupancy Grid

Create a 10m-by-10m empty map.

```
map = robotics.OccupancyGrid(10,10,10);
```

Update the occupancy of world locations with specific probability values.

```
map = robotics.OccupancyGrid(10,10,10);
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

pvalues = [0.2 0.4 0.6 0.8 1];

updateOccupancy(map,[x y],pvalues)
figure
show(map)
```

Inflate occupied areas by a given radius. Larger occupancy values overwrite the smaller values.

```
inflate(map,0.5)
figure
show(map)
```

Get grid locations from world locations.

```
ij = world2grid(map,[x y]);
```

Set grid locations to occupied locations.

```
setOccupancy(map,ij,ones(5,1),'grid')
figure
show(map)
```
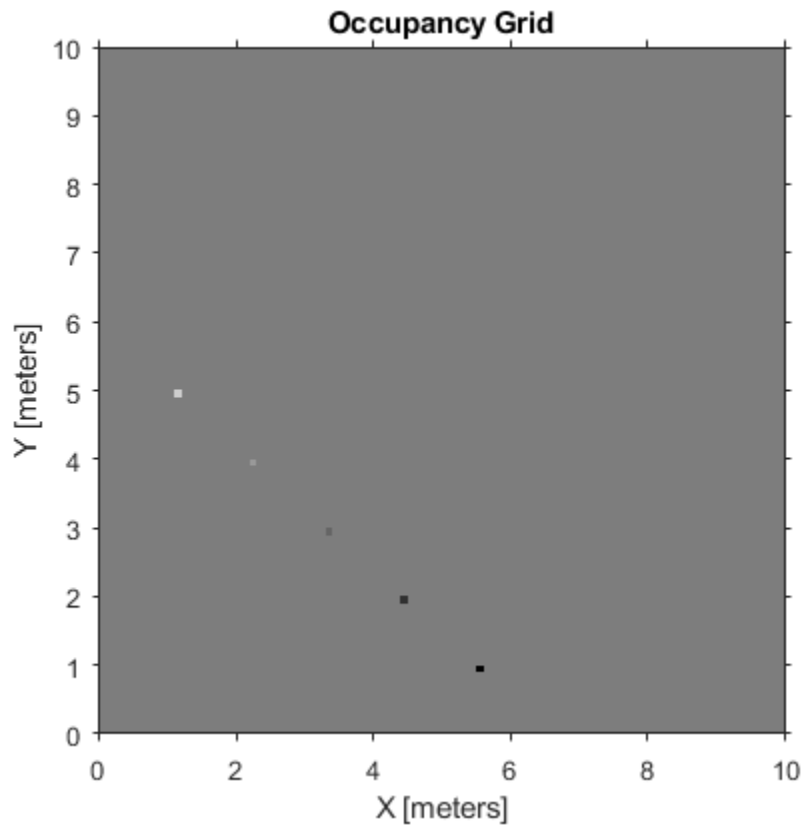
Occupancy Grid

Definitions

Grayscale Inflation

In *grayscale inflation*, the strel function creates a circular structuring element using the inflation radius. The grayscale inflation of $A(x, y)$ by $B(x, y)$ is defined as:

$$(A \oplus B)(x, y) = \max \{A(x - x', y' - y') + B(x', y') \mid (x', y') \in D_B\}.$$

D_B is the domain of the probability values in the structuring element B. $A(x,y)$ is assumed to be $+\infty$ outside the domain of the grid.

Grayscale inflation acts as a local maximum operator and finds the highest probability values for nearby cells. The `inflate` method uses this definition to inflate the higher probability values throughout the grid. This inflation increases the size of any occupied locations and creates a buffer zone for robots to use as they navigate.

See Also

OccupancyGrid | robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | robotics.OccupancyGrid.getOccupancy

Topics
"Occupancy Grids"

Introduced in R2016b

insertRay

Class: robotics.OccupancyGrid
Package: robotics

Insert ray from laser scan observation

Syntax

```
insertRay(map,pose,scan,maxrange)
insertRay(map,pose,ranges,angles,maxrange)
insertRay(map,startpt,endpoints)
insertRay( ___ ,invModel)
```

Description

`insertRay(map,pose,scan,maxrange)` inserts one or more lidar scan sensor observations in the occupancy grid, `map`, using the input `lidarScan` object, `scan`, to get ray endpoints. The ray endpoints are considered free space if the input scan ranges are below `maxrange`. Cells observed as occupied are updated with an observation of 0.7. All other points along the ray are treated as obstacle free and updated with an observation of 0.4. Endpoints above `maxrange` are not updated. `NaN` values are ignored. This behavior correlates to the inverse sensor model.

`insertRay(map,pose,ranges,angles,maxrange)` specifies the range readings as vectors, `ranges` and `angles`.

`insertRay(map,startpt,endpoints)` inserts observations between the line segments from the start point to the end points. The endpoints are updated with a probability observation of 0.7. Cells along the line segments are updated with an observation of 0.4.

`insertRay( ___ ,invModel)` inserts rays with updated probabilities given in the two-element vector, `invModel`, that corresponds to obstacle-free and occupied observations. Use any of the previous syntaxes to input the rays.

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Input Arguments

`map` — Map representation
OccupancyGrid object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

`pose` — Position and orientation of robot
[x y theta] vector

Position and orientation of robot, specified as an `[x y theta]` vector. The robot pose is an *x* and *y* position with angular orientation (in radians) measured from the *x*-axis.

`scan` — Lidar scan readings
lidarScan object

Lidar scan readings, specified as a `lidarScan` object.

`ranges` — Range values from scan data
vector of scalars

Range values from scan data, specified as a vector of scalars in meters. These range values are distances from a sensor at given `angles`. The vector must be the same length as the corresponding `angles` vector.

`angles` — Angle values from scan data
vector of scalars

Angle values from scan data, specified as a vector of scalars in radians. These angle values are the specific angles of the given `ranges`. The vector must be the same length as the corresponding `ranges` vector.

`maxrange` — Maximum range of sensor
scalar

Maximum range of laser range sensor, specified as a scalar. Range values greater than or equal to `maxrange` are considered free along the whole length of the ray, up to `maxrange`.

`startpt` — Start point for rays
two-element vector

Start point for rays, specified as a two-element vector, `[x y]`, in the world coordinate frame. All rays are line segments that originate at this point.

`endpoints` — Endpoints for rays
n-by-2 matrix

Endpoints for rays, specified as an *n*-by-2 matrix, `[x y]`, in the world coordinate frame, where *n* is the length of `ranges` or `angles`. All rays are line segments that originate at `startpt`.

`invModel` — Inverse sensor model values
two-element vector

Inverse sensor model values, specified as a two-element vector corresponding to obstacle-free and occupied probabilities. Points along the ray are updated according to the inverse sensor model and the specified range readings. `NaN` range values are ignored. Range values greater than `maxrange` are not updated. See "Inverse Sensor Model" on page 3-70.

Examples

Insert Laser Scans Into Occupancy Grid

Take range and angle readings from a laser scan and insert these readings into an occupancy grid.

Create an empty occupancy grid map.

```
map = robotics.OccupancyGrid(10,10,20);
```

Insert a laser scan into the occupancy grid. Specify the pose of the robot ranges and angles and the max range of the laser scan.

```
pose = [5,5,0];
ranges = 3*ones(100, 1);
angles = linspace(-pi/2, pi/2, 100);
maxrange = 20;
```

```
insertRay(map,pose,ranges,angles,maxrange);
```

Show the map to see the results of inserting the laser scan. Check the occupancy of the spot directly in front of the robot.

```
show(map)
getOccupancy(map,[8 5])
```

```
ans =

    0.7000
```

Add a second reading and view the update to the occupancy values. The additional reading increases the confidence in the readings. The free and occupied values become more distinct.

```
insertRay(map,pose,ranges,angles,maxrange);
show(map)
getOccupancy(map,[8 5])
```

```
ans =

    0.8448
```

Definitions

Inverse Sensor Model

The inverse sensor model determines how values are set along a ray from a range sensor reading to the obstacles in the map. You can customize this model by specifying different probabilities for free and occupied locations in the `invModel` argument. `NaN` range values are ignored. Range values greater than `maxrange` are not updated.
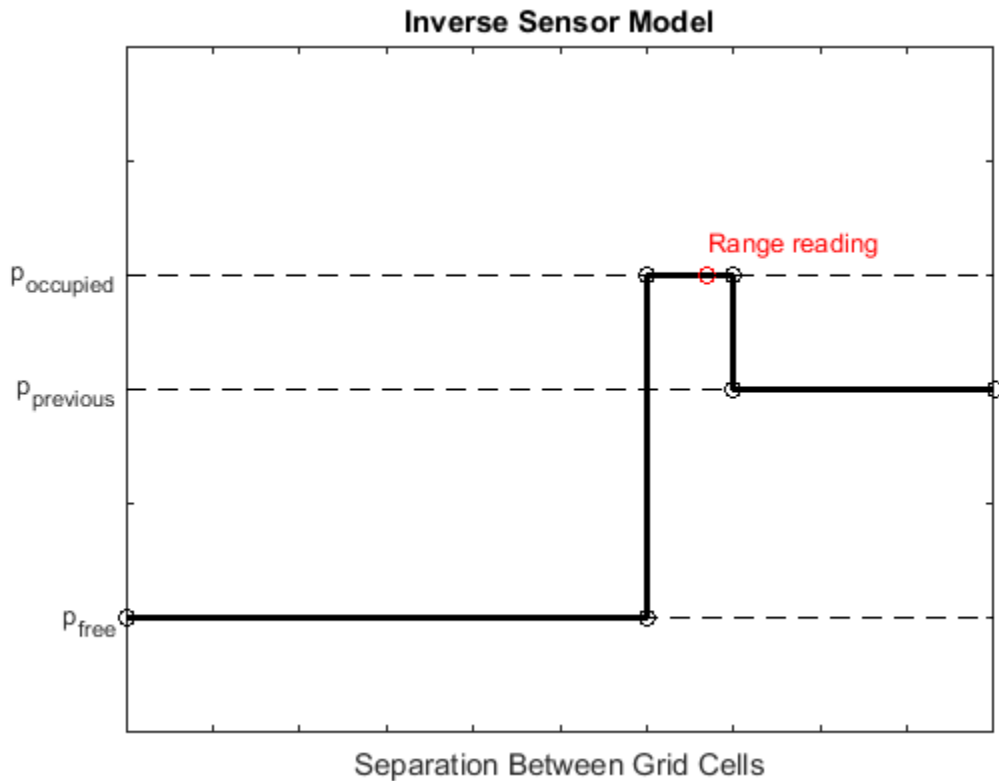
Inverse Sensor Model

Grid locations that contain range readings are updated with the occupied probability. Locations before the reading are updated with the free probability. All locations after the reading are not updated.

See Also

`lidarScan` | `robotics.BinaryOccupancyGrid` | `robotics.OccupancyGrid` | `robotics.OccupancyGrid.raycast`

Topics

"Occupancy Grids"

Introduced in R2016b

occupancyMatrix

Class: robotics.OccupancyGrid
Package: robotics

Convert occupancy grid to double matrix

Syntax

```
mat = occupancyMatrix(map)
mat = occupancyMatrix(map,'ternary')
```

Description

`mat = occupancyMatrix(map)` returns probability values stored in the occupancy grid object as a matrix.

`mat = occupancyMatrix(map,'ternary')` returns the occupancy status of each grid cell as a matrix. The `OccupiedThreshold` and `FreeThreshold` properties on the occupancy grid determine the obstacle free cells (0) and occupied cells (1). Unknown values are returned as –1.

Input Arguments

map — Map representation
OccupancyGrid object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

Output Arguments

mat — Occupancy grid values
matrix

Occupancy grid values, returned as an *h*-by-*w* matrix, where *h* and *w* are defined by the two elements of the `GridSize` property of the occupancy grid object.

See Also

robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | robotics.OccupancyGrid.getOccupancy | robotics.OccupancyGrid.show

Topics

"Occupancy Grids"

Introduced in R2016b

raycast

Class: robotics.OccupancyGrid
Package: robotics

Compute cell indices along a ray

Syntax

```
[endpoints,midpoints] = raycast(map,pose,range,angle)
[endpoints,midpoints] = raycast(map,p1,p2)
```

Description

`[endpoints,midpoints] = raycast(map,pose,range,angle)` returns cell indices of the specified `map` for all cells traversed by a ray originating from the specified `pose` at the specified `angle` and `range` values. `endpoints` contains all indices touched by the end of the ray, with all other points included in `midpoints`.

`[endpoints,midpoints] = raycast(map,p1,p2)` returns the cell indices of the line segment between the two specified points.

Examples

Get Grid Cells Along A Ray

Use the `raycast` method to generate cell indices for all cells traversed by a ray.

Create an empty map. A low resolution map is used to illustrate the affect of grid locations.

```
map = robotics.OccupancyGrid(10,10,1);
show(map)
```

3-75
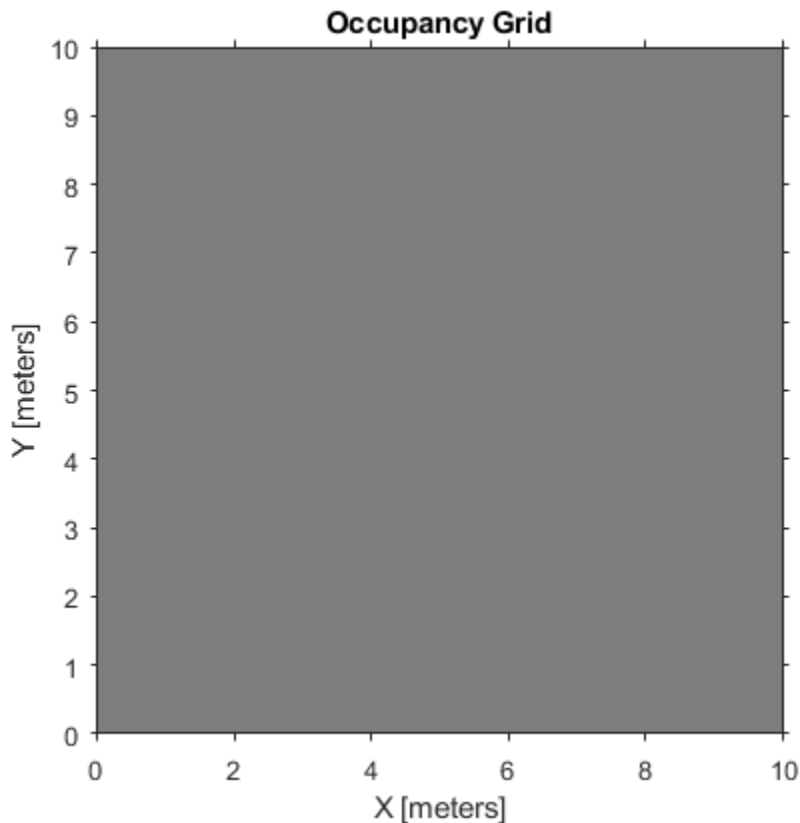
Get the grid indices of the midpoints and end points of a ray from `p1` to `p2`. Set occupancy values for these grid indices. Midpoints are treated as open space. Endpoints are updated with an occupied observation.

```
p1 = [2 3];
p2 = [8.5 8];
[endPts,midPts] = raycast(map,p1,p2);
setOccupancy(map,midPts,zeros(length(midPts),1),'grid');
setOccupancy(map,endPts,ones(length(endPts),1),'grid');
```

Plot the original ray over the map. Notice that each grid cell touched by the line is updated. The starting point overlaps multiple cells and the line touches the edge of certain cells, but all the cells are still updated.

```
show(map);
hold on
plot([p1(1) p2(1)],[p1(2) p2(2)],'-b','LineWidth',2)
plot(p2(1),p2(2),'or')
grid on
```


Input Arguments

map — Map representation
OccupancyGrid object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

pose — Position and orientation of robot
[x y theta] vector

Position and orientation of robot, specified as an [x y theta] vector. The robot pose is an *x* and *y* position with angular orientation (in radians) measured from the *x*-axis.

range — Range value
scalar

Range value, specified as a scalar in meters.

angle — Angle value
scalar

Angle value, specified as a scalar in radians. The angle value is the specific angle orientation of the given `range`.

p1 — Starting point of ray
[x y] two-element vector

Starting point of ray, specified as an [x y] two-element vector. The point is defined in the robot coordinate frame.

p2 — Endpoint of ray
[x y] two-element vector

Endpoint of ray, specified as an [x y] two-element vector. The point is defined in the robot coordinate frame.

Output Arguments

endpoints — Endpoint grid indices
[i j] matrix

Endpoint indices, returned as an `[i j]` matrix. The endpoints are where the `range` value hits at the specified `angle`. Multiple indices are only given if the point intersect grid locations.

`midpoints` — Midpoint grid indices
[i j] matrix

Midpoint indices, returned as an `[i j]` matrix. This argument includes all grid indices the ray intersects, excluding the endpoint.

See Also

`robotics.BinaryOccupancyGrid` | `robotics.OccupancyGrid` | `robotics.OccupancyGrid.insertray`

Topics
"Occupancy Grids"

Introduced in R2016b

rayIntersection

Class: robotics.OccupancyGrid
Package: robotics

Compute map intersection points of rays

Syntax

```
intersectionPts = rayIntersection(map,pose,angles,maxrange)
intersectionPts = rayIntersection(map,pose,angles,maxrange,
threshold)
```

Description

`intersectionPts = rayIntersection(map,pose,angles,maxrange)` returns intersection points in the world coordinate frame of the specified `map` for rays emanating from the specified `pose` with the specified `angles`. If there is no intersection up to the specified `maxrange`, `[NaN NaN]` is returned. By default, the `OccupiedThreshold` property is used to determine occupied cells.

`intersectionPts = rayIntersection(map,pose,angles,maxrange, threshold)` returns intersection points based on the specified `threshold` for the occupancy values. Values greater than or equal to the threshold are considered occupied.

Examples

Get Ray Intersection Points on Occupancy Grid

Get the ray intersection points on an occupancy grid that has obstacles in the map. The rays are defined ranges and angles from a starting robot pose.

Create an occupancy grid map. Add obstacles and inflate them. A lower resolution map is used to illustrate the importance of using grid cells. Show the map.

```
map = robotics.OccupancyGrid(10,10,2);
obstacles = [4 10; 3 5; 7 7];
setOccupancy(map,obstacles,ones(length(obstacles),1))
inflate(map,0.25)
show(map)
```
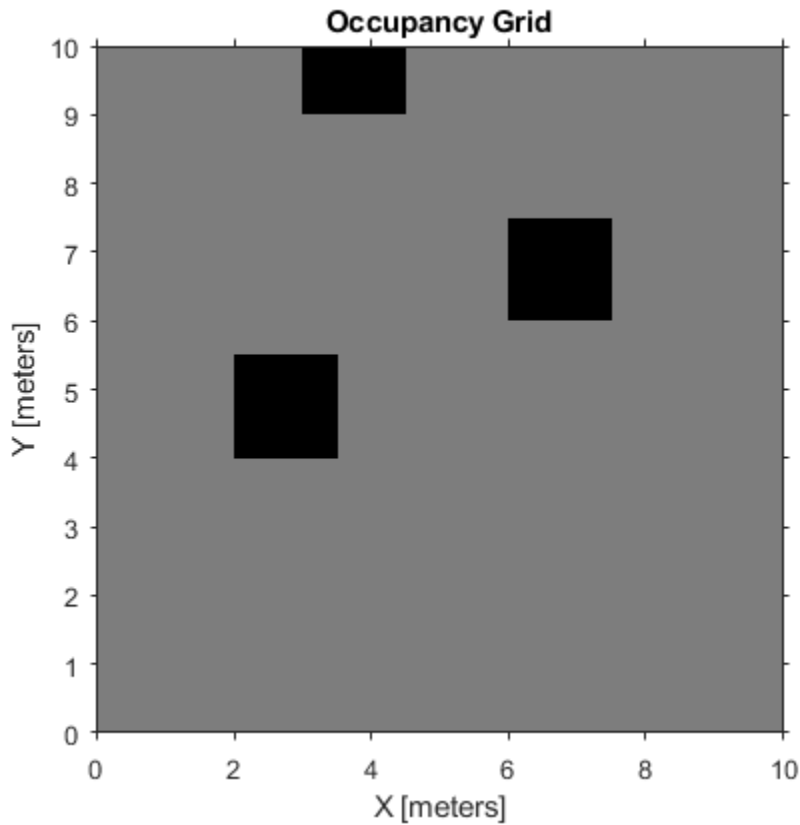

Find the intersection point for rays that emit from the given robot pose. The max range and angles for these rays are specified. The last ray does not intersect with an obstacle within the max range, thus it has no collision point.

```
maxrange = 6;
angles = [pi/4,-pi/4,0,-pi/8];
robotPose = [4,4,pi/2];
intsectionPts = rayIntersection(map,robotPose,angles,maxrange,0.7)
```

```
intsectionPts =

    3.5000    4.5000
    6.0000    6.0000
    4.0000    9.0000
       NaN       NaN
```

Plot the intersection points and rays from the pose.

```
hold on
plot(intsectionPts(:,1),intsectionPts(:,2) , '*r') % Intersection points
plot(robotPose(1),robotPose(2),'ob') % Robot pose
for i = 1:3
    plot([robotPose(1),intsectionPts(i,1)],...
        [robotPose(2),intsectionPts(i,2)],'-b') % Plot intersecting rays
end
plot([robotPose(1),robotPose(1)-6*sin(angles(4))],...
    [robotPose(2),robotPose(2)+6*cos(angles(4))],'-b') % No intersection ray

legend('Collision Points','Robot Position','Rays','Location','SouthEast')
```

Input Arguments

map — Map representation
OccupancyGrid object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

pose — Position and orientation of robot
[x y theta] vector

Position and orientation of robot, specified as an [x y theta] vector. The robot pose is an *x* and *y* position with angular orientation (in radians) measured from the *x*-axis.

angles — Ray angles emanating from the robot
vector in radians

Ray angles emanating from the robot, specified as a vector in radians. These angles are relative to the specified robot pose.

maxrange — Maximum range of sensor
scalar

Maximum range of laser range sensor, specified as a scalar. Range values greater than or equal to maxrange are considered free along the whole length of the ray, up to maxrange.

threshold — Threshold for occupied cells
scalar from 0 to 1

Threshold for occupied cells, specified as a scalar from 0 to 1. Occupancy values greater than or equal to the threshold are treated as occupied cells to trigger intersections.

Output Arguments

intersectionPts — Intersection points
n-by-2 matrix

Intersection points, returned as *n*-by-2 matrix, [x y], in the world coordinate frame, where *n* is the length of angles.

See Also

robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | robotics.OccupancyGrid.raycast | robotics.OccupancyGrid.updateOccupancy

Topics
"Occupancy Grids"

Introduced in R2016b

setOccupancy

Class: robotics.OccupancyGrid
Package: robotics

Set occupancy of a location

Syntax

```
setOccupancy(map,xy,occval)
setOccupancy(map,ij,occval,'grid')
```

Description

`setOccupancy(map,xy,occval)` assigns the occupancy values to each coordinate specified in `xy`. `occval` can be an array the length of `xy` or a scalar, which is applied to all coordinates.

`setOccupancy(map,ij,occval,'grid')` assigns occupancy values to the specified grid locations, `ij`, instead of to world coordinates.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

xy — World coordinates
n-by-2 matrix

World coordinates, specified as an *n*-by-2 matrix of [x y] pairs, where *n* is the number of world coordinates.

Data Types: `double`

ij — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 matrix of [i j] pairs in [`rows cols`] format, where *n* is the number of grid positions.

Data Types: `double`

occval — Probability occupancy values
scalar | column vector

Probability occupancy values, specified as a scalar or a column vector the same size as either xy or ij. A scalar input is applied to all coordinates in either xy or ij.

Values close to 0 represent certainty that the cell is not occupied and obstacle free.

Examples

Create and Modify Occupancy Grid

Create a 10m-by-10m empty map.

```
map = robotics.OccupancyGrid(10,10,10);
```

Update the occupancy of world locations with specific probability values.

```
map = robotics.OccupancyGrid(10,10,10);
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

pvalues = [0.2 0.4 0.6 0.8 1];

updateOccupancy(map,[x y],pvalues)
figure
show(map)
```

Inflate occupied areas by a given radius. Larger occupancy values overwrite the smaller values.

```
inflate(map,0.5)
figure
show(map)
```

Get grid locations from world locations.

```
ij = world2grid(map,[x y]);
```

Set grid locations to occupied locations.

```
setOccupancy(map,ij,ones(5,1),'grid')
figure
show(map)
```

Limitations

Occupancy values have a limited resolution of ±0.001. The values are stored as `int16` using a log-odds representation. This data type limits resolution, but saves you memory when storing large maps in MATLAB. When calling `set` and then `get`, the value returned might not equal the value you set. For more information, see the log-odds representations section in "Occupancy Grids".

