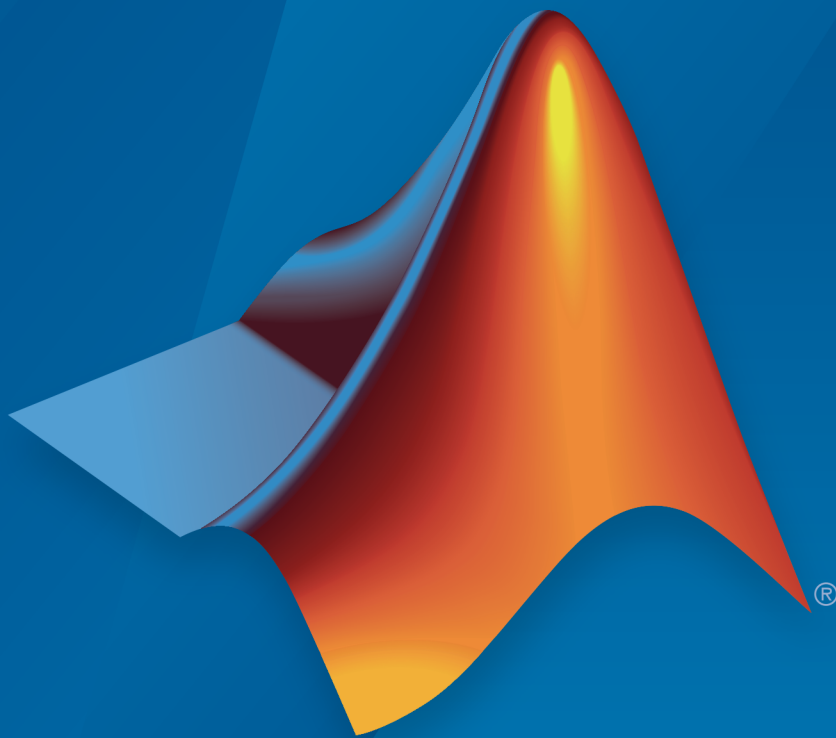


Robotics System Toolbox™

User's Guide



MATLAB® & SIMULINK®

R2015b

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Robotics System Toolbox™ User Guide

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Coordinate System Transformations

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Standard Units for Robotics System Toolbox

Robotics System Toolbox™ uses a fixed set of standards for units to ensure consistency across algorithms and applications. Unless specified otherwise, functions and classes in this toolbox represent all values in units based on the International System of Units (SI). The table below summarizes the relevant quantities and their SI derived units.

Quantity	Unit (abbrev.)
Length	meter (m)
Time	second (s)
Angle	radian (rad)
Velocity	meter/second (m/s)
Angular Velocity	radian/second (rad/s)
Acceleration	meter/second ² (m/s ²)
Angular Acceleration	radian/second ² (rad/s ²)
Mass	kilogram (kg)
Force	Newton (N)
Torque	Newton-meter (N-m)
Moment of Inertia	kilogram-meter ² (kg-m ²)

Coordinate Transformations in Robotics

In this section...

“Axis-Angle” on page 1-3

“Euler Angles” on page 1-4

“Homogeneous Transformation Matrix” on page 1-4

“Quaternion” on page 1-5

“Rotation Matrix” on page 1-5

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In robotics applications, many different coordinate systems can be used to define where robots, sensors, and other objects are located. In general, the location of an object in 3-D space is defined by its position and orientation. There are multiple possible representations for these quantities, some of which are specific to certain applications. Translation and rotation are alternative terms for position and orientation. Robotics System Toolbox supports representations that are commonly used in robotics and allows you to convert between them. You can transform between coordinate systems when you apply these representations to 3-D points. These supported representations are detailed below with brief explanations of their usage and numeric equivalent in MATLAB[®]. Each representation has an abbreviation for its name. This is used in the naming of arguments and conversion functions that are supported in this toolbox.

At the end of this section, you can find out about the conversion functions that we offer to convert between these representations.

Robotics System Toolbox assumes that positions and orientations are defined in a right-handed Cartesian coordinate system.

Axis-Angle

Abbreviation: `axang`

A rotation in 3-D space described by a scalar rotation around a fixed axis defined by a vector.

Numeric Representation: 1-by-3 unit vector and a scalar angle combined as a 1-by-4 vector

For example, a rotation of $\pi/2$ radians around the y -axis would be:

```
axang = [0 1 0 pi/2]
```

Euler Angles

Abbreviation: eul

Euler angles are three angles that describe the orientation of a rigid body. Each angle is a scalar rotation around a given coordinate frame axis. The Robotics System Toolbox supports two rotation orders. The 'ZYX' axis order is commonly used for robotics applications. We also support the 'ZYX' axis order which is also denoted as "Roll Pitch Yaw (rpy)." Knowing which axis order you use is important for apply the rotation to points and in converting to other representations.

Numeric Representation: 1-by-3 vector of scalar angles

For example, a rotation around the y -axis of π would be expressed as:

```
eul = [0 pi 0]
```

Note: The axis order is not stored in the transformation, so you must be aware of what rotation order is to be applied.

Homogeneous Transformation Matrix

Abbreviation: tform

A homogeneous transformation matrix combines a translation and rotation into one matrix.

Numeric Representation: 4-by-4 matrix

For example, a rotation of angle α around the y -axis and a translation of 4 units along the y -axis would be expressed as:

```
tform =  
  cos  $\alpha$   0      sin  $\alpha$   0  
  0          1      0          4  
 -sin  $\alpha$   0      cos  $\alpha$   0  
  0          0      0          1
```

You should **pre-multiply** your transformation matrix with your homogeneous coordinates, which are represented as a matrix of row vectors (n -by-4 matrix of points). For example:

```
points = rand(100,4);
tformPoints = tform*points;
```

Quaternion

Abbreviation: quat

A quaternion is a four-element vector with a scalar rotation and 3-element vector. Quaternions are advantageous because they avoid singularity issues that are inherent in other representations. The first element, w , is a scalar to normalize the vector with the three other values, $[x\ y\ z]$ defining the axis of rotation.

Numeric Representation: 1-by-4 vector

For example, a rotation of $\pi/2$ around the y -axis would be expressed as:

```
quat = [0.7071 0 0.7071 0]
```

Rotation Matrix

Abbreviation: rotm

A rotation matrix describes a rotation in 3-D space. It is a square, orthonormal matrix with a determinant of 1.

Numeric Representation: 3-by-3 matrix

For example, a rotation of α degrees around the x -axis would be:

```
rotm =
    1     0     0
    0   cos α  -sin α
    0   sin α   cos α
```

You should **pre-multiply** your rotation matrix with your coordinates, which are represented as a matrix of row vectors (n -by-3 matrix of points). For example:

```
points = rand(100,3);
rotPoints = rotm*points;
```

Translation Vector

Abbreviation: trvec

A translation vector is represented in 3-D Euclidean space as Cartesian coordinates. It only involves coordinate translation applied equally to all points. There is no rotation involved.

Numeric Representation: 1-by-3 vector

For example, a translation by 3 units along the x -axis and 2.5 units along the z -axis would be expressed as:

```
trvec = [3 0 2.5]
```

Conversion Functions and Transformations

Robotics System Toolbox provides conversion functions for the previously mentioned transformation representations. Not all conversions are supported by a dedicated function. Below is a table showing which conversions are supported (in blue). The abbreviations for the rotation and translation representations are shown as well.

Converting To \ Converting From	Axis-Angle (axang)	Euler Angles (eul)	Quaternion (quat)	Rotation Matrix (rotm)	Homogeneous Transformation (tform)	Translation Vector (trvec)
Axis-Angle (axang)						
Euler Angles (eul)						
Quaternion (quat)						
Rotation Matrix (rotm)						
Homogeneous Transformation (tform)						
Translation Vector (trvec)						

The names of all the conversion functions follow a standard format. They follow the form $\alpha\beta$ where α is the abbreviation for what you are converting from and β is what you are converting to as an abbreviation. For example, converting from Euler angles to quaternion would be `eul2quat`.

All the functions expect valid inputs. If you specify invalid inputs, the outputs will be undefined.

There are other conversion functions for converting between radians and degrees, Cartesian and homogeneous coordinates, and for calculating wrapped angle differences. For a full list of conversions, see “Coordinate System Transformations”.

Algorithm Design

- “Occupancy Grids” on page 2-2
- “Probabilistic Roadmaps (PRM)” on page 2-7
- “Pure Pursuit Controller” on page 2-17
- “Vector Field Histogram” on page 2-20

Occupancy Grids

In this section...

“Binary Occupancy Grid” on page 2-2

“World and Grid Coordinates” on page 2-2

“Inflation of Coordinates” on page 2-5

Binary Occupancy Grid

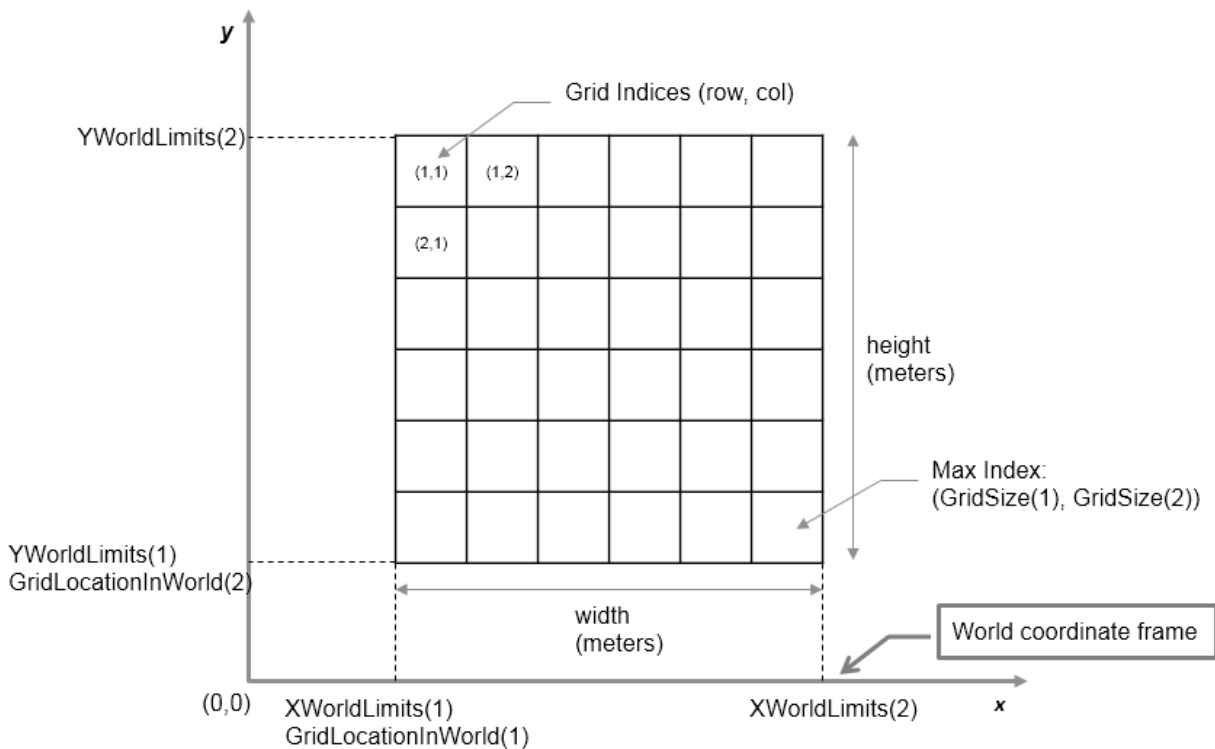
Occupancy grids are used to represent a robot’s workspace as a discrete grid. Information about the environment can be collected from sensors in real time or be loaded from prior knowledge. For robotics applications, laser range finders, bump sensors, cameras, and depth sensors are commonly used to find obstacles. A binary occupancy grid uses simple `true` and `false` values to represent the occupied workspace (obstacles) and free workspace respectively. This map shows where obstacles are and whether a robot can move through that space.

World and Grid Coordinates

When working with occupancy grids, you have the option to use either world or grid coordinates. This section describes the difference between these coordinate systems and how to work with them in MATLAB.

The absolute reference frame in which the robot operates is referred to as the "world" frame in the occupancy grid. Most operations using Robotics System Toolbox are performed in the world frame, and this is the default selection when using MATLAB functions in this toolbox. World coordinates are used as an absolute coordinate frame with a fixed origin and have unlimited resolution when specifying locations. However, all locations are converted to grid locations because of data storage and resolution limits.

Grid coordinates define the actual resolution of the occupancy grid and the finite locations of obstacles. The origin of grid coordinates is in the top-left of the grid with the first location having a location of $(1, 1)$. However, the location of the grid in world coordinates is defined by the property, `GridLocationInWorld` and specifies the bottom-left location of the grid. When creating a `robotics.BinaryOccupancyGrid` object, other properties such as `XWorldLimits` and `YWorldLimits` are defined by the input `width`, `height`, and `resolution`. The figure below shows a visual representation of these properties and the relation between world and grid coordinates.



Grid Coordinates from World Coordinate Inputs

When setting occupancy locations, you can input the locations in either grid or world coordinates. However, based on the limits of the grid, the locations are set to the closest grid locations. Edges of the grid belong to the lower left grid location.

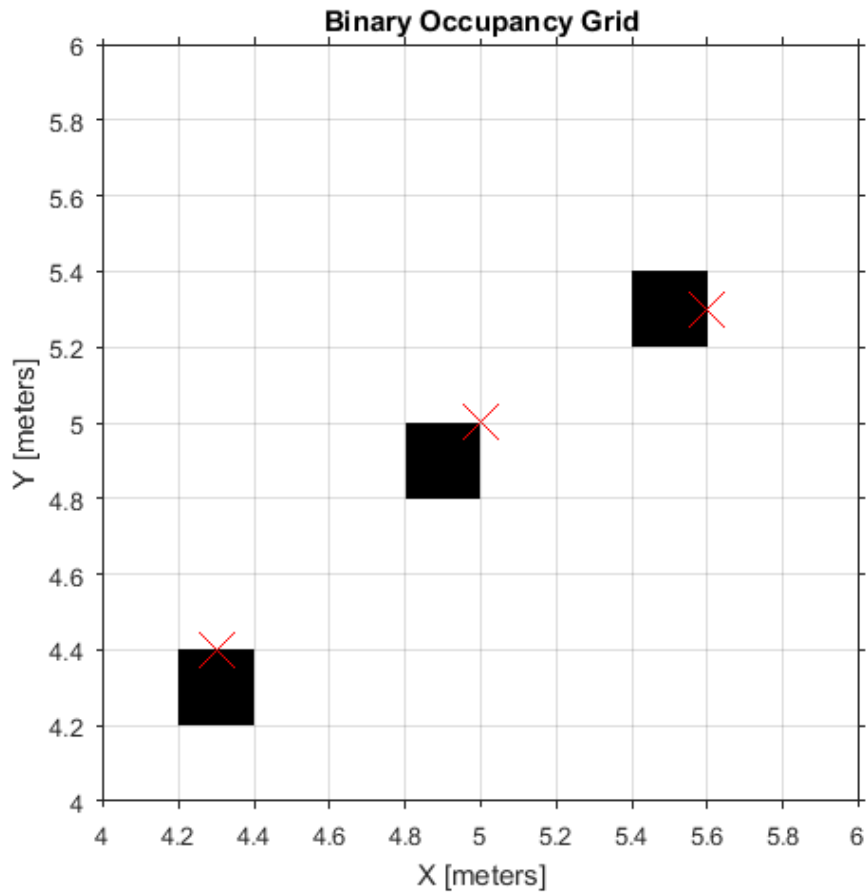
This example shows how the locations are interpreted on the grid. An occupancy grid is created and three points are set as occupied by obstacles. The original input points are then plotted over the map to show how they are interpreted. Also note that the entire grid cell is set as occupied if any point within the grid cell is set as occupied.

Create occupancy grid and set obstacle locations.

```
map = robotics.BinaryOccupancyGrid(10,10,5);
xy = [5 5; 4.3 4.4; 5.5 5.4];
setOccupancy(map,xy, 1);
```

Display map, original points and set axes.

```
show(map);  
hold on  
plot(xy(:,1),xy(:,2),'xr','MarkerSize', 20)  
grid on  
set(gca,'XTick', 0:0.2:10,'YTick',0:0.2:10)  
xlim([4 6])  
ylim([4 6])
```

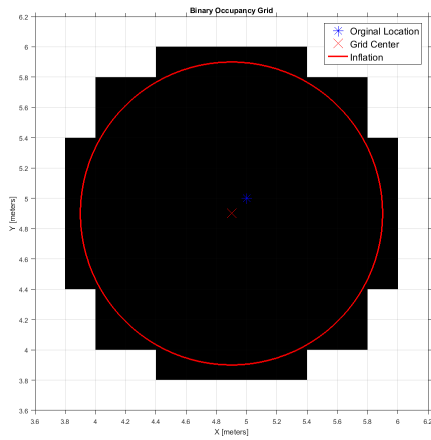


Inflation of Coordinates

The `inflate` method (`robotics.BinaryOccupancyGrid.inflate`) is used to account for the robot's dimensions. By inflating the obstacle locations, you can create buffer zones for the robot to have space to navigate without hitting obstacles. When inflating obstacles, the specified `radius` is converted to the number of cells rounded up from the value `resolution*radius`. Each occupied cell is then inflated by this cell value. This inflation can have some important effects if the accuracy of the map at individual grid locations is extremely important. A basic inflation example is shown to illustrate how the radius value is used. The result of `inflate` by `1m` on an obstacle at world location `[5 5]` is shown. The input `radius` is plotted as a circle from the obstacle grid location. **Note:** *The center location of the obstacle is converted to a grid location (from `[5 5]` in blue to `[4.9 4.9]` in red), which accounts for a small shift in the circle center as well.*

This example shows how to create the map, set the obstacle locations and inflate it by a radius of `1m`. Extra plots on the figure help illustrate the inflation and shifting due to conversion to grid locations.

```
map = robotics.BinaryOccupancyGrid(10,10,5);
setOccupancy(map,[5 5], 1);
inflate(map,1);
show(map)
hold on
theta = linspace(0,2*pi);
x = 4.9+cos(theta);
y = 4.9+sin(theta);
plot(5,5,'*b','MarkerSize',10)
plot(4.9,4.9,'xr','MarkerSize',10)
plot(x,y,'-r','LineWidth',2);
xlim([3.6 6.2])
ylim([3.6 6.2])
grid on
legend('Original Location','Grid Center','Inflation')
```



As you can see from the above figure, even cells that barely overlap with the inflation radius are labeled as occupied.

