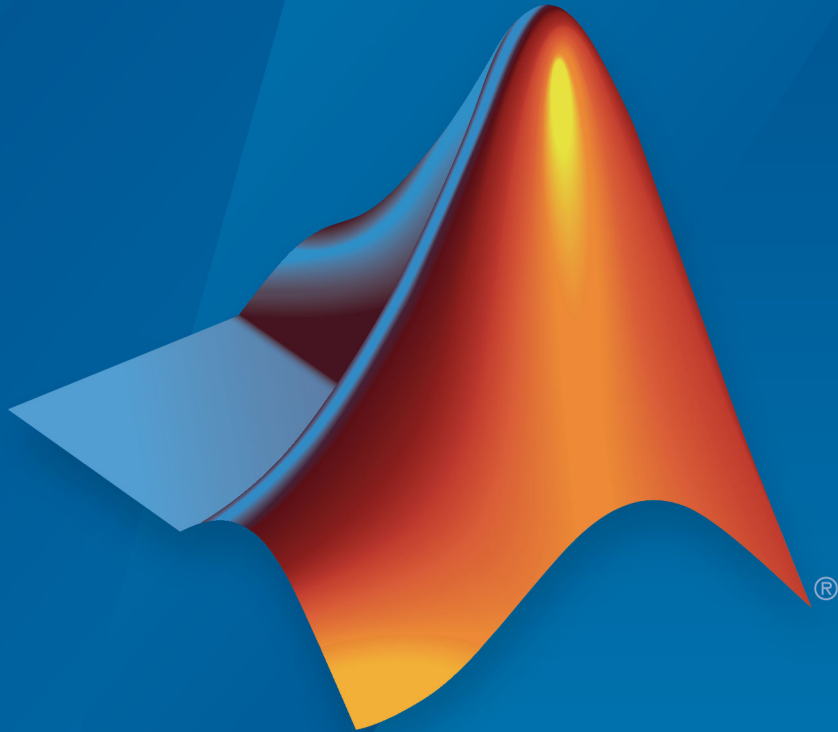


Automated Driving Toolbox™

Reference



MATLAB® & SIMULINK®

R2019b



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Automated Driving Toolbox™ Reference

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Revision History

March 2017	Online only	New for Version 1.0 (Release 2017a)
September 2017	Online only	Revised for Version 1.1 (Release 2017b)
March 2018	Online only	Revised for Version 1.2 (Release 2018a)
September 2018	Online only	Revised for Version 1.3 (Release 2018b)
March 2019	Online only	Revised for Version 2.0 (Release 2019a)
September 2019	Online only	Revised for Version 3.0 (Release 2019b)

1	<u>Apps in Automated Driving Toolbox</u>
2	<u>Blocks in Automated Driving Toolbox</u>
3	<u>Functions in Automated Driving Toolbox</u>
4	<u>Objects in Automated Driving Toolbox</u>
5	<u>Scene Dimensions</u>
6	<u>Vehicle Dimensions</u>

Apps in Automated Driving Toolbox

Bird's-Eye Scope

Visualize sensor coverages, detections, and tracks

Description

The **Bird's-Eye Scope** visualizes aspects of a driving scenario found in your Simulink® model. Using the scope, you can:

- Inspect the coverage areas of radar and vision sensors.
- Analyze the sensor detections of actors, road boundaries, and lane boundaries.
- Analyze the tracking results of moving actors within the scenario.

To get started, open the scope and click **Find Signals**. The scope updates the block diagram, finds signals representing aspects of the driving scenario, organizes the signals into groups, and displays the signals. You can then analyze the signals as you simulate, organize the signals into new groups, and modify the graphical display of the signals.

For more details about using the scope, see “Visualize Sensor Data and Tracks in Bird's-Eye Scope”.

Open the Bird's-Eye Scope

Simulink Toolstrip: On the **Simulation** tab, under **Review Results**, click **Bird's-Eye Scope**.

Examples

- “Visualize Sensor Data and Tracks in Bird's-Eye Scope”
- “Sensor Fusion Using Synthetic Radar and Vision Data in Simulink”
- “Lane Following Control with Sensor Fusion and Lane Detection”
- “Autonomous Emergency Braking with Sensor Fusion”
- “Test Open-Loop ADAS Algorithm Using Driving Scenario”

- “Test Closed-Loop ADAS Algorithm Using Driving Scenario”

Parameters

Settings

To access the settings of the **Bird's-Eye Scope**, on the scope toolstrip, click **Settings**.

Vehicle Coordinates View Settings

Longitudinal axis limits — Longitudinal axis limits

$[-60, 60]$ (default) | $[min, max]$ vector

Longitudinal axis limits, specified as a $[min, max]$ vector.

Tunable: Yes

Lateral axis limits — Lateral axis limits

$[-30, 30]$ (default) | $[min, max]$ vector

Lateral axis limits, specified as a $[min, max]$ vector.

Tunable: Yes

Track position selector — Selection matrix used to extract positions of tracked objects

$[1, 0, 0, 0, 0, 0; 0, 0, 1, 0, 0, 0]$ (default) | 2-by- n matrix of zeros and ones

Selection matrix used to extract the positions of tracked objects, specified as a 2-by- n matrix of zeros and ones. n is the size of the state vector for each tracked object in the scenario. The scope multiplies the selection matrix by the state vector of a tracked object to return the (x, y) position of the object.

- The first row of the matrix corresponds to the x -coordinate stored within the state vector.
- The second row of the matrix corresponds to the y -coordinate stored within the state vector.

This parameter applies to signals from a Multi Object Tracker block that were initialized by a linear Kalman filter. The state vector format depends on the motion model used to

initialize the Kalman filter. For more details on these motion models, see `trackingKF` and “Linear Kalman Filters”.

The default selection matrix is for a 3-D constant velocity motion model. In this motion model, the state vectors of tracked objects are of the form $[x; vx; y; vy; z; vz]$, where:

- x is the x -coordinate of a tracked object.
- vx is the velocity of a tracked object in the x -direction.
- y is the y -coordinate of a tracked object.
- vy is the velocity of a tracked object in the y -direction.
- z is the z -coordinate of a tracked object.
- vz is the velocity of a tracked object in the z -direction.

Multiplying the state vector by this selection matrix returns only the first element of the state vector, x , and the third element of the state vector, y .

$$[1, 0, 0, 0, 0, 0; 0, 0, 1, 0, 0, 0] * [x; vx; y; vy; z; vz] = [x; y]$$

Tunable: No

Track velocity selector — Selection matrix used to extract velocities of tracked objects

$[0, 1, 0, 0, 0, 0; 0, 0, 0, 1, 0, 0]$ (default) | 2-by- n matrix of zeros and ones

Selection matrix used to extract the velocities of tracked objects, specified as a 2-by- n matrix of zeros and ones. n is the size of the state vector for each tracked object in the scenario. The scope multiplies the selection matrix by the state vector of a tracked object to return the velocity of the object in the (x, y) direction.

- The first row of the matrix corresponds to the x -direction velocity stored within the state vector.
- The second row of the matrix corresponds to the y -direction velocity stored within the state vector.

This parameter applies to signals from a Multi Object Tracker block that were initialized by a linear Kalman filter. The state vector format depends on the motion model used to initialize the Kalman filter. For more details on these motion models, see `trackingKF` and “Linear Kalman Filters”.

The default selection matrix is for a 3-D constant velocity motion model. In this motion model, the state vectors of tracked objects are of the form $[x; vx; y; vy; z; vz]$, where:

- x is the x -coordinate of a tracked object.
- v_x is the velocity of a tracked object in the x -direction.
- y is the y -coordinate of a tracked object.
- v_y is the velocity of a tracked object in the y -direction.
- z is the z -coordinate of a tracked object.
- v_z is the velocity of a tracked object in the z -direction.

Multiplying the state vector by this selection matrix returns only the second element of the state vector, v_x , and the fourth element of the state vector, v_y .

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} * \begin{bmatrix} x \\ v_x \\ y \\ v_y \\ z \\ v_z \end{bmatrix} = \begin{bmatrix} v_x \\ v_y \end{bmatrix}$$

Tunable: No

Global Settings

Display short signal names — Display signal names without path information

on (default) | off

- Select this parameter to display short signal names (signals without path information).
- Clear this parameter to display long signal names (signals with path information).

Consider the signal `VisionDetection` within subsystem `Sensor Simulation`. When you select this parameter, the short name, `VisionDetection`, is displayed. When you clear this parameter, the long name, `Sensor Simulation/VisionDetection`, is displayed.

Tunable: Yes

Signal Properties

These properties are a subset of the available signal properties. To view all the properties of a signal, first select that signal from the left pane. Then, on the scope toolstrip, click **Properties**.

Alpha — Transparency of coverage area

0.1 (default) | real scalar in the range [0, 1]

Transparency of the coverage area, specified as a real scalar in the range [0, 1]. A value of 0 makes the coverage area fully transparent. A value of 1 makes the coverage area fully opaque.

This property is available only for signals in the **Sensor Coverage** group.

Tunable: Yes

Velocity Scaling — Scale factor for magnitude length of velocity vectors

1 (default) | real scalar in the range [0, 20]

Scale factor for the magnitude length of the velocity vectors, specified as a real scalar in the range [0, 20]. The scope renders the magnitude vector value as $M \times$ **Velocity Scaling**, where M is the magnitude of the velocity.

This property is available only for signals in the **Detections** or **Tracks** groups.

Tunable: Yes

Limitations

General Limitations

- Referenced models are not supported. To visualize signals that are within referenced models, move the output of these signals to the top-level model.
- Rapid accelerator mode is not supported.
- If you initialize your model in fast restart, then after the first time you simulate, the **Find Signals** button is disabled. To enable **Find Signals** again, on the **Debug** tab of the Simulink toolstrip, click **Fast Restart**.

Scenario Reader Block Limitations

- The **Bird's-Eye Scope** does not support visualization in a model that contains:
 - More than one Scenario Reader block.
 - A Scenario Reader block within a nonvirtual subsystem, such as an atomic or enabled subsystem.
 - A Scenario Reader block that is configured to output actors and lane boundaries in world coordinates (**Coordinate system of outputs** parameter set to **World Coordinates**).

- For Scenario Reader blocks in which you specify the ego vehicle using the **Ego Vehicle** input port, the ego vehicle signal must be connected directly to the block. Visualization of ego vehicle signals that are output from a nonvirtual subsystem or referenced model are not supported.

3D Simulation Block Limitations

- The visualization of ground truth data (roads, lanes, and actors) from Simulation 3D Scene Configuration blocks is not supported. The **Bird's-Eye Scope** still visualizes the ego vehicle, but it is shown with default vehicle dimensions.
- The visualization of sensor coverage areas from Simulation 3D Probabilistic Radar blocks is not supported.

More About

Applicable Signals

When the **Bird's-Eye Scope** finds signals in your model, it automatically groups signals by type. These groupings are based on the sources of the signals within the model.

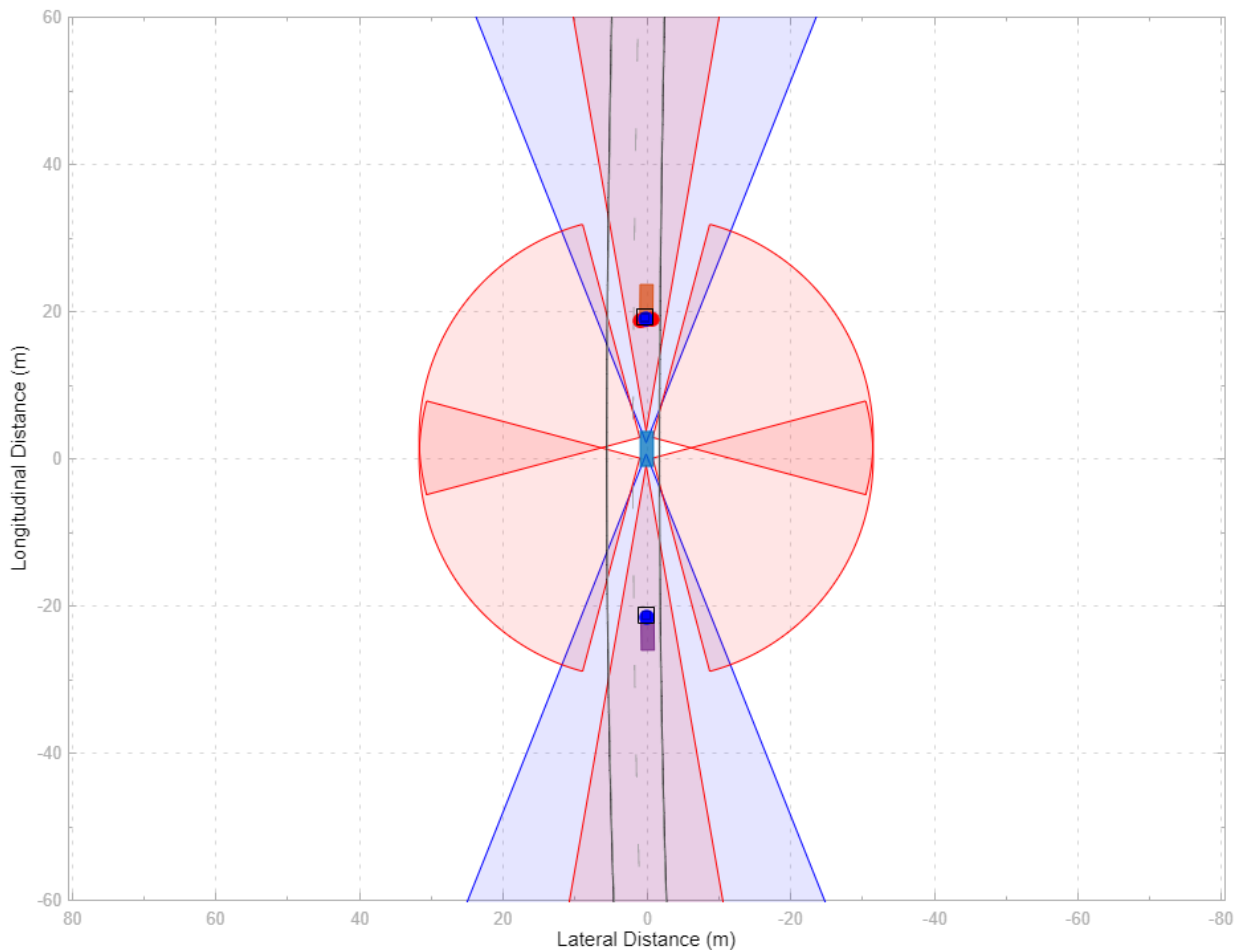
Signal Group	Description	Signal Sources
Ground Truth	<p>Road boundaries, lane markings, and actors in the scenario, including the ego vehicle</p> <p>You cannot modify this group or any of the signals within it.</p> <p>To inspect large road networks or to view actors that are located away from the ego vehicle, use the World Coordinates View window. See “Vehicle and World Coordinate Views” on page 1-10.</p>	<ul style="list-style-type: none"> • Scenario Reader block • Vision Detection Generator and Radar Detection Generator blocks (for actor profile information only, such as the length, width, and height of actors) • If actor profile information is not set or is inconsistent between blocks, the scope sets the actor profiles to the block defaults. • The profile of the ego vehicle is always set to the block defaults.
Sensor Coverage	<p>Coverage areas of your vision and radar sensors, sorted into Vision and Radar subgroups</p> <p>You can move or modify these subgroups and their signals. You cannot move or modify the top-level Sensor Coverage group.</p>	<ul style="list-style-type: none"> • Vision Detection Generator block • Radar Detection Generator block

Signal Group	Description	Signal Sources
Detections	<p>Detections obtained from your vision and radar sensors, sorted into Vision and Radar subgroups</p> <p>You can move or modify these subgroups and their signals. You cannot move or modify the top-level Detections group.</p>	<ul style="list-style-type: none"> • Vision Detection Generator block • Radar Detection Generator block • Simulation 3D Probabilistic Radar block • When you first click Find Signals, detection signals from these blocks appear under Other Applicable Signals. To display the detections, move the signals to the Detections group. • The Bird's-Eye Scope does not display sensor coverage areas from these blocks.
Tracks	Tracks of objects in the scenario	<ul style="list-style-type: none"> • Multi Object Tracker block
Other Applicable Signals	<p>Signals that the scope cannot automatically group, such as ones that combine information from multiple sensors</p> <p>Signals in this group do not display during simulation.</p>	<ul style="list-style-type: none"> • Blocks that combine or cluster signals (such as the Detection Concatenation block) • Nonvirtual Simulink buses containing position and velocity information for detections and tracks

To view a model that includes samples of all these signals types, see the “Sensor Fusion Using Synthetic Radar and Vision Data in Simulink” example.

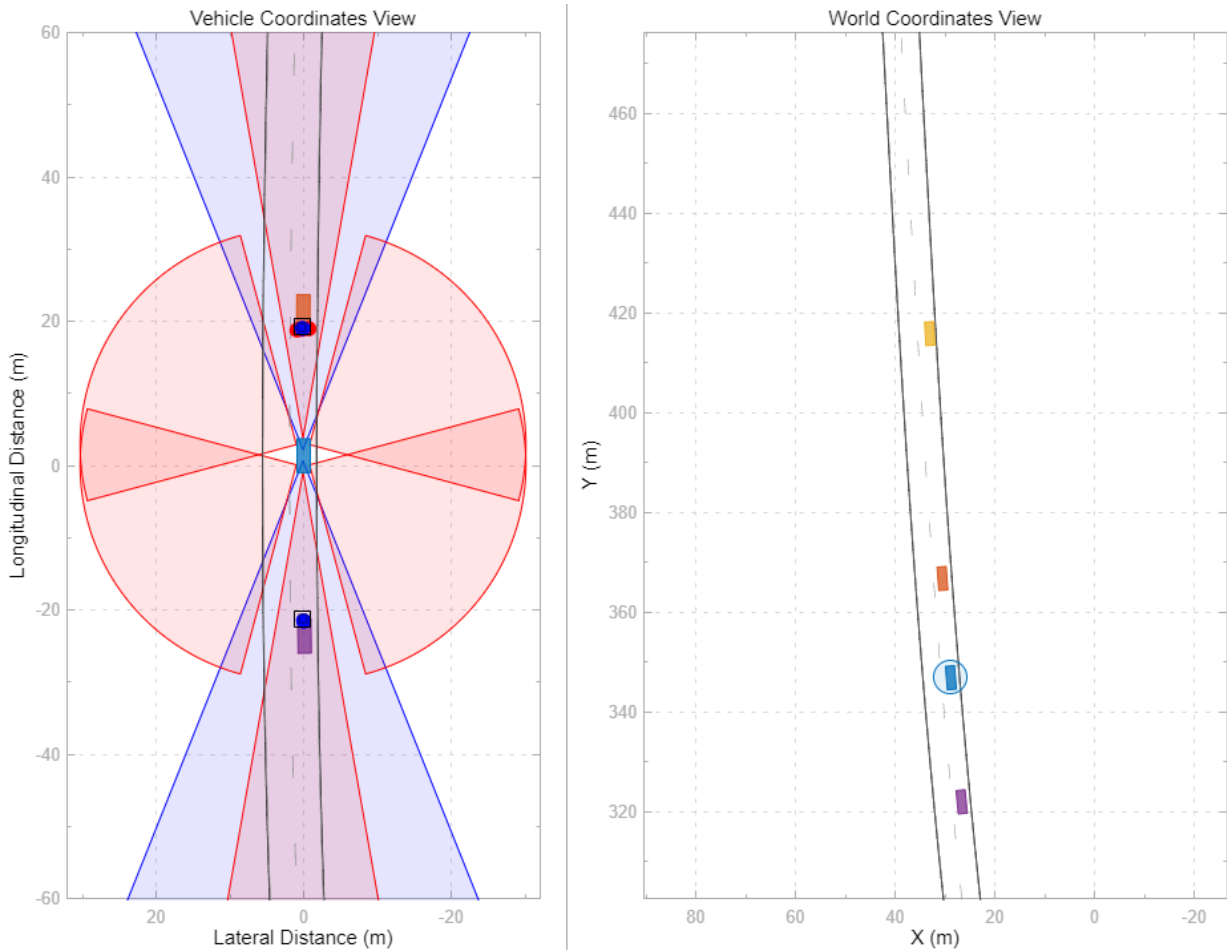
Vehicle and World Coordinate Views

In the **Bird's-Eye Scope**, the default view displays the driving scenario in vehicle coordinates. During simulation, this view displays the scenario from the perspective of the ego vehicle. Use this view to inspect aspects of the scenario in the immediate vicinity of the ego vehicle.



You can also display the driving scenario in world coordinates. On the scope toolstrip, click **World Coordinates** to open the **World Coordinates View** window. Use this


window to view the scenario as a whole. You can also use this view to inspect the trajectories of actors that are not in the immediate vicinity of the ego vehicle.



To display the roads and lanes within the **World Coordinates View**, click **Find Signals**. To display the ego vehicle and other actors in the scenario, run the simulation. This view does not display detections, tracks, sensor coverage areas, and other applicable signals. You can view these signals only in the **Vehicle Coordinates View** window.

Note In the **World Coordinates View** window, the circle around the ego vehicle highlights the location of the vehicle in the scenario. It is not a sensor coverage area.

Tips

- Make sure that all sensor blocks have unique sensor identifiers. These identifiers are specified in the **Unique identifier of sensor** parameter of Vision Detection Generator and Radar Detection Generator blocks. If two sensor blocks have the same identifier, the **Bird's-Eye Scope** visualizes sensor data from only the first sensor block specified in the model. Duplicate sensor identifiers can occur when you add a default Vision Detection Generator block and Radar Detection Generator blocks to your model. The default **Unique identifier of sensor** parameter value for these sensor blocks is always 1.
- To find the source of a signal within the model, in the left pane of the scope, right-click a signal and select **Highlight in Model**.
- You can show or hide signals while simulating. For example, to hide a sensor coverage, first select it from the left pane. Then, from the **Properties** tab, clear the **Show Sensor Coverage** check box.
- When you reopen the scope after saving and closing a model, the scope canvas is initially blank. Click **Find Signals** to find the signals again. The signals have the same properties from when you last saved the model.
- If the simulation runs too quickly, you can slow it down by using simulation pacing. On the **Simulation** tab of the Simulink toolstrip, select **Run > Simulation Pacing**. Then, select the **Enable pacing to slow down simulation** check box and decrease the simulation time to less than the default of one second per wall clock second.
- To better inspect the scenario, you can pan and zoom within the **Vehicle Coordinates View** and **World Coordinates View** windows. To return to the default display of either window, in the upper-right corner of that window, click the home button .
- When you first click **Find Signals**, detection signals from Simulation 3D Probabilistic Radar blocks appear under **Other Applicable Signals**. To display the detections, move these signals to the **Detections** group.

See Also

Detection Concatenation | Multi Object Tracker | Radar Detection Generator | Scenario Reader | Simulation 3D Probabilistic Radar | Vision Detection Generator

Topics

“Visualize Sensor Data and Tracks in Bird's-Eye Scope”

“Sensor Fusion Using Synthetic Radar and Vision Data in Simulink”

“Lane Following Control with Sensor Fusion and Lane Detection”

“Autonomous Emergency Braking with Sensor Fusion”

“Test Open-Loop ADAS Algorithm Using Driving Scenario”

“Test Closed-Loop ADAS Algorithm Using Driving Scenario”

Introduced in R2018b

Driving Scenario Designer

Design driving scenarios, configure sensors, and generate synthetic object detections

Description

The **Driving Scenario Designer** app enables you to design synthetic driving scenarios for testing your autonomous driving systems.

Using the app, you can:

- Create road and actor models using a drag-and-drop interface.
- Configure vision and radar sensors mounted on the ego vehicle, and use these sensors to simulate detections of actors and lane boundaries in the scenario.
- Load driving scenarios representing European New Car Assessment Programme (Euro NCAP®) test protocols [1][2][3] and other prebuilt scenarios.
- Import OpenDRIVE® roads and lanes into a driving scenario. The app supports OpenDRIVE format specification version 1.4H [4].
- Export synthetic sensor detections to MATLAB®.
- Generate MATLAB code of the scenario and sensors, and then programmatically modify the scenario and import it back into the app for further simulation.
- Generate a Simulink model from the scenario and sensors, and use the generated models to test your sensor fusion or vehicle control algorithms.

To learn more about the app, see [Driving Scenario Designer](#).

Open the Driving Scenario Designer App

- MATLAB Toolstrip: On the **Apps** tab, under **Automotive**, click the app icon.
- MATLAB command prompt: Enter `drivingScenarioDesigner`.

Examples

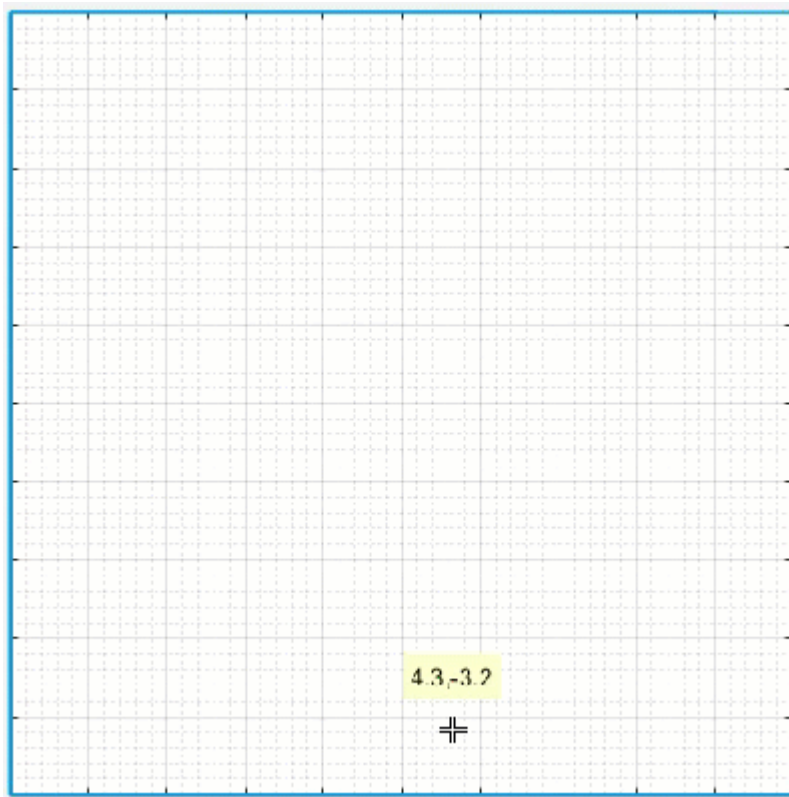
Build a Driving Scenario

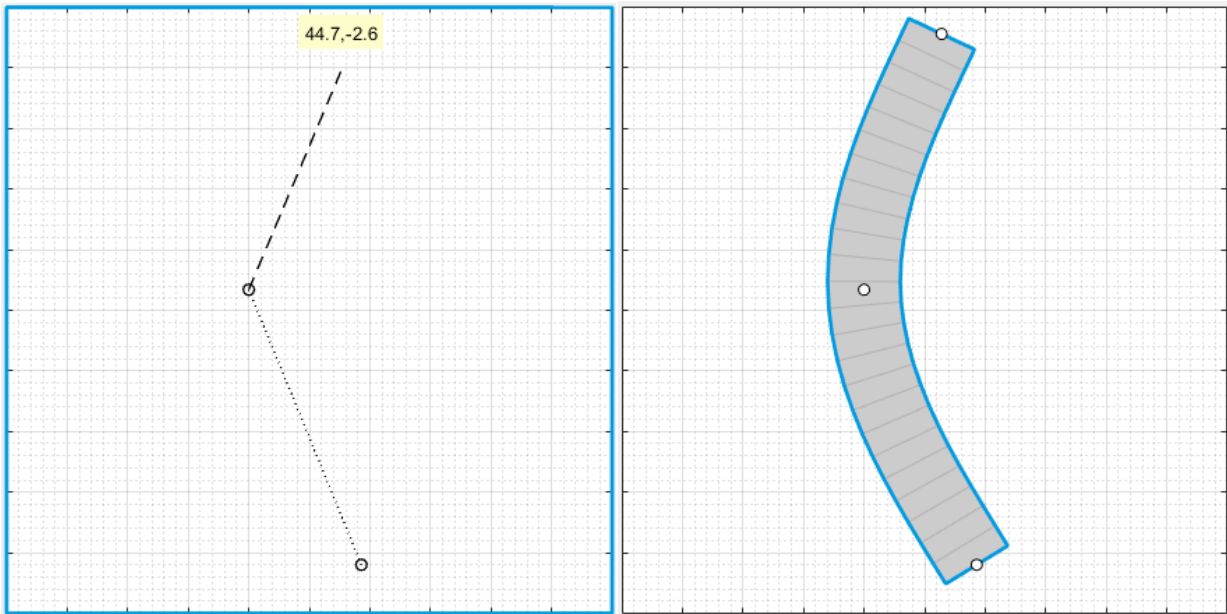
Build a driving scenario of a vehicle driving down a curved road, and export the road and vehicle models to the MATLAB workspace. For a more detailed example of building a driving scenario, see “Build a Driving Scenario and Generate Synthetic Detections”.

Open the **Driving Scenario Designer** app.

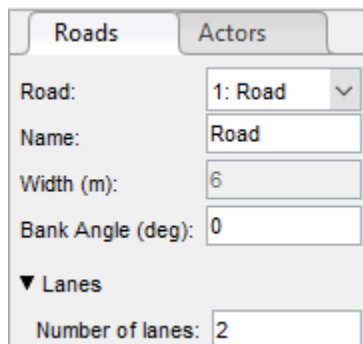
```
drivingScenarioDesigner
```

Create a curved road. On the app toolstrip, click **Add Road**. Click the bottom of the canvas, extend the road path to the middle of the canvas, and click the canvas again. Extend the road path to the top of the canvas, and then double-click to create the road. To make the curve more complex, click and drag the road centers (open circles), or double-click the road to add more road centers.

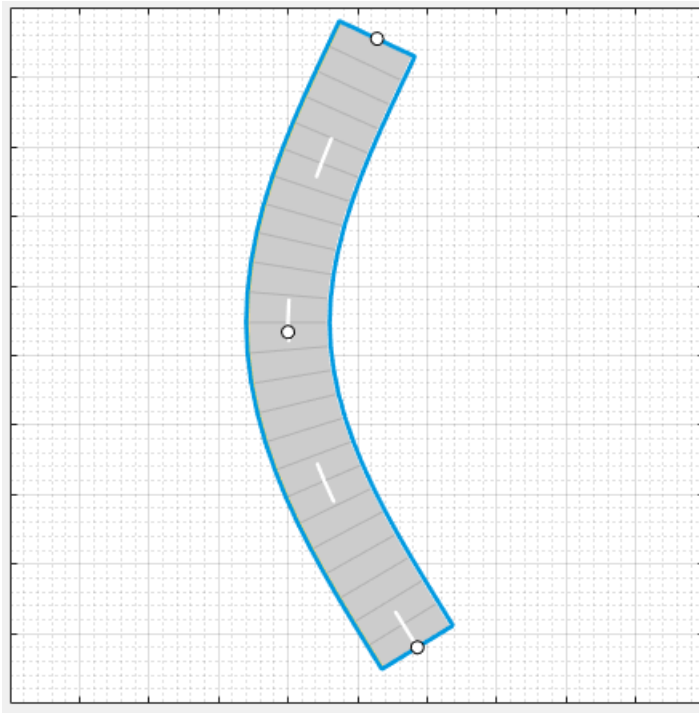




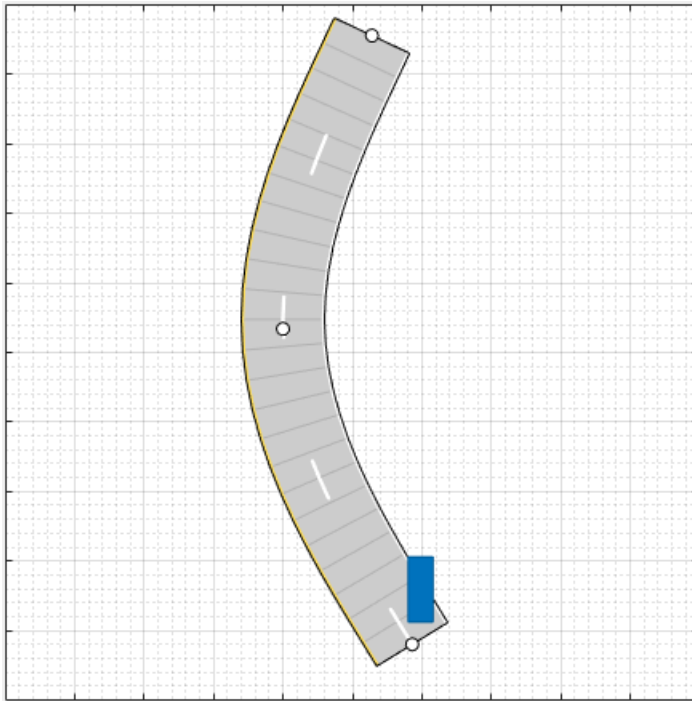
Add lanes to the road. In the left pane, on the **Roads** tab, expand the **Lanes** section. Set the **Number of lanes** to 2.



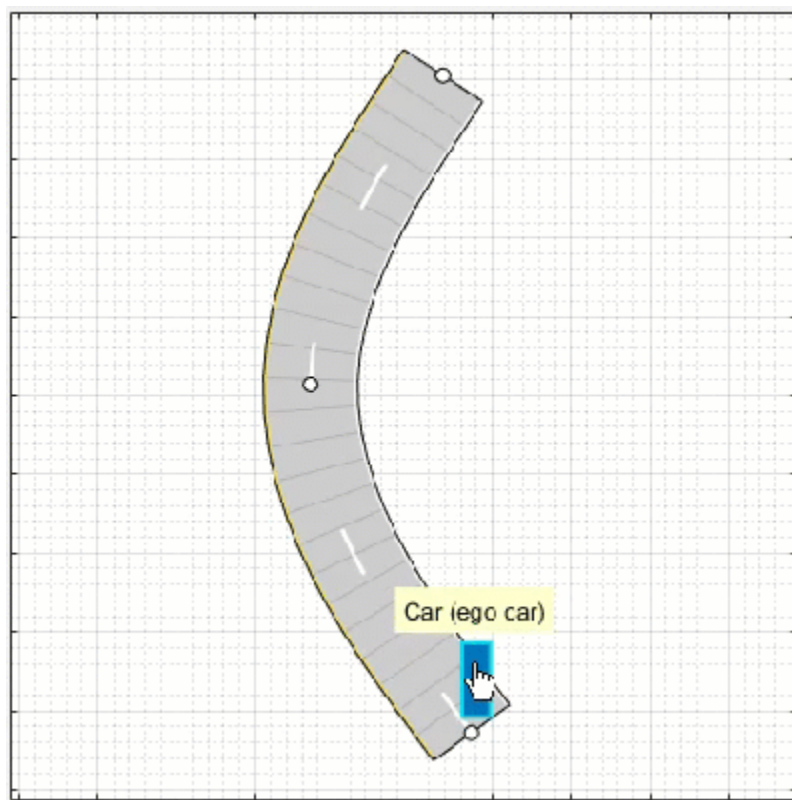
By default, the road is one-way and has solid lane markings on either side to indicate the shoulder.

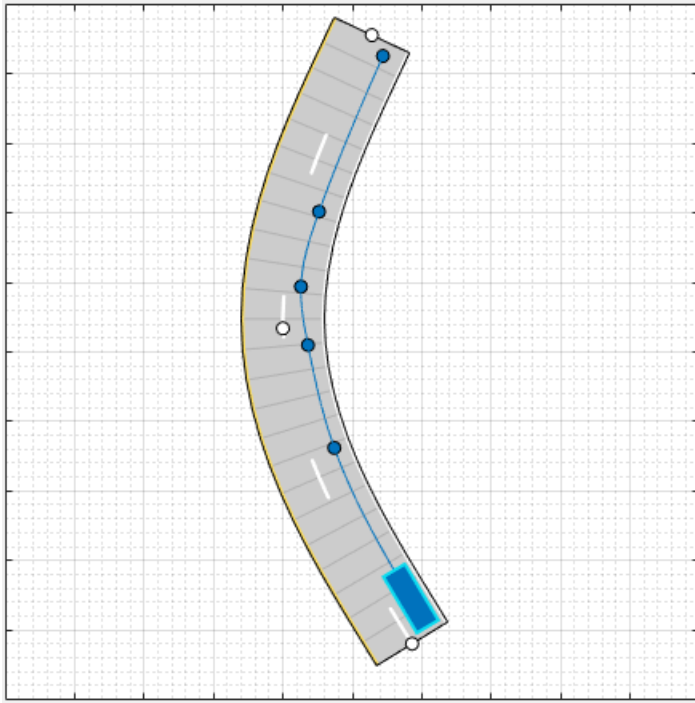


Add a vehicle at one end of the road. On the app toolbar, select **Add Actor > Car**. Then click the road to set the initial position of the car.

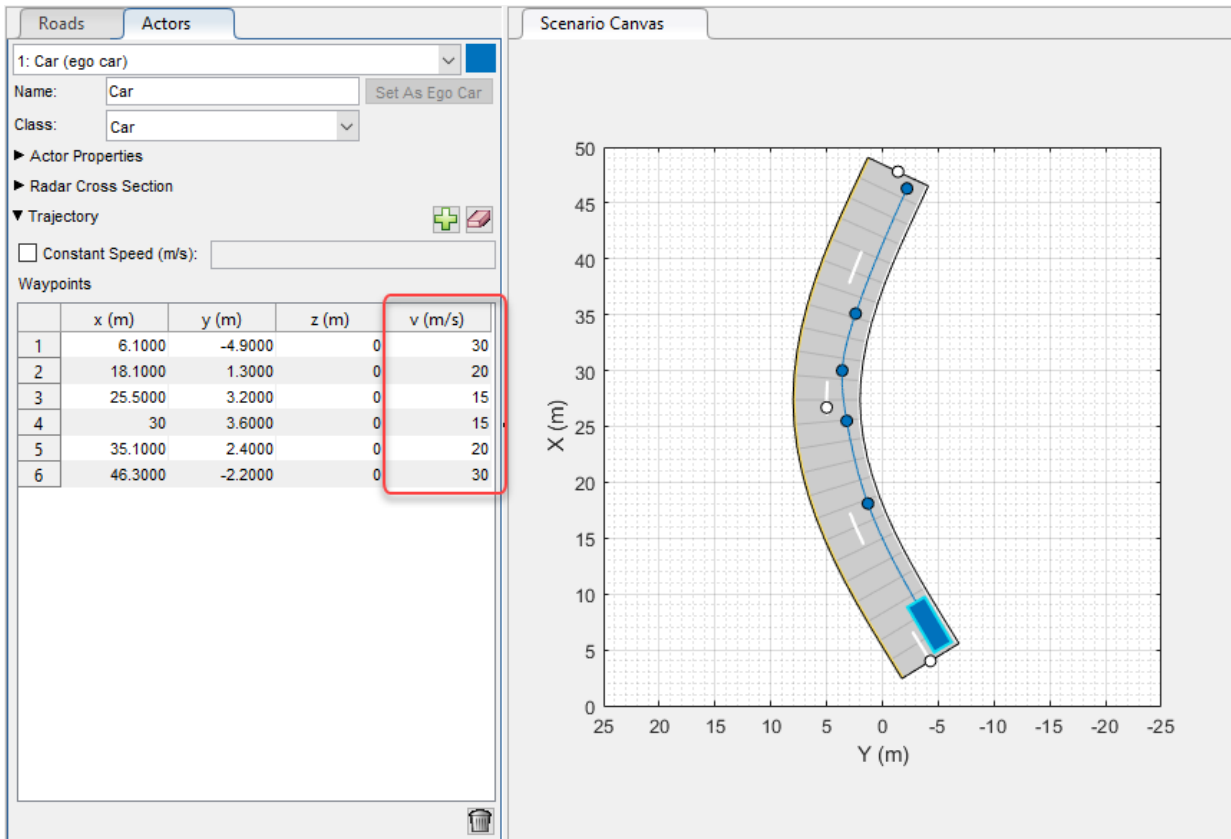


Set the driving path of the car. Right-click the car, select **Add Waypoints**, and add waypoints for the car to pass through. After you add the last waypoint, press **Enter**. The car autorotates in the direction of the first waypoint.





Adjust the speed of the car as it passes between waypoints. In the left pane, on the **Actors** tab, in the **Path** section, clear the **Constant Speed** check box. Then, in the **Waypoints** table, set the velocity, v (m/s), of the car in m/s as it enters each waypoint segment. To model more realistic conditions, increase the speed of the car for the straight segments and decrease its speed for the curved segments. For example:



Run the scenario, and adjust settings as needed. Then click **Save > Roads & Actors** to save the road and car models to a MAT-file.

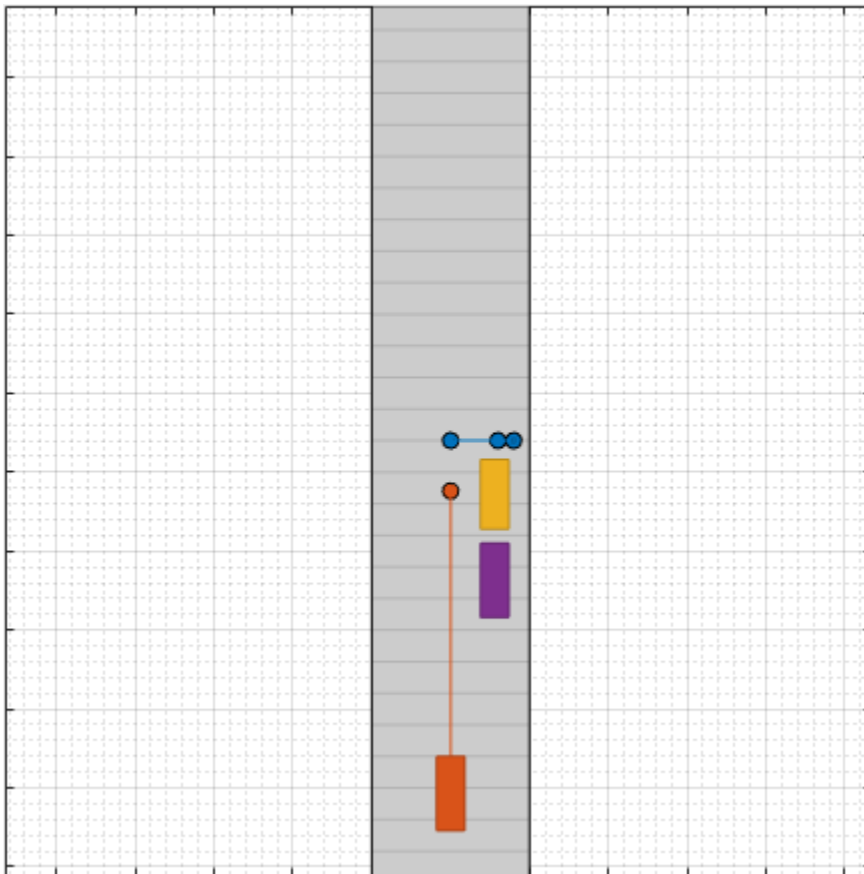
Generate Detections from Prebuilt Scenario

Generate vision sensor detections from a prebuilt driving scenario of a Euro NCAP test protocol.