See Also

robotics.BinaryOccupancyGrid | robotics.OccupancyGrid |
robotics.OccupancyGrid.getOccupancy

Topics

"Occupancy Grids"

Introduced in R2016b

show

Class: robotics.OccupancyGrid
Package: robotics

Show grid values in a figure

Syntax

```
show(map)
show(map, 'grid')

show( ___ ,'Parent',parent)

mapImage= show(map, ___ )
```

Description

`show(map)` displays the occupancy grid `map` in the current axes, with the axes labels representing the world coordinates.

`show(map, 'grid')` displays the occupancy grid with the axes labels representing the grid coordinates.

`show( ___ ,'Parent',parent)` uses the axes handle specified as a parent to display the occupancy grid. Use any of the arguments from previous syntaxes.

`mapImage= show(map, ___ )` returns the handle to the image object created by `show`.

Input Arguments

map — Map representation
OccupancyGrid object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values

representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

parent — Axes to plot the map
Axes object | UIAxes object

Axes to plot the map specified as either an Axes or UIAxesobject. See axes or uiaxes.

Outputs

mapImage — Map image
object handle

Map image, specified as an object handle.

Examples

Create and Modify Occupancy Grid

Create a 10m-by-10m empty map.

```
map = robotics.OccupancyGrid(10,10,10);
```

Update the occupancy of world locations with specific probability values.

```
map = robotics.OccupancyGrid(10,10,10);
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

pvalues = [0.2 0.4 0.6 0.8 1];

updateOccupancy(map,[x y],pvalues)
figure
show(map)
```
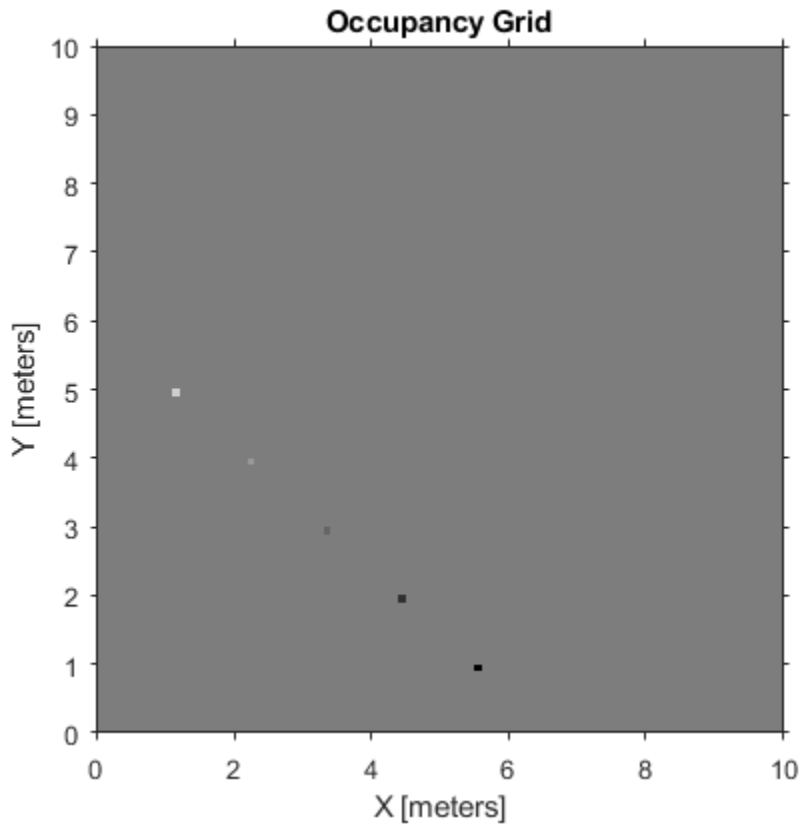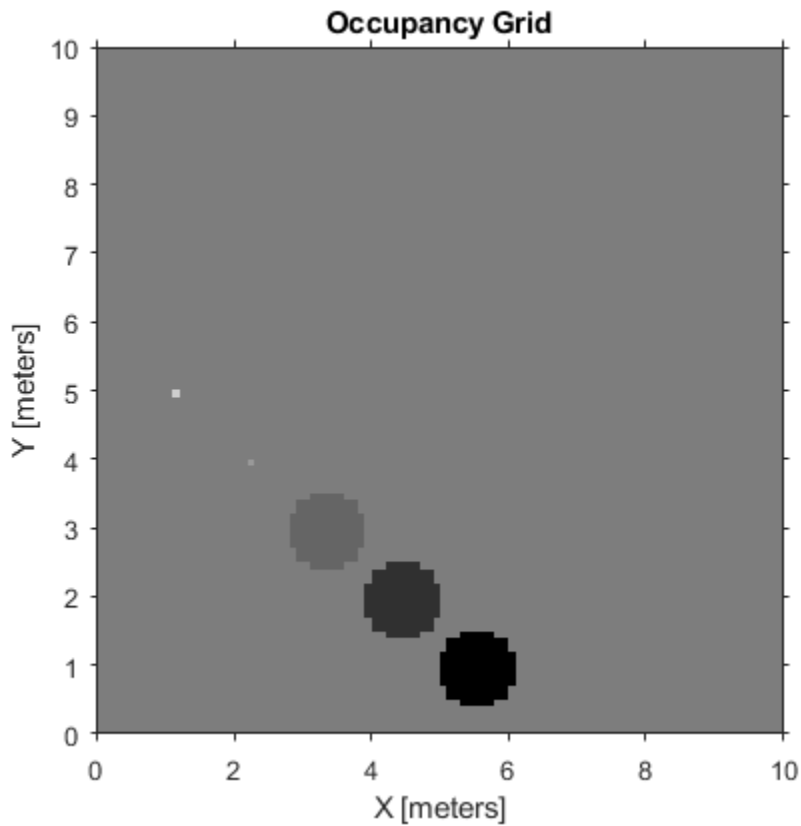
Inflate occupied areas by a given radius. Larger occupancy values overwrite the smaller values.

```
inflate(map,0.5)
figure
show(map)
```

Occupancy Grid

Get grid locations from world locations.

```
ij = world2grid(map,[x y]);
```

Set grid locations to occupied locations.

```
setOccupancy(map,ij,ones(5,1),'grid')
figure
show(map)
```

Convert PGM Image to Map

Convert a portable graymap (`.pgm`) file containing a ROS map into an `OccupancyGrid` map for use in MATLAB.

Import the image using `imread`. Crop the image to the relevant area.

```
image = imread(fullfile(matlabroot,'examples','robotics','playpen_map.pgm'));
imageCropped = image(750:1250,750:1250);
imshow(imageCropped)
```

PGM values are expressed from 0 to 255 as `uint8`. Normalize these values by converting the cropped image to `double` and dividing each cell by 255. This image shows obstacles as values close to 0. Subtract the normalized image from 1 to get occupancy values with 1 representing occupied space.

```
imageNorm = double(imageCropped)/255;
imageOccupancy = 1 - imageNorm;
```

Create the `OccupancyGrid` object using an adjusted map image. The imported map resolution is 20 cells per meter.

```
map = robotics.OccupancyGrid(imageOccupancy,20);
show(map)
```

Occupancy Grid

See Also

axes | robotics.BinaryOccupancyGrid | robotics.OccupancyGrid |
robotics.OccupancyGrid.occupancyMatrix

Introduced in R2016b

updateOccupancy

Class: robotics.OccupancyGrid
Package: robotics

Integrate probability observation at a location

Syntax

```
updateOccupancy(map,xy,obs)
updateOccupancy(map,ij,occval,'grid')
```

Description

`updateOccupancy(map,xy,obs)` probabilistically integrates the observation values, `obs`, to each coordinate specified in `xy`. Observation values are determined based on the "Inverse Sensor Model" on page 3-105.

`updateOccupancy(map,ij,occval,'grid')` probabilistically integrates the observation values to the specified grid locations, `ij`, instead of to world coordinates.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

xy — World coordinates
n-by-2 matrix

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World coordinates, specified as an *n*-by-2 vertical matrix of [x y] pairs, where *n* is the number of world coordinates.

Data Types: `double`

`ij` — Grid positions
n-by-2 matrix

Grid positions, specified as an *n*-by-2 matrix of [i j] pairs in [rows cols] format, where *n* is the number of grid positions.

Data Types: `double`

`obs` — Probability observation values
n-by-1 column vector | scalar | logical

Probability observation values, specified as a scalar or an *n*-by-1 column vector the same size as either `xy` or `ij`.

`obs` values can be any value from 0 to 1, but if `obs` is a logical array, the default observation values of 0.7 (`true`) and 0.4 (`false`) are used. These values correlate to the inverse sensor model for ray casting. If `obs` is a scalar or logical, the value is applied to all coordinates in `xy` or `ij`.

Examples

Create and Modify Occupancy Grid

Create a 10m-by-10m empty map.

```
map = robotics.OccupancyGrid(10,10,10);
```

Update the occupancy of world locations with specific probability values.

```
map = robotics.OccupancyGrid(10,10,10);
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

pvalues = [0.2 0.4 0.6 0.8 1];

updateOccupancy(map,[x y],pvalues)
```
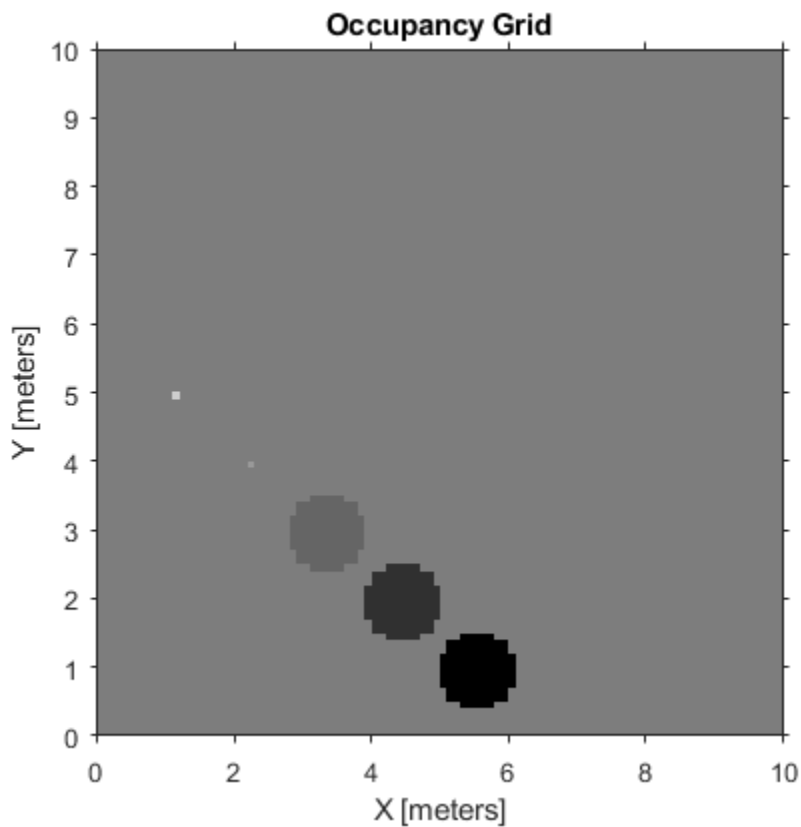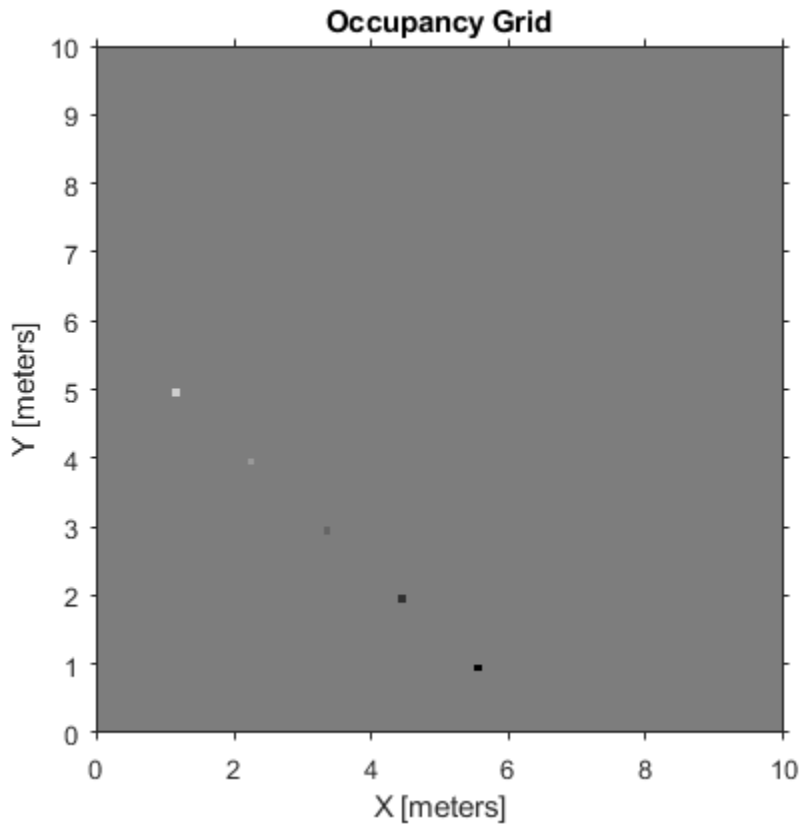
```
figure
show(map)
```


Inflate occupied areas by a given radius. Larger occupancy values overwrite the smaller values.

```
inflate(map,0.5)
figure
show(map)
```
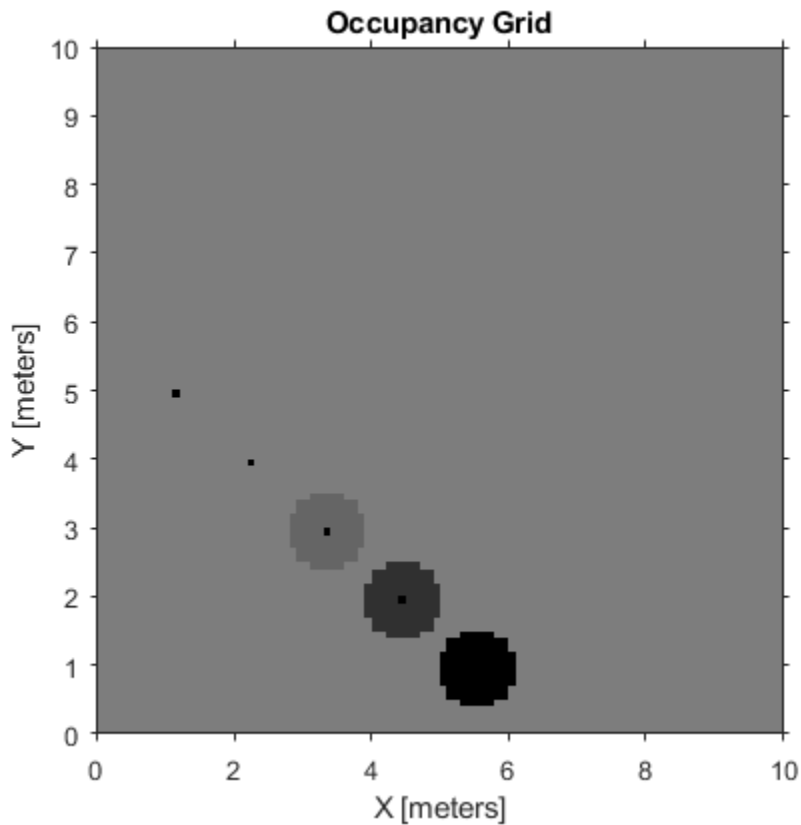
Occupancy Grid

Get grid locations from world locations.

```
ij = world2grid(map,[x y]);
```
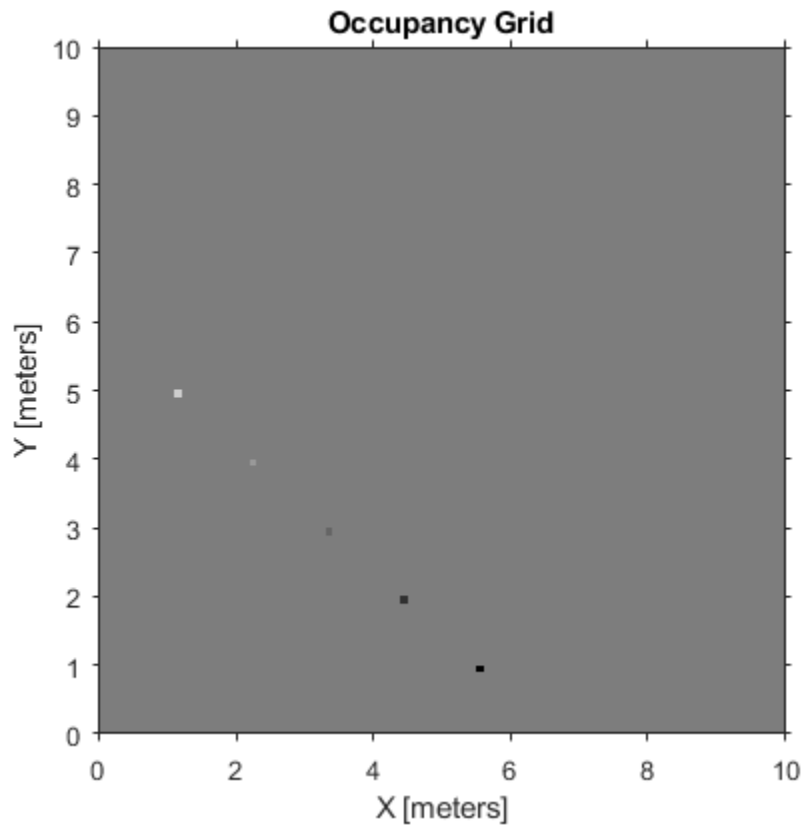
Set grid locations to occupied locations.

```
setOccupancy(map,ij,ones(5,1),'grid')
figure
show(map)
```

Definitions
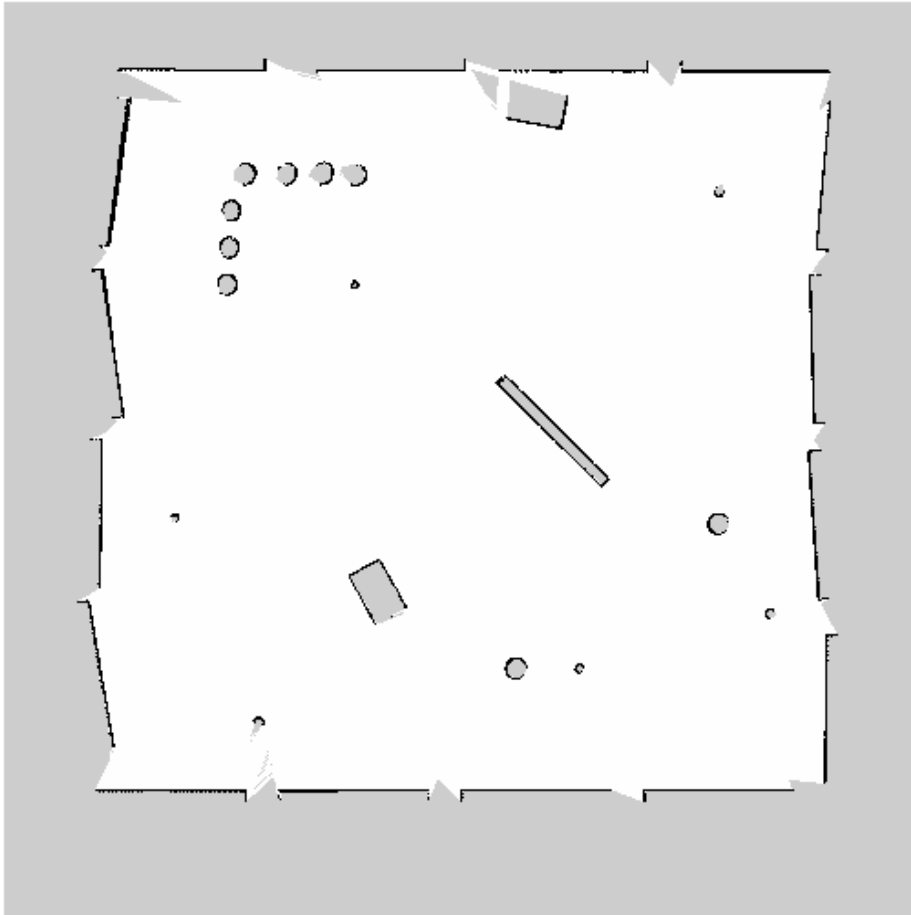
Inverse Sensor Model

The inverse sensor model determines how values are set along a ray from a range sensor reading to the obstacles in the map. NaN range values are ignored. Range values greater than maxrange are not updated.
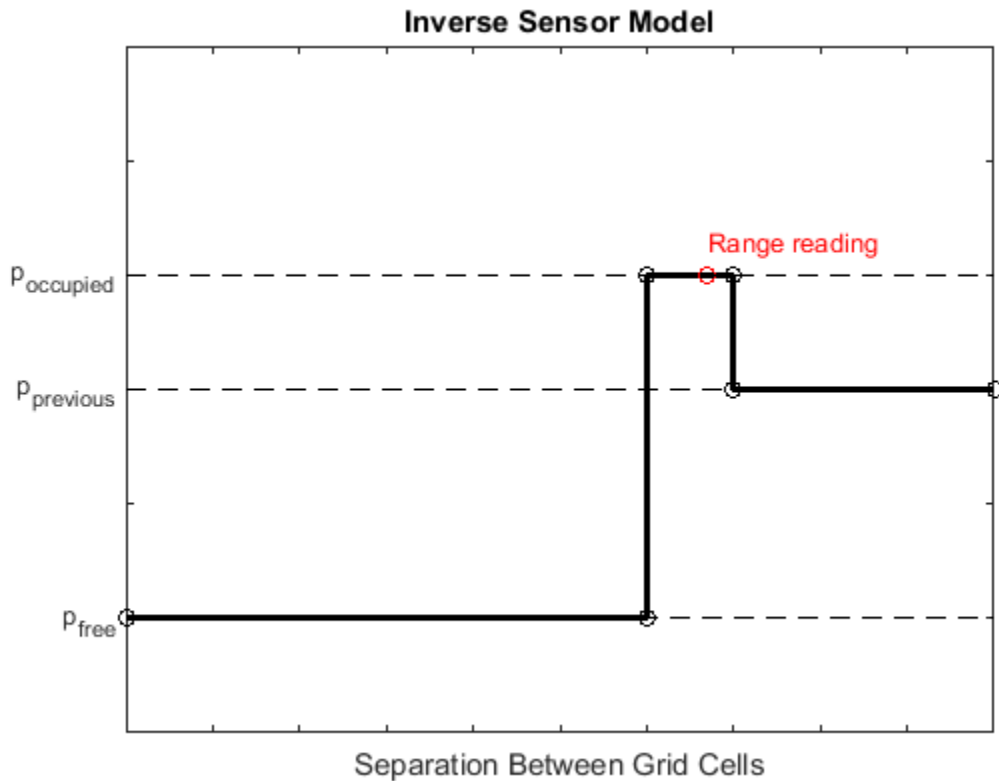
Grid locations that contain range readings are updated with the occupied probability. Locations before the reading are updated with the free probability. All locations after the reading are not updated.

See Also

`robotics.BinaryOccupancyGrid` | `robotics.OccupancyGrid` | `robotics.OccupancyGrid.setOccupancy`

Topics

"Occupancy Grids"

Introduced in R2016b

world2grid

Class: robotics.OccupancyGrid
Package: robotics

Convert world coordinates to grid indices

Syntax

```
ij = world2grid(map,xy)
```

Description

`ij = world2grid(map,xy)` converts an array of world coordinates, `xy`, to an array of grid indices, `ij` in `[row col]` format.

Input Arguments

map — Map representation
`OccupancyGrid` object

Map representation, specified as a `robotics.OccupancyGrid` object. This object represents the environment of the robot. The object contains a matrix grid with values representing the probability of the occupancy of that cell. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle free.

xy — World coordinates
n-by-2 matrix

World coordinates, specified as an *n*-by-2 matrix of `[x y]` pairs, where *n* is the number of world coordinates.