Probabilistic Roadmaps (PRM)

In this section...

“Tune the Number of Nodes” on page 2-7

“Tune the Connection Distance” on page 2-11

“Create or Update PRM” on page 2-14

A probabilistic roadmap (PRM) is a network graph of possible paths in a given map based on free and occupied spaces. The `robotics.PRM` class randomly generates nodes and creates connections between these nodes based on the PRM algorithm parameters. Nodes are connected based on the obstacle locations specified in `Map`, and on the specified `ConnectionDistance`. You can customize the number of nodes, `NumNodes`, to fit the complexity of the map and the desire to find the most efficient path. The PRM algorithm uses the network of connected nodes to find an obstacle-free path from a start to an end location. To plan a path through an environment effectively, tune the `NumNodes` and `ConnectionDistance` properties.

When creating or updating the `robotics.PRM` class, the node locations are randomly generated, which can affect your final path between multiple iterations. This selection of nodes occurs when you specify `Map` initially, change the parameters, or `update` is called. To get consistent results with the same node placement, use `rng` to save the state of the random number generation. See “Tune the Connection Distance” on page 2-11 for an example using `rng`.

Tune the Number of Nodes

This example shows how to use the `NumNodes` property to tune the PRM algorithm. `NumNodes` specifies the number of points, or nodes, placed on the map, which the algorithm uses to generate a roadmap. Using the `ConnectionDistance` property as a threshold for distance, the algorithm connects all points that do not have obstacles blocking the direct path between them.

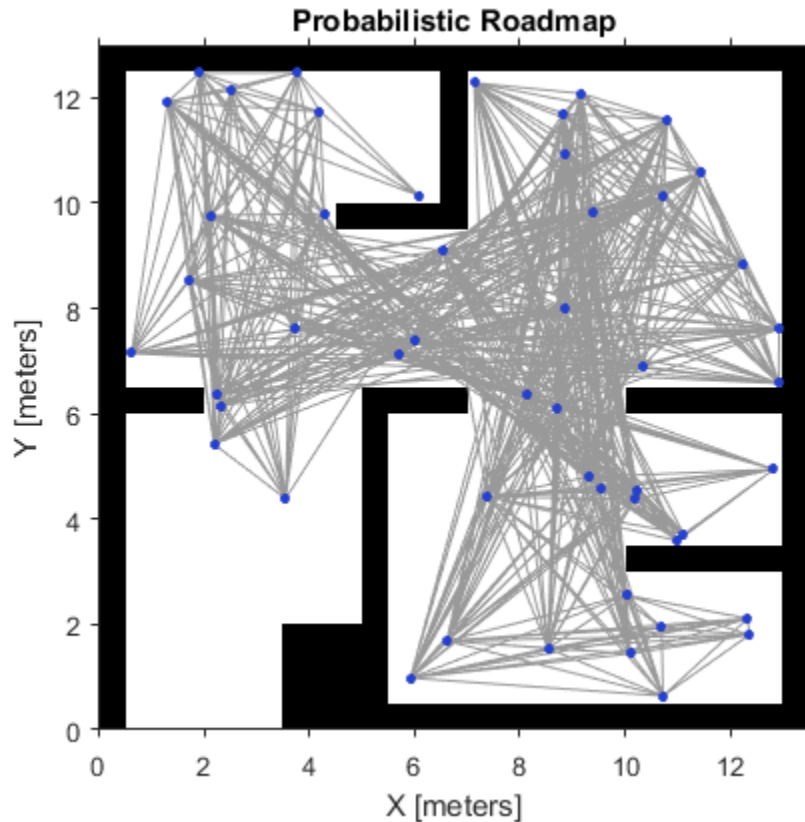
Increasing the number of nodes can increase the efficiency of the path by giving more feasible paths. However, the increased complexity increases computation time. To get good coverage of the map, you might need a large number of nodes. Due to the random placement of nodes, some areas of the map may not have enough nodes to connect to the rest of the map. In this example, you create a large and small number of nodes in a roadmap.

Load a map file and create an occupancy grid.

```
filePath = fullfile(fileparts(which('PathPlanningExample')), 'data', 'exampleMaps.mat');  
load(filePath)  
map = robotics.BinaryOccupancyGrid(simpleMap,2);
```

Create a simple roadmap with 50 nodes.

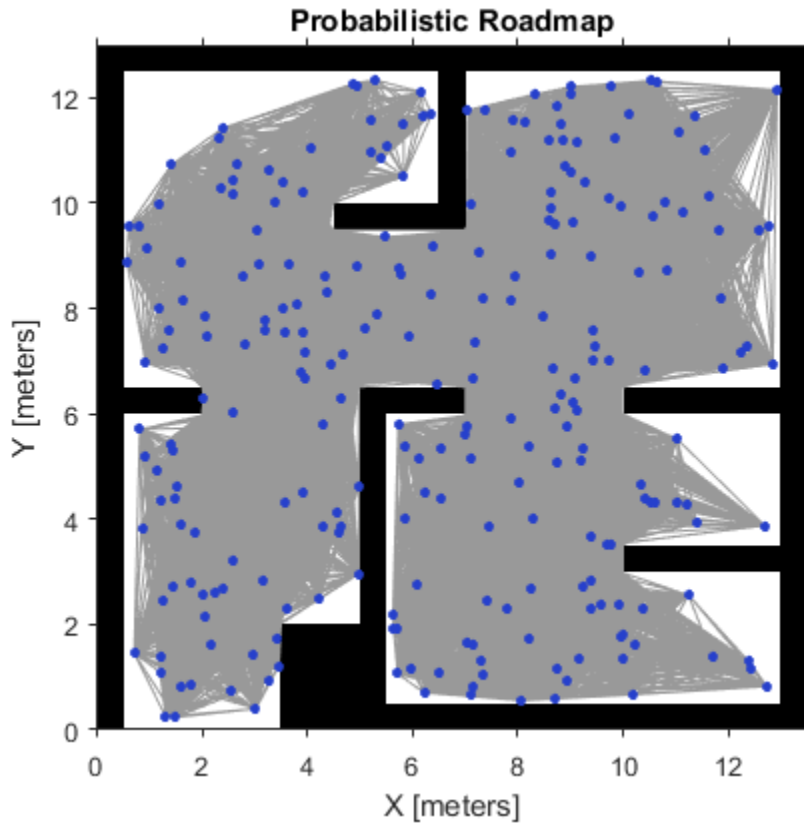
```
prmSimple = robotics.PRM(map,50);  
show(prmSimple)
```



Create a dense roadmap with 250 nodes.

```
prmComplex = robotics.PRM(map,250);
```

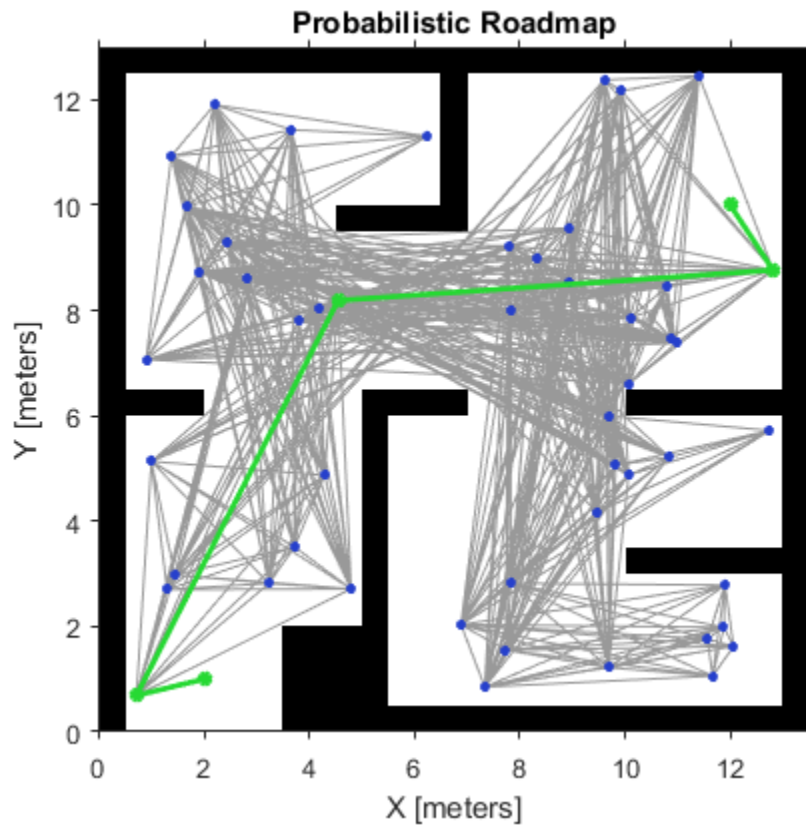
```
show(prmComplex)
```



The additional nodes increase the complexity but yield more options to improve the path. Given these two maps, you can calculate a path using the PRM algorithm and see the effects.

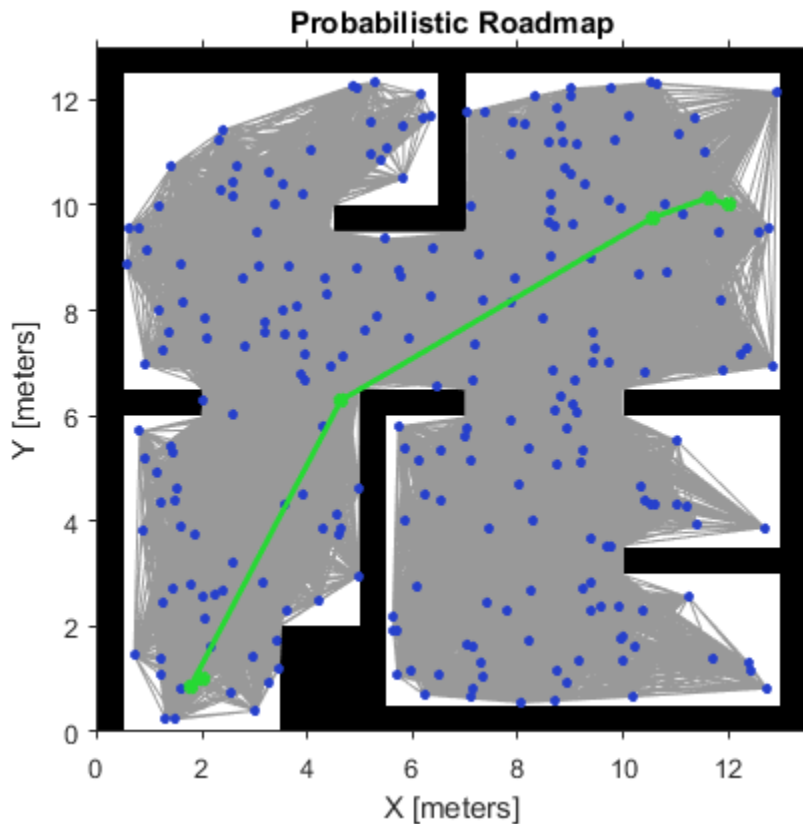
Calculate a simple path.

```
startLocation = [2 1];
endLocation = [12 10];
path = findpath(prmSimple,startLocation,endLocation);
show(prmSimple)
```



Calculate a complex path.

```
path = findpath(prmComplex, startLocation, endLocation);  
show(prmComplex)
```

Increasing the nodes allows for a more direct path, but adds more computation time to finding a feasible path. Because of the random placement of points, the path is not always more direct or efficient. Using a small number of nodes can make paths worse than depicted and even restrict the ability to find a complete path.

Tune the Connection Distance

This example shows how to use the `ConnectionDistance` property to tune the PRM algorithm. `ConnectionDistance` is an upper threshold for points that are connected in the roadmap. Each node is connected to all nodes within this connection distance that do not have obstacles between them. By lowering the connection distance, you can limit the number of connections to reduce the computation time and simplify the map. However,

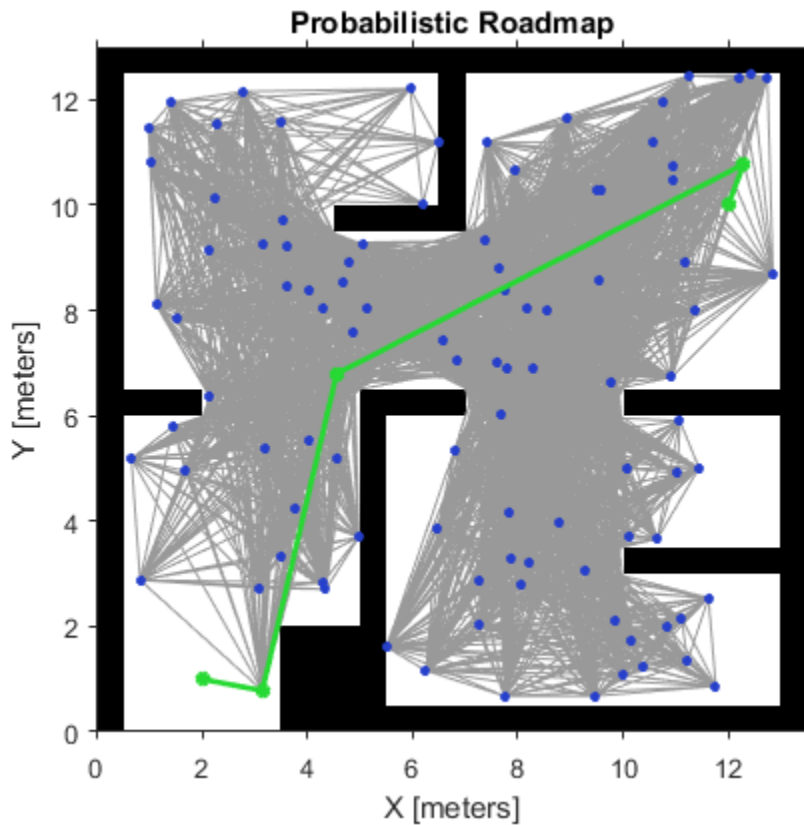
a lowered distance limits the number of available paths from which to find a complete obstacle-free path. When working with simple maps, you can use a higher connection distance with a small number of nodes to increase efficiency. For complex maps with lots of obstacles, a higher number of nodes with a lowered connection distance increases the chance of finding a solution.

Load a map file and create an occupancy grid.

```
filePath = fullfile(fileparts(which('PathPlanningExample')), 'data', 'exampleMaps.mat');  
load(filePath)  
map = robotics.BinaryOccupancyGrid(simpleMap,2);
```

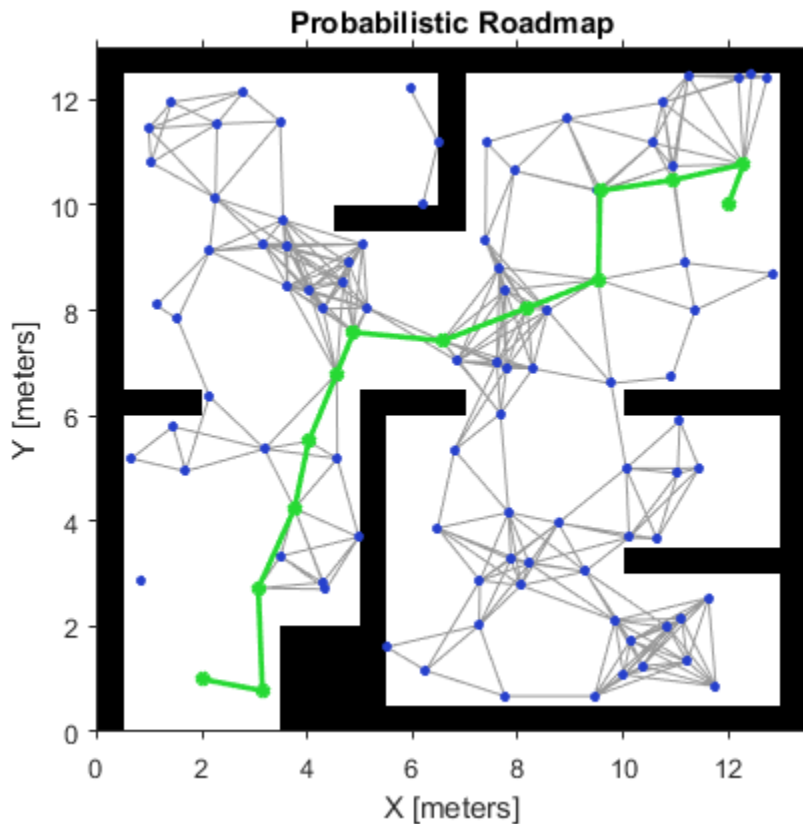
Create a roadmap with 100 nodes and calculate the path. The default `ConnectionDistance` is set to `inf`. Save the random number generation settings using the `rng` function. The saved settings enable you to reproduce the same points and see the effect of changing `ConnectionDistance`.

```
rngState = rng;  
prm = robotics.PRM(map,100);  
startLocation = [2 1];  
endLocation = [12 10];  
path = findpath(prm,startLocation,endLocation);  
show(prm)
```



Reload the random number generation settings to have PRM use the same nodes. Lower ConnectionDistance to 2 m. Show the calculated path.

```
rng(rngState);  
prm.ConnectionDistance = 2;  
path = findpath(prm,startLocation,endLocation);  
show(prm)
```



Create or Update PRM

This example shows how to create or update your roadmap. To create the roadmap, call `prm = robotics.PRM(map, __)` or specify the `prm.Map` property. Then, call the `update`, `findpath`, or `show` method. At this point, the nodes are randomly generated and the connections are made.