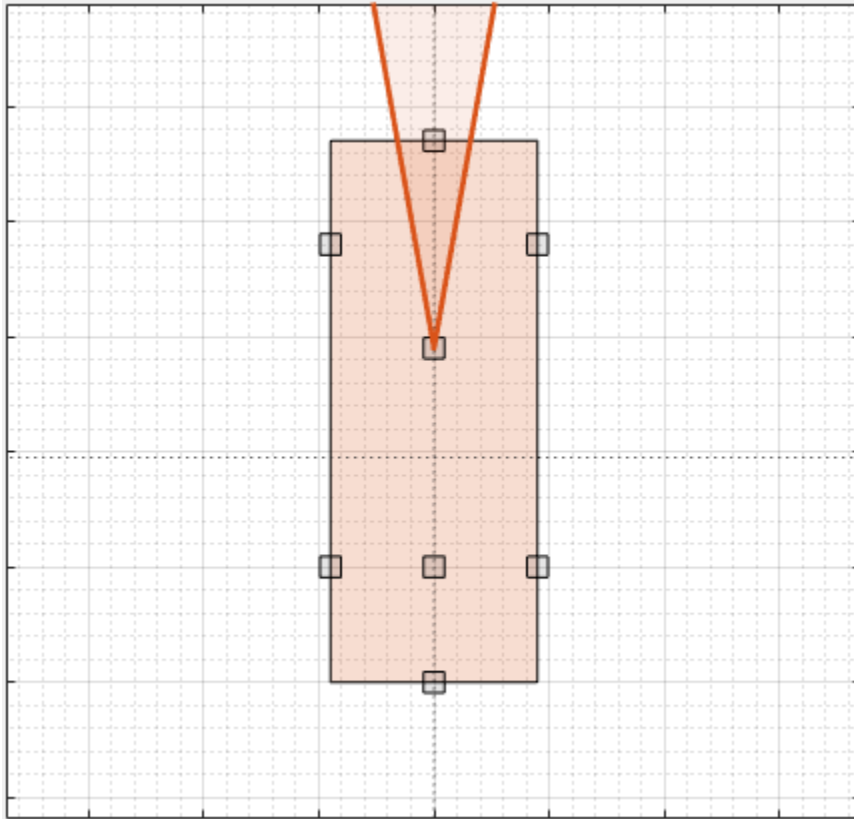
- For more details on prebuilt scenarios available from the app, see “Prebuilt Driving Scenarios in Driving Scenario Designer”.
- For more details on available Euro NCAP scenarios, see “Euro NCAP Driving Scenarios in Driving Scenario Designer”.

Load a Euro NCAP autonomous emergency braking (AEB) scenario of a collision with a pedestrian child. At collision time, the point of impact occurs 50% of the way across the width of the car.

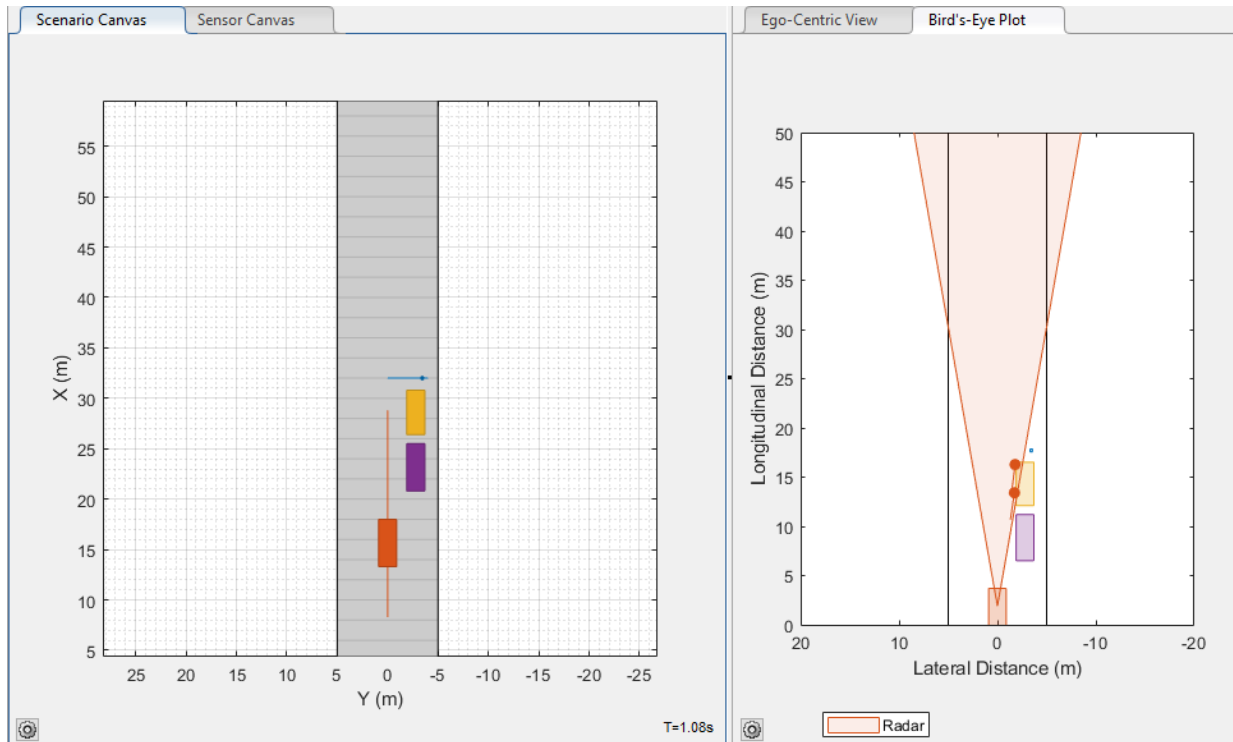
```
path = fullfile(matlabroot, 'toolbox', 'shared', 'drivingscenario', ...  
    'PrebuiltScenarios', 'EuroNCAP');  
addpath(genpath(path)) % Add folder to path  
drivingScenarioDesigner('AEB_PedestrianChild_Nearside_50width.mat')  
rmpath(path) % Remove folder from path
```



Add a front-facing radar sensor to the ego vehicle. First click **Add Radar**. Then, on the **Sensor Canvas**, click the predefined sensor location at the front window of the car. By default, the radar is long-range.



Run the scenario. While the scenario simulation runs, inspect different aspects of the simulation by toggling between canvases and views. You can toggle between the **Sensor Canvas** and **Scenario Canvas** and between the **Bird's-Eye Plot** and **Ego-Centric View**.



Export the sensor data to the MATLAB workspace. Click **Export** > **Export Sensor Data**, enter a workspace variable name, and click **OK**.

Import Programmatic Driving Scenario

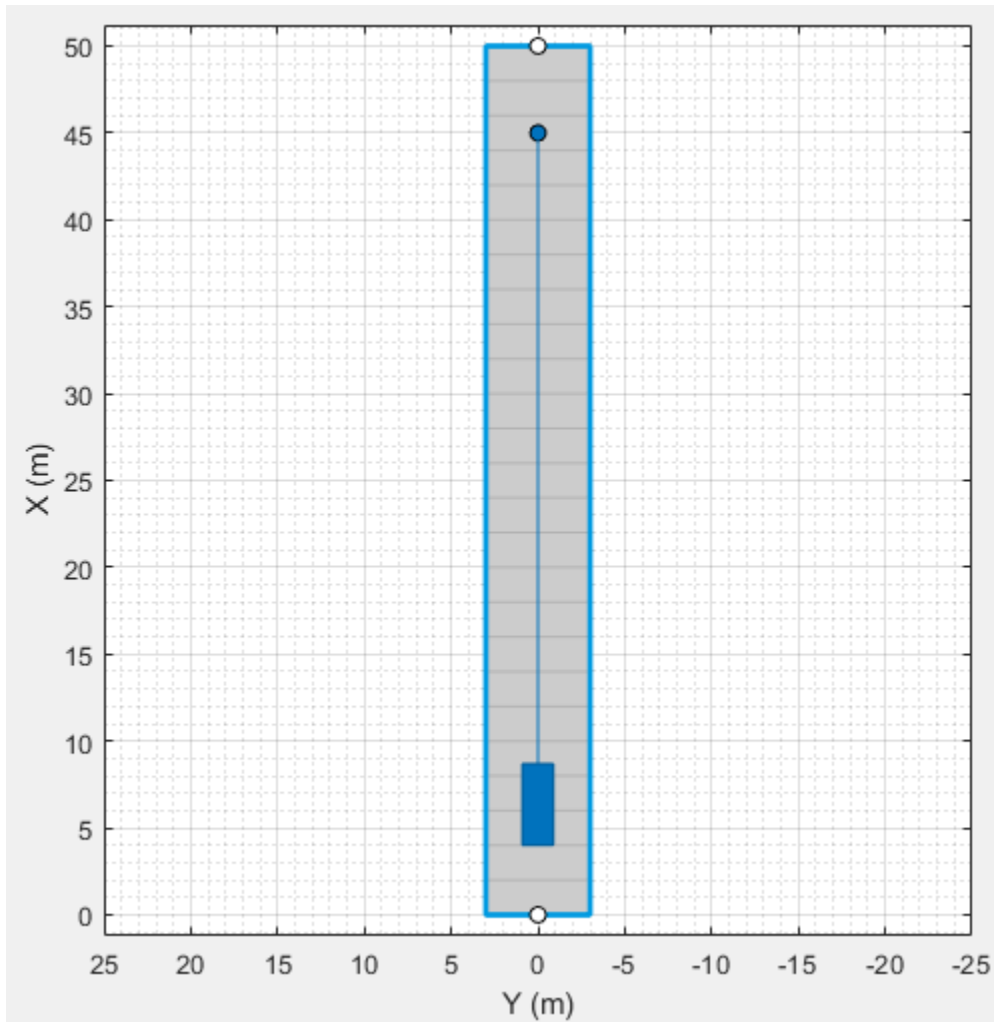
Create a driving scenario programmatically and import that scenario into the app. For more details on working with programmatic driving scenarios, see “Create Driving Scenario Variations Programmatically”.

Create a simple driving scenario by using a `drivingScenario` object. In this scenario, the ego vehicle travels straight on a 50-meter road segment at a constant speed of 30 meters per second. For the ego vehicle, specify a `ClassID` of 1. This value corresponds to the app `Class ID` of 1, which refers to actors of class `Car`. For more details on how the app defines classes, see the `Class` parameter description under “Actors” on page 1-0 .

```
scenario = drivingScenario;  
roadCenters = [0 0 0; 50 0 0];  
road(scenario, roadCenters);  
  
egoVehicle = vehicle(scenario, 'ClassID', 1, 'Position', [5 0 0]);  
waypoints = [5 0 0; 45 0 0];  
speed = 30;  
trajectory(egoVehicle, waypoints, speed);
```

Import the scenario into the app. Then, run the scenario or modify it. To generate a new `drivingScenario` object, on the app toolbar, select **Export** > **Export MATLAB Function**, and then run the generated function.

```
drivingScenarioDesigner(scenario)
```



Import OpenDRIVE Roads and Lanes into Scenario

Import roads and lanes from an OpenDRIVE road network into the **Driving Scenario Designer** app. For a more detailed example, see “Import OpenDRIVE Roads into Driving Scenario”.

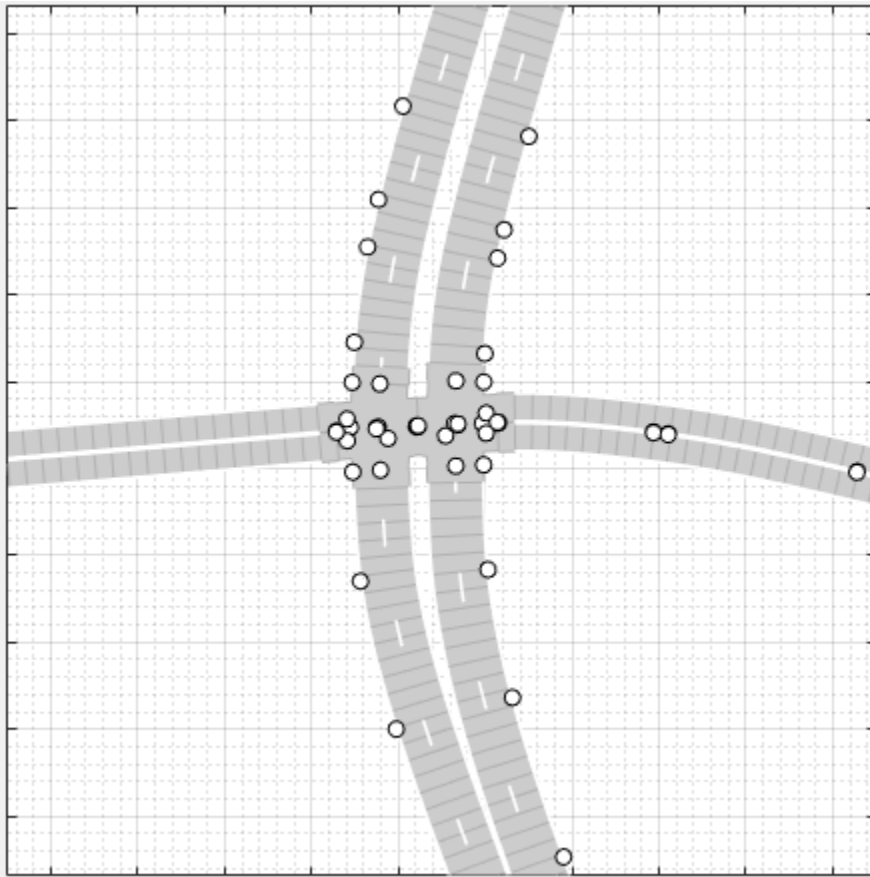
Open the **Driving Scenario Designer** app.

```
drivingScenarioDesigner
```

On the app toolstrip, select **Open > OpenDRIVE Road Network**. Then, from your MATLAB root folder, navigate to and open this file:

```
matlabroot/examples/driving/intersection.xodr
```

Inspect the road network by zooming in on the scenario.

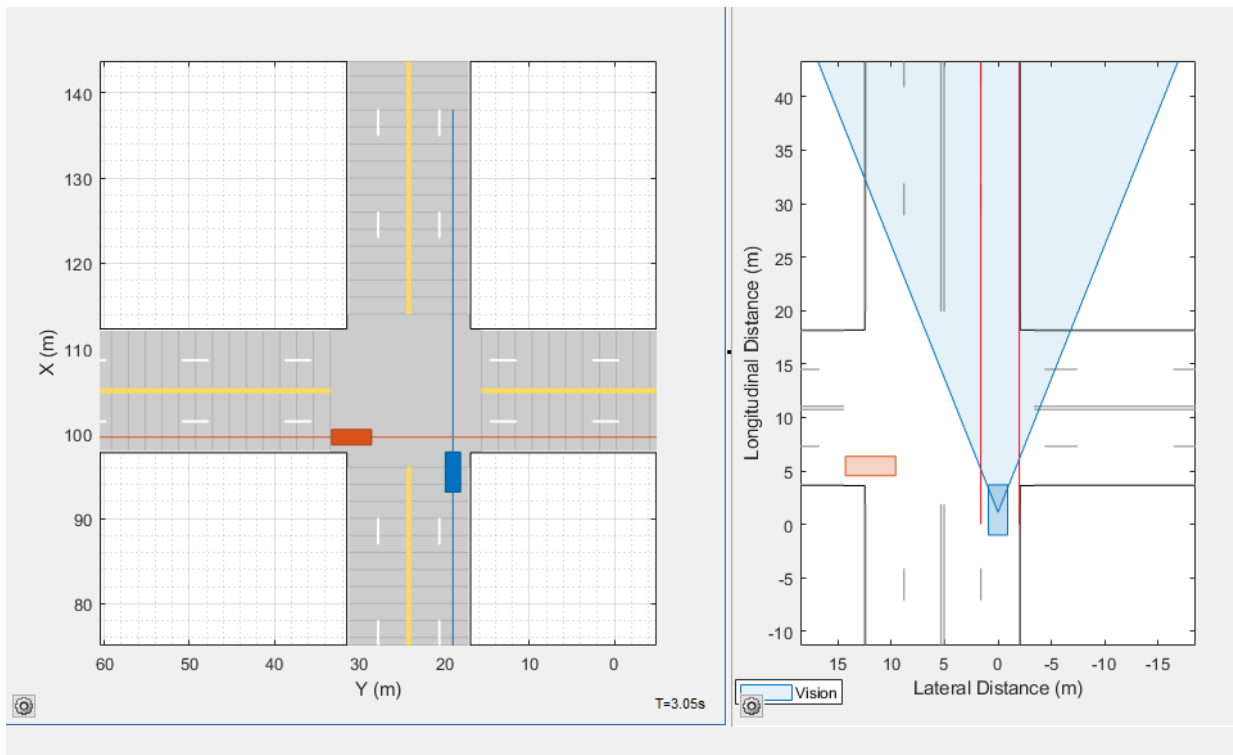


Generate Simulink Model of Scenario and Sensor

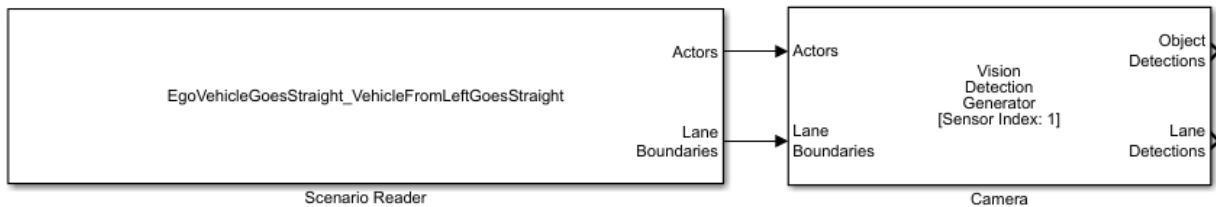
Load a driving scenario containing a sensor and generate a Simulink model from the scenario and sensor. For a more detailed example on generating Simulink models from the app, see “Generate Sensor Detection Blocks Using Driving Scenario Designer”.

Load a prebuilt driving scenario into the app. The scenario contains two vehicles crossing through an intersection. The ego vehicle travels north and contains a camera sensor. This sensor is configured to detect both objects and lanes.

```
path = fullfile(matlabroot, 'toolbox', 'shared', 'drivingscenario', 'PrebuiltScenarios');
addpath(genpath(path)) % Add folder to path
drivingScenarioDesigner('EgoVehicleGoesStraight_VehicleFromLeftGoesStraight.mat')
rmpath(path) % Remove folder from path
```



Generate a Simulink model of the scenario and sensor. On the app toolstrip, select **Export** > **Export Simulink Model**. If you are prompted, save the scenario file.



The Scenario Reader block reads the road and actors from the scenario file. To update the scenario data in the model, update the scenario in the app and save the file.

The Vision Detection Generator block recreates the camera sensor defined in the app. To update the sensor in the model, update the sensor in the app, select **Export > Export Sensor Simulink Model**, and copy the newly generated sensor block into the model. If you updated any roads or actors while updating the sensors, then select **Export > Export Simulink Model**. In this case, the Scenario Reader block accurately reads the actor profile data and passes it to the sensor.

Parameters

Roads — Road width, bank angle, lane specifications, and road center locations tab

To enable the **Roads** parameters, add at least one road to the scenario. Then, select a road from either the **Scenario Canvas** or the **Road** parameter. The parameter values in the **Roads** tab are based on the road you select.

Parameter	Description
Road	Road to modify, specified as a list of the roads in the scenario.
Name	Name of road.

Parameter	Description
Width (m)	<p>Width of the road, in meters, specified as a decimal scalar in the range (0, 50].</p> <p>If the curvature of the road is too sharp to accommodate the specified road width, the app does not generate the road.</p> <p>Default: 6</p>
Bank Angle (deg)	<p>Side-to-side incline of the road, in degrees, specified as one of these values:</p> <ul style="list-style-type: none">• Decimal scalar — Applies a uniform bank angle along the entire length of the road• N-element vector of decimal values — Applies a different bank angle to each road center, where N is the number of road centers in the selected road <p>When you add an actor to a road, you do not have to change the actor position to match the bank angles specified by this parameter. The actor automatically follows the bank angles of the road.</p> <p>Default: 0</p>

Lanes

Parameter	Description
Number of lanes	<p>Number of lanes in the road, specified as one of these values:</p> <ul style="list-style-type: none"> • Integer, M, in the range $[1, 30]$ — Creates an M-lane road whose default lane markings indicate that the road is one-way. • Two-element vector, $[M N]$, where M and N are positive integers whose sum must be in the range $[2, 30]$ — Creates a road with $(M + N)$ lanes. The default lane markings of this road indicate that it is two-way. The first M lanes travel in one direction. The next N lanes travel in the opposite direction. <p>If you increase the number of lanes, the added lanes are of the width specified in the Lane Width (m) parameter. If Lane Width (m) is a vector of differing lane widths, then the added lanes are of the width specified in the last vector element.</p>

Parameter	Description
Lane Width (m)	<p>Width of each lane in the road, in meters, specified as one of these values:</p> <ul style="list-style-type: none">• Decimal scalar in the range (0, 50] — The same width applies to all lanes.• N-element vector of decimal values in the range (0, 50] — A different width applies to each lane, where N is the total number of lanes specified in the Number of lanes parameter. <p>The width of each lane must be greater than the width of the lane markings it contains. These lane markings are specified by the Marking > Width (m) parameter.</p>
Marking	<p>Lane marking to modify, specified as a list of lane markings in the selected road.</p> <p>A road with N lanes has $(N + 1)$ lane markings.</p>

Parameter	Description
Marking > Type	<p>Type of lane marking, specified as one of these values:</p> <ul style="list-style-type: none">• Unmarked — No lane marking• Solid — Solid line• Dashed — Dashed line• DoubleSolid — Two solid lines• DoubleDashed — Two dashed lines• SolidDashed — Solid line on left, dashed line on right• DashedSolid — Dashed line on left, solid line on right <p>By default, for a one-way road, the leftmost lane is solid and yellow, the rightmost lane is solid and white, and the inner lanes are dashed and white. For two-way roads, the dividing lane marking is two solid yellow lines.</p>

Parameter	Description																		
Marking > Color	<p>Color of lane marking, specified as an RGB triplet or color name.</p> <p>For a custom color, specify an RGB triplet. An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7]. Alternatively, you can specify some common colors by name. This table lists the named color options and the equivalent RGB triplet values.</p> <table border="1" data-bbox="793 737 1334 1137"> <thead> <tr> <th data-bbox="793 737 1025 777">Color Name</th> <th data-bbox="1025 737 1334 777">RGB Triplet</th> </tr> </thead> <tbody> <tr> <td data-bbox="793 777 1025 817">red</td> <td data-bbox="1025 777 1334 817">[1 0 0]</td> </tr> <tr> <td data-bbox="793 817 1025 857">green</td> <td data-bbox="1025 817 1334 857">[0 1 0]</td> </tr> <tr> <td data-bbox="793 857 1025 897">blue</td> <td data-bbox="1025 857 1334 897">[0 0 1]</td> </tr> <tr> <td data-bbox="793 897 1025 937">cyan</td> <td data-bbox="1025 897 1334 937">[0 1 1]</td> </tr> <tr> <td data-bbox="793 937 1025 977">magenta</td> <td data-bbox="1025 937 1334 977">[1 0 1]</td> </tr> <tr> <td data-bbox="793 977 1025 1017">yellow</td> <td data-bbox="1025 977 1334 1017">[0.98 0.86 0.36]</td> </tr> <tr> <td data-bbox="793 1017 1025 1057">black</td> <td data-bbox="1025 1017 1334 1057">[0 0 0]</td> </tr> <tr> <td data-bbox="793 1057 1025 1097">white</td> <td data-bbox="1025 1057 1334 1097">[1 1 1]</td> </tr> </tbody> </table> <p>For a double lane marker, the same color is used for both lines.</p>	Color Name	RGB Triplet	red	[1 0 0]	green	[0 1 0]	blue	[0 0 1]	cyan	[0 1 1]	magenta	[1 0 1]	yellow	[0.98 0.86 0.36]	black	[0 0 0]	white	[1 1 1]
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magenta	[1 0 1]																		
yellow	[0.98 0.86 0.36]																		
black	[0 0 0]																		
white	[1 1 1]																		

Parameter	Description
Marking > Strength	<p>Saturation strength of lane marking color, specified as a decimal scalar in the range [0, 1].</p> <ul style="list-style-type: none"> • A value of 0 corresponds to a marking whose color is fully unsaturated. The marking appears as gray. • A value of 1 corresponds to a marking whose color is fully saturated. <p>For a double lane marking, the same strength is used for both lines.</p> <p>Default: 1</p>
Marking > Width (m)	<p>Width of lane marking, in meters, specified as a positive decimal scalar.</p> <p>The width of the lane marking must be less than the width of its enclosing lane. The enclosing lane is the lane directly to the left of the lane marking.</p> <p>For a double lane marker, the same width is used for both lines.</p> <p>Default: 0.15</p>
Marking > Length (m)	<p>Length of dashes in dashed lane markings, in meters, specified as a positive decimal scalar in the range (0, 50].</p> <p>For a double lane marking, the same length is used for both lines.</p> <p>Default: 3</p>

Parameter	Description
Marking > Space (m)	Length of spaces between dashes in dashed lane markings, in meters, specified as a decimal scalar in the range (0, 150]. Default: 9

Road Centers

Each row of the **Road Centers** table contains the x -, y -, and z -positions of a road center within the selected road. All roads must have at least two unique road center positions. When you update the cell within the table, the **Scenario Canvas** updates to reflect the new road center position.

Parameter	Description
x (m)	x -axis position of the road center, in meters, specified as a decimal scalar.
y (m)	y -axis position of the road center, in meters, specified as a decimal scalar.

Parameter	Description
z (m)	<p>z-axis position of the road center, in meters, specified as a decimal scalar.</p> <ul style="list-style-type: none"> • The z-axis specifies the elevation of the road. If the elevation between road centers is too abrupt, adjust these elevation values. • When you add an actor to a road, you do not have to change the actor position to match changes in elevation. The actor automatically follows the elevation of the road. • When two elevated roads form a junction, the elevation around that junction can vary widely. The exact amount of elevation depends on how close the road centers of each road are to each other. If you try to place an actor at the junction, the app might be unable to compute the precise elevation of the actor. In this case, the app cannot place the actor at that junction. <p>To address this issue, in the Scenario Canvas, modify the intersecting roads by moving the road centers of each road away from each other. Alternatively, manually adjust the elevation of the actor to match the elevation of the road surface.</p> <p>Default: 0</p>

Actors — Actor positions, orientations, RCS patterns, and trajectories tab

To enable the **Actors** parameters, add at least one actor to the scenario. Then, select an actor from either the **Scenario Canvas** or from the list on the **Actors** tab. The parameter values in the **Actors** tab are based on the actor you select.

Parameter	Description
Set as Ego Vehicle	<p>Set the selected actor as the ego vehicle in the scenario.</p> <p>When you add sensors to your scenario, the app adds them to the ego vehicle. In addition, the Ego-Centric View and Bird's-Eye Plot windows display simulations from the perspective of the ego vehicle.</p> <p>Only actors who have vehicle classes, such as Car or Truck, can be set as the ego vehicle. For more details on actor classes, see the Class parameter description.</p>
Name	Name of actor.

Parameter	Description												
<p>Class</p>	<p>Class of actor, specified as the list of classes to which you can change the selected actor.</p> <p>You can change the class of vehicle actors only to other vehicle classes, such as Car and Truck. Similarly, you can change the class of nonvehicle actors only to other nonvehicle classes, such as Pedestrian, Bicycle, and Barrier.</p> <p>The list of vehicle and nonvehicle classes appear in the app toolbar, in the Add Actor > Vehicles and Add Actor > Other sections, respectively.</p> <p>Actors created in the app have default set of dimensions, radar cross-section patterns, and other properties based on their Class ID value. The table shows the default Class ID values and actor classes.</p> <table border="1" data-bbox="795 951 1338 1220"> <thead> <tr> <th data-bbox="795 951 1062 994">Class ID</th> <th data-bbox="1062 951 1338 994">Actor Class</th> </tr> </thead> <tbody> <tr> <td data-bbox="795 994 1062 1041">1</td> <td data-bbox="1062 994 1338 1041">Car</td> </tr> <tr> <td data-bbox="795 1041 1062 1088">2</td> <td data-bbox="1062 1041 1338 1088">Truck</td> </tr> <tr> <td data-bbox="795 1088 1062 1135">3</td> <td data-bbox="1062 1088 1338 1135">Bicycle</td> </tr> <tr> <td data-bbox="795 1135 1062 1182">4</td> <td data-bbox="1062 1135 1338 1182">Pedestrian</td> </tr> <tr> <td data-bbox="795 1182 1062 1220">5</td> <td data-bbox="1062 1182 1338 1220">Barrier</td> </tr> </tbody> </table> <p>To modify actor classes or create new actor classes, on the app toolbar, select Add Actor > Edit Actor Classes or Add Actor > New Actor Class, respectively.</p>	Class ID	Actor Class	1	Car	2	Truck	3	Bicycle	4	Pedestrian	5	Barrier
Class ID	Actor Class												
1	Car												
2	Truck												
3	Bicycle												
4	Pedestrian												
5	Barrier												

Actor Properties

Actor properties include the position and orientation of an actor.

Parameter	Description
Length (m)	<p>Length of actor, in meters, specified as a decimal scalar in the range (0, 60].</p> <p>For vehicles, the length must be greater than (Front Overhang + Rear Overhang).</p>
Width (m)	<p>Width of actor, in meters, specified as a decimal scalar in the range (0, 20].</p>
Height (m)	<p>Height of actor, in meters, specified as a decimal scalar in the range (0, 20].</p>
Front Overhang	<p>Distance between the front axle and front bumper, in meters, specified as a decimal scalar.</p> <p>The front overhang must be less than (Length (m) - Rear Overhang).</p> <p>This parameter applies to vehicles only.</p> <p>Default: 0.9</p>
Rear Overhang	<p>Distance between the rear axle and rear bumper, in meters, specified as a decimal scalar.</p> <p>The rear overhang must be less than (Length (m) - Front Overhang).</p> <p>This parameter applies to vehicles only.</p> <p>Default: 1</p>

Parameter	Description
Roll	<p>Orientation angle of the actor about its x-axis, in degrees, specified as a decimal scalar.</p> <p>Roll is clockwise-positive when looking in the forward direction of the x-axis, which points forward from the actor.</p> <p>When you export the MATLAB function of the driving scenario and run that function, the roll angles of actors in the output scenario are wrapped to the range [-180, 180].</p> <p>Default: 0</p>
Pitch	<p>Orientation angle of the actor about its y-axis, in degrees, specified as a decimal scalar.</p> <p>Pitch is clockwise-positive when looking in the forward direction of the y-axis, which points to the left of the actor.</p> <p>When you export the MATLAB function of the driving scenario and run that function, the pitch angles of actors in the output scenario are wrapped to the range [-180, 180].</p> <p>Default: 0</p>

Parameter	Description
Yaw	<p>Orientation angle of the actor about its z-axis, in degrees, specified as a decimal scalar.</p> <p>Yaw is clockwise-positive when looking in the forward direction of the z-axis, which points up from the ground. However, the Scenario Canvas has a bird's-eye-view perspective that looks in the reverse direction of the z-axis. Therefore, when viewing actors on this canvas, Yaw is counterclockwise-positive.</p> <p>When you export the MATLAB function of the driving scenario and run that function, the yaw angles of actors in the output scenario are wrapped to the range [-180, 180].</p> <p>Default: 0</p>

Radar Cross Section

Use these parameters to manually specify the radar cross-section (RCS) of an actor. Alternatively, to import an RCS from a file or from the MATLAB workspace, expand this parameter section and click **Import**.

Parameter	Description
Azimuth Angles (deg)	<p>Horizontal reflection pattern of actor, in degrees, specified as a vector of monotonically increasing decimal values in the range [-180, 180].</p> <p>Default: [-180 180]</p>

Parameter	Description
Elevation Angles (deg)	Vertical reflection pattern of actor, in degrees, specified as a vector of monotonically increasing decimal values in the range [-90, 90]. Default: [-90 90]
Pattern (dBsm)	RCS pattern, in decibels per square meter, specified as a <i>Q</i> -by- <i>P</i> table of decimal values. RCS is a function of the azimuth and elevation angles, where: <ul style="list-style-type: none"> • <i>Q</i> is the number of elevation angles specified by the Elevation Angles (deg) parameter. • <i>P</i> is the number of azimuth angles specified by the Azimuth Angles (deg) parameter.

Trajectory

Manually set or modify the positions and velocities of actors at their specified waypoints.

Parameter	Description
Constant Speed (m/s)	Select this parameter to set a constant speed for the actor through all of its waypoints. Specify this constant speed as a positive decimal scalar in meters per second. If you clear this parameter, use the Waypoints table to specify the velocity of the actor at each waypoint. Default: 30

Parameter	Description
Waypoints	<p>Actor waypoints, specified as a table.</p> <p>Each table row contains the position and velocity information of a waypoint. Table columns are as follows:</p> <ul style="list-style-type: none"> • x (m) — World coordinate x-position of each waypoint, in meters. • y (m) — World coordinate y-position of each waypoint, in meters. • z (m) — World coordinate z-position of each waypoint, in meters. • v (m/s) — Vehicle velocity, in meters per second, at each waypoint. This column applies only when you disable the Constant Speed (m/s) parameter.

Sensors (Camera) — Camera sensor placement, intrinsic camera parameters, and detection parameters

tab

To access these parameters, add at least one camera sensor to the scenario by following these steps:

- 1 on the app toolstrip, click **Add Camera**.
- 2 From the **Sensors** tab, select the sensor from the list. The parameter values in this tab are based on the sensor you select.

Parameter	Description
Enabled	Enable or disable the selected sensor. Select this parameter to capture sensor data during simulation and visualize that data in the Bird's-Eye Plot pane.
Name	Name of sensor.

Parameter	Description
Update Interval (ms)	<p>Frequency at which the sensor updates, in milliseconds, specified as an integer multiple of the app sample time defined under Settings, in the Sample Time (ms) parameter.</p> <p>The default Update Interval (ms) value of 100 is an integer multiple of the default Sample Time (ms) parameter value of 10. Having the update interval be a multiple of the sample time ensures that the app samples and displays the detections found at these intervals during simulation.</p> <p>If you update the app sample time such that a sensor is no longer a multiple of the app sample time, the app prompts you with the option to automatically update the Update Interval (ms) parameter to the closest integer multiple.</p> <p>Default: 100</p>
Type	Type of sensor, specified as either Radar for radar sensors or Vision for camera sensors.

Sensor Placement

Parameter	Description
X (m)	<p>X-axis position of the sensor in the vehicle coordinate system, in meters, specified as a decimal scalar.</p> <p>The X-axis points forward from the vehicle. The origin is located at the center of the vehicle's rear axle.</p>

Parameter	Description
Y (m)	<p>Y-axis position of the sensor in the vehicle coordinate system, in meters, specified as a decimal scalar.</p> <p>The Y-axis points to the left of the vehicle. The origin is located at the center of the vehicle's rear axle.</p>
Height (m)	<p>Height of the sensor above the ground, in meters, specified as a positive decimal scalar.</p> <p>Default: 1.1</p>
Roll	<p>Orientation angle of the sensor about its X-axis, in degrees, specified as a decimal scalar.</p> <p>Roll is clockwise-positive when looking in the forward direction of the X-axis, which points forward from the sensor.</p> <p>Default: 0</p>
Pitch	<p>Orientation angle of the sensor about its Y-axis, in degrees, specified as a decimal scalar.</p> <p>Pitch is clockwise-positive when looking in the forward direction of the Y-axis, which points to the left of the sensor.</p> <p>Default: 1</p>

Parameter	Description
Yaw	<p>Orientation angle of the sensor about its Z-axis, in degrees, specified as a decimal scalar.</p> <p>Yaw is clockwise-positive when looking in the forward direction of the Z-axis, which points up from the ground. However, the Sensor Canvas has a bird's-eye-view perspective that looks in the reverse direction of the Z-axis. Therefore, when viewing sensor coverage areas on this canvas, Yaw is counterclockwise-positive.</p>

Camera Settings

Parameter	Description
Focal Length X	<p>Horizontal point at which the camera is in focus, in pixels, specified as a positive decimal scalar.</p> <p>The default focal length changes depending on where you place the sensor on the ego vehicle.</p>
Focal Length Y	<p>Vertical point at which the camera is in focus, in pixels, specified as a positive decimal scalar.</p> <p>The default focal length changes depending on where you place the sensor on the ego vehicle.</p>
Image Width	<p>Horizontal camera resolution, in pixels, specified as a positive integer.</p> <p>Default: 640</p>

Parameter	Description
Image Height	Vertical camera resolution, in pixels, specified as a positive integer. Default: 480
Principal Point X	Horizontal image center, in pixels, specified as a positive decimal scalar. Default: 320
Principal Point Y	Vertical image center, in pixels, specified as a positive decimal scalar. Default: 240

Detection Parameters

To view all camera detection parameters in the app, expand the **Sensor Limits, Lane Settings,** and **Accuracy & Noise Settings** sections.

Parameter	Description
Detection Type	Type of detections reported by camera, specified as one of these values: <ul style="list-style-type: none"> • Objects — Report object detections only. • Objects & Lanes — Report object and lane boundary detections. • Lanes — Report lane boundary detections only. Default: Objects
Detection Probability	Probability that the camera detects an object, specified as a decimal scalar in the range (0, 1]. Default: 0.9

Parameter	Description
False Positives Per Image	<p>Number of false positives reported per update interval, specified as a nonnegative decimal scalar. This value must be less than or equal to the maximum number of detections specified in the Limit # of Detections parameter.</p> <p>Default: 0.1</p>
Limit # of Detections	<p>Select this parameter to limit the number of simultaneous object detections that the sensor reports. Specify Limit # of Detections as a positive integer less than 2^{63}.</p> <p>To enable this parameter, set the Detection Type parameter to Objects or Objects & Lanes.</p> <p>Default: off</p>
Detection Coordinates	<p>Coordinate system of output detection locations, specified as one of these values:</p> <ul style="list-style-type: none"> • Ego Cartesian — The app outputs detections in the coordinate system of the ego vehicle. • Sensor Cartesian — The app outputs detections in the coordinate system of the sensor. <p>Default: Ego Cartesian</p>

Sensor Limits

Parameter	Description
Max Speed (m/s)	Fastest relative speed at which the camera can detect objects, in meters per second, specified as a nonnegative decimal scalar. Default: 50
Max Range (m)	Farthest distance at which the camera can detect objects, in meters, specified as a positive decimal scalar. Default: 150
Max Allowed Occlusion	Maximum percentage of object that can be blocked while still being detected, specified as a decimal scalar in the range [0, 1). Default: 0.5
Min Object Image Width	Minimum horizontal size of objects that the camera can detect, in pixels, specified as positive decimal scalar. Default: 15
Min Object Image Height	Minimum vertical size of objects that the camera can detect, in pixels, specified as positive decimal scalar. Default: 15

Lane Settings

Parameter	Description
Lane Update Interval (ms)	<p>Frequency at which the sensor updates lane detections, in milliseconds, specified as a decimal scalar.</p> <p>Default: 100</p>
Min Lane Image Width	<p>Minimum horizontal size of objects that the sensor can detect, in pixels, specified as a decimal scalar.</p> <p>To enable this parameter, set the Detection Type parameter to Lanes or Objects & Lanes.</p> <p>Default: 3</p>
Min Lane Image Height	<p>Minimum vertical size of objects that the sensor can detect, in pixels, specified as a decimal scalar.</p> <p>To enable this parameter, set the Detection Type parameter to Lanes or Objects & Lanes.</p> <p>Default: 20</p>
Boundary Accuracy	<p>Accuracy with which the sensor places a lane boundary, in pixels, specified as a decimal scalar.</p> <p>To enable this parameter, set the Detection Type parameter to Lanes or Objects & Lanes.</p> <p>Default: 3</p>

Parameter	Description
Limit # of Lanes	<p>Select this parameter to limit the number of lane detections that the sensor reports. Specify Limit # of Lanes as a positive integer.</p> <p>To enable this parameter, set the Detection Type parameter to Lanes or Objects & Lanes.</p> <p>Default: off</p>

Accuracy & Noise Settings

Parameter	Description
Bounding Box Accuracy	<p>Positional noise used for fitting bounding boxes to targets, in pixels, specified as a positive decimal scalar.</p> <p>Default: 5</p>
Process Noise Intensity (m/s²)	<p>Noise intensity used for smoothing position and velocity measurements, in meters per second squared, specified as a positive decimal scalar.</p> <p>Default: 5</p>
Has Noise	<p>Select this parameter to enable adding noise to sensor measurements.</p> <p>Default: off</p>

Sensors (Radar) — Radar sensor placement and detection parameters

tab

To access these parameters, add at least one radar sensor to the scenario.

- 1 On the app toolstrip, click **Add Radar**.
- 2 On the **Sensors** tab, select the sensor from the list. The parameter values changes based on the sensor you select.

Parameter	Description
Enabled	Enable or disable the selected sensor. Select this parameter to capture sensor data during simulation and visualize that data in the Bird's-Eye Plot pane.
Name	Name of sensor.
Update Interval (ms)	<p>Frequency at which the sensor updates, in milliseconds, specified as an integer multiple of the app sample time defined under Settings, in the Sample Time (ms) parameter.</p> <p>The default Update Interval (ms) value of 100 is an integer multiple of the default Sample Time (ms) parameter value of 10. Having the update interval be a multiple of the sample time ensures that the app samples and displays the detections found at these intervals during simulation.</p> <p>If you update the app sample time such that a sensor is no longer a multiple of the app sample time, the app prompts you with the option to automatically update the Update Interval (ms) parameter to the closest integer multiple.</p> <p>Default: 100</p>
Type	Type of sensor, specified as either Radar for radar sensors or Vision for camera sensors.

Sensor Placement

Parameter	Description
X (m)	<p>X-axis position of the sensor in the vehicle coordinate system, in meters, specified as a decimal scalar.</p> <p>The X-axis points forward from the vehicle. The origin is located at the center of the vehicle's rear axle.</p>
Y (m)	<p>Y-axis position of the sensor in the vehicle coordinate system, in meters, specified as a decimal scalar.</p> <p>The Y-axis points to the left of the vehicle. The origin is located at the center of the vehicle's rear axle.</p>
Height (m)	<p>Height of the sensor above the ground, in meters, specified as a positive decimal scalar.</p> <p>Default: 1.1</p>
Roll	<p>Orientation angle of the sensor about its X-axis, in degrees, specified as a decimal scalar.</p> <p>Roll is clockwise-positive when looking in the forward direction of the X-axis, which points forward from the sensor.</p> <p>Default: 0</p>

Parameter	Description
Pitch	<p>Orientation angle of the sensor about its Y-axis, in degrees, specified as a decimal scalar.</p> <p>Pitch is clockwise-positive when looking in the forward direction of the Y-axis, which points to the left of the sensor.</p> <p>Default: 1</p>
Yaw	<p>Orientation angle of the sensor about its Z-axis, in degrees, specified as a decimal scalar.</p> <p>Yaw is clockwise-positive when looking in the forward direction of the Z-axis, which points up from the ground. However, the Sensor Canvas has a bird's-eye-view perspective that looks in the reverse direction of the Z-axis. Therefore, when viewing sensor coverage areas on this canvas, Yaw is counterclockwise-positive.</p>

Detection Parameters

To view all radar detection parameters in the app, expand the **Advanced Parameters** and **Accuracy & Noise Settings** sections.