Data Types: `double`

Output Arguments

ij — Grid positions
n-by-2 matrix

Grid positions, returned as an *n*-by-2 matrix of [i j] pairs in [rows cols] format, where *n* is the number of grid positions. The grid cell locations are counted from the top left corner of the grid.

Data Types: double

Examples

Create and Modify Occupancy Grid

Create a 10m-by-10m empty map.

```
map = robotics.OccupancyGrid(10,10,10);
```

Update the occupancy of world locations with specific probability values.

```
map = robotics.OccupancyGrid(10,10,10);
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

pvalues = [0.2 0.4 0.6 0.8 1];

updateOccupancy(map,[x y],pvalues)
figure
show(map)
```

Inflate occupied areas by a given radius. Larger occupancy values overwrite the smaller values.

```
inflate(map,0.5)
figure
show(map)
```

Occupancy Grid

Get grid locations from world locations.

```
ij = world2grid(map,[x y]);
```

Set grid locations to occupied locations.

```
setOccupancy(map,ij,ones(5,1),'grid')
figure
show(map)
```

See Also

robotics.BinaryOccupancyGrid | robotics.OccupancyGrid | robotics.OccupancyGrid.grid2world

Topics

"Occupancy Grids"

Introduced in R2016b

checkOccupancy

Class: robotics.OccupancyMap3D
Package: robotics

Check if locations are free or occupied

Syntax

```
iOccval = checkOccupancy(map3D,xyz)
```

Description

`iOccval = checkOccupancy(map3D,xyz)` returns an array of occupancy values specified at the *xyz* locations using the `OccupiedThreshold` and `FreeThreshold` properties of the input `OccupancyMap3D` object. Each row is a separate *xyz* location in the map to check the occupancy of. Occupancy values can be obstacle-free (0), occupied (1), or unknown (–1).

Input Arguments

map3D — 3-D occupancy map
`OccupancyMap3D` object

3-D occupancy map, specified as an `OccupancyMap3D` object.

xyz — World coordinates
n-by-3 matrix

World coordinates, specified as an *n*-by-3 matrix of [x y z] points, where *n* is the number of world coordinates.

Output Arguments

iOccval — Interpreted occupancy values
column vector

Interpreted occupancy values, returned as a column vector with the same length as xyz.

Occupancy values can be obstacle-free (0), occupied (1), or unknown (–1). These values are determined from the actual probability values and the OccupiedThreshold and FreeThreshold properties of the map3D object.

See Also

Classes
LidarSLAM | OccupancyGrid | OccupancyMap3D

Functions
inflate | insertPointCloud | setOccupancy | show

Introduced in R2018a

getOccupancy

Class: robotics.OccupancyMap3D
Package: robotics

Get occupancy probability of locations

Syntax

```
occval = getOccupancy(map3D,xyz)
```

Description

`occval = getOccupancy(map3D,xyz)` returns an array of probability occupancy values at the specified *xyz* locations in the `OccupancyMap3D` object. Values close to 1 represent a high certainty that the cell contains an obstacle. Values close to 0 represent certainty that the cell is not occupied and obstacle-free.

Input Arguments

map3D — 3-D occupancy map
OccupancyMap3D object

3-D occupancy map, specified as an `OccupancyMap3D` object.

xyz — World coordinates
n-by-3 matrix

World coordinates, specified as an *n*-by-3 matrix of [x y z] points, where *n* is the number of world coordinates.

Output Arguments

occval — Probability occupancy values
column vector

Probability occupancy values, returned as a column vector with the same length as xyz.

Values close to 0 represent certainty that the cell is not occupied and obstacle-free.

See Also

Classes
LidarSLAM | OccupancyGrid | OccupancyMap3D

Functions
inflate | insertPointCloud | setOccupancy | show

Introduced in R2018a

inflate

Class: robotics.OccupancyMap3D
Package: robotics

Inflate map

Syntax

```
inflate(map3D,radius)
```

Description

`inflate(map3D,radius)` inflates each occupied position of the specified in the input `OccupancyMap3D` object by the `radius` specified in meters. `radius` is rounded up to the nearest equivalent cell based on the resolution of the map. This inflation increases the size of the occupied locations in the map.

Input Arguments

map3D — 3-D occupancy map
`OccupancyMap3D` object

3-D occupancy map, specified as an `OccupancyMap3D` object.

radius — Amount to inflate occupied locations
scalar

Amount to inflate occupied locations, specified as a scalar. `radius` is rounded up to the nearest cell value.

See Also

Classes
LidarSLAM | OccupancyGrid | OccupancyMap3D

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Functions
insertPointCloud | setOccupancy | show

Introduced in R2018a

insertPointCloud

Class: robotics.OccupancyMap3D
Package: robotics

Insert 3-D points or point cloud observation into map

Syntax

```
insertRay(map3D,pose,points,maxrange)
insertRay(map3D,pose,ptcloud,maxrange)
```

Description

`insertRay(map3D,pose,points,maxrange)` inserts one or more sensor observations at the given `points` in the occupancy map, `map3D`. Occupied points are updated with an observation of 0.7. All other points between the sensor `pose` and `points` are treated as obstacle-free and updated with an observation of 0.4. Points outside `maxrange` are not updated. `NaN` values are ignored.

`insertRay(map3D,pose,ptcloud,maxrange)` inserts a `ptcloud` object into the map.

Input Arguments

map3D — 3-D occupancy map
`OccupancyMap3D` object

3-D occupancy map, specified as a `OccupancyMap3D` object.

points — Points of point cloud
n-by-3 matrix

Points of point cloud in sensor coordinates, specified as an *n*-by-3 matrix of [x y z] points, where *n* is the number of points in the point cloud.

ptcloud — Point cloud reading
pointCloud object

Point cloud reading, specified as a `pointCloud` object.

Note Using `pointCloud` objects requires Computer Vision System Toolbox™.

---

pose — Position and orientation of robot
[x y z qw qx qy qz] vector

Position and orientation of robot, specified as an [x y z qw qx qy qz] vector. The robot pose is an *xyz*-position vector with a quaternion orientation vector specified as [qw qx qy qz].

maxrange — Maximum range of sensor
scalar

Maximum range of point cloud sensor, specified as a scalar. Points outside this range are ignored.

See Also

Classes
LidarSLAM | OccupancyGrid | OccupancyMap3D

Functions
inflate | setOccupancy | show

Introduced in R2018a

setOccupancy

Class: robotics.OccupancyMap3D
Package: robotics

Set occupancy probability of locations

Syntax

setOccupancy(map3D,xyz,occval)

Description

setOccupancy(map3D,xyz,occval) assigns the occupancy values to each specified xyz coordinate in the 3-D occupancy map.

Input Arguments

map3D — 3-D occupancy map
OccupancyMap3D object

3-D occupancy map, specified as an OccupancyMap3D object.

xyz — World coordinates
n-by-3 matrix

World coordinates, specified as an *n*-by-3 matrix of [x y z] points, where *n* is the number of world coordinates.

occval — Probability occupancy values
scalar | column vector

Probability occupancy values, specified as a scalar or a column vector with the same length as xyz. A scalar input is applied to all coordinates in xyz.

Values close to 0 represent certainty that the cell is not occupied and obstacle-free.

See Also

Classes
LidarSLAM | OccupancyGrid | OccupancyMap3D

Functions
inflate | insertPointCloud | setOccupancy | show

Introduced in R2018a

show

Class: robotics.OccupancyMap3D
Package: robotics

Show occupancy map

Syntax

```
axes = show(map3D)
show(map3D,'Parent',parent)
```

Description

`axes = show(map3D)` displays the occupancy map, `map3D`, in the current axes, with the axes labels representing the world coordinates.

The function displays the 3-D environment using 3-D voxels for areas with occupancy values greater than the `OccupiedThreshold` property value specified in `map3D`. The color of the 3-D plot is strictly height-based.

`show(map3D,'Parent',parent)` displays the occupancy map in the axes handle specified by `parent`.

Input Arguments

map3D — 3-D occupancy map
`OccupancyMap3D` object

3-D occupancy map, specified as an `OccupancyMap3D` object.

parent — Axes used to plot the map
`Axes` object | `UIAxes` object

Axes used to plot the map, specified as either an `Axes` or `UIAxes` object. See `axes` or `uiaxes`.

Output Arguments

axes — Axes handle for map
Axes object | UIAxes object

Axes handle for map, returned as either an Axes or UIAxes object. See axes or uiaxes.

See Also

Classes
LidarSLAM | OccupancyGrid | OccupancyMap3D

Functions
insertPointCloud | setOccupancy | show

Introduced in R2018a

updateOccupancy

Class: robotics.OccupancyMap3D
Package: robotics

Update occupancy probability at locations

Syntax

updateOccupancy(map3D,xyz,obs)

Description

updateOccupancy(map3D,xyz,obs) probabilistically integrates the observation values, obs, to each specified xyz coordinate in the OccupancyMap3D object, map3D.

Input Arguments

map3D — 3-D occupancy map
OccupancyMap3D object

3-D occupancy map, specified as an OccupancyMap3D object.

xyz — World coordinates
n-by-3 matrix

World coordinates, specified as an *n*-by-3 matrix of [x y z] points, where *n* is the number of world coordinates.

obs — Probability observation values
numberic scalar | logical scalar | *n*-by-1 column vector

Probability observation values, specified as a numeric or logical scalar, or as an *n*-by-1 column vector with the same size as xyz.

obs values can be from 0 to 1, but if obs is a logical array, the function uses the default observation values of 0.7 (`true`) and 0.4 (`false`). If obs is a numeric or logical scalar, the value is applied to all coordinates in xyz.

See Also

Classes
LidarSLAM | OccupancyGrid | OccupancyMap3D

Functions
inflate | insertPointCloud | setOccupancy | show

Introduced in R2018a

showNoiseDistribution

Class: robotics.OdometryMotionModel
Package: robotics

Display noise parameter effects

Syntax

```
showNoiseDistribution(ommObj)
showNoiseDistribution(ommObj)
showNoiseDistribution(ommObj,Name,Value)
```

Description

`showNoiseDistribution(ommObj)` shows the noise distribution for a default odometry pose update, number of samples and the current noise parameters on the input object.

`axes = showNoiseDistribution(ommObj)` shows the noise distribution and returns the axes handle.

`showNoiseDistribution(ommObj,Name,Value)` provides additional options specified by one or more `Name,Value` pairs. Name is the 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 not specified retain their default values.

Input Arguments

ommObj — OdometryMotionModel object
handle

`OdometryMotionModel` object, specified as a handle. Create this object using `robotics.OdometryMotionModel`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

OdometryPoseChange — Change in odometry
three-element vector

Change in odometry of the robot, specified as a comma-separated pair consisting of `'OdometryPoseChange'` and a three-element vector, `[x y theta]`.

NumSamples — Number of particles to display
scalar

Number of particles to display, specified as a specified as a comma-separated pair consisting of `'NumSamples'` and a scalar.

Parent — Axes to plot the map
`Axes` object | `UIAxes` object

Axes to plot the map specified as a comma-separated pair consisting of `'Parent'` and either an `Axes` or `UIAxes`object. See `axes` or `uiaxes`.

Examples

Show Noise Distribution Effects for Odometry Motion Model

This example shows how to visualize the effect of different noise parameters on the `robotics.OdometryMotionModel` class. An `OdometryMotionModel` object contains the motion model noise parameters for a differential drive robot. Use `showNoiseDistribution` to visualize how changing these values affect the distribution of predicted poses.

Create a motion model object.

```
motionModel = robotics.OdometryMotionModel;
```

Show the distribution of particles with the existing noise parameters. Each particle is a hypothesis for the predicted pose.

```
showNoiseDistribution(motionModel);
```


Show the distribution with a specified odometry pose change and number of samples. The change in odometry is used as the final pose with hypotheses distributed around based on the `Noise` parameters.

```
showNoiseDistribution(motionModel, ...
            'OdometryPoseChange', [0.5 0.1 0.25], ...
            'NumSamples', 1000);
```

Change the `Noise` parameters and visualize the effects. Use the same odometry pose change and number of samples.

```
motionModel.Noise = [0.2 1 0.2 1];

showNoiseDistribution(motionModel, ...
          'OdometryPoseChange', [0.5 0.1 0.25], ...
          'NumSamples', 1000);
```

See Also

robotics.LikelihoodFieldSensorModel | robotics.MonteCarloLocalization |
robotics.OdometryMotionModel

Introduced in R2016b

step

Class: robotics.OdometryMotionModel
Package: robotics

Computer next pose from previous pose

Syntax

```
currentPoses = step(ommObj,previousPoses,odomPose)
```

Description

`currentPoses = step(ommObj,previousPoses,odomPose)` returns the current poses by propagating the previous poses using a sampling-based odometry motion model, which uses the difference between the specified `odomPose` and the `LastOdometryPose` property of the `ommObj`. The first `step` call instantiates the object and sets the `LastOdometryPose` property.

Input Arguments

ommObj — OdometryMotionModel object
handle

`OdometryMotionModel` object, specified as a handle. Create this object using `robotics.OdometryMotionModel`.

previousPoses — Previous poses
n-by-3 array

Previous poses, specified as an *n*-by-3 array, `[x y theta]`. Each row of the `previousPoses` vector is treated as a separate robot and a corresponding predicted pose is present in `currentPoses`

odomPose — Current robot pose
three-element vector

Current robot pose, specified as a three-element vector, `[x y theta]`.

Output Arguments

`currentPoses` — Current poses
n-by-3 array

Current poses, returned as an *n*-by-3 array, `[x y theta]`. Each row of the `previousPoses` vector is treated as a separate robot and a corresponding predicted pose is present in `currentPoses`.

Examples

Predict Poses Based On An Odometry Motion Model

This example shows how to use the `robotics.OdometryMotionModel` class to predict the pose of a robot. An `OdometryMotionModel` object contains the motion model parameters for a differential drive robot. Use the object to predict the pose of a robot based on its current and previous poses and the motion model parameters.

Create odometry motion model object.

```
motionModel = robotics.OdometryMotionModel;
```

Define previous poses and the current odometry reading. Each pose prediction corresponds to a row in `previousPoses` vector.

```
previousPoses =  rand(10,3);
currentOdom = [0.1 0.1 0.1];
```

The first call to the object initializes values and returns the previous poses as the current poses.

```
currentPoses = motionModel(previousPoses, currentOdom);
```

Subsequent calls to the object with updated odometry poses returns the predicted poses based on the motion model.

```
currentOdom = currentOdom + [0.1 0.1 0.05];
predPoses = motionModel(previousPoses, currentOdom);
```

See Also

`robotics.LikelihoodFieldSensorModel` | `robotics.MonteCarloLocalization` |
`robotics.OdometryMotionModel`

Introduced in R2016b

copy

Class: robotics.ParticleFilter
Package: robotics

Create copy of particle filter

Syntax

```
b = copy(a)
```

Description

`b = copy(a)` copies each element in the array of handles, `a`, to the new array of handles, `b`.

The `copy` method does not copy dependent properties. MATLAB does not call `copy` recursively on any handles contained in property values. MATLAB also does not call the class constructor or property-set methods during the copy operation.

Input Arguments

a — Object array
handle

Object array, specified as a handle.

Output Arguments

b — Object array containing copies of the objects in a
handle

Object array containing copies of the object in `a`, specified as a handle.

b has the same number of elements and is the same size and class of a. b is the same class as a. If a is empty, b is also empty. If a is heterogeneous, b is also heterogeneous. If a contains deleted handles, then copy creates deleted handles of the same class in b. Dynamic properties and listeners associated with objects in a are not copied to objects in b.

See Also

robotics.ParticleFilter

Topics
"Particle Filter Parameters"
"Particle Filter Workflow"

Introduced in R2016a

correct

Class: robotics.ParticleFilter
Package: robotics

Adjust state estimate based on sensor measurement

Syntax

```
[stateCorr,stateCov] = correct(pf,measurement)
[stateCorr,stateCov] = correct(pf,measurement,varargin)
```

Description

`[stateCorr,stateCov] = correct(pf,measurement)` calculates the corrected system state and its associated uncertainty covariance based on a sensor `measurement` at the current time step. `correct` uses the `MeasurementLikelihoodFcn` property from the particle filter object, `pf`, as a function to calculate the likelihood of the sensor measurement for each particle. The two inputs to the `MeasurementLikelihoodFcn` function are:

1 `pf` – The `ParticleFilter` object, which contains the particles of the current iteration

2 `measurement` – The sensor measurements used to correct the state estimate

The `MeasurementLikelihoodFcn` function then extracts the best state estimate and covariance based on the setting in the `StateEstimationMethod` property.

`[stateCorr,stateCov] = correct(pf,measurement,varargin)` passes all additional arguments in `varargin` to the underlying `MeasurementLikelihoodFcn` after the first three required inputs.

Input Arguments

pf — ParticleFilter object
handle

`ParticleFilter` object, specified as a handle. See `robotics.ParticleFilter` for more information.

measurement — Sensor measurements
array

Sensor measurements, specified as an array. This input is passed directly into the `MeasurementLikelihoodFcn` property of `pf`. It is used to calculate the likelihood of the sensor measurement for each particle.

varargin — Variable-length input argument list
comma-separated list

Variable-length input argument list, specified as a comma-separated list. This input is passed directly into the `MeasurementLikelihoodFcn` property of `pf`. It is used to calculate the likelihood of the sensor measurement for each particle. When you call:

`correct(pf,measurement,arg1,arg2)`

MATLAB essentially calls `measurementLikelihoodFcn` as:

`measurementLikelihoodFcn(pf,measurement,arg1,arg2)`

Output Arguments

stateCorr — Corrected system state
vector with length `NumStateVariables`

Corrected system state, returned as a row vector with length `NumStateVariables`. The corrected state is calculated based on the `StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`.

stateCov — Corrected system covariance
N-by-N matrix | [ ]

Corrected system variance, returned as an N-by-N matrix, where N is the value of `NumStateVariables` property from `pf`. The corrected state is calculated based on the `StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the function returns `stateCov` as [ ].

Examples

Particle Filter Prediction and Correction

Create a `ParticleFilter` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = robotics.ParticleFilter

pf =
  ParticleFilter with properties:

            NumStateVariables: 3
                 NumParticles: 1000
             StateTransitionFcn: @robotics.algs.gaussianMotion
      MeasurementLikelihoodFcn: @robotics.algs.fullStateMeasurement
        IsStateVariableCircular: [0 0 0]
               ResamplingPolicy: [1x1 robotics.ResamplingPolicy]
               ResamplingMethod: 'multinomial'
          StateEstimationMethod: 'mean'
               StateOrientation: 'row'
                      Particles: [1000x3 double]
                        Weights: [1000x1 double]
                          State: 'Use the getStateEstimate function to see the value.'
                 StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

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```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

```
stateEst = getStateEstimate(pf)
```

stateEst = *1×3*

    4.1562   0.9185   9.0202

- "Track a Car-Like Robot Using Particle Filter"

See Also

robotics.ParticleFilter | robotics.ParticleFilter.getStateEstimate | robotics.ParticleFilter.initialize | robotics.ParticleFilter.predict

Topics

"Track a Car-Like Robot Using Particle Filter"
"Particle Filter Parameters"
"Particle Filter Workflow"

Introduced in R2016a

getStateEstimate

Class: robotics.ParticleFilter
Package: robotics

Extract best state estimate and covariance from particles

Syntax

```
stateEst = getStateEstimate(pf)
[stateEst,stateCov] = getStateEstimate(pf)
```

Description

`stateEst = getStateEstimate(pf)` returns the best state estimate based on the current set of particles. The estimate is extracted based on the `StateEstimationMethod` property from the `ParticleFilter` object, `pf`.

`[stateEst,stateCov] = getStateEstimate(pf)` also returns the covariance around the state estimate. The covariance is a measure of the uncertainty of the state estimate. Not all state estimate methods support covariance output. In this case, `getStateEstimate` returns `stateCov` as `[]`.

Input Arguments

pf — ParticleFilter object
handle

`ParticleFilter` object, specified as a handle. See `robotics.ParticleFilter` for more information.

Output Arguments

stateEst — Best state estimate
vector

Best state estimate, returned as a row vector with length `NumStateVariables`. The estimate is extracted based on the `StateEstimationMethod` algorithm specified in `pf`.

stateCov — Corrected system covariance
N-by-*N* matrix | [ ]

Corrected system variance, returned as an *N*-by-*N* matrix, where *N* is the value of `NumStateVariables` property from `pf`. The corrected state is calculated based on the `StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the function returns `stateCov` as [ ].

Examples

Particle Filter Prediction and Correction

Create a `ParticleFilter` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = robotics.ParticleFilter

pf =
  ParticleFilter with properties:

          NumStateVariables: 3
               NumParticles: 1000
          StateTransitionFcn: @robotics.algs.gaussianMotion
    MeasurementLikelihoodFcn: @robotics.algs.fullStateMeasurement
      IsStateVariableCircular: [0 0 0]
            ResamplingPolicy: [1x1 robotics.ResamplingPolicy]
             ResamplingMethod: 'multinomial'
```

```
     StateEstimationMethod: 'mean'
           StateOrientation: 'row'
                  Particles: [1000x3 double]
                    Weights: [1000x1 double]
                      State: 'Use the getStateEstimate function to see the value.'
            StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (eye(3)). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the StateEstimationMethod algorithm.

```
stateEst = getStateEstimate(pf)
```

stateEst = *1×3*

```
    4.1562    0.9185    9.0202
```

- "Track a Car-Like Robot Using Particle Filter"

See Also
robotics.ParticleFilter | robotics.ParticleFilter.correct | robotics.ParticleFilter.initialize | robotics.ParticleFilter.predict

Topics
"Track a Car-Like Robot Using Particle Filter"
"Particle Filter Parameters"

"Particle Filter Workflow"

Introduced in R2016a

initialize

Class: robotics.ParticleFilter
Package: robotics

Initialize the state of the particle filter

Syntax

```
initialize(pf,numParticles,mean,covariance)
initialize(pf,numParticles,stateBounds)
initialize( ___ ,Name,Value)
```

Description

initialize(pf,numParticles,mean,covariance) initializes the particle filter object, pf, with a specified number of particles, numParticles. The initial states of the particles in the state space are determined by sampling from the multivariate normal distribution with the specified mean and covariance.

initialize(pf,numParticles,stateBounds) determines the initial location of the particles by sample from the multivariate uniform distribution within the specified stateBounds.

initialize(___ ,Name,Value) initializes the particles with additional options specified by one or more Name,Value pair arguments.

Input Arguments

pf — ParticleFilter object
handle

ParticleFilter object, specified as a handle. See robotics.ParticleFilter for more information.

`numParticles` — Number of particles used in the filter
scalar

Number of particles used in the filter, specified as a scalar.

`mean` — Mean of particle distribution
vector

Mean of particle distribution, specified as a vector. The `NumStateVariables` property of `pf` is set based on the length of this vector.

`covariance` — Covariance of particle distribution
N-by-*N* matrix

Covariance of particle distribution, specified as an *N*-by-*N* matrix, where *N* is the value of `NumStateVariables` property from `pf`.

`stateBounds` — Bounds of state variables
n-by-2 matrix

Bounds of state variables, specified as an *n*-by-2 matrix. The `NumStateVariables` property of `pf` is set based on the value of *n*. Each row corresponds to the lower and upper limit of the corresponding state variable.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

`CircularVariables` — Circular variables
logical vector

Circular variables, specified as a logical vector. Each state variable that uses circular or angular coordinates is indicated with a 1. The length of the vector is equal to the `NumStateVariables` property of `pf`.