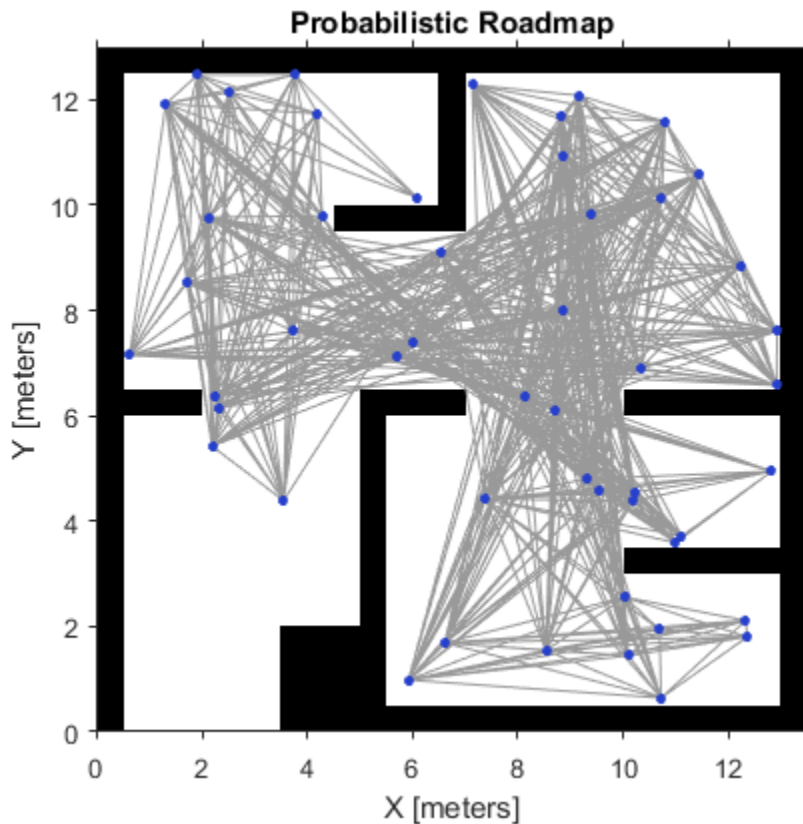
This roadmap changes only if you call `update` or change the properties in the `robotics.PRM` object. When properties change, any method (`update`, `findpath`, or `show`) called on the object triggers the roadmap points and connections to be recalculated. Because recalculating the map can be computationally intensive, you can reuse the same roadmap by calling `findpath` with different starting and ending locations.

Load a map file and create an occupancy grid.

```
filePath = fullfile(fileparts(which('PathPlanningExample')), 'data', 'exampleMaps.mat');  
load(filePath)  
map = robotics.BinaryOccupancyGrid(simpleMap,2);
```

Create a roadmap. Your nodes and connections might look different due to the random placement of nodes.

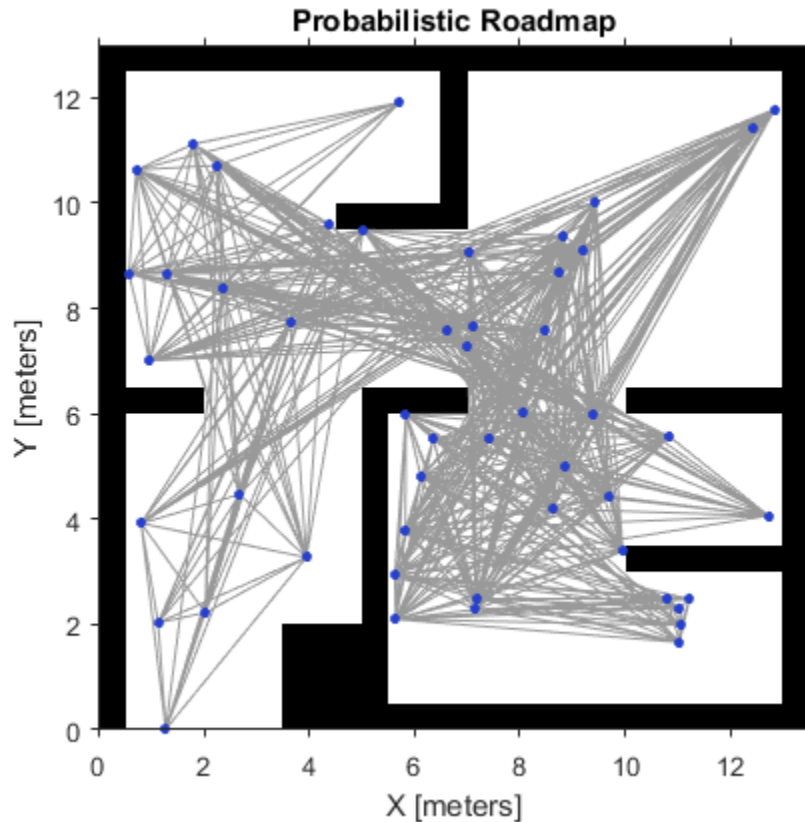
```
prm = robotics.PRM(map,100);  
show(prm)
```



Call `update` or change a parameter to update the PRM nodes and connections.

```
update(prm)
```

```
show(prm)
```



The PRM algorithm recalculates the node placement and generates a new network of nodes.

References

- [1] Kavraki, L.E., P. Svestka, J.-C. Latombe, and M.H. Overmars. "Probabilistic roadmaps for path planning in high-dimensional configuration spaces," *IEEE Transactions on Robotics and Automation*. Vol. 12, No. 4, Aug 1996 pp. 566—580.

See Also

`robotics.PRM` | `robotics.PRM.findpath` | `robotics.PRM.show` | `robotics.PRM.update`

Pure Pursuit Controller

In this section...

“Reference Coordinate System” on page 2-17

“Look Ahead Distance” on page 2-18

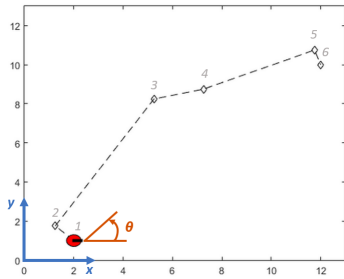
“Limitations” on page 2-19

PurePursuit is a path tracking algorithm. It computes the angular velocity command that moves the robot from its current position to reach some look-ahead point in front of the robot. The linear velocity is assumed constant, hence you can change the linear velocity of the robot at any point. The algorithm then moves the look-ahead point on the path based on the current position of the robot until the last point of the path. You can think of this as the robot constantly chasing a point in front of it. The property `LookAheadDistance` decides how far the look-ahead point is placed.

The `PurePursuit` class (`robotics.PurePursuit`) is not a traditional controller, but acts as a tracking algorithm for path following purposes. In the Robotics System Toolbox, you create a `PurePursuit` controller and specify a list of waypoints. The desired linear and maximum angular velocities can be specified. These properties are determined based on the robot’s specifications. Given the pose (position and orientation) of the robot as an input, the `step` function can be used to calculate the linear and angular velocities commands for the robot. How the robot uses these commands is dependent on the system you are using, so consider how robots can execute a motion given these commands. The final important property is the `LookAheadDistance`, which tells the robot how far along on the path to track towards. This property is explained in more detail in a section below.

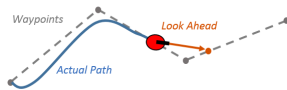
Reference Coordinate System

It is important to understand the reference coordinate frame used by the `PurePursuit` algorithm for its inputs and outputs. The figure below shows the reference coordinate system. The input waypoints are `[x y]` coordinates, which are used to compute the robot velocity commands. The robot’s pose is input as a pose and orientation (`theta`) list of points as `[x y theta]`. The positive `x` and `y` directions are in the right and up directions respectively (blue in figure). The `theta` value is the angular orientation of the robot measured counterclockwise in radians from the `x`-axis (robot currently at 0 radians).

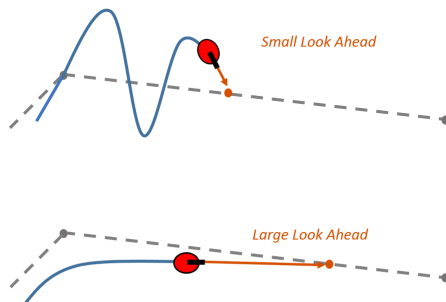


Look Ahead Distance

The `LookAheadDistance` property is the main tuning property for the `PurePursuit` controller. The look ahead distance is how far along the path the robot should look from the current location to compute the angular velocity commands. The figure below shows the robot and the look-ahead point. As displayed in this image, note that the actual path does not match the direct line between waypoints.



The effect of changing this parameter can change how your robot tracks the path and there are two major goals: regaining the path and maintaining the path. In order to quickly regain the path between waypoints, a small `LookAheadDistance` will cause your robot to move quickly towards the path. However, as can be seen in the figure below, the robot overshoots the path and oscillates along the desired path. In order to reduce the oscillations along the path, a larger look ahead distance can be chosen, however, it might result in larger curvatures near the corners.



The `LookAheadDistance` property should be tuned for your application and robot system. Different linear and angular velocities will affect this response as well and should be considered for the path following controller.

Limitations

There are a few limitations to note about this `PurePursuit` algorithm:

- As shown above, the controller cannot exactly follow direct paths between waypoints. Parameters must be tuned to optimize the performance and to converge to the path over time.
- This `PurePursuit` algorithm does not stabilize the robot at a point. In your application, a distance threshold for a goal location should be applied to stop the robot near the desired goal. This can be seen in the path following example: “Path Following for a Differential Drive Robot”.

References

- [1] Coulter, R. *Implementation of the Pure Pursuit Path Tracking Algorithm*. Carnegie Mellon University, Pittsburgh, Pennsylvania, Jan 1990.

Vector Field Histogram

In this section...

“Robot Dimensions” on page 2-20

“Cost Function Weights” on page 2-22

“Histogram Properties” on page 2-23

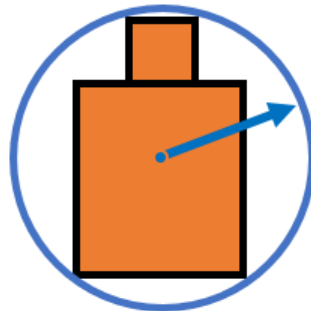
“Tune Parameters Using show” on page 2-27

The vector field histogram (VFH) algorithm computes obstacle-free steering directions for a robot based on range sensor readings. Range sensor readings are used to compute polar density histograms to identify obstacle location and proximity. Based on the specified parameters and thresholds, these histograms are converted to binary histograms to indicate valid steering directions for the robot. The VFH algorithm factors in robot size and turning radius to output a steering direction for the robot to avoid obstacles and follow a target direction.

Robot Dimensions

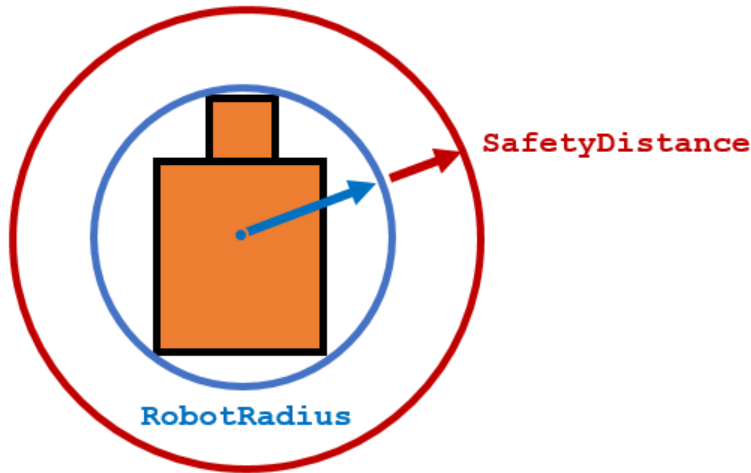
To calculate steering directions, you must specify information about the robot size and its driving capabilities. The VFH algorithm requires only four input parameters for the robot. These parameters are properties of the `robotics.VectorFieldHistogram` class: `RobotRadius`, `SafetyDistance`, `MinTurningRadius`, and `DistanceLimits`.

- `RobotRadius` specifies the radius of the smallest circle that can encircle all parts of the robot. This radius ensures that the robot avoids obstacles based on its size.

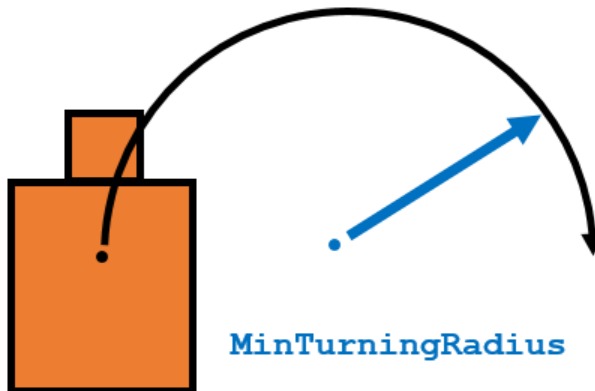


RobotRadius

- **SafetyDistance** optionally specifies an added distance on top of the **RobotRadius**. You can use this property to add a factor of safety when navigating an environment.

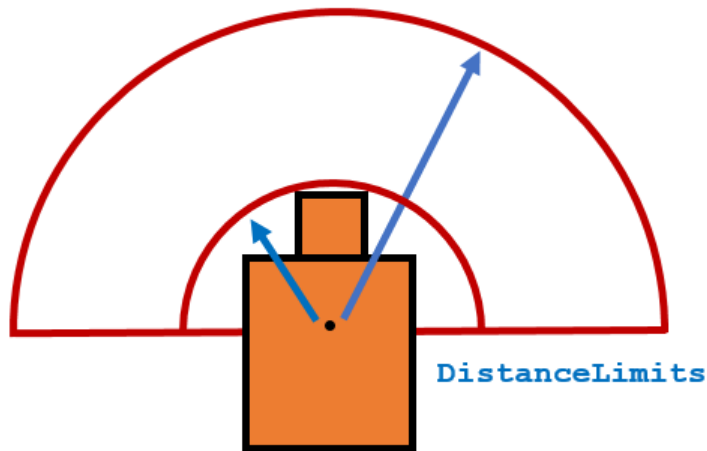


- **MinTurningRadius** specifies the minimum turning radius for the robot traveling at the desired velocity. The robot may not be able to make sharp turns at high velocities. This property factors in navigating around obstacles and gives it enough space to maneuver.



- **DistanceLimits** specifies the distance range that you want to consider for obstacle avoidance. You specify the limits in a two-element vector, [lower upper]. The

Lower limit is used to ignore sensor readings that intersect with parts on the robot, sensor inaccuracies at short distances, or sensor noise. The upper limit is the effective range of the sensor or is based on your application. You might not want to consider all obstacles in the full sensor range.



Note: All information about the range sensor readings assumes that your range finder is mounted in the center of your robot. If the range sensor is mounted elsewhere, transform your range sensor readings from the laser coordinate frame to the robot base frame. See “Transform Laser Scan Data” on page 6-2 for an example.

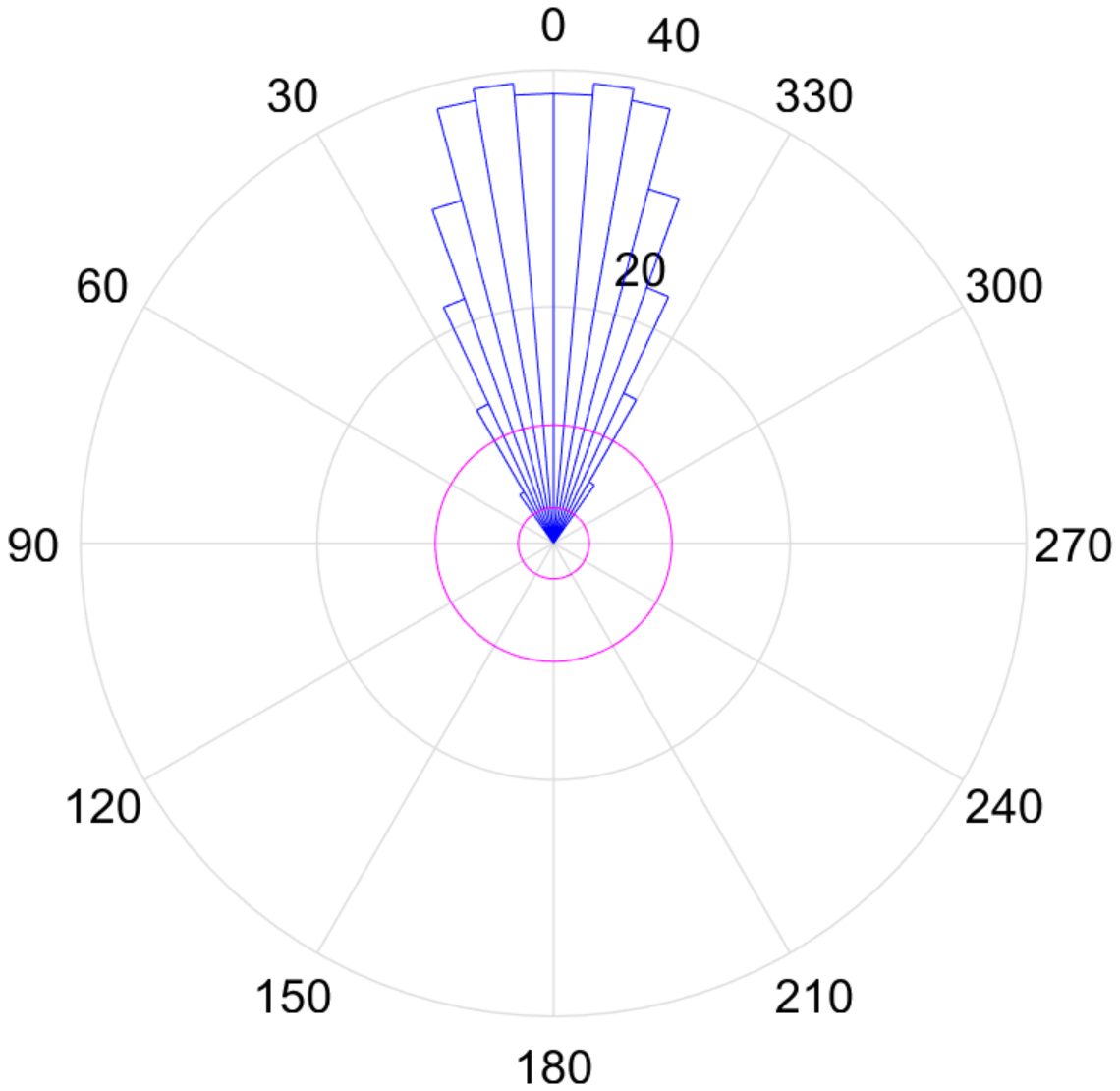
Cost Function Weights

Cost function weights are used to calculate the final steering directions. The VFH algorithm considers multiple steering directions based on your current, previous, and target directions. By setting the `CurrentDirectionWeight`, `PreviousDirectionWeight`, and `TargetDirectionWeight` properties, you can modify the steering behavior of your robot. Changing these weights affects the responsiveness of the robot and how it reacts to obstacles. To make the robot head towards its goal location, set `TargetDirectionWeight` higher than the sum of the other weights. This high `TargetDirectionWeight` value helps to ensure the computed steering direction is close to the target direction. Depending on your application, you might need to tune these weights.