Parameter	Description
Detection Probability	<p>Probability that the radar detects an object, specified as a decimal scalar in the range (0, 1].</p> <p>Default: 0.9</p>
False Alarm Rate	<p>Probability of a false detection per resolution rate, specified as a decimal scalar in the range [1e-07, 1e-03].</p> <p>Default: 1e-06</p>

Parameter	Description
Field of View Azimuth	Horizontal field of view of radar, in degrees, specified as a positive decimal scalar. Default: 20
Field of View Elevation	Vertical field of view of radar, in degrees, specified as a positive decimal scalar. Default: 5
Max Range (m)	Farthest distance at which the radar can detect objects, in meters, specified as a positive decimal scalar. Default: 150
Range Rate Min, Range Rate Max	Select this parameter to set minimum and maximum range rate limits for the radar. Specify Range Rate Min and Range Rate Max as decimal scalars, in meters per second, where Range Rate Min is less than Range Rate Max . Default (Min): -100 Default (Max): 100
Has Elevation	Select this parameter to enable the radar to measure the elevation of objects. This parameter enables the elevation parameters in the Accuracy & Noise Settings section. Default: off
Has Occlusion	Select this parameter to enable the radar to model occlusion. Default: on

Advanced Parameters

Parameter	Description
Reference Range	<p>Reference range for a given probability of detection, in meters, specified as a positive decimal scalar.</p> <p>The reference range is the range at which the radar detects a target of the size specified by Reference RCS, given the probability of detection specified by Detection Probability.</p> <p>Default: 100</p>
Reference RCS	<p>Reference RCS for a given probability of detection, in decibels per square meter, specified as a nonnegative decimal scalar.</p> <p>The reference RCS is the target size at which the radar detects a target, given the reference range specified by Reference Range and the probability of detection specified by Detection Probability.</p> <p>Default: 0</p>
Limit # of Detections	<p>Select this parameter to limit the number of simultaneous detections that the sensor reports. Specify Limit # of Detections as a positive integer less than 2^{63}.</p> <p>Default: off</p>

Parameter	Description
Detection Coordinates	Coordinate system of output detection locations, specified as one of these values: <ul style="list-style-type: none">• Ego Cartesian — The app outputs detections in the coordinate system of the ego vehicle.• Sensor Cartesian — The app outputs detections in the coordinate system of the sensor. Default: Ego Cartesian

Accuracy & Noise Settings

Parameter	Description
Azimuth Resolution	<p>Minimum separation in azimuth angle at which the radar can distinguish between two targets, in degrees, specified as a positive decimal scalar.</p> <p>The azimuth resolution is typically the 3 dB downpoint in the azimuth angle beamwidth of the radar.</p> <p>Default: 4</p>
Azimuth Bias Fraction	<p>Maximum azimuth accuracy of the radar, specified as a nonnegative decimal scalar.</p> <p>The azimuth bias is expressed as a fraction of the azimuth resolution specified by the Azimuth Resolution parameter. Units are dimensionless.</p> <p>Default: 0.1</p>
Elevation Resolution	<p>Minimum separation in elevation angle at which the radar can distinguish between two targets, in degrees, specified as a positive decimal scalar.</p> <p>The elevation resolution is typically the 3 dB downpoint in the elevation angle beamwidth of the radar.</p> <p>To enable this parameter, in the Detection Parameters section, select the Has Elevation parameter.</p> <p>Default: 10</p>

Parameter	Description
<p>Elevation Bias Fraction</p>	<p>Maximum elevation accuracy of the radar, specified as a nonnegative decimal scalar.</p> <p>The elevation bias is expressed as a fraction of the elevation resolution specified by the Elevation Resolution parameter. Units are dimensionless.</p> <p>To enable this parameter, under Detection Parameters, select the Has Elevation parameter.</p> <p>Default: 0.1</p>
<p>Range Resolution</p>	<p>Minimum range separation at which the radar can distinguish between two targets, in meters, specified as a positive decimal scalar.</p> <p>Default: 2.5</p>
<p>Range Bias Fraction</p>	<p>Maximum range accuracy of the radar, specified as a nonnegative decimal scalar.</p> <p>The range bias is expressed as a fraction of the range resolution specified in the Range Resolution parameter. Units are dimensionless.</p> <p>Default: 0.05</p>

Parameter	Description
Range Rate Resolution	<p>Minimum range rate separation at which the radar can distinguish between two targets, in meters per second, specified as a positive decimal scalar.</p> <p>To enable this parameter, in the Detection Parameters section, select the Range Rate Min, Range Rate Max parameter and set the range rate values.</p> <p>Default: 0.5</p>
Range Rate Bias Fraction	<p>Maximum range rate accuracy of the radar, specified as a nonnegative decimal scalar.</p> <p>The range rate bias is expressed as a fraction of the range rate resolution specified in the Range Rate Resolution parameter. Units are dimensionless.</p> <p>To enable this parameter, under the Detection Parameters section, select the Range Rate Min, Range Rate Max parameter and set the range rate values.</p> <p>Default: 0.05</p>
Has Noise	<p>Select this parameter to enable adding noise to sensor measurements.</p> <p>Default: off</p>
Has False Alarms	<p>Select this parameter to enable false alarms in sensor detections.</p> <p>Default: off</p>

Settings – Simulation sample time, stop condition, and stop time dialog box

To access these parameters, on the app toolstrip, click **Settings**.

Simulation Settings

Parameter	Description
Sample Time (ms)	<p>Frequency at which the simulation updates, in milliseconds.</p> <p>Increase the sample time to speed up simulation. This increase has no effect on actor speeds, even though actors can appear to go faster during simulation. The actor positions are just being sampled and displayed on the app at less frequent intervals, resulting in faster, choppy animations. Decreasing the sample time results in smoother animations, but the actors appear to move slower, and the simulation takes longer.</p> <p>The sample time does not correlate to the actual time. For example, if the app samples every 0.1 seconds (Sample Time (ms) = 100) and runs for 10 seconds, the amount of elapsed actual time might be less than the 10 seconds of elapsed simulation time. Any apparent synchronization between the sample time and actual time is coincidental.</p> <p>Default: 10</p>

Parameter	Description
Stop Condition	<p>Stop condition of simulation, specified as one of these values:</p> <ul style="list-style-type: none"> • First actor stops — Simulation stops when the first actor reaches the end of its trajectory. • Set time — Simulation stops at the time specified by the Stop Time (s) parameter. <p>Default: Set time</p>
Stop Time (s)	<p>Stop time of simulation, in seconds, specified as a positive decimal scalar.</p> <p>To enable this parameter, set the Stop Condition parameter to Set time.</p> <p>Default: 0.1</p>
Use RNG Seed	<p>Select this parameter to use a random number generator (RNG) seed to reproduce the same results for each simulation. Specify the RNG seed as a nonnegative integer less than 2^{32}.</p> <p>Default: off</p>

Programmatic Use

`drivingScenarioDesigner` opens the **Driving Scenario Designer** app.

`drivingScenarioDesigner(scenarioFileName)` opens the app and loads the specified scenario MAT-file into the app. This file must be a scenario file saved from the app. This file can include all roads, actors, and sensors in the scenario. It can also include only the roads and actors component, or only the sensors component.

If the scenario file is not in the current folder or not in a folder on the MATLAB path, specify the full path name. For example:

```
drivingScenarioDesigner('C:\Desktop\myDrivingScenario.mat');
```

You can also load prebuilt scenario files. Before loading a prebuilt scenario, add the folder containing the scenario to the MATLAB path. For an example, see “Generate Detections from Prebuilt Scenario” on page 1-21.

`drivingScenarioDesigner(scenario)` opens the app and loads the specified `drivingScenario` object into the app. The `ClassID` properties of actors in this object must correspond to these default **Class ID** parameter values in the app:

- 1 — Car
- 2 — Truck
- 3 — Bicycle
- 4 — Pedestrian
- 5 — Barrier

When you create actors in the app, the actors with these **Class ID** values have a default set of dimensions, radar cross-section patterns, and other properties. The camera and radar sensors process detections differently depending on type of actor specified by the **Class ID** values.

When importing `drivingScenario` objects into the app, the behavior of the app depends on the `ClassID` of the actors in that scenario.

- If an actor has a `ClassID` of 0, the app returns an error. In `drivingScenario` objects, a `ClassID` of 0 is reserved for an object of an unknown or unassigned class. The app does not recognize or use this value. Assign these actors one of the app **Class ID** values and import the `drivingScenario` object again.
- If an actor has a nonzero `ClassID` that does not correspond to a **Class ID** value, the app returns an error. Either change the `ClassID` of the actor or add a new actor class to the app. On the app toolstrip, select **Add Actor > New Actor Class**.
- If an actor has properties that differ significantly from the properties of its corresponding **Class ID** actor, the app returns a warning. The `ActorID` property referenced in the warning corresponds to the ID value of an actor in the list at the top of the **Actors** tab. The ID value precedes the actor name. To address this warning, consider updating the actor properties or its `ClassID` value. Alternatively, consider adding a new actor class to the app.

Limitations

Euro NCAP Limitations

- Scenarios of speed assistance systems (SAS) are not supported. These scenarios require the detection of speed limits from traffic signs, which the app does not support.

OpenDRIVE Limitations

- You can import only lanes, lane type information, and roads. The import of road objects and traffic signals is not supported.
- OpenDRIVE files containing large road networks can take up to several minutes to load. In addition, these road networks can cause slow interactions on the app canvas. Examples of large road networks include ones that model the roads of a city or ones with roads that are thousands of meters long.
- Lanes with variable widths are not supported. The width is set to the highest width found within that lane. For example, if a lane has a width that varies from 2 meters to 4 meters, the app sets the lane width to 4 meters throughout.
- Roads with lane type information specified as **driving**, **border**, **restricted**, **shoulder**, and **parking** are supported. Lanes with any other lane type information are imported as border lanes.
- Roads with multiple lane marking styles are not supported. The app applies the first found marking style to all lanes in the road. For example, if a road has **Dashed** and **Solid** lane markings, the app applies **Dashed** lane markings throughout.
- Lane marking styles **Bott Dots**, **Curbs**, and **Grass** are not supported. Lanes with these marking styles are imported as unmarked.

Tips

- You can undo (press **Ctrl+Z**) and redo (press **Ctrl+Y**) changes you make on the scenario and sensor canvases. For example, you can use these shortcuts to delete a recently placed road center or redo the movement of a radar sensor.

Compatibility Considerations

Corrections to Image Width and Image Height camera parameters of Driving Scenario Designer

Behavior changed in R2018b

Starting in R2018b, in the **Camera Settings** group of the **Driving Scenario Designer** app, the **Image Width** and **Image Height** parameters set their expected values. Previously, **Image Width** set the height of images produced by the camera, and **Image Height** set the width of images produced by the camera.

If you are using R2018a, to produce the expected image sizes, transpose the values set in the **Image Width** and **Image Height** parameters.

References

- [1] European New Car Assessment Programme. *Euro NCAP Assessment Protocol - SA*. Version 8.0.2. January 2018.
- [2] European New Car Assessment Programme. *Euro NCAP AEB C2C Test Protocol*. Version 2.0.1. January 2018.
- [3] European New Car Assessment Programme. *Euro NCAP LSS Test Protocol*. Version 2.0.1. January 2018.
- [4] Dupuis, Marius, et al. *OpenDRIVE Format Specification*. Revision 1.4, Issue H, Document No. VI2014.106. Bad Aibling, Germany: VIRES Simulationstechnologie GmbH, November 4, 2015.

See Also

Bird's-Eye Scope | Radar Detection Generator | Scenario Reader | Vision Detection Generator | drivingScenario | radarDetectionGenerator | visionDetectionGenerator

Topics

“Build a Driving Scenario and Generate Synthetic Detections”
“Create Driving Scenario Variations Programmatically”

“Import OpenDRIVE Roads into Driving Scenario”
“Prebuilt Driving Scenarios in Driving Scenario Designer”
“Euro NCAP Driving Scenarios in Driving Scenario Designer”
“Generate Sensor Detection Blocks Using Driving Scenario Designer”
“Test Open-Loop ADAS Algorithm Using Driving Scenario”
“Test Closed-Loop ADAS Algorithm Using Driving Scenario”

External Websites

Euro NCAP Safety Assist Protocols
opendrive.org

Introduced in R2018a

Ground Truth Labeler

Label ground truth data for automated driving applications

Description

The **Ground Truth Labeler** app enables you to label ground truth data in a video, in an image sequence, or from a custom data source reader. Using the app, you can:

- Define rectangular regions of interest (ROI) labels, polyline ROI labels, pixel ROI labels, and scene labels. Use these labels to interactively label your ground truth data.
- Use built-in detection or tracking algorithms to label your ground truth data.
- Write, import, and use your own custom automation algorithm to automatically label ground truth.
- Evaluate the performance of your label automation algorithms using a visual summary.
- Export the labeled ground truth as a `groundTruth` object. You can use this object for system verification or for training an object detector or semantic segmentation network.
- Display time-synchronized signals, such as lidar or CAN bus data, using the `driving.connector.Connector` API.

To learn more about this app, see “Get Started with the Ground Truth Labeler”.

Open the Ground Truth Labeler App

- MATLAB Toolstrip: On the **Apps** tab, under **Automotive**, click the app icon.
- MATLAB command prompt: Enter `groundTruthLabeler`.

Examples

- “Get Started with the Ground Truth Labeler”
- “Automate Ground Truth Labeling of Lane Boundaries”
- “Automate Ground Truth Labeling for Semantic Segmentation”

- “Automate Attributes of Labeled Objects”
- “Evaluate Lane Boundary Detections Against Ground Truth Data”
- “Evaluate and Visualize Lane Boundary Detections Against Ground Truth”

Programmatic Use

`groundTruthLabeler` opens a new session of the app, enabling you to label ground truth data.

`groundTruthLabeler(videoFileName)` opens the app and loads the input video. The video file must have an extension supported by `VideoReader`.

Example: `groundTruthLabeler('caltech_cordova1.avi')`

`groundTruthLabeler(imageSeqFolder)` opens the app and loads the image sequence from the input folder. An image sequence is an ordered set of images that resemble a video. The images must be the same size. `imageSeqFolder` must be a string scalar or character vector that specifies the folder containing the image files. The image files must have extensions supported by `imformats` and are loaded in the order returned by the `dir` function.

To label a collection of unordered images that can vary in size, use the **Image Labeler** app instead.

`groundTruthLabeler(imageSeqFolder, timestamps)` opens the app and loads a sequence of images with their corresponding timestamps. `timestamps` must be a duration vector of the same length as the number of images in the sequence.

For example, load a sequence of road images and their corresponding timestamps into the app.

```
imageDir = fullfile(toolboxdir('driving'),'drivingdata','roadSequence');  
load(fullfile(imageDir,'timeStamps.mat'))  
groundTruthLabeler(imageDir,timeStamps)
```

`groundTruthLabeler(gtSource)` opens the app and loads the `groundTruthDataSource` object, `gtSource`. The object contains a custom data source and corresponding timestamps.

`groundTruthLabeler(sessionFile)` opens the app and loads a saved app session, `sessionFile`. The `sessionFile` input contains the path and file name. The MAT-file that `sessionFile` points to contains the saved session.

`groundTruthLabeler(____, 'ConnectorTargetHandle', 'connector')` opens the app with a custom connector. 'connector' is a handle to a `driving.connector.Connector` class. The handle implements a custom analysis or visualization tool that is time-synchronized with the **Ground Truth Labeler** app. For example, to associate a connector target defined in class `MyConnectorClass`, specify `@MyConnectorClass`.

For example, open the app, load a 10-second video into it, and open a lidar visualization tool that is time-synchronized to the video.

```
groundTruthLabeler('01_city_c2s_fcw_10s.mp4','ConnectorTargetHandle',@LidarDisplay);
```

Limitations

- The built-in automation algorithms support the automation of rectangular ROI labels only. When you select a built-in algorithm and click **Automate**, scene labels, pixel labels, polyline labels, sublabels, and attributes are not imported into the automation session. To automate the labeling of these features, create a custom automation algorithm.
- Pixel ROI labels do not support sublabels or attributes.
- The Label Summary window does not support sublabels or attributes

Tips

- To avoid having to relabel ground truth with new labels, organize the labeling scheme you want to use before marking your ground truth.

Algorithms

You can use label automation algorithms to speed up labeling within the app. To create your own label automation algorithm to use within the app, see “Create Automation Algorithm for Labeling” (Computer Vision Toolbox). You can also use one of the provided built-in algorithms. Follow these steps:

- 1 Load the data you want to label, and create at least one label definition.
- 2 On the app toolstrip, click **Select Algorithm**, and select one of the built-in automation algorithms.
- 3 Click **Automate**, and then follow the automation instructions in the right pane of the automation window.

ACF Vehicle Detector

Detect and label vehicles using aggregate channel features (ACF). This algorithm is based on the `vehicleDetectorACF` function. To use this algorithm, you must define at least one rectangle ROI label. You do not need to draw any ROI labels.

To help improve the algorithm results, first click **Settings**. You can change any of these settings.

- The pretrained vehicle detector model that the algorithm uses — The 'full-view' model was trained using unoccluded images of the front, rear, left, and right sides of vehicles. The 'front-rear-view' model was trained using images of only the front and rear sides of the vehicle.
- The overlap ratio threshold, from 0 to 1, for detecting vehicles — When rectangle ROIs overlap by more than this threshold, the algorithm discards one of the ROIs.
- The classification score threshold for detecting vehicles — Increase the score to increase the prediction confidence of the algorithm. Rectangles with scores below this threshold are discarded.

You can also configure the detector with a calibrated monocular camera by importing a `monoCamera` object into the MATLAB workspace. Specify the length and width ranges of the vehicle in world units, such as meters.

ACF People Detector

Detect and label people using aggregate channel features (ACF). This algorithm is based on the `peopleDetectorACF` function. To use this algorithm, you must define at least one rectangle ROI label. You do not need to draw any ROI labels.

To help improve the algorithm results, first click **Settings**. You can change any of these settings.

- The pretrained people detector model that the algorithm uses — The 'inria-100x41' model was trained using the INRIA person data set. The 'caltech-50x21' model was trained using the Caltech Pedestrian data set.
- The overlap ratio threshold, from 0 to 1, for detecting people — When rectangle ROIs overlap by more than this threshold, the algorithm discards one of the ROIs.
- The classification score threshold for detecting people — Increase the score to increase the prediction confidence of the algorithm. Rectangles with scores below this threshold are discarded.

Point Tracker

Track and label one or more rectangle ROI labels over short intervals by using the Kanade-Lucas-Tomasi (KLT) algorithm. This algorithm is based on the `vision.PointTracker` System object™. To use this algorithm, you must define at least one rectangle ROI label, but you do not need to draw any ROI labels.

To change the feature detector used to obtain the initial points for tracking, click **Settings**. This table shows the feature detector options.

Feature Detector	Description	Equivalent Function
Minimum Eigen Value	Detect corners by using the minimum eigenvalue algorithm.	<code>detectMinEigenFeatures</code>
Harris	Detect corners by using the Harris-Stephens algorithm.	<code>detectHarrisFeatures</code>
FAST	Detect corners by using the features from accelerated segment test (FAST) algorithm.	<code>detectFASTFeatures</code>
BRISK	Detect features by using the binary robust invariant scalable keypoints (BRISK) algorithm.	<code>detectBRISKFeatures</code>

Feature Detector	Description	Equivalent Function
KAZE	Detect features by using nonlinear diffusion to construct a scale space of an image, and then detecting multiscale corner features (KAZE features) from that scale space.	detectKAZEFeatures
SURF	Detect blob features by using the speeded-up robust features (SURF) algorithm.	detectSURFFeatures
MSER	Detect regions by using the maximally stable extremal regions (MSER) algorithm.	detectMSERFeatures

Temporal Interpolator

Estimate rectangle ROIs between frames by interpolating the ROI locations across the time interval. To use this algorithm, you must draw a rectangle ROI on a minimum of two frames: one at the beginning of the interval and one at the end of the interval. The interpolation algorithm estimates and draws ROIs in the intermediate frames.

Consider a video with 10 frames. The first frame has a rectangle ROI centered at [5, 5]. The 10th frame has a rectangle ROI centered at [25, 25]. At each frame, the algorithm moves the ROI 2 pixels in the x -direction and 2 pixels in the y -direction. Therefore, the algorithm centers the ROI at [7, 7] in the second frame, [9, 9] in the third frame, and so on, up to [23, 23] in the second-to-last frame.

Lane Boundary Detector

Detect and label lane boundaries using an estimated bird's-eye-view projected image. To use this algorithm, you must define at least one line ROI label. You do not need to draw any ROI labels. To detect lane boundaries, the algorithm follows these steps:

- 1 It makes an initial guess at the placement of the lane boundaries in the image.
- 2 It transforms the ROI around the lanes into a bird's-eye view image to make the lanes parallel and remove distortion.

3 It uses this image to segment the lane boundaries.

To help improve the algorithm results, first click **Settings**. You can change any of these settings.

- The placement of the lane lines for generating the bird's-eye view image
- The ROI around the lanes, which you can expand to include more than just the ego lane boundaries in the image
- The pixel width of detected lane boundaries in the image

You can also change the number of lane boundaries that you want to detect. The default number of lane boundaries is 2.

See Also

Apps

[Image Labeler](#) | [Video Labeler](#)

Functions

[objectDetectorTrainingData](#) | [pixelLabelTrainingData](#)

Objects

[groundTruth](#) | [groundTruthDataSource](#) | [labelDefinitionCreator](#)

Topics

[“Get Started with the Ground Truth Labeler”](#)

[“Automate Ground Truth Labeling of Lane Boundaries”](#)

[“Automate Ground Truth Labeling for Semantic Segmentation”](#)

[“Automate Attributes of Labeled Objects”](#)

[“Evaluate Lane Boundary Detections Against Ground Truth Data”](#)

[“Evaluate and Visualize Lane Boundary Detections Against Ground Truth”](#)

[“Choose an App to Label Ground Truth Data”](#) (Computer Vision Toolbox)

[“Use Custom Data Source Reader for Ground Truth Labeling”](#) (Computer Vision Toolbox)

[“Keyboard Shortcuts and Mouse Actions for Ground Truth Labeler”](#)

[“Use Sublabels and Attributes to Label Ground Truth Data”](#) (Computer Vision Toolbox)

[“Label Pixels for Semantic Segmentation”](#) (Computer Vision Toolbox)

[“Create Automation Algorithm for Labeling”](#) (Computer Vision Toolbox)

[“Share and Store Labeled Ground Truth Data”](#) (Computer Vision Toolbox)

“Training Data for Object Detection and Semantic Segmentation” (Computer Vision Toolbox)

Introduced in R2017a

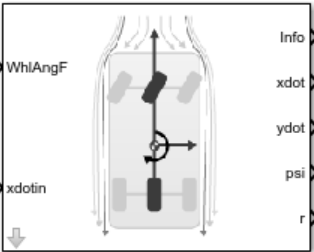
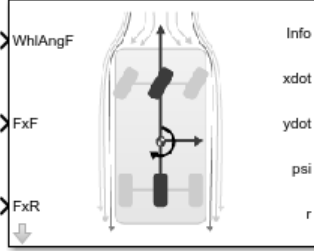
Blocks in Automated Driving Toolbox

Bicycle Model

Implement a single track 3DOF rigid vehicle body to calculate longitudinal, lateral, and yaw motion

Description

The Bicycle Model block implements a rigid two-axle single track vehicle body model to calculate longitudinal, lateral, and yaw motion. The block accounts for body mass, aerodynamic drag, and weight distribution between the axles due to acceleration and steering. There are two types of Bicycle Model blocks.

Block	Implementation
<p>Bicycle Model - Velocity Input</p>  <p>Bicycle Model - Velocity Input</p>	<ul style="list-style-type: none"> Block assumes that the external longitudinal velocity is quasi-steady state so the longitudinal acceleration is approximately zero. Since the motion is quasi-steady, the block calculates only lateral forces using the tire slip angles and linear cornering stiffness.
<p>Bicycle Model - Force Input</p>  <p>Bicycle Model - Force Input</p>	<ul style="list-style-type: none"> Block uses the external longitudinal force to accelerate or brake the vehicle. Block calculates lateral forces using the tire slip angles and linear cornering stiffness.

To calculate the normal forces on the front and rear axles, the block uses rigid-body vehicle motion, suspension system forces, and wind and drag forces. The block resolves the force and moment components on the rigid vehicle body frame.

Ports

Input

WhlAngF — Wheel angle

scalar

Front wheel angle, in rad.

FxF — Force Input: Total longitudinal force on the front axle

scalar

Longitudinal force on the front axle, F_{x_F} , along vehicle-fixed x-axis, in N.

Bicycle Model - Force Input block input port.

FxR — Force Input: Total longitudinal force on the rear axle

scalar

Longitudinal force on the rear axle, F_{x_R} , along vehicle-fixed x-axis, in N.

Bicycle Model - Force Input block input port.

xdotin — Velocity Input: Longitudinal velocity

scalar

Vehicle CG velocity along vehicle-fixed x-axis, in m/s.

Bicycle Model - Velocity Input block input port.

Output

Info — Bus signal

bus

Bus signal containing these block values.

Signal				Description	Value	Units
InertFr m	Cg	Disp	X	Vehicle CG displacement along earth-fixed X-axis	Computed	m
			Y	Vehicle CG displacement along earth-fixed Y-axis	0	m
			Z	Vehicle CG displacement along earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle CG velocity along earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CG velocity along earth-fixed Y-axis	0	m/s
			Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
		Ang	phi	Rotation of vehicle-fixed frame about earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw)	0	rad
	FrntAx l	Disp	X	Front axle displacement along the earth-fixed X-axis	Computed	m
			Y	Front axle displacement along the earth-fixed Y-axis	0	m
			Z	Front axle displacement along the earth-fixed Z-axis	Computed	m

Signal				Description	Value	Units	
	Vel	Xdot	Xdot	Front axle velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Front axle velocity along the earth-fixed Y-axis	0	m/s	
			Zdot	Front axle velocity along the earth-fixed Z-axis	Computed	m/s	
	RearAx l	Disp	X	X	Rear axle displacement along the earth-fixed X-axis	Computed	m
				Y	Rear axle displacement along the earth-fixed Y-axis	0	m
				Z	Rear axle displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Xdot	Rear axle velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Rear axle velocity along the earth-fixed Y-axis	0	m/s
				Zdot	Rear axle velocity along the earth-fixed Z-axis	Computed	m/s
BdyFrm	Cg	Vel	xdot	Vehicle CG velocity along vehicle-fixed x-axis	Computed	m/s	
			ydot	Vehicle CG velocity along vehicle-fixed y-axis	0	m/s	
			zdot	Vehicle CG velocity along vehicle-fixed z-axis	Computed	m/s	
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s	

Signal			Description	Value	Units	
	Acc	q	q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	Computed	rad/s
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	0	rad/s
		ax	ax	Vehicle CG acceleration along vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CG acceleration along vehicle-fixed y-axis	0	gn
			az	Vehicle CG acceleration along vehicle-fixed z-axis	Computed	gn
			xddot	Vehicle CG acceleration along vehicle-fixed x-axis	Computed	gn
			yddot	Vehicle CG acceleration along vehicle-fixed y-axis	0	gn
	zddot	Vehicle CG acceleration along vehicle-fixed z-axis	Computed	gn		
	Forces	Body	Fx	Net force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Net force on vehicle CG along vehicle-fixed z-axis	Computed	N

Signal		Description		Value	Units			
	FrntAx l	Fx	Longitudinal force on front axle, along the vehicle-fixed x-axis	Computed	N			
			Fy	Lateral force on front axle, along the vehicle-fixed y-axis	0	N		
				Fz	Normal force on front axle, along the vehicle-fixed z-axis	Computed	N	
		RearAx l			Fx	Longitudinal force on rear axle, along the vehicle-fixed x-axis	Computed	N
			Fy			Lateral force on rear axle, along the vehicle-fixed y-axis	0	N
				Fz		Normal force on rear axle, along the vehicle-fixed z-axis	Computed	N
		Tires			FrntTi re	Fx	Front tire force, along vehicle-fixed x-axis	0
			Fy			Front tire force, along vehicle-fixed y-axis	0	N
			Fz	Front tire force, along vehicle-fixed z-axis		Computed	N	
	RearTi re		Fx	Rear tire force, along vehicle-fixed x-axis	0	N		
			Fy	Rear tire force, along vehicle-fixed y-axis	0	N		
			Fz	Rear tire force, along vehicle-fixed z-axis	Computed	N		
	Drag	Fx	Drag force on vehicle CG along vehicle-fixed x-axis	Computed	N			

Signal			Description	Value	Units	
			Fy	Drag force on vehicle CG along vehicle-fixed y-axis	Computed	N
			Fz	Drag force on vehicle CG along vehicle-fixed z-axis	Computed	N
		Grvty	Fx	Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along vehicle-fixed z-axis	Computed	N
		Moment s	Body	Mx	Body moment on vehicle CG about vehicle-fixed x-axis	0
	My			Body moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m
	Mz			Body moment on vehicle CG about vehicle-fixed z-axis	0	N·m
	Drag		Mx	Drag moment on vehicle CG about vehicle-fixed x-axis	0	N·m
			My	Drag moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m
			Mz	Drag moment on vehicle CG about vehicle-fixed z-axis	0	N·m

Signal				Description	Value	Units
	FrntAx l	Disp	x	Front axle displacement along the vehicle-fixed x-axis	Computed	m
			y	Front axle displacement along the vehicle-fixed y-axis	0	m
			z	Front axle displacement along the vehicle-fixed z-axis	Computed	m
		Vel	xdot	Front axle velocity along the vehicle-fixed x-axis	Computed	m/s
			ydot	Front axle velocity along the vehicle-fixed y-axis	0	m/s
			zdot	Front axle velocity along the vehicle-fixed z-axis	Computed	m/s
	RearAx l	Disp	x	Rear axle displacement along the vehicle-fixed x-axis	Computed	m
			y	Rear axle displacement along the vehicle-fixed y-axis	0	m
			z	Rear axle displacement along the vehicle-fixed z-axis	Computed	m
		Vel	xdot	Rear axle velocity along the vehicle-fixed x-axis	Computed	m/s
			ydot	Rear axle velocity along the vehicle-fixed y-axis	0	m/s
			zdot	Rear axle velocity along the vehicle-fixed z-axis	Computed	m/s
Pwr	PwrExt		Applied external power	Computed	W	

Signal			Description	Value	Units
		Drag	Power loss due to drag	Computed	W

xdot — Vehicle body longitudinal velocity

scalar

Vehicle CG velocity along vehicle-fixed x-axis, in m/s.

ydot — Vehicle body lateral velocity

scalar

Vehicle CG velocity along vehicle-fixed y-axis, in m/s.

psi — Yaw

scalar

Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad..

r — Yaw rate

scalar

Vehicle angular velocity, r , about the vehicle-fixed z-axis (yaw rate), in rad/s.

Parameters

Longitudinal

Number of wheels on front axle, NF — Front wheel count

scalar

Number of wheels on front axle, N_F , dimensionless.

Number of wheels on rear axle, NR — Rear wheel count

scalar

Number of wheels on rear axle, N_R , dimensionless.

Vehicle mass, m — Vehicle mass

scalar

Vehicle mass, m , in kg.

Longitudinal distance from center of mass to front axle, a – Front axle distance

scalar

Horizontal distance a from the vehicle CG to the front wheel axle, in m.

Longitudinal distance from center of mass to rear axle, b – Rear axle distance

scalar

Horizontal distance b from the vehicle CG to the rear wheel axle, in m.

Vertical distance from center of mass to axle plane, h – Height

scalar

Height of vehicle CG above the axles, h , in m.

Initial inertial frame longitudinal position, X_o – Position

scalar

Initial vehicle CG displacement along earth-fixed X -axis, in m.

Initial longitudinal velocity, \dot{x}_o – Velocity

scalar

Initial vehicle CG velocity along vehicle-fixed x -axis, in m/s.

Dependencies

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

Lateral

Front tire corner stiffness, C_{y_f} – Stiffness

scalar

Front tire corner stiffness, C_{y_f} , in N/rad.

Dependencies

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
 - External longitudinal velocity
 - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

Rear tire corner stiffness, C_{y_r} – Stiffness

scalar

Rear tire corner stiffness, C_{y_r} , in N/rad.

Dependencies

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
 - External longitudinal velocity
 - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

Initial inertial frame lateral displacement, Y_o – Position

scalar

Initial vehicle CG displacement along earth-fixed Y-axis, in m.

Initial lateral velocity, $ydot_o$ – Velocity

scalar

Initial vehicle CG velocity along vehicle-fixed y-axis, in m/s.

Yaw

Yaw polar inertia, I_{zz} – Inertia

scalar

Yaw polar inertia, in $\text{kg}\cdot\text{m}^2$.

Initial yaw angle, psi_o – Psi

scalar

Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad.

Initial yaw rate, r_o – Yaw rate

scalar

Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s.

Aerodynamic**Longitudinal drag area, Af – Area**

scalar

Effective vehicle cross-sectional area, A_f to calculate the aerodynamic drag force on the vehicle, in m^2 .

Longitudinal drag coefficient, Cd – Drag

scalar

Air drag coefficient, C_d , dimensionless.

Longitudinal lift coefficient, Cl – Lift

scalar

Air lift coefficient, C_l , dimensionless.

Longitudinal drag pitch moment, Cpm – Pitch drag

scalar

Longitudinal drag pitch moment coefficient, C_{pm} , dimensionless.

Relative wind angle vector, beta_w – Wind angle

vector

Relative wind angle vector, β_w , in rad.

Side force coefficient vector, Cs – Side force drag

vector

Side force coefficient vector coefficient, C_s , dimensionless.

Yaw moment coefficient vector, C_{ym} – Yaw moment drag
vector

Yaw moment coefficient vector coefficient, C_{ym} , dimensionless.

Environment

Absolute air pressure, P_{abs} – Pressure
scalar

Environmental absolute pressure, P_{abs} , in Pa.

Air temperature, T_{air} – Temperature
scalar

Environmental absolute temperature, T , in K.

Dependencies

To enable this parameter, clear **Air temperature**.

Gravitational acceleration, g – Gravity
scalar

Gravitational acceleration, g , in m/s^2 .

Nominal friction scaling factor, μ – Friction scale factor
scalar

Nominal friction scale factor, μ , dimensionless.

Dependencies

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
 - External longitudinal velocity
 - External longitudinal forces
- 2 Clear **External Friction**.

Simulation

Longitudinal velocity tolerance, `xdot_tol` – Tolerance

scalar

Longitudinal velocity tolerance, in m/s.

Nominal normal force, `Fznom` – Normal force

scalar

Nominal normal force, in N.

Dependencies

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

Geometric longitudinal offset from axle plane, `longOff` – Longitudinal offset

scalar

Vehicle chassis offset from axle plane along body-fixed x-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

Geometric lateral offset from center plane, `latOff` – Lateral offset

scalar

Vehicle chassis offset from center plane along body-fixed y-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

Geometric vertical offset from axle plane, `vertOff` – Vertical offset

scalar

Vehicle chassis offset from axle plane along body-fixed z-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

Wrap Euler angles, wrapAng – Selection

off (default) | on

Wrap the Euler angles to the interval $[-\pi, \pi]$. For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of the interval, consider deselecting the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

References

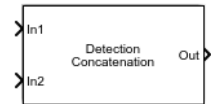
[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

Introduced in R2018a

Detection Concatenation

Combine detection reports from different sensors

Library: Automated Driving Toolbox



Description

The Detection Concatenation block combines detection reports from multiple sensor blocks onto a single output bus. Sensor blocks include the Radar Detection Generator and Vision Detection Generator blocks. Concatenation is useful when detections from multiple sensor blocks are passed into a Multi-Object Tracker block. You can accommodate additional sensors by changing the **Number of input sensors to combine** parameter to increase the number of input ports.

Ports

Input

In1, In2, . . . , InN — Sensor detections to combine

Simulink buses containing MATLAB structures

Sensor detections to combine, where each detection is a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink) for more details.

The definitions of the detection lists are found in the **Detections** output port descriptions of the Radar Detection Generator and Vision Detection Generator blocks.

By default, the block includes two ports for input detections. To add more ports, use the **Number of input sensors to combine** parameter.

Output

Out — Combined sensor detections

Simulink bus containing MATLAB structure

Combined sensor detections from all input buses, returned as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink). The definitions of the detection lists are found in the **Detections** output port descriptions of the Radar Detection Generator and Vision Detection Generator blocks

The **Maximum number of reported detections** output is the sum of the **Maximum number of reported detections** of all input ports. The number of actual detections is the sum of the number of actual detections in each input port. The **ObjectAttributes** fields in the detection structure are the union of the **ObjectAttributes** fields in each input port.

Parameters

Number of input sensors to combine — Number of input sensor ports

2 (default) | positive integer

Number of input sensor ports, specified as a positive integer. Each input port is labeled **In1**, **In2**, ..., **InN**, where *N* is the value set by this parameter.

Data Types: double

Source of output bus name — Source of output bus name

Auto (default) | Property

Source of output bus name, specified as Auto or Property.

- If you select Auto, the block automatically generates a bus name.
- If you select Property, specify the bus name using the **Specify an output bus name** parameter.

Specify an output bus name — Name of output bus

no default

Dependencies

To enable this parameter, set the **Source of output bus name** parameter to Property.

Simulate using — Type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** — Simulate the model using the MATLAB interpreter. This option shortens startup time. In Interpreted execution mode, you can debug the source code of the block.
- **Code generation** — Simulate the model using generated C/C++ code. The first time you run a simulation, Simulink generates C/C++ code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time.

Extended Capabilities

C/C++ Code Generation

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

See Also

Bird's-Eye Scope | Multi-Object Tracker | Radar Detection Generator | Scenario Reader | Vision Detection Generator

Topics

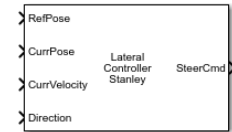
“Getting Started with Buses” (Simulink)

Introduced in R2017b

Lateral Controller Stanley

Control steering angle of vehicle for path following by using Stanley method

Library: Automated Driving Toolbox / Vehicle Control



Description

The Lateral Controller Stanley block computes the steering angle command, in degrees, that adjusts the current pose of a vehicle to match a reference pose, given the vehicle's current velocity and direction. The controller computes this command using the Stanley method [1], whose control law is based on both a kinematic and dynamic bicycle model. To change between models, use the **Vehicle model** parameter.

- The kinematic bicycle model is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.
- The dynamic bicycle model is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced. This vehicle model provides additional parameters that describe the dynamics of the vehicle.

Ports

Input

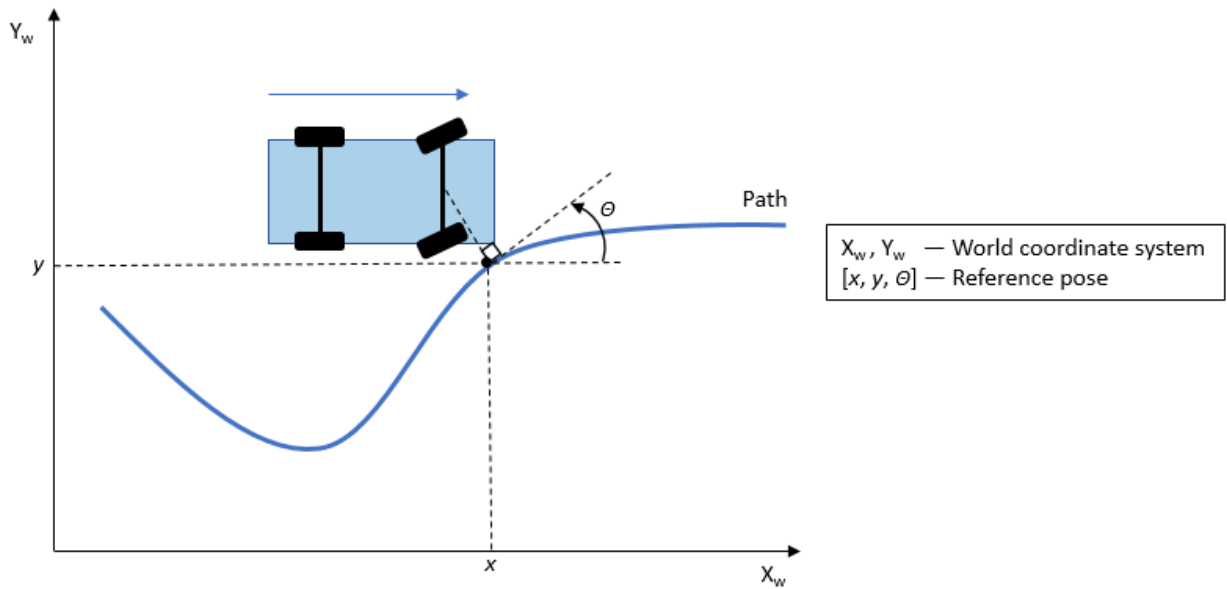
RefPose — Reference pose

$[x, y, \theta]$ vector

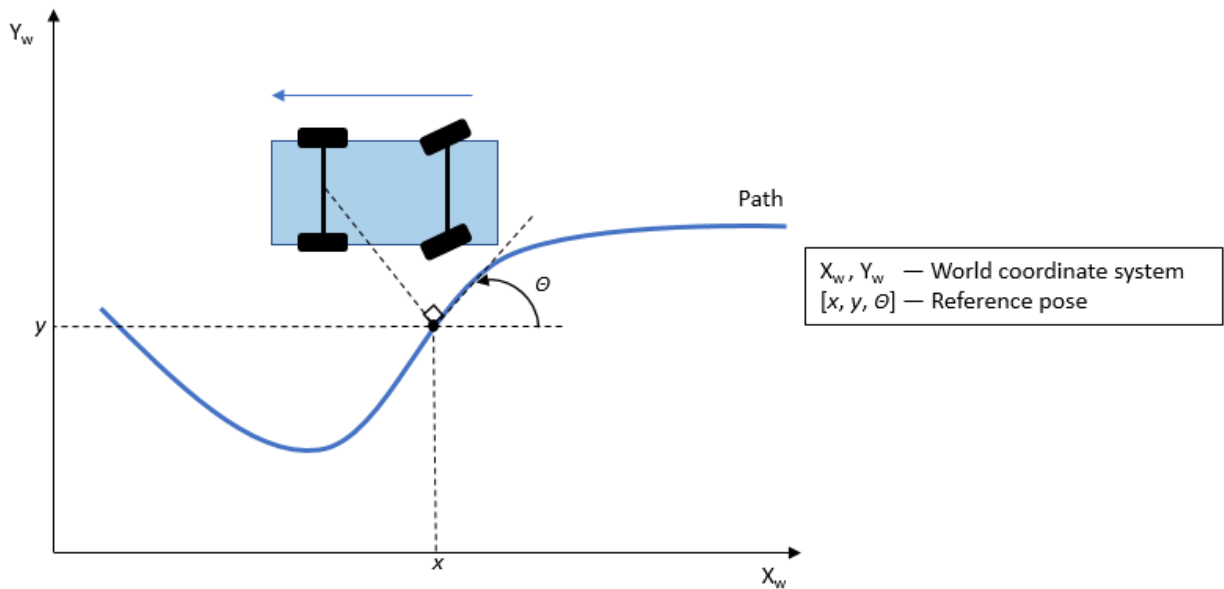
Reference pose, specified as an $[x, y, \theta]$ vector. x and y are in meters, and θ is in degrees.

x and y specify the reference point to steer the vehicle toward. θ specifies the orientation angle of the path at this reference point and is positive in the counterclockwise direction.

- For a vehicle in forward motion, the reference point is the point on the path that is closest to the center of the vehicle's front axle.



- For a vehicle in reverse motion, the reference point is the point on the path that is closest to the center of the vehicle's rear axle.