Examples

Particle Filter Prediction and Correction

Create a `ParticleFilter` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = robotics.ParticleFilter

pf =
  ParticleFilter with properties:

           NumStateVariables: 3
               NumParticles: 1000
          StateTransitionFcn: @robotics.algs.gaussianMotion
   MeasurementLikelihoodFcn: @robotics.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
           ResamplingPolicy: [1x1 robotics.ResamplingPolicy]
           ResamplingMethod: 'multinomial'
      StateEstimationMethod: 'mean'
           StateOrientation: 'row'
                   Particles: [1000x3 double]
                     Weights: [1000x1 double]
                       State: 'Use the getStateEstimate function to see the value.'
             StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

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```
stateEst = getStateEstimate(pf)
```

stateEst = *1×3*

    4.1562   0.9185   9.0202

* "Track a Car-Like Robot Using Particle Filter"

See Also
robotics.ParticleFilter.correct |
robotics.ParticleFilter.getStateEstimate |
robotics.ParticleFilter.predict | robotics.ParticleFilter.predict

Topics
"Track a Car-Like Robot Using Particle Filter"
"Particle Filter Parameters"
"Particle Filter Workflow"

Introduced in R2016a

predict

Class: robotics.ParticleFilter
Package: robotics

Predict state of robot in next time step

Syntax

```
[statePred,stateCov] = predict(pf)
[statePred,stateCov] = predict(pf,varargin)
```

Description

`[statePred,stateCov] = predict(pf)` calculates the predicted system state and its associated uncertainty covariance. `predict` uses the `StateTransitionFcn` property of `ParticleFilter` object, `pf`, to evolve the state of all particles. It then extracts the best state estimate and covariance based on the setting in the `StateEstimationMethod` property.

`[statePred,stateCov] = predict(pf,varargin)` passes all additional arguments specified in `varargin` to the underlying `StateTransitionFcn` property of `pf`. The first input to `StateTransitionFcn` is the set of particles from the previous time step, followed by all arguments in `varargin`.

Input Arguments

`pf` — `ParticleFilter` object
handle

`ParticleFilter` object, specified as a handle. See `robotics.ParticleFilter` for more information.

`varargin` — Variable-length input argument list
comma-separated list

Variable-length input argument list, specified as a comma-separated list. This input is passed directly into the `StateTransitionFcn` property of `pf` to evolve the system state for each particle. When you call:

```
predict(pf,arg1,arg2)
```

MATLAB essentially calls the `stateTranstionFcn` as:

```
stateTransitionFcn(pf,prevParticles,arg1,arg2)
```

Output Arguments

statePred — Predicted system state
vector

Predicted system state, returned as a vector with length `NumStateVariables`. The predicted state is calculated based on the `StateEstimationMethod` algorithm.

stateCov — Corrected system covariance
N-by-*N* matrix | [ ]

Corrected system variance, returned as an *N*-by-*N* matrix, where *N* is the value of `NumStateVariables` property from `pf`. The corrected state is calculated based on the `StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the function returns `stateCov` as `[]`.

Examples

Particle Filter Prediction and Correction

Create a `ParticleFilter` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = robotics.ParticleFilter
```

```
pf =
  ParticleFilter with properties:

            NumStateVariables: 3
                 NumParticles: 1000
            StateTransitionFcn: @robotics.algs.gaussianMotion
    MeasurementLikelihoodFcn: @robotics.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
             ResamplingPolicy: [1x1 robotics.ResamplingPolicy]
             ResamplingMethod: 'multinomial'
        StateEstimationMethod: 'mean'
             StateOrientation: 'row'
                    Particles: [1000x3 double]
                      Weights: [1000x1 double]
                        State: 'Use the getStateEstimate function to see the value.'
              StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

```
stateEst = getStateEstimate(pf)
```

stateEst = *1×3*

    4.1562   0.9185   9.0202

- "Track a Car-Like Robot Using Particle Filter"

See Also

robotics.ParticleFilter | robotics.ParticleFilter.correct |
robotics.ParticleFilter.getStateEstimate |
robotics.ParticleFilter.initialize

Topics

"Track a Car-Like Robot Using Particle Filter"
"Particle Filter Parameters"
"Particle Filter Workflow"

Introduced in R2016a

findpath

Class: robotics.PRM
Package: robotics

Find path between start and goal points on roadmap

Syntax

```
xy = findpath(prm,start,goal)
```

Description

`xy = findpath(prm,start,goal)` finds an obstacle-free path between `start` and `goal` locations within `prm`, a roadmap object that contains a network of connected points.

If any properties of `prm` change, or if the roadmap is not created, `update` is called.

Input Arguments

prm — Roadmap path planner
PRM object

Roadmap path planner, specified as a `robotics.PRM` object.

start — Start location of path
2-by-1 vector

Start location of path, specified as a 2-by-1 vector representing an `[x y]` pair.

Example: [0 0]

goal — Final location of path
2-by-1 vector

Final location of path, specified as a 2-by-1 vector representing an `[x y]` pair.

Example: [10 10]

Output Arguments

xy — Waypoints for a path between `start` and `goal`
2-by-*n* column vector

Waypoints for a path between start and goal, specified as a 2-by-*n* column vector of [x y] pairs, where *n* is the number of waypoints. These pairs represent the solved path from the `start` and `goal` locations, given the roadmap from the `prm` input object.

See Also

robotics.PRM | robotics.PRM.show | robotics.PRM.update

Introduced in R2015a

show

Class: robotics.PRM
Package: robotics

Show map, roadmap, and path

Syntax

```
show(prm)
show(prm,Name,Value)
```

Description

show(prm) shows the map and the roadmap, specified as prm in a figure window. If no roadmap exists, update is called. If a path is computed before calling show, the path is also plotted on the figure.

show(prm,Name,Value) sets the specified Value to the property Name.

Input Arguments

prm — Roadmap path planner
PRM object

Roadmap path planner, specified as a robotics.PRM object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments. Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

`Parent` — Axes to plot the map
`Axes` object | `UIAxes` object

Axes to plot the map specified as a comma-separated pair consisting of `'Parent'` and either an `Axes` or `UIAxes`object. See `axes` or `uiaxes`.

Map — Map display option
'on' (default) | 'off'

Map display option, specified as the comma-separated pair consisting of `'Map'` and either 'on' or 'off'.

Roadmap — Roadmap display option
'on' (default) | 'off'

Roadmap display option, specified as the comma-separated pair consisting of `'Roadmap'` and either 'on' or 'off'.

Path — Path display option
`'on'` (default) | `'off'`

Path display option, specified as `'on'` or `'off'`. This controls whether the computed path is shown in the plot.

See Also
`robotics.PRM` | `robotics.PRM.findpath` | `robotics.PRM.update`

Topics
"Path Following for a Differential Drive Robot"

Introduced in R2015a

update

Class: robotics.PRM
Package: robotics

Create or update roadmap

Syntax

```
update(prm)
```

Description

update(prm) creates a roadmap if called for the first time after creating the PRM object, prm. Subsequent calls of update recreate the roadmap by resampling the map. update creates the new roadmap using the Map, NumNodes, and ConnectionDistance property values specified in prm.

Input Arguments

prm — Roadmap path planner
PRM object

Roadmap path planner, specified as a robotics.PRM object.

See Also
robotics.PRM | robotics.PRM.findpath | robotics.PRM.show

Introduced in R2015a

addVisual

Class: robotics.RigidBody
Package: robotics

Add visual geometry data to rigid body

Syntax

```
addVisual(body,'Mesh',filename)
addVisual(body,'Mesh',filename,tform)
```

Description

`addVisual(body,'Mesh',filename)` adds a polygon mesh on top of any current visual geometry using the specified `.stl` file, `filename`. Multiple visual geometries can be added to a single body. The coordinate frame is assumed to coincide with the frame of `body`. You can view the meshes for an entire rigid body tree using `robotics.RigidBodyTree.show`.

`addVisual(body,'Mesh',filename,tform)` specifies a homogeneous transformation for the polygon mesh relative to the body frame.

Input Arguments

body — RigidBody object
handle

`RigidBody` object, specified as a handle. Create a rigid body object using `robotics.RigidBody`.

filename — .stl file name
character vector

`.stl` file name, specified as a character vector.

`tform` — Polygon mesh transformation
4-by-4 homogeneous transformation

Mesh transformation relative to the body coordinate frame, specified as a 4-by-4 homogeneous transformation.

See Also

robotics.RigidBody.clearVisual | robotics.RigidBodyTree | robotics.RigidBodyTree.show

Introduced in R2017b

clearVisual

Class: robotics.RigidBody
Package: robotics

Clear all visual geometries

Syntax

```
clearVisual(body)
```

Description

`clearVisual(body)` clears all visual geometries attached to the given rigid body object.

Input Arguments

body — RigidBody object
handle

`RigidBody` object, specified as a handle. Create a rigid body object using `robotics.RigidBody`.

See Also

`robotics.RigidBody.addVisual` | `robotics.RigidBodyTree` | `robotics.RigidBodyTree.show`

Introduced in R2017b

copy

Class: robotics.RigidBody
Package: robotics

Create a deep copy of rigid body

Syntax

```
copyObj = copy(bodyObj)
```

Description

`copyObj = copy(bodyObj)` creates a copy of the rigid body object with the same properties.

Input Arguments

bodyObj — RigidBody object
handle

`RigidBody` object, specified as a handle. Create a rigid body object using `robotics.RigidBody`.

Output Arguments

copyObj — RigidBody object
handle

`RigidBody` object, returned as a handle. Create a rigid body object using `robotics.RigidBody`.

See Also

robotics.Joint | robotics.RigidBodyTree

Introduced in R2016b

addBody

Class: robotics.RigidBodyTree
Package: robotics

Add a body to robot

Syntax

addBody(robot,body,parentname)

Description

addBody(robot,body,parentname) adds a rigid body to the robot object and is attached to the rigid body parent specified by parentname. The body.Joint property defines how this body moves relative to the parent body.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a RigidBodyTree object.

body — Rigid body
RigidBody object

Rigid body, specified as a RigidBody object.

parentname — Parent body name
character vector

Parent body name, specified as a character vector. This parent body must already exist in the robot model. The new body is attached to this parent body.

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `RigidBody` object contains a `Joint` object and must be added to the `RigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = robotics.RigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = robotics.RigidBody('b1');
```

Create a revolute joint. By default, the `RigidBody` object comes with a fixed joint. Replace the joint by assigning a new `Joint` object to the `body1.Joint` property.

```
jnt1 = robotics.Joint('jnt1','revolute');
body1.Joint = jnt1;
```

Add the rigid body to the tree. Specify the body name that you are attaching the rigid body to. Because this is the first body, use the base name of the tree.

```
basename = rbtree.BaseName;
addBody(rbtree,body1,basename)
```

Use `showdetails` on the tree to confirm the rigid body and joint were added properly.

```
showdetails(rbtree)
```

```
--------------------
Robot: (1 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            b1         jnt1     revolute             base(0)
--------------------
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix. The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0        pi/2    0        0;
            0.4318   0       0        0
            0.0203   -pi/2   0.15005  0;
            0        pi/2    0.4318   0;
            0        -pi/2   0        0;
            0        0       0        0];
```

Create a rigid body tree object to build the robot.

```
robot = robotics.RigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1 Create a `RigidBody` object and give it a unique name.

2 Create a `Joint` object and give it a unique name.

3 Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.

4 Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = robotics.RigidBody('body1');
jnt1 = robotics.Joint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = robotics.RigidBody('body2');
jnt2 = robotics.Joint('jnt2','revolute');
body3 = robotics.RigidBody('body3');
jnt3 = robotics.Joint('jnt3','revolute');
body4 = robotics.RigidBody('body4');
jnt4 = robotics.Joint('jnt4','revolute');
body5 = robotics.RigidBody('body5');
jnt5 = robotics.Joint('jnt5','revolute');
body6 = robotics.RigidBody('body6');
jnt6 = robotics.Joint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

Verify that your robot was built properly by using the `showdetails` or `show` function.
`showdetails` lists all the bodies in the MATLAB® command window. `show` displays the
robot with a given configuration (home by default). Calls to `axis` modify the axis limits
and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name    Joint Name    Joint Type    Parent Name(Idx)    Children Name(s)
 ---     ---------    ----------    ----------    ----------------    ----------------
   1         body1          jnt1      revolute             base(0)    body2(2)
   2         body2          jnt2      revolute            body1(1)    body3(3)
   3         body3          jnt3      revolute            body2(2)    body4(4)
   4         body4          jnt4      revolute            body3(3)    body5(5)
```

```
   5         body5         jnt5     revolute              body4(4)   body6(6)
   6         body6         jnt6     revolute              body5(5)
-------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)    Children Name(s)
 ---     ---------   ----------   ----------    ----------------    ----------------
   1          L1         jnt1      revolute              base(0)    L2(2)
   2          L2         jnt2      revolute                L1(1)    L3(3)
   3          L3         jnt3      revolute                L2(2)    L4(4)
   4          L4         jnt4      revolute                L3(3)    L5(5)
   5          L5         jnt5      revolute                L4(4)    L6(6)
   6          L6         jnt6      revolute                L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

           Name: 'L4'
          Joint: [1x1 robotics.Joint]
           Mass: 1
   CenterOfMass: [0 0 0]
        Inertia: [1 1 1 0 0 0]
         Parent: [1x1 robotics.RigidBody]
       Children: {[1x1 robotics.RigidBody]}
        Visuals: {}


body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx      Body Name      Joint Name      Joint Type     Parent Name(Idx)   Children Name
 ---      ---------      ----------      ----------     ----------------   -------------
   1            L1            jnt1          revolute              base(0)   L2(2)
   2            L2            jnt2          revolute                L1(1)   L3(3)
   3            L3       prismatic             fixed                L2(2)   L4(4)
   4            L4            jnt4          revolute                L3(3)   L5(5)
   5            L5            jnt5          revolute                L4(4)   L6(6)
   6            L6            jnt6          revolute                L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')

subtree =
  RigidBodyTree with properties:

    NumBodies: 3
       Bodies: {1x3 cell}
         Base: [1x1 robotics.RigidBody]
    BodyNames: {'L4'  'L5'  'L6'}
     BaseName: 'L3'
      Gravity: [0 0 0]
   DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
  1            L1         jnt1     revolute              base(0)   L2(2)
  2            L2         jnt2     revolute               L1(1)    L3(3)
  3            L3         jnt3     revolute               L2(2)    L4(4)
  4            L4         jnt4     revolute               L3(3)    L5(5)
  5            L5         jnt5     revolute               L4(4)    L6(6)
  6            L6         jnt6     revolute               L5(5)
--------------------
```
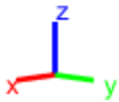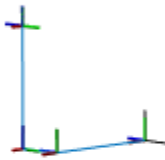
See Also
robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree.removeBody
| robotics.RigidBodyTree.replaceBody

Introduced in R2016b

addSubtree

Class: robotics.RigidBodyTree
Package: robotics

Add subtree to robot

Syntax

`addSubtree(robot,parentname,subtree)`

Description

`addSubtree(robot,parentname,subtree)` attaches the robot model, `subtree`, to an existing robot model, `robot`, at the body specified by `parentname`. The subtree base is not added as a body.

Input Arguments

`robot` — Robot model
`RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object.

`parentname` — Parent body name
character vector

Parent body name, specified as a character vector. This parent body must already exist in the robot model. The new body is attached to this parent body.

`subtree` — Subtree robot model
`RigidBodyTree` object

Subtree robot model, specified as a `RigidBodyTree` object.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name    Joint Name    Joint Type    Parent Name(Idx)    Children Name(s)
 ---    ---------    ----------    ----------    ----------------    ----------------
   1           L1          jnt1      revolute             base(0)    L2(2)
   2           L2          jnt2      revolute             L1(1)      L3(3)
   3           L3          jnt3      revolute             L2(2)      L4(4)
   4           L4          jnt4      revolute             L3(3)      L5(5)
   5           L5          jnt5      revolute             L4(4)      L6(6)
   6           L6          jnt6      revolute             L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

           Name: 'L4'
          Joint: [1x1 robotics.Joint]
           Mass: 1
     CenterOfMass: [0 0 0]
        Inertia: [1 1 1 0 0 0]
         Parent: [1x1 robotics.RigidBody]
```

```
        Children: {[1x1 robotics.RigidBody]}
         Visuals: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);
```

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name      Joint Name      Joint Type     Parent Name(Idx)    Children Name
 ---     ---------      ----------      ----------     ----------------    -------------
   1            L1            jnt1        revolute              base(0)    L2(2)
   2            L2            jnt2        revolute                L1(1)    L3(3)
   3            L3       prismatic           fixed                L2(2)    L4(4)
   4            L4            jnt4        revolute                L3(3)    L5(5)
   5            L5            jnt5        revolute                L4(4)    L6(6)
   6            L6            jnt6        revolute                L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree =
  RigidBodyTree with properties:

    NumBodies: 3
       Bodies: {1x3 cell}
         Base: [1x1 robotics.RigidBody]
    BodyNames: {'L4'  'L5'  'L6'}
     BaseName: 'L3'
      Gravity: [0 0 0]
   DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through showdetails.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------   ----------------   ----------------
   1            L1         jnt1     revolute            base(0)   L2(2)
   2            L2         jnt2     revolute             L1(1)    L3(3)
   3            L3         jnt3     revolute             L2(2)    L4(4)
   4            L4         jnt4     revolute             L3(3)    L5(5)
   5            L5         jnt5     revolute             L4(4)    L6(6)
   6            L6         jnt6     revolute             L5(5)
--------------------
```

See Also

robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree.addBody | robotics.RigidBodyTree.removeBody | robotics.RigidBodyTree.replaceBody

Introduced in R2016b

centerOfMass

Class: robotics.RigidBodyTree
Package: robotics

Center of mass position and Jacobian

Syntax

```
com = centerOfMass(robot)
com = centerOfMass(robot,configuration)
[com,comJac] = centerOfMass(robot,configuration)
```

Description

`com = centerOfMass(robot)` computes the center of mass position of the robot model at its home configuration, relative to the base frame.

`com = centerOfMass(robot,configuration)` computes the center of mass position of the robot model at the specified joint configuration, relative to the base frame.

`[com,comJac] = centerOfMass(robot,configuration)` also returns the center of mass Jacobian, which relates the center of mass velocity to the joint velocities.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. To use the `centerOfMass` function, set the `DataFormat` property to either `'row'` or `'column'`.

configuration — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`,

randomConfiguration(robot), or by specifying your own joint positions. To use the vector form of configuration, set the DataFormat property for the robot to either 'row' or 'column' .

Output Arguments

com — Center of mass location
[x y z] vector

Center of mass location, returned as an [x y z] vector. The vector describes the location of the center of mass for the specified configuration relative to the body frame, in meters.

comJac — Center of mass Jacobian
3-by-n matrix

Center of mass Jacobian, returned as a 3-by-n matrix, where n is the robot velocity degrees of freedom.

Examples

Calculate Center of Mass and Jacobian for Robot Configuration

Load a predefined KUKA LBR robot model, which is specified as a RigidBodyTree object.

```
load exampleRobots.mat lbr
```

Set the data format to 'row'. For all dynamics calculations, the data format must be either 'row' or 'column'.

```
lbr.DataFormat = 'row';
```

Compute the center of mass position and Jacobian at the home configuration of the robot.

```
[comLocation,comJac] = centerOfMass(lbr);
```

See Also

RigidBodyTree | gravityTorque | massMatrix | velocityProduct

Introduced in R2017a

copy

Class: robotics.RigidBodyTree
Package: robotics

Copy robot model

Syntax

```
newrobot = copy(robot)
```

Description

`newrobot = copy(robot)` creates a deep copy of `robot` with the same properties. Any changes in `newrobot` are not reflected in `robot`.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object.

Output Arguments

newrobot — Robot model
RigidBodyTree object

Robot model, returned as a `RigidBodyTree` object.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1           L1         jnt1      revolute             base(0)   L2(2)
   2           L2         jnt2      revolute               L1(1)   L3(3)
   3           L3         jnt3      revolute               L2(2)   L4(4)
   4           L4         jnt4      revolute               L3(3)   L5(5)
   5           L5         jnt5      revolute               L4(4)   L6(6)
   6           L6         jnt6      revolute               L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

          Name: 'L4'
         Joint: [1x1 robotics.Joint]
          Mass: 1
   CenterOfMass: [0 0 0]
       Inertia: [1 1 1 0 0 0]
        Parent: [1x1 robotics.RigidBody]
      Children: {[1x1 robotics.RigidBody]}
       Visuals: {}


body3Copy = copy(body3);
```

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Replace the joint on the L3 body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name      Joint Name      Joint Type     Parent Name(Idx)   Children Name
 ---     ---------      ----------      ----------     ----------------   -------------
   1            L1            jnt1        revolute               base(0)   L2(2)
   2            L2            jnt2        revolute                 L1(1)   L3(3)
   3            L3       prismatic           fixed                 L2(2)   L4(4)
   4            L4            jnt4        revolute                 L3(3)   L5(5)
   5            L5            jnt5        revolute                 L4(4)   L6(6)
   6            L6            jnt6        revolute                 L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')

subtree =
  RigidBodyTree with properties:

      NumBodies: 3
         Bodies: {1x3 cell}
           Base: [1x1 robotics.RigidBody]
      BodyNames: {'L4'  'L5'  'L6'}
       BaseName: 'L3'
        Gravity: [0 0 0]
     DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx      Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---      ---------   ----------   ----------    ----------------   ----------------
   1             L1         jnt1     revolute             base(0)   L2(2)
   2             L2         jnt2     revolute              L1(1)    L3(3)
   3             L3         jnt3     revolute              L2(2)    L4(4)
   4             L4         jnt4     revolute              L3(3)    L5(5)
   5             L5         jnt5     revolute              L4(4)    L6(6)
   6             L6         jnt6     revolute              L5(5)
--------------------
```

See Also

robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree

Introduced in R2016b

externalForce

Class: robotics.RigidBodyTree
Package: robotics

Compose external force matrix relative to base

Syntax

```
fext = externalForce(robot,bodyname,wrench)
fext = externalForce(robot,bodyname,wrench,configuration)
```

Description

`fext = externalForce(robot,bodyname,wrench)` composes the external force matrix, which you can use as inputs to `inverseDynamics` and `forwardDynamics` to apply an external force, `wrench`, to the body specified by `bodyname`. The `wrench` input is assumed to be in the base frame.

`fext = externalForce(robot,bodyname,wrench,configuration)` composes the external force matrix assuming that `wrench` is in the `bodyname` frame for the specified `configuration`. The force matrix `fext` is given in the base frame.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. To use the `externalForce` function, set the `DataFormat` property to either `'row'` or `'column'`.

bodyname — Name of body to which external force is applied
character vector

Name of body to which the external force is applied, specified as a character vector. This body name must match a body on the `robot` object.

wrench — Torques and forces applied to body
[Tx Ty Tz Fx Fy Fz] vector

Torques and forces applied to the body, specified as a [Tx Ty Tz Fx Fy Fz] vector. The first three elements of the wrench correspond to the moments around xyz-axes. The last three elements are linear forces along the same axes. Unless you specify the robot configuration, the wrench is assumed to be relative to the base frame.

configuration — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using homeConfiguration(robot), randomConfiguration(robot), or by specifying your own joint positions. To use the vector form of configuration, set the DataFormat property for the robot to either 'row' or 'column'.

Output Arguments

fext — External force matrix
n-by-6 matrix | 6-by-*n* matrix

External force matrix, returned as either an *n*-by-6 or 6-by-*n* matrix, where *n* is the velocity number (degrees of freedom) of the robot. The shape depends on the DataFormat property of robot. The 'row' data format uses an *n*-by-6 matrix. The 'column' data format uses a 6-by-*n* .

The composed matrix lists only values other than zero at the locations relevant to the body specified. You can add force matrices together to specify multiple forces on multiple bodies. Use the external force matrix to specify external forces to dynamics functions inverseDynamics and forwardDynamics.

Examples

Compute Forward Dynamics Due to External Forces on Rigid Body Tree Model

Calculate the resultant joint accelerations for a given robot configuration with applied external forces and forces due to gravity. A wrench is applied to a specific body with the gravity being specified for the whole robot.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the gravity. By default, gravity is assumed to be zero.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for the `lbr` robot.

```
q = homeConfiguration(lbr);
```

Specify the wrench vector that represents the external forces experienced by the robot. Use the `externalForce` function to generate the external force matrix. Specify the robot model, the end effector that experiences the wrench, the wrench vector, and the current robot configuration. `wrench` is given relative to the `'tool0'` body frame, which requires you to specify the robot configuration, `q`.

```
wrench = [0 0 0.5 0 0 0.3];
fext = externalForce(lbr,'tool0',wrench,q);
```

Compute the resultant joint accelerations due to gravity, with the external force applied to the end-effector `'tool0'` when `lbr` is at its home configuration. The joint velocities and joint torques are assumed to be zero (input as an empty vector `[]`).

```
qddot = forwardDynamics(lbr,q,[],[],fext);
```

Compute Joint Torque to Counter External Forces

Use the `externalForce` function to generate force matrices to apply to a rigid body tree model. The force matrix is an *m*-by-6 vector that has a row for each joint on the robot to

apply a six-element wrench. Use the `externalForce` function and specify the end effector to properly assign the wrench to the correct row of the matrix. You can add multiple force matrices together to apply multiple forces to one robot.