Histogram Properties

The VFH algorithm calculates a histogram based on the given range sensor data. It takes all directions around the robot and converts them to angular sectors that are specified by the `NumAngularSectors` property. This property is non-tunable and remains fixed once the `step` method is called on the `robotics.VectorFieldHistogram` object. The range sensor data is used to calculate a polar density histogram over these angular sectors.

Polar Obstacle Density

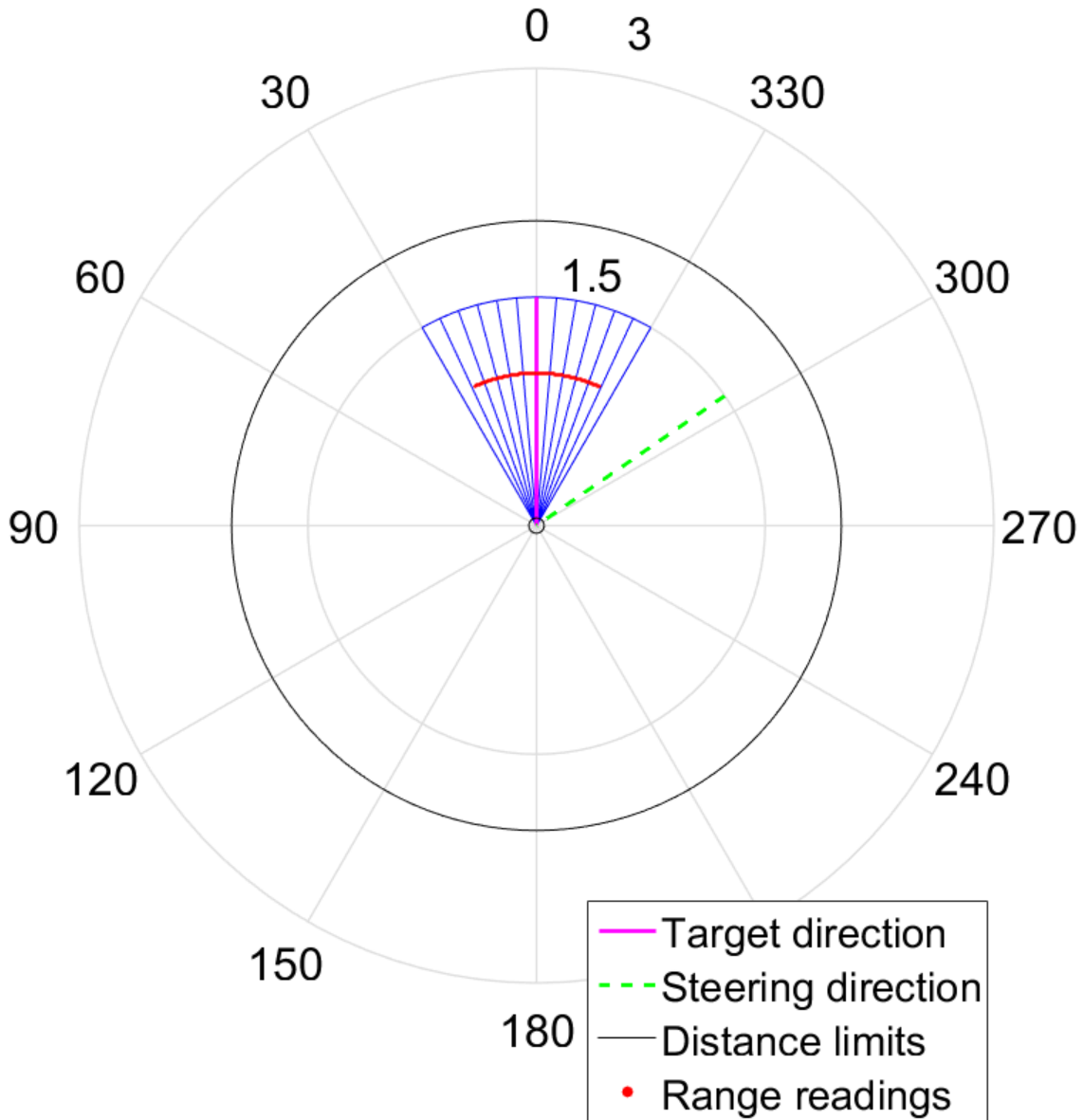


Note: Using a small `NumAngularSectors` value can cause the VFH algorithm to miss smaller obstacles. Missed obstacles do not appear on the histogram.

This histogram displays the angular sectors in blue and the histogram thresholds in pink. The `HistogramThresholds` property is a two-element vector that determines the values of the masked histogram, specified as `[lower upper]`. Polar obstacle density values higher than the upper threshold are represented as occupied space (1) in the masked 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). The masked histogram also factors in the `MinTurningRadius`, `RobotSize`, and `SafetyDistance`.

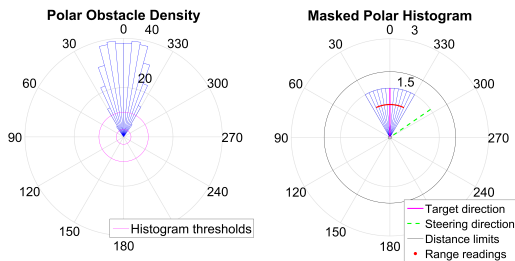
The polar density plot has the following corresponding masked histogram plot. This plot shows the target and steering directions, range readings, and distance limits.

Masked Polar Histogram



Tune Parameters Using show

When working with a `robotics.VectorFieldHistogram` object, you can visualize the properties and parameters of the algorithm using the `robotics.VectorFieldHistogram.show` method. This method displays the polar density plot and masked binary histogram. It also displays the algorithm parameters and the output steering direction for the VFH.



You can then tune parameters to help you prototype your obstacle avoidance application. For example, if you see that certain obstacles do not appear in the **Masked Polar Histogram** plot (right), then in the **Polar Obstacle Density** plot, consider adjusting the histogram thresholds to appropriate values. After you make the adjustments in the **Masked Polar Histogram** plot, the range sensor readings, shown in red, should match up with locations in the masked histogram (blue). Also, you can see the target and steering directions. You specify the target direction. The steering direction is the main output from the VFH algorithm. Adjusting the “Cost Function Weights” on page 2-22 can help you tune the output of the final steering direction.

Although you can use the `show` method in a loop, it slows computation speed due to the graphical plotting. If you are running this algorithm for real-time applications, get and display the VFH data in separate operations.

See Also

`robotics.VectorFieldHistogram` | `robotics.VectorFieldHistogram.show`

ROS Network Concepts

ROS Network Setup

In this section...
“Introduction” on page 3-2
“Network Connection Layout” on page 3-2
“Examples” on page 3-3

Introduction

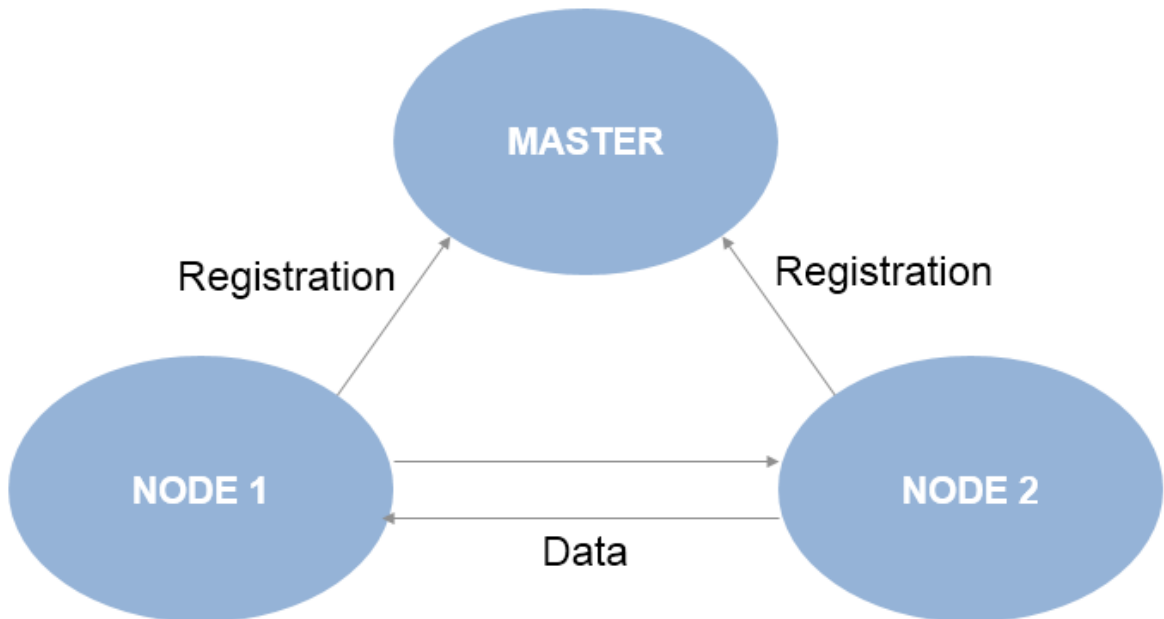
Setting up a ROS network allows for communication between different devices. Different participants or *nodes* all register with a ROS master to share information. The ROS master is unique and each ROS network only has one master. Each node is usually a separate device, although one device can have multiple nodes running. MATLAB acts as one of these nodes when using it to communicate with ROS.

All devices must be connected to the same actual or virtual network for ROS connections to work. You can create a new ROS master in MATLAB, or you can connect to an existing ROS master that is running on a different device. If you connect to an external master, you have to know the IP address or hostname of the device. The initial ROS master connection is done by calling `rosinit`. For more information on setting up and using the ROS network, see “Network Connection and Exploration”.

Data communication is achieved by sending messages using entities called publishers, subscribers, and services. Publishers send data via topic names, which subscribers then receive over the network. Services use clients to request information from a server. For more information on sending messages, see “Publishers, Subscribers, and Services”

Network Connection Layout

The ROS network is a collection of nodes that are all connected to the ROS master. The number of nodes can be quite large depending on your application and devices. When nodes get registered with the master, communication with all other nodes becomes possible. Each node registers different publishers, subscribers, and services on the ROS master to send and receive information between nodes. Even though all nodes in the ROS network are registered with the master, data is exchanged directly between nodes. The following figure shows the layout of a ROS network with two ROS nodes. It is important that all nodes have bidirectional connectivity to share data across the network. Verifying these connections is important during setup.



Each node registers its own Node URI with the master. Other participants in the ROS network will use this URI to contact the node. Again, this URI must be reachable by every other node in the ROS network. To create a node in MATLAB, call `rosinit`. If a ROS master is already set up, MATLAB detects it and sets the Node URI appropriately. Otherwise, it creates both a ROS master and node that are connected.

By default, each MATLAB instance has a single “global” node. The node has a randomly-generated name assigned to it for uniqueness. All publishers, subscribers, service clients, and service servers will operate on this global node.

Examples

To better understand how the ROS network is set up in MATLAB, see the following examples:

- “Getting Started with ROS”
- “Connecting to a ROS Network”

ROS Messages

Built-In Message Support

In this section...

“ROS Message Structure” on page 4-2

“Limitations of ROS Messages in MATLAB” on page 4-3

“ROS Data Type Conversions” on page 4-3

“Supported Message List” on page 4-4

MATLAB has support for a large library of ROS message types. How messages are structured, limitations for ROS messages, and supported ROS data types are described in order to understand how MATLAB works with ROS messages. Also, a full list of built-in message types are shown.

ROS Message Structure

In MATLAB, ROS messages are stored as handle objects. Therefore, all the rules of handle objects apply including copying, modifying and other performance considerations. For more information on handle objects, see “Using Handles”. Each handle points to the object for that specific message, which contains the information relevant to that message type. The message type has a built in structure for the data it contains.

ROS messages are similar to *structure arrays* with how they store the data relevant to that message type. Each message type has a specific set of properties with their corresponding values that are individually stored and accessed. You can specifically point to and modify each property on its own. All messages have the `MessageType` property to view the message type as a string. Also, you can use the `showdetails` function to view the contents of the message.

Here is a sample 'geometry_msgs/Point' created in MATLAB using `rosmessage`. It contains 3 properties corresponding to a 3-D point in XYZ coordinates.

```
pointMsg = rosmessage('geometry_msgs/Point')
```

```
pointMsg =
```

```
ROS Point message with properties:
```

```
MessageType: 'geometry_msgs/Point'  
X: 0  
Y: 0
```



```
Z: 0
```

Use `showdetails` to show the contents of the message

You can access and modify each property by using the created `pointMsg` handle.

```
pointMsg.Y = 2
```

```
pointMsg =
```

ROS Point message with properties:

```
MessageType: 'geometry_msgs/Point'
X: 0
Y: 2
Z: 0
```

Use `showdetails` to show the contents of the message

To explore further the ROS message structure in MATLAB, see “Working with Basic ROS Messages”.

Limitations of ROS Messages in MATLAB

Because ROS messages use structure arrays, this creates a limitation on the validation of certain messages with multiple values. Because each value can be set separately, the message does not validate the properties as a whole entity. For example, a quaternion message contains w , x , y , and z properties, but the message does not enforce that the quaternion as a whole is valid. When modifying properties, you should ensure you are maintaining the rules required for that message.

Message properties can also have a variety of data types. MATLAB uses the rules set by ROS to determine what these data types are. However, if they are to be used in calculations, you might have to cast them to another value. The ROS data types do not convert directly to MATLAB data types, so the next section described the corresponding types.

ROS Data Type Conversions

ROS message types have predetermined properties and data types for the values of those properties. These data types must be mapped to MATLAB data types to be used in MATLAB. This table summarizes how ROS data types are converted to MATLAB data types.

ROS Data Type	Description	MATLAB
bool	Boolean / Unsigned 8-bit integer	logical
int8	Signed 8-bit integer	int8
uint8	Unsigned 8-bit integer	uint8
int16	Signed 16-bit integer	int16
uint16	Unsigned 16-bit integer	uint16
int32	Signed 32-bit integer	int32
uint32	Unsigned 32-bit integer	uint32
int64	Signed 64-bit integer	int64
uint64	Unsigned 64-bit integer	uint64
float32	32-bit IEEE floating point	single
float64	64-bit IEEE floating point	double
string	ASCII string (utf-8 only)	char
time	Seconds and nanoseconds as signed 32-bit integers	Time object
duration	Seconds and nanoseconds as signed 32-bit integers	Duration object