Data Types: single | double

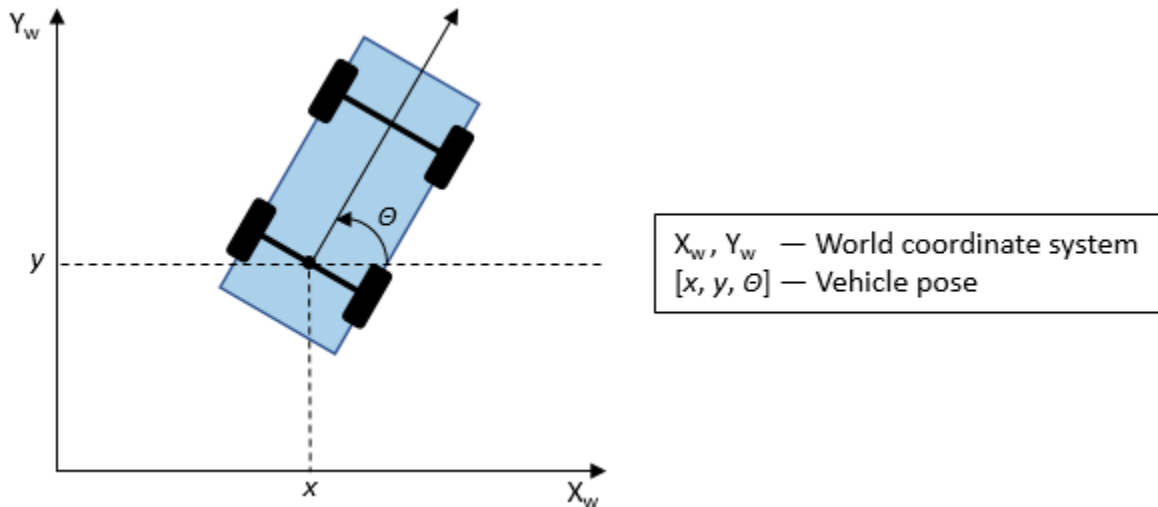
CurrPose — Current pose

$[x, y, \theta]$ vector

Current pose of the vehicle, specified as an $[x, y, \theta]$ vector. x and y are in meters, and θ is in degrees.

x and y specify the location of the vehicle, which is defined as the center of the vehicle's rear axle.

θ specifies the orientation angle of the vehicle at location (x, y) and is positive in the counterclockwise direction.



For more details on vehicle pose, see “Coordinate Systems in Automated Driving Toolbox”.

Data Types: `single` | `double`

CurrVelocity — Current longitudinal velocity

real scalar

Current longitudinal velocity of the vehicle, specified as a real scalar. Units are in meters per second.

- If the vehicle is in forward motion, then this value must be greater than 0.
- If the vehicle is in reverse motion, then this value must be less than 0.
- A value of 0 represents a vehicle that is not in motion.

Data Types: `single` | `double`

Direction — Driving direction of vehicle

1 (forward motion) | -1 (reverse motion)

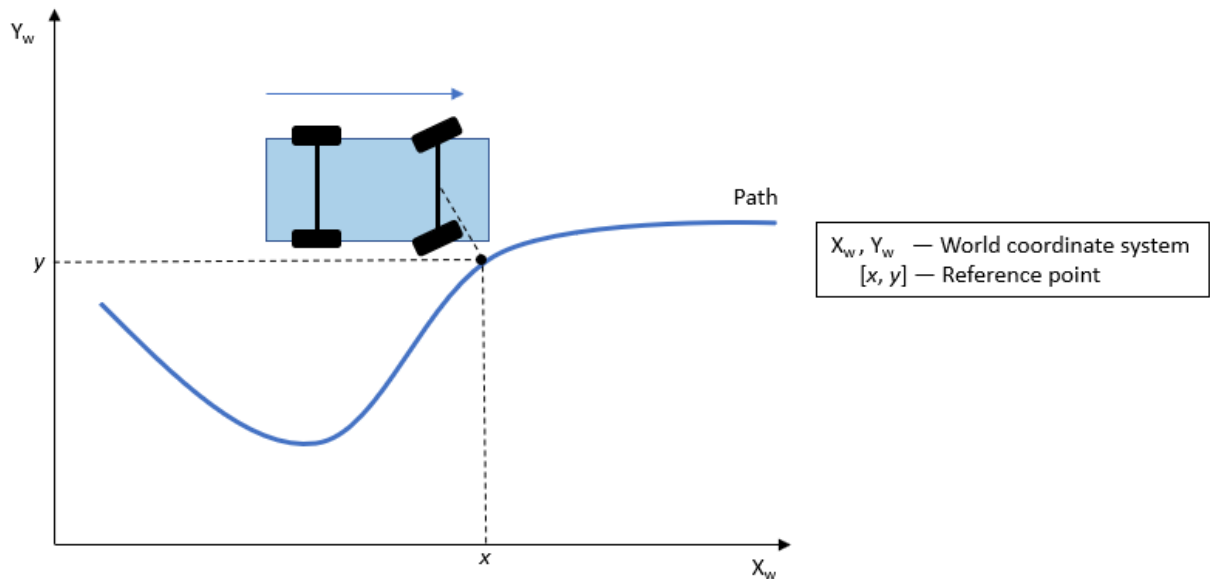
Driving direction of the vehicle, specified as 1 for forward motion or -1 for reverse motion. The driving direction determines the position error and angle error used to compute the steering angle command. For more details, see “Algorithms” on page 2-30.

Curvature — Curvature of path

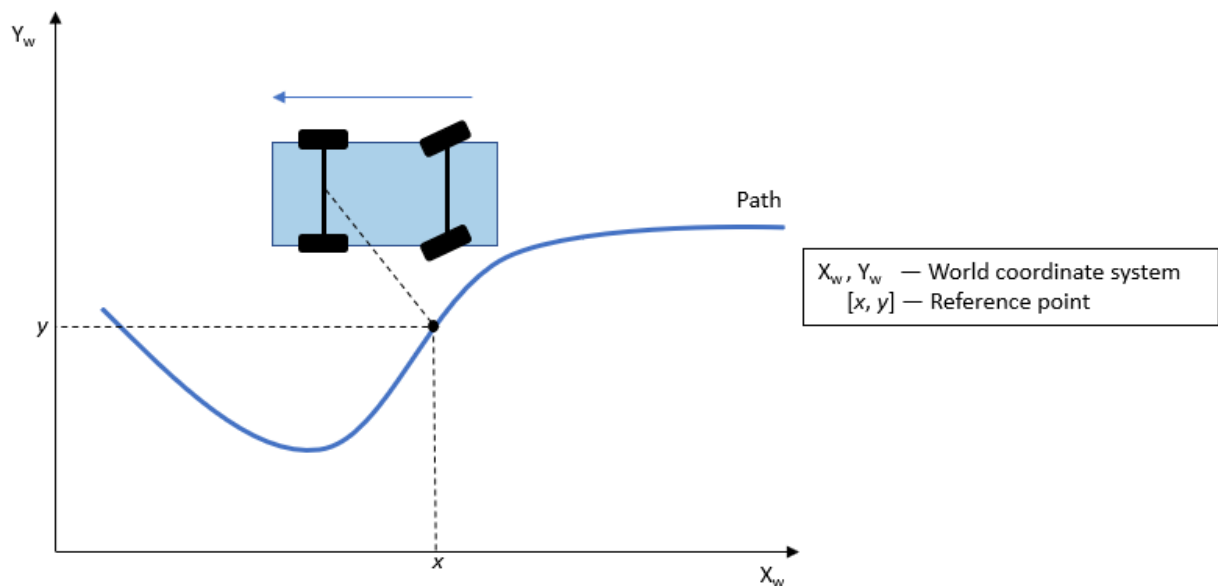
real scalar

Curvature of the path at the reference point, in radians per meter, specified as a real scalar.

- For a vehicle in forward motion, the reference point is the point on the path that is closest to the center of the vehicle's front axle.



- For a vehicle in reverse motion, the reference point is the point on the path that is closest to the center of the vehicle's rear axle.



You can obtain the curvature of a path from the **Curvatures** output port of a Path Smoother Spline block. You can also obtain curvatures of lane boundaries from the output lane boundary structures of a Scenario Reader block.

Dependencies

To enable this port, set **Vehicle model** to `Dynamic bicycle model`.

CurrYawRate — Current yaw rate

real scalar

Current yaw rate of the vehicle, in degrees per second, specified as a real scalar. The current yaw rate is the rate of change in the angular velocity of the vehicle.

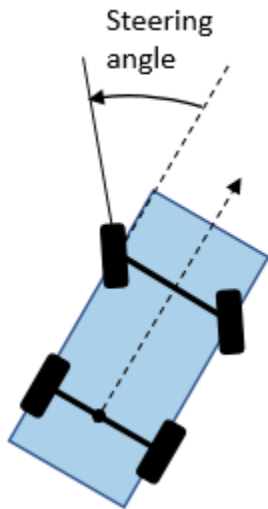
Dependencies

To enable this port, set **Vehicle model** to `Dynamic bicycle model`.

CurrSteer — Current steering angle

real scalar

Current steering angle of the vehicle, in degrees, specified as a real scalar. This value is positive in the counterclockwise direction.



For more details, see “Coordinate Systems in Automated Driving Toolbox”.

Dependencies

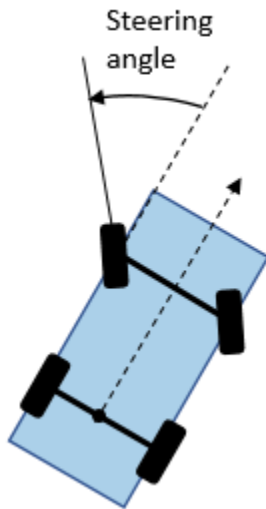
To enable this port, set **Vehicle model** to `Dynamic bicycle model`.

Output

SteerCmd — Steering angle command

real scalar

Steering angle command, in degrees, returned as a real scalar. This value is positive in the counterclockwise direction.



For more details, see “Coordinate Systems in Automated Driving Toolbox”.

Parameters

Vehicle model — Vehicle model

Kinematic bicycle model (default) | Dynamic bicycle model

Select the type of vehicle model to set the Stanley method control law used by the block.

- **Kinematic bicycle model** — Kinematic bicycle model for path following in low-speed environments such as parking lots, where inertial effects are minimal
- **Dynamic bicycle model** — Dynamic bicycle model for path following in high-speed environments such as highways, where inertial effects are more pronounced

Position gain of forward motion — Position gain of vehicle in forward motion

2.5 (default) | positive real scalar

Position gain of the vehicle when it is in forward motion, specified as a positive scalar. This value determines how much the position error affects the steering angle. Typical values are in the range [1, 5]. Increase this value to increase the magnitude of the steering angle.

Position gain of reverse motion — Position gain of vehicle in reverse motion

2.5 (default) | positive real scalar

Position gain of the vehicle when it is in reverse motion, specified as a positive scalar. This value determines how much the position error affects the steering angle. Typical values are in the range [1, 5]. Increase this value to increase the magnitude of the steering angle.

Yaw rate feedback gain — Yaw rate feedback gain

2.5 (default) | nonnegative real scalar

Yaw rate feedback gain, specified as a nonnegative real scalar. This value determines how much weight is given to the current yaw rate of the vehicle when the block computes the steering angle command.

Dependencies

To enable this parameter, set **Vehicle model** to `Dynamic bicycle model`.

Steering angle feedback gain — Steering angle feedback gain

2.5 (default) | nonnegative real scalar

Steering angle feedback gain, specified as a nonnegative real scalar. This value determines how much the difference between the current steering angle command, **SteerCmd**, and the current steering angle, **CurrSteer**, affects the next steering angle command.

Dependencies

To enable this parameter, set **Vehicle model** to `Dynamic bicycle model`.

Wheelbase of vehicle (m) — Distance between front and rear axle

2.8 (default) | real scalar

Distance between the front and rear axle of the vehicle, in meters, specified as a real scalar. This value applies only when the vehicle is in forward motion, that is, when the **Direction** input port is 1.

Dependencies

To enable this parameter, set **Vehicle model** to `Kinematic bicycle model`.

Vehicle mass (kg) — Vehicle mass

1575 (default) | positive real scalar

Vehicle mass, in kilograms, specified as a positive real scalar.

Dependencies

To enable this parameter, set **Vehicle model** to `Dynamic bicycle model`.

Longitudinal distance from center of mass to front axle (m) — Distance to front axle

1.2 (default) | positive real scalar

Longitudinal distance from the vehicle's center of mass to its front wheel axle, in meters, specified as a positive real scalar.

Dependencies

To enable this parameter, set **Vehicle model** to `Dynamic bicycle model`.

Longitudinal distance from center of mass to rear axle (m) — Distance to rear axle

1.6 (default) | positive real scalar

Longitudinal distance from the vehicle's center of mass to its rear wheel axle, in meters, specified as a positive real scalar.

Dependencies

To enable this parameter, set **Vehicle model** to `Dynamic bicycle model`.

Front tire corner stiffness (N/rad) — Cornering stiffness of front tires

19000 (default) | positive real scalar

Cornering stiffness of front tires, in Newtons per radian, specified as a positive real scalar.

Dependencies

To enable this parameter, set **Vehicle model** to `Dynamic bicycle model`.

Maximum steering angle (deg) — Maximum allowed steering angle

35 (default) | real scalar in the range (0, 180)

Maximum allowed steering angle of the vehicle, in degrees, specified as a real scalar in the range (0, 180).

The output from the **SteerCmd** port is saturated to the range $[-M, M]$, where M is the value of the **Maximum steering angle (deg)** parameter.

- Values below $-M$ are set to $-M$.
- Values above M are set to M .

Tips

- You can switch between bicycle models as the vehicle environment changes. Add two Lateral Controller Stanley blocks to a variant subsystem and specify a different bicycle model for each block. For an example, see “Lateral Control Tutorial”.

Algorithms

To compute the steering angle command, the controller minimizes the position error and the angle error of the current pose with respect to the reference pose. The driving direction of the vehicle determines these error values.

When the vehicle is in forward motion (**Direction** parameter is 1):

- The position error is the lateral distance from the center of the front axle to the reference point on the path.
- The angle error is the angle of the front wheel with respect to reference path.

When the vehicle is in reverse motion (**Direction** parameter is -1):

- The position error is the lateral distance from the center of the rear axle to the reference point on the path.
- The angle error is the angle of the rear wheel with respect to reference path.

For details on how the controller minimizes these errors for kinematic and dynamic bicycle models, see [1].

References

- [1] Hoffmann, Gabriel M., Claire J. Tomlin, Michael Montemerlo, and Sebastian Thrun. "Autonomous Automobile Trajectory Tracking for Off-Road Driving: Controller

Design, Experimental Validation and Racing." *American Control Conference*.
2007, pp. 2296-2301. doi:10.1109/ACC.2007.4282788

Extended Capabilities

C/C++ Code Generation

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

See Also

Blocks

Longitudinal Controller Stanley | Path Smoother Spline | Velocity Profiler

Functions

lateralControllerStanley

Objects

pathPlannerRRT

Topics

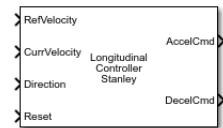
“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2018b

Longitudinal Controller Stanley

Control longitudinal velocity of vehicle by using Stanley method

Library: Automated Driving Toolbox / Vehicle Control



Description

The Longitudinal Controller Stanley block computes the acceleration and deceleration commands, in meters per second, that control the velocity of the vehicle. Specify the reference velocity, current velocity, and current driving direction. The controller computes these commands using the Stanley method [1], which the block implements as a discrete proportional-integral (PI) controller with integral anti-windup. For more details, see “Algorithms” on page 2-34.

You can also compute the steering angle command of a vehicle using the Stanley method. See the Lateral Controller Stanley block.

Ports

Input

RefVelocity — Reference velocity

real scalar

Reference velocity, in meters per second, specified as a real scalar.

CurrVelocity — Current velocity

real scalar

Current velocity of the vehicle, in meters per second, specified as a real scalar.

Direction — Driving direction

1 (forward motion) | -1 (reverse motion)

Driving direction of vehicle, specified as 1 for forward motion and -1 for reverse motion.

Reset — Trigger to reset integral of velocity error

0 (hold steady) | nonzero scalar (reset)

Trigger to reset the integral of velocity error, $e(k)$, to zero. A value of 0 holds $e(k)$ steady. A nonzero value resets $e(k)$.

Output

AccelCmd — Acceleration command

real scalar in the range $[0, M_A]$

Acceleration command, returned as a real scalar in the range $[0, M_A]$, where M_A is the value of the **Maximum longitudinal acceleration (m/s²)** parameter.

DecelCmd — Deceleration command

real scalar in the range $[0, M_D]$

Deceleration command, returned as a real scalar in the range $[0, M_D]$, where M_D is the value of the **Maximum longitudinal deceleration (m/s²)** parameter.

Parameters

Proportional gain, Kp — Proportional gain

2.5 (default) | positive real scalar

Proportional gain of controller, K_p , specified as a positive real scalar.

Integral gain, Ki — Integral gain

1 (default) | positive real scalar

Integral gain of controller, K_i , specified as a positive real scalar.

Sample time (s) — Sample time

0.05 (default) | positive real scalar

Sample time of controller, in seconds, specified as a positive real scalar.

Maximum longitudinal acceleration (m/s²) – Maximum longitudinal acceleration

3 (default) | positive real scalar

Maximum longitudinal acceleration, in meters per second squared, specified as a positive real scalar.

The block saturates the output from the **AccelCmd** to the range $[0, M_A]$, where M_A is the value of this parameter. Values above M_A are set to M_A .

Maximum longitudinal deceleration (m/s²) – Maximum longitudinal deceleration

6 (default) | positive real scalar

Maximum longitudinal deceleration, in meters per second squared, specified as a positive real scalar.

The block saturates the output from the **DecelCmd** port to the range $[0, M_D]$, where M_D is the value of this parameter. Values above M_D are set to M_D .

Algorithms

The Longitudinal Controller Stanley block implements a discrete proportional-integral (PI) controller with integral anti-windup, as described by the “Anti-windup method” (Simulink) parameter of the PID Controller block. The block uses this equation:

$$u(k) = (K_p + K_i \frac{T_s z}{z-1}) e(k)$$

- $u(k)$ is the control signal at the k th time step.
- K_p is the proportional gain, as set by the **Proportional gain, Kp** parameter.
- K_i is the integral gain, as set by the **Integral gain, Ki** parameter.
- T_s is the sample time of the block in seconds, as set by the **Sample time (s)** parameter.
- $e(k)$ is the velocity error (**CurrVelocity - RefVelocity**) at the k th time step. For each k , this error is equal to the difference between the current velocity and reference velocity inputs (**CurrVelocity - RefVelocity**).

The control signal, u , determines the value of acceleration command **AccelCmd** and deceleration command **DecelCmd**. The block saturates the acceleration and deceleration commands to respective ranges of $[0, M_A]$ and $[0, M_D]$, where:

- M_A is value of the **Maximum longitudinal acceleration (m/s²)** parameter.
- M_D is the value of the **Maximum longitudinal deceleration (m/s²)** parameter.

At each time step, only one of the **AccelCmd** and **DecelCmd** port values is positive, and the other port value is \emptyset . In other words, the vehicle can either accelerate or decelerate in one time step, but it cannot do both at one time.

The direction of motion, as specified in the **Direction** input port, determines which command is positive at the given time step.

Direction Port Value	Control Signal Value $u(k)$	AccelCmd Port Value	DecelCmd Port Value	Description
1 (forward motion)	$u(k) > 0$	positive real scalar	\emptyset	Vehicle speeds up as it travels forward
	$u(k) < 0$	\emptyset	positive real scalar	Vehicle slows down as it travels forward
-1 (reverse motion)	$u(k) > 0$	\emptyset	positive real scalar	Vehicle slows down as it travels in reverse
	$u(k) < 0$	positive real scalar	\emptyset	Vehicle speeds up as it travels in reverse

References

- [1] Hoffmann, Gabriel M., Claire J. Tomlin, Michael Montemerlo, and Sebastian Thrun. "Autonomous Automobile Trajectory Tracking for Off-Road Driving: Controller Design, Experimental Validation and Racing." *American Control Conference*. August 2007, pp. 2296-2301. doi:10.1109/ACC.2007.4282788.

Extended Capabilities

C/C++ Code Generation

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

See Also

Blocks

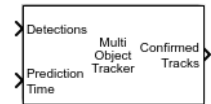
Lateral Controller Stanley | PID Controller | Path Smoother Spline | Velocity Profiler

Introduced in R2019a

Multi-Object Tracker

Create and manage tracks of multiple objects

Library: Automated Driving Toolbox



Description

The Multi-Object Tracker block initializes, confirms, predicts, corrects, and deletes the tracks of moving objects. Inputs to the multi-object tracker are detection reports generated by Radar Detection Generator and Vision Detection Generator blocks. The multi-object tracker accepts detections from multiple sensors and assigns them to tracks using a global nearest neighbor (GNN) criterion. Each detection is assigned to a separate track. If the detection cannot be assigned to any track, the multi-object tracker creates a new track.

A new track starts in a *tentative* state. If enough detections are assigned to a tentative track, its status changes to *confirmed*. When a track is confirmed, the multi-object tracker considers that track to represent a physical object. If detections are not added to the track within a specifiable number of updates, the track is deleted.

The multi-object tracker also estimates the state vector and state vector covariance matrix for each track using a Kalman filter. These state vectors are used to predict a track's location in each frame and determine the likelihood of each detection being assigned to each track.

Ports

Input

Detections — Detection list

Simulink bus containing MATLAB structure

Detection list, specified as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink). The structure has the form:

Field	Description	Type
NumDetections	Number of detections	integer
IsValidTime	False when updates are requested at times that are between block invocation intervals	Boolean
Detections	Object detections	Array of object detection structures. The first NumDetections of these detections are actual detections.

The definitions of the object detection structures are found in the **Detections** output port descriptions of the Radar Detection Generator and Vision Detection Generator blocks.

Note The object detection structure contains a **Time** field. The time tag of each object detection must be less than or equal to the time of the current invocation of the block. The time tag must also be greater than the update time specified in the previous invocation of the block.

Prediction Time — Track update time

real scalar

Track update time, specified as a real scalar. The multi-object tracker updates all tracks to this time. Update time must always increase with each invocation of the block. Units are in seconds.

Note The object detection structure contains a **Time** field. The time tag of each object detection must be less than or equal to the time of the current invocation of the block. The time tag must also be greater than the update time in the previous invocation of the block.

Dependencies

To enable this port, set **Prediction time source** to Input port.

Cost Matrix — Cost matrix

real-valued N_t -by- N_d matrix

Cost matrix, specified as a real-valued N_t -by- N_d matrix, where N_t is the number of existing tracks and N_d is the number of current detections.

The rows of the cost matrix correspond to the existing tracks. The columns correspond to the detections. Tracks are ordered as they appear in the list of tracks in the **All Tracks** output port of the previous invocation of the block.

In the first update to the multi-object tracker, or if the track has no previous tracks, assign the cost matrix a size of $[0, N_d]$. The cost must be calculated so that lower costs indicate a higher likelihood that the multi-object tracker assigns a detection to a track. To prevent certain detections from being assigned to certain tracks, use `Inf`.

Dependencies

To enable this port, select **Enable cost matrix input**.

Output

Confirmed Tracks — Confirmed tracks

Simulink bus containing MATLAB structure

Confirmed tracks, returned as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink).

This table shows the structure fields.

Field	Description
NumTracks	Number of tracks
Tracks	Array of track structures of a length set by the Maximum number of tracks parameter. Only the first NumTracks of these are actual tracks.

This table shows the fields of each track structure.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

A track is confirmed if:

- At least M detections are assigned to the track during the first N updates after track initialization. To specify the values M and N , use the **M and N for the M-out-of-N confirmation** parameter.
- The detection initiating the track has an `ObjectClassID` greater than zero.

Tentative Tracks – Tentative tracks

Simulink bus containing MATLAB structure

Tentative tracks, returned as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink). A track is tentative before it is confirmed.

This table shows the structure fields.

Field	Description
NumTracks	Number of tracks
Tracks	Array of track structures of a length set by the Maximum number of tracks parameter. Only the first NumTracks of these are actual tracks.

This table shows the fields of each track structure.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

Dependencies

To enable this port, select **Enable tentative tracks output**.

ALL Tracks – All tracks

Simulink bus containing MATLAB structure

Combined list of confirmed and tentative tracks, returned as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink).

This table shows the structure fields.

Field	Description
NumTracks	Number of tracks
Tracks	Array of track structures of a length set by the Maximum number of tracks parameter. Only the first NumTracks of these are actual tracks.

This table shows the fields of each track structure.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.

Field	Definition
ObjectClassID	Integer value representing the object classification. The value 0 represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

Dependencies

To enable this port, select **Enable all tracks output**.

Parameters

Tracker Management

Filter initialization function name — Kalman filter initialization function

`initcvkf` (default) | function name

Kalman filter initialization function, specified as a function name. The toolbox provides several initialization functions. For an example of an initialization function, see `initcvkf`.

Threshold for assigning detections to tracks — Detection assignment threshold

`30.0` (default) | positive real scalar

Detection assignment threshold, specified as a positive real scalar. To assign a detection to a track, the detection's normalized distance from the track must be less than the assignment threshold. If some detections remain unassigned to tracks that you want them assigned to, then increase the threshold. If some detections are assigned to incorrect tracks, decrease the threshold.

M and N for the M-out-of-N confirmation — Confirmation parameters for track creation

`[2, 3]` (default) | two-element vector of positive integers

Confirmation parameters for track creation, specified as a two-element vector of positive integers, $[M, N]$. A track is confirmed when at least M detections are assigned to the track during the first N updates after track initialization. M must be less than or equal to N .

- When setting N , consider the number of times you want the tracker to update before it confirms a track. For example, if a tracker updates every 0.05 seconds, and you allow 0.5 seconds to make a confirmation decision, set $N = 10$.
- When setting M , take into account the probability of object detection for the sensors. The probability of detection depends on factors such as occlusion or clutter. You can reduce M when tracks fail to be confirmed or increase M when too many false detections are assigned to tracks.

Example: $[3, 5]$

Number of times a confirmed track is coasted – Coasting threshold for track deletion

5 (default) | positive integer

Coasting threshold for track deletion, specified as a positive integer. A track coasts when no detections are assigned to the track after one or more prediction steps. If the number of coasting steps exceeds this threshold, the block deletes the track.

Maximum number of tracks – Maximum number of tracks

200 (default) | positive integer

Maximum number of tracks that the block can process, specified as a positive integer.

Maximum number of sensors – Maximum number of sensors

20 (default) | positive integer

Maximum number of sensors that the block can process, specified as a positive integer. This value should be greater than or equal to the highest `SensorIndex` value used in the **Detections** input port.

Inputs and Outputs

Prediction time source – Source for prediction time

Input port (default) | Auto

Source for prediction time, specified as `Input port` or `Auto`. Select `Input port` to input an update time by using the **Prediction Time** input port. Otherwise, the simulation clock managed by Simulink determines the update time.

Example: Auto

Source of output bus name — Source of output bus name

Auto (default) | Property

Source of output bus name, specified as Auto or Property.

- If you select Auto, the block automatically creates a bus name.
- If you select Property, specify the bus name using the **Specify an output bus name** parameter.

Specify an output bus name — Name of output bus

no default

Dependencies

To enable this parameter, set the **Source of output bus name** parameter to Property.

Enable cost matrix input — Enable input port for cost matrix

off (default) | on

Select this check box to enable the input of a cost matrix by using the **Cost Matrix** input port.

Enable tentative tracks output — Enable output port for tentative tracks

off (default) | on

Select this check box to enable the output of tentative tracks by using the **Tentative Tracks** output port.

Enable all tracks output — Enable output port for all tracks

off (default) | on

Select this check box to enable the output of all the tracks by using the **All Tracks** output port.

Simulate using — Type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** — Simulate the model using the MATLAB interpreter. This option shortens startup time. In Interpreted execution mode, you can debug the source code of the block.

- **Code generation** — Simulate the model using generated C/C++ code. The first time you run a simulation, Simulink generates C/C++ code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time.

Extended Capabilities

C/C++ Code Generation

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

See Also

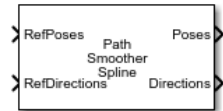
Bird's-Eye Scope | **Detection Concatenation** | **Radar Detection Generator** | **Scenario Reader** | **Vision Detection Generator** | **multiObjectTracker**

Introduced in R2017b

Path Smoother Spline

Smooth vehicle path using cubic spline interpolation

Library: Automated Driving Toolbox



Description

The Path Smoother Spline block generates a smooth vehicle path, consisting of a sequence of discretized poses, by fitting the input reference path poses to a cubic spline. Given the input reference path directions, the block also returns the directions that correspond to each pose.

Use this block to convert a C^1 -continuous path to a C^2 -continuous path. C^1 -continuous paths include Dubins or Reeds-Shepp paths that are returned by path planners. For more details on these path types, see “ C^1 -Continuous and C^2 -Continuous Paths” on page 2-50.

You can use the returned poses and directions with a vehicle controller, such as the Lateral Controller Stanley block.

Ports

Input

RefPoses — Reference poses

M -by-3 matrix of $[x, y, \theta]$ vectors

Reference poses of the vehicle along the path, specified as an M -by-3 matrix of $[x, y, \theta]$ vectors, where M is the number of poses.

x and y specify the location of the vehicle in meters. θ specifies the orientation angle of the vehicle in degrees.

Data Types: single | double

RefDirections — Reference directions

M -by-1 column vector of 1s (forward motion) and -1s (reverse motion)

Reference directions of the vehicle along the path, specified as an M -by-1 column vector of 1s (forward motion) and -1s (reverse motion). M is the number of reference directions. Each element of **RefDirections** corresponds to a pose in the **RefPoses** input port.

Data Types: single | double

Output

Poses — Discretized poses of smoothed path

N -by-3 matrix of $[x, y, \theta]$ vectors

Discretized poses of the smoothed path, returned as an N -by-3 matrix of $[x, y, \theta]$ vectors. N is the number of poses specified in the **Number of output poses** parameter.

x and y specify the location of the vehicle in meters. θ specifies the orientation angle of the vehicle in degrees.

The values in **Poses** are of the same data type as the values in the **RefPoses** input port.

Directions — Driving directions at each output pose

N -by-1 column vector of 1s (forward motion) and -1s (reverse motion)

Driving directions of the vehicle at each output pose in **Poses**, returned as an N -by-1 column vector of 1s (forward motion) and -1s (reverse motion). N is the number of poses specified in the **Number of output poses** parameter.

The values in **Directions** are of the same data type as the values in the **RefDirections** input port.

You can use **Directions** to specify the reference path of a vehicle. You can also use **Directions**, along with **CumLengths** and **Curvatures**, to generate a reference velocity profile for the vehicle. See the Velocity Profiler block and the “Automated Parking Valet in Simulink” example.

CumLengths — Cumulative path lengths

N -by-1 real-valued column vector

Cumulative path lengths at each output pose in **Poses**, returned as an N -by-1 real-valued column vector. N is the number of poses specified in the **Number of output poses** parameter. Units are in meters.

You can use **CumLengths**, along with **Directions** and **Curvatures**, to generate a reference velocity profile for the vehicle. See the Velocity Profiler block and the “Automated Parking Valet in Simulink” example.

Dependencies

To enable this port, select the **Show CumLengths and Curvatures output ports** parameter.

Curvatures — Signed path curvatures

N -by-1 real-valued column vector

Signed path curvatures at each output pose in **Poses**, returned as an N -by-1 real-valued column vector. N is the number of poses specified in the **Number of output poses** parameter. Units are in radians per meter.

You can use **Curvatures**, along with **Directions** and **CumLengths**, to generate a reference velocity profile for the vehicle. See the Velocity Profiler block and the “Automated Parking Valet in Simulink” example.

Dependencies

To enable this port, select the **Show CumLengths and Curvatures output ports** parameter.

Parameters

Number of output poses — Number of smooth poses to return

100 (default) | positive integer

Number of smooth poses to return in the **Poses** output port, specified as a positive integer. To increase the granularity of the returned poses, increase this parameter value.

Minimum separation of input poses — Minimum separation between poses

1e-3 (default) | positive real scalar

Minimum separation between poses, in meters, specified as a positive real scalar. If the Euclidean (x, y) distance between two poses is less than this value, then the block uses only one of these poses for interpolation.

Sample time — Sample time

-1 (default) | positive real scalar

Sample time of the block, in seconds, specified as -1 or as a positive real scalar. The default of -1 means that the block inherits its sample time from upstream blocks.

Show CumLengths and Curvatures output ports — Output cumulative path lengths and curvatures

off (default) | on

Select this parameter to enable the **CumLengths** and **Curvatures** output ports.

Simulate using — Type of simulation to run

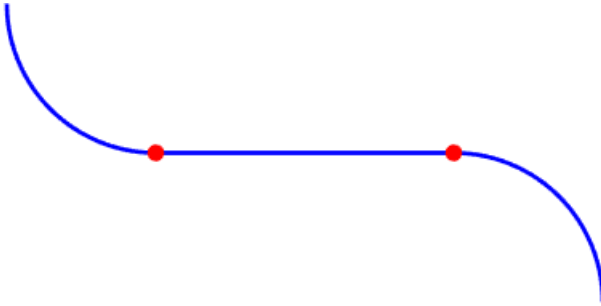
Code Generation (default) | Interpreted Execution

- **Code generation** — Simulate the model using generated C/C++ code. The first time you run a simulation, Simulink generates C/C++ code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time.
- **Interpreted execution** — Simulate the model using the MATLAB interpreter. This option shortens startup time. In Interpreted execution mode, you can debug the source code of the block.

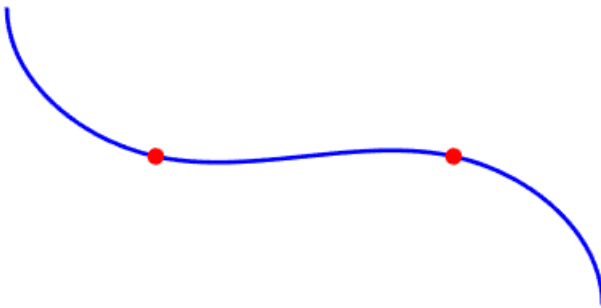
More About

C¹-Continuous and C²-Continuous Paths

A path is C¹-continuous if its derivative exists and is continuous. Paths that are only C¹-continuous have discontinuities in their curvature. For example, a path composed of Dubins or Reeds-Sheep path segments has discontinuities in curvature at the points where the segments join. These discontinuities result in changes in direction that are not smooth enough for driving with passengers.



A path is also C^2 -continuous if its second derivative exists and is continuous. C^2 -continuous paths have continuous curvature and are smooth enough for driving with passengers.



Algorithms

- The path-smoothing algorithm interpolates a parametric cubic spline that passes through all input reference pose points. The parameter of the spline is the cumulative chord length at these points. [1]
- The tangent direction of the smoothed output path approximately matches the orientation angle of the vehicle at the starting and goal poses.

References

- [1] Floater, Michael S. "On the Deviation of a Parametric Cubic Spline Interpolant from Its Data Polygon." *Computer Aided Geometric Design*. Vol. 25, Number 3, 2008, pp. 148-156.

[2] Lepetic, Marko, Gregor Klancar, Igor Skrjanc, Drago Matko, and Bostjan Potocnik. "Time Optimal Path Planning Considering Acceleration Limits." *Robotics and Autonomous Systems*. Vol. 45, Numbers 3-4, 2003, pp. 199-210.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

smoothPathSpline

Blocks

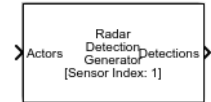
Lateral Controller Stanley | Longitudinal Controller Stanley | Velocity Profiler

Introduced in R2019a

Radar Detection Generator

Create detection objects from radar measurements

Library: Automated Driving Toolbox / Driving Scenario and Sensor Modeling



Description

The Radar Detection Generator block generates detections from radar measurements taken by a radar sensor mounted on an ego vehicle. Detections are derived from simulated actor poses and are generated at intervals equal to the sensor update interval. All detections are referenced to the coordinate system of the ego vehicle. The generator can simulate real detections with added random noise and also generate false alarm detections. A statistical model generates the measurement noise, true detections, and false positives. The random numbers generated by the statistical model are controlled by random number generator settings on the **Measurements** tab. You can use the Radar Detection Generator to create input to a Multi-Object Tracker block. When building scenarios and sensor models using the **Driving Scenario Designer** app, the radar sensors exported to Simulink are output as Radar Detection Generator blocks.

Ports

Input

Actors — Scenario actor poses

Simulink bus containing MATLAB structure

Scenario actor poses, specified as a Simulink bus containing a MATLAB structure.

The structure has these fields.

Field	Description	Type
NumActors	Number of actors (ego vehicle excluded)	Nonnegative integer
Time	Current simulation time	Real scalar
Actors	Actor poses in ego vehicle coordinates	NumActors-length array of actor pose structures

Each actor pose structure in Actors has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x-, y-, and z-directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x-, y-, and z-directions, specified as an [ω_x ω_y ω_z] real-valued vector. Units are in degrees per second.

Output

Detections – Detections

Simulink bus containing MATLAB structure

Detections, returned as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink). The structure has the form:

Field	Description	Type
NumDetections	Number of detections	integer
IsValidTime	False when updates are requested at times that are between block invocation intervals	Boolean
Detections	Object detections	Array of object detection structures of length set by the Maximum number of reported detections parameter. Only NumDetections of these are actual detections.

Each object detection structure contains these properties.

Property	Definition
Time	Measurement time
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor
ObjectClassID	Object classification
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

- For Cartesian coordinates, Measurement and MeasurementNoise are reported in the coordinate system specified by the **Coordinate system used to report detections** parameter.
- For spherical coordinates, Measurement and MeasurementNoise are reported in the spherical coordinate system based on the sensor Cartesian coordinate system.

Measurement and Measurement Noise

Coordinate System Used to Report Detections	Measurement and Measurement Noise Coordinates		
'Ego Cartesian'	Coordinate dependence on Enable range rate measurements		
'Sensor Cartesian'	Enable range rate measurements		Coordinates
	true		[x;y;z;vx;vy;vz]
	false		[x;y;z]
'Sensor spherical'	Coordinate dependence on Enable elevation angle measurements and Enable range rate measurements		
	Enable range rate measurements	Enable elevation angle measurements	Coordinates
	true	true	[az;el;rng;rr]
	true	false	[az;rng;rr]
	false	true	[az;el;rng]
	false	false	[az;rng]

MeasurementParameters

Parameter	Definition
Frame	Enumerated type indicating the frame used to report measurements. When Frame is set to 'rectangular', detections are reported in Cartesian coordinates. When Frame is set 'spherical', detections are reported in spherical coordinates.
OriginPosition	3-D vector offset of the sensor origin from the ego vehicle origin. The vector is derived from the SensorLocation and Height properties specified in the radarDetectionGenerator.
Orientation	Orientation of the radar sensor coordinate system with respect to the ego vehicle coordinate system. The orientation is derived from the Yaw, Pitch, and Roll properties of the radarDetectionGenerator.
HasVelocity	Indicates whether measurements contain velocity or range rate components.
HasElevation	Indicates whether measurements contain elevation components.

The ObjectAttributes property of each detection is a structure with these fields.

Field	Definition
TargetIndex	Identifier of the actor, ActorID, that generated the detection. For false alarms, this value is negative.
SNR	Signal-to-noise ratio of the detection. Units are in dB.

Parameters

Parameters

Sensor Identification

Unique identifier of sensor — Unique sensor identifier

1 (default) | positive integer

Unique sensor identifier, specified as a positive integer. The sensor identifier distinguishes detections that come from different sensors in a multi-sensor system. If a model contains multiple Radar Detection Generator blocks with the same sensor identifier, the **Bird's-Eye Scope** displays sensor data for only one of the blocks.

Example: 5

Required interval between sensor updates (s) — Required time interval

0.1 (default) | positive real scalar

Required time interval between sensor updates, specified as a positive real scalar. The value of this parameter must be an integer multiple of the **Actors** input port data interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Sensor Extrinsic

Sensor's (x,y) position (m) — Location of the radar sensor center

[3.4 0] (default) | real-valued 1-by-2 vector

Location of the radar sensor center, specified as a real-valued 1-by-2 vector. The **Sensor's (x,y) position (m)** and **Sensor's height (m)** parameters define the coordinates of the radar sensor with respect to the ego vehicle coordinate system. The default value corresponds to a radar mounted at the center of the front grill of a sedan. Units are in meters.

Sensor's height (m) — Radar sensor height above the ground plane

0.2 (default) | positive real scalar

Radar sensor height above the ground plane, specified as a positive real scalar. The height is defined with respect to the vehicle ground plane. The **Sensor's (x,y) position (m)** and **Sensor's height (m)** parameters define the coordinates of the radar sensor with

respect to the ego vehicle coordinate system. The default value corresponds to a radar mounted at the center of the front grill of a sedan. Units are in meters.

Example: 0.25

Yaw angle of sensor mounted on ego vehicle (deg) — Yaw angle of sensor

0 (default) | real scalar

Yaw angle of radar sensor, specified as a real scalar. Yaw angle is the angle between the center line of the ego vehicle and the downrange axis of the radar sensor. A positive yaw angle corresponds to a clockwise rotation when looking in the positive direction of the z-axis of the ego vehicle coordinate system. Units are in degrees.

Example: -4.0

Pitch angle of sensor mounted on ego vehicle (deg) — Pitch angle of sensor

0 (default) | real scalar

Pitch angle of sensor, specified as a real scalar. The pitch angle is the angle between the downrange axis of the radar sensor and the x-y plane of the ego vehicle coordinate system. A positive pitch angle corresponds to a clockwise rotation when looking in the positive direction of the y-axis of the ego vehicle coordinate system. Units are in degrees.

Example: 3.0

Roll angle of sensor mounted on ego vehicle (deg) — Roll angle of sensor

0 (default) | real scalar

Roll angle of the radar sensor, specified as a real scalar. The roll angle is the angle of rotation of the downrange axis of the radar around the x-axis of the ego vehicle coordinate system. A positive roll angle corresponds to a clockwise rotation when looking in the positive direction of the x-axis of the coordinate system. Units are in degrees.

Port Settings

Source of output bus name — Source of output bus name

Auto (default) | Property

Source of output bus name, specified as Auto or Property. If you choose Auto, the block will automatically create a bus name. If you choose Property, specify the bus name using the **Specify an output bus name** parameter.

Example: Property

Specify an output bus name — Name of output bus

no default

Name of output bus.

Dependencies

To enable this parameter, set the **Source of output bus name** parameter to Property.

Detection Reporting

Maximum number of reported detections — Maximum number of reported detections

50 (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. Detections are reported in order of increasing distance from the sensor until the maximum number is reached.

Example: 100

Coordinate system used to report detections — Coordinate system of reported detections

Ego Cartesian (default) | Sensor Cartesian | Sensor Spherical

Coordinate system of reported detections, specified as one of these values:

- **Ego Cartesian** — Detections are reported in the ego vehicle Cartesian coordinate system.
- **Sensor Cartesian**— Detections are reported in the sensor Cartesian coordinate system.
- **Sensor spherical** — Detections are reported in a spherical coordinate system. This coordinate system is centered at the radar and aligned with the orientation of the radar on the ego vehicle.

Simulate using — Type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** — Simulate the model using the MATLAB interpreter. This option shortens startup time. In Interpreted execution mode, you can debug the source code of the block.
- **Code generation** — Simulate the model using generated C/C++ code. The first time you run a simulation, Simulink generates C/C++ code for the block. The C code is

reused for subsequent simulations as long as the model does not change. This option requires additional startup time.

Measurements

Accuracy Settings

Azimuthal resolution of radar (deg) — Azimuth resolution of radar

4.0 (default) | positive real scalar

Azimuth resolution of the radar, specified as a positive real scalar. The azimuth resolution defines the minimum separation in azimuth angle at which the radar can distinguish two targets. The azimuth resolution is typically the 3dB-downpoint in azimuth angle beamwidth of the radar. Units are in degrees.