To calculate the joint torques that counter these external forces, use the `inverseDynamics` function.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for `lbr`.

```
q = homeConfiguration(lbr);
```

Set external force on `link1`. The input wrench vector is expressed in the base frame.

```
fext1 = externalForce(lbr,'link_1',[0 0 0.0 0.1 0 0]);
```

Set external force on the end effector, `tool0`. The input wrench vector is expressed in the `tool0` frame.

```
fext2 = externalForce(lbr,'tool0',[0 0 0.0 0.1 0 0],q);
```

Compute the joint torques required to balance the external forces. To combine the forces, add the force matrices together. Joint velocities and accelerations are assumed to be zero (input as `[]`).

```
tau = inverseDynamics(lbr,q,[],[],fext1+fext2);
```

- "Control LBR Manipulator Motion Through Joint Torque Commands"

See Also

RigidBodyTree | forwardDynamics | inverseDynamics

Topics

"Control LBR Manipulator Motion Through Joint Torque Commands"

Introduced in R2017a

forwardDynamics

Class: robotics.RigidBodyTree
Package: robotics

Joint accelerations given joint torques and states

Syntax

```
jointAccel = forwardDynamics(robot)
jointAccel = forwardDynamics(robot,configuration)
jointAccel = forwardDynamics(robot,configuration,jointVel)
jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq)
jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq,
fext)
```

Description

`jointAccel = forwardDynamics(robot)` computes joint accelerations due to gravity at the robot home configuration, with zero joint velocities and no external forces.

`jointAccel = forwardDynamics(robot,configuration)` also specifies the joint positions of the robot configuration.

`jointAccel = forwardDynamics(robot,configuration,jointVel)` also specifies the joint velocities of the robot.

`jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq)` also specifies the joint torques applied to the robot.

`jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq, fext)` also specifies an external force matrix that contains forces applied to each joint.

To specify the home configuration, zero joint velocities, or zero torques, use `[]` for that input argument.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a RigidBodyTree object. To use the forwardDynamics function, set the DataFormat property to either 'row' or 'column'.

configuration — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using homeConfiguration(robot), randomConfiguration(robot), or by specifying your own joint positions. To use the vector form of configuration, set the DataFormat property for the robot to either 'row' or 'column'.

jointVel — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom of the robot. To use the vector form of jointVel, set the DataFormat property for the robot to either 'row' or 'column'.

jointTorq — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. To use the vector form of jointTorq, set the DataFormat property for the robot to either 'row' or 'column'.

fext — External force matrix
n-by-6 matrix | 6-by-n matrix

External force matrix, specified as either an n-by-6 or 6-by-n matrix, where n is the number of bodies of the robot. The shape depends on the DataFormat property of robot. The 'row' data format uses an n-by-6 matrix. The 'column' data format uses a 6-by-n .

The matrix lists only values other than zero at the locations relevant to the body specified. You can add force matrices together to specify multiple forces on multiple bodies.

To create the matrix for a specified force or torque, see `externalForce`.

Output Arguments

jointAccel — Joint accelerations
vector

Joint accelerations, returned as a vector. The dimension of the joint accelerations vector is equal to the degrees of freedom of the robot. Each element corresponds to a specific joint on the `robot`.

Examples

Compute Forward Dynamics Due to External Forces on Rigid Body Tree Model

Calculate the resultant joint accelerations for a given robot configuration with applied external forces and forces due to gravity. A wrench is applied to a specific body with the gravity being specified for the whole robot.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the gravity. By default, gravity is assumed to be zero.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for the `lbr` robot.

```
q = homeConfiguration(lbr);
```

Specify the wrench vector that represents the external forces experienced by the robot. Use the `externalForce` function to generate the external force matrix. Specify the robot

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model, the end effector that experiences the wrench, the wrench vector, and the current robot configuration. `wrench` is given relative to the `'tool0'` body frame, which requires you to specify the robot configuration, `q`.

```
wrench = [0 0 0.5 0 0 0.3];
fext = externalForce(lbr,'tool0',wrench,q);
```

Compute the resultant joint accelerations due to gravity, with the external force applied to the end-effector `'tool0'` when `lbr` is at its home configuration. The joint velocities and joint torques are assumed to be zero (input as an empty vector `[]`).

```
qddot = forwardDynamics(lbr,q,[],[],fext);
```

•   "Control LBR Manipulator Motion Through Joint Torque Commands"

See Also
RigidBodyTree | externalForce | inverseDynamics

Topics
"Control LBR Manipulator Motion Through Joint Torque Commands"

Introduced in R2017a

geometricJacobian

Class: robotics.RigidBodyTree
Package: robotics

Geometric Jacobian for robot configuration

Syntax

```
jacobian = geometricJacobian(robot,configuration,endeffectorname)
```

Description

`jacobian = geometricJacobian(robot,configuration,endeffectorname)`
computes the geometric Jacobian relative to the base for the specified end-effector name
and configuration for the robot model.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object.

configuration — Robot configuration
vector | structure

Robot configuration, specified as a vector of joint positions or a structure with joint names
and positions for all the bodies in the robot model. You can generate a configuration using
`homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your
own joint positions in a structure. To use the vector form of `configuration`, set the
`DataFormat` property for the `robot` to either `'row'` or `'column'`.

endeffectorname — End-effector name
character vector

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End-effector name, specified as a character vector. An end effector can be any body in the robot model.

Output Arguments

`jacobian` — Geometric Jacobian
6-by-*n* matrix

Geometric Jacobian of the end effector with the specified `configuration`, returned as a 6-by-*n* matrix, where *n* is the number of degrees of freedom for the end effector. The Jacobian maps the joint-space velocity to the end-effector velocity, relative to the base coordinate frame. The end-effector velocity equals:

$$V_{EE} = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \\ v_x \\ v_y \\ v_z \end{bmatrix} = J\dot{q} = J \begin{bmatrix} \dot{q}_1 \\ \vdots \\ \dot{q}_n \end{bmatrix}$$

ω is the angular velocity, v is the linear velocity, and $\dot{q}$ is the joint-space velocity.

Examples

Geometric Jacobian for Robot Configuration

Calculate the geometric Jacobian for a specific end effector and configuration of a robot.

Load a Puma robot, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat puma1
```

Calculate the geometric Jacobian of body `'L6'` on the Puma robot for a random configuration.

```
geoJacob = geometricJacobian(puma1,randomConfiguration(puma1),'L6')
```

```
geoJacob = 6×6

   -0.0000    0.9826    0.9826    0.0286   -0.9155    0.2045
   -0.0000    0.1859    0.1859   -0.1512    0.3929    0.2690
    1.0000   -0.0000   -0.0000    0.9881    0.0866    0.9412
    0.4175    0.0530    0.0799    0.0000         0         0
    0.2317   -0.2802   -0.4223    0.0000         0         0
         0   -0.4532   -0.0464    0.0000         0         0
```

See Also
Joint | RigidBody | getTransform | homeConfiguration | randomConfiguration

Introduced in R2016b

gravityTorque

Class: robotics.RigidBodyTree
Package: robotics

Joint torques that compensate gravity

Syntax

```
gravTorq = gravityTorque(robot)
gravTorq = gravityTorque(robot,configuration)
```

Description

`gravTorq = gravityTorque(robot)` computes the joint torques required to hold the robot at its home configuration.

`gravTorq = gravityTorque(robot,configuration)` specifies a joint configuration for calculating the gravity torque.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. To use the `gravityTorque` function, set the `DataFormat` property to either `'row'` or `'column'`.

configuration — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Output Arguments

gravTorq — Gravity-compensating torque for each joint
vector

Gravity-compensating torque for each joint, returned as a vector.

Examples

Compute Gravity Torque for Robot Configuration

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`. Set the `Gravity` property.

```
lbr.DataFormat = 'row';
lbr.Gravity = [0 0 -9.81];
```

Get a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Compute the gravity-compensating torques for each joint.

```
gtau = gravityTorque(lbr,q);
```

•   "Control LBR Manipulator Motion Through Joint Torque Commands"

See Also
RigidBodyTree | inverseDynamics | velocityProduct

Topics
"Control LBR Manipulator Motion Through Joint Torque Commands"

Introduced in R2017a

getBody

Class: robotics.RigidBodyTree
Package: robotics

Get robot body handle by name

Syntax

```
body = getBody(robot,bodyname)
```

Description

`body = getBody(robot,bodyname)` gets a body handle by name from the robot model.

Input Arguments

robot — Robot model
`RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object.

bodyname — Body name
character vector

Body name, specified as a character vector. A body with this name must be on the robot model specified by `robot`.

Output Arguments

body — Rigid body
`RigidBody` object

Rigid body, returned as a `RigidBody` object. The returned `RigidBody` object is still a part of the `RigidBodyTree` robot model. Use `robotics.RigidBodyTree.replaceBody` with a new body to modify the body in the robot model.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type     Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------     ----------------   ----------------
   1            L1         jnt1     revolute               base(0)   L2(2)
   2            L2         jnt2     revolute                 L1(1)   L3(3)
   3            L3         jnt3     revolute                 L2(2)   L4(4)
   4            L4         jnt4     revolute                 L3(3)   L5(5)
   5            L5         jnt5     revolute                 L4(4)   L6(6)
   6            L6         jnt6     revolute                 L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:
```

```
            Name: 'L4'
           Joint: [1x1 robotics.Joint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 robotics.RigidBody]
        Children: {[1x1 robotics.RigidBody]}
          Visuals: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new Joint object and use
replaceJoint to ensure the downstream body geometry is unaffected. Call
setFixedTransform if necessary to define a transform between the bodies instead of
with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);
```

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name     Joint Name     Joint Type    Parent Name(Idx)   Children Name
 ---    ---------     ----------     ----------    ----------------   -------------
   1           L1           jnt1       revolute            base(0)    L2(2)
   2           L2           jnt2       revolute              L1(1)    L3(3)
   3           L3       prismatic          fixed              L2(2)    L4(4)
   4           L4           jnt4       revolute              L3(3)    L5(5)
   5           L5           jnt5       revolute              L4(4)    L6(6)
   6           L6           jnt6       revolute              L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using removeBody. The removed
body is included in the subtree.

```
subtree = removeBody(puma1,'L4')

subtree =
  RigidBodyTree with properties:

    NumBodies: 3
       Bodies: {1x3 cell}
```

```
      Base: [1x1 robotics.RigidBody]
 BodyNames: {'L4'  'L5'  'L6'}
  BaseName: 'L3'
   Gravity: [0 0 0]
DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through showdetails.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx      Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
 ---      ---------   ----------   ----------   ----------------   ----------------
   1             L1         jnt1     revolute             base(0)   L2(2)
   2             L2         jnt2     revolute             L1(1)     L3(3)
   3             L3         jnt3     revolute             L2(2)     L4(4)
   4             L4         jnt4     revolute             L3(3)     L5(5)
   5             L5         jnt5     revolute             L4(4)     L6(6)
   6             L6         jnt6     revolute             L5(5)
--------------------
```

See Also

robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree.addBody | robotics.RigidBodyTree.replaceBody

Introduced in R2016b

getTransform

Class: robotics.RigidBodyTree
Package: robotics

Get transform between body frames

Syntax

```
transform = getTransform(robot,configuration,bodyname)
transform = getTransform(robot,configuration,sourcebody,targetbody)
```

Description

`transform = getTransform(robot,configuration,bodyname)` computes the transform that converts points in the `bodyname` frame to the robot base frame, using the specified robot configuration.

`transform = getTransform(robot,configuration,sourcebody,targetbody)` computes the transform that converts points from the source body frame to the target body frame, using the specified robot configuration.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object.

configuration — Robot configuration
structure array

Robot configuration, specified as a structure array with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint names and positions in a structure array.

bodyname — Body name
character vector

Body name, specified as a character vector. This body must be on the robot model specified in `robot`.

`targetbody` — Target body name
character vector

Target body name, specified as a character vector. This body must be on the robot model specified in `robot`. The target frame is the coordinate system you want to transform points into.

`sourcebody` — Body name
character vector

Body name, specified as a character vector. This body must be on the robot model specified in `robot`. The source frame is the coordinate system you want points transformed from.

Output Arguments

`transform` — Homogeneous transform
4-by-4 matrix

Homogeneous transform, returned as a 4-by-4 matrix.

Examples

Get Transform Between Frames for Robot Configuration

Get the transform between two frames for a specific robot configuration.

Load a sample robots that include the `puma1` robot.

```
load exampleRobots.mat
```

Get the transform between the `'L2'` and `'L6'` bodies of the `puma1` robot given a specific configuration. The transform converts points in 'L6' frame to the 'L2' frame.

```
transform = getTransform(puma1,randomConfiguration(puma1),'L2','L6')
```

```
transform = 4×4

   -0.2232    0.4179    0.8807    0.0212
   -0.8191    0.4094   -0.4018    0.1503
   -0.5284   -0.8111    0.2509   -0.4317
         0         0         0    1.0000
```

See Also

robotics.Joint | robotics.RigidBody |
robotics.RigidBodyTree.geometricJacobian |
robotics.RigidBodyTree.homeConfiguration |
robotics.RigidBodyTree.randomConfiguration

Introduced in R2016b

homeConfiguration

Class: robotics.RigidBodyTree
Package: robotics

Get home configuration of robot

Syntax

```
configuration = homeConfiguration(robot)
```

Description

`configuration = homeConfiguration(robot)` returns the home configuration of the robot model. The home configuration is the ordered list of `HomePosition` properties of each nonfixed joint.

Input Arguments

robot — Robot model
`RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object.

Output Arguments

configuration — Robot configuration
vector | structure

Robot configuration, returned as a vector of joint positions or a structure with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions in a structure. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

Examples

Visualize Robot Configurations

Show different configurations of a robot created using a `RigidBodyTree` model. Use the `homeConfiguration` or `randomConfiguation` functions to generate the structure that defines all the joint positions.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

Create a structure for the home configuration of a Puma robot. The structure has joint names and positions for each body on the robot model.

```
config = homeConfiguration(puma1)

config =

  1x6 struct array with fields:

    JointName
    JointPosition
```

Show the home configuration using `show`. You do not need to specify a configuration input.

```
show(puma1);
```

Modify the configuration and set the second joint position to `pi/2`. Show the resulting change in the robot configuration.

```
config(2).JointPosition = pi/2;
show(puma1,config);
```

Create random configurations and show them.

```
show(puma1,randomConfiguration(puma1));
```

See Also

robotics.RigidBodyTree.geometricJacobian |
robotics.RigidBodyTree.getTransform |
robotics.RigidBodyTree.randomConfiguration

Introduced in R2016b

inverseDynamics

Class: robotics.RigidBodyTree
Package: robotics

Required joint torques for given motion

Syntax

```
jointTorq = inverseDynamics(robot)
jointTorq = inverseDynamics(robot,configuration)
jointTorq = inverseDynamics(robot,configuration,jointVel)
jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel)
jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel,
fext)
```

Description

`jointTorq = inverseDynamics(robot)` computes joint torques required for the robot to statically hold its home configuration with no external forces applied.

`jointTorq = inverseDynamics(robot,configuration)` computes joint torques to hold the specified robot configuration.

`jointTorq = inverseDynamics(robot,configuration,jointVel)` computes joint torques for the specified joint configuration and velocities with zero acceleration and no external forces.

`jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel)` computes joint torques for the specified joint configuration, velocities, and accelerations with no external forces.

`jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel, fext)` computes joint torques for the specified joint configuration, velocities, accelerations, and external forces. Use the `externalForce` function to generate `fext`.

To specify the home configuration, zero joint velocities, or zero accelerations, use `[]` for that input argument.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. To use the `inverseDynamics` function, set the `DataFormat` property to either `'row'` or `'column'`.

configuration — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

jointVel — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the velocity degrees of freedom of the robot. To use the vector form of `jointVel`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

jointAccel — Joint accelerations
vector

Joint accelerations, returned as a vector. The dimension of the joint accelerations vector is equal to the velocity degrees of freedom of the robot. Each element corresponds to a specific joint on the `robot`. To use the vector form of `jointAccel`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

fext — External force matrix
n-by-6 matrix | 6-by-n matrix

External force matrix, specified as either an n-by-6 or 6-by-n matrix, where n is the velocity degrees of freedom of the robot. The shape depends on the `DataFormat`

property of `robot`. The `'row'` data format uses an *n*-by-6 matrix. The `'column'` data format uses a 6-by-*n* .

The matrix lists only values other than zero at the locations relevant to the body specified. You can add force matrices together to specify multiple forces on multiple bodies.

To create the matrix for a specified force or torque, see `externalForce`.

Output Arguments

`jointTorq` — Joint torques
vector

Joint torques, returned as a vector. Each element corresponds to a torque applied to a specific joint.

Examples

Compute Inverse Dynamics from Static Joint Configuration

Use the `inverseDynamics` function to calculate the required joint torques to statically hold a specific robot configuration. You can also specify the joint velocities, joint accelerations, and external forces using other syntaxes.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Generate a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Compute the required joint torques for `lbr` to statically hold that configuration.

```
tau = inverseDynamics(lbr,q);
```

Compute Joint Torque to Counter External Forces

Use the `externalForce` function to generate force matrices to apply to a rigid body tree model. The force matrix is an *m*-by-6 vector that has a row for each joint on the robot to apply a six-element wrench. Use the `externalForce` function and specify the end effector to properly assign the wrench to the correct row of the matrix. You can add multiple force matrices together to apply multiple forces to one robot.

To calculate the joint torques that counter these external forces, use the `inverseDynamics` function.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for `lbr`.

```
q = homeConfiguration(lbr);
```

Set external force on `link1`. The input wrench vector is expressed in the base frame.

```
fext1 = externalForce(lbr,'link_1',[0 0 0.0 0.1 0 0]);
```

Set external force on the end effector, `tool0`. The input wrench vector is expressed in the `tool0` frame.

```
fext2 = externalForce(lbr,'tool0',[0 0 0.0 0.1 0 0],q);
```

Compute the joint torques required to balance the external forces. To combine the forces, add the force matrices together. Joint velocities and accelerations are assumed to be zero (input as []).

```
tau = inverseDynamics(lbr,q,[],[],fext1+fext2);
```

- "Control LBR Manipulator Motion Through Joint Torque Commands"

See Also
RigidBodyTree | externalForce | forwardDynamics

Topics
"Control LBR Manipulator Motion Through Joint Torque Commands"

Introduced in R2017a

massMatrix

Class: robotics.RigidBodyTree
Package: robotics

Joint-space mass matrix

Syntax

```
H = massMatrix(robot)
H = massMatrix(robot,configuration)
```

Description

`H = massMatrix(robot)` returns the joint-space mass matrix of the home configuration of a robot.

`H = massMatrix(robot,configuration)` returns the mass matrix for a specified robot configuration.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. To use the `massMatrix` function, set the `DataFormat` property to either `'row'` or `'column'`.

configuration — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Output Arguments

H — Mass matrix
positive-definite symmetric matrix

Mass matrix of the robot, returned as a positive-definite symmetric matrix with size n-by-n, where n is the velocity degrees of freedom of the robot.

Examples

Calculate The Mass Matrix For A Robot Configuration

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Generate a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Get the mass matrix at configuration `q`.

```
H = massMatrix(lbr,q);
```

- "Control LBR Manipulator Motion Through Joint Torque Commands"

See Also
RigidBodyTree | gravityTorque | homeConfiguration | velocityProduct

Topics
"Control LBR Manipulator Motion Through Joint Torque Commands"

Introduced in R2017a

randomConfiguration

Class: robotics.RigidBodyTree
Package: robotics

Generate random configuration of robot

Syntax

```
configuration = randomConfiguration(robot)
```

Description

`configuration = randomConfiguration(robot)` returns a random configuration of the specified robot. Each joint position in this configuration respects the joint limits set by the `PositionLimits` property of the corresponding `Joint` object in the robot model.

Input Arguments

robot — Robot model
`RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object.

Output Arguments

configuration — Robot configuration
vector | structure

Robot configuration, returned as a vector of joint positions or a structure with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions in a structure. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

Examples

Visualize Robot Configurations

Show different configurations of a robot created using a `RigidBodyTree` model. Use the `homeConfiguration` or `randomConfiguation` functions to generate the structure that defines all the joint positions.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

Create a structure for the home configuration of a Puma robot. The structure has joint names and positions for each body on the robot model.

```
config = homeConfiguration(puma1)
```

```
config =

  1x6 struct array with fields:

    JointName
    JointPosition
```

Show the home configuration using `show`. You do not need to specify a configuration input.

```
show(puma1);
```

Modify the configuration and set the second joint position to `pi/2`. Show the resulting change in the robot configuration.

```
config(2).JointPosition = pi/2;
show(puma1,config);
```

Create random configurations and show them.

```
show(puma1,randomConfiguration(puma1));
```

See Also

`robotics.RigidBodyTree.geometricJacobian` |
`robotics.RigidBodyTree.getTransform` |
`robotics.RigidBodyTree.homeConfiguration`

Introduced in R2016b

removeBody

Class: robotics.RigidBodyTree
Package: robotics

Remove body from robot

Syntax

```
removeBody(robot,bodyname)
newSubtree = removeBody(robot,bodyname)
```

Description

`removeBody(robot,bodyname)` removes the body and all subsequently attached bodies from the robot model.

`newSubtree = removeBody(robot,bodyname)` returns the subtree created by removing the body and all subsequently attached bodies from the robot model.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object.

bodyname — Body name
character vector

Body name, specified as a character vector. This body must be on the robot model specified in `robot`.