Supported Message List

Here is an alphabetized list of messages types supported. You can get this list by calling `rosmmsg list` in the MATLAB command prompt. When specifying message types, input strings must match the following strings exactly. To enable you to use custom message type that are not listed here, MATLAB also provides a custom message support package. For more information, see `roboticsSupportPackages` to install the support package.

```
'ackermann_msgs/AckermannDrive'
'ackermann_msgs/AckermannDriveStamped'
'actionlib_msgs/GoalID'
'actionlib_msgs/GoalStatus'
'actionlib_msgs/GoalStatusArray'
'adhoc_communication/BroadcastCMgrRobotUpdate'
'adhoc_communication/BroadcastCMgrRobotUpdateRequest'
'adhoc_communication/BroadcastCMgrRobotUpdateResponse'
```

```
'ad hoc_communication/BroadcastString'  
'ad hoc_communication/BroadcastStringRequest'  
'ad hoc_communication/BroadcastStringResponse'  
'ad hoc_communication/CMgrDimensions'  
'ad hoc_communication/CMgrRobotUpdate'  
'ad hoc_communication/ChangeMCMembership'  
'ad hoc_communication/ChangeMCMembershipRequest'  
'ad hoc_communication/ChangeMCMembershipResponse'  
'ad hoc_communication/ExpAuction'  
'ad hoc_communication/ExpCluster'  
'ad hoc_communication/ExpFrontier'  
'ad hoc_communication/ExpFrontierElement'  
'ad hoc_communication/GetGroupState'  
'ad hoc_communication/GetGroupStateRequest'  
'ad hoc_communication/GetGroupStateResponse'  
'ad hoc_communication/GetNeighbors'  
'ad hoc_communication/GetNeighborsRequest'  
'ad hoc_communication/GetNeighborsResponse'  
'ad hoc_communication/MmControl'  
'ad hoc_communication/MmListOfPoints'  
'ad hoc_communication/MmMapUpdate'  
'ad hoc_communication/MmPoint'  
'ad hoc_communication/MmRobotPosition'  
'ad hoc_communication/RecvString'  
'ad hoc_communication/SendCMgrRobotUpdate'  
'ad hoc_communication/SendCMgrRobotUpdateRequest'  
'ad hoc_communication/SendCMgrRobotUpdateResponse'  
'ad hoc_communication/SendExpAuction'  
'ad hoc_communication/SendExpAuctionRequest'  
'ad hoc_communication/SendExpAuctionResponse'  
'ad hoc_communication/SendExpCluster'  
'ad hoc_communication/SendExpClusterRequest'  
'ad hoc_communication/SendExpClusterResponse'  
'ad hoc_communication/SendExpFrontier'  
'ad hoc_communication/SendExpFrontierRequest'  
'ad hoc_communication/SendExpFrontierResponse'  
'ad hoc_communication/SendMmControl'  
'ad hoc_communication/SendMmControlRequest'  
'ad hoc_communication/SendMmControlResponse'  
'ad hoc_communication/SendMmMapUpdate'  
'ad hoc_communication/SendMmMapUpdateRequest'  
'ad hoc_communication/SendMmMapUpdateResponse'  
'ad hoc_communication/SendMmPoint'  
'ad hoc_communication/SendMmPointRequest'
```

```
'ad_hoc_communication/SendMmPointResponse'  
'ad_hoc_communication/SendMmRobotPosition'  
'ad_hoc_communication/SendMmRobotPositionRequest'  
'ad_hoc_communication/SendMmRobotPositionResponse'  
'ad_hoc_communication/SendOccupancyGrid'  
'ad_hoc_communication/SendOccupancyGridRequest'  
'ad_hoc_communication/SendOccupancyGridResponse'  
'ad_hoc_communication/SendQuaternion'  
'ad_hoc_communication/SendQuaternionRequest'  
'ad_hoc_communication/SendQuaternionResponse'  
'ad_hoc_communication/SendString'  
'ad_hoc_communication/SendStringRequest'  
'ad_hoc_communication/SendStringResponse'  
'ad_hoc_communication/SendTwist'  
'ad_hoc_communication/SendTwistRequest'  
'ad_hoc_communication/SendTwistResponse'  
'ad_hoc_communication/ShutDown'  
'ad_hoc_communication/ShutDownRequest'  
'ad_hoc_communication/ShutDownResponse'  
'app_manager/App'  
'app_manager/AppInstallationState'  
'app_manager/AppList'  
'app_manager/AppStatus'  
'app_manager/ClientApp'  
'app_manager/ExchangeApp'  
'app_manager/GetAppDetails'  
'app_manager/GetAppDetailsRequest'  
'app_manager/GetAppDetailsResponse'  
'app_manager/GetInstallationState'  
'app_manager/GetInstallationStateRequest'  
'app_manager/GetInstallationStateResponse'  
'app_manager/Icon'  
'app_manager/InstallApp'  
'app_manager/InstallAppRequest'  
'app_manager/InstallAppResponse'  
'app_manager/KeyValue'  
'app_manager/ListApps'  
'app_manager/ListAppsRequest'  
'app_manager/ListAppsResponse'  
'app_manager/StartApp'  
'app_manager/StartAppRequest'  
'app_manager/StartAppResponse'  
'app_manager/StatusCodes'  
'app_manager/StopApp'
```

```
'app_manager/StopAppRequest'  
'app_manager/StopAppResponse'  
'app_manager/UninstallApp'  
'app_manager/UninstallAppRequest'  
'app_manager/UninstallAppResponse'  
'applanix_msgs/Ack'  
'applanix_msgs/AidingSensorIntegrationControl'  
'applanix_msgs/AidingSensorParams'  
'applanix_msgs/BaseGNSSModemStatus'  
'applanix_msgs/BaseGNSSSetup'  
'applanix_msgs/BinaryMessageSelect'  
'applanix_msgs/COMPortMessages'  
'applanix_msgs/COMPortParams'  
'applanix_msgs/COMPortSetup'  
'applanix_msgs/CalibratedInstallationParameters'  
'applanix_msgs/CommonFooter'  
'applanix_msgs/CommonHeader'  
'applanix_msgs/DGPSSourceControl'  
'applanix_msgs/DMIData'  
'applanix_msgs/Event'  
'applanix_msgs/EventSetup'  
'applanix_msgs/GAMS'  
'applanix_msgs/GAMSCalibrationControl'  
'applanix_msgs/GAMSPParams'  
'applanix_msgs/GNSSAuxStatus'  
'applanix_msgs/GNSSChannelStatus'  
'applanix_msgs/GNSSControl'  
'applanix_msgs/GNSSDGPSSChannelStatus'  
'applanix_msgs/GNSSDGPSSStation'  
'applanix_msgs/GNSSDGPSSStationDatabase'  
'applanix_msgs/GNSSDGPSSStatus'  
'applanix_msgs/GNSSSetup'  
'applanix_msgs/GNSSStatus'  
'applanix_msgs/GeneralParams'  
'applanix_msgs/GeneralStatus'  
'applanix_msgs/Groups'  
'applanix_msgs/IINSolutionStatus'  
'applanix_msgs/IMUData'  
'applanix_msgs/IPAddress'  
'applanix_msgs/InstallationCalibrationControl'  
'applanix_msgs/IntegrationDiagnosticsControl'  
'applanix_msgs/LoggingControl'  
'applanix_msgs/LoggingStatus'  
'applanix_msgs/NMEAMessageSelect'
```

```
'applanix_msgs/NavModeControl'  
'applanix_msgs/NavigationPerformance'  
'applanix_msgs/NavigationSolution'  
'applanix_msgs/OutputGroup'  
'applanix_msgs/PPSStatus'  
'applanix_msgs/PortControl'  
'applanix_msgs/PreciseGravitySpecs'  
'applanix_msgs/ProgramControl'  
'applanix_msgs/RawDMI'  
'applanix_msgs/RawData'  
'applanix_msgs/RawPPS'  
'applanix_msgs/SaveRestoreControl'  
'applanix_msgs/TimeDistance'  
'applanix_msgs/TimeSyncControl'  
'applanix_msgs/UserAccuracySpecs'  
'applanix_msgs/UserTimeStatus'  
'applanix_msgs/Version'  
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'ar_track_alvar/AlvarMarkers'  
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'arbotix_msgs/Digital'  
'arbotix_msgs/Enable'  
'arbotix_msgs/EnableRequest'  
'arbotix_msgs/EnableResponse'  
'arbotix_msgs/Relax'  
'arbotix_msgs/RelaxRequest'  
'arbotix_msgs/RelaxResponse'  
'arbotix_msgs/SetSpeed'  
'arbotix_msgs/SetSpeedRequest'  
'arbotix_msgs/SetSpeedResponse'  
'arbotix_msgs/SetupChannel'  
'arbotix_msgs/SetupChannelRequest'  
'arbotix_msgs/SetupChannelResponse'  
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'ardrone_autonomy/CamSelectRequest'  
'ardrone_autonomy/CamSelectResponse'  
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'ardrone_autonomy/FlightAnimRequest'  
'ardrone_autonomy/FlightAnimResponse'  
'ardrone_autonomy/LedAnim'  
'ardrone_autonomy/LedAnimRequest'  
'ardrone_autonomy/LedAnimResponse'  
'ardrone_autonomy/Navdata'  
'ardrone_autonomy/RecordEnable'
```

```
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'ardrone_autonomy/navdata_demo'  
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'ardrone_autonomy/navdata_hdvideo_stream'  
'ardrone_autonomy/navdata_kalman_pressure'  
'ardrone_autonomy/navdata_magneto'  
'ardrone_autonomy/navdata_phys_measures'  
'ardrone_autonomy/navdata_pressure_raw'  
'ardrone_autonomy/navdata_pwm'  
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'ardrone_autonomy/navdata_references'  
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'baxter_core_msgs/AnalogIOStates'  
'baxter_core_msgs/AnalogOutputCommand'  
'baxter_core_msgs/AssemblyState'  
'baxter_core_msgs/AssemblyStates'  
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'baxter_core_msgs/CameraSettings'  
'baxter_core_msgs/CloseCamera'
```

```
'baxter_core_msgs/CloseCameraRequest'  
'baxter_core_msgs/CloseCameraResponse'  
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'baxter_core_msgs/CollisionDetectionState'  
'baxter_core_msgs/DigitalIOState'  
'baxter_core_msgs/DigitalIOStates'  
'baxter_core_msgs/DigitalOutputCommand'  
'baxter_core_msgs/EndEffectorCommand'  
'baxter_core_msgs/EndEffectorProperties'  
'baxter_core_msgs/EndEffectorState'  
'baxter_core_msgs/EndpointState'  
'baxter_core_msgs/EndpointStates'  
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'baxter_core_msgs/ListCamerasResponse'  
'baxter_core_msgs/NavigatorState'  
'baxter_core_msgs/NavigatorStates'  
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'baxter_core_msgs/OpenCameraRequest'  
'baxter_core_msgs/OpenCameraResponse'  
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'baxter_core_msgs/SolvePositionIKResponse'  
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'baxter_maintenance_msgs/CalibrateArmEnable'  
'baxter_maintenance_msgs/TareData'  
'baxter_maintenance_msgs/TareEnable'  
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'baxter_maintenance_msgs/UpdateSources'  
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```

```
'turtlesim/TeleportRelative'  
'turtlesim/TeleportRelativeRequest'  
'turtlesim/TeleportRelativeResponse'  
'um6/Reset'  
'um6/ResetRequest'  
'um6/ResetResponse'  
'underwater_sensor_msgs/DVL'  
'underwater_sensor_msgs/Pressure'  
'universal_teleop/Control'  
'universal_teleop/Event'  
'uuid_msgs/UniqueID'  
'velodyne_msgs/VelodynePacket'  
'velodyne_msgs/VelodyneScan'  
'view_controller_msgs/CameraPlacement'  
'visp_camera_calibration/CalibPoint'  
'visp_camera_calibration/CalibPointArray'  
'visp_camera_calibration/ImageAndPoints'  
'visp_camera_calibration/ImagePoint'  
'visp_camera_calibration/calibrate'  
'visp_camera_calibration/calibrateRequest'  
'visp_camera_calibration/calibrateResponse'  
'visp_hand2eye_calibration/TransformArray'  
'visp_hand2eye_calibration/compute_effector_camera'  
'visp_hand2eye_calibration/compute_effector_cameraRequest'  
'visp_hand2eye_calibration/compute_effector_cameraResponse'  
'visp_hand2eye_calibration/compute_effector_camera_quick'  
'visp_hand2eye_calibration/compute_effector_camera_quickRequest'  
'visp_hand2eye_calibration/compute_effector_camera_quickResponse'  
'visp_hand2eye_calibration/reset'  
'visp_hand2eye_calibration/resetRequest'  
'visp_hand2eye_calibration/resetResponse'  
'visp_tracker/Init'  
'visp_tracker/InitRequest'  
'visp_tracker/InitResponse'  
'visp_tracker/KltPoint'  
'visp_tracker/KltPoints'  
'visp_tracker/KltSettings'  
'visp_tracker/MovingEdgeSettings'  
'visp_tracker/MovingEdgeSite'  
'visp_tracker/MovingEdgeSites'  
'visualization_msgs/ImageMarker'  
'visualization_msgs/InteractiveMarker'  
'visualization_msgs/InteractiveMarkerControl'  
'visualization_msgs/InteractiveMarkerFeedback'
```

```
'visualization_msgs/InteractiveMarkerInit'  
'visualization_msgs/InteractiveMarkerPose'  
'visualization_msgs/InteractiveMarkerUpdate'  
'visualization_msgs/Marker'  
'visualization_msgs/MarkerArray'  
'visualization_msgs/MenuEntry'  
'wfov_camera_msgs/WFOVCompressedImage'  
'wfov_camera_msgs/WFOVImage'  
'wfov_camera_msgs/WFOVTrigger'  
'wge100_camera/BoardConfig'  
'wge100_camera/BoardConfigRequest'  
'wge100_camera/BoardConfigResponse'  
'wifi_ddwrt/Network'  
'wifi_ddwrt/SiteSurvey'  
'wireless_msgs/Connection'  
'wireless_msgs/Network'  
'wireless_msgs/Quality'  
'wireless_msgs/Scan'  
'yocs_msgs/Column'  
'yocs_msgs/ColumnList'  
'yocs_msgs/Wall'  
'yocs_msgs/WallList'  
'zeroconf_msgs/AddListener'  
'zeroconf_msgs/AddListenerRequest'  
'zeroconf_msgs/AddListenerResponse'  
'zeroconf_msgs/AddService'  
'zeroconf_msgs/AddServiceRequest'  
'zeroconf_msgs/AddServiceResponse'  
'zeroconf_msgs/DiscoveredService'  
'zeroconf_msgs/ListDiscoveredServices'  
'zeroconf_msgs/ListDiscoveredServicesRequest'  
'zeroconf_msgs/ListDiscoveredServicesResponse'  
'zeroconf_msgs/ListPublishedServices'  
'zeroconf_msgs/ListPublishedServicesRequest'  
'zeroconf_msgs/ListPublishedServicesResponse'  
'zeroconf_msgs/Protocols'  
'zeroconf_msgs/PublishedService'  
'zeroconf_msgs/RemoveListener'  
'zeroconf_msgs/RemoveListenerRequest'  
'zeroconf_msgs/RemoveListenerResponse'  
'zeroconf_msgs/RemoveService'  
'zeroconf_msgs/RemoveServiceRequest'  
'zeroconf_msgs/RemoveServiceResponse'
```


ROS Log Files

ROS Log Files (rosbags)

In this section...

“Introduction” on page 5-2

“MATLAB rosbag Structure” on page 5-2

“Workflow for rosbag Selection” on page 5-3

“Limitations” on page 5-5

Introduction

A rosbag or bag is a file format in ROS for storing ROS message data. These bags are often created by subscribing to one or more ROS topics, and storing the received message data in an efficient file structure. MATLAB® can read these rosbag files and help with filtering and extracting message data. The following sections detail the structure of rosbags in MATLAB and the workflow for extracting data from them.

MATLAB rosbag Structure

When accessing rosbag log files, call `rosbag` and specify the file path to the object. MATLAB then creates a `BagSelection` object that contains an index of all the messages from the rosbag.

The `BagSelection` object has the following properties related to the rosbag:

- `FilePath`: a string of the absolute path to the rosbag file.
- `StartTime`: a scalar indicating the time the first message was recorded
- `EndTime`: a scalar indicating the time the last message was recorded
- `NumMessages`: a scalar indicating how many messages are contained in the file
- `AvailableTopics`: a list of what topic and message types were recorded in the bag. This is stored as table data that lists the number of messages, message type, and message definition for each topic. For more information on table data types, see “Access Data in a Table”. Here is an example output of this table:

```
ans =
```

	NumMessages	MessageType	MessageDefinition
/clock	12001	rosgraph_msgs/Clock	[1x185 char]
/gazebo/link_states	11999	gazebo_msgs/LinkStates	[1x1247 char]
/odom	11998	nav_msgs/Odometry	[1x2918 char]
/scan	965	sensor_msgs/LaserScan	[1x2123 char]

- **MessageList:** a list of every message in the bag with rows sorted by time stamp of when the message was recorded. This list can be indexed and you can select a portion of the list this way. Calling `select` allows you to select subsets based on time stamp, topic or message type.

Also, note that the `BagSelection` object contains an index for all the messages. However, you must still use functions to extract the data. For extracting this information, see `readMessages` for getting messages based on indices as a cell array or see `timeseries` for reading the data of specified properties as a time series.

Workflow for rosbag Selection

When working with rosbags, there is a general procedure of how you should extract data.

- **Load a rosbag:** Call `rosbag` and the file path to load file and create `BagSelection`.
- **Examine available messages:** Examine `BagSelection` properties (`AvailableTopics`, `NumMessages`, `StartTime`, `EndTime`, and `MessageList`) to determine how to select a subset of messages for analysis.
- **Select messages:** Call `select` to create a selection of messages based on your desired properties.
- **Extract message data:** Call `readMessages` or `timeseries` to get message data as either a cell array or time series data structure.
- **Visualize, analyze or process data:** Use the extracted data for your specific application. You can plot data or develop algorithms to process data.

The following figure also shows the workflow.

Load a rosbag

```
>> filePath = fullfile('rosbags', 'bag1.bag');
>> bagSelect = rosbag(filePath);
```

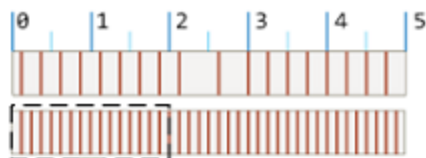
Examine available messages

Topic Name Message Type

/scan sensor_msgs/LaserScan

/odom nav_msgs/Odometry

Time-stamped Messages



Select messages

Select Topic: /odom
Select Time Interval: [0, 2]

select()

/odom nav_msgs/Odometry



Extract message data

Select Message Indices

readMessages()

Select Property: Pose.X
Select Property: Pose.Y
Select Property: Orient.Z

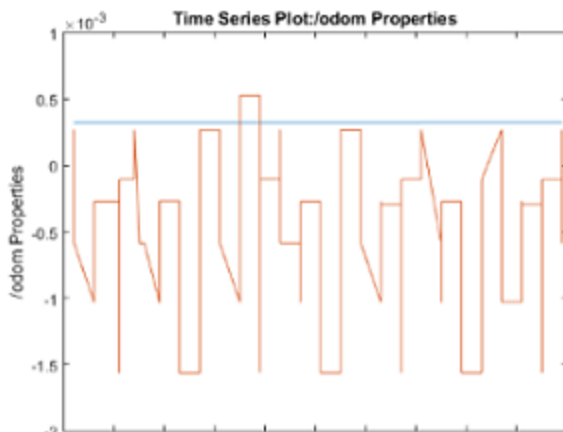
timeseries()

Message Object(s)
(nav_msgs/Odometry)
...

Timeseries Object

Time	Pose.X	Pose.Y	Orient.Z
0.125	0.000	1.254	0.000
0.250	0.123	1.254	1.571
...
2.000	0.297	1.254	3.142

Visualize, analyze, or process data



Limitations

There are a few limitations in the rosbag support within MATLAB:

- MATLAB can only parse uncompressed rosbags. See the ROS Wiki for a tool to decompress a compressed rosbag.
- Only rosbags in the v2.0 format are supported. See the ROS Wiki for more information on different bag formats
- The file path to the rosbag must always be accessible. Because the message selection process does not retrieve any data, the file needs to be available for reading when the message data is accessed.

Application Design

- “Transform Laser Scan Data” on page 6-2
- “Obstacle Avoidance with Turtlebot and VFH” on page 6-4

Transform Laser Scan Data

This example shows how to transform laser scan data using a ROS transformation tree. When working with laser scan data, your sensor might not be mounted in the center of the robot. Many algorithms make this assumption, so that you might need to transform your data so it is relative to the robot center. This example uses a ROS transformation tree to receive the transformations between different coordinate frames. To transform the sensor data, you must be connected to a ROS network and have transformations available.

Create the ROS transformation tree from the ROS network using `rostopic`. Get the transform between `'/laser'` and `'/base_link'` coordinate frames. Change the coordinate frame names based on your robot configuration.