Example: 6.5

Elevation resolution of radar (deg) — Elevation resolution of radar

10.0 (default) | positive real scalar

Elevation resolution of the radar, specified as a positive real scalar. The elevation resolution defines the minimum separation in elevation angle at which the radar can distinguish two targets. The elevation resolution is typically the 3dB-downpoint in elevation angle beamwidth of the radar. Units are in degrees.

Example: 3.5

Dependencies

To enable this parameter, select the **Enable elevation angle measurements** check box.

Range resolution of radar (m) — Range resolution of radar

2.5 (default) | positive real scalar

Range resolution of the radar, specified as a positive real scalar. The range resolution defines the minimum separation in range at which the radar can distinguish between two targets. Units are in meters.

Example: 5.0

Range rate resolution of radar (m/s) — Range rate resolution of the radar

0.5 (default) | positive real scalar

Range rate resolution of the radar, specified as a positive real scalar. The range rate resolution defines the minimum separation in range rate at which the radar can distinguish between two targets. Units are in meters per second.

Example: 0.75

Dependencies

To enable this parameter, select the **Enable range rate measurements** check box.

Bias Settings

Fractional azimuthal bias component of radar — Azimuth bias fraction

0.1 (default) | nonnegative real scalar

Azimuth bias fraction of the radar, specified as a nonnegative real scalar. The azimuth bias is expressed as a fraction of the azimuth resolution specified in the **Azimuthal resolution of radar (deg)** parameter. Units are dimensionless.

Example: 0.3

Fractional elevation bias component of radar — Elevation bias fraction

0.1 (default) | nonnegative real scalar

Elevation bias fraction of the radar, specified as a nonnegative real scalar. The elevation bias is expressed as a fraction of the elevation resolution specified in the **Elevation resolution of radar (deg)** parameter. Units are dimensionless.

Example: 0.2

Dependencies

To enable this parameter, select the **Enable elevation angle measurements** check box.

Fractional range bias component of radar — Range bias fraction

0.05 (default) | nonnegative real scalar

Range bias fraction of the radar, specified as a nonnegative real scalar. Range bias is expressed as a fraction of the range resolution specified in the **Range resolution of radar (m)** parameter. Units are dimensionless.

Example: 0.15

Fractional range rate bias component of radar — Range rate bias fraction of the radar

0.05 (default) | nonnegative real scalar

Range rate bias fraction of the radar, specified as a nonnegative real scalar. Range rate bias is expressed as a fraction of the range rate resolution specified in **Range rate resolution of radar (m)** parameter. Units are dimensionless.

Example: 0.2

Dependencies

To enable this parameter, select the **Enable range rate measurements** check box.

Detector Settings

Total angular field of view for radar (deg) — Field of view of radar sensor

[20 5] (default) | real-valued 1-by-2 vector of positive values

Field of view of radar sensor, specified as a real-valued 1-by-2 vector of positive values, [azfov elfov]. The field of view defines the angular extent spanned by the sensor. Each component must lie in the interval (0,180]. Targets outside of the field of view of the radar are not detected. Units are in degrees.

Example: [14 7]

Maximum detection range (m) — Maximum detection range

150 (default) | positive real scalar

Maximum detection range, specified as a positive real scalar. The radar cannot detect a target beyond this range. Units are in meters.

Example: 250

Minimum and maximum range rates that can be reported — Minimum and maximum detection range rates

[-100 100] (default) | real-valued 1-by-2 vector

Minimum and maximum detection range rates, specified as a real-valued 1-by-2 vector. The radar cannot detect a target outside of this range rate interval. Units are in meters per second.

Example: [-200 200]

Dependencies

To enable this parameter, select the **Enable range rate measurements** check box.

Detection probability — Probability of detecting a target

0.9 (default) | positive real scalar less than or equal to 1

Probability of detecting a target, specified as a positive real scalar less than or equal to one. This quantity defines the probability of detecting target that has a radar cross-section specified by the **Radar cross section at which detection probability is achieved (dBsm)** parameter at the reference detection range specified by the **Range where detection probability is achieved (m)** parameter.

Example: 0.95

Rate at which false alarms are reported — False alarm rate

1e-6 (default) | positive real scalar

False alarm rate within a radar resolution cell, specified as a positive real scalar in the range $[10^{-7}, 10^{-3}]$. Units are dimensionless.

Example: 1e-5

Range where detection probability is achieved (m): — Reference range for given probability of detection

100 (default) | positive real scalar

Reference range for a given probability of detection, specified as a positive real scalar. The reference range is the range when a target having a radar cross-section specified by **Radar cross section at which detection probability is achieved (dBsm)** is detected with a probability of specified by **Detection probability**. Units are in meters.

Example: 150

Radar cross section at which detection probability is achieved (dBsm) — Reference radar cross-section for given probability of detection

0.0 (default) | nonnegative real scalar

Reference radar cross-section (RCS) for given probability of detection, specified as a nonnegative real scalar. The reference RCS is the value at which a target is detected with probability specified by **Detection probability**. Units are in dBsm.

Example: 2.0

Measurement Settings

Enable elevation angle measurements — Enable radar to measure elevation

off (default) | on

Select this check box to model a radar that can measure target elevation angles.

Enable range rate measurements — Enable radar to measure range rate

on (default) | off | on

Select this check box to model a radar that can measure target range rate.

Add noise to measurements — Enable adding noise to radar sensor measurements

on (default) | off

Select this check box to add noise to radar sensor measurements. Otherwise, the measurements are noise-free. The `MeasurementNoise` property of each detection is always computed and is not affected by the value you specify for the **Add noise to measurements** parameter. By leaving this check box off, you can pass the sensor's ground truth measurements into a Multi-Object Tracker block.

Enable false detections — Enable creating false alarm radar detections

on (default) | off

Select this check box to enable reporting false alarm radar measurements. Otherwise, only actual detections are reported.

Random Number Generator Settings

Select method to specify initial seed — Method to specify random number generator seed

Repeatable (default) | Specify seed | Nonrepeatable

Method to set the random number generator seed, specified as `Repeatable`, `Specify seed`, or `Nonrepeatable`. When set to `Specify seed`, the value set in the `InitialSeed` parameter is used. When set to `Repeatable`, a random initial seed is generated for the first simulation and then reused for all subsequent simulations. You can, however, change the seed by issuing a `clear all` command. When set to `Nonrepeatable`, a new initial seed is generated each time the simulation runs.

Example: `Specify seed`

Initial seed — Random number generator seed

0 (default) | nonnegative integer less than 2^{32}

Random number generator seed, specified as a nonnegative integer less than 2^{32} .

Example: 2001

Dependencies

To enable this parameter, set the Random Number Generator Settings parameter to Specify seed.

Actor Profiles

Select method to specify actor profiles — Method to specify actor profiles

Parameters (default) | MATLAB expression

Method to specify actor profiles, specified as Parameters or MATLAB expression. When you select Parameters, you set the actor profiles using the parameters in the **Actor Profiles** tab. When you select MATLAB expression, set the actor profiles using the **MATLAB expression for actor profiles** parameter.

MATLAB expression for actor profiles — MATLAB expression for actor profiles

struct('ClassID',0,'Length',4.7,'Width',1.8,'Height',1.4,'OriginOffset',[-1.35,0,0]) (default) | MATLAB structure | MATLAB structure array | valid MATLAB expression

MATLAB expression for actor profiles, specified as a MATLAB structure, a MATLAB structure array, or a valid MATLAB expression that produces such a structure or structure array.

If your Scenario Reader block reads data from a drivingScenario object, to obtain the actor profiles directly from this object, set this expression to call the actorProfiles function on the object. For example: actorProfiles(scenario).

Example:

```
struct('ClassID',5,'Length',5.0,'Width',2,'Height',2,'OriginOffset',[-1.55,0,0])
```

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to MATLAB expression.

Unique identifier for actors — Scenario-defined actor identifier

[] (default) | positive integer | length-L vector of unique positive integers

Scenario-defined actor identifier, specified as a positive integer or length- L vector of unique positive integers. L must equal the number of actors input into the **Actor** input port. The vector elements must match **ActorID** values of the actors. You can specify **Unique identifier for actors** as `[]`. In this case, the same actor profile parameters apply to all actors.

Example: `[1, 2]`

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to **Parameters**.

User-defined integer to classify actors – User-defined classification identifier

0 (default) | integer | length- L vector of integers

User-defined classification identifier, specified as an integer or length- L vector of integers. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, `[]`, you must specify this parameter as a single integer whose value applies to all actors.

Example: `2`

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to **Parameters**.

Length of actors cuboids (m) – Length of cuboid

4.7 (default) | positive real scalar | length- L vector of positive values

Length of cuboid, specified as a positive real scalar or length- L vector of positive values. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, `[]`, you must specify this parameter as a positive real scalar whose value applies to all actors. Units are in meters.

Example: `6.3`

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to **Parameters**.

Width of actors cuboids (m) — Width of cuboid

4.7 (default) | positive real scalar | length-*L* vector of positive values

Width of cuboid, specified as a positive real scalar or length-*L* vector of positive values. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, [], you must specify this parameter as a positive real scalar whose value applies to all actors. Units are in meters.

Example: 4.7

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Height of actors cuboids (m) — Height of cuboid

4.7 (default) | positive real scalar | length-*L* vector of positive values

Height of cuboid, specified as a positive real scalar or length-*L* vector of positive values. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, [], you must specify this parameter as a positive real scalar whose value applies to all actors. Units are in meters.

Example: 2.0

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Rotational center of actors from bottom center (m) — Rotational center of the actor

{ [-1.35, 0, 0] } (default) | length-*L* cell array of real-valued 1-by-3 vectors

Rotational center of the actor, specified as a length-*L* cell array of real-valued 1-by-3 vectors. Each vector represents the offset of the rotational center of the actor from the bottom-center of the actor. For vehicles, the offset corresponds to the point on the ground beneath the center of the rear axle. When **Unique identifier for actors** is a vector, this parameter is a cell array of vectors with cells in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, [], you must specify this parameter as a cell array of one element containing the offset vector whose values apply to all actors. Units are in meters.

Example: [-1.35, .2, .3]

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Radar cross section pattern (dBsm) — Radar cross-section

{ [10, 10; 10, 10] } (default) | real-valued Q -by- P matrix | length- L cell array of real-valued Q -by- P matrices

Radar cross-section (RCS) of actor, specified as a real-valued Q -by- P matrix or length- L cell array of real-valued Q -by- P matrices. Q is the number of elevation angles specified by the corresponding cell in the **Elevation angles defining RCSPattern (deg)** parameter. P is the number of azimuth angles specified by the corresponding cell in **Azimuth angles defining RCSPattern (deg)** property. When **Unique identifier for actors** is a vector, this parameter is a cell array of matrices with cells in one-to-one correspondence to the actors in **Unique identifier for actors**. Q and P can vary in the cell array. When **Unique identifier for actors** is empty, [], you must specify this parameter as a cell array with one element containing a matrix whose values apply to all actors. Units are in dBsm.

Example: [10 14 10; 9 13 9]

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Azimuth angles defining RCSPattern (deg) — Azimuth angles of radar cross-section pattern

{ [-180 180] } (default) | length- L cell array of real-valued P -length vectors

Azimuth angles of radar cross-section pattern, specified as a length- L cell array of real-valued P -length vectors. Each vector represents the azimuth angles of the P -columns of the radar cross section specified in **Radar cross section pattern (dBsm)**. When **Unique identifier for actors** is a vector, this parameter is a cell array of vectors with cells in one-to-one correspondence to the actors in **Unique identifier for actors**. P can vary in the cell array. When **Unique identifier for actors** is empty, [], you must specify this parameter as a cell array with one element containing a vector whose values apply to all actors. Units are in degrees. Azimuth angles lie in the range -180° to 180° and must be in strictly increasing order.

When the radar cross sections specified in the cells of **Radar cross section pattern (dBsm)** all have the same dimensions, you need only specify a cell array with one element containing the azimuth angle vector.

Example: [-90:90]

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Elevation angles defining RCSPattern (deg) — Elevation angles of radar cross-section pattern

{ [-90 90] } (default) | length-*L* cell array of real-valued *Q*-length vectors

Elevation angles of radar cross-section pattern, specified as a length-*L* cell array of real-valued *Q*-length vectors. Each vector represent the elevation angles of the *Q*-columns of the radar cross section specified in **Radar cross section pattern (dBsm)**. When **Unique identifier for actors** is a vector, this parameter is a cell array of vectors with cells in one-to-one correspondence to the actors in **Unique identifier for actors**. *Q* can vary in the cell array. When **Unique identifier for actors** is empty, [], you must specify this parameter as a cell array with one element containing a vector whose values apply to all actors. Units are in degrees. Elevation angles lie in the range -90° to 90° and must be in strictly increasing order.

When the radar cross sections that are specified in the cells of **Radar cross section pattern (dBsm)** all have the same dimensions, you need only specify a cell array with one element containing an elevation angle vector.

Example: [-25:25]

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

See Also

Bird's-Eye Scope | Detection Concatenation | Multi-Object Tracker | Scenario Reader | Vision Detection Generator | radarDetectionGenerator

Topics

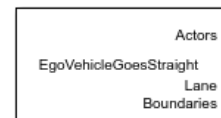
“Getting Started with Buses” (Simulink)

Introduced in R2017b

Scenario Reader

Read driving scenario into model

Library: Automated Driving Toolbox / Driving Scenario and Sensor Modeling



Description

The Scenario Reader block reads the roads and actors from a scenario file created using the **Driving Scenario Designer** app or from a `drivingScenario` object. The block outputs the poses of actors in either the coordinate system of the ego vehicle or the world coordinates of the scenario. You can also output the lane boundaries.

To generate object and lane boundary detections from output actor poses and lane boundaries, pass the pose and boundary outputs to Vision Detection Generator and Radar Detection Generator sensor blocks. Use the generated, synthetic detections to test the performance of sensor fusion algorithms, tracking algorithms, and other automated driving assistance system (ADAS) algorithms. To visualize the performance of these algorithms, use the **Bird's-Eye Scope**.

You can read the ego vehicle from the scenario or specify an ego vehicle defined in your model as an input to the Scenario Reader block. Use this option to test closed-loop vehicle controller algorithms, such as autonomous emergency braking (AEB), lane keeping assist (LKA), or adaptive cruise control (ACC).

Limitations

- The Scenario Reader block does not read sensor data from scenario files saved from the **Driving Scenario Designer** app. To reproduce sensors in Simulink, in the app, open the scenario file that contains the sensors. Then, from the app toolstrip, select **Export > Export Sensor Simulink Model**. Copy the generated Radar Detection Generator and Vision Detection Generator sensor blocks into an existing model. Alternatively, select **Export > Export Simulink Model** and start a new model from the generated Scenario Reader block and sensor blocks.

- Large road networks, including OpenDRIVE road networks, can take up to several minutes to read into models.

Ports

Input

Ego Vehicle — Ego vehicle pose

Simulink bus containing MATLAB structure

Ego vehicle pose, specified as a Simulink bus containing a MATLAB structure.

The structure must contain these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x-, y-, and z-directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x-, y-, and z-directions, specified as an [ω_x ω_y ω_z] real-valued vector. Units are in degrees per second.

Dependencies

To enable this port, set the **Source of ego vehicle** parameter to Input port.

Output

Actors — Scenario actor poses

Simulink bus containing MATLAB structure

Scenario actor poses, returned as a Simulink bus containing a MATLAB structure.

The structure has these fields.

Field	Description	Type
NumActors	Number of actors (ego vehicle excluded)	Nonnegative integer
Time	Current simulation time	Real scalar
Actors	Actor poses in ego vehicle coordinates	NumActors-length array of actor pose structures

Each actor pose structure in Actors has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an $[x \ y \ z]$ real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x -, y -, and z -directions, specified as a $[v_x \ v_y \ v_z]$ real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.

Field	Description
AngularVelocity	Angular velocity (ω) of actor in the x -, y -, and z -directions, specified as an $[\omega_x \ \omega_y \ \omega_z]$ real-valued vector. Units are in degrees per second.

The pose of the ego vehicle is excluded from the Actors array.

Lane Boundaries – Scenario lane boundaries

Simulink bus containing MATLAB structure

Scenario lane boundaries, returned as a Simulink bus containing a MATLAB structure.

The structure has these fields.

Field	Description	Type
NumLaneBoundaries	Number of lane boundaries	Nonnegative integer
Time	Current simulation time	Real scalar
LaneBoundaries	Lane boundaries in ego vehicle coordinates	NumLaneBoundaries-length array of lane boundary structures

Each lane boundary structure in LaneBoundaries has these fields.

Field	Description
Coordinates	Lane boundary coordinates, specified as a real-valued N -by-3 matrix, where N is the number of lane boundaries. Lane boundary coordinates define the position of points on the boundary at distances specified by the 'XDistance' name-value pair argument of the laneBoundaries function. In addition, a set of boundary coordinates are inserted into the matrix at zero distance. Units are in meters.

Curvature	Lane boundary curvature at each row of the <code>Coordinates</code> matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per meter.
CurvatureDerivative	Derivative of lane boundary curvature at each row of the <code>Coordinates</code> matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per square meter.
HeadingAngle	Initial lane boundary heading angle, specified as a real scalar. The heading angle of the lane boundary is relative to the ego vehicle heading. Units are in degrees.
LateralOffset	Distance of the lane boundary from the ego vehicle position, specified as a real scalar. An offset to a lane boundary to the left of the ego vehicle is positive. An offset to the right of the ego vehicle is negative. Units are in meters.
BoundaryType	Type of lane boundary marking, specified as one of these values: <ul style="list-style-type: none"> • 'Unmarked' — No physical lane marker exists • 'Solid' — Single unbroken line • 'Dashed' — Single line of dashed lane markers • 'DoubleSolid' — Two unbroken lines • 'DoubleDashed' — Two dashed lines • 'SolidDashed' — Solid line on the left and a dashed line on the right • 'DashedSolid' — Dashed line on the left and a solid line on the right

Strength	Saturation strength of the lane boundary marking, specified as a real scalar from 0 to 1. A value of 0 corresponds to a marking whose color is fully unsaturated. The marking appears gray. A value of 1 corresponds to a marking whose color is fully saturated.
Width	Lane boundary width, specified as a positive real scalar. In a double-line lane marker, the same width is used for both lines and for the space between lines. Units are in meters.
Length	Length of dash in dashed lines, specified as a positive real scalar. In a double-line lane marker, the same length is used for both lines.
Space	Length of space between dashes in dashed lines, specified as a positive real scalar. In a dashed double-line lane marker, the same space is used for both lines.

The number of returned lane boundary structures depends on the **Lane boundaries to output** parameter value.

Dependencies

To enable this port, set **Lane boundaries to output** to Ego lane boundaries or All lane boundaries.

Parameters

Source of driving scenario — Source of driving scenario

From file (default) | From workspace

Source of driving scenario, specified as one these options:

- From file — In the **Driving Scenario Designer file name** parameter, specify the name of a scenario file that was saved from the **Driving Scenario Designer** app.

- From workspace — In the **MATLAB or model workspace variable name** parameter, specify the name of a MATLAB or model workspace variable that contains a `drivingScenario` object.

Driving Scenario Designer file name — Scenario file name

`EgoVehicleGoesStraight.mat` (default) | scenario file on MATLAB search path | path to scenario file

Scenario file name, specified as a scenario file on the MATLAB search path or as the full path to a scenario file. A scenario file must be a MAT-file saved from the **Driving Scenario Designer** app. If the **Source of ego vehicle** parameter is set to `Scenario`, then the scenario must contain an ego vehicle. Otherwise, the block returns an error during simulation.

If the specified scenario file contains sensors, the block ignores them. To include sensors from the scenario in your model, see “Tips” on page 2-84.

The default scenario file shows an ego vehicle traveling north on a straight, two-lane road, with another vehicle traveling south in the opposite lane.

To add a scenario file to the MATLAB search path, use the `addpath` function. For example, this code adds the set of folders containing prebuilt Euro NCAP scenarios to the MATLAB search path.

```
path = fullfile(matlabroot, 'toolbox', 'driving', 'drivingdata', ...  
    'PrebuiltScenarios', 'EuroNCAP');  
addpath(genpath(path))
```

In the **Driving Scenario Designer file name** parameter, you can then specify the name of any scenario located in these folders, without having to specify the full file path. For example: `AEB_PedestrianChild_Nearside_50width.mat`.

When you are done using the scenario in your models, you can remove any added folders from the MATLAB search path by using the `rmpath` function.

```
rmpath(genpath(path))
```

Dependencies

To enable this parameter, set **Source of driving scenario** to `From file`.

MATLAB or model workspace variable name — Scenario variable name

`scenario` (default) | `drivingScenario` object variable name

Scenario variable name, specified as the name of a MATLAB or model workspace variable that contains a valid `drivingScenario` object. If a scenario variable with the same name appears in both the MATLAB and model workspace, the block uses the variable defined in the model workspace.

If the **Source of ego vehicle** parameter is set to `Scenario`, then the `drivingScenario` object must contain an ego vehicle. To designate which actor in the object is the ego vehicle, in the **Ego vehicle ActorID** parameter, specify the `ActorID` property value of that actor.

When connecting the **Actors** output port to Radar Detection Generator or Vision Detection Generator blocks, update these blocks to obtain the actor profiles directly from the `drivingScenario` object. On the **Actor Profiles** tab of each block, set the **Select method to specify actor profiles** parameter to `MATLAB expression`. Then, set the **MATLAB expression for actor profiles** parameter to call the `actorProfiles` function on the object. For example: `actorProfiles(scenario)`.

The default variable name, `scenario`, is the default name of `drivingScenario` objects produced by the MATLAB functions that are exported from the **Driving Scenario Designer** app. By default, this variable is not included in the MATLAB or model workspace.

Dependencies

To enable this parameter, set **Source of driving scenario** to `From workspace`.

Coordinate system of outputs — Coordinate system of outputs

Vehicle coordinates (default) | World coordinates

Coordinate system of the output actors and lane boundaries, specified as one of these values:

- **Vehicle coordinates** — Coordinates are defined with respect to the ego vehicle. Select this value when your scenario has only one ego vehicle.
- **World coordinates** — Coordinates are defined with respect to the driving scenario. Select this value in multi-agent scenarios that contain more than one ego vehicle. If you select this value, model visualization using the **Bird's-Eye Scope** is not supported.

For more details on the vehicle and world coordinate systems, see “Coordinate Systems in Automated Driving Toolbox”.

Source of ego vehicle — Source of ego vehicle

Scenario (default) | Input port

Source of ego vehicle, specified as one of these options:

- **Scenario** — Use the ego vehicle defined in the scenario that is specified by the **Driving Scenario Designer file name** or **MATLAB or model workspace variable name** parameter. The pose of the ego vehicle is excluded from the **Actors** output port. Actor positions are in vehicle coordinates, meaning that they are relative to the world coordinate position of the ego vehicle in the scenario.

Select this option to test open-loop ADAS algorithms, where the ego vehicle behavior is predefined and does not change as the scenario advances. For an example, see “Test Open-Loop ADAS Algorithm Using Driving Scenario”.

- **Input port** — Specify the ego vehicle by using the **Ego Vehicle** input port. The pose of the ego vehicle is not included in the **Actors** output port.

With this option, the ego vehicle in your model must include a starting position that is in world coordinates. All other actor poses are in vehicle coordinates and are positioned relative to the ego vehicle. For an example of an ego vehicle with defined position information, see “Lane Keeping Assist with Lane Detection”. When defining the starting position of the ego vehicle, consider using the position that is already defined in the scenario. By using this position, if you set **Source of ego vehicle** to **Scenario** and then back to **Input port**, you do not have to manually change the starting position.

Select this option to test closed-loop ADAS algorithms, where the ego vehicle reacts to changes as the scenario advances. For an example, see “Test Closed-Loop ADAS Algorithm Using Driving Scenario”.

Dependencies

To enable this parameter, set **Coordinate system of outputs** to **Vehicle coordinates**.

Ego vehicle ActorID — Actor ID of ego vehicle

1 (default) | positive integer

Actor ID of ego vehicle, specified as a positive integer. Use this parameter when you want to simulate using the ego vehicle that is read from a `drivingScenario` object. The block obtains the ID value from the `ActorID` property of a vehicle stored in the `Actors` property of the `drivingScenario` object.

The vehicle must be a `Vehicle` object created using the `vehicle` function. The ID value must be a valid `ActorID` within the scenario.

To check the valid `ActorID` values of a `drivingScenario` object, use this syntax.

```
actorIDs = [scenarioVariableName.actors.ActorID]
```

Dependencies

To enable this parameter, set these parameters in this order:

- 1 Set **Source of driving scenario** to `From workspace`.
- 2 Set **Coordinate system of outputs** to `Vehicle coordinates`.
- 3 Set **Source of ego vehicle** to `Scenario`.

Sample time (s) – Sample time of simulation

0.1 (default) | positive real scalar

Sample time of simulation, in seconds, specified as a positive real scalar. Inherited and continuous sample times are not supported. This sample time is separate from the sample times that the **Driving Scenario Designer** app and `drivingScenario` object use for simulations.

Lane boundaries to output – Lane boundaries to output

None (default) | `Ego vehicle lane boundaries` | `All lane boundaries`

Lane boundaries to output, specified as one of these options:

- `None` — Do not output any lane boundaries.
- `Ego vehicle lane boundaries` — Output the left and right lane boundaries of the ego vehicle.
- `All lane boundaries` — Output all lane boundaries of the road on which the ego vehicle is traveling.

If you select `Ego vehicle lane boundaries` or `All lane boundaries`, then the block returns the lane boundaries in the **Lane Boundaries** output port.

Dependencies

To enable this parameter, set **Coordinate system of outputs** to `Vehicle coordinates`.

Distances ahead of ego vehicle to compute boundaries (m) — Distances ahead of ego vehicle at which to compute lane boundaries

0:0.5:9.5 (default) | *N*-element real-valued vector

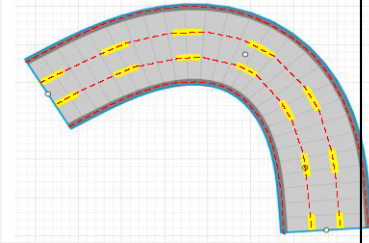
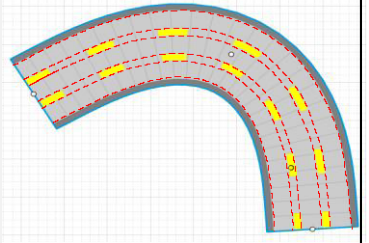
Distances ahead of the ego vehicle at which to compute the lane boundaries, specified as an *N*-element real-valued vector. *N* is the number of distance values. Units are in meters.

Example: 1:0.1:10 computes the lane boundaries every 0.1 meters over the range from 1 to 10 meters ahead of the ego vehicle.

Location of boundaries on lane markings — Lane boundary location

Center of lane markings (default) | Inner edge of lane markings

Lane boundary location on the lane markings, specified as one of the options in this table.

Lane Boundary Location	Description	Example
Center of lane markings	Lane boundaries are centered on the lane markings.	<p>A three-lane road has four lane boundaries: one per lane marking.</p> 
Inner edge of lane markings	Lane boundaries are placed at the inner edges of the lane markings.	<p>A three-lane road has six lane boundaries: two per lane.</p> 

Source of actors bus name — Source of name for actor poses bus

Auto (default) | Property

Source of the name for the actor poses bus returned in the **Actors** output port, specified as one of these options:

- **Auto** — The block automatically creates an actor poses bus name.
- **Property** — Specify the actor poses bus name by using the **Actors bus name** parameter.

Actors bus name — Name of actor poses bus

valid bus name

Name of the actor poses bus returned in the **Actors** output port, specified as a valid bus name.

Dependencies

To enable this parameter, set **Source of actors bus name** to Property.

Source of lane boundaries bus name — Source of name for lane boundaries bus

Auto (default) | Property

Source of the name for the lane boundaries bus returned in the **Lane Boundaries** output port, specified as one of these options:

- **Auto** — The block automatically creates a lane boundaries bus name.
- **Property** — Specify the lane boundaries bus name by using the **Lane boundaries bus name** parameter.

Dependencies

To enable this parameter, set **Lane boundaries to output** to Ego vehicle lane boundaries or All lane boundaries.

Lane boundaries bus name — Name of lane boundaries bus

valid bus name

Name of the lane boundaries bus returned in the **Lane Boundaries** output port, specified as a valid bus name.

Dependencies

To enable this parameter:

- 1 Set **Lane boundaries to output** to Ego vehicle lane boundaries or All lane boundaries.
- 2 Set **Source of lane boundaries bus name** to Property.

Simulate using — Type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** — Simulate the model using the MATLAB interpreter. This option shortens startup time. In Interpreted execution mode, you can debug the source code of the block.
- **Code generation** — Simulate the model using generated C/C++ code. The first time you run a simulation, Simulink generates C/C++ code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time.

Tips

- For best results, use only one active Scenario Reader block per model. To use multiple Scenario Reader blocks in one model, switch between the blocks by specifying them in a variant subsystem.
- To test your algorithm on variations of a driving scenario, you can update the scenario between simulations.
 - If the source of the scenario is a scenario file, open the scenario file in the **Driving Scenario Designer** app, update the parameters, and resave the file.
 - If the source of the scenario is a `drivingScenario` object, update the object in the MATLAB or model workspace. Alternatively, import the object into the app, modify the scenario in the app, and then generate a new object from the app. For more details, see “Create Driving Scenario Variations Programmatically”.
- To switch between scenarios with different parameter settings, you can use Simulink Test™ software. For an example, see “Testing a Lane-Following Controller with Simulink Test” (Simulink Test).

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- When a model is in rapid accelerator mode, the Scenario Reader block does not automatically regenerate code based on changes made to the driving scenario between simulations. To regenerate these changes, manually delete the Simulink project folder, `slprj`, that was generated from the previous simulation. Then, rerun the simulation. Alternatively, either change modes or disable code generation by setting the **Simulate using** parameter to `Interpreted execution`.
- The **Driving Scenario Designer file name** and **MATLAB or model workspace variable name** parameters are character vectors. The limitations described in “Encoding of Characters in Code Generation” (Simulink) apply to these parameters.

See Also

Bird's-Eye Scope | **Detection Concatenation** | **Driving Scenario Designer** | **Lateral Controller Stanley** | **Longitudinal Controller Stanley** | **Multi-Object Tracker** | **Radar Detection Generator** | **Vision Detection Generator**

Topics

“Coordinate Systems in Automated Driving Toolbox”

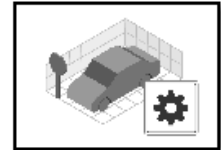
“Getting Started with Buses” (Simulink)

Introduced in R2019a

Simulation 3D Scene Configuration

Scene configuration for 3D simulation environment

Library: Automated Driving Toolbox / Simulation 3D
Vehicle Dynamics Blockset / Vehicle Scenarios /
Sim3D / Sim3D Core



Description

The Simulation 3D Scene Configuration block implements a 3D simulation environment that is rendered by using the Unreal Engine® from Epic Games®. Automated Driving Toolbox integrates the 3D simulation environment with Simulink so that you can query the world around the vehicle and virtually test perception, control, and planning algorithms.

Note The Simulation 3D Scene Configuration block must execute after blocks that send data to the 3D environment and before blocks that receive data from the 3D environment. To verify the execution order of such blocks, right-click the blocks and select **Properties**. Then, on the **General** tab, confirm these **Priority** settings:

- For blocks that send data to the 3D environment, such as Simulation 3D Vehicle with Ground Following blocks, **Priority** must be set to -1. That way, these blocks prepare their data before the 3D environment receives it.
- For the Simulation 3D Scene Configuration block in your model, **Priority** must be set to 0.
- For blocks that receive data from the 3D environment, such as Simulation 3D Camera blocks, **Priority** must be set to 1. That way, the 3D environment can prepare the data before these blocks receive it.

For more information about execution order, see “How 3D Simulation for Automated Driving Works”.

Parameters

Simulation Configuration

Scene description — 3D scene

Straight road (default) | Curved road | Parking lot | Double lane change | Open surface | US city block | US highway | Virtual Mcity | Large parking lot

Specify the name of the 3D scene in which to simulate. To learn more about a scene, see these reference pages:

- Straight road — **Straight Road**
- Curved road — **Curved Road**
- Parking lot — **Parking Lot**
- Large parking lot — **Large Parking Lot**
- Double lane change — **Double Lane Change**
- Open surface — **Open Surface**
- US city block — **US City Block**
- US highway — **US Highway**
- Virtual Mcity — **Virtual Mcity**

Scene view — Configure placement of virtual camera that displays scene

Scene Origin (default) | vehicle name

Configure the placement of the virtual camera that displays the scene in the AutoVrtlEnv window during simulation.

- If your model contains no Simulation 3D Vehicle with Ground Following blocks, then during simulation, you view the scene from a camera positioned at the scene origin.
- If your model contains at least one vehicle block, then by default, you view the scene from behind the first vehicle that was placed in your model. To change the view to a different vehicle, set **Scene view** to the name of that vehicle. The **Scene view** parameter list is populated with all the **Name** parameter values of the vehicle blocks contained in your model.

If you add a Simulation 3D Scene Configuration block to your model before adding any vehicle blocks, the virtual camera remains positioned at the scene. To reposition the camera to follow a vehicle, update this parameter.

When **Scene view** is set to a vehicle name, during simulation, you can change the location of the camera around the vehicle.

To change the camera views in the AutoVrtlEnv window, use these key commands.

Key	Camera View	
1	Back left	
2	Back	
3	Back right	
4	Left	
5	Internal	
6	Right	
7	Front left	
8	Front	
9	Front right	
0	Overhead	

Sample time – Sample time of visualization engine

1/60 (default) | scalar greater than or equal to 0.01

Sample time, T_s , of the visualization engine, specified as a scalar greater than or equal to 0.01. Units are in seconds.

The graphics frame rate of the visualization engine is the inverse of the sample time. For example, if **Sample time** is 1/60, then the visualization engine solver tries to achieve a frame rate of 60 frames per second. However, the real-time graphics frame rate is often lower due to factors such as graphics card performance and model complexity.

By default, blocks that receive data from the visualization engine, such as Simulation 3D Camera blocks, inherit this sample rate.

See Also

Simulation 3D Camera | Simulation 3D Fisheye Camera | Simulation 3D Lidar | Simulation 3D Probabilistic Radar | Simulation 3D Vehicle with Ground Following

Topics

"3D Simulation for Automated Driving"

"3D Simulation Environment Requirements and Limitations"

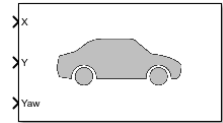
"How 3D Simulation for Automated Driving Works"

Introduced in R2019b

Simulation 3D Vehicle with Ground Following

Implement vehicle that follows ground in 3D environment

Library: Automated Driving Toolbox / Simulation 3D
Vehicle Dynamics Blockset / Vehicle Scenarios /
Sim3D / Sim3D Vehicle / Components



Description

The Simulation 3D Vehicle with Ground Following block implements a vehicle with four wheels in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The block uses the input (X , Y) position and yaw angle of the vehicle to adjust the elevation, roll angle, and pitch angle of the vehicle so that it follows the ground terrain. The block determines the vehicle velocity and heading and adjusts the steering angle and rotation for each wheel. Use this block for automated driving applications.

To use this block, ensure that the Simulation 3D Scene Configuration block is in your model. If you set the **Sample time** parameter of the Simulation 3D Vehicle with Ground Following block to -1 , the block inherits the sample time specified in the Simulation 3D Scene Configuration block.

The block input uses the vehicle Z-up right-handed (RH) Cartesian coordinate system defined in SAE J670 [1] and ISO 8855 [2]. The coordinate system is inertial and initially aligned with the vehicle geometric center:

- The X -axis is along the longitudinal axis of the vehicle and points forward.
- The Y -axis is along the lateral axis of the vehicle and points to the left.
- The Z -axis points upward.

The yaw, pitch, and roll angles of the Z -axis, Y -axis, and X -axis, respectively, are positive in the clockwise directions, when looking in the positive directions of these axes. Vehicles are placed in the world coordinate system of the scenes. For more details, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Note The Simulation 3D Vehicle with Ground Following block must execute before the Simulation 3D Scene Configuration block. That way, the Simulation 3D Vehicle with Ground Following block prepares the signal data before the Unreal Engine 3D visualization environment receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Vehicle with Ground Following — -1

For more information about execution order, see “How 3D Simulation for Automated Driving Works”.

Limitations

- The **Bird's-Eye Scope** is unable to find ground truth signals, such as roads, lanes, and actors, from the Simulation 3D Scene Configuration block.

Ports

Input

X — Longitudinal position of vehicle

scalar

Longitudinal position of the vehicle along the X-axis of the scene. **X** is in the inertial Z-up coordinate system. Units are in meters.

The X value of the **Initial position [X, Y, Z] (m)** parameter must match the value of this port at the start of simulation.

To specify multiple positions at port **X** along an entire vehicle path, first define a time series of X waypoints in MATLAB. Then, feed these waypoints to **X** by using a From Workspace block. To learn how to select and specify waypoints, see the “Select Waypoints for 3D Simulation” example.

Y — Lateral position of vehicle

scalar

Lateral position of the vehicle along the Y-axis of the scene. **Y** is in the inertial Z-up coordinate system. Units are in meters.

The Y value of the **Initial position [X, Y, Z] (m)** parameter must match the value of this port at the start of simulation.

To specify multiple positions at port **Y** along an entire vehicle path, first define a time series of Y waypoints in MATLAB. Then, feed these waypoints to **Y** by using a From Workspace block. To learn how to select and specify waypoints, see the “Select Waypoints for 3D Simulation” example.

Yaw — Yaw orientation angle of vehicle

scalar

Yaw orientation angle of the vehicle along the Z-axis of the scene. **Yaw** is in the Z-up coordinate system. Units are in degrees.

The yaw value of the **Initial rotation [Roll, Pitch, Yaw] (deg)** parameter must match the value of this port at the start of simulation.

To specify multiple orientation angles at port **Yaw** along an entire vehicle path, first define a time series of yaw waypoints in MATLAB. Then, feed these waypoints to **Yaw** by using a From Workspace block. To learn how to select and specify waypoints, see the “Select Waypoints for 3D Simulation” example.

Output

Location — Location of vehicle

real-valued 1-by-3 vector

(X, Y, Z) location of the vehicle in the scene, returned as a real-valued 1-by-3 vector. This location is based on the vehicle origin, which is on the ground, at the geometric center of the vehicle. **Location** values are in the inertial Z-up world coordinate system. Units are in meters.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: double

Orientation — Orientation of vehicle

real-valued 1-by-3 vector

Yaw, pitch, and roll orientation angles of the vehicle about the Z-axis, Y-axis, and X-axes of the scene, respectively, returned as a real-valued 1-by-3 vector. This orientation is based on the vehicle origin, which is on the ground, at the geometric center of the vehicle.

Orientation values are in the inertial Z-up coordinate system. Units are in radians.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: double

Parameters

Vehicle Parameters

Type — Type of vehicle

Muscle car (default) | Sedan | Sport utility vehicle | Small pickup truck | Hatchback

Select the type of vehicle. To obtain the dimensions of each vehicle type, see these reference pages:

- Muscle car — **Muscle Car**
- Sedan — **Sedan**
- Sport utility vehicle — **Sport Utility Vehicle**
- Small pickup truck — **Small Pickup Truck**
- Hatchback — **Hatchback**

Color — Color of vehicle

Red (default) | Orange | Yellow | Green | Blue | Black | White | Silver

Select the color of the vehicle.

Initial position [X, Y, Z] (m) — Initial vehicle position

[0, 0, 0] (default) | real-valued 1-by-3 vector

Initial vehicle position along the X -axis, Y -axis, and Z -axis of the scene. This position is in the inertial Z -up coordinate system. Units are in meters.

Set the X and Y values of this parameter to match the **X** and **Y** input port values at the start of simulation.

Initial rotation [Roll, Pitch, Yaw] (deg) – Initial angle of vehicle rotation

[0, 0, 0] (default) | real-valued 1-by-3 vector

Initial angle of vehicle rotation. The angle of rotation is defined by the roll, pitch, and yaw of the vehicle. Units are in degrees.

Set the yaw value of this parameter to match the **Yaw** input port value at the start of simulation.

Name – Name of vehicle

SimulinkVehicle1 (default) | vehicle name

Name of vehicle. By default, when you use the block in your model, the block sets the **Name** parameter to `SimulinkVehicleX`. The value of X depends on the number of Simulation 3D Vehicle with Ground Following blocks that you have in your model.

The vehicle name appears as a selection in the **Parent name** parameter of any Automated Driving Toolbox Simulation 3D sensor blocks within the same model as the vehicle. With the **Parent name** parameter, you can select the vehicle on which to mount the sensor.

Sample time – Sample time

-1 (default) | positive scalar

Sample time, T_s , in seconds. The graphics frame rate is the inverse of the sample time.

If you set the sample time to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

Ground Truth

Output location (m) and orientation (rad) – Output location and orientation of vehicle

off (default) | on

Select this parameter to output the location and orientation of the vehicle at the **Location** and **Orientation** ports, respectively.

References

- [1] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [2] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

See Also

[Simulation 3D Camera](#) | [Simulation 3D Fisheye Camera](#) | [Simulation 3D Lidar](#) | [Simulation 3D Probabilistic Radar](#) | [Simulation 3D Scene Configuration](#)

Topics

[“How 3D Simulation for Automated Driving Works”](#)

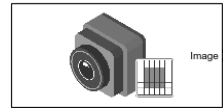
[“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”](#)

Introduced in R2019b

Simulation 3D Camera

Camera sensor model with lens in 3D simulation environment

Library: Automated Driving Toolbox / Simulation 3D

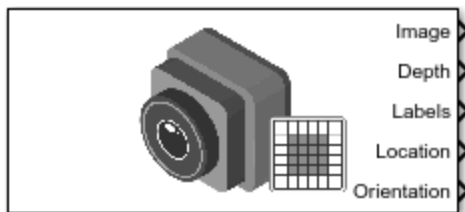


Description



The Simulation 3D Camera block provides an interface to a camera with a lens in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The sensor is based on the ideal pinhole camera model, with a lens added to represent a full camera model, including lens distortion. For more details, see “Algorithms” on page 2-115.

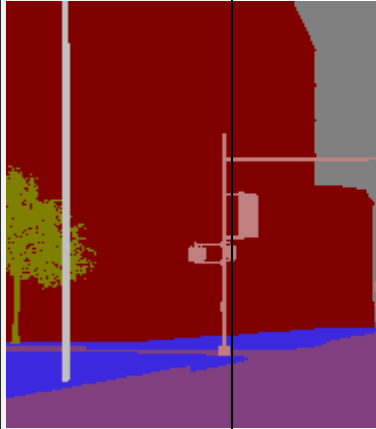
If you set **Sample time** to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block. To use this sensor, you must include a Simulation 3D Scene Configuration block in your model.

The block outputs images captured by the camera during simulation. You can use these images to visualize and verify your driving algorithms. In addition, on the **Ground Truth** tab, you can select options to output the ground truth data for developing depth estimation and semantic segmentation algorithms. You can also output the location and orientation of the camera in the world coordinate system of the scene. The image shows the block with all ports enabled.



The table summarizes the ports and how to enable them.

Port	Description	Parameter for Enabling Port	Sample Visualization
Image	Outputs an RGB image captured by the camera	n/a	
Depth	Outputs a depth map with values from 0 m to 1000 meters	Output depth	

Port	Description	Parameter for Enabling Port	Sample Visualization
Labels	Outputs a semantic segmentation map of label IDs that correspond to objects in the scene	Output semantic segmentation	
Location	Outputs the location of the camera in the world coordinate system	Output location (m) and orientation (rad)	n/a
Orientation	Outputs the orientation of the camera in the world coordinate system	Output location (m) and orientation (rad)	n/a

Note The Simulation 3D Scene Configuration block must execute before the Simulation 3D Camera block. That way, the Unreal Engine 3D visualization environment prepares the data before the Simulation 3D Camera block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Camera — 1

For more information about execution order, see “How 3D Simulation for Automated Driving Works”.