Output Arguments

newSubtree — Robot subtree
RigidBodyTree object

Robot subtree, returned as a `RigidBodyTree` object. This new subtree uses the parent name of the body specified by `bodyname` as the base name. All bodies that are attached in the previous robot model (including the body with `bodyname` specified) are added to the subtree.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

load exampleRobots.mat

View the details of the Puma robot using `showdetails`.

showdetails(puma1)

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1          L1         jnt1     revolute             base(0)    L2(2)
   2          L2         jnt2     revolute             L1(1)      L3(3)
   3          L3         jnt3     revolute             L2(2)      L4(4)
   4          L4         jnt4     revolute             L3(3)      L5(5)
   5          L5         jnt5     revolute             L4(4)      L6(6)
   6          L6         jnt6     revolute             L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

            Name: 'L4'
           Joint: [1x1 robotics.Joint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 robotics.RigidBody]
        Children: {[1x1 robotics.RigidBody]}
          Visuals: {}


body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new Joint object and use replaceJoint to ensure the downstream body geometry is unaffected. Call setFixedTransform if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx    Body Name     Joint Name     Joint Type    Parent Name(Idx)    Children Name
 ---    ---------     ----------     ----------    ----------------    -------------
   1           L1           jnt1       revolute            base(0)     L2(2)
   2           L2           jnt2       revolute              L1(1)     L3(3)
   3           L3      prismatic          fixed              L2(2)     L4(4)
   4           L4           jnt4       revolute              L3(3)     L5(5)
   5           L5           jnt5       revolute              L4(4)     L6(6)
   6           L6           jnt6       revolute              L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using removeBody. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree =
  RigidBodyTree with properties:

      NumBodies: 3
         Bodies: {1x3 cell}
           Base: [1x1 robotics.RigidBody]
      BodyNames: {'L4'  'L5'  'L6'}
       BaseName: 'L3'
        Gravity: [0 0 0]
     DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through showdetails.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------   ----------------   ----------------
   1            L1         jnt1     revolute            base(0)   L2(2)
   2            L2         jnt2     revolute             L1(1)    L3(3)
   3            L3         jnt3     revolute             L2(2)    L4(4)
   4            L4         jnt4     revolute             L3(3)    L5(5)
   5            L5         jnt5     revolute             L4(4)    L6(6)
   6            L6         jnt6     revolute             L5(5)
--------------------
```

See Also

robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree.addBody | robotics.RigidBodyTree.replaceBody

Introduced in R2016b

replaceBody

Class: robotics.RigidBodyTree
Package: robotics

Replace body on robot

Syntax

```
replaceBody(robot,bodyname,newbody)
```

Description

replaceBody(`robot,bodyname,newbody`) replaces the body in the robot model with the new body. All properties of the body are updated accordingly, except the `Parent` and `Children` properties. The rest of the robot model is unaffected.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. The rigid body is added to this object and attached at the rigid body specified by `bodyname`.

bodyname — Body name
character vector

Body name, specified as a character vector. This body must be on the robot model specified in `robot`.

newbody — Rigid body
RigidBody object

Rigid body, specified as a `RigidBody` object.

See Also

robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree.addBody |
robotics.RigidBodyTree.removeBody |
robotics.RigidBodyTree.replaceJoint

Introduced in R2016b

replaceJoint

Class: robotics.RigidBodyTree
Package: robotics

Replace joint on body

Syntax

```
replaceJoint(robot,bodyname,joint)
```

Description

`replaceJoint(robot,bodyname,joint)` replaces the joint on the specified body in the robot model if the body is a part of the robot model. This method is the only way to change joints in a robot model. You cannot directly assign the `Joint` property of a rigid body.

Input Arguments

robot — Robot model
`RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object.

bodyname — Body name
character vector

Body name, specified as a character vector. This body must be on the robot model specified in `robot`.

joint — Replacement joint
`Joint` object

Replacement joint, specified as a `Joint` object.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)    Children Name(s)
 ---    ---------   ----------   ----------    ----------------    ----------------
   1          L1         jnt1     revolute              base(0)    L2(2)
   2          L2         jnt2     revolute                L1(1)    L3(3)
   3          L3         jnt3     revolute                L2(2)    L4(4)
   4          L4         jnt4     revolute                L3(3)    L5(5)
   5          L5         jnt5     revolute                L4(4)    L6(6)
   6          L6         jnt6     revolute                L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

           Name: 'L4'
          Joint: [1x1 robotics.Joint]
           Mass: 1
   CenterOfMass: [0 0 0]
        Inertia: [1 1 1 0 0 0]
         Parent: [1x1 robotics.RigidBody]
```

```
        Children: {[1x1 robotics.RigidBody]}
         Visuals: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);
```

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name       Joint Name      Joint Type    Parent Name(Idx)   Children Name
 ---     ---------       ----------      ----------    ----------------   -------------
   1            L1             jnt1        revolute            base(0)     L2(2)
   2            L2             jnt2        revolute             L1(1)      L3(3)
   3            L3        prismatic           fixed             L2(2)      L4(4)
   4            L4             jnt4        revolute             L3(3)      L5(5)
   5            L5             jnt5        revolute             L4(4)      L6(6)
   6            L6             jnt6        revolute             L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree =
  RigidBodyTree with properties:

    NumBodies: 3
       Bodies: {1x3 cell}
         Base: [1x1 robotics.RigidBody]
    BodyNames: {'L4'  'L5'  'L6'}
     BaseName: 'L3'
      Gravity: [0 0 0]
   DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through showdetails.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type     Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------     ----------------   ----------------
   1            L1         jnt1     revolute              base(0)   L2(2)
   2            L2         jnt2     revolute              L1(1)     L3(3)
   3            L3         jnt3     revolute              L2(2)     L4(4)
   4            L4         jnt4     revolute              L3(3)     L5(5)
   5            L5         jnt5     revolute              L4(4)     L6(6)
   6            L6         jnt6     revolute              L5(5)
--------------------
```

See Also

robotics.Joint | robotics.RigidBody | robotics.RigidBodyTree.addBody | robotics.RigidBodyTree.replaceBody

Introduced in R2016b

show

Class: robotics.RigidBodyTree
Package: robotics

Show robot model in a figure

Syntax

```
show(robot)
show(robot,configuration)
show( ___ ,Name,Value)
ax = show( ___ )
```

Description

`show(robot)` plots the body frames of the robot model in a figure with the predefined home configuration. Both `Frames` and `Visuals` are displayed automatically.

`show(robot,configuration)` uses the joint positions specified in `configuration` to show the robot body frames.

`show( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments. Name must appear inside single quotes (`''`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`, using any combination of previous syntaxes.

`ax = show( ___ )` returns the axes handle the robot is plotted on.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object.

configuration — Robot configuration
vector | structure

Robot configuration, specified as a vector of joint positions or a structure with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions in a structure. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Parent — Parent of axes
Axes object

Parent of axes, specified as the comma-separated pair consisting of `Parent` and an `Axes` object in which to draw the robot. By default, the robot is plotted in the active axes.

PreservePlot — Preserve robot plot
`true` (default) | `false`

Option to reserve robot plot, specified as the comma-separated pair consisting of `'PreservePlot'` and `true` or `false`. When this property is set to `true`, previous plots displayed by calling `show` are not overwritten. This setting functions similar to calling `hold on` for a standard MATLAB figure, but is limited to the robot body frames. When this property is set to `false`, previous plots of the robot are overwritten.

Frames — Display body frames
`'on'` (default) | `'off'`

Display body frames, specified as `'on'` or `'off'`. These frames are the coordinate frames of individual bodies on the rigid body tree.

Visuals — Display visual geometries
`'on'` (default) | `'off'`

Display visual geometries, specified as `'on'` or `'off'`. Individual visual geometries can also be turned off by right-clicking them in the figure.

You can either specify individual visual geometries using `robotics.RigidBody.addVisual` or by using the `importrobot` to import a robot model with `.stl` files specified.

Output Arguments

ax — Axes graphic handle
Axes object

Axes graphic handle, returned as an `Axes` object. This object contains the properties of the figure that the robot is plotted onto.

Examples
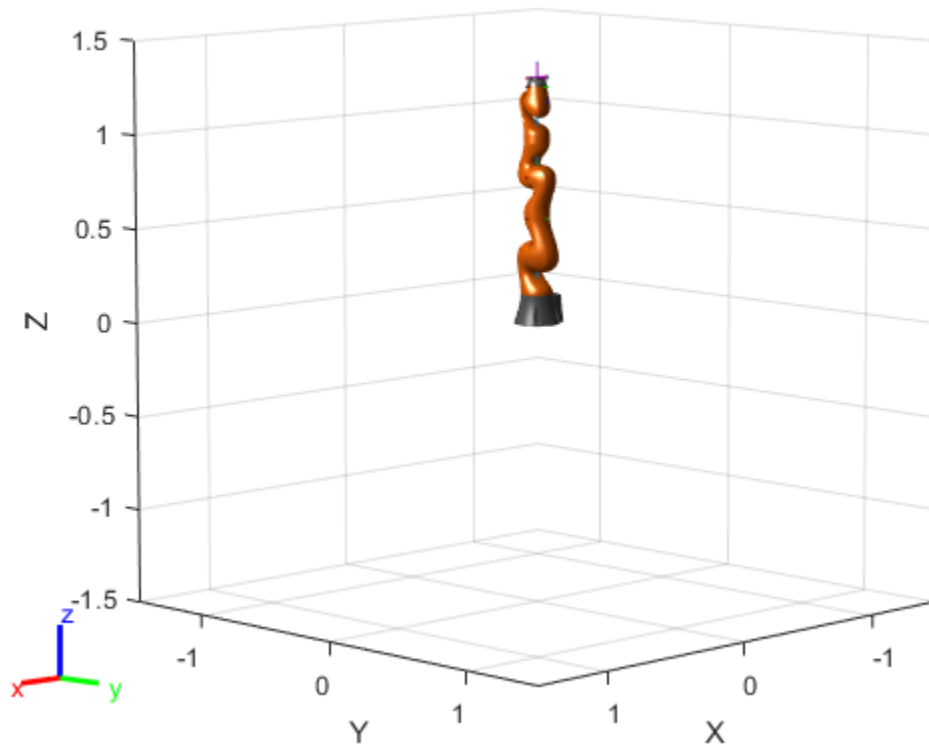
Display a Robot Model with Visual Geometries

You can import robots that have `.stl` files associated with the Unified Robot Description format (URDF) file to describe the visual geometries of the robot. Each rigid body has an individual visual geometry specified. The `importrobot` function parses to URDF file to get the robot model and visual geometries. Use the `show` function to visualize the robot model in a figure. You can then interact with the model by clicking components to inspect them and right-clicking to toggle visibility.

Import a robot model as a URDF file. The `.stl` file locations must be properly specified in this URDF. To add other `.stl` files to individual rigid bodies, see `addVisual`.

```
robot = importrobot('iiwa14.urdf');
```

Visualize the robot with the associated visual model. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each visual geometry.

```
show(robot);
```

Visualize Robot Configurations

Show different configurations of a robot created using a `RigidBodyTree` model. Use the `homeConfiguration` or `randomConfiguation` functions to generate the structure that defines all the joint positions.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

Create a structure for the home configuration of a Puma robot. The structure has joint names and positions for each body on the robot model.
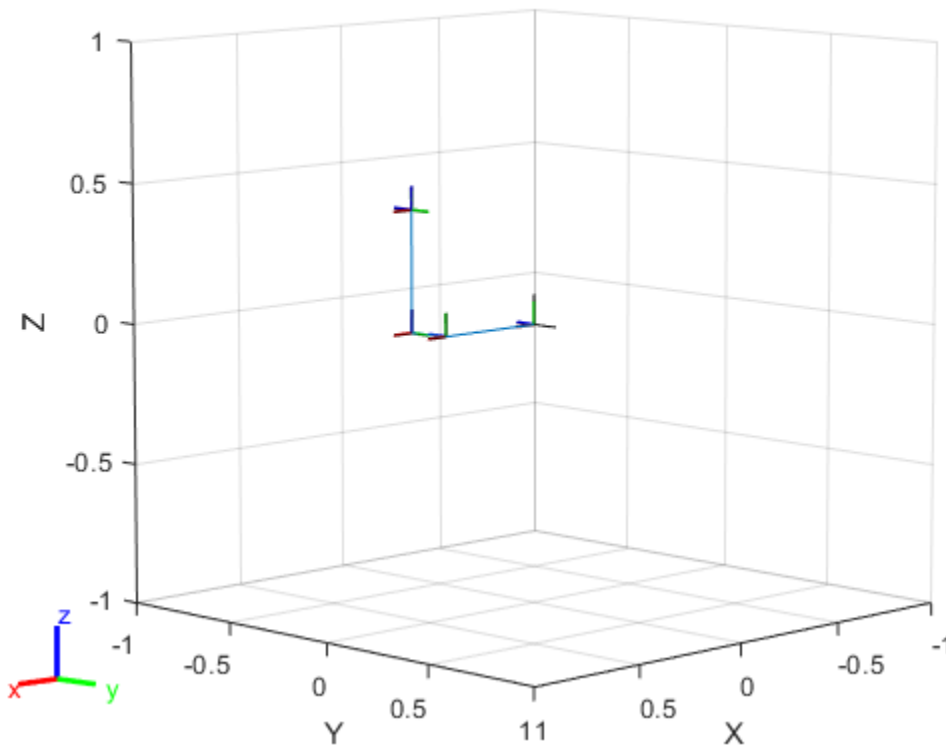
```
config = homeConfiguration(puma1)

config =

  1x6 struct array with fields:

    JointName
    JointPosition
```
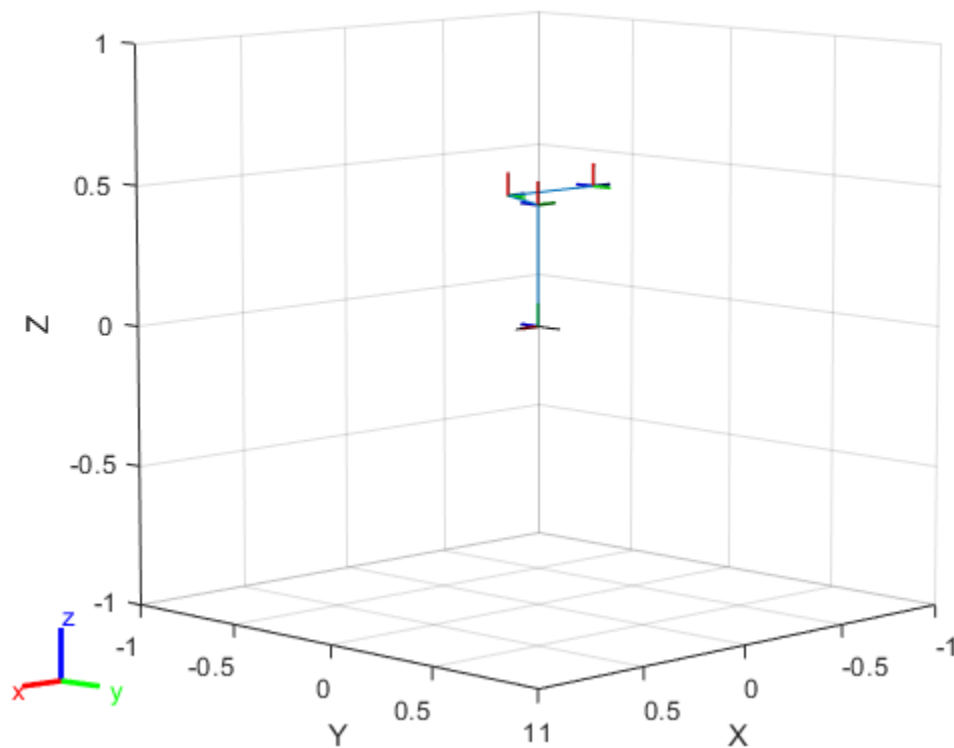
Show the home configuration using show. You do not need to specify a configuration input.
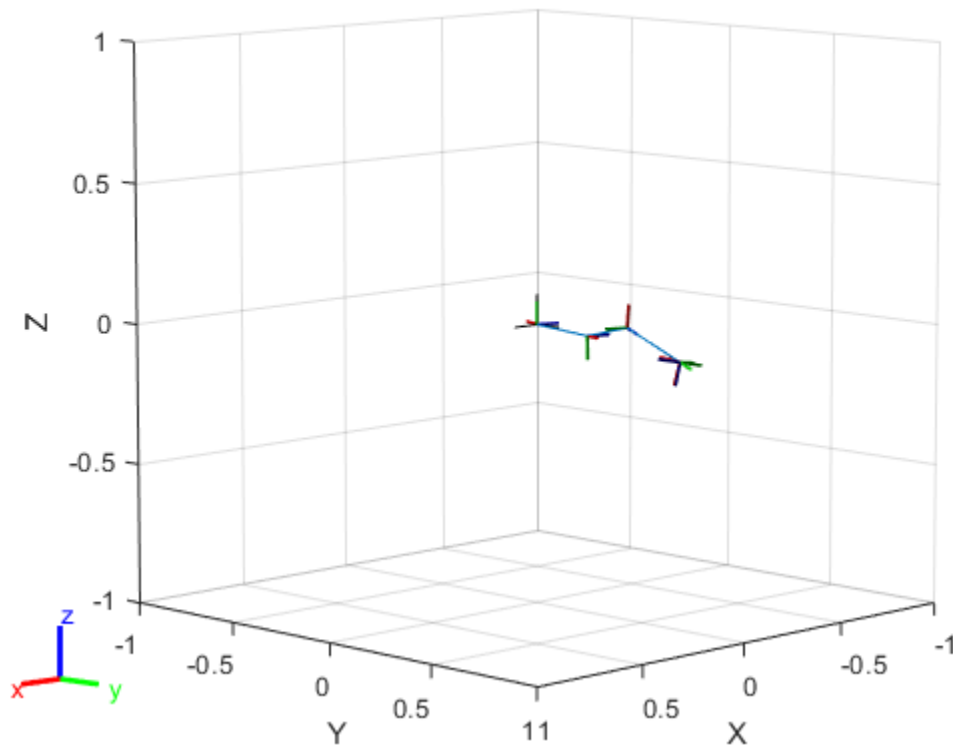
```
show(puma1);
```

Modify the configuration and set the second joint position to `pi/2`. Show the resulting change in the robot configuration.

```
config(2).JointPosition = pi/2;
show(puma1,config);
```


Create random configurations and show them.

```
show(puma1,randomConfiguration(puma1));
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix. The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0          pi/2    0         0;
            0.4318     0       0         0
            0.0203     -pi/2   0.15005   0;
            0          pi/2    0.4318    0;
            0          -pi/2   0         0;
            0          0       0         0];
```

Create a rigid body tree object to build the robot.

```
robot = robotics.RigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1   Create a `RigidBody` object and give it a unique name.
2   Create a `Joint` object and give it a unique name.
3   Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4   Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = robotics.RigidBody('body1');
jnt1 = robotics.Joint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = robotics.RigidBody('body2');
jnt2 = robotics.Joint('jnt2','revolute');
body3 = robotics.RigidBody('body3');
jnt3 = robotics.Joint('jnt3','revolute');
body4 = robotics.RigidBody('body4');
jnt4 = robotics.Joint('jnt4','revolute');
body5 = robotics.RigidBody('body5');
jnt5 = robotics.Joint('jnt5','revolute');
body6 = robotics.RigidBody('body6');
jnt6 = robotics.Joint('jnt6','revolute');
```

```
setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```
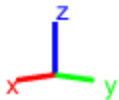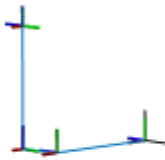
Verify that your robot was built properly by using the `showdetails` or `show` function. `showdetails` lists all the bodies in the MATLAB® command window. `show` displays the robot with a given configuration (home by default). Calls to `axis` modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)    Children Name(s)
 ---     ---------   ----------   ----------    ----------------    ----------------
   1         body1         jnt1     revolute             base(0)    body2(2)
   2         body2         jnt2     revolute            body1(1)    body3(3)
   3         body3         jnt3     revolute            body2(2)    body4(4)
   4         body4         jnt4     revolute            body3(3)    body5(5)
   5         body5         jnt5     revolute            body4(4)    body6(6)
   6         body6         jnt6     revolute            body5(5)
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```

Tips

Visual Components

Your robot model has visual components associated with it. Each `RigidBody` object contains a coordinate frame that is displayed as the body frame. Each body also can have visual meshes associated with them. By default, both of these components are displayed automatically. You can inspect or modify the visual components of the rigid body tree display. Click body frames or visual meshes to highlight them in yellow and see the

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associated body name, index, and joint type. Right-click to toggle visibility of individual components.

- **Body Frames**: Individual body frames are displayed as a 3-axis coordinate frame. Fixed frames are pink frames. Movable joint types are displayed as RGB axes. You can click a body frame to see the axis of motion. Prismatic joints show a yellow arrow in the direction of the axis of motion and, revolute joints show a circular arrow around the rotation axis.
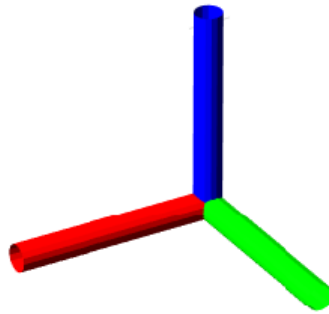
Fixed Joint Frame   Moveable Joint Frame   Selected Revolute Joint
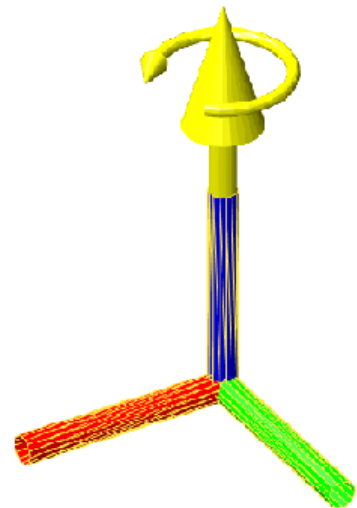
- **Visual Meshes**: Individual visual geometries are specified using `robotics.RigidBody.addVisual` or by using the `importrobot` to import a robot model with `.stl` files specified. By right-clicking individual bodies in a figure, you can turn off their meshes or specify the `Visuals` name-value pair to hide all visual geometries.
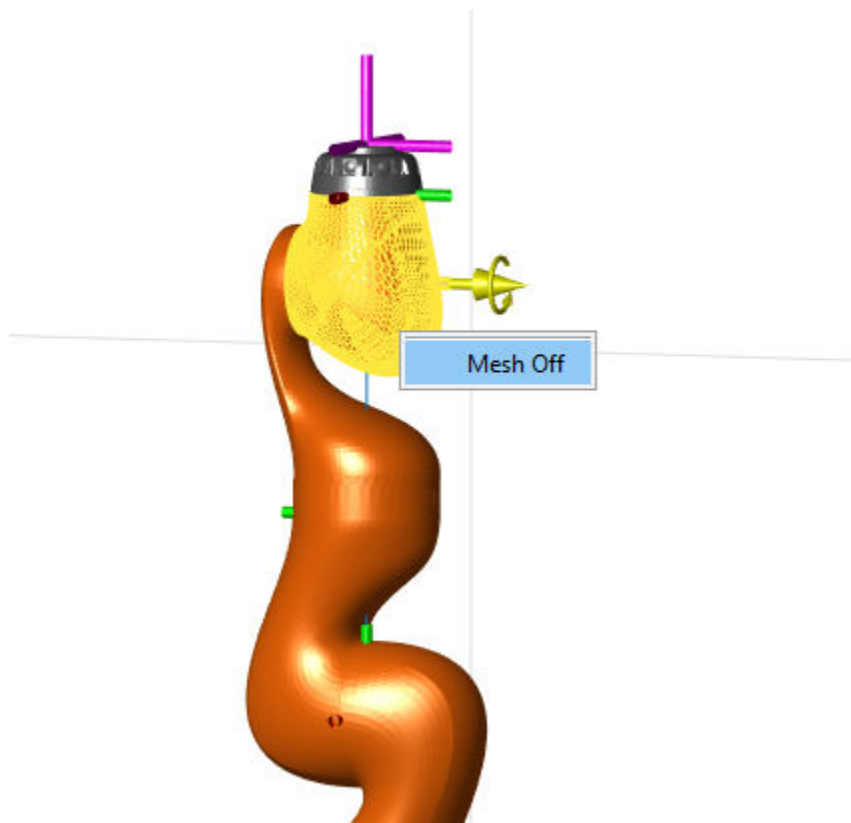
See Also

importrobot | robotics.RigidBodyTree.randomConfiguration |
robotics.RigidBodyTree.showdetails

Introduced in R2016b

showdetails

Class: robotics.RigidBodyTree
Package: robotics

Show details of robot model

Syntax

```
showdetails(robot)
```

Description

`showdetails(robot)` displays in the MATLAB command window the details of each body in the robot model. These details include the body name, associated joint name, joint type, parent name, and children names.

Input Arguments

robot — Robot model
`RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object.

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `RigidBody` object contains a `Joint` object and must be added to the `RigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = robotics.RigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = robotics.RigidBody('b1');
```

Create a revolute joint. By default, the `RigidBody` object comes with a fixed joint. Replace the joint by assigning a new `Joint` object to the `body1.Joint` property.

```
jnt1 = robotics.Joint('jnt1','revolute');
body1.Joint = jnt1;
```

Add the rigid body to the tree. Specify the body name that you are attaching the rigid body to. Because this is the first body, use the base name of the tree.

```
basename = rbtree.BaseName;
addBody(rbtree,body1,basename)
```

Use `showdetails` on the tree to confirm the rigid body and joint were added properly.