```
tftree = rostopic;  
tf = getTransform(tftree, '/laser', '/base_link');
```

Get the rotation and translation matrix from the transform.

```
quat = [tf.Transform.Rotation.W tf.Transform.Rotation.X ...  
        tf.Transform.Rotation.Y tf.Transform.Rotation.Z];  
rotm = quat2rotm(quat);  
trvec = [tf.Transform.Translation.X tf.Transform.Translation.Y ...  
         tf.Transform.Translation.Z];
```

Create a homogenous transform from the translation and rotation matrices.

```
tform = trvec2tform(trvec);  
tform(1:3,1:3) = rotm(1:3,1:3);
```

Set up a subscriber to get laser scan data. Get the laser scan data as Cartesian points. Pad the points with zeros and convert them to homogeneous coordinates.

```
scansub = rossubscriber('/scan');  
scan = receive(scansub)  
cartScanData = scan.readCartesian;  
cartScanData(:,3) = 0;  
homScanData = cart2hom(cartScanData);
```

Apply the homogeneous transform and convert scan data back to Cartesian points.

```
trPts = tform*homScanData';  
cartScanDataTransformed = hom2cart(trPts');
```

Get the polar angles and ranges from the Cartesian points.

```
[angles,ranges] = cart2pol(cartScanDataTransformed(:,1), cartScanDataTransformed(:,2))
```

See Also

`robotics.VectorFieldHistogram` | `apply` | `getTransform` | `rostopf`

Obstacle Avoidance with Turtlebot and VFH

This example shows how to use a TurtleBot[®] with Vector Field Histograms (VFH) in order to perform obstacle avoidance when driving a robot in an environment. The robot wanders by driving forward until obstacles get in the way. The `robotics.ros.VectorFieldHistogram` class computes steering directions to avoid objects while trying to drive forwards.

Optional: If you do not already have a TurtleBot (simulated or real) set up, install a virtual machine with the Gazebo simulator and TurtleBot package. See “Getting Started with Gazebo and a Simulated TurtleBot” to install and set up a TurtleBot in Gazebo.

Connect to the TurtleBot using the IP address obtained from setup.

```
rosinit('192.168.1.1')
```

Create a publisher and subscriber to share information with the VFH class. The subscriber receives the laser scan data from the robot. The publisher sends velocity commands to the robot.

The topics used are for the simulated TurtleBot. Adjust the topic names for your specific robot.

```
laserSub = rossubscriber('/scan');  
[velPub, velMsg] = rospublisher('/mobile_base/commands/velocity');
```

Set up VFH object for obstacle avoidance. Specify algorithm properties for robot specifications. Set target direction to 0 in order to drive straight.

```
vfh = robotics.VectorFieldHistogram;  
vfh.DistanceLimits = [0.05 1];  
vfh.RobotRadius = 0.1;  
vfh.MinTurningRadius = 0.2;  
vfh.SafetyDistance = 0.1;
```

```
targetDir = 0;
```

Create a loop that collects data, calculates steering direction, and drives the robot. Use the ROS subscriber to collect laser scan data. Calculate the steering direction with the VFH step method based on the input laser scan data. Convert the steering direction to a desired linear and an angular velocity. If a steering direction is not found, the robot stops and searches by rotating in place. Drive the robot by sending a message containing the angular velocity and the desired linear velocity using the ROS publisher.

```
while true
  % Get laser scan data
  laserScan = receive(laserSub);
  ranges = double(laserScan.Ranges);
  angles = double(laserScan.readScanAngles);

  % Call VFH step method to computer steering direction
  steerDir = vfh.step(ranges, angles, targetDir);

  % Calculate velocities
  if ~isnan(steerDir) % If steering direction is valid
    desiredV = 0.2;
    w = exampleHelperComputeAngularVelocity(steerDir, 1);
  else % Stop and search for valid direction
    desiredV = 0.0;
    w = 0.5;
  end

  % Assign and send velocity commands
  velMsg.Linear.X = desiredV;
  velMsg.Angular.Z = w;
  velPub.send(velMsg);
end
```

This code shows how you can use the Robotics System Toolbox algorithms to control robots and react to dynamic changes in their environment. The loop should operate continuously until you stop it, but other conditions can be set to exit the loop (i.e. robot position or time elapsed) based on information on the ROS network.

See Also

[robotics.VectorFieldHistogram](#) | [rospublisher](#) | [rossubscriber](#)

Related Examples

- “Getting Started with Gazebo and a Simulated TurtleBot”
- “Communicating with the TurtleBot”

Code Generation

- “Code Generation from MATLAB Code” on page 7-2
- “Code Generation Support, Usage Notes and Limitations” on page 7-4

Code Generation from MATLAB Code

Several Robotics System Toolbox functions are enabled to generate C/C++ code. Code generation from MATLAB code requires the MATLAB Coder™ product. To generate code from computer vision functions, follow these steps:

- Write your function or application that uses Robotics System Toolbox functions that are enabled for code generation. For code generation, some of these functions have requirements that you must follow. See “Code Generation Support, Usage Notes and Limitations” on page 7-4.
- Add the `%#codegen` directive to your MATLAB code.
- Follow the workflow for code generation from MATLAB code using either the MATLAB Coder app or the command-line interface.

Using the app, the basic workflow is:

- 1 Set up a project. Specify your top-level functions and define input types.

The app screens your code for code generation readiness. It reports issues such as a function that is not supported for code generation.

- 2 Check for run-time issues.

The app generates and runs a MEX version of your function. This step detects issues that can be hard to detect in the generated C/C++ code.

- 3 Configure the code generation settings for your application.
- 4 Generate C/C++ code.
- 5 Verify the generated C/C++ code. If you have an Embedded Coder® license, you can use software-in-the-loop execution (SIL) or processor-in-the-loop (PIL) execution.

For a tutorial, see “C Code Generation Using the MATLAB Coder App”.

Using the command-line interface, the basic workflow is:

- To detect issues and verify the behavior of the generated code, generate a MEX version of your function.
- Use `coder.config` to create a code configuration object for a library or executable.
- Modify the code configuration object properties as required for your application.
- Generate code using the `codegen` command.

- Verify the generated code. If you have an Embedded Coder license, you can use software-in-the-loop execution (SIL) or processor-in-the-loop (PIL) execution.

For a tutorial, see “C Code Generation at the Command Line”.

Code Generation Support, Usage Notes and Limitations

To generate code from MATLAB code that contains Robotics System Toolbox functions, classes, or System objects, you must have the MATLAB Coder software.

The following functions support code generation using MATLAB Coder, but have the following limitations.

Name	Remarks and Limitations
Algorithm Design	
robotics.PurePursuit	Supports MATLAB Function block: No
robotics.VectorFieldHistogram	Supports MATLAB Function block: No
Coordinate System Transformations	
angdiff	Supports MATLAB Function block: No
axang2quat	Supports MATLAB Function block: No
axang2rotm	Supports MATLAB Function block: No
axang2tform	Supports MATLAB Function block: No
cart2hom	Supports MATLAB Function block: No
eul2quat	Supports MATLAB Function block: No
eul2rotm	Supports MATLAB Function block: No
eul2tform	Supports MATLAB Function block: No
hom2cart	Supports MATLAB Function block: No
quat2axang	Supports MATLAB Function block: No
quat2eul	Supports MATLAB Function block: No
quat2rotm	Supports MATLAB Function block: No
quat2tform	Supports MATLAB Function block: No
rotm2axang	Supports MATLAB Function block: No
rotm2eul	Supports MATLAB Function block: No
rotm2quat	Supports MATLAB Function block: No
rotm2tform	Supports MATLAB Function block: No
tform2axang	Supports MATLAB Function block: No

Name	Remarks and Limitations
tform2eul	Supports MATLAB Function block: No
tform2quat	Supports MATLAB Function block: No
tform2rotm	Supports MATLAB Function block: No
tform2trvec	Supports MATLAB Function block: No
trvec2tform	Supports MATLAB Function block: No

ROS Custom Message Support

- “Create Custom Messages from ROS Package” on page 8-2
- “ROS Custom Message Support” on page 8-8
- “Install Robotics System Toolbox Support Packages” on page 8-13

Create Custom Messages from ROS Package

In this example, you will go through the procedure for creating ROS custom messages in MATLAB. It assumes you have already gone through the installation process shown in “Install Robotics System Toolbox Support Packages” on page 8-13. Also, you must have a ROS package that contains the required `msg`, `srv`, and `package.xml` files. The correct file contents and folder structure are described in “Custom Message Contents” on page 8-8. This structure follows the standard ROS package conventions. Therefore, if you have any existing packages, they should match this structure.

It is recommended you start this procedure after opening a new MATLAB session to ensure that there are no lingering changes to MATLAB preferences from previous work. After ensuring that your custom message package is correct, note the folder path location. Then, call `rosgenmsg` with the specified path and follow the steps output in the command window. The following example has three messages, A, B, and C, that have dependencies on each other. It illustrates that you can use a folder containing multiple messages and generate them all at the same time.

Here are the first steps to setting up custom messages in MATLAB:

- Open MATLAB in a new session
- Place your custom message folder in a location and note the folder path. In this example, we provide a location of example packages and copy them to `userFolder`, which is then used for the custom message generation. Make sure that the `userFolder` directory exists prior to running this code.

```
examplePackages = fullfile(fileparts(which('rosgenmsg')), 'examples', 'packages');  
userFolder = 'c:\MATLAB\custom_msg_test';  
copyfile(examplePackages, userFolder)
```

- Specify the folder path of the custom messages.

```
folderpath = userFolder;
```

(Optional) If you have an existing catkin workspace (`catkin_ws`), you can specify the path to its `src` folder instead. However, this workspace might contain a large number of packages and message generation will be run for all of them.

```
folderpath = fullfile('catkin_ws', 'src');
```

- Specify the folder path for custom message files and call `rosgenmsg` to create custom messages for MATLAB.


```
rosgenmsg(folderpath)
```

```
Checking subfolder "A" for custom messages.
```

```
Checking subfolder "B" for custom messages.
```

```
Checking subfolder "C" for custom messages.
```

```
Building custom message files for the following packages:
```

```
A  
B  
C
```

```
Generating MATLAB classes for message packages in  
C:\MATLAB\custom_msgs\matlab_gen\jar
```

```
Loading file A-1.0.jar.
```

```
Generating MATLAB code for A/DependsOnB message type.  
Generating MATLAB code for B/Standalone message type.
```

```
Loading file B-1.0.jar.
```

```
Loading file C-1.0.jar.  
Generating MATLAB code for C/DependsOnB message type.
```

To use the custom messages, follow these steps:

1. Edit `javaclasspath.txt`, add the following file locations as new lines, and save the file:

```
C:\MATLAB\custom_msgs\matlab_gen\jar\A-1.0.jar  
C:\MATLAB\custom_msgs\matlab_gen\jar\B-1.0.jar  
C:\MATLAB\custom_msgs\matlab_gen\jar\C-1.0.jar
```

2. Add the custom message folder to the MATLAB path by executing:

```
addpath('C:\MATLAB\custom_msgs\matlab_gen\msggen')  
savepath
```

3. Restart MATLAB and verify that you can use the custom messages. Type `"rosmg list"` and ensure that the output contains the generated custom message types.

Tip If you see the following warning

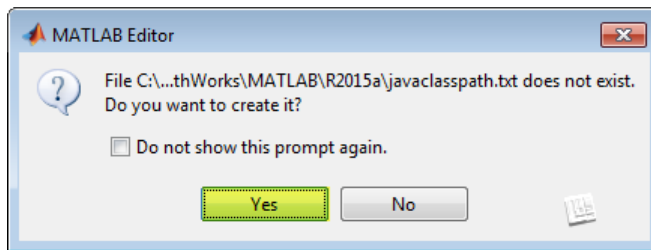
```
Objects of *** class exist - not clearing java
```

Try either calling `rosmsg` at the beginning of your MATLAB session or make sure that no Java objects are created with any startup functions called.

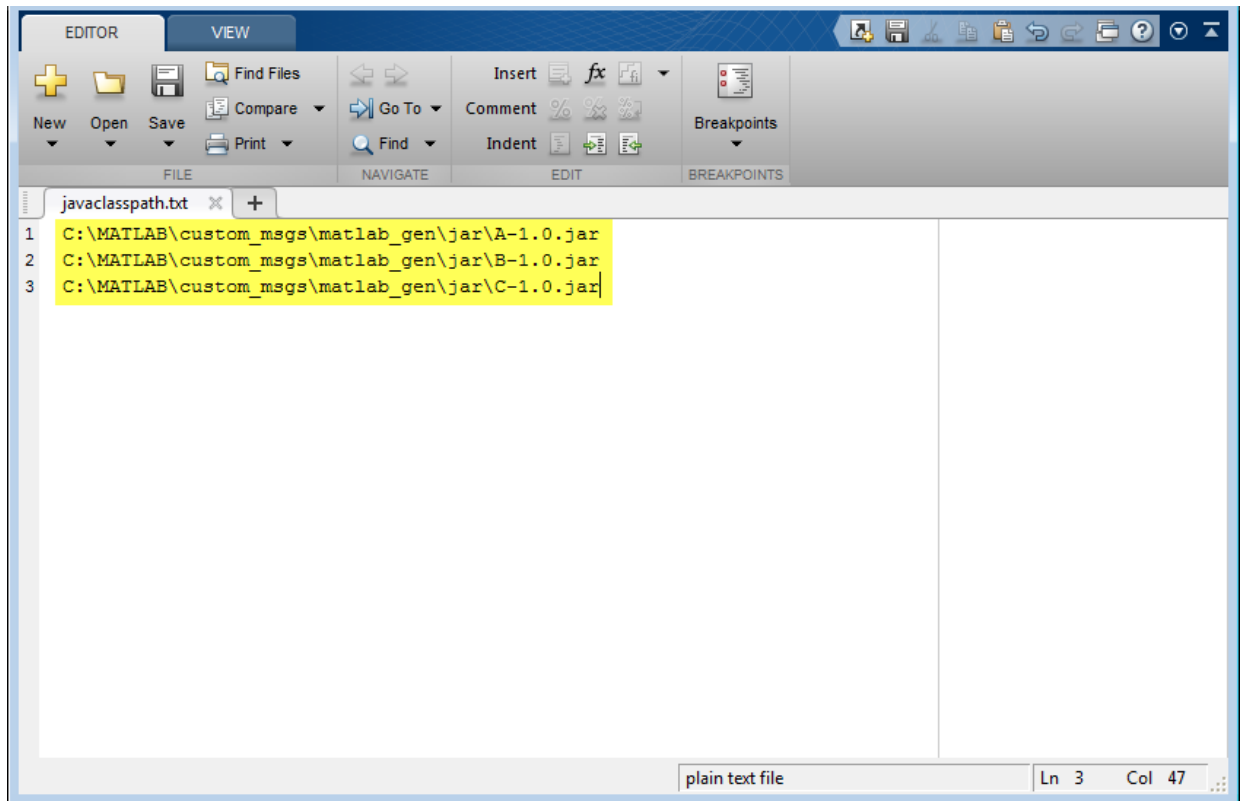
- You will then follow steps 1–3 from the output of `rosmsg`.
- 1 Edit `javaclasspath.txt`, add the following file locations as new lines, and save the file:

```
C:\MATLAB\custom_msgs\matlab_gen\jar\A-1.0.jar  
C:\MATLAB\custom_msgs\matlab_gen\jar\B-1.0.jar  
C:\MATLAB\custom_msgs\matlab_gen\jar\C-1.0.jar
```

Click the `javaclasspath.txt` link and it will open the file in the Editor. Copy and paste the different jar file locations as new lines in the file. If this file does not exist, you will be prompted to create it. Click **Yes** and then copy and paste the file locations into the file.



Here is what the `javaclasspath.txt` should look like after adding lines. Other paths may also already exist in this file:



- 2 Add the custom message folder to the MATLAB path by executing:

```
addpath('C:\MATLAB\custom_msgs\matlab_gen\msggen')
savepath
```

Add the given files to the MATLAB path by running `addpath` and `savepath` in the command window. You can either highlight the commands shown and press **F9** or copy and paste it into the MATLAB Command Window.

```
addpath('C:\MATLAB\custom_msgs\matlab_gen\msggen')
savepath
```

- 3 Restart MATLAB and verify that you can use the custom messages. Type "rosmmsg list" and ensure that the output contains the generated custom message types.

Restart MATLAB for the path changes to be applied. You can then use the custom messages like any other ROS messages supported in Robotics System Toolbox. Verify these changes by either calling `rosmmsg list` and search for your message types, or use `rosmessage` to create a new message.