Ports

Output

Image — 3D output camera image

m-by-n-by-3 array of RGB triplet values

3D output camera image, returned as an *m-by-n-by-3* array of RGB triplet values. *m* is the vertical resolution of the image, and *n* is the horizontal resolution of the image.

Data Types: int8 | uint8

Depth — Object depth from 0 m to 1000 m

m-by-n array of object depths

Object depth for each pixel in the image, output as an *m-by-n* array. *m* is the vertical resolution of the image, and *n* is the horizontal resolution of the image. Depth is in the range from 0 to 1000 meters.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output depth**.

Data Types: double

Labels — Label identifiers

m-by-n array of label identifiers

Label identifier for each pixel in the image, output as an *m-by-n* array. *m* is the vertical resolution of the image, and *n* is the horizontal resolution of the image.

The label identifiers have values that correspond to these object types. If the scene contains an object that does not belong to any of the object types shown, that object is assigned an ID of 0.

ID	Type
0	None/default
1	Building
2	Fence
3	Other

ID	Type
4	Pedestrian
5	Pole
6	Road line
7	Road
8	Sidewalk
9	Vegetation
10	Vehicle
11	Wall
12	Generic traffic sign
13	Stop sign
14	Yield sign
15	Speed limit sign
16	Weight limit sign
17	Right arrow warning sign
18	Left arrow warning sign
19	Left and right arrow warning sign
20	Left chevron warning sign
21	Right chevron warning sign
22	Left one-way sign
23	Right one-way sign
24	Wheelchair warning sign
25	School bus only sign
26	Right turn only arrow sign
27	Left turn only arrow sign
28	Straight only arrow sign
29	Right turn only sign
30	Left turn only sign
31	Straight only sign

ID	Type
32	No left turn sign
33	No right turn sign
34	No thru traffic sign
35	No U-turn symbol sign
36	No right turn symbol sign
37	No left turn symbol sign
38	No right turn on red sign
39	Crosswalk sign
40	Crosswalk signal
41	Traffic signal
42	Curve right warning sign
43	Curve left warning sign
44	Up right arrow warning sign
45	Up left arrow warning sign
46	Down right arrow warning sign
47	Down left arrow warning sign
48	Railroad crossing sign
49	Street sign
50	Roundabout warning sign
51	Fire hydrant
52	Exit sign
53	Bike lane sign
54	Keep right sign
55	Keep left sign
56	Disability sign
57	Sky
58	Curb
59	Flyover ramp

ID	Type
60	Road guard rail
61-63	<i>Not used</i>
64	Adult pedestrian
65	Young pedestrian
66	Generic animal
67	Deer
68	Kangaroo
69	Dog
70	Cat
71	Barricade
72	Motorcycle
73	Commercial vehicle

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output semantic segmentation**.

Data Types: uint8

Location — Sensor location

real-valued 1-by-3 vector

Sensor location along the X-axis, Y-axis, and Z-axis of the scene. The **Location** values are in the world coordinates of the scene. In this coordinate system, the Z-axis points up from the ground. Units are in meters.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: double

Orientation — Sensor orientation

real-valued 1-by-3 vector

Roll, pitch, and yaw sensor orientation about the X-axis, Y-axis, and Z-axis of the scene. The **Orientation** values are in the world coordinates of the scene. These values are

positive in the clockwise direction when looking in the positive directions of these axes. Units are in radians.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: double

Parameters

Mounting

Sensor identifier — Unique sensor identifier

1 (default) | positive integer

Unique sensor identifier, specified as a positive integer. In a multisensor system, the sensor identifier distinguishes between sensors. When you add a new sensor block to your model, the **Sensor identifier** of that block is $N + 1$. N is the highest **Sensor identifier** value among existing sensor blocks in the model.

Example: 2

Parent name — Name of parent to which sensor is mounted

Scene Origin (default) | vehicle name

Name of the parent to which the sensor is mounted, specified as Scene Origin or as the name of a vehicle in your model. The vehicle names that you can select correspond to the **Name** parameters of the Simulation 3D Vehicle with Ground Following blocks in your model. If you select Scene Origin, the block places a sensor at the scene origin.


Example: SimulinkVehicle1

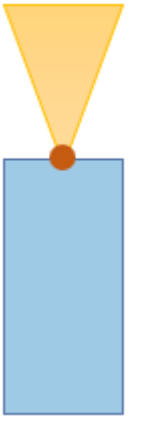
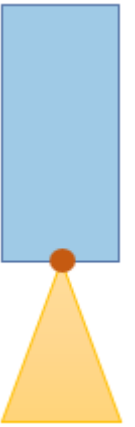
Mounting location — Sensor mounting location

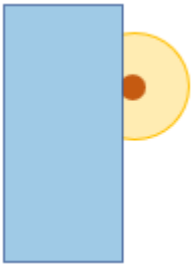
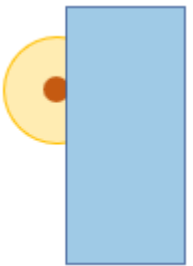
Origin (default) | Front bumper | Rear bumper | Right mirror | Left mirror | Rearview mirror | Hood center | Roof center


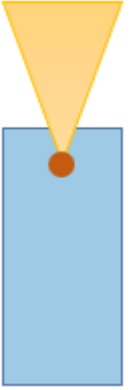
Sensor mounting location.


- When **Parent name** is `Scene Origin`, the block mounts the sensor to the origin of the scene, and **Mounting location** can be set to `Origin` only. During simulation, the sensor remains stationary.
- When **Parent name** is the name of a vehicle (for example, `SimulinkVehicle1`) the block mounts the sensor to one of the predefined mounting locations described in the table. During simulation, the sensor travels with the vehicle.

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Origin	<p>Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle (see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”)</p> 	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Front bumper	<p data-bbox="605 368 884 461">Forward-facing sensor mounted to the front bumper</p> 	[0, 0, 0]
Rear bumper	<p data-bbox="605 940 957 1003">Backward-facing sensor mounted to the rear bumper</p> 	[0, 0, 180]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Right mirror	Downward-facing sensor mounted to the right side-view mirror 	[0, -90, 0]
Left mirror	Downward-facing sensor mounted to the left side-view mirror 	[0, -90, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Rearview mirror	Forward-facing sensor mounted to the rearview mirror, inside the vehicle 	[0, 0, 0]
Hood center	Forward-facing sensor mounted to the center of the hood 	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Roof center	Forward-facing sensor mounted to the center of the roof 	[0, 0, 0]

The (X, Y, Z) location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D Vehicle with Ground Following block to which you are mounting. The tables show the X , Y , and Z locations of sensors in the vehicle coordinate system. In this coordinate system:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward.
- The Z -axis points up from the ground.
- Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the X -axis, Y -axis, and Z -axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

Muscle Car – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.47	0	0.45
Rear bumper	-2.47	0	0.45
Right mirror	0.43	-1.08	1.01
Left mirror	0.43	1.08	1.01
Rearview mirror	0.32	0	1.20
Hood center	1.28	0	1.14
Roof center	-0.25	0	1.58

Sedan – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.59	-0.94	1.09
Left mirror	0.59	0.94	1.09
Rearview mirror	0.43	0	1.31
Hood center	1.46	0	1.11
Roof center	-0.45	0	1.69

Sport Utility Vehicle – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.60	-1	1.35
Left mirror	0.60	1	1.35
Rearview mirror	0.39	0	1.55
Hood center	1.58	0	1.39
Roof center	-0.56	0	2

Small Pickup Truck – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	3.07	0	0.51
Rear bumper	-3.07	0	0.51
Right mirror	1.10	-1.13	1.52
Left mirror	1.10	1.13	1.52
Rearview mirror	0.85	0	1.77
Hood center	2.22	0	1.59
Roof center	0	0	2.27

Hatchback – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	1.93	0	0.51
Rear bumper	-1.93	0	0.51
Right mirror	0.43	-0.84	1.01
Left mirror	0.43	0.84	1.01
Rearview mirror	0.32	0	1.27
Hood center	1.44	0	1.01
Roof center	0	0	1.57

To determine the location of the sensor in world coordinates, open the sensor block. Then, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)** and inspect the data from the **Location** output port.

Specify offset – Specify offset from mounting location

off (default) | on

Select this parameter to specify an offset from the mounting location by using the **Relative translation [X, Y, Z] (m)** and **Relative rotation [Roll, Pitch, Yaw] (deg)** parameters.

Relative translation [X, Y, Z] (m) – Translation offset relative to mounting location

[0, 0, 0] (default) | real-valued 1-by-3 vector

Translation offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[X, Y, Z]$. Units are in meters.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then X , Y , and Z are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: $[0, 0, 0.01]$

Dependencies

To enable this parameter, select **Specify offset**.

Relative rotation [Roll, Pitch, Yaw] (deg) – Rotational offset relative to mounting location

$[0, 0, 0]$ (default) | real-valued 1-by-3 vector

Rotational offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[Roll, Pitch, Yaw]$. Roll, pitch, and yaw are the angles of rotation about the X -, Y -, and Z -axes, respectively. Units are in degrees.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.
- Roll, pitch, and yaw are clockwise-positive when looking in the forward direction of the X -axis, Y -axis, and Z -axis, respectively. If you view a scene from a 2D top-down

perspective, then the yaw angle (also called the orientation angle) is counterclockwise-positive, because you are viewing the scene in the negative direction of the Z-axis.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then X, Y, and Z are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: `[0,0,10]`

Dependencies

To enable this parameter, select **Specify offset**.

Sample time — Sample time

-1 (default) | positive scalar

Sample time of the block in seconds, specified as a positive scalar. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to -1, the block inherits its sample time from the Simulation 3D Scene Configuration block.

Parameters

These intrinsic camera parameters are equivalent to the properties of a `cameraIntrinsics` object. To obtain the intrinsic parameters for your camera, use the **Camera Calibrator** app.

Focal length (pixels) — Focal length of camera

`[1109, 1109]` (default) | 1-by-2 positive integer vector

Focal length of the camera, specified as a 1-by-2 positive integer vector of the form $[f_x, f_y]$. Units are in pixels.

$$f_x = F \times s_x$$

$$f_y = F \times s_y$$

where:

- F is the focal length in world units, typically millimeters.
- $[sx, sy]$ are the number of pixels per world unit in the x and y direction, respectively.

This parameter is equivalent to the `FocalLength` property of a `cameraIntrinsics` object.

Optical center (pixels) – Optical center of camera

`[640, 360]` (default) | 1-by-2 positive integer vector

Optical center of the camera, specified as a 1-by-2 positive integer vector of the form $[cx, cy]$. Units are in pixels.

This parameter is equivalent to the `PrincipalPoint` property of a `cameraIntrinsics` object.

Image size (pixels) – Image size produced by camera

`[720, 1280]` (default) | 1-by-2 positive integer vector

Image size produced by the camera, specified as a 1-by-2 positive integer vector of the form $[mrows, ncols]$. Units are in pixels.

This parameter is equivalent to the `ImageSize` property of a `cameraIntrinsics` object.

Radial distortion coefficients – Radial distortion coefficients

`[0, 0]` (default) | real-valued 1-by-2 nonnegative vector | real-valued 1-by-3 nonnegative vector

Radial distortion coefficients, specified as a real-valued 1-by-2 or 1-by-3 nonnegative vector. Radial distortion occurs when light rays bend more than the edges of a lens than they do at its optical center. The distortion is greater when the lens is smaller. The block calculates the radial-distorted location of a point. Units are dimensionless.

This parameter is equivalent to the `RadialDistortion` property of a `cameraIntrinsics` object.

Tangential distortion coefficients – Tangential distortion coefficients

`[0, 0]` (default) | real-valued 1-by-2 nonnegative vector

Tangential distortion coefficients, specified as a real-valued 1-by-2 nonnegative vector. Tangential distortion occurs when the lens and the image plane are not parallel. The coordinates are expressed in world units. Units are dimensionless.

This parameter is equivalent to the `TangentialDistortion` property of a `cameraIntrinsics` object.

Axis skew — Skew angle of camera axes

0 (default) | nonnegative scalar

Skew angle of the camera axes, specified as a nonnegative scalar. If the *X*-axis and *Y*-axis are exactly perpendicular, then the skew must be 0. Units are dimensionless.

This parameter is equivalent to the `Skew` property of a `cameraIntrinsics` object.

Ground Truth

Output depth — Output depth map

off (default) | on

Select this parameter to output a depth map at the **Depth** port.

Output semantic segmentation — Output semantic segmentation map of label IDs

off (default) | on

Select this parameter to output a semantic segmentation map of label IDs at the **Labels** port.

Output location (m) and orientation (rad) — Output location and orientation of sensor

off (default) | on

Select this parameter to output the location and orientation of the sensor at the **Location** and **Orientation** ports, respectively.

Tips

- To visualize the camera images that are output by the **Image** port, use a Video Viewer or To Video Display block.

To learn how to visualize the depth and semantic segmentation maps that are output by the **Depth** and **Labels** ports, see the “Visualize Depth and Semantic Segmentation Data in 3D Environment” example.

- Because the Unreal Engine can take a long time to start between simulations, consider logging the signals that the sensors output. You can then use this data to develop perception algorithms in MATLAB. See “Configure a Signal for Logging” (Simulink).

You can also save image data as a video by using a To Multimedia File block. For an example of this setup, see “Design of Lane Marker Detector in 3D Simulation Environment”.

Algorithms

The block uses the camera model proposed by Jean-Yves Bouguet [1]. The model includes:

- The pinhole camera model [2]
- Lens distortion [3]

The pinhole camera model does not account for lens distortion because an ideal pinhole camera does not have a lens. To accurately represent a real camera, the full camera model used by the block includes radial and tangential lens distortion.

For more details, see “What Is Camera Calibration?” (Computer Vision Toolbox)

References

- [1] Bouguet, J. Y. *Camera Calibration Toolbox for Matlab*. http://www.vision.caltech.edu/bouguetj/calib_doc
- [2] Zhang, Z. "A Flexible New Technique for Camera Calibration." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 22, No. 11, 2000, pp. 1330-1334.
- [3] Heikkila, J., and O. Silven. "A Four-step Camera Calibration Procedure with Implicit Image Correction." *IEEE International Conference on Computer Vision and Pattern Recognition*. 1997.

See Also

Blocks

Simulation 3D Lidar | Simulation 3D Probabilistic Radar | Simulation 3D Fisheye Camera | Simulation 3D Scene Configuration | Simulation 3D Vehicle with Ground Following

Apps

Camera Calibrator

Objects

cameraIntrinsics

Topics

“3D Simulation for Automated Driving”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

“Choose a Sensor for 3D Simulation”

“What Is Camera Calibration?” (Computer Vision Toolbox)

“Depth Estimation From Stereo Video” (Computer Vision Toolbox)

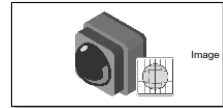
“Semantic Segmentation Using Deep Learning” (Computer Vision Toolbox)

Introduced in R2019b

Simulation 3D Fisheye Camera

Fisheye camera sensor model in 3D simulation environment

Library: Automated Driving Toolbox / Simulation 3D



Description

The Simulation 3D Fisheye Camera block provides an interface to a camera with a fisheye lens in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The sensor is based on the fisheye camera model proposed by Scaramuzza [1] on page 2-129. The block outputs an image with the specified camera distortion and size. You can also output the location and orientation of the camera in the world coordinate system of the scene.

If you set **Sample time** to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block. To use this sensor, you must include a Simulation 3D Scene Configuration block in your model.

Note The Simulation 3D Scene Configuration block must execute before the Simulation 3D Fisheye Camera block. That way, the Unreal Engine 3D visualization environment prepares the data before the Simulation 3D Fisheye Camera block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Fisheye Camera — 1

For more information about execution order, see “How 3D Simulation for Automated Driving Works”.

Ports

Output

Image — 3D output camera image

m-by-n-by-3 array of RGB triplet values

3D output camera image, returned as an *m-by-n-by-3* array of RGB triplet values. *m* is the vertical resolution of the image, and *n* is the horizontal resolution of the image.

Data Types: `int8` | `uint8`

Location — Sensor location

real-valued 1-by-3 vector

Sensor location along the *X*-axis, *Y*-axis, and *Z*-axis of the scene. The **Location** values are in the world coordinates of the scene. In this coordinate system, the *Z*-axis points up from the ground. Units are in meters.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: `double`

Orientation — Sensor orientation

real-valued 1-by-3 vector

Roll, pitch, and yaw sensor orientation about the *X*-axis, *Y*-axis, and *Z*-axis of the scene. The **Orientation** values are in the world coordinates of the scene. These values are positive in the clockwise direction when looking in the positive directions of these axes. Units are in radians.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: `double`

Parameters

Mounting

Sensor identifier — Unique sensor identifier

1 (default) | positive integer

Unique sensor identifier, specified as a positive integer. In a multisensor system, the sensor identifier distinguishes between sensors. When you add a new sensor block to your model, the **Sensor identifier** of that block is $N + 1$. N is the highest **Sensor identifier** value among existing sensor blocks in the model.

Example: 2

Parent name — Name of parent to which sensor is mounted

Scene Origin (default) | vehicle name

Name of the parent to which the sensor is mounted, specified as Scene Origin or as the name of a vehicle in your model. The vehicle names that you can select correspond to the **Name** parameters of the Simulation 3D Vehicle with Ground Following blocks in your model. If you select Scene Origin, the block places a sensor at the scene origin.


Example: SimulinkVehicle1


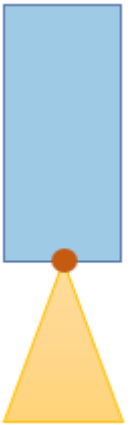
Mounting location — Sensor mounting location

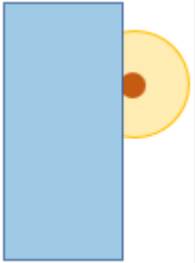
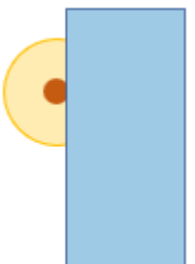
Origin (default) | Front bumper | Rear bumper | Right mirror | Left mirror | Rearview mirror | Hood center | Roof center


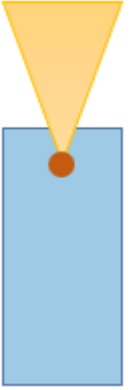
Sensor mounting location.


- When **Parent name** is Scene Origin, the block mounts the sensor to the origin of the scene, and **Mounting location** can be set to Origin only. During simulation, the sensor remains stationary.
- When **Parent name** is the name of a vehicle (for example, SimulinkVehicle1) the block mounts the sensor to one of the predefined mounting locations described in the table. During simulation, the sensor travels with the vehicle.

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Origin	<p>Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle (see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”)</p>  A diagram showing a blue rectangular vehicle body. At the top center, there is a yellow trapezoidal sensor. A grey cone representing the sensor's field of view extends downwards from the sensor to a small grey circle at the geometric center of the vehicle body.	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Front bumper	Forward-facing sensor mounted to the front bumper 	[0, 0, 0]
Rear bumper	Backward-facing sensor mounted to the rear bumper 	[0, 0, 180]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Right mirror	Downward-facing sensor mounted to the right side-view mirror 	[0, -90, 0]
Left mirror	Downward-facing sensor mounted to the left side-view mirror 	[0, -90, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Rearview mirror	Forward-facing sensor mounted to the rearview mirror, inside the vehicle 	[0, 0, 0]
Hood center	Forward-facing sensor mounted to the center of the hood 	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Roof center	Forward-facing sensor mounted to the center of the roof 	[0, 0, 0]

The (X, Y, Z) location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D Vehicle with Ground Following block to which you are mounting. The tables show the X , Y , and Z locations of sensors in the vehicle coordinate system. In this coordinate system:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward.
- The Z -axis points up from the ground.
- Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the X -axis, Y -axis, and Z -axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

Muscle Car – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.47	0	0.45
Rear bumper	-2.47	0	0.45
Right mirror	0.43	-1.08	1.01
Left mirror	0.43	1.08	1.01
Rearview mirror	0.32	0	1.20
Hood center	1.28	0	1.14
Roof center	-0.25	0	1.58

Sedan – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.59	-0.94	1.09
Left mirror	0.59	0.94	1.09
Rearview mirror	0.43	0	1.31
Hood center	1.46	0	1.11
Roof center	-0.45	0	1.69

Sport Utility Vehicle – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.60	-1	1.35
Left mirror	0.60	1	1.35
Rearview mirror	0.39	0	1.55
Hood center	1.58	0	1.39
Roof center	-0.56	0	2

Small Pickup Truck – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	3.07	0	0.51
Rear bumper	-3.07	0	0.51
Right mirror	1.10	-1.13	1.52
Left mirror	1.10	1.13	1.52
Rearview mirror	0.85	0	1.77
Hood center	2.22	0	1.59
Roof center	0	0	2.27

Hatchback – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	1.93	0	0.51
Rear bumper	-1.93	0	0.51
Right mirror	0.43	-0.84	1.01
Left mirror	0.43	0.84	1.01
Rearview mirror	0.32	0	1.27
Hood center	1.44	0	1.01
Roof center	0	0	1.57

To determine the location of the sensor in world coordinates, open the sensor block. Then, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)** and inspect the data from the **Location** output port.

Specify offset – Specify offset from mounting location

off (default) | on

Select this parameter to specify an offset from the mounting location by using the **Relative translation [X, Y, Z] (m)** and **Relative rotation [Roll, Pitch, Yaw] (deg)** parameters.

Relative translation [X, Y, Z] (m) – Translation offset relative to mounting location

[0, 0, 0] (default) | real-valued 1-by-3 vector

Translation offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[X, Y, Z]$. Units are in meters.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then X , Y , and Z are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: $[0, 0, 0.01]$

Dependencies

To enable this parameter, select **Specify offset**.

Relative rotation [Roll, Pitch, Yaw] (deg) – Rotational offset relative to mounting location

$[0, 0, 0]$ (default) | real-valued 1-by-3 vector

Rotational offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[Roll, Pitch, Yaw]$. Roll, pitch, and yaw are the angles of rotation about the X -, Y -, and Z -axes, respectively. Units are in degrees.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.
- Roll, pitch, and yaw are clockwise-positive when looking in the forward direction of the X -axis, Y -axis, and Z -axis, respectively. If you view a scene from a 2D top-down

perspective, then the yaw angle (also called the orientation angle) is counterclockwise-positive, because you are viewing the scene in the negative direction of the Z-axis.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then *X*, *Y*, and *Z* are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: `[0, 0, 10]`

Dependencies

To enable this parameter, select **Specify offset**.

Sample time — Sample time

-1 (default) | positive scalar

Sample time of the block in seconds, specified as a positive scalar. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to -1, the block inherits its sample time from the Simulation 3D Scene Configuration block.

Parameters

These intrinsic camera parameters are equivalent to the properties of a `fisheyeIntrinsics` object. To obtain the intrinsic parameters for your camera, use the **Camera Calibrator** app.

Distortion center (pixels) — Center of distortion

`[320, 320]` (default) | real-valued 1-by-2 vector

Center of distortion, specified as real-valued 2-element vector. Units are in pixels.

Image size (pixels) — Image size produced by camera

`[640, 640]` (default) | real-valued 1-by-2 vector of positive integers

Image size produced by the camera, specified as a real-valued 1-by-2 vector of positive integers of the form `[mrows, ncols]`. Units are in pixels.

Mapping coefficients – Polynomial coefficients for projection function

[640, 0, 0, 0] (default) | real-valued 1-by-4 vector

Polynomial coefficients for the projection function described by Scaramuzza's Taylor model [1], specified as a real-valued 1-by-4 vector of the form [a0 a2 a3 a4].

Example: [1, 1, 0, 0]

Ground Truth**Output location (m) and orientation (rad) – Output location and orientation of sensor**

off (default) | on

Select this parameter to output the location and orientation of the sensor at the **Location** and **Orientation** ports, respectively.

Tips

- To visualize the camera images that are output by the **Image** port, use a Video Viewer or To Video Display block.
- Because the Unreal Engine can take a long time to start up between simulations, consider logging the signals that the sensors output. You can then use this data to develop perception algorithms in MATLAB. See “Configure a Signal for Logging” (Simulink).

You can also save image data as a video by using a To Multimedia File block. For an example of this setup, see “Design of Lane Marker Detector in 3D Simulation Environment”.

References

- [1] Scaramuzza, D., A. Martinelli, and R. Siegwart. "A Toolbox for Easy Calibrating Omnidirectional Cameras." *Proceedings to IEEE International Conference on Intelligent Robots and Systems (IROS 2006)*. Beijing, China, October 7-15, 2006.

See Also

Blocks

Simulation 3D Camera | Simulation 3D Lidar | Simulation 3D Probabilistic Radar | Simulation 3D Scene Configuration | Simulation 3D Vehicle with Ground Following

Apps

Camera Calibrator

Objects

fisheyeIntrinsics

Topics

“3D Simulation for Automated Driving”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

“Choose a Sensor for 3D Simulation”

“Fisheye Calibration Basics” (Computer Vision Toolbox)

Introduced in R2019b

Simulation 3D Lidar

Lidar sensor model in 3D simulation environment

Library: Automated Driving Toolbox / Simulation 3D



Description

The Simulation 3D Lidar block provides an interface to the lidar sensor in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The block returns a point cloud with the specified field of view and angular resolution. You can also output the distances from the sensor to object points. In addition, you can output the location and orientation of the sensor in the world coordinate system of the scene.

If you set **Sample time** to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block. To use this sensor, ensure that the Simulation 3D Scene Configuration block is in your model.

Note The Simulation 3D Scene Configuration block must execute before the Simulation 3D Lidar block. That way, the Unreal Engine 3D visualization environment prepares the data before the Simulation 3D Lidar block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Lidar — 1

For more information about execution order, see “How 3D Simulation for Automated Driving Works”.

Ports

Output

Point cloud — Point cloud data

m-by-*n*-by-3 array of positive real-valued [*x*, *y*, *z*] points

Point cloud data, returned as an *m*-by-*n*-by 3 array of positive, real-valued [*x*, *y*, *z*] points. *m* and *n* define the number of points in the point cloud, as shown in this equation:

$$m \times n = \frac{V_{\text{FOV}}}{V_{\text{RES}}} \times \frac{H_{\text{FOV}}}{H_{\text{RES}}}$$

where:

- V_{FOV} is the vertical field of view of the lidar, in degrees, as specified by the **Vertical field of view (deg)** parameter.
- V_{RES} is the vertical angular resolution of the lidar, in degrees, as specified by the **Vertical resolution (deg)** parameter.
- H_{FOV} is the horizontal field of view of the lidar, in degrees, as specified by the **Horizontal field of view (deg)** parameter.
- H_{RES} is the horizontal angular resolution of the lidar, in degrees, as specified by the **Horizontal resolution (deg)** parameter.

Each *m*-by-*n* entry in the array specifies the *x*, *y*, and *z* coordinates of a detected point in the sensor coordinate system. If the lidar does not detect a point at a given coordinate, then *x*, *y*, and *z* are returned as NaN.

You can create a point cloud from these returned points by using point cloud functions in a MATLAB Function block. For a list of point cloud processing functions, see “Lidar Processing”. For an example that uses these functions, see “Simulate Lidar Sensor Perception Algorithm”.

Data Types: `single`

Distance — Distance to object points

m-by-*n* positive real-valued matrix

Distance to object points measured by the lidar sensor, returned as an *m*-by-*n* positive real-valued matrix. Each *m*-by-*n* value in the matrix corresponds to an [*x*, *y*, *z*] coordinate point returned by the **Point cloud** output port.

Dependencies

To enable this port, on the **Parameters** tab, select **Distance output**.

Data Types: single

Location — Sensor location

real-valued 1-by-3 vector

Sensor location along the *X*-axis, *Y*-axis, and *Z*-axis of the scene. The **Location** values are in the world coordinates of the scene. In this coordinate system, the *Z*-axis points up from the ground. Units are in meters.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: double

Orientation — Sensor orientation

real-valued 1-by-3 vector

Roll, pitch, and yaw sensor orientation about the *X*-axis, *Y*-axis, and *Z*-axis of the scene. The **Orientation** values are in the world coordinates of the scene. These values are positive in the clockwise direction when looking in the positive directions of these axes. Units are in radians.

Dependencies

To enable this port, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)**.

Data Types: double

Parameters

Mounting

Sensor identifier — Unique sensor identifier

1 (default) | positive integer

Unique sensor identifier, specified as a positive integer. In a multisensor system, the sensor identifier distinguishes between sensors. When you add a new sensor block to your model, the **Sensor identifier** of that block is $N + 1$. N is the highest **Sensor identifier** value among existing sensor blocks in the model.

Example: 2

Parent name — Name of parent to which sensor is mounted

Scene Origin (default) | vehicle name

Name of the parent to which the sensor is mounted, specified as Scene Origin or as the name of a vehicle in your model. The vehicle names that you can select correspond to the **Name** parameters of the Simulation 3D Vehicle with Ground Following blocks in your model. If you select Scene Origin, the block places a sensor at the scene origin.


Example: SimulinkVehicle1

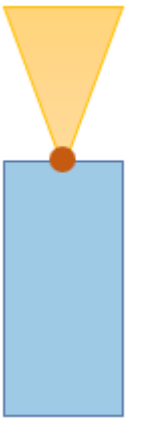
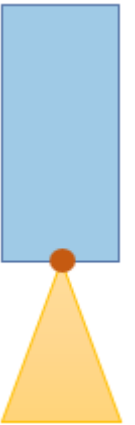
Mounting location — Sensor mounting location

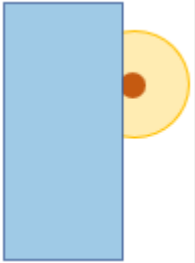
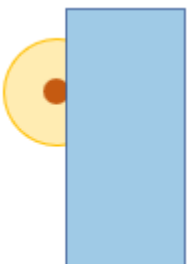
Origin (default) | Front bumper | Rear bumper | Right mirror | Left mirror | Rearview mirror | Hood center | Roof center



Sensor mounting location.


- When **Parent name** is Scene Origin, the block mounts the sensor to the origin of the scene, and **Mounting location** can be set to Origin only. During simulation, the sensor remains stationary.
- When **Parent name** is the name of a vehicle (for example, SimulinkVehicle1) the block mounts the sensor to one of the predefined mounting locations described in the table. During simulation, the sensor travels with the vehicle.

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Origin	<p>Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle (see "Coordinate Systems for 3D Simulation in Automated Driving Toolbox")</p>  A diagram showing a blue rectangular vehicle body. At the top center of the vehicle, there is a grey circular sensor. A yellow trapezoidal shape is positioned above the sensor, representing the sensor's field of view or mounting. A grey cone originates from the sensor, pointing downwards, representing the sensor's beam or field of view.	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Front bumper	<p>Forward-facing sensor mounted to the front bumper</p> 	[0, 0, 0]
Rear bumper	<p>Backward-facing sensor mounted to the rear bumper</p> 	[0, 0, 180]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Right mirror	Downward-facing sensor mounted to the right side-view mirror 	[0, -90, 0]
Left mirror	Downward-facing sensor mounted to the left side-view mirror 	[0, -90, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Rearview mirror	<p>Forward-facing sensor mounted to the rearview mirror, inside the vehicle</p> 	[0, 0, 0]
Hood center	<p>Forward-facing sensor mounted to the center of the hood</p> 	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Roof center	Forward-facing sensor mounted to the center of the roof 	[0, 0, 0]

The (X, Y, Z) location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D Vehicle with Ground Following block to which you are mounting. The tables show the X , Y , and Z locations of sensors in the vehicle coordinate system. In this coordinate system:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward.
- The Z -axis points up from the ground.
- Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the X -axis, Y -axis, and Z -axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

Muscle Car – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.47	0	0.45
Rear bumper	-2.47	0	0.45
Right mirror	0.43	-1.08	1.01
Left mirror	0.43	1.08	1.01
Rearview mirror	0.32	0	1.20
Hood center	1.28	0	1.14
Roof center	-0.25	0	1.58

Sedan – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.59	-0.94	1.09
Left mirror	0.59	0.94	1.09
Rearview mirror	0.43	0	1.31
Hood center	1.46	0	1.11
Roof center	-0.45	0	1.69

Sport Utility Vehicle – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.60	-1	1.35
Left mirror	0.60	1	1.35
Rearview mirror	0.39	0	1.55
Hood center	1.58	0	1.39
Roof center	-0.56	0	2

Small Pickup Truck – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	3.07	0	0.51
Rear bumper	-3.07	0	0.51
Right mirror	1.10	-1.13	1.52
Left mirror	1.10	1.13	1.52
Rearview mirror	0.85	0	1.77
Hood center	2.22	0	1.59
Roof center	0	0	2.27

Hatchback – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	1.93	0	0.51
Rear bumper	-1.93	0	0.51
Right mirror	0.43	-0.84	1.01
Left mirror	0.43	0.84	1.01
Rearview mirror	0.32	0	1.27
Hood center	1.44	0	1.01
Roof center	0	0	1.57

To determine the location of the sensor in world coordinates, open the sensor block. Then, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)** and inspect the data from the **Location** output port.

Specify offset – Specify offset from mounting location

off (default) | on

Select this parameter to specify an offset from the mounting location by using the **Relative translation [X, Y, Z] (m)** and **Relative rotation [Roll, Pitch, Yaw] (deg)** parameters.

Relative translation [X, Y, Z] (m) – Translation offset relative to mounting location

[0, 0, 0] (default) | real-valued 1-by-3 vector

Translation offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[X, Y, Z]$. Units are in meters.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then X , Y , and Z are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: $[0, 0, 0.01]$

Dependencies

To enable this parameter, select **Specify offset**.

Relative rotation [Roll, Pitch, Yaw] (deg) – Rotational offset relative to mounting location

$[0, 0, 0]$ (default) | real-valued 1-by-3 vector

Rotational offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[Roll, Pitch, Yaw]$. Roll, pitch, and yaw are the angles of rotation about the X -, Y -, and Z -axes, respectively. Units are in degrees.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.
- Roll, pitch, and yaw are clockwise-positive when looking in the forward direction of the X -axis, Y -axis, and Z -axis, respectively. If you view a scene from a 2D top-down

perspective, then the yaw angle (also called the orientation angle) is counterclockwise-positive, because you are viewing the scene in the negative direction of the Z-axis.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to Scene Origin, then X, Y, and Z are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: [0,0,10]

Dependencies

To enable this parameter, select **Specify offset**.

Sample time — Sample time

-1 (default) | positive scalar

Sample time of the block in seconds, specified as a positive scalar. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to -1, the block inherits its sample time from the Simulation 3D Scene Configuration block.

Parameters

Detection range (m) — Maximum distance measured by lidar sensor

120 (default) | positive scalar

Maximum distance measured by the lidar sensor, specified as a positive scalar. Points outside this range are ignored. Units are in meters.

Range resolution (m) — Resolution of lidar sensor range

0.002 (default) | positive real scalar

Resolution of the lidar sensor range, in meters, specified as a positive real scalar. The range resolution is also known as the quantization factor. The minimal value of this factor is $D_{\text{range}} / 2^{24}$, where D_{range} is the maximum distance measured by the lidar sensor, as specified in the **Detection range (m)** parameter.

Vertical field of view (deg) – Vertical field of view

40 (default) | positive scalar

Vertical field of view of the lidar sensor, specified as a positive scalar. Units are in degrees.

Vertical resolution (deg) – Vertical angular resolution

1.25 (default) | positive scalar

Vertical angular resolution of the lidar sensor, specified as a positive scalar. Units are in degrees.

Horizontal field of view (deg) – Horizontal field of view

360 (default) | positive scalar

Horizontal field of view of the lidar sensor, specified as a positive scalar. Units are in degrees.

Horizontal resolution (deg) – Horizontal angular (azimuth) resolution

0.16 (default) | positive scalar

Horizontal angular (azimuth) resolution of the lidar sensor, specified as a positive scalar. Units are in degrees.

Distance output – Output distance to measured object points

off (default) | on

Select this parameter to output the distance to measured object points at the **Distance** port.

Ground Truth

Output location (m) and orientation (rad) – Output location and orientation of sensor

off (default) | on

Select this parameter to output the location and orientation of the sensor at the **Location** and **Orientation** ports, respectively.

Tips

- To visualize the point clouds that are output by the **Point cloud** port, use a `pcplayer` object in a MATLAB Function block. For an example of this visualization setup, see “Simulate Lidar Sensor Perception Algorithm”.
- Because the Unreal Engine can take a long time to start up between simulations, consider logging the signals that the sensors output. You can then use this data to develop perception algorithms in MATLAB. See “Configure a Signal for Logging” (Simulink).

See Also

`pcplayer` | `pointCloud`

Topics

“3D Simulation for Automated Driving”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

“Choose a Sensor for 3D Simulation”

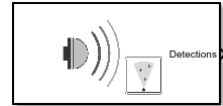
“Lidar Processing”

Introduced in R2019b

Simulation 3D Probabilistic Radar

Probabilistic radar sensor model in 3D simulation environment

Library: Automated Driving Toolbox / Simulation 3D



Description

The Simulation 3D Probabilistic Radar block provides an interface to the probabilistic radar sensor in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. You can specify the radar model and accuracy, bias, and detection parameters. The block uses the sample time to capture the radar detections and outputs a list of object detection reports. To configure the probabilistic radar signatures of actors in the 3D environment across all radars in your model, use a Simulation 3D Probabilistic Radar Configuration block.

If you set **Sample time** to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block. To use this sensor, you must include a Simulation 3D Scene Configuration block in your model.

Note The Simulation 3D Scene Configuration block must execute before the Simulation 3D Probabilistic Radar block. That way, the Unreal Engine 3D visualization environment prepares the data before the Simulation 3D Probabilistic Radar block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Probabilistic Radar — 1

For more information about execution order, see “How 3D Simulation for Automated Driving Works”.

Limitations

In the **Bird's-Eye Scope**, the visualization of sensor coverage areas from Simulation 3D Probabilistic Radar blocks is not supported.

Ports

Output

Detections – Object detections

Simulink bus containing MATLAB structure

Object detections, returned as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink). The structure has this form.

Field	Description	Type
NumDetections	Number of detections	integer
IsValidTime	False when updates are requested at times that are between block invocation intervals	Boolean
Detections	Object detections	Array of object detection structures of length set by the Maximum reported parameter. Only NumDetections of these are actual detections.

Each object detection structure contains these properties.

Property	Definition
Time	Measurement time
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor

Property	Definition
ObjectClassID	Object classification
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

- For Cartesian coordinates, `Measurement` and `MeasurementNoise` are reported in the coordinate system specified by the **Coordinate system** parameter.
- For spherical coordinates, `Measurement` and `MeasurementNoise` are reported in the spherical coordinate system based on the sensor Cartesian coordinate system. `MeasurementParameters` is reported in sensor Cartesian coordinates.

Measurement and MeasurementNoise

Coordinate System Used to Report Detections	Measurement and MeasurementNoise Coordinates															
'Ego Cartesian'	<p>This table shows the coordinate dependence when you enable or disable range rate measurements using the Enable range rate measurements parameter.</p> <table border="1"> <thead> <tr> <th>Range rate measurements</th> <th>Coordinates</th> </tr> </thead> <tbody> <tr> <td>Enabled</td> <td>[x;y;z;vx;vy;vz]</td> </tr> <tr> <td>Disabled</td> <td>[x;y;z]</td> </tr> </tbody> </table>	Range rate measurements	Coordinates	Enabled	[x;y;z;vx;vy;vz]	Disabled	[x;y;z]									
Range rate measurements		Coordinates														
Enabled		[x;y;z;vx;vy;vz]														
Disabled		[x;y;z]														
'Sensor Cartesian'																
'Sensor spherical'	<p>This table shows the coordinate dependence when you enable or disable the range rate and elevation angle measurements, by using the Enable range rate measurements and Enable elevation angle measurements parameters, respectively.</p> <table border="1"> <thead> <tr> <th>Range rate measurements</th> <th>Elevation angle measurements</th> <th>Coordinates</th> </tr> </thead> <tbody> <tr> <td>Enabled</td> <td>Enabled</td> <td>[az;el;rng;rr]</td> </tr> <tr> <td>Enabled</td> <td>Disabled</td> <td>[az;rng;rr]</td> </tr> <tr> <td>Disabled</td> <td>Enabled</td> <td>[az;el;rng]</td> </tr> <tr> <td>Disabled</td> <td>Disabled</td> <td>[az;rng]</td> </tr> </tbody> </table>	Range rate measurements	Elevation angle measurements	Coordinates	Enabled	Enabled	[az;el;rng;rr]	Enabled	Disabled	[az;rng;rr]	Disabled	Enabled	[az;el;rng]	Disabled	Disabled	[az;rng]
Range rate measurements	Elevation angle measurements	Coordinates														
Enabled	Enabled	[az;el;rng;rr]														
Enabled	Disabled	[az;rng;rr]														
Disabled	Enabled	[az;el;rng]														
Disabled	Disabled	[az;rng]														

Measurement Parameters

Parameter	Definition
Frame	Enumerated type that indicates the frame used to report measurements. When Frame is set to 'rectangular', detections are reported in Cartesian coordinates. When Frame is set to 'spherical', detections are reported in spherical coordinates.
OriginPosition	3D vector offset of the sensor origin from the ego vehicle origin. The vector is derived from the location and height of the sensor, as specified by the Mounting location parameter and the Z value of the Relative translation [X, Y, Z] (m) parameter, respectively.
Orientation	Orientation of the radar sensor coordinate system with respect to the ego vehicle coordinate system. The orientation is derived from the roll, pitch, and yaw values specified in the Relative rotation [Roll, Pitch, Yaw] (deg) parameter.
HasVelocity	Indicates whether measurements contain velocity or range rate components.
HasElevation	Indicates whether measurements contain elevation components.

The `ObjectAttributes` property of each detection is a structure with these fields.

Field	Definition
TargetIndex	Identifier of the actor, <code>ActorID</code> , that generated the detection. For false alarms, this value is negative.
SNR	Signal-to-noise ratio of the detection. Units are in decibels.

The `ObjectClassID` property of each detection has a value that corresponds to these object types.

ID	Type
0	None/default
1	Building
2	Fence
3	Other
4	Pedestrian
5	Pole
6	Road line
7	Road
8	Sidewalk
9	Vegetation
10	Vehicle
11	Wall
12	Generic traffic sign
13	Stop sign
14	Yield sign
15	Speed limit sign
16	Weight limit sign
17	Right arrow warning sign
18	Left arrow warning sign
19	Left and right arrow warning sign
20	Left chevron warning sign
21	Right chevron warning sign
22	Left one-way sign
23	Right one-way sign
24	Wheelchair warning sign
25	School bus only sign
26	Right turn only arrow sign
27	Left turn only arrow sign

ID	Type
28	Straight only arrow sign
29	Right turn only sign
30	Left turn only sign
31	Straight only sign
32	No left turn sign
33	No right turn sign
34	No thru traffic sign
35	No U-turn symbol sign
36	No right turn symbol sign
37	No left turn symbol sign
38	No right turn on red sign
39	Crosswalk sign
40	Crosswalk signal
41	Traffic signal
42	Curve right warning sign
43	Curve left warning sign
44	Up right arrow warning sign
45	Up left arrow warning sign
46	Down right arrow warning sign
47	Down left arrow warning sign
48	Railroad crossing sign
49	Street sign
50	Roundabout warning sign
51	Fire hydrant
52	Exit sign
53	Bike lane sign
54	Keep right sign
55	Keep left sign

ID	Type
56	Disability sign
57	Sky
58	Curb
59	Flyover ramp
60	Road guard rail
61-63	<i>Not used</i>
64	Adult pedestrian
65	Young pedestrian
66	Generic animal
67	Deer
68	Kangaroo
69	Dog
70	Cat
71	Barricade
72	Motorcycle
73	Commercial vehicle

Parameters

Mounting

Sensor identifier — Unique sensor identifier

1 (default) | positive integer

Unique sensor identifier, specified as a positive integer. In a multisensor system, the sensor identifier distinguishes between sensors. When you add a new sensor block to your model, the **Sensor identifier** of that block is $N + 1$. N is the highest **Sensor identifier** value among existing sensor blocks in the model.