```
showdetails(rbtree)
```

```
--------------------
Robot: (1 bodies)

 Idx     Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------   ----------------   ----------------
   1            b1         jnt1     revolute            base(0)
--------------------
```

Modify a Robot Rigid Body Tree Model

Make changes to an existing `RigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)
```

```
Idx      Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
---      ---------   ----------   ----------   ----------------   ----------------
  1             L1         jnt1     revolute            base(0)   L2(2)
  2             L2         jnt2     revolute             L1(1)    L3(3)
  3             L3         jnt3     revolute             L2(2)    L4(4)
  4             L4         jnt4     revolute             L3(3)    L5(5)
  5             L5         jnt5     revolute             L4(4)    L6(6)
  6             L6         jnt6     revolute             L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the L3 body is the L4 body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}

childBody =
  RigidBody with properties:

          Name: 'L4'
         Joint: [1x1 robotics.Joint]
          Mass: 1
  CenterOfMass: [0 0 0]
       Inertia: [1 1 1 0 0 0]
        Parent: [1x1 robotics.RigidBody]
      Children: {[1x1 robotics.RigidBody]}
       Visuals: {}


body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new Joint object and use replaceJoint to ensure the downstream body geometry is unaffected. Call setFixedTransform if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = robotics.Joint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)

--------------------
Robot: (6 bodies)
```

```
Idx     Body Name      Joint Name      Joint Type     Parent Name(Idx)    Children Name
---     ---------      ---------       ---------      ----------------    ------------
  1        L1            jnt1           revolute           base(0)        L2(2)
  2        L2            jnt2           revolute            L1(1)         L3(3)
  3        L3          prismatic         fixed             L2(2)         L4(4)
  4        L4            jnt4           revolute            L3(3)         L5(5)
  5        L5            jnt5           revolute            L4(4)         L6(6)
  6        L6            jnt6           revolute            L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')

subtree =
  RigidBodyTree with properties:

     NumBodies: 3
        Bodies: {1x3 cell}
          Base: [1x1 robotics.RigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type     Parent Name(Idx)    Children Name(s)
 ---     ---------   ----------   ---------      ----------------    ----------------
   1        L1          jnt1       revolute           base(0)        L2(2)
   2        L2          jnt2       revolute            L1(1)         L3(3)
   3        L3          jnt3       revolute            L2(2)         L4(4)
```

```
4          L4          jnt4     revolute              L3(3)   L5(5)
5          L5          jnt5     revolute              L4(4)   L6(6)
6          L6          jnt6     revolute              L5(5)
--------------------
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix. The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0        pi/2    0        0;
            0.4318    0       0        0
            0.0203   -pi/2    0.15005    0;
            0        pi/2    0.4318    0;
            0        -pi/2    0        0;
            0         0       0        0];
```

Create a rigid body tree object to build the robot.

```
robot = robotics.RigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1 Create a `RigidBody` object and give it a unique name.

2 Create a `Joint` object and give it a unique name.

3 Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.

4 Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = robotics.RigidBody('body1');
jnt1 = robotics.Joint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
```

```
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = robotics.RigidBody('body2');
jnt2 = robotics.Joint('jnt2','revolute');
body3 = robotics.RigidBody('body3');
jnt3 = robotics.Joint('jnt3','revolute');
body4 = robotics.RigidBody('body4');
jnt4 = robotics.Joint('jnt4','revolute');
body5 = robotics.RigidBody('body5');
jnt5 = robotics.Joint('jnt5','revolute');
body6 = robotics.RigidBody('body6');
jnt6 = robotics.Joint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```
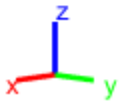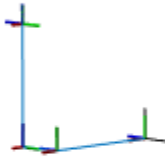
Verify that your robot was built properly by using the `showdetails` or `show` function. `showdetails` lists all the bodies in the MATLAB® command window. `show` displays the robot with a given configuration (home by default). Calls to `axis` modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
-------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type   Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------   ----------------   ----------------
   1        body1         jnt1     revolute             base(0)   body2(2)
   2        body2         jnt2     revolute           body1(1)   body3(3)
   3        body3         jnt3     revolute           body2(2)   body4(4)
   4        body4         jnt4     revolute           body3(3)   body5(5)
   5        body5         jnt5     revolute           body4(4)   body6(6)
   6        body6         jnt6     revolute           body5(5)
-------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```

See Also

robotics.RigidBodyTree.replaceBody |
robotics.RigidBodyTree.replaceJoint | robotics.RigidBodyTree.show

Introduced in R2016b

subtree

Class: robotics.RigidBodyTree
Package: robotics

Create subtree from robot model

Syntax

```
newSubtree = subtree(robot,bodyname)
```

Description

`newSubtree = subtree(robot,bodyname)` creates a new robot model using the parent name of the body specified by `bodyname` as the base name. All subsequently attached bodies (including the body with `bodyname` specified) are added to the subtree. The original `robot` model is unaffected.

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object.

bodyname — Body name
character vector

Body name, specified as a character vector. This body must be on the robot model specified in `robot`.

Output Arguments

newSubtree — Robot subtree
RigidBodyTree object

Robot subtree, returned as a `RigidBodyTree` object. This new subtree uses the parent name of the body specified by `bodyname` as the base name. All bodies that are attached in the previous robot model (including the body with `bodyname` specified) are added to the subtree.

See Also

`robotics.Joint` | `robotics.RigidBody` | `robotics.RigidBodyTree.addBody` | `robotics.RigidBodyTree.replaceBody`

Introduced in R2016b

velocityProduct

Class: robotics.RigidBodyTree
Package: robotics

Joint torques that cancel velocity-induced forces

Syntax

```
jointTorq = velocityProduct(robot,configuration,jointVel)
```

Description

`jointTorq = velocityProduct(robot,configuration,jointVel)` computes the joint torques required to cancel the forces induced by the specified joint velocities under a certain joint configuration. Gravity torque is not included in this calculation.

Input Arguments

robot — Robot model
`RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object. To use the `velocityProduct` function, set the `DataFormat` property to either `'row'` or `'column'`.

configuration — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

jointVel — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the velocity degrees of freedom of the robot. To use the vector form of `jointVel`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

Output Arguments

`jointTorq` — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint.

Examples

Compute Velocity-Induced Joint Torques

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the joint velocity vector.

```
qdot = [0 0 0.2 0.3 0 0.1 0];
```

Compute the joint torques required to cancel the velocity-induced joint torques at the robot home configuration (`[]` input). The velocity-induced joint torques equal the negative of the `velocityProduct` output.

```
tau = -velocityProduct(lbr,[],qdot);
```

- "Control LBR Manipulator Motion Through Joint Torque Commands"

See Also

RigidBodyTree | gravityTorque | inverseDynamics | massMatrix

Topics

"Control LBR Manipulator Motion Through Joint Torque Commands"

Introduced in R2017a

Blocks — Alphabetical List

Blank Message

Create blank message using specified message type
Library: Robotics System Toolbox / ROS

Description

The Blank Message block creates a Simulink nonvirtual bus corresponding to the selected ROS message type. On each sample hit, the block outputs a blank or "zero" signal for the designated message type. All elements of the bus are initialized to 0. The lengths of the variable-length arrays are also initialized to 0.

Limitations

Prior to R2016b, models using ROS message types that have certain reserved property names could not generate code. In 2016b, this limitation has been removed. These properties are renamed with an appended underscore (e.g. `Vector_`). If you use models prior to R2016b, update the ROS message types using these names and redefine custom maximum sizes for variable length arrays.

The affected message types are:

- `'geometry_msgs/Vector3Stamped'`
- `'jsk_pcl_ros/TransformScreenpointResponse'`
- `'pddl_msgs/PDDLAction'`
- `'rocon_interaction_msgs/Interaction'`
- `'capabilities/GetRemappingsResponse'`
- `'dynamic_reconfigure/Group'`

Input/Output Ports

Output

Msg — Blank ROS message
nonvirtual bus

Blank ROS message, returned as a nonvirtual bus. To specify the type of ROS message, use the **Message type** parameter. All elements of the bus are initialized to 0. The lengths of the variable-length arrays are also initialized to 0.

Data Types: `bus`

Parameters

Message type — ROS message type
`'geometry_msgs/Point'` (default) | string

ROS message type, specified as a string. Use **Select** to select a message from a list of supported ROS messages. Service message types are not supported and are not included in the list.

Sample time — Interval between outputs
`inf` (default) | scalar

Interval between outputs, specified as a scalar. The default value indicates that the block output never changes. Using this value speeds simulation and code generation by eliminating the need to recompute the block output. Otherwise, the block outputs a new blank message at each interval of `Sample time`.

For more information, see "Specify Sample Time" (Simulink).

See Also
Publish | Subscribe

Topics
"Virtual and Nonvirtual Buses" (Simulink)

Introduced in R2015a

Coordinate Transformation Conversion

Convert to a specified coordinate transformation representation
Library: Robotics System Toolbox / Utilities

Coordinate Transformation Conversion

Description

The Coordinate Transformation Conversion block converts a coordinate transformation from the input representation to a specified output representation. The input and output representations use the following forms:

- Axis-Angle (`AxAng`) – `[x y z theta]`
- Euler Angles (`Eul`) – `[z y x]`, `[z y z]`, or `[x y z]`
- Homogeneous Transformation (`TForm`) – 4-by-4 matrix
- Quaternion (`Quat`) – `[w x y z]`
- Rotation Matrix (`RotM`) – 3-by-3 matrix
- Translation Vector (`TrVec`) – `[x y z]`

All vectors must be **column vectors**.

To accommodate representations that only contain position or orientation information (`TrVec` or `Eul`, for example), you can specify two inputs or outputs to handle all transformation information. When you select the Homogeneous Transformation as an input or output, an optional `Show TrVec input/output port` parameter can be selected on the block mask to toggle the multiple ports.

For more information about the different coordinate transformation representations, see "Coordinate Transformations in Robotics".

Ports

Input

Input transformation — Coordinate transformation
column vector | 3-by-3 matrix | 4-by-4 matrix

Input transformation, specified as a coordinate transformation. The following representations are supported:

- Axis-Angle (AxAng) – [x y z theta]
- Euler Angles (Eul) – [z y x], [z y z], or [x y z]
- Homogeneous Transformation (TForm) – 4-by-4 matrix
- Quaternion (Quat) – [w x y z]
- Rotation Matrix (RotM) – 3-by-3 matrix
- Translation Vector (TrVec) – [x y z]

All vectors must be **column vectors**.

To accommodate representations that only contain position or orientation information (TrVec or Eul, for example), you can specify two inputs or outputs to handle all transformation information. When you select the Homogeneous Transformation as an input or output, an optional Show TrVec input/output port parameter can be selected on the block mask to toggle the multiple ports.

TrVec — Translation vector
3-element column vector

Translation vector, specified as a 3-element column vector, [x y z], which corresponds to a translation in the x, y, and z axes respectively. This port can be used to input or output the translation information separately from the rotation vector.

Dependencies

You must select Homogeneous Transformation (TForm) for the opposite transformation port to get the option to show the additional TrVec port. Enable the port by clicking Show TrVec input/output port.

Output Arguments

`Output transformation` — **Coordinate transformation**
column vector | 3-by-3 matrix | 4-by-4 matrix

Output transformation, specified as a coordinate transformation with the specified representation. The following representations are supported:

- Axis-Angle (`AxAng`) – `[x y z theta]`
- Euler Angles (`Eul`) – `[z y x]`, `[z y z]`, or `[x y z]`
- Homogeneous Transformation (`TForm`) – 4-by-4 matrix
- Quaternion (`Quat`) – `[w x y z]`
- Rotation Matrix (`RotM`) – 3-by-3 matrix
- Translation Vector (`TrVec`) – `[x y z]`

To accommodate representations that only contain position or orientation information (`TrVec` or `Eul`, for example), you can specify two inputs or outputs to handle all transformation information. When you select the Homogeneous Transformation as an input or output, an optional `Show TrVec input/output port` parameter can be selected on the block mask to toggle the multiple ports.

`TrVec` — **Translation vector**
three-element column vector

Translation vector, specified as a three-element column vector, `[x y z]`, which corresponds to a translation in the *x*, *y*, and *z* axes respectively. This port can be used to input or output the translation information separately from the rotation vector.

Dependencies

You must select Homogeneous Transformation (`TForm`) for the opposite transformation port to get the option to show the additional `TrVec` port. Enable the port by clicking `Show TrVec input/output port`.

Parameters

Representation — **Input or output representation**
`Axis-Angle` | `Euler Angles` | `Homogeneous Transformation` | `Rotation Matrix` | `Translation Vector` | `Quaternion`

Select the representation for both the input and output port for the block. If you are using a transformation with only orientation information, you can also select the Show TrVec input/output port when converting to or from a homogeneous transformation.

Show TrVec input/output port — Toggle TrVec port
off (default) | on

Toggle the TrVec input or output port when you want to specify or receive a separate translation vector for position information along with an orientation representation.

Dependencies

You must select Homogeneous Transformation (TForm) for the opposite transformation port to get the option to show the additional TrVec port.
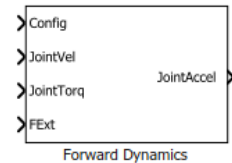
See Also
axang2quat | eul2tform | trvec2tform

Topics
"Coordinate Transformations in Robotics"

Introduced in R2017b

Forward Dynamics

Joint accelerations given joint torques and states
Library: Robotics System Toolbox / Manipulator Algorithms

Forward Dynamics

Description

The Forward Dynamics block computes joint accelerations for a robot model given a robot state that is made up of joint torques, joint states, and external forces. To get the joint accelerations, specify the robot configuration (joint positions), joint velocities, applied torques, and external forces.

Specify the robot model in the **Rigid body tree** parameter as a `RigidBodyTree` object, and set the Gravity property on the object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

`JointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom (number of nonfixed joints) of the robot.

JointTorq — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

FExt — External force matrix
6-by-*n* matrix

External force matrix, specified as a 6-by-*n* matrix, where *n* is the number of bodies in the robot model. The matrix contains nonzero values in the rows corresponding to specific bodies. Each row is a vector of applied forces and torques that act as a wrench for that specific body. Generate this matrix using `externalForce` with a MATLAB Function block

Output

JointAccel — Joint accelerations
vector

Joint accelerations, returned as a vector. The number of joint accelerations is equal to the degrees of freedom of the robot.

Parameters

Rigid body tree — Robot model
twoJointRigidBodyTree (default) | RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

See Also

Blocks
Get Jacobian | Get Transform | Gravity Torque | Inverse Dynamics | Joint Space Mass Matrix | Velocity Product Torque

Classes
`RigidBodyTree`

Functions
`externalForce` | `forwardDynamics` | `homeConfiguration` | `importrobot` | `randomConfiguration`
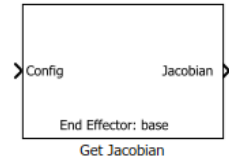
Topics
"Perform Safe Trajectory Tracking Control Using Robotics Manipulator Blocks"

Introduced in R2018a

Get Jacobian

Geometric Jacobian for robot configuration
Library: Robotics System Toolbox / Manipulator Algorithms

Description

The Get Jacobian block returns the geometric Jacobian relative to the base for the specified end effector at the given configuration of a `RigidBodyTree` robot model.

The Jacobian maps the joint-space velocity to the end-effector velocity relative to the base coordinate frame. The end-effector velocity equals:

$$V_{EE} = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \\ v_x \\ v_y \\ v_z \end{bmatrix} = J\dot{q} = J \begin{bmatrix} \dot{q}_1 \\ \vdots \\ \dot{q}_n \end{bmatrix}$$

ω is the angular velocity, v is the linear velocity, and $\dot{q}$ is the joint-space velocity.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

Jacobian — Geometric Jacobian of end effector
6-by-*n* matrix

Geometric jacobian of the end effector with the specified configuration, **Config**, returned as a 6-by-*n* matrix, where *n* is the number of degrees of freedom of the end effector. The Jacobian maps the joint-space velocity to the end-effector velocity relative to the base coordinate frame. The end-effector velocity equals:

$$V_{EE} = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \\ v_x \\ v_y \\ v_z \end{bmatrix} = J\dot{q} = J \begin{bmatrix} \dot{q}_1 \\ \vdots \\ \dot{q}_n \end{bmatrix}$$

ω is the angular velocity, v is the linear velocity, and $\dot{q}$ is the joint-space velocity.

Parameters

Rigid body tree — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

End effector — End effector for Jacobian
body name

End effector for `Jacobian`, specified as a body name from the **Rigid body tree** robot model. To access body names from the robot model, click **Select body**.

See Also

Blocks
Forward Dynamics | Get Transform | Gravity Torque | Inverse Dynamics | Joint Space Mass Matrix | Velocity Product Torque

Classes
`RigidBodyTree`

Functions
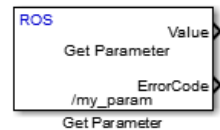`geometricJacobian` | `homeConfiguration` | `importrobot` | `randomConfiguration`

Introduced in R2018a

Get Parameter

Get values from ROS parameter server
Library: Robotics System Toolbox / ROS

Description

The Get Parameter block outputs the value of the specified ROS parameter. The block uses the ROS node of the Simulink model to connect to the ROS network. This node is created when you run the model and is deleted when the model terminates. If the model does not have a node, the block creates one.

On each sample hit, the block checks the ROS parameter server for the specified ROS parameter and outputs its value.

Input/Output Ports

Output

`Value` — Parameter value
scalar | logical | uint8 array

Parameter value from the ROS network. The value depends on the **Data type** parameter.

`ErrorCode` — Status of ROS parameter
0 | 1 | 2 | 3

Status of ROS parameter, specified as one of the following:

- **0 —** ROS parameter retrieved successfully. The retrieved value is output in the **Value** port.
- **1 —** No ROS parameter with specified name found. If there is no known value, **Value** is set to the last received value or to **Initial value**.

- **2 —** ROS parameter retrieved, but its type is different than the specified **Data type**. If there is no known value, Value is set to the last received value or to **Initial value**.

- **3 —** For string parameters, the incoming string has been truncated based on the specified length.

Length — Length of string parameter
integer

Length of the string parameter, returned as an integer. This length is the number of elements of the `uint8` array or the number of characters in the string that you cast to `uint8`.

Note When getting string parameters from the ROS network, an ASCII value of 13 returns an error due to its incompatible character type.

Dependencies

To enable this port, set the **Data type** to `uint8[] (string)`.

Parameters

Source — Source for specifying the parameter name
Select from ROS network | Specify your own

Source for specifying the parameter name as one of the following:

- `Select from ROS network` — Use **Select** to select a parameter name. The **Data type** parameter is set automatically. You must be connected to a ROS network.

- `Specify your own` — Enter a parameter name in **Name** and specify its data type in **Data type**. You must match a parameter name exactly.

Name — Parameter name
string

Parameter name to get from the ROS network, specified as a string. When **Source** is set to `Select from ROS network`, use **Select** to select an existing parameter. You must be connected to a ROS network to get a list of parameters. Otherwise, specify the parameter and data type.

Parameter name strings must follow the rules of ROS graph names. Valid names have these characteristics:

- The first character is an alpha character ([a-z|A-Z]), tilde (~), or forward slash (/).
- Subsequent characters are alphanumeric ([0-9|a-z|A-Z]), underscores(_), or forward slashes (/).

Data type — Data type of your parameter
double | int32 | boolean | uint8[] (string)

Data type of your parameter, specified as a string. The uint8[] (string) enables the **Maximum length** parameter.

Note The uint8[] (string) data type is an array of ASCII values corresponding to the characters in a string. When getting string parameters, you can create a MATLAB Function block to compare the string to a desired parameter value. For more information, see "ROS String Parameters".

Data Types: double | int32 | Boolean | uint8

Maximum length — Maximum length of the uint8 array
scalar

Maximum length of the uint8 array, specified as a scalar. If the parameter string has a length greater than **Maximum length**, the **ErrorCode** output is set to 3.

Dependencies

To enable this port, set the **Data type** to uint8[] (string).

Initial value — Default parameter value output
double | int32 | boolean | uint8

Default parameter value output from when an error occurs and no valid value has been received from the parameter server. The data type must match the specified **Data type**.

Sample time — Interval between outputs
inf (default) | scalar

Interval between outputs, specified as a scalar. This default value indicates that the block output never changes. Using this value speeds simulation and code generation by

eliminating the need to recompute the block output. Otherwise, the block outputs a new blank message at each interval of `Sample time`.

For more information, see "Specify Sample Time" (Simulink).

`Show ErrorCode output port` — Display error code output
on | off

To enable error code output, select this parameter. When you clear this parameter, the **ErrorCode** output port is removed from the block. The status options are:

- **0 —** ROS parameter retrieved successfully. The retrieved value is output in the **Value** port.
- **1 —** No ROS parameter with specified name found. If there is no known value, **Value** is set to the last received value or to **Initial value**.
- **2 —** ROS parameter retrieved, but its type is different than the specified **Data type**. If there is no known value, Value is set to the last received value or to **Initial value**.
- **3 —** For string parameters, the incoming string has been truncated based on the specified length.

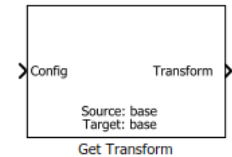# See Also
Set Parameter

External Websites
ROS Parameter Server
ROS Graph Names

Introduced in R2015b

Get Transform

Get transform between body frames
Library:　　　　　Robotics System Toolbox / Manipulator Algorithms

Description

The Get Transform block returns the homogeneous transformation between body frames on the **Rigid body tree** robot model. Specify a `RigidBodyTree` object for the robot model, and select a source and target body in the block.

The block uses **Config**, the robot configuration (joint positions) input, to calculate the transformation from the source body to the target body. This transformation is used to convert coordinates from the source to the target body. To convert to base coordinates, use the base body name as the **Target body** parameter.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

`Transform` — Homogeneous transform
4-by-4 matrix

Homogeneous transform, returned as a 4-by-4 matrix.

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`Target body` — Target body name
body name

Target body name, specified as a body name from the robot model specified in **Rigid body tree**. To access body names from the robot model, click **Select body**. The target frame is the coordinate system you want to transform points into.

`Source body` — Source body name
body name

Source body name, specified as a body name from the robot model specified in **Rigid body tree**.To access body names from the robot model, click **Select body**. The source frame is the coordinate system you want points transformed from.

See Also

Blocks
Get Jacobian | Gravity Torque | Inverse Dynamics | Joint Space Mass Matrix | Velocity Product Torque

Classes
RigidBodyTree

Functions
getTransform | homeConfiguration | importrobot | randomConfiguration
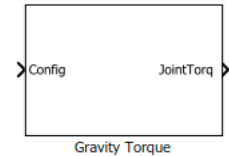
Topics
"Perform Safe Trajectory Tracking Control Using Robotics Manipulator Blocks"

Introduced in R2018a

Gravity Torque

Joint torques that compensate gravity
Library: Robotics System Toolbox / Manipulator Algorithms