```
custommsg = rosmessage('B/Standalone')
```

```
custommsg =
```

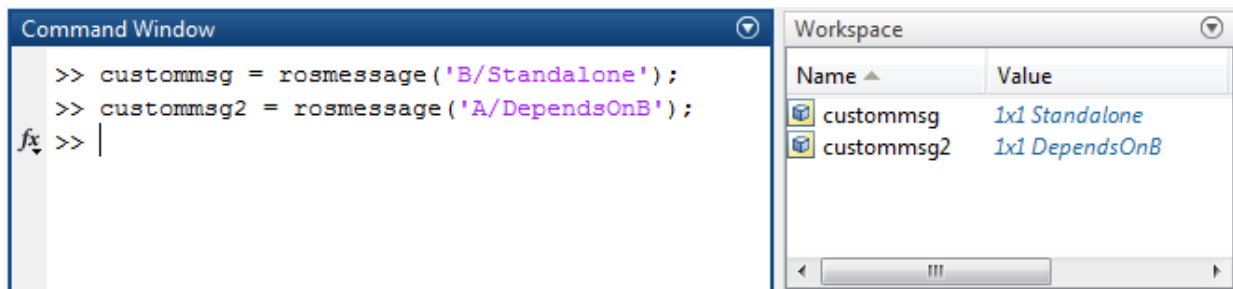
```
ROS Standalone message with properties:
```

```
    MessageType: 'B/Standalone'
    IntProperty: 0
    StringPropert: ''
```

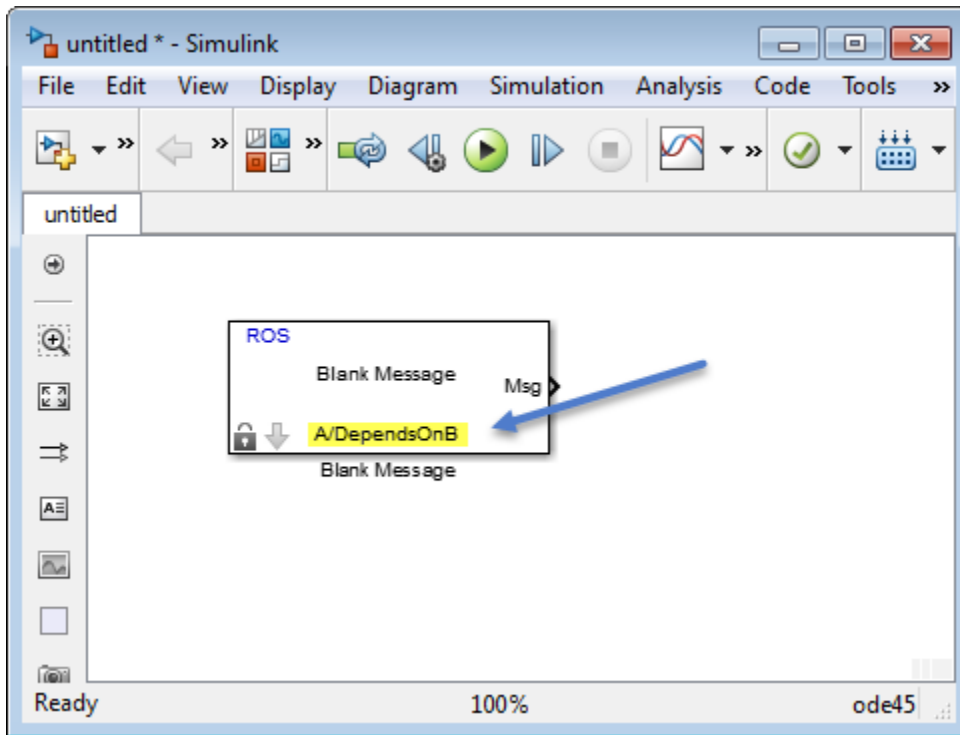
Use `showdetails` to show the contents of the message

This final verification shows that you have performed the custom message generation process correctly. You can now send and receive these messages over a ROS network using MATLAB and Simulink®. The new custom messages can be used like normal message types. You should see them create objects specific to their message type and be displayed in your workspace.

```
custommsg = rosmessage('B/Standalone');
custommsg2 = rosmessage('A/DependsOnB');
```



Custom messages can also be used with the ROS Simulink blocks.



ROS Custom Message Support

In this section...
“Custom Message Overview” on page 8-8
“Custom Message Contents” on page 8-8
“Custom Message Creation Workflow” on page 8-10

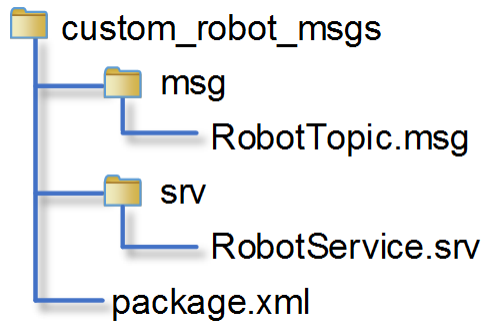
Custom Message Overview

Custom messages are user-defined messages that you can use to extend the set of message types currently supported in Robotics System Toolbox. If you are sending and receiving supported message types, you do not need to use custom messages. To see a list of supported message types, call `rosmmsg list` in the MATLAB Command Window.

To install custom message support, call `roboticsSupportPackages` and follow the instructions for installation. Custom message creation requires ROS packages, which are detailed in the ROS Wiki at Packages. After ensuring that you have valid ROS packages for custom messages, call `rosgenmsg` to generate the necessary MATLAB code to use custom messages. For an example on how to generate a ROS custom message in MATLAB, see “Create Custom Messages from ROS Package” on page 8-2.

Custom Message Contents

ROS custom messages are specified in ROS package folders that contain a `package.xml` file and optional `msg` and `srv` directories. The `msg` folder contains all your custom message type definitions. You should also add all custom service type definitions to the `srv` folder. For example, the package `custom_robot_msgs` has this folder and file structure.



The package contains one custom message type in `RobotTopic.msg` and one custom service type in `RobotService.srv`. MATLAB uses these files to generate the necessary files for using the custom messages contained in the package. For more information on creating `msg` and `srv` files, see [Creating a ROS msg and srv](#) and [Defining Custom Messages on the ROS Wiki](#). The syntax of these files is described on the pages specific to `msg` and `srv`.

In all packages, you must define a `package.xml` file, which has the following contents:

- Name — `custom_robot_msgs`
- Version — `1.1.01`
- Dependency — `message_generation`
- Other dependencies on message packages (optional) — `geometry_msgs`, `std_msgs`

Here is a sample `package.xml` file with the previously shown contents.

```
<package>
  <name>custom_robot_msgs</name>
  <version>1.1.01</version>

  <build_depend>message_generation</build_depend>
  <build_depend>geometry_msgs</build_depend>
  <build_depend>std_msgs</build_depend>
</package>
```

Note:

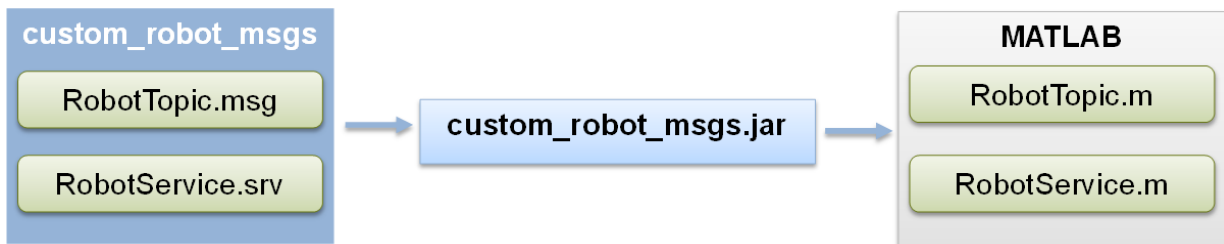
- You must have write access to the custom messages folder.

- At any time, there should only be one custom messages folder on the MATLAB path. This folder can contain multiple packages, but it is recommended that you keep them all in one unique folder.
- ROS actions are not currently supported and will be ignored during the custom message generation.
- ROS packages will not be processed if both of these conditions are met:
 - A package with the same name already exists
 - The version number of that existing package is the same

Custom Message Creation Workflow

Once you have your custom message structure set up as described in the previous section, you can create the code needed to use these custom messages. First, you call `rosgenmsg` with your known path to the custom message files to create MATLAB code.

Then, the two main creation steps that are handled by the `rosgenmsg` function. This function takes your custom message files (`.msg`, `.srv` and `package.xml`) and converts each message type to working MATLAB code. The `rosgenmsg` function will look for `.msg` files in the `msg` folder and for `.srv` files in the `srv` folder. This code is a group of classes that define the message properties when you create new custom messages. The basic procedure takes the custom message files and converts them to `.jar` files and then creates MATLAB M-files for each topic and service. Do not modify the `.jar` files because MATLAB uses them internally.



After the `rosgenmsg` function creates these files, you must add the files to the Java class path and the MATLAB path before you can use the custom messages. These steps are given as prompts in the MATLAB Command Window:

- 1 Add location of files to `javaclasspath.txt`:** Add the specified paths as new lines of text in the `javaclasspath.txt` file. If this file does not exist, a message in the command window prompts you to create it. This text file defines the static class path for Java classes. For more information on the Java class path, see “Java Class Path”.
- 2 Add location of class files to MATLAB path:** Use `addpath` to add new locations of M-files to the MATLAB path and use `savepath` to save these changes.
- 3 Restart MATLAB and verify messages are available:** After restarting MATLAB, call `rosmmsg list` or `rosmmessage` to check that you can use the messages as expected.

For an example of this procedure, see “Create Custom Messages from ROS Package” on page 8-2. This example uses sample custom message files to create custom messages in MATLAB.

You need to complete this procedure only once for a specific set of custom messages. After that, you can use the new custom messages like any other ROS message in MATLAB and take advantage of the full ROS functionality that Robotics System Toolbox provides. Repeat this generation procedure when you would like to update or create new message types.

You must maintain the Java class path and MATLAB path that contain the files directories. Make sure that the MATLAB path has only one folder at a time that contains custom message artifacts. Also, ensure you add the correct paths to the `javaclasspath.txt`, as the prompt directs. Do not modify the path. This file is used to load Java files at the start of each MATLAB session.

Sharing Custom Messages

After creating your custom message files, you can share them with other users. Other people do not need to call `rosgenmsg` to access your messages. Instead, to share your messages, access the `_matlab_gen` folder and follow the same three steps for specifying paths as described previously. If you have access to these files, either over a network or shared drive, add the `matlab_gen/jar` folder path to the `javaclasspath.txt` file and the `matlab_gen/msggen` path to the MATLAB path. After restarting MATLAB, other users can use the custom messages like any other ROS message.

Code Generation with Custom messages

Custom message and service types can be used with ROS Simulink blocks for generating C++ code for a standalone ROS node. The generated code (.tgz archive) will include

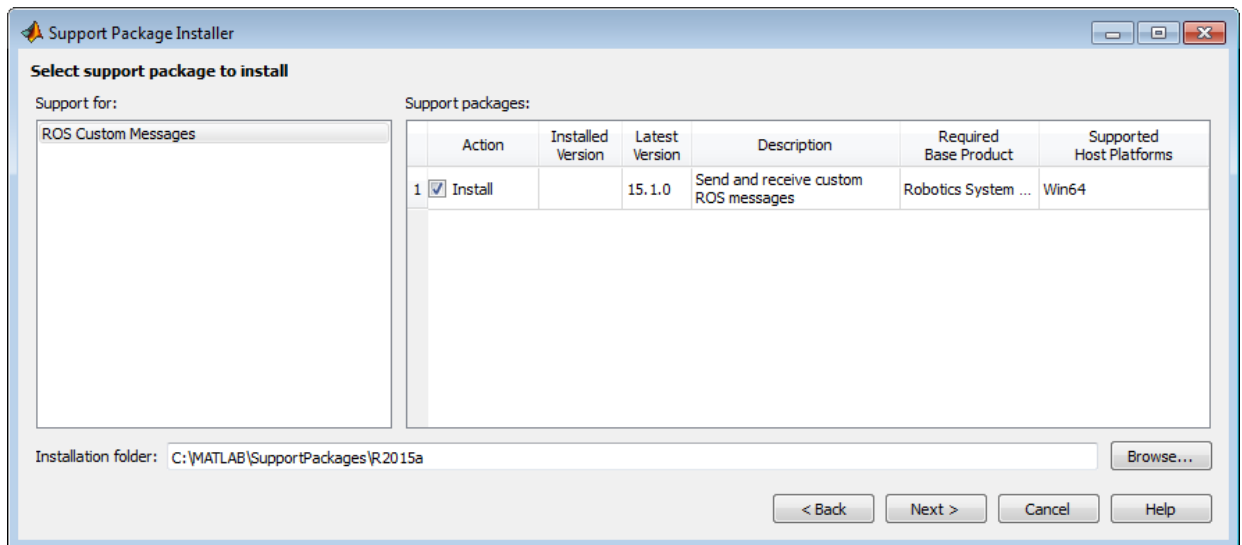
Simulink definitions for the custom messages, but it will not include the ROS custom message packages. When the generated code is built in the destination Linux System, it expects the custom message packages to be available in the catkin workspace or on the `ROS_PACKAGE_PATH`. Please ensure that you either install or copy the custom message package to your Linux system before building the generated code.

Install Robotics System Toolbox Support Packages

Robotics System Toolbox support packages enable you to generate ROS custom messages to send and receive in MATLAB.

- 1 In a MATLAB Command Window, type:


```
roboticsSupportPackages
```
- 2 In the Support Package Installer, follow the instructions for installation. For more information about the options on a particular screen, click **Help**.
- 3 At **Select support package to install**, select the component you want to add. For example:
 - ROS Custom Messages



- 4 Accept or change the installation folder and click **Next**.

Note: You must have write privileges for the installation folder.

- 5 Follow the remaining prompts to download and install the support package.

When a new version of MATLAB software is released, repeat this process to check for updates. You can also check for updates between releases.

Related Examples

- “Create Custom Messages from ROS Package” on page 8-2

More About

- “ROS Custom Message Support” on page 8-8

Simulink ROS Concepts

- “Selecting ROS Topics, Messages, and Parameters” on page 9-2
- “Configuring ROS Network Addresses” on page 9-5
- “Managing Array Sizes in Simulink ROS” on page 9-8
- “Simulink and ROS Interaction” on page 9-10
- “ROS Parameters in Simulink” on page 9-12
- “Simulink Support and Limitations” on page 9-13

Selecting ROS Topics, Messages, and Parameters

In this section...

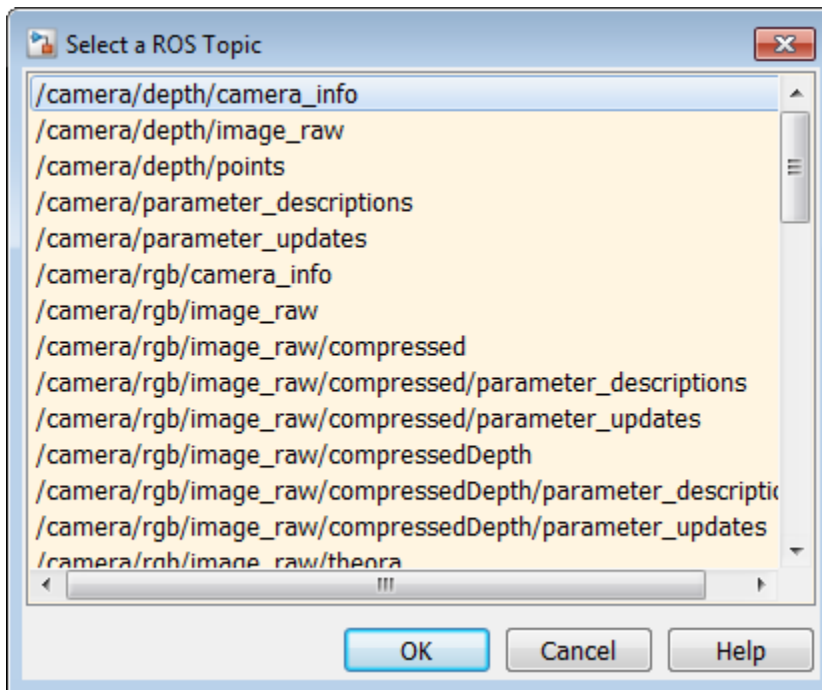
“Selecting ROS Topics” on page 9-2

“Selecting ROS Message Types” on page 9-3

“Selecting ROS Parameter Names” on page 9-4

Selecting ROS Topics

When using Simulink with ROS, you can publish or subscribe to topics on the ROS network. In the dialog boxes for the **Publish** and **Subscribe** blocks, you can select from a list of topics on the ROS network. You must be currently connected to a ROS network to get a list of topics. You can select a topic using the following:



This dialog shows the list of topics available on the ROS master. Selecting a topic from the list automatically populates the **Topic** and **Message type** parameters for the

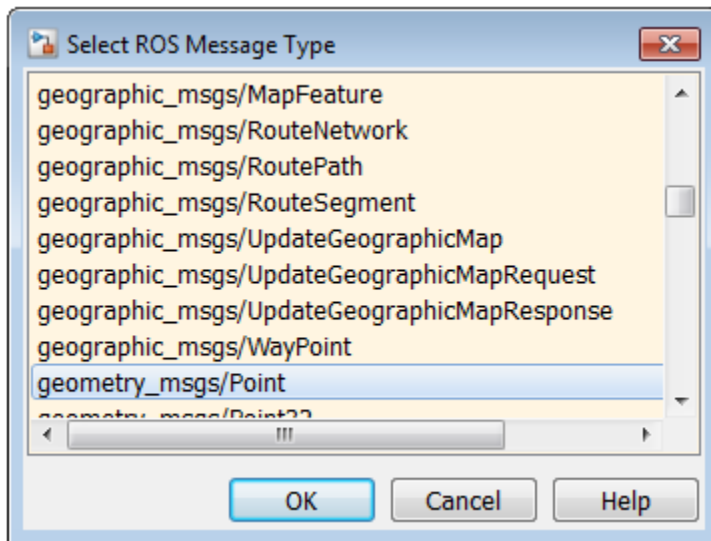
corresponding block mask dialog. If the message type is not supported in MATLAB ROS, Simulink will throw an error. Once the topic is selected, it is saved with the block. Even if the topic is not longer available on the network, the block will still use that topic name.

To refresh the list, close and open the dialog again.

To use a topic not currently posted on the ROS network or if you are not currently connected, use the “Specify your own” option under the **Topic Source** parameter in your block mask dialog.

Selecting ROS Message Types

Simulink ROS allows you to select from a list of message types currently supported by MATLAB ROS when setting the **Message type** for Publish, Subscribe, or BlankMessage blocks.



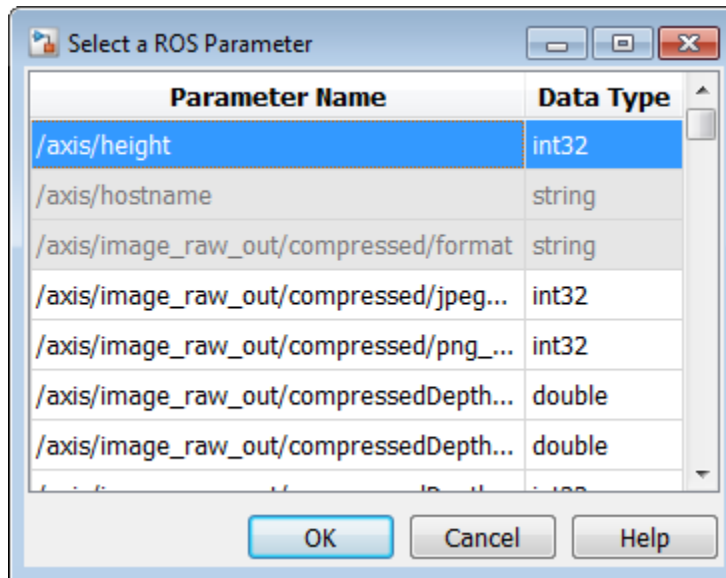
This is the list of all message types supported in MATLAB ROS including any custom message types. You can begin typing in the name of your desired message type or manually search through the list.

The selected message type is stored with the block and saved with the model.

Note: When using code generation, message type information is not included. You must ensure that your Linux ROS environment has the ROS packages installed that contain the necessary message type definitions.

Selecting ROS Parameter Names

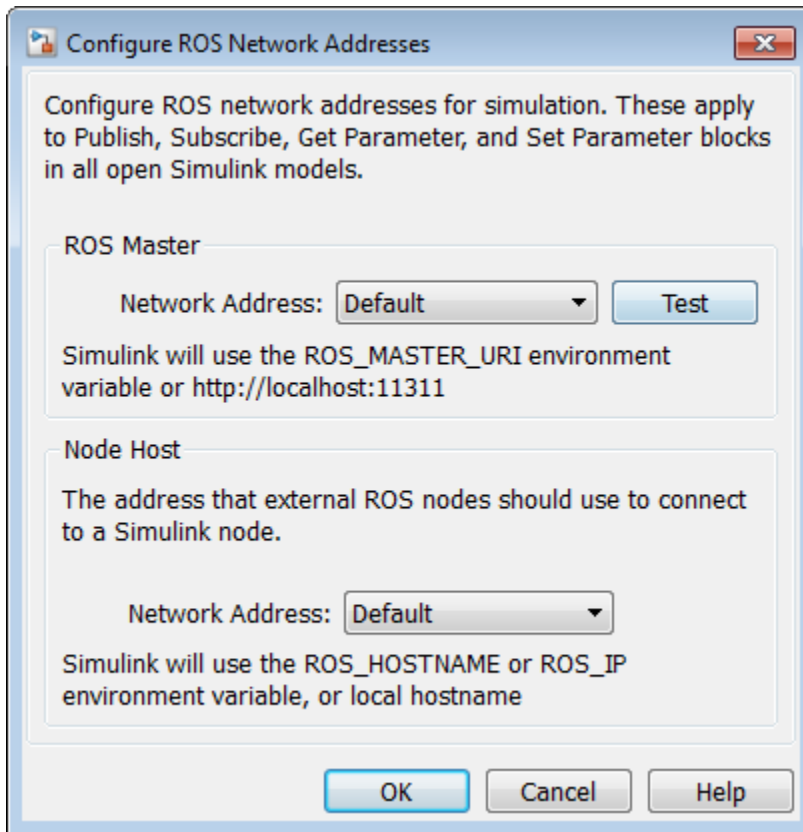
When using the `Get Parameter` and `Set Parameter` blocks, you have the option of "Select from ROS Network" in the block parameters, which gets a list of parameters currently on the server. When clicking **Select**, you should see this dialog box.



This is the list of parameters you can select from the ROS parameter server. The parameters that are grayed out have unsupported data types. Select a parameter name that is not grayed out and click **OK**. This should auto-fill the **Name** and **Data type** into the block parameters.

Configuring ROS Network Addresses

During model initialization, Simulink connects to a ROS master and also creates a node associated with the model. The ROS master URI and Node Host are specified in the “Configure ROS Network Addresses” dialog. You can access this in the menu under *Tools>>Robot Operating System (ROS)* by selecting “Configure ROS Network Addresses”.



The **Network Address** parameter can be set to “Default” or “Custom”.

For the ROS master URI, if **Network Address** is set to “Default”, Simulink uses the following rules to set the ROS Master URI:

- Use `ROS_MASTER_URI` environment variable if it is set.

- If a MATLAB global ROS node exists, use the Master URI associated with the global node. The global node is created automatically when `rosinit` is called.
- Use address `http://localhost:11311` if other two rules do not apply.

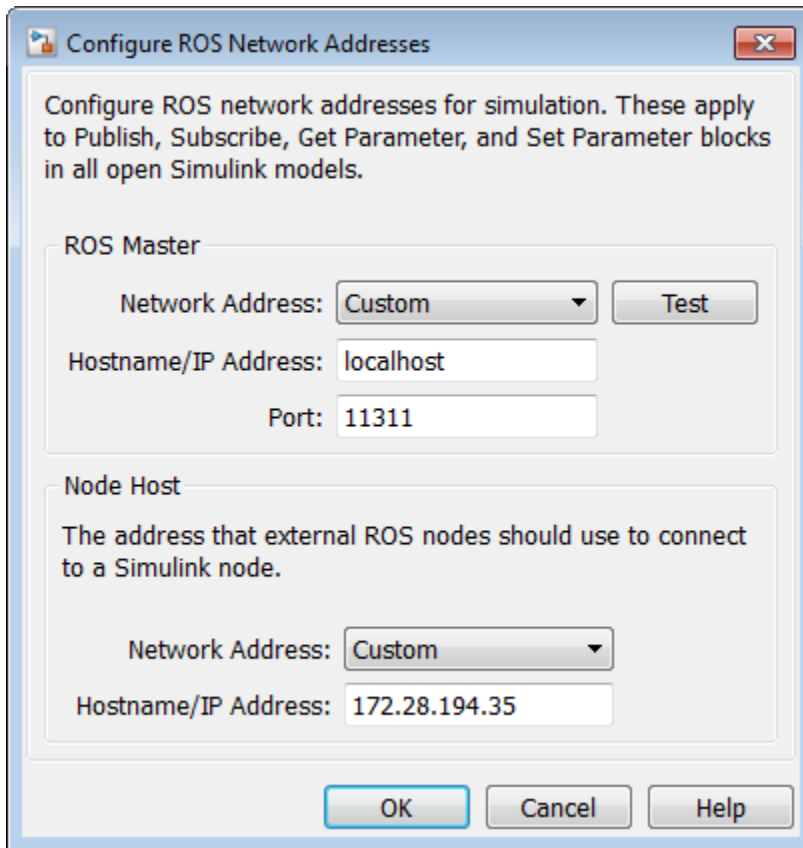
For the Node Host, if **Network Address** is set to “Default”, Simulink uses the following rules to set the ROS Node Host:

- Use `ROS_HOSTNAME` environment variable if it is set.
- Use `ROS_IP` environment variable if it is set.
- Use hostname or IP address of the first network interface on the system if available.
- Use address `http://localhost:11311` if other rules do not apply.

For both, these are the same rules that MATLAB uses to resolve its ROS network addresses.

Otherwise, if you chose “Custom”, you can set all the variables as shown below. This overrides the environment variables.

Note: These addresses are saved in MATLAB preferences, not the model. Therefore, this information is shared across all Simulink models and multiple MATLAB installs of the same release.



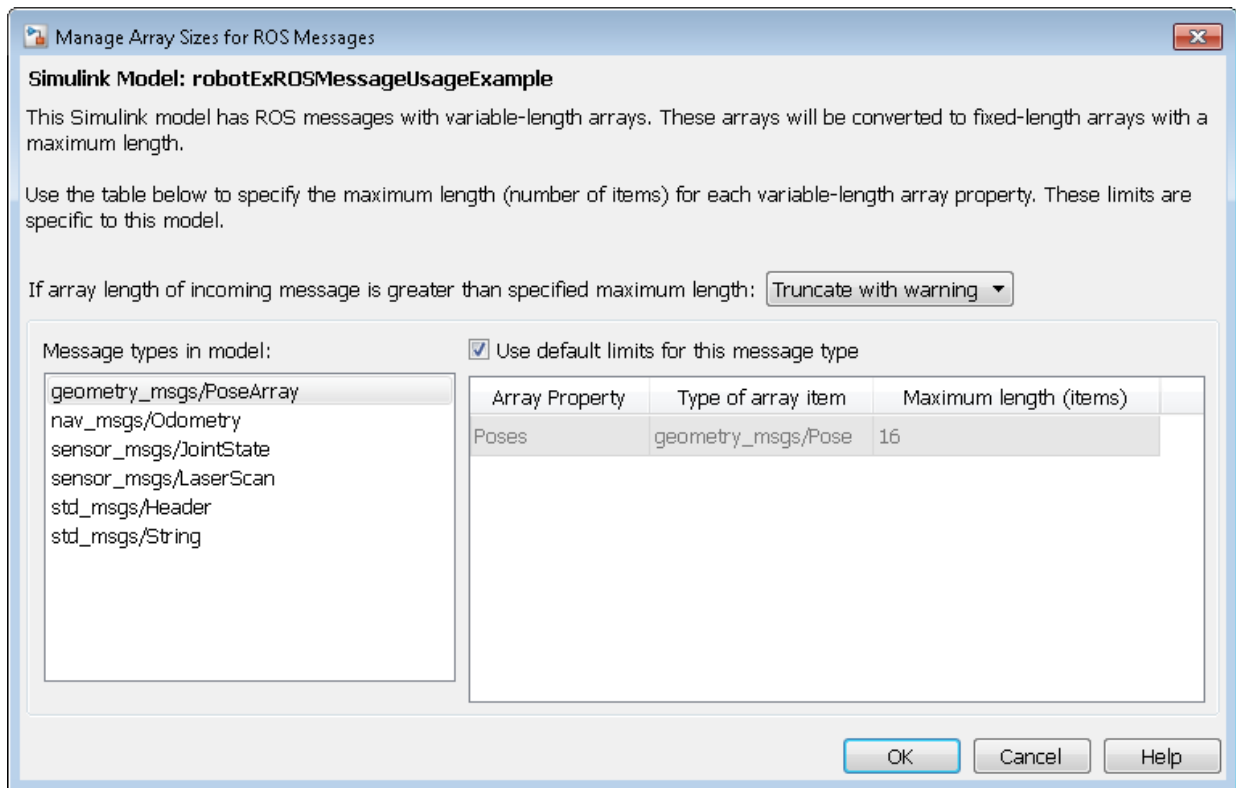
You can also use the “Test” button to ensure you can connect to the ROS master. If you get an error, call `rosinit` to setup a local ROS network, or if you specified a remote ROS master, check your settings are correct.

The custom ROS master or node host settings are not used in generated code when deploying a standalone node.

Managing Array Sizes in Simulink ROS

A ROS message is represented as a bus signal. For more information on bus signals, see “Buses”.

If you are working with variable-length signals in Simulink, the non-virtual bus used for messages cannot contain variable-length arrays as properties. All variable-length arrays are converted to fixed-length arrays for non-virtual buses. Therefore, you must manage the maximum size for these fixed-size arrays. To manage array sizes, select *Tools*>>*Robot Operating System* in the menu and select “Manage Array Sizes”. If your model uses ROS messages with variable-length arrays, the following dialog box opens. Otherwise, Simulink displays a message.



Because the message properties have a variable length, it is possible that they can be truncated if they exceed the maximum size set for that array. You have the option of

Truncate with warning or Truncate silently. Either way, the simulation will run, but Truncate with warning displays a warning in the Diagnostic Viewer that the message property has been truncated. When using generated code, the warning will be emitted using Log Statements in ROS. The warning will be a ROS_WARN_NAMED log statement and the *name* is the model name.

The **Message types in model** section shows all the ROS message types that are currently used by Publish, Subscribe and Blank Message blocks in your Simulink model. You have the option to use the default limits for this message type by clicking the check box. Otherwise, select each message type individually to set the **Maximum length (items)** of each **Array Property** as desired. This maximum length is applied to all instances of that message type for that model. The maximum length is also stored with the model. Therefore, it is possible to have two models accessing the same message type with different maximum length limits.

Managing the size of your variable-length arrays can help improve performance. If you limit the size of the array to only include relevant data, you can process data more effectively. However, when running these models, consider possible issues associated with truncation and what could happen to your system if some data is ignored.

Note: If you would like to know the appropriate maximum lengths for different message types. You can simulate the model and observe the sizes output in the warning. To see an example of using ROS messages and working with variable-length arrays, see “Working with ROS messages in Simulink®”.

Simulink and ROS Interaction

When using Simulink to communicate with a ROS network or work with ROS functionality, there are several points to note regarding its interaction with MATLAB and the ROS network.

In this section...
“MATLAB ROS Information” on page 9-10
“Simulink ROS Node” on page 9-10
“Differences Between Simulation and Generated Code” on page 9-11
“Publishers and Subscribers in Simulink” on page 9-11

MATLAB ROS Information

Simulink uses the functionality built into MATLAB to communicate with the ROS network during simulation. When trying to debug issues in Simulink, you can use MATLAB to view topics or messages available on the ROS master. For more information on ROS topics and messages, see `rosnode`, `rostopic`, or `rosmmsg`.

By default, Simulink uses MATLAB ROS capabilities to resolve network information such as the address of the ROS master. This network information can also be specified in Simulink using the “Configuring ROS Network Addresses” on page 9-5 dialog.

Simulink ROS Node

Each model is associated with a unique ROS node. At the start of each simulation, Simulink creates the node and deletes it when the simulation is terminated. If multiple models are open and being simulated, each model will get its own dedicated node, but all the nodes will connect to the same ROS master. This is because all the models use the same ROS network address settings.

In simulation, the Simulink ROS node name is `<modelName>_<random#>`. This takes the model name and adds a random number to the end to avoid node name conflicts.

In generated code, the node name is `<modelName>` (casing preserved). The model name is also used in the archive used for generated code. Do **not** rename the `tgz` file from code generation (e.g. `ModelName.tgz`). The file name is used to get the ROS package name and initiate the build.

Differences Between Simulation and Generated Code

In simulation, the model execution does not match real elapsed time. The blocks in the model are evaluated in a loop that only simulates the progression of time, and whose speed depends on complexity of the model and computer speed. It is not intended to track actual clock time.

In generated code, the model execution attempts to match actual elapsed time (the Fixed-step size defines the actual time step, in seconds, that is used for the model update loop). However, this does not guarantee real-time performance, as it is dependent on other processes running on the Linux system and the complexity of the model. For more information, see the *Tasking Mode* section in the “Generating a standalone ROS node from Simulink®” example.

Publishers and Subscribers in Simulink

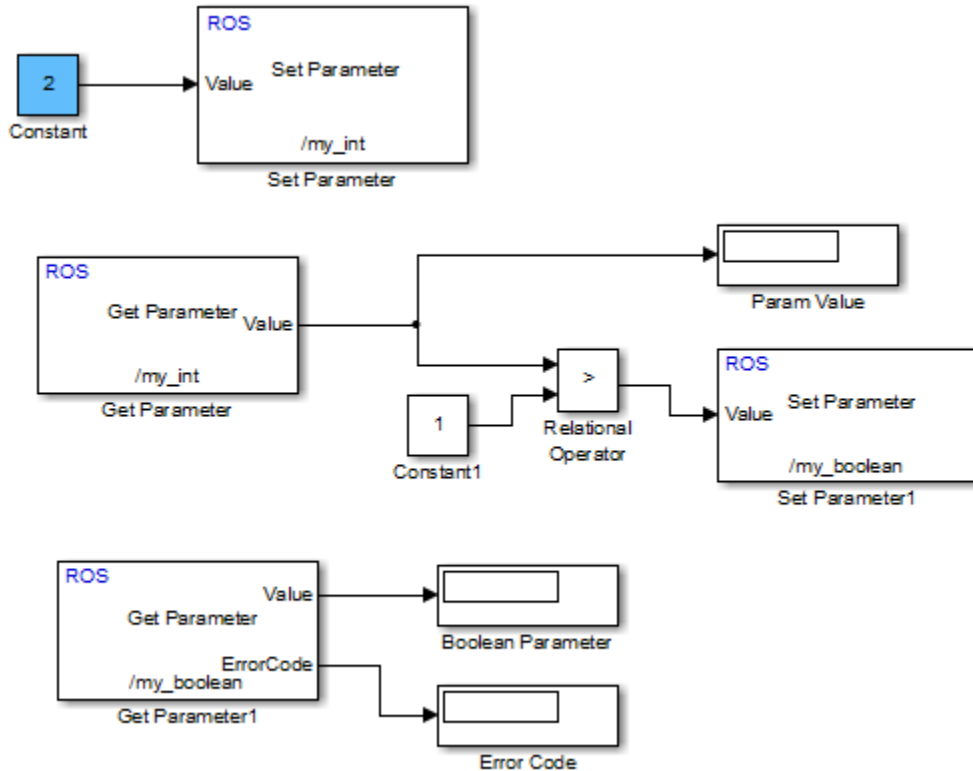
All publishers and subscribers created using **Publish** and **Subscribe** blocks will connect with the ROS node for that model. They are created during the model initialization and topic names are resolved at the same time. The publishers and subscribers are deleted when the simulation is terminated.

NOTE: If a custom topic name is specified for a **Subscribe** block, the topic is not required to exist when the model is initialized. The **Subscribe** block will output blank messages until it receives a message on the topic name you specify. This allows you to setup and test models before the rest of the network has been setup.

ROS Parameters in Simulink

Get and Set ROS Parameters

This model gets and sets ROS parameters using Simulink®. This example illustrates how to use ROS parameters in Simulink and to share data over the ROS network. An integer value is set as a parameter on the ROS network. This integer is retrieved from the parameter server and compared to a constant. The output Boolean from the comparison is also set on the network. Change the constant block in the top left (blue) when you run the model to set network parameters based on user input conditions.



Simulink Support and Limitations

Robotics System Toolbox does not support the following ROS features in Simulink:

- ROS Services
- ROS Parameter Server
- Transformation trees
- Messages containing cell arrays of strings

If your application requires these features, consider using MATLAB ROS functionality. You can write a ROS node using MATLAB that can publish services, parameters, and transformation trees to a topic as ROS messages. Simulink can then subscribe to that topic to work with those messages. The following functions are used in MATLAB to work with these features:

- ROS Services: `rosservice`, `rossvcserver`, `rossvcclient`, `call`
- ROS Parameter Servers: `rosparam`
- Transformation trees: `rostf`, `transform`, `getTransform`
- Messages containing cell arrays of strings: `rosmessage`