Example: 2

Parent name — Name of parent to which sensor is mounted

Scene Origin (default) | vehicle name

Name of the parent to which the sensor is mounted, specified as `Scene Origin` or as the name of a vehicle in your model. The vehicle names that you can select correspond to the **Name** parameters of the Simulation 3D Vehicle with Ground Following blocks in your model. If you select `Scene Origin`, the block places a sensor at the scene origin.


Example: `SimulinkVehicle1`

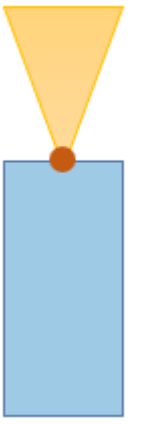
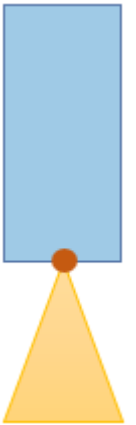
Mounting location — Sensor mounting location

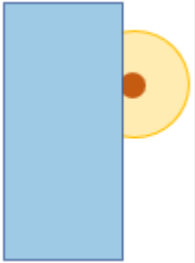
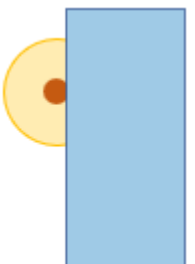
Origin (default) | Front bumper | Rear bumper | Right mirror | Left mirror |
Rearview mirror | Hood center | Roof center



Sensor mounting location.


- When **Parent name** is `Scene Origin`, the block mounts the sensor to the origin of the scene, and **Mounting location** can be set to `Origin` only. During simulation, the sensor remains stationary.
- When **Parent name** is the name of a vehicle (for example, `SimulinkVehicle1`) the block mounts the sensor to one of the predefined mounting locations described in the table. During simulation, the sensor travels with the vehicle.

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Origin	<p>Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle (see "Coordinate Systems for 3D Simulation in Automated Driving Toolbox")</p>  A diagram showing a blue rectangular vehicle body. At the top center, there is a yellow trapezoidal sensor. A grey cone representing the sensor's field of view extends downwards from the sensor, with a small grey circle at its base, indicating the sensor's location at the vehicle's origin.	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Front bumper	<p>Forward-facing sensor mounted to the front bumper</p> 	[0, 0, 0]
Rear bumper	<p>Backward-facing sensor mounted to the rear bumper</p> 	[0, 0, 180]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Right mirror	Downward-facing sensor mounted to the right side-view mirror 	[0, -90, 0]
Left mirror	Downward-facing sensor mounted to the left side-view mirror 	[0, -90, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Rearview mirror	<p>Forward-facing sensor mounted to the rearview mirror, inside the vehicle</p> 	[0, 0, 0]
Hood center	<p>Forward-facing sensor mounted to the center of the hood</p> 	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Roof center	Forward-facing sensor mounted to the center of the roof 	[0, 0, 0]

The (X, Y, Z) location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D Vehicle with Ground Following block to which you are mounting. The tables show the X , Y , and Z locations of sensors in the vehicle coordinate system. In this coordinate system:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward.
- The Z -axis points up from the ground.
- Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the X -axis, Y -axis, and Z -axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

Muscle Car – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.47	0	0.45
Rear bumper	-2.47	0	0.45
Right mirror	0.43	-1.08	1.01
Left mirror	0.43	1.08	1.01
Rearview mirror	0.32	0	1.20
Hood center	1.28	0	1.14
Roof center	-0.25	0	1.58

Sedan – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.59	-0.94	1.09
Left mirror	0.59	0.94	1.09
Rearview mirror	0.43	0	1.31
Hood center	1.46	0	1.11
Roof center	-0.45	0	1.69

Sport Utility Vehicle – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.60	-1	1.35
Left mirror	0.60	1	1.35
Rearview mirror	0.39	0	1.55
Hood center	1.58	0	1.39
Roof center	-0.56	0	2

Small Pickup Truck – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	3.07	0	0.51
Rear bumper	-3.07	0	0.51
Right mirror	1.10	-1.13	1.52
Left mirror	1.10	1.13	1.52
Rearview mirror	0.85	0	1.77
Hood center	2.22	0	1.59
Roof center	0	0	2.27

Hatchback – Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	1.93	0	0.51
Rear bumper	-1.93	0	0.51
Right mirror	0.43	-0.84	1.01
Left mirror	0.43	0.84	1.01
Rearview mirror	0.32	0	1.27
Hood center	1.44	0	1.01
Roof center	0	0	1.57

To determine the location of the sensor in world coordinates, open the sensor block. Then, on the **Ground Truth** tab, select **Output location (m) and orientation (rad)** and inspect the data from the **Location** output port.

Specify offset – Specify offset from mounting location

off (default) | on

Select this parameter to specify an offset from the mounting location by using the **Relative translation [X, Y, Z] (m)** and **Relative rotation [Roll, Pitch, Yaw] (deg)** parameters.

Relative translation [X, Y, Z] (m) – Translation offset relative to mounting location

[0, 0, 0] (default) | real-valued 1-by-3 vector

Translation offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[X, Y, Z]$. Units are in meters.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then X , Y , and Z are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: $[0, 0, 0.01]$

Dependencies

To enable this parameter, select **Specify offset**.

Relative rotation [Roll, Pitch, Yaw] (deg) – Rotational offset relative to mounting location

$[0, 0, 0]$ (default) | real-valued 1-by-3 vector

Rotational offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form $[Roll, Pitch, Yaw]$. Roll, pitch, and yaw are the angles of rotation about the X -, Y -, and Z -axes, respectively. Units are in degrees.

If you mount the sensor to a vehicle by setting **Parent name** to the name of that vehicle, then X , Y , and Z are in the vehicle coordinate system, where:

- The X -axis points forward from the vehicle.
- The Y -axis points to the left of the vehicle, as viewed when facing forward .
- The Z -axis points up.
- Roll, pitch, and yaw are clockwise-positive when looking in the forward direction of the X -axis, Y -axis, and Z -axis, respectively. If you view a scene from a 2D top-down

perspective, then the yaw angle (also called the orientation angle) is counterclockwise-positive, because you are viewing the scene in the negative direction of the Z-axis.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to Scene Origin, then X, Y, and Z are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for 3D Simulation in Automated Driving Toolbox”.

Example: [0, 0, 10]

Dependencies

To enable this parameter, select **Specify offset**.

Sample time — Sample time

-1 (default) | positive scalar

Sample time of the block in seconds, specified as a positive scalar. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to -1, the block inherits its sample time from the Simulation 3D Scene Configuration block.

Parameters

Accuracy Settings

Azimuthal resolution of radar (deg) — Azimuth resolution of radar

4 (default) | positive real scalar

Azimuth resolution of the radar, specified as a positive real scalar. The azimuth resolution defines the minimum separation in azimuth angle at which the radar can distinguish between two targets. The azimuth resolution is typically the 3dB-downpoint in azimuth angle beamwidth of the radar. Units are in degrees.

Example: 6.5

Elevation resolution of radar (deg) — Elevation resolution of radar

10 (default) | positive real scalar

Elevation resolution of the radar, specified as a positive real scalar. The elevation resolution defines the minimum separation in elevation angle at which the radar can distinguish between two targets. The elevation resolution is typically the 3dB-downpoint in elevation angle beamwidth of the radar. Units are in degrees.

Example: 3.5

Dependencies

To enable this parameter, on the **Parameters** tab, in the **Radar model** section, select **Enable elevation angle measurements**.

Range resolution of radar (m) — Range resolution of radar

2.5 (default) | positive real scalar

Range resolution of the radar, specified as a positive real scalar. The range resolution defines the minimum separation in range at which the radar can distinguish between two targets. Units are in meters.

Example: 5.0

Range rate resolution of radar (m/s) — Range rate resolution of the radar

0.5 (default) | positive real scalar

Range rate resolution of the radar, specified as a positive real scalar. The range rate resolution defines the minimum separation in range rate at which the radar can distinguish between two targets. Units are in meters per second.

Example: 0.75

Dependencies

To enable this parameter, on the **Parameters** tab, in the **Radar model** section, select **Enable range rate measurements**.

Bias Settings

Fractional azimuthal bias component — Azimuth bias fraction

0.1 (default) | nonnegative real scalar

Azimuth bias fraction of the radar, specified as a nonnegative real scalar. The azimuth bias is expressed as a fraction of the azimuth resolution specified in the **Azimuthal resolution of radar (deg)** parameter. Units are dimensionless.

Example: 0.3

Fractional elevation bias component — Elevation bias fraction

0.1 (default) | nonnegative real scalar

Elevation bias fraction of the radar, specified as a nonnegative real scalar. The elevation bias is expressed as a fraction of the elevation resolution specified in the **Elevation resolution of radar (deg)** parameter. Units are dimensionless.

Example: 0.2

Dependencies

To enable this parameter, on the **Parameters** tab, in the **Radar model** section, select **Enable elevation angle measurements**.

Fractional range bias component — Range bias fraction

0.05 (default) | nonnegative real scalar

Range bias fraction of the radar, specified as a nonnegative real scalar. Range bias is expressed as a fraction of the range resolution specified in the **Range resolution of radar (m)** parameter. Units are dimensionless.

Example: 0.15

Fractional range rate bias component — Range rate bias fraction

0.05 (default) | nonnegative real scalar

Range rate bias fraction of the radar, specified as a nonnegative real scalar. Range rate bias is expressed as a fraction of the range rate resolution specified in the **Range rate resolution of radar (m/s)** parameter. Units are dimensionless.

Example: 0.2

Dependencies

To enable this parameter, on the **Parameters** tab, in the **Radar model** section, select **Enable range rate measurements**.

Detector Settings**Field of view (deg) — Field of view**

[20, 5] (default) | positive real-valued 1-by-2 vector

Field of view of the radar, specified as a positive real-valued 1-by-2 vector of the form [azfov, elfov]. azfov is the azimuth angle field of view. elfov is the elevation angle field of view. The field of view defines the angular extent spanned by the sensor. Each

component must lie in the interval (0,180]. Targets outside of the field of view of the radar are not detected. Units are in degrees.

Example: [14 7]

Detection ranges (m) — Detection range

[1, 150] (default) | positive real-valued 1-by-2 vector

Detection range, in meters, at which the radar can detect a target.

- To set only a maximum detection range, specify this parameter as a positive real scalar. By default, the minimum detection range is 0.
- To set both a minimum and maximum detection range, specify this parameter as a positive real-valued 1-by-2 vector of the form [min, max].

Example: 250

Range rates (m/s) — Minimum and maximum detection range rates

[-100, 100] (default) | real-valued 1-by-2 vector

Minimum and maximum detection range rates, specified as a real-valued 1-by-2 vector. The radar can detect targets only within this range rate interval. Units are in meters per second.

Example: [-200 200]

Dependencies

To enable this parameter, on the **Parameters** tab, in the **Radar model** section, select **Enable range rate measurements**.

Detection probability — Probability that radar detects a target

0.9 (default) | real scalar in the range (0, 1]

Probability that the radar detects a target, specified as a real scalar in the range (0, 1]. This quantity defines the probability of detecting a target that has a radar cross section specified by the **Reference radar cross section (dBsm)** parameter, at the reference detection range specified by the **Detection ranges (m)** parameter.

Example: 0.95

False alarm rate — False alarm rate

1e-6 (default) | positive real scalar in range [10⁻⁷, 10⁻³]

False alarm rate within a radar resolution cell, specified as a positive real scalar in the range $[10^{-7}, 10^{-3}]$. Units are dimensionless.

Example: 1e-5

Detection probability range (m) — Reference range for given probability of detection

100 (default) | positive real scalar

Reference range for a given probability of detection, specified as a positive real scalar. The reference range is the range at which the radar detects targets that have a radar cross section specified by **Reference radar cross section (dBsm)**, given a detection probability specified by **Detection probability**. Units are in meters.

Example: 150

Reference radar cross section (dBsm) — Reference radar cross section for given probability of detection

0 (default) | nonnegative real scalar

Reference radar cross section (RCS) for a given probability of detection, specified as a nonnegative real scalar. A radar with the detection probability specified by **Detection probability** detects targets at this reference RCS value. Units are in decibels per square meter.

Example: 2.0

Radar Model

Enable elevation angle measurements — Enable radar to measure elevation

on (default) | off

Select this parameter to model a radar that can measure target elevation angles. This parameter enables the **Elevation resolution of radar (deg)** and **Fractional elevation bias component** parameters.

Enable range rate measurements — Enable radar to measure range rate

on (default) | off

Select this parameter to model a radar that can measure target range rates. This parameter enables the **Range rate resolution of radar (m/s)**, **Fractional range bias component**, and **Range rates (m/s)** parameters.

Enable measurement noise — Enable adding noise to radar sensor measurements

on (default) | off

Select this parameter to add noise to radar sensor measurements. Otherwise, the measurements are noise-free. The `MeasurementNoise` property of each detection is always computed and is not affected by the value you specify for the **Measurement noise** parameter. By not selecting this parameter, you can pass the sensor ground truth measurements into a Multi-Object Tracker block.

Enable false detections — Enable reporting false alarm radar detections

on (default) | off

Select this parameter to enable reporting false alarm radar measurements. Otherwise, only actual detections are reported.

Random number generator method — Method to set random number generator seed

Repeatable (default) | Specify seed | Not repeatable

Method to set the random number generator seed. This parameter controls whether results are repeatable after each simulation. You can select one of these options:

- **Repeatable** — The block generates a random initial seed for the first simulation and reuses that seed for all subsequent simulations. To generate a new random seed, at the MATLAB command prompt, enter `clear all`.
- **Specify seed** — The block generates a random initial seed based on the value specified in the **Initial seed** parameter.
- **Not repeatable** — At each new simulation, the block generates a new initial seed.

Initial seed — Random number generator seed

0 (default) | scalar in range [0, 2^{32})

Random number generator seed, specified as a scalar in the range [0, 2^{32})

Example: 2001

Dependencies

To enable this parameter, set the **Random number generator method** parameter to `Specify seed`.

Detection Reporting

Maximum reported — Maximum number of reported detections

50 (default) | positive integer

Maximum number of reported detections, specified as a positive integer. Units are dimensionless.

Example: 35

Coordinate system — Coordinate system of reported detections

Ego Cartesian (default) | Sensor Cartesian | Sensor spherical

Coordinate system of reported detections, specified as one of these values:

- `Ego Cartesian` — The radar reports detections in the ego vehicle Cartesian coordinate system.
- `Sensor Cartesian`— The radar reports detections in the sensor Cartesian coordinate system.
- `Sensor spherical` — The radar reports detections in the spherical coordinate system. This coordinate system is centered at the radar and aligned with the orientation of the radar on the ego vehicle.

Specify output bus name — Specify name of output bus

off (default) | on

Select this parameter to specify the name of the bus that the block outputs to the base workspace. Specify this name in the **Output bus name** parameter.

Output bus name — Name of output bus

BusSimulation3DRadarTruthSensor (default) | valid bus name

Name of the bus that the block outputs to the base workspace.

Dependencies

To enable this parameter, select the **Specify output bus name** parameter.

Tips

- To visualize detections, use the **Bird's-Eye Scope**. In the scope, when you first click **Find Signals**, detection signals from Simulation 3D Probabilistic Radar blocks appear

under **Other Applicable Signals**. To display the detections, move these signals to the **Detections** group.

- Because the Unreal Engine can take a long time to start between simulations, consider logging the signals that the sensors output. For more details, see “Configure a Signal for Logging” (Simulink).

References

- [1] Blacksmith, P., R. E. Hiatt, and R. B. Mack. "Introduction to radar cross-section measurements." *Proceedings of the IEEE*. Volume 53, No. 8, August 1965, pp. 901-920. doi: 10.1109/PROC.1965.4069.

See Also

Bird's-Eye Scope | Detection Concatenation | Multi-Object Tracker | Simulation 3D Probabilistic Radar Configuration | Simulation 3D Scene Configuration | Simulation 3D Vehicle with Ground Following

Topics

“3D Simulation for Automated Driving”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

“Choose a Sensor for 3D Simulation”

“Visualize Sensor Data and Tracks in Bird's-Eye Scope”

Introduced in R2019b

Simulation 3D Probabilistic Radar Configuration

Configure probabilistic radar signatures in 3D simulation environment

Library: Automated Driving Toolbox / Simulation 3D



Description

The Simulation 3D Probabilistic Radar Configuration block configures the probabilistic radar signatures for actors in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. To model the probabilistic radars, use Simulation 3D Probabilistic Radar blocks. The configured radar signatures apply to all Simulation 3D Probabilistic Radar blocks in your model.

Parameters

Radar targets — Identifiers corresponding to radar targets

[] (default) | positive integer | L -length vector of unique positive integers

Identifiers that correspond to radar targets, specified as a positive integer or L -length vector of unique positive integers. L equals the number of radar targets for which you want to specify a nondefault radar cross section (RCS).

This table provides the identifiers that radars can detect in a scene and the corresponding object type. For example, to specify a nondefault RCS for a building and a pedestrian, set **Radar targets** to [1, 4].

ID	Type
0	None/default
1	Building
2	Fence

ID	Type
3	Other
4	Pedestrian
5	Pole
6	Road line
7	Road
8	Sidewalk
9	Vegetation
10	Vehicle
11	Wall
12	Generic traffic sign
13	Stop sign
14	Yield sign
15	Speed limit sign
16	Weight limit sign
17	Right arrow warning sign
18	Left arrow warning sign
19	Left and right arrow warning sign
20	Left chevron warning sign
21	Right chevron warning sign
22	Left one-way sign
23	Right one-way sign
24	Wheelchair warning sign
25	School bus only sign
26	Right turn only arrow sign
27	Left turn only arrow sign
28	Straight only arrow sign
29	Right turn only sign
30	Left turn only sign

ID	Type
31	Straight only sign
32	No left turn sign
33	No right turn sign
34	No thru traffic sign
35	No U-turn symbol sign
36	No right turn symbol sign
37	No left turn symbol sign
38	No right turn on red sign
39	Crosswalk sign
40	Crosswalk signal
41	Traffic signal
42	Curve right warning sign
43	Curve left warning sign
44	Up right arrow warning sign
45	Up left arrow warning sign
46	Down right arrow warning sign
47	Down left arrow warning sign
48	Railroad crossing sign
49	Street sign
50	Roundabout warning sign
51	Fire hydrant
52	Exit sign
53	Bike lane sign
54	Keep right sign
55	Keep left sign
56	Disability sign
57	Sky
58	Curb

ID	Type
59	Flyover ramp
60	Road guard rail
61-63	<i>Not used</i>
64	Adult pedestrian
65	Young pedestrian
66	Generic animal
67	Deer
68	Kangaroo
69	Dog
70	Cat
71	Barricade
72	Motorcycle
73	Commercial vehicle

Radar cross sections (dBsm) – Radar cross sections

{ } (default) | real-valued Q -by- P matrix | L -length cell array of real-valued Q_1 -by- P_1, \dots, Q_L -by- P_L matrices

Radar cross sections of target actors, in decibels per square meter, specified as a matrix or cell array of matrices. Each matrix defines the RCS for the corresponding target actor specified by **Radar targets**.

If **Radar targets** is a scalar (that is, a single target actor), then specify **Radar cross sections (dBsm)** as a real-valued Q -by- P matrix, where:

- Q is the number of elevation angle samples for the actor.
- P is the number of azimuth angle samples for the actor.

If **Radar targets** is a vector (that is, multiple target actors), then specify **Radar cross sections (dBsm)** as a L -length cell array of real-valued Q_1 -by- P_1, \dots, Q_L -by- P_L matrices, where:

- L is the number of actors.
- Q_1, \dots, Q_L are the number of elevation angle samples per actor.

- P_1, \dots, P_L are the number of azimuth angle samples per actor.

Q and P can vary for each actor. For each RCS matrix:

- The rows correspond to uniformly sampled elevation angles over the interval $[0, 180]$.
- The columns correspond to uniformly sampled azimuth angles over the interval $[0, 360]$.

For example, the number of elevation and azimuth samples for RCS matrix `RCS` are as follows:

```
el = linspace(0,180,size(RCS,1));  
az = linspace(0,360,size(RCS,2));
```

Default radar cross section (dBsm) — Default radar cross section

-20 (default) | real scalar

Default radar cross section, in decibels per square meter, specified as a real scalar. The block uses this RCS value for actors whose RCS is not specified by **Radar cross sections (dBsm)**.

Example: -10

See Also

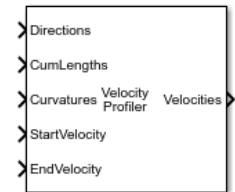
Simulation 3D Probabilistic Radar

Introduced in R2019b

Velocity Profiler

Generate velocity profile of vehicle path given kinematic constraints

Library: Automated Driving Toolbox



Description

The Velocity Profiler block generates a velocity profile of a driving path that satisfies this set of specified kinematic constraints:

- The maximum allowable speed of the vehicle
- The maximum longitudinal acceleration and deceleration of the vehicle
- The maximum longitudinal jerk on page 2-181 of the vehicle
- The maximum lateral acceleration on page 2-181 of the vehicle

Specify the cumulative lengths along the path and the driving directions and curvatures at each point along the path. You can obtain these values from the output of a Path Smoother Spline block. Also specify the longitudinal velocity of the vehicle at the start and end of the path.

Use the generated velocity profile as the input reference velocities of a longitudinal controller, as shown in the “Automated Parking Valet in Simulink” example.

Ports

Input

Directions – Driving directions along path

M-by-1 vector of 1s (forward motion) and -1s (reverse motion)

Driving directions of the vehicle along the length of the path, specified as an M -by-1 vector of 1s (forward motion) and -1s (reverse motion). Each vector element represents the driving direction of the vehicle at the corresponding cumulative path length specified by the **CumLengths** input port. M is the number of driving directions and must be equal to the lengths of the **CumLengths** and **Curvatures** inputs.

You can obtain **Directions** from the output of a Path Smoother Spline block.

CumLengths — Cumulative path lengths

M-by-1 vector of monotonically increasing real-valued elements

Cumulative path lengths, in meters, specified as an M -by-1 vector of monotonically increasing real-valued elements. Each vector element represents a point along the path. M is the number of cumulative path lengths and must be equal to the lengths of the **Directions** and **Curvatures** inputs.

You can obtain **CumLengths** from the output of a Path Smoother Spline block.

Curvatures — Signed path curvatures along path

M-by-1 real-valued vector

Signed path curvatures along the length of the path, in radians per meter, specified as an M -by-1 real-valued vector. Each vector element represents the curvature of the path at the corresponding cumulative path length specified by the **CumLengths** input port. M is the number of curvatures and must be equal to the lengths of the **Directions** and **CumLengths** inputs.

You can obtain **Curvatures** from the output of a Path Smoother Spline block.

StartVelocity — Longitudinal velocity of vehicle at start of path

real scalar

Longitudinal velocity of the vehicle at the start of the path, in meters per second, specified as a real scalar.

EndVelocity — Longitudinal velocity of vehicle at end of path

real scalar

Longitudinal velocity of the vehicle at the end of the path, in meters per second, specified as a real scalar.

Output

Velocities — Velocity profile along path

M-by-1 real-valued vector

Velocity profile along the length of the path, in meters per second, returned as an *M*-by-1 real-valued column vector. Each vector element represents a reference longitudinal velocity for the vehicle at the corresponding cumulative path length specified by the **CumLengths** input port. *M* is the number of velocities and is equal to the length of **CumLengths**.

The output velocity values satisfy the speed, acceleration, and jerk constraints specified in the parameters of the Velocity Profiler block. You can use this output as the reference velocity for a vehicle controller.

Velocities is a variable-size output with the limitations described in “Variable-Size Signal Limitations” (Simulink).

Times — Vehicle times of arrival for velocity profile

M-by-1 real-valued vector

Vehicle times of arrival for the velocity profile specified in **Velocities**, returned as an *M*-by-1 real-valued vector. *M* is the number of vehicle times of arrival and is equal to the length of **Velocities**. Units are in seconds.

Each vector element represents the time that a vehicle traveling at velocity *v* arrives at cumulative path length *p*, where:

- *v* is the corresponding velocity returned by the **Velocities** output port.
- *p* is the corresponding cumulative path length specified by the **CumLengths** input port.

Use **Times** to visualize the velocity profile over time, as shown in the “Velocity Profile of Straight Path” and “Velocity Profile of Path with Curve and Direction Change” examples.

Times is a variable-size output with the limitations described in “Variable-Size Signal Limitations” (Simulink).

Dependencies

To enable this port, select the **Show Times output port** parameter.

Parameters

Maximum longitudinal acceleration (m/s²) – Maximum longitudinal acceleration of vehicle

3 (default) | positive real scalar

Maximum longitudinal acceleration of the vehicle, in meters per second squared, specified as a positive real scalar.

When developing a longitudinal controller, this parameter must be equal to the corresponding parameter in the Longitudinal Controller Stanley block. Otherwise, the vehicle is unable to run the generated velocity profile.

Maximum longitudinal deceleration (m/s²) – Maximum longitudinal deceleration of vehicle

6 (default) | positive real scalar

Maximum longitudinal deceleration of the vehicle, in meters per second squared, specified as a positive real scalar.

When developing a longitudinal controller, this parameter must be equal to the corresponding parameter in the Longitudinal Controller Stanley block. Otherwise, the vehicle is unable to run the generated velocity profile.

Maximum allowable speed (m/s) – Maximum allowable speed along path

10 (default) | positive real scalar

Maximum allowable speed of the vehicle along the path, in meters per second, specified as a positive real scalar. Use this parameter to constrain the speed of the vehicle based on passenger comfort or speed limit requirements.

When the path length is too short for the vehicle to reach this maximum speed, the block calculates a smaller maximum speed that satisfies the path length constraint.

In the output velocity profile, the speed of the vehicle is constrained to $[-V_{\max}, V_{\max}]$, where V_{\max} is the value of this parameter.

Maximum longitudinal jerk (m/s³) – Maximum longitudinal jerk

1 (default) | positive real scalar

Maximum longitudinal jerk of the vehicle along the path, in meters per second cubed, specified as a positive real scalar.

In the output velocity profile, the longitudinal jerk of the vehicle is constrained to $[-J_{\max}, J_{\max}]$, where J_{\max} is the value of this parameter.

Maximum lateral acceleration (m/s²) – Maximum lateral acceleration

1 (default) | positive real scalar

Maximum lateral acceleration of the vehicle along the path, in meters per second squared, specified as a positive real scalar.

In the output velocity profile, the lateral acceleration of the vehicle is constrained to $[-A_{\max}, A_{\max}]$, where A_{\max} is the value of this parameter.

Show Times output port – Output times of arrival for velocity profile

off (default) | on

Select this parameter to enable the **Times** output port.

Sample time – Sample time of block

-1 (default) | positive real scalar

Sample time of the block, in seconds, specified as -1 or as a positive real scalar. The default of -1 means that the block inherits its sample time from upstream blocks.

Because the Velocity Profiler block outputs variable-size signals, the sample time of the block must be discrete (nonzero). If the block inherits its sample time from upstream blocks, those blocks must also have discrete sample times.

Simulate using – Type of simulation to run

Code Generation (default) | Interpreted Execution

- **Code generation** – Simulate the model using generated C/C++ code. The first time you run a simulation, Simulink generates C/C++ code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time.
- **Interpreted execution** – Simulate the model using the MATLAB interpreter. This option shortens startup time. In Interpreted execution mode, you can debug the source code of the block.

More About

Jerk

Jerk is the rate of change of acceleration in a vehicle. Jerk minimization is a key comfort requirement for vehicle passengers. Rapid changes in acceleration or deceleration result in a "jerky" ride for passengers. Jerk is measured in units of meters per second cubed.

Lateral Acceleration

Lateral acceleration is defined as $a_{\text{lat}} = v^2\kappa$, where:

- v is the longitudinal velocity of the vehicle.
- κ is the curvature of the path. Units are in radians per meter.

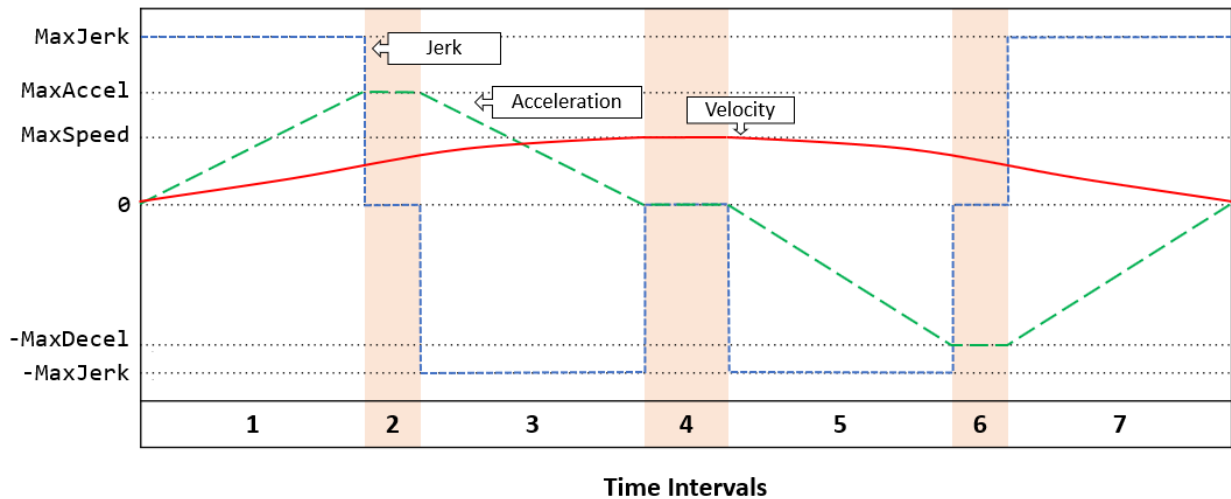
Lateral acceleration is measured in units of meters per second squared.

Algorithms

To generate the velocity profile for a reference path, the Velocity Profiler block performs these steps:

- 1 Generate a continuous velocity profile that satisfies all kinematic constraints (speed, acceleration, and jerk) specified by the block parameters.
- 2 Discretize the velocity profile by mapping poses in the reference path to velocity values, based on how far away the poses are from the starting pose. The cumulative path lengths specified in the **CumLengths** input port contain these distances. The Path Smoother Spline block returns these cumulative path lengths, along with the smooth path.

The generated velocity profile is a seven-interval curve. At each time interval within the curve, the jerk, acceleration, and velocity of the vehicle change to satisfy the specified constraints. The figure and table show how these values change for a vehicle traveling in forward motion along a path. For simplicity, the starting and ending velocity of the vehicle, as specified by the **StartVelocity** and **EndVelocity** input ports, are both 0.



Time Interval	Jerk	Acceleration	Velocity	Notes
1	Set to MaxJerk	Increases from 0 to MaxAccel	Increases from starting velocity	-
2	Set to 0	Held constant at MaxAccel	Keeps increasing	During the previous interval, if the vehicle cannot reach MaxAccel given the MaxSpeed constraint, then interval 2 does not occur.
3	Set to -MaxJerk	Decreases from MaxAccel to 0	Increases to MaxSpeed	-
4	Set to 0	Held constant at 0	Held constant at MaxSpeed	-
5	Set to -MaxJerk	Decreases from 0 to -MaxDecel	Starts decreasing	-

Time Interval	Jerk	Acceleration	Velocity	Notes
6	Set to 0	Held constant at -MaxDecel	Keeps decreasing	During the previous interval, if the vehicle cannot reach -MaxDecel given the MaxSpeed constraint, then interval 6 does not occur.
7	Set to MaxJerk	Increases from -MaxDecel to 0	Decreases to ending velocity	-

In the figure and table:

- MaxJerk and -MaxJerk are set by the **Maximum longitudinal jerk (m/s³)** parameter.
- MaxAccel and -MaxDecel are set by the **Maximum longitudinal acceleration (m/s²)** and **Maximum longitudinal deceleration (m/s²)** parameters, respectively. You can specify asymmetric values for these parameters.
- MaxSpeed is set by the **Maximum allowable speed (m/s)** parameter.

For a vehicle in reverse motion, the curves in the figure are reversed. The signs of the parameter values shown in the figure and table are also reversed.

If the vehicle includes multiple changes in direction, the block generates separate velocity profiles for each driving direction. Then the block concatenates these profiles in the final **Velocities** output. For an example, see "Velocity Profile of Path with Curve and Direction Change".

References

- [1] Villagra, Jorge, Vicente Milanés, Joshué Pérez, and Jorge Godoy. "Smooth path and speed planning for an automated public transport vehicle." *Robotics and Autonomous Systems*. Vol. 60, Number 2, February 2012, pp. 252-265.

Extended Capabilities

C/C++ Code Generation

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

See Also

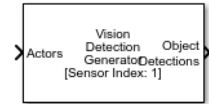
Lateral Controller Stanley | Longitudinal Controller Stanley | Path Smoother Spline

Introduced in R2019b

Vision Detection Generator

Detect objects and lanes from visual measurements

Library: Automated Driving Toolbox / Driving Scenario and Sensor Modeling



Description

The Vision Detection Generator block generates detections from camera measurements taken by a vision sensor mounted on an ego vehicle. Detections are derived from simulated actor poses and are generated at intervals equal to the sensor update interval. All detections are referenced to the coordinate system of the ego vehicle. The generator can simulate real detections with added random noise and also generate false positive detections. A statistical model generates the measurement noise, true detections, and false positives. The random numbers generated by the statistical model are controlled by random number generator settings on the **Measurements** tab. You can use the Vision Detection Generator to create input to a Multi-Object Tracker block. When building scenarios and sensor models using the **Driving Scenario Designer** app, the camera sensors exported to Simulink are output as Vision Detection Generator blocks.

Ports

Input

Actors — Scenario actor poses

Simulink bus containing MATLAB structure

Scenario actor poses, specified as a Simulink bus containing a MATLAB structure.

The structure has these fields.

Field	Description	Type
NumActors	Number of actors (ego vehicle excluded)	Nonnegative integer
Time	Current simulation time	Real scalar
Actors	Actor poses in ego vehicle coordinates	NumActors-length array of actor pose structures

Each actor pose structure in Actors has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x-, y-, and z-directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x-, y-, and z-directions, specified as an [ω_x ω_y ω_z] real-valued vector. Units are in degrees per second.

Dependencies

To enable this input port, set the **Types of detections generated by sensor** parameter to Objects only, Lanes with occlusion, or Lanes and objects.

Lane Boundaries — Lane boundaries

Simulink bus containing MATLAB structure

Lane boundaries, specified as a Simulink bus containing a MATLAB structure.

The structure has these fields.

Field	Description	Type
NumLaneBoundaries	Number of lane boundaries	Nonnegative integer
Time	Current simulation time	Real scalar
LaneBoundaries	Lane boundaries in ego vehicle coordinates	NumLaneBoundaries-length array of lane boundary structures

Each lane boundary structure in `LaneBoundaries` has these fields.

Field	Description
Coordinates	Lane boundary coordinates, specified as a real-valued N -by-3 matrix, where N is the number of lane boundaries. Lane boundary coordinates define the position of points on the boundary at distances specified by the 'XDistance' name-value pair argument of the <code>laneBoundaries</code> function. In addition, a set of boundary coordinates are inserted into the matrix at zero distance. Units are in meters.
Curvature	Lane boundary curvature at each row of the <code>Coordinates</code> matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per meter.
CurvatureDerivative	Derivative of lane boundary curvature at each row of the <code>Coordinates</code> matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per square meter.

HeadingAngle	Initial lane boundary heading angle, specified as a real scalar. The heading angle of the lane boundary is relative to the ego vehicle heading. Units are in degrees.
LateralOffset	Distance of the lane boundary from the ego vehicle position, specified as a real scalar. An offset to a lane boundary to the left of the ego vehicle is positive. An offset to the right of the ego vehicle is negative. Units are in meters.
BoundaryType	<p>Type of lane boundary marking, specified as one of these values:</p> <ul style="list-style-type: none"> • 'Unmarked' — No physical lane marker exists • 'Solid' — Single unbroken line • 'Dashed' — Single line of dashed lane markers • 'DoubleSolid' — Two unbroken lines • 'DoubleDashed' — Two dashed lines • 'SolidDashed' — Solid line on the left and a dashed line on the right • 'DashedSolid' — Dashed line on the left and a solid line on the right
Strength	Saturation strength of the lane boundary marking, specified as a real scalar from 0 to 1. A value of 0 corresponds to a marking whose color is fully unsaturated. The marking appears gray. A value of 1 corresponds to a marking whose color is fully saturated.
Width	Lane boundary width, specified as a positive real scalar. In a double-line lane marker, the same width is used for both lines and for the space between lines. Units are in meters.

Length	Length of dash in dashed lines, specified as a positive real scalar. In a double-line lane marker, the same length is used for both lines.
Space	Length of space between dashes in dashed lines, specified as a positive real scalar. In a dashed double-line lane marker, the same space is used for both lines.

Dependencies

To enable this input port, set the **Types of detections generated by sensor** parameter to Lanes only, Lanes only, Lanes with occlusion, or Lanes and objects.

Output

Object Detections – Object detections

Simulink bus containing MATLAB structure

Object detections, returned as a Simulink bus containing a MATLAB structure. See “Getting Started with Buses” (Simulink). The structure has the form:

Field	Description	Type
NumDetections	Number of detections	Integer
IsValidTime	False when updates are requested at times that are between block invocation intervals	Boolean
Detections	Object detections	Array of object detection structures of length set by the Maximum number of reported detections parameter. Only NumDetections of these detections are actual detections.

The object detection structure contains these properties.

Property	Definition
Time	Measurement time
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor
ObjectClassID	Object classification
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

- For Cartesian coordinates, `Measurement` and `MeasurementNoise` are reported in the coordinate system specified by the **Coordinate system used to report detections** parameter.
- For spherical coordinates, `Measurement` and `MeasurementNoise` are reported in the spherical coordinate system based on the sensor Cartesian coordinate system. `MeasurementParameters` are reported in sensor Cartesian coordinates.

Measurement and Measurement Noise

Coordinate system used to report detections	Measurement and Measurement Noise Coordinates		
'Ego Cartesian'	Coordinate Dependence on Enable range rate measurements		
'Sensor Cartesian'	Enable range rate measurements		Coordinates
	true		[x;y;z;vx;vy;vz]
	false		[x;y;z]
'Sensor Spherical'	Coordinate dependence on Enable elevation angle measurements and Enable range rate measurements		
	Enable range rate measurements	Enable elevation angle measurements	Coordinates
	true	true	[az;el;rng;rr]
	true	false	[az;rng;rr]
	false	true	[az;el;rng]
	false	false	[az;rng]

MeasurementParameters

Parameter	Definition
Frame	Enumerated type indicating the frame used to report measurements. Frame is always set to 'rectangular', because the Vision Detection Generator reports detections in Cartesian coordinates.
OriginPosition	3-D vector offset of the sensor origin from the ego vehicle origin. The vector is derived from the Sensor's (x,y) position (m) and Sensor's height (m) properties specified in the Vision Detection Generator.
Orientation	Orientation of the vision sensor coordinate system with respect to the ego vehicle coordinate system. The orientation is derived from the Yaw angle of sensor mounted on ego vehicle (deg) , Pitch angle of sensor mounted on ego vehicle (deg) , and Roll angle of sensor mounted on ego vehicle (deg) parameters of the Vision Detection Generator.
HasVelocity	Indicates whether measurements contain velocity.

The ObjectAttributes property of each detection is a structure with these fields.

Field	Definition
TargetIndex	Identifier of the actor, ActorID, that generated the detection. For false alarms, this value is negative.
SNR	Signal-to-noise ratio of the detection. Units are in dB.

Dependencies

To enable this output port, set the **Types of detections generated by sensor** parameter to Objects only, Lanes with occlusion, or Lanes and objects.

Lane Detections — Lane boundary detections

Simulink bus containing MATLAB structure

Lane boundary detections, returned as a Simulink bus containing a MATLAB structure. The structure had these fields:

Field	Description	Type
Time	Lane detection time	Real scalar
IsValidTime	False when updates are requested at times that are between block invocation intervals	Boolean
SensorIndex	Unique identifier of sensor	Positive integer
NumLaneBoundaries	Number of lane boundary detections	Nonnegative integer
LaneBoundaries	Lane boundary detections	Array of clothoidLaneBoundary objects

Dependencies

To enable this output port, set the **Types of detections generated by sensor** parameter to Lanes only, Lanes with occlusion, or Lanes and objects.

Parameters

Parameters

Sensor Identification

Unique identifier of sensor — Unique sensor identifier

1 (default) | positive integer

Unique sensor identifier, specified as a positive integer. The sensor identifier distinguishes detections that come from different sensors in a multi-sensor system. If a model contains multiple Vision Detection Generator blocks with the same sensor identifier, the **Bird's-Eye Scope** displays sensor data for only one of the blocks.

Example: 5

Types of detections generated by sensor — Select the types of detections

Objects only (default) | Lanes only | Lanes with occlusion | Lanes and objects

Types of detections generated by the sensor, specified as `Objects only`, `Lanes only`, `Lanes with occlusion`, or `Lanes and objects`.

- When set to `Objects only`, no road information is used to occlude actors.
- When set to `Lanes only`, no actor information is used to detect lanes.
- When set to `Lanes with occlusion`, actors in the camera field of view can impair the sensor ability to detect lanes.
- When set to `Lanes and objects`, the sensor generates object both object detections and occluded lane detections.

Required interval between sensor updates (s) — Required time interval

0.1 (default) | positive real scalar

Required time interval between sensor updates, specified as a positive real scalar. The value of this parameter must be an integer multiple of the **Actors** input port data interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Required interval between lane detections updates (s) — Time interval between lane detection updates

0.1 (default) | positive real scalar

Required time interval between lane detection updates, specified as a positive real scalar. The vision detection generator is called at regular time intervals. The vision detector generates new lane detections at intervals defined by this parameter which must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no lane detections. Units are in seconds.

Sensor Extrinsic

Sensor's (x,y) position (m) — Location of the vision sensor center

[3.4 0] (default) | real-valued 1-by-2 vector

Location of the vision sensor center, specified as a real-valued 1-by-2 vector. The **Sensor's (x,y) position (m)** and **Sensor's height (m)** parameters define the coordinates of the

vision sensor with respect to the ego vehicle coordinate system. The default value corresponds to a forward-facing vision sensor mounted a sedan dashboard. Units are in meters.

Sensor's height (m) – Vision sensor height above the ground plane

0.2 (default) | positive real scalar

Vision sensor height above the ground plane, specified as a positive real scalar. The height is defined with respect to the vehicle ground plane. The **Sensor's (x,y) position (m)** and **Sensor's height (m)** parameters define the coordinates of the vision sensor with respect to the ego vehicle coordinate system. The default value corresponds to a forward-facing vision sensor mounted a sedan dashboard. Units are in meters.

Example: 0.25

Yaw angle of sensor mounted on ego vehicle (deg) – Yaw angle of sensor

0 (default) | real scalar

Yaw angle of vision sensor, specified as a real scalar. Yaw angle is the angle between the center line of the ego vehicle and the optical axis of the camera. A positive yaw angle corresponds to a clockwise rotation when looking in the positive direction of the z-axis of the ego vehicle coordinate system. Units are in degrees.

Example: -4.0

Pitch angle of sensor mounted on ego vehicle (deg) – Pitch angle of sensor

0 (default) | real scalar

Pitch angle of sensor, specified as a real scalar. The pitch angle is the angle between the optical axis of the camera and the x-y plane of the ego vehicle coordinate system. A positive pitch angle corresponds to a clockwise rotation when looking in the positive direction of the y-axis of the ego vehicle coordinate system. Units are in degrees.

Example: 3.0

Roll angle of sensor mounted on ego vehicle (deg) – Roll angle of sensor

0 (default) | real scalar

Roll angle of the vision sensor, specified as a real scalar. The roll angle is the angle of rotation of the optical axis of the camera around the x-axis of the ego vehicle coordinate system. A positive roll angle corresponds to a clockwise rotation when looking in the positive direction of the x-axis of the coordinate system. Units are in degrees.

Output Port Settings

Source of object bus name — Source of object bus name

Auto (default) | Property

Source of object bus name, specified as Auto or Property. If you choose Auto, the block automatically creates a bus name. If you choose Property, specify the bus name using the **Specify an object bus name** parameter.

Example: Property

Source of output lane bus name — Source of object bus name

Auto (default) | Property

Source of output lane bus name, specified as Auto or Property. If you choose Auto, the block will automatically create a bus name. If you choose Property, specify the bus name using the **Specify an object bus name** parameter.

Example: Property

Object bus name — Name of object bus

no default

Object bus name.

Example: visionbus

Dependencies

To enable this parameter, set the **Source of object bus name** parameter to Property.

Specify an output lane bus name — Name of output lane bus

no default

Namer of output lane bus.

Example: lanebus

Dependencies

To enable this parameter, set the **Source of output lane bus name** parameter to Property.

Detection Reporting

Maximum number of reported detections — Maximum number of reported detections

50 (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. Detections are reported in order of increasing distance from the sensor until the maximum number is reached.

Example: 100

Dependencies

To enable this parameter, set the **Types of detections generated by sensor** parameter to `Objects only` or `Lanes and objects`.

Maximum number of reported lanes — Maximum number of reported lanes

30 (default) | positive integer

Maximum number of reported lanes, specified as a positive integer.

Example: 100

Dependencies

To enable this parameter, set the **Types of detections generated by sensor** parameter to `Lanes only`, `Lanes with occlusion`, or `Lanes and objects`.

Coordinate system used to report detections — Coordinate system of reported detections

Ego Cartesian (default) | Sensor Cartesian | Sensor Spherical

Coordinate system of reported detections, specified as one of these values:

- `Ego Cartesian` — Detections are reported in the ego vehicle Cartesian coordinate system.
- `Sensor Cartesian`— Detections are reported in the sensor Cartesian coordinate system.

Simulation

Simulate using — Type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** — Simulate the model using the MATLAB interpreter. This option shortens startup time. In **Interpreted execution** mode, you can debug the source code of the block.
- **Code generation** — Simulate the model using generated C/C++ code. The first time you run a simulation, Simulink generates C/C++ code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time.

Measurements

Settings

Maximum detection range (m) — Maximum detection range

150 (default) | positive real scalar

Maximum detection range, specified as a positive real scalar. The vision sensor cannot detect objects beyond this range. Units are in meters.

Example: 250

Object Detector Settings

Bounding box accuracy (pixels) — Bounding box accuracy

5 (default) | positive real scalar

Bounding box accuracy, specified as a positive real scalar. This quantity defines the accuracy with which the detector can match a bounding box to a target. Units are in pixels.

Example: 9

Smoothing filter noise intensity (m/s²) — Noise intensity used for filtering position and velocity measurements

5 (default) | positive real scalar

Noise intensity used for filtering position and velocity measurements, specified as a positive real scalar. Noise intensity defines the standard deviation of the process noise of the internal constant-velocity Kalman filter used in a vision sensor. The filter models the process noise using a piecewise-constant white noise acceleration model. Noise intensity is typically of the order of the maximum acceleration magnitude expected for a target. Units are in m/s².

Example: 2

Maximum detectable object speed (m/s) — Maximum detectable object speed
50 (default) | nonnegative real scalar

Maximum detectable object speed, specified as a nonnegative real scalar. Units are in meters per second.

Example: 20

Maximum allowed occlusion for detector — Maximum detectable object speed
0.5 (default) | real scalar in the range [0 1)

Maximum allowed occlusion of an object, specified as a real scalar in the range [0 1). Occlusion is the fraction of the total surface area of an object not visible to the sensor. A value of one indicates that the object is fully occluded. Units are dimensionless.

Example: 0.2

Minimum detectable image size of an object — Minimum height and width of an object
[15, 15] (default) | 1-by-2 vector of positive values

Minimum height and width of an object that the vision sensor detects within an image, specified as a [minHeight, minWidth] vector of positive values. The 2-D projected height of an object must be greater than or equal to minHeight. The projected width of an object must be greater than or equal to minWidth. Units are in pixels.

Example: [25 20]

Probability of detecting a target — Probability of detection
0.9 (default) | positive real scalar less than or equal to 1

Probability of detecting a target, specified as a positive real scalar less than or equal to 1. This quantity defines the probability that the sensor detects a detectable object. A detectable object is an object that satisfies the minimum detectable size, maximum range, maximum speed, and maximum allowed occlusion constraints.

Example: 0.95

Number of false positives per image — Number of false detections generated by the vision sensor per image
0.1 (default) | nonnegative real scalar

Number of false detections generated by the vision sensor per image, specified as a nonnegative real scalar.

Example: 1.0

Lane Detector Settings

Minimum lane size in image (pixels) — Maximum size of lane

[20 5] (default) | 1-by-2 real-valued vector

Minimum size of a projected lane marking in the camera image that can be detected by the sensor after accounting for curvature, specified as a 1-by-2 real-valued vector, [minHeight minWidth]. Lane markings must exceed both of these values to be detected. Units are in pixels.

Dependencies

To enable this parameter, set the **Types of detections generated by sensor** parameter to Lanes only, Lanes only, or Lanes and objects.

Accuracy of lane boundary (pixels) — Accuracy of lane boundary

3 (default) | positive real scalar

Accuracy of lane boundaries, specified as a positive real scalar. This property defines the accuracy with which the lane sensor can place a lane boundary. Units are in pixels. This property is used only when detecting lanes.

Example: 2.5

Dependencies

To enable this parameter, set the **Types of detections generated by sensor** parameter to Lanes only, Lanes only, or Lanes and objects.

Random Number Generator Settings

Add noise to measurements — Enable adding noise to vision sensor measurements

on (default) | off

Select this check box to add noise to vision sensor measurements. Otherwise, the measurements are noise-free. The MeasurementNoise property of each detection is always computed and is not affected by the value you specify for the **Add noise to measurements** parameter.

Select method to specify initial seed — Method to specify random number generator seed

Repeatable (default) | Specify seed | Nonrepeatable

Method to set the random number generator seed, specified as Repeatable, Specify seed, or Nonrepeatable. When set to Specify seed, the value set in the InitialSeed parameter is used. When set to Repeatable, a random initial seed is generated for the first simulation and then reused for all subsequent simulations. You can, however, change the seed by issuing a clear all command. When set to Nonrepeatable, a new initial seed is generated each time the simulation runs.

Example: Specify seed

Initial seed — Random number generator seed0 (default) | nonnegative integer less than 2^{32}

Random number generator seed, specified as a nonnegative integer less than 2^{32} .

Example: 2001

Dependencies

To enable this parameter, set the Random Number Generator Settings parameter to Specify seed.

Actor Profiles**Select method to specify actor profiles — Method to specify actor profiles**

Parameters (default) | MATLAB expression

Method to specify actor profiles, specified as Parameters or MATLAB expression. When you select Parameters, set the actor profiles using the parameters in the **Actor Profiles** tab. When you select MATLAB expression, set the actor profiles using the **MATLAB expression for actor profiles** parameter.

MATLAB expression for actor profiles — MATLAB expression for actor profiles

```
struct('ClassID',0,'Length',4.7,'Width',1.8,'Height',1.4,'OriginOffset',[-1.35,0,0]) (default) | MATLAB structure | MATLAB structure array
```

MATLAB expression for actor profiles, specified as a MATLAB structure or MATLAB structure array.

Example:

```
struct('ClassID',5,'Length',5.0,'Width',2,'Height',2,'OriginOffset',  
[-1.55,0,0])
```

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to MATLAB expression.

MATLAB expression for actor profiles — MATLAB expression for actor profiles

```
struct('ClassID',0,'Length',4.7,'Width',1.8,'Height',1.4,'OriginOffset',  
[-1.35,0,0]) (default) | MATLAB structure | MATLAB structure array | valid  
MATLAB expression
```

MATLAB expression for actor profiles, specified as a MATLAB structure, a MATLAB structure array, or a valid MATLAB expression that produces such a structure or structure array.

If your Scenario Reader block reads data from a `drivingScenario` object, to obtain the actor profiles directly from this object, set this expression to call the `actorProfiles` function on the object. For example: `actorProfiles(scenario)`.

Example:

```
struct('ClassID',5,'Length',5.0,'Width',2,'Height',2,'OriginOffset',  
[-1.55,0,0])
```

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to MATLAB expression.

Unique identifier for actors — Scenario-defined actor identifier

```
[] (default) | positive integer | length-L vector of unique positive integers
```

Scenario-defined actor identifier, specified as a positive integer or length-*L* vector of unique positive integers. *L* must equal the number of actors input into the **Actor** input port. The vector elements must match **ActorID** values of the actors. You can specify **Unique identifier for actors** as []. In this case, the same actor profile parameters apply to all actors.

Example: [1,2]

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

User-defined integer to classify actors — User-defined classification identifier

0 (default) | integer | length-*L* vector of integers

User-defined classification identifier, specified as an integer or length-*L* vector of integers. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, [], you must specify this parameter as a single integer whose value applies to all actors.

Example: 2

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Length of actors cuboids (m) — Length of cuboid

4.7 (default) | positive real scalar | length-*L* vector of positive values

Length of cuboid, specified as a positive real scalar or length-*L* vector of positive values. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, [], you must specify this parameter as a positive real scalar whose value applies to all actors. Units are in meters.

Example: 6.3

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Width of actors cuboids (m) — Width of cuboid

4.7 (default) | positive real scalar | length-*L* vector of positive values

Width of cuboid, specified as a positive real scalar or length-*L* vector of positive values. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for**

actors. When **Unique identifier for actors** is empty, [], you must specify this parameter as a positive real scalar whose value applies to all actors. Units are in meters.

Example: 4.7

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Height of actors cuboids (m) — Height of cuboid

4.7 (default) | positive real scalar | length-*L* vector of positive values

Height of cuboid, specified as a positive real scalar or length-*L* vector of positive values. When **Unique identifier for actors** is a vector, this parameter is a vector of the same length with elements in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, [], you must specify this parameter as a positive real scalar whose value applies to all actors. Units are in meters.

Example: 2.0

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Rotational center of actors from bottom center (m) — Rotational center of the actor

{ [-1.35, 0, 0] } (default) | length-*L* cell array of real-valued 1-by-3 vectors

Rotational center of the actor, specified as a length-*L* cell array of real-valued 1-by-3 vectors. Each vector represents the offset of the rotational center of the actor from the bottom-center of the actor. For vehicles, the offset corresponds to the point on the ground beneath the center of the rear axle. When **Unique identifier for actors** is a vector, this parameter is a cell array of vectors with cells in one-to-one correspondence to the actors in **Unique identifier for actors**. When **Unique identifier for actors** is empty, [], you must specify this parameter as a cell array of one element containing the offset vector whose values apply to all actors. Units are in meters.

Example: [-1.35, .2, .3]

Dependencies

To enable this parameter, set the **Select method to specify actor profiles** parameter to Parameters.

Camera Intrinsics

Focal length (pixels) — Camera focal length

[800,800] (default) | two-element real-valued vector

Camera focal length, in pixels, specified as a two-element real-valued vector. See also the `FocalLength` property of `cameraIntrinsics`.

Example: [480,320]

Optical center of the camera (pixels) — Optical center of camera

[320,240] (default) | two-element real-valued vector

Optical center of the camera, in pixels, specified as a two-element real-valued vector. See also the `PrincipalPoint` property of `cameraIntrinsics`.

Example: [480,320]

Image size produced by the camera (pixels) — Image size produced by camera

[480,640] (default) | two-element vector of positive integers

Image size produced by the camera, in pixels, specified as a two-element vector of positive integers. See also the `ImageSize` property of `cameraIntrinsics`.

Example: [240,320]

Radial distortion coefficients — Radial distortion coefficients

[0,0] (default) | two-element real-valued vector | three-element real-valued vector

Radial distortion coefficients, specified as a two-element or three-element real-valued vector. For details on setting these coefficients, see the `RadialDistortion` property of `cameraIntrinsics`.

Example: [1,1]

Tangential distortion coefficients — Tangential distortion coefficients

[0,0] (default) | two-element real-valued vector

Tangential distortion coefficients, specified as a two-element real-valued vector. For details on setting these coefficients, see the `TangentialDistortion` property of `cameraIntrinsics`.

Example: [1,1]

Skew of the camera axes — Skew angle of camera axes

0 (default) | real scalar

Skew angle of the camera axes, specified as a real scalar. See also the Skew property of `cameraIntrinsics`.

Example: 0.1

See Also

Bird's-Eye Scope | [Detection Concatenation](#) | [Multi-Object Tracker](#) | [Radar Detection Generator](#) | [Scenario Reader](#) | `cameraIntrinsics` | `visionDetectionGenerator`

Topics

"Getting Started with Buses" (Simulink)

Introduced in R2017b

Functions in Automated Driving Toolbox

addCustomBasemap

Add custom basemap

Syntax

```
addCustomBasemap(basemapName,URL)  
addCustomBasemap( ____,Name,Value)
```

Description

`addCustomBasemap(basemapName,URL)` adds the custom basemap specified by `URL` to the list of basemaps available for use with mapping functions. `basemapName` is the name you choose to call the custom basemap. Added basemaps remain available for use in future MATLAB sessions.

You can use the custom basemap with the `geoplayer` object and with MATLAB geographic axes and charts.

`addCustomBasemap(____,Name,Value)` specifies name-value pairs that set additional parameters of the basemap.

Examples

Display Data on OpenStreetMap Basemap

This example shows how to display a driving route and vehicle positions on an OpenStreetMap® basemap.

Add the OpenStreetMap basemap to the list of basemaps available for use with the `geoplayer` object. After you add the basemap, you do not need to add it again in future sessions.

```
name = 'openstreetmap';  
url = 'https://a.tile.openstreetmap.org/{z}/{x}/{y}.png';
```



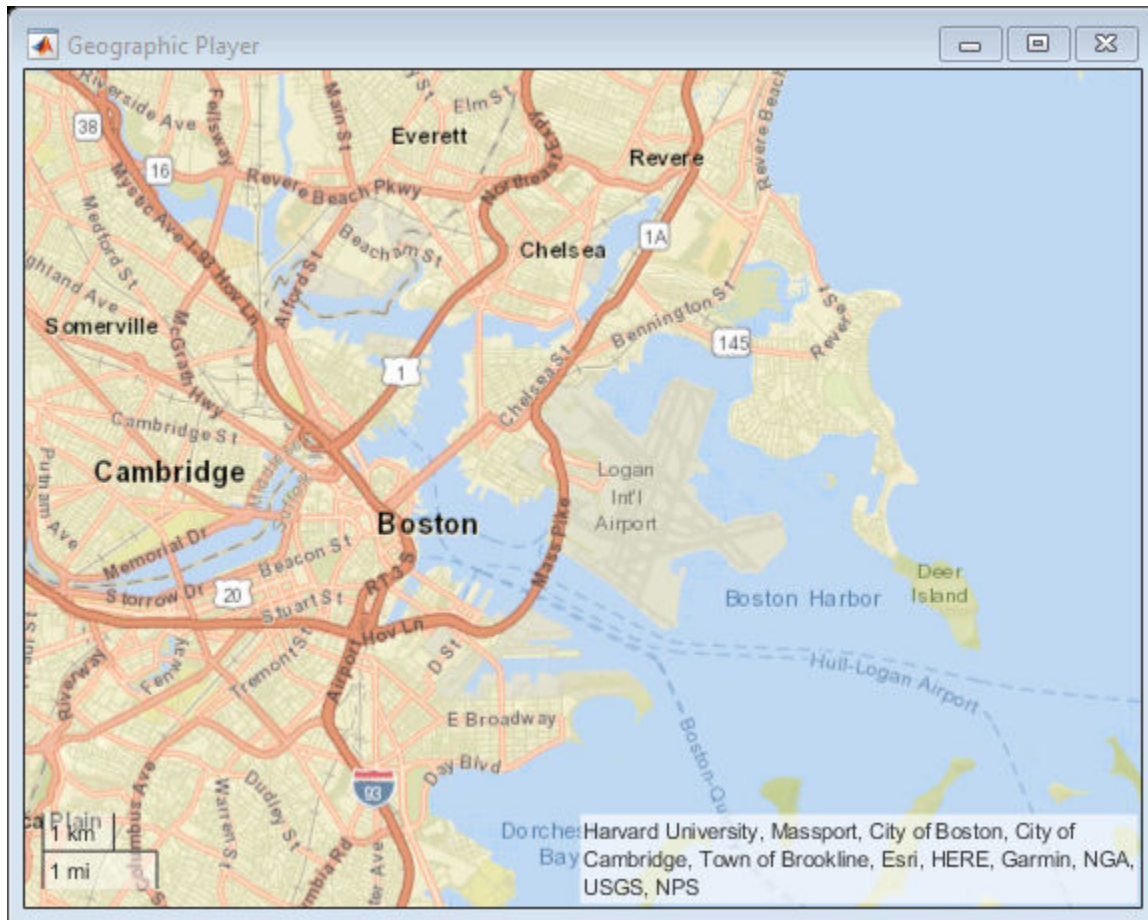
```
copyright = char(uint8(169));  
attribution = copyright + "OpenStreetMap contributors";  
addCustomBasemap(name,url,'Attribution',attribution)
```

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

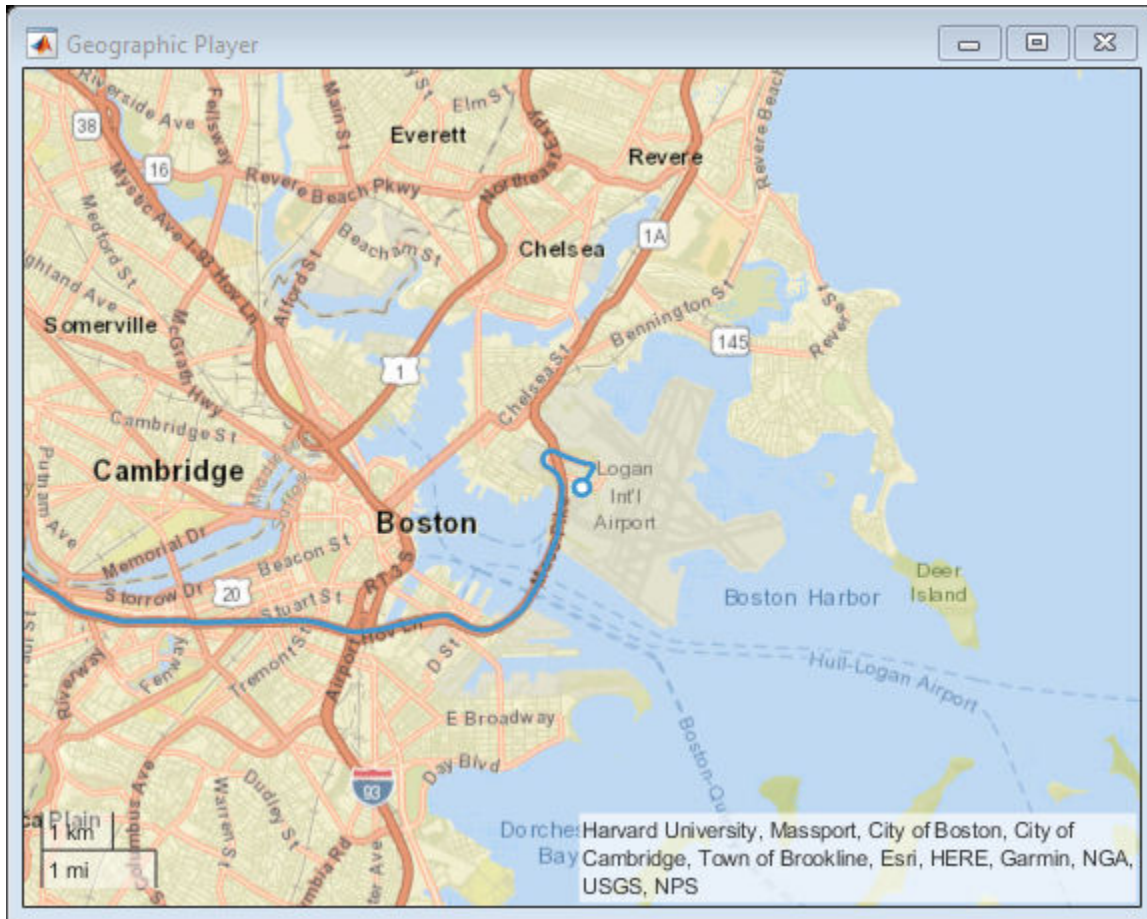
Create a geographic player. Center the geographic player on the first position of the driving route and set the zoom level to 12.

```
zoomLevel = 12;  
player = geoplayer(data.latitude(1),data.longitude(1),zoomLevel);
```



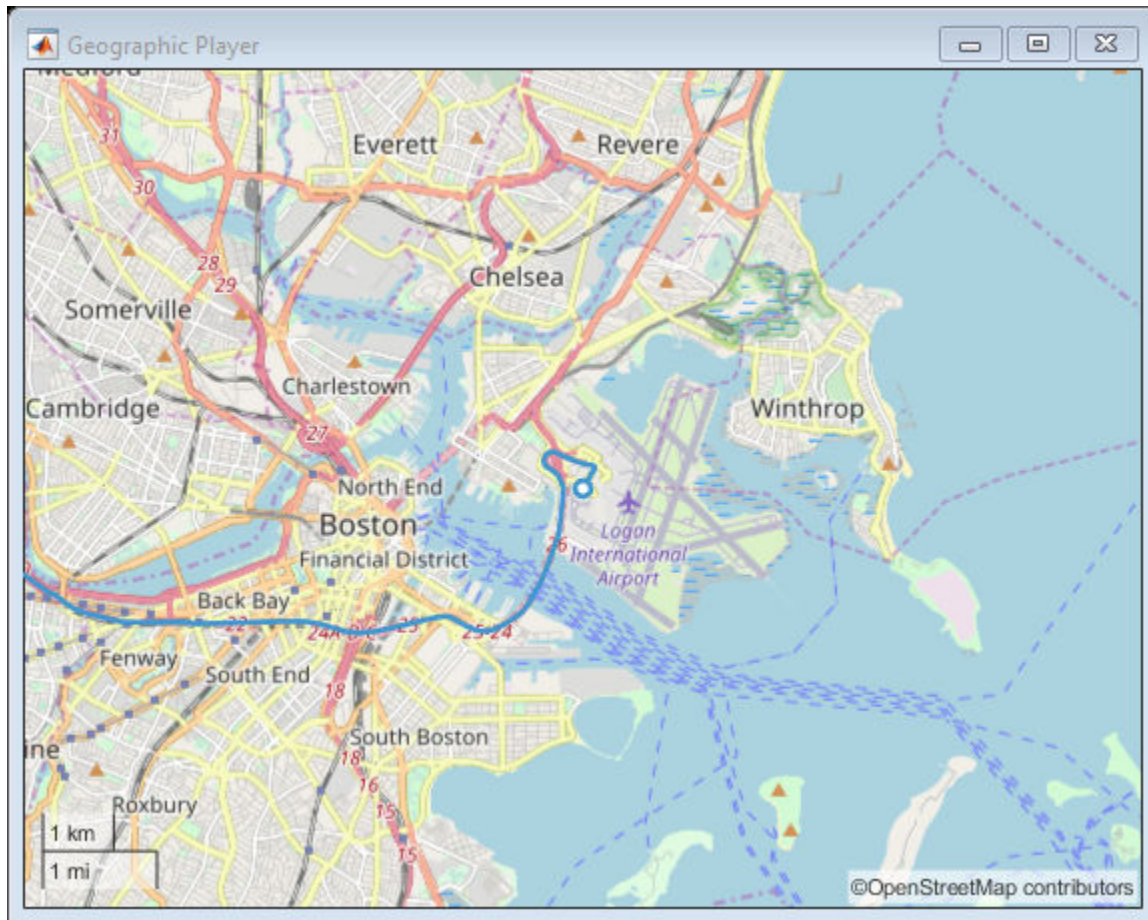
Display the full route.

```
plotRoute(player,data.latitude,data.longitude);
```



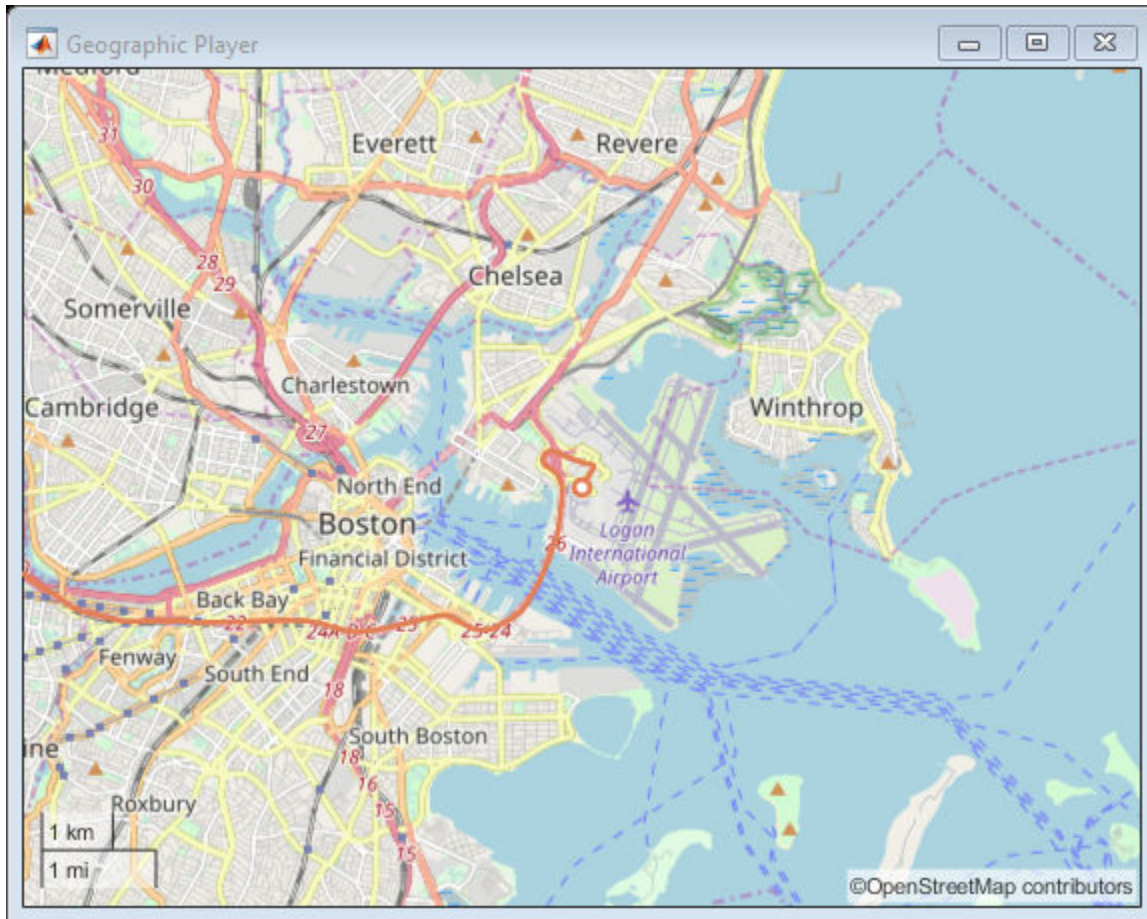
By default, the geographic player uses the World Street Map basemap ('streets') provided by Esri®. Update the geographic player to use the added OpenStreetMap basemap instead.

```
player.Basemap = 'openstreetmap';
```



Display the route again.

```
plotRoute(player,data.latitude,data.longitude);
```

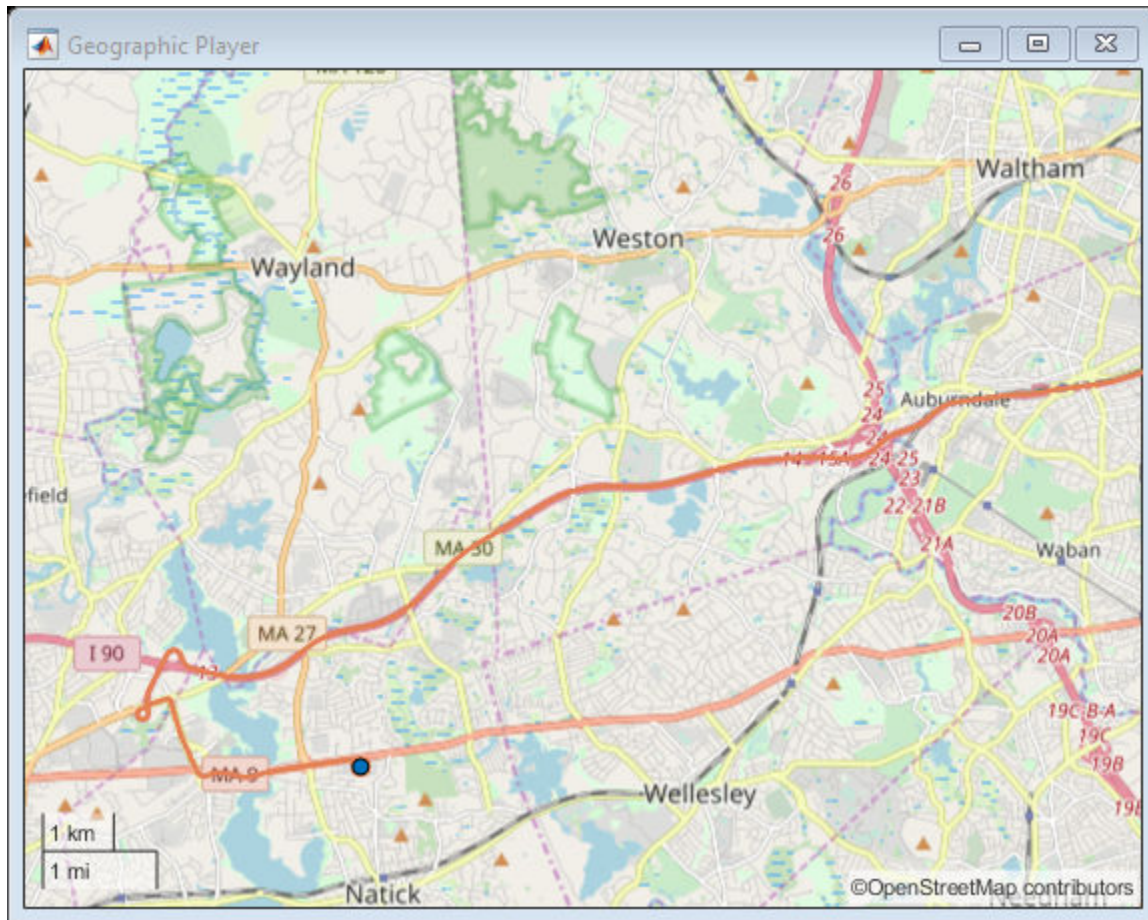


Display the positions of the vehicle in a sequence.

```

for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i))
end

```



Display Map Data on HERE Basemap

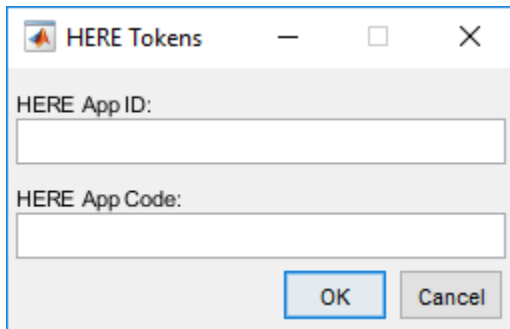
Display a driving route on a basemap provided by HERE Technologies. To use this example, you must have a valid license from HERE Technologies.

Specify the basemap name and map URL.

```
name = 'herestreets';
url = ['https://2.base.maps.cit.api.here.com/maptile/2.1/maptile/', ...
      'newest/normal.day/{z}/{x}/{y}/256/png?app_id=%s&app_code=%s'];
```

Maps from HERE Technologies require a valid license. Create a dialog box. In the dialog box, enter the App ID and App Code corresponding to your HERE license.

```
prompt = {'HERE App ID:', 'HERE App Code:'};
title = 'HERE Tokens';
dims = [1 40]; % Text edit field height and width
hereTokens = inputdlg(prompt,title,dims);
```



If the license is valid, specify the HERE credentials and a custom attribution, load coordinate data, and display the coordinates on the HERE basemap using a `geoplayer` object. If the license is not valid, display an error message.

```
if ~isempty(hereTokens)

    % Add HERE basemap with custom attribution.
    url = sprintf(url,hereTokens{1},hereTokens{2});
    copyrightSymbol = char(169); % Alt code
    attribution = [copyrightSymbol, ' ', datestr(now, 'yyyy'), ' HERE'];
    addCustomBasemap(name,url,'Attribution',attribution);

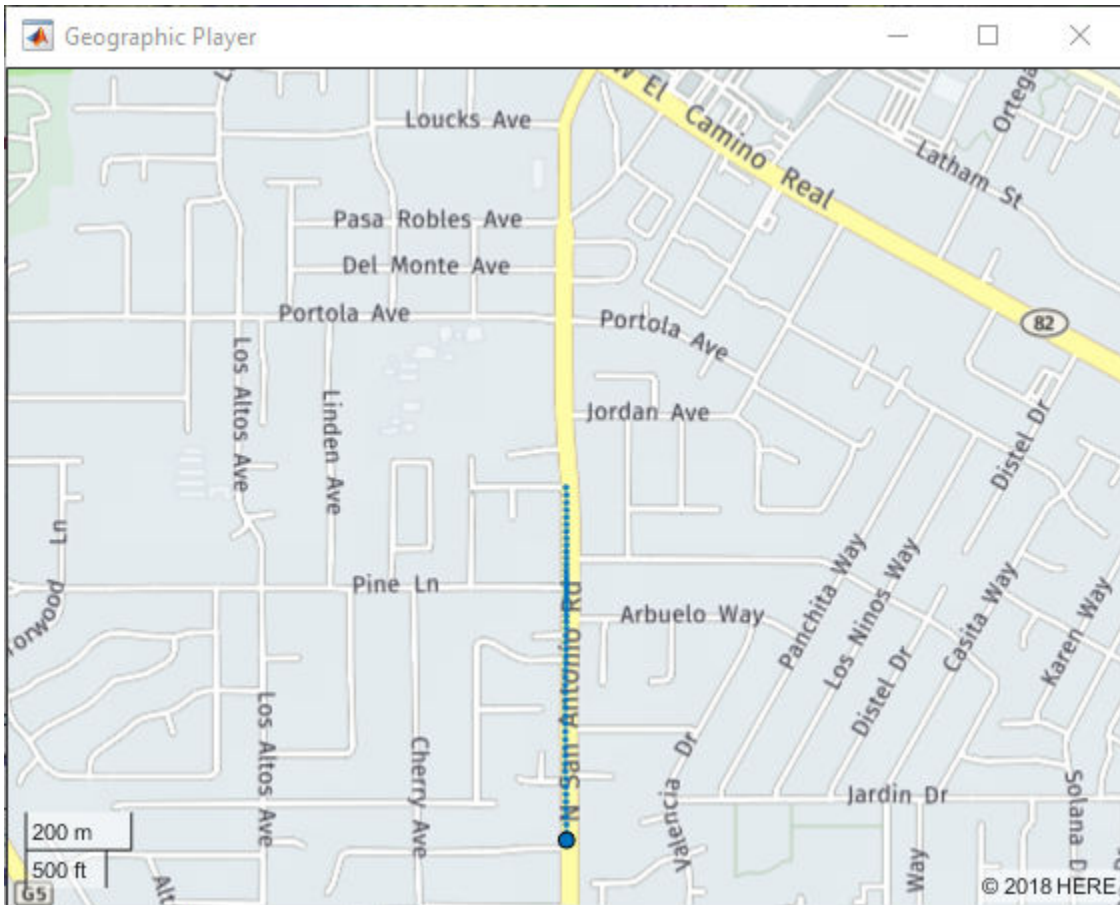
    % Load sample lat,lon coordinates.
    data = load('geoSequence.mat');

    % Create geoplayer with HERE basemap.
    player = geoplayer(data.latitude(1),data.longitude(1), ...
                      'Basemap','herestreets','HistoryDepth',Inf);

    % Display the coordinates in a sequence.
```

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
end

else
    error('You must enter valid credentials to access maps from HERE Technologies');
end
```

Input Arguments

basemapName — Name used to identify basemap programmatically

string scalar | character vector

Name used to identify basemap programmatically, specified as a string scalar or character vector.

Example: 'openstreetmap'

Data Types: string | char

URL — Parameterized map URL

string scalar | character vector

Parameterized map URL, specified as a string scalar or character vector. A parameterized URL is an index of the map tiles, formatted as `#{z}/#{x}/#{y}.png` or `{z}/{x}/{y}.png`, where:

- `#{z}` or `{z}` is the tile zoom level.
- `#{x}` or `{x}` is the tile column index.
- `#{y}` or `{y}` is the tile row index.

Example: `'https://hostname/#{z}/#{x}/#{y}.png'`

Data Types: string | char

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `addCustomBasemap(basemapName, URL, 'Attribution', attribution)`

Attribution — Attribution of custom basemap

'Tiles courtesy of *DOMAIN_NAME_OF_URL*' (default) | string scalar | string array | character vector | cell array of character vectors

Attribution of custom basemap, specified as the comma-separated pair consisting of 'Attribution' and a string scalar, string array, character vector, or cell array of character vectors. If the host is 'localhost', or if URL contains only IP numbers, specify an empty value (''). To create a multiline attribution, specify a string array or nonscalar cell array of character vectors.

If you do not specify an attribution, the default attribution is 'Tiles courtesy of *DOMAIN_NAME_OF_URL*', where the `addCustomBasemap` function obtains the domain name from the URL input argument.

Example: `'Credit: U.S. Geological Survey'`

Data Types: string | char | cell

DisplayName — Display name of custom basemap

string scalar | character vector

Display name of the custom basemap, specified as the comma-separated pair consisting of 'DisplayName' and a string scalar or character vector.

Example: 'OpenStreetMap'

Data Types: string | char

MaxZoomLevel — Maximum zoom level of basemap

18 (default) | integer in the range [0, 25]

Maximum zoom level of the basemap, specified as the comma-separated pair consisting of 'MaxZoomLevel' and an integer in the range [0, 25].

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

IsDeployable — Map is deployable using MATLAB Compiler™

false (default) | true

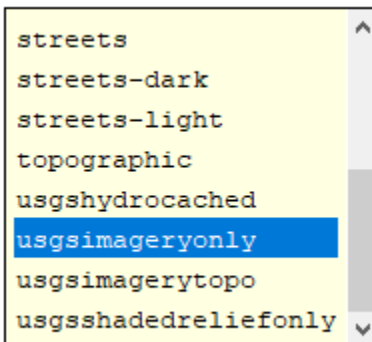
Map is deployable using MATLAB Compiler, specified as the comma-separated pair consisting of 'IsDeployable' and false or true.

If you are deploying a map application and want users to have access to the added basemap, set 'IsDeployable' to true. Maps in the `geoplayer` object are not deployable. If you are using a `geoplayer` object, leave 'IsDeployable' set to false.

Data Types: logical

Tips

- You can find tiled web maps from various vendors, such as OpenStreetMap®, the USGS National Map, Mapbox, DigitalGlobe, Esri® ArcGIS Online, the Geospatial Information Authority of Japan (GSI), and HERE Technologies. Abide by the map vendors terms-of-service agreement and include accurate attribution with the maps you use.
- To access a list of available basemaps, press **Tab** before specifying the basemap in your plotting function.



```
geobubble(lat, lon, 'Basemap', '
```

See Also

[geoaxes](#) | [geobasemap](#) | [geobubble](#) | [geodensityplot](#) | [geoplayer](#) | [geoplot](#) | [geoscatter](#) | [removeCustomBasemap](#)

Introduced in R2019a

cameas

Measurement function for constant-acceleration motion

Syntax

```
measurement = cameas(state)
measurement = cameas(state, frame)
measurement = cameas(state, frame, sensorpos)
measurement = cameas(state, frame, sensorpos, sensorvel)
measurement = cameas(state, frame, sensorpos, sensorvel, laxes)
measurement = cameas(state, measurementParameters)
```

Description

`measurement = cameas(state)` returns the measurement, for the constant-acceleration Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the filter.

`measurement = cameas(state, frame)` also specifies the measurement coordinate system, `frame`.

`measurement = cameas(state, frame, sensorpos)` also specifies the sensor position, `sensorpos`.

`measurement = cameas(state, frame, sensorpos, sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurement = cameas(state, frame, sensorpos, sensorvel, laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurement = cameas(state, measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Create Measurement from Accelerating Object in Rectangular Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. The measurements are in rectangular coordinates.

```
state = [1,10,3,2,20,0.5].';  
measurement = cameas(state)
```

```
measurement = 3×1
```

```
    1  
    2  
    0
```

The measurement is returned in three-dimensions with the z-component set to zero.

Create Measurement from Accelerating Object in Spherical Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. The measurements are in spherical coordinates.

```
state = [1,10,3,2,20,5].';  
measurement = cameas(state, 'spherical')
```

```
measurement = 4×1
```

```
63.4349  
    0  
 2.2361  
22.3607
```

The elevation of the measurement is zero and the range rate is positive. These results indicate that the object is moving away from the sensor.

Create Measurement from Accelerating Object in Translated Spherical Frame

Define the state of an object moving in 2-D constant-acceleration motion. The state consists of position, velocity, and acceleration in each dimension. The measurements are in spherical coordinates with respect to a frame located at $(20;40;0)$ meters from the origin.

```
state = [1,10,3,2,20,5].';
measurement = cameas(state, 'spherical', [20;40;0])
```

```
measurement = 4×1
```

```
-116.5651
      0
   42.4853
  -22.3607
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

Create Measurement from Constant-Accelerating Object Using Measurement Parameters

Define the state of an object moving in 2-D constant-acceleration motion. The state consists of position, velocity, and acceleration in each dimension. The measurements are in spherical coordinates with respect to a frame located at $(20;40;0)$ meters from the origin.

```
state2d = [1,10,3,2,20,5].';
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

```
frame = 'spherical';
sensorpos = [20;40;0];
sensorvel = [0;5;0];
laxes = eye(3);
measurement = cameas(state2d, 'spherical', sensorpos, sensorvel, axes)
```

```
measurement = 4×1
```

```
-116.5651  
      0  
  42.4853  
 -17.8885
```

The elevation of the measurement is zero and the range rate is negative. These results indicate that the object is moving toward the sensor.

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,  
    'Orientation',laxes);  
measurement = cameas(state2d,measparm)  
  
measurement = 4×1
```

```
-116.5651  
      0  
  42.4853  
 -17.8885
```

Input Arguments

state — Kalman filter state vector

real-valued $3N$ -element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued $3N$ -element vector. N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx;ax]
2-D	[x;vx;ax;y;vy;ay]
3-D	[x;vx;ax;y;vy;ay;z;vz;az]

For example, x represents the x -coordinate