```
┌─────────────────────────┐
│ Config         JointTorq │
│                         │
└─────────────────────────┘
       Gravity Torque
```

Description

The Gravity Torque block returns the joint torques required to hold the robot at a given configuration with the current Gravity setting on the **Rigid body tree** robot model.

Ports

Input

Config — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

JointTorq — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Parameters

Rigid body tree — Robot model
twoJointRigidBodyTree (default) | RigidBodyTree object

Robot model, specified as a `RigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

See Also

Blocks
Forward Dynamics | Get Jacobian | Inverse Dynamics | Joint Space Mass Matrix | Velocity Product Torque
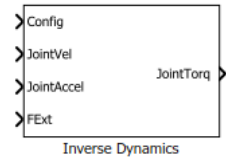
Classes
RigidBodyTree

Functions
gravityTorque | homeConfiguration | importrobot | randomConfiguration

Introduced in R2018a

Inverse Dynamics

Required joint torques for given motion
Library: Robotics System Toolbox / Manipulator Algorithms

Description

The Inverse Dynamics block returns the joint torques required for the robot to maintain the specified robot state. To get the required joint torques, specify the robot configuration (joint positions), joint velocities, joint accelerations, and external forces.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

`JointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom (number of nonfixed joints) of the robot.

`JointAccel` — Joint accelerations
vector

Joint accelerations, specified as a vector. The number of joint accelerations is equal to the degrees of freedom of the robot.

FExt — External force matrix
6-by-*n* matrix

External force matrix, specified as a 6-by-*n* matrix, where *n* is the number of bodies in the robot model. The matrix contains nonzero values in the rows corresponding to specific bodies. Each row is a vector of applied forces and torques that act as a wrench for that specific body. Generate this matrix using `externalForce` with a MATLAB Function block

Output

JointTorq — Joint torques
vector

Joint torques, returned as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Parameters

Rigid body tree — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

See Also

Blocks
Forward Dynamics | Get Jacobian | Gravity Torque | Joint Space Mass Matrix | Velocity Product Torque
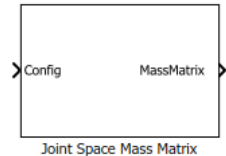
Classes
`RigidBodyTree`

Functions
externalForce | homeConfiguration | importrobot | inverseDynamics |
randomConfiguration

Introduced in R2018a

Joint Space Mass Matrix

Joint-space mass matrix for robot configuration
Library: Robotics System Toolbox / Manipulator Algorithms

Joint Space Mass Matrix

Description

The Joint Space Mass Matrix block returns the joint-space mass matrix for the given robot configuration (joint positions) for the **Rigid body tree** robot model.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

`MassMatrix` — Joint-space mass matrix for configuration
positive-definite symmetric matrix

Joint-space mass matrix for the given robot configuration, returned as a positive-definite symmetric matrix.

Parameters

Rigid body tree — Robot model
twoJointRigidBodyTree (default) | RigidBodyTree object

Robot model, specified as a RigidBodyTree object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using importrobot.

The default robot model, twoJointRigidBodyTree, is a robot with revolute joints and two degrees of freedom.

See Also

Blocks
Forward Dynamics | Get Jacobian | Gravity Torque | Inverse Dynamics | Velocity Product Torque

Classes
RigidBodyTree

Functions
homeConfiguration | importrobot | massMatrix | randomConfiguration

Introduced in R2018a

Publish

Send messages to ROS network
Library: Robotics System Toolbox / ROS

Description

The Publish block takes in as its input a Simulink nonvirtual bus that corresponds to the specified ROS message type and publishes it to the ROS network. It uses the node of the Simulink model to create a ROS publisher for a specific topic. This node is created when the model runs and is deleted when the model terminates. If the model does not have a node, the block creates one.

On each sample hit, the block converts the **Msg** input from a Simulink bus signal to a ROS message and publishes it. The block does not distinguish whether the input is a new message but merely publishes it on every sample hit. For simulation, this input is a MATLAB ROS message. In code generation, it is a C++ ROS message.

Input/Output Ports

Input

Msg — ROS message
nonvirtual bus

ROS message, specified as a nonvirtual bus. To specify the type of ROS message, use the **Message type** parameter.

Data Types: bus

Parameters

Topic source — Source for specifying topic name
Select from ROS network|Specify your own

Source for specifying the topic name, specified as one of the following:

- Select from ROS network — Use **Select** to select a topic name. The **Topic** and **Message type** parameters are set automatically. You must be connected to a ROS network.

- Specify your own — Enter a topic name in **Topic** and specify its message type in **Message type**. You must match a topic name exactly.

Topic — Topic name to publish to
string

Topic name to publish to, specified as a string. When **Topic source** is set to Select from ROS network, use **Select** to select a topic from the ROS network. You must be connected to a ROS network to get a list of topics. Otherwise, set **Topic source** to Specify your own and specify the topic you want.

Message type — ROS message type
string

ROS message type, specified as a string. Use **Select** to select from a full list of supported ROS messages. Service message types are not supported and are not included in the list.

Length of publish queue — Message queue length
1 (default) | integer

Message queue length in code generation, specified as an integer.In simulation, the message queue is always 1 and cannot be adjusted. To ensure each message is processed, use a smaller model step or only execute the model when publishing a new message.

Tips

You can also set the addresses for the ROS master and node host by clicking the **Configure network addresses** link in the block.
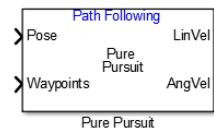
See Also

Blank Message | Subscribe

Topics

"Virtual and Nonvirtual Buses" (Simulink)
"Simulink and ROS Interaction"

Introduced in R2015a

Pure Pursuit

Linear and angular velocity control commands
Library: Robotics System Toolbox / Mobile Robot Algorithms

Description

The Pure Pursuit block computes linear and angular velocity commands for following a path using a set of waypoints and the current pose of a differential drive robot. The block takes updated poses to update velocity commands for the robot to follow a path along a desired set of waypoints. Use the **Max angular velocity** and **Desired linear velocity** parameters to update the velocities based on the performance of the robot.

The **Lookahead distance** parameter computes a look-ahead point on the path, which is an instantaneous local goal for the robot. The angular velocity command is computed based on this point. Changing **Lookahead distance** has a significant impact on the performance of the algorithm. A higher look-ahead distance results in a smoother trajectory for the robot, but can cause the robot to cut corners along the path. Too low of a look-ahead distance can result in oscillations in tracking the path, causing unstable behavior. For more information on the pure pursuit algorithm, see "Pure Pursuit Controller".

Input/Output Ports

Input

Pose — Current robot pose
[x y theta] vector

Current robot pose, specified as an [x y theta] vector, which corresponds to the *x-y* position and orientation angle, *theta*. Positive angles are measured counterclockwise from the positive *x*-axis.

Waypoints — Waypoints
[ ] (default) | *n*-by-2 array

Waypoints, specified as an *n*-by-2 array of [x y] pairs, where *n* is the number of waypoints. You can generate the waypoints from the `robotics.PRM` class or specify them as an array in Simulink.

Output

LinVel — Linear velocity
scalar in meters per second

Linear velocity, specified as a scalar in meters per second.

Data Types: `double`

AngVel — Angular velocity
scalar in radians per second

Angular velocity, specified as a scalar in radians per second.

Data Types: `double`

TargetDir — Target direction for robot
scalar in radians

Target direction for the robot, specified as a scalar in radians. The forward direction of the robot is considered zero radians, with positive angles measured counterclockwise. This output can be used as the input to the **TargetDir** port for the Vector Field Histogram block.

Dependencies

To enable this port, select the **Show TargetDir output port** parameter.

Parameters

Desired linear velocity (m/s) — Linear velocity
`0.1` (default) | scalar

Desired linear velocity, specified as a scalar in meters per second. The controller assumes that the robot drives at a constant linear velocity and that the computed angular velocity is independent of the linear velocity.

`Maximum angular velocity (rad/s)` — Angular velocity
`1.0` (default) | scalar

Maximum angular velocity, specified as a scalar in radians per second. The controller saturates the absolute angular velocity output at the given value.

`Lookahead distance (m)` — Look-ahead distance
`1.0` (default) | scalar

Look-ahead distance, specified as a scalar in meters. The look-ahead distance changes the response of the controller. A robot with a higher look-ahead distance produces smooth paths but takes larger turns at corners. A robot with a smaller look-ahead distance follows the path closely and takes sharp turns, but oscillate along the path. For more information on the effects of look-ahead distance, see "Pure Pursuit Controller".

`Show TargetDir output port` — Target direction indicator
off (default) | on

Select this parameter to enable the **TargetDir** out port. This port gives the target direction as an angle in radians from the forward position, with positive angles measured counterclockwise.

See Also

Blocks
Publish | Subscribe | Vector Field Histogram

Classes
`robotics.PRM` | `robotics.PurePursuit`

Topics
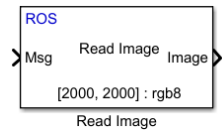"Path Following for a Differential Drive Robot"
"Pure Pursuit Controller"

Introduced in R2016b

Read Image

Extract image from ROS Image message
Library: Robotics System Toolbox / ROS

Description

The Read Image block extracts an image from a ROS `Image` or `CompressedImage` message. You can select the ROS message parameters of a topic active on a live ROS network or specify the message parameters separately. The ROS messages are specified as a nonvirtual bus. Use the Subscribe block output to receive a message from a ROS network and input the message to the Read Image block.

Note When reading ROS image messages from the network, the `Data` property of the message can exceed the maximum array length set in Simulink. To increase the maximum array length, click **Tools** > **Manage Array Lengths** > **Robot Operating System**, select the **Data** array, and increase the size based on the number of points in the image.

Ports

Input

Msg — ROS `Image` or `CompressedImage` message
nonvirtual bus

ROS `Image` or `CompressedImage` message, specified as a nonvirtual bus. You can use the Subscribe block to get a message from an active ROS network.

Data Types: `bus`

Output

Image — Extracted image signal
M-by-*N*-by-3 matrix | *M*-by-*N* matrix

Extracted image signal from ROS message, returned as an *M*-by-*N*-by-3 matrix for color images, and an *M*-by-*N* matrix for grayscale images. The matrix contains the pixel data from the `Data` property of the ROS message.

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

AlphaChannel — Alpha channel for image
M-by-*N* matrix

Alpha channel for image, returned as an *M*-by-*N* matrix. This matrix is the same height and width as the image output and has values `[0 1]` to indicate the opacity of each corresponding pixel, with a value of 0 being completely transparent.

> **Note** For `CompressedImage` messages, the Alpha channel returns all zeros if the `Show Alpha output port` is enabled.

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

ErrorCode — Error code for image conversion
scalar

Error code for image conversion, returned as a scalar. The error code values are:

- `0` – Successfully converted the image message.
- `1` – Incorrect image encoding. Check that the incoming message encoding matches the `ImageEncoding` parameter.
- `2` – The dimensions of the image message exceed the limits specified in the `Maximum Image Size` parameter.
- `3` – The `Data` field of the image message was truncated. See "Managing Array Sizes in Simulink ROS" to increase the maximum length of the array.
- `04` – Image decompression failed.

Data Types: `uint8`

Parameters

`Maximum Image Size` — Maximum image size
`[2000 2000]` (default) | two-element vector

Maximum image size, specified as a two-element `[height width]` vector.

Click **Configure using ROS ...** to set this parameter automatically using an active topic on a ROS network. You must be connected to the ROS network.

`Image Encoding` — Image encoding
`rgb8` (default) | `rgba8` | ...

Image encoding for the input `ImageMsg`. Select the supported encoding type which matches the `Encoding` property of the message. For more information about encoding types, see `readImage`.

`Show Alpha output port` — Toggle AlphaChannel port
off (default) | on

Toggle Alpha channel output port if your encoding supports an Alpha channel.

Dependencies

Only certain encoding types support alpha channels. The `ImageEncoding` parameter determines if this parameter appears in the block mask.

`Show error code output port` — Toggle ErrorCode port
on (default) | off

Toggle the `ErrorCode` port to monitor errors.

`Output variable-size signals` — Toggle variable-size signal output
off (default) | on

Toggle variable-size signal output. Variable-sized signals should only be used if the image size is expected to change over time. For more information about variable sized signals, see "Variable-Size Signal Basics" (Simulink).

See Also

Blank Message | `CompressedImage` | Image | Subscribe | `readImage`

Topics
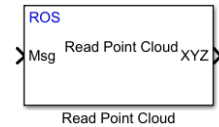"Managing Array Sizes in Simulink ROS"
"Variable-Size Signal Basics" (Simulink)

Introduced in R2017b

Read Point Cloud

Extract point cloud from ROS PointCloud2 message
Library: Robotics System Toolbox / ROS

Description

The Read Point Cloud block extracts a point cloud from a ROS `PointCloud2` message. You can select the ROS message parameters of a topic active on a live ROS network or specify the message parameters separately. The ROS messages are specified as a nonvirtual bus. Use the Subscribe block to receive a message from a ROS network and input the message to the Read Point Cloud block.

Note When reading ROS point cloud messages from the network, the `Data` property of the message can exceed the maximum array length set in Simulink. To increase the maximum array length, click **Tools > Manage Array Lengths > Robot Operating System** , select the **Data** array, and increase the size based on the number of points in the point cloud.

Ports

Input

Msg — ROS `PointCloud2` message
nonvirtual bus

ROS `PointCloud2` message, specified as a nonvirtual bus. You can use the Subscribe block to get a message from the ROS network.

Data Types: `bus`

Output

XYZ — XYZ coordinates
matrix | multidimensional array

x, *y*, and *z* coordinates of the point cloud data, output as either an *N*-by-3 matrix or *h*-by-*w*-by-3 multidimensional array. *N* is the number of points. *h* and *w* are the height and width of the image in pixels. To get the *x*, *y*, and *z* coordinates as a multidimensional array, select the `Preserve point cloud structure` check box in the block mask parameters.

Data Types: `single`

RGB — RGB values for each point
matrix | multidimensional array

RGB values for each point of the point cloud data, output as either an *N*-by-3 matrix or *h*-by-*w*-by-3 multidimensional array. *N* is the number of points. *h* and *w* are the height and width of the image in pixels. The RGB values correspond to the red, green, and blue color intensities with a range of `[0 1]`.To get the RGB values as a multidimensional array, select the `Preserve point cloud structure` check box in the block mask parameters.

Data Types: `double`

`Intensity` — Intensity values for each point
array | matrix

Intensity values for each point of the point cloud data, output as either an array or a *h*-by-*w* matrix. *h* and *w* are the height and width of the image in pixels. To get the intensity values as a matrix, select the `Preserve point cloud structure` check box in the block mask parameters.

Data Types: `single`

`ErrorCode` — Error code for image conversion
scalar

Error code for image conversion, returned as a scalar. The error code values are:

- `0` – Successfully converted the point cloud message.
- `1` – The dimensions of the incoming point cloud exceed the limits set in `Maximum point cloud size`.

- **2** – One of the variable-length arrays in the incoming message was truncated. See "Managing Array Sizes in Simulink ROS" to increase the maximum length of the array.
- **3** – The X, Y, or Z field of the point cloud message is missing.
- **4** –The point cloud does not contain any RGB color data. You must have toggled `Show RGB output port` to on to get this error .
- **5** –The point cloud does not contain any intensity data. You must have toggled `Show Intensity output port` to on to get this error.
- **6** – The X, Y, or Z field of the point cloud message does not have the correct data type (`float32`).
- **7** – The `RGB` field of the point cloud message does not have the correct data type (`float32`).
- **8** – The `Intensity` field of the point cloud message does not have the correct data type (`float32`).

For certain error codes, data is truncated or populated with `NaN` values where appropriate.

Data Types: `uint8`

Parameters

`Maximum point cloud size` — Maximum point cloud image size
`[480 640]` (default) | two-element vector

Maximum point cloud image size, specified as a two-element `[height width]` vector.

Click **Configure using ROS ...** to set this parameter automatically using an active topic on a ROS network. You must be connected to the ROS network.

`Preserve point cloud structure` — Preserve point cloud data output shape
off (default) | on

When this check box is selected, the cloud data output shape for XYZ, RGB, and `Intensity` are preserved. The outputs maintain the structure of the original image. Therefore, XYZ and RGB are output as multidimensional arrays, and `Intensity` is output as a matrix.

`Show RGB output port` — Toggle RGB port
on (default) | off

Select this check box to get RGB values for each point of the point cloud message from the RGB port. The RGB data must be supplied by the message.

`Show Intensity output port` — Toggle Intensity port
off (default) | on

Select this check box to get intensity values for each point of the point cloud message from the `Intensity` port. The intensity data must be supplied by the message.

`Show error code output port` — Toggle ErrorCode port
off (default) | on

Select this check box to monitor errors with the `ErrorCode` port.

`Output variable-size signals` — Toggle variable-size signal output
off (default) | on

Select this check box to output variable-size signals. Variable-sized signals should only be used if the image size is expected to change over time. For more information about variable sized signals, see "Variable-Size Signal Basics" (Simulink).

See Also
Blank Message | `PointCloud2` | Subscribe

Topics
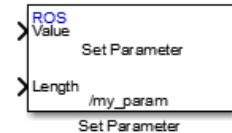"Managing Array Sizes in Simulink ROS"
"Variable-Size Signal Basics" (Simulink)

Introduced in R2017b

Set Parameter

Set values on ROS parameter server
Library: Robotics System Toolbox / ROS

Description

The Set Parameter block sets the **Value** input to the specified name on the ROS parameter server. The block uses the ROS node of the Simulink model to connect to the ROS network. This node is created when you run the model and is deleted when the model terminates. If the model does not have a node, the block creates one.

Input/Output Ports

Input

Value — Parameter value
scalar | logical | uint8 array

Parameter value from the ROS network. The value depends on the **Data type** parameter.

Length — Length of string parameter
integer

Length of the string parameter, specified as an integer. This length is the number of elements of the `uint8` array or the number of characters in the string that you cast to `uint8`.

Note When casting your string parameters to `uint8`, ASCII values 0–31 (control characters) return an error due to their incompatible character type.

Dependencies

To enable this port, set the **Data type** to `uint8[] (string)`.

Parameters

`Source` — Source for specifying the parameter name
`Select from ROS network` | `Specify your own`

Source for specifying the parameter name as one of the following:

- `Select from ROS network` — Use **Select** to select a parameter name. The **Data type** parameter is set automatically. You must be connected to a ROS network.
- `Specify your own` — Enter a parameter name in **Name** and specify its data type in **Data type**. You must match a parameter name exactly.

`Name` — Parameter name
string

Parameter name to get from the ROS network, specified as a string. When **Source** is set to `Select from ROS network`, use **Select** to select an existing parameter. You must be connected to a ROS network to get a list of parameters. Otherwise, specify the parameter and data type.

Parameter name strings must follow the rules of ROS graph names. Valid names have these characteristics:

- The first character is an alpha character ([a-z|A-Z]), tilde (~), or forward slash (/).
- Subsequent characters are alphanumeric ([0-9|a-z|A-Z]), underscores(_), or forward slashes (/).

`Data type` — Data type of your parameter
double | int32 | boolean | uint8[] (string)

Data type of your parameter, specified as a string.

Note The `uint8[] (string)` data type is an array of ASCII values corresponding to the characters in a string. When getting string parameters, you can create a MATLAB Function block to compare the string to a desired parameter value. For more information, see "ROS String Parameters".

Data Types: double | int32 | Boolean | uint8

See Also
Get Parameter

External Websites
ROS Parameter Servers
ROS Graph Names

Introduced in R2015b

Subscribe

Receive messages from ROS network
Library: Robotics System Toolbox / ROS

Description

The Subscribe block creates a Simulink nonvirtual bus that corresponds to the specified ROS message type. The block uses the node of the Simulink model to create a ROS subscriber for a specific topic. This node is created when the model runs and is deleted when the model terminates. If the model does not have a node, the block creates one.

On each simulation step, the block checks if a new message is available on the specific topic.If a new message is available, the block retrieves the message and converts it to a Simulink bus signal. The **Msg** port outputs this new message. If a new message is not available, **Msg** outputs the last received ROS message. If a message has not been received since the start of the simulation, **Msg** outputs a blank message.

Input/Output Ports

Output

`IsNew` — New message indicator
`0` | `1`

New message indicator, returned as a logical. If the output is `1`, then a new message was received since the last sample hit. This output can be used to trigger subsystems for processing new messages received in the ROS network.

`Msg` — ROS message
nonvirtual bus

ROS message, returned as a nonvirtual bus. The type of ROS message is specified in the **Message type** parameter. The Subscribe block outputs blank messages until it receives a

message on the topic name you specify. These blank messages allow you to create and test full models before the rest of the network has been setup.

Data Types: bus

Parameters

Topic source — Source for specifying topic name
Select from ROS network | Specify your own

Source for specifying the topic name, specified as one of the following:

- Select from ROS network — Use **Select** to select a topic name. The **Topic** and **Message type** parameters are set automatically. You must be connected to a ROS network.
- Specify your own — Enter a topic name in **Topic** and specify its message type in **Message type**. You must match a topic name exactly.

Topic — Topic name to subscribe to
string

Topic name to subscribe to, specified as a string. When **Topic source** is set to Select from ROS network, use **Select** to select a topic from the ROS network. You must be connected to a ROS network to get a list of topics. Otherwise, set **Topic source** to Specify your own and specify the topic you want.

Message type — ROS message type
string

ROS message type, specified as a string. Use **Select** to select from a full list of supported ROS messages. Service message types are not supported and are not included in the list.

Sample time — Interval between outputs
−1 (default) | scalar

Interval between outputs, specified as a scalar. In simulation, the sample time follows simulation time and not actual wall-block time.

This default value indicates that the block sample time is *inherited*.

For more information about the inherited sample time type, see "Specify Sample Time" (Simulink).

Length of subscribe callback queue — Message queue length
1 (default) | integer

Message queue length in code generation, specified as an integer. In simulation, the message queue is always 1 and cannot be adjusted. To ensure each message is caught, use a smaller model step or only execute the model if `IsNew` returns `1`.

Tips

You can also set the addresses for the ROS master and node host by clicking the **Configure network addresses** link in the block.

See Also

Blank Message | Publish

Topics

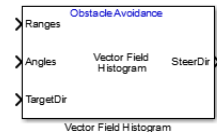"Virtual and Nonvirtual Buses" (Simulink)
"Simulink and ROS Interaction"

Introduced in R2015a

Vector Field Histogram

Avoid obstacles using vector field histogram
Library: Robotics System Toolbox / Mobile Robot Algorithms

Description

The Vector Field Histogram (VFH) block enables your robot to avoid obstacles based on range sensor data. Given a range sensor reading in terms of ranges and angles, and a target direction to drive toward, the VFH controller computes an obstacle-free steering direction.

For more information on the algorithm details, see "Vector Field Histogram" on page 4-52 under Algorithms.

Limitations

- The `Ranges` and `Angles` inputs are limited to 4000 elements when generating code for models that use this block.

Input/Output Ports

Input

Ranges — Range values from scan data
vector of scalars

Range values from scan data, specified as a vector of scalars in meters. These range values are distances from a sensor at specified angles. The vector must be the same length as the corresponding **Angles** vector.

Angles — Angle values from scan data
vector of scalars

Angle values from scan data, specified as a vector of scalars in radians. These angle values are the specific angles of the specified ranges. The vector must be the same length as the corresponding **Ranges** vector.

TargetDir — Target direction for robot
scalar

Target direction for the robot, specified as a scalar in radians. The forward direction of the robot is considered zero radians, with positive angles measured counterclockwise. You can use the **TargetDir** output from the Pure Pursuit block when generating controls from a set of waypoints.

Output

steeringDir — Steering direction for robot
scalar

Steering direction for the robot, specified as a scalar in radians. This obstacle-free direction is calculated based on the VFH+ algorithm. The forward direction of the robot is considered zero radians, with positive angles measured counterclockwise.

Parameters

Main

Number of angular sectors — Number of bins used to create the histograms
180 (default) | scalar

Number of bins used to create the histograms, specified as a scalar. This parameter is nontunable. You can set this parameter only when the object is initialized.

Range distance limits (m) — Limits for range readings
[0.05 2] (default) | two-element vector of scalars

Limits for range readings in meters, specified as a two-element vector of scalars. The range readings input are only considered if they fall within the distance limits. Use the

lower distance limit to ignore false positives from poor sensor performance at lower ranges. Use the upper limit to ignore obstacles that are too far away from the robot.

Histogram thresholds — Thresholds for computing binary histogram
[3 10] (default) | two-element vector of scalars

Thresholds for computing binary histogram, specified as a two-element vector of scalars. The algorithm uses these thresholds to compute the binary histogram from the polar obstacle density. Polar obstacle density values higher than the upper threshold are represented as occupied space (1) in the binary histogram. Values smaller than the lower threshold are represented as free space (0). Values that fall between the limits are set to the values of a previous computed binary histogram if one exists from previous iterations. If a previous histogram does not exist, the value is set as free space (0).

Robot radius (m) — Radius of the robot
0.1 (default) | scalar

Radius of the robot, specified as a scalar in meters. This dimension defines the smallest circle that can circumscribe your robot. The robot radius is used to account for robot size when computing the obstacle-free direction.

Safety distance (m) — Safety distance around the robot
0.1 (default) | scalar

Safety distance left around the robot position in addiction to **Robot radius**, specified as a scalar in meters. The robot radius and safety distance are used to compute the obstacle-free direction.

Minimum turning radius (m) — Minimum turning radius at current speed
0.1 (default) | scalar

Minimum turning radius for the robot moving at its current speed, specified as a scalar in meters.

Simulate using — Specify type of simulation to run
Code generation (default) | Interpreted execution

- Code generation — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time but the speed of the subsequent simulations is comparable to Interpreted execution.

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.

Tunable: No

Cost Function Weights

`Target direction weight` — Cost function weight for target direction
5 (default) | scalar

Cost function weight for moving toward the target direction, specified as a scalar. To follow a target direction, set this weight to be higher than the sum of **Current direction weight** and **Previous direction weight**. To ignore the target direction cost, set this weight to 0.

`Current direction weight` — Cost function weight for current direction
2 (default) | scalar

Cost function weight for moving the robot in the current heading direction, specified as a scalar. Higher values of this weight produce efficient paths. To ignore the current direction cost, set this weight to 0.

`Previous direction weight` — Cost function weight for previous direction
2 (default) | scalar

Cost function weight for moving in the previously selected steering direction, specified as a scalar. Higher values of this weight produce smoother paths. To ignore the previous direction cost, set this weight to 0.

Algorithms

Vector Field Histogram

The block uses the VFH+ algorithm to compute the obstacle-free direction. First, the algorithm takes the ranges and angles from range sensor data and builds a polar histogram for obstacle locations. Then, it uses the input histogram thresholds to calculate a binary histogram that indicates occupied and free directions. Finally, the algorithm computes a masked histogram, which is computed from the binary histogram based on the minimum turning radius of the robot.

The algorithm selects multiple steering directions based on the open space and possible driving directions. A cost function, with weights corresponding to the previous, current, and target directions, calculates the cost of different possible directions. The algorithm then returns an obstacle-free direction with minimal cost. Using the obstacle-free direction, you can input commands to move your robot in that direction.

To use this block for your own application and environment, you must tune the algorithm parameters. Parameter values depend on the type of robot, the range sensor, and the hardware you use. For more information on the VFH algorithm, see "Vector Field Histogram".

See Also

Blocks
Publish | Pure Pursuit | Subscribe

Classes
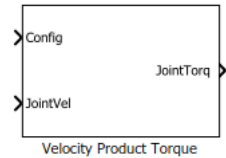`robotics.VectorFieldHistogram`

Topics
"Vector Field Histogram"

Introduced in R2016b

Velocity Product Torque

Joint torques that cancel velocity-induced forces
Library: Robotics System Toolbox / Manipulator Algorithms

Description

The Velocity Product Torque block returns the torques that cancel the velocity-induced forces for the given robot configuration (joint positions) and joint velocities for the **Rigid body tree** robot model.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

`JointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Output

`JointTorq` — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

See Also

Blocks
Forward Dynamics | Get Jacobian | Gravity Torque | Inverse Dynamics | Joint Space Mass Matrix

Classes
`RigidBodyTree`

Functions
`homeConfiguration` | `importrobot` | `randomConfiguration` | `velocityProduct`

Introduced in R2018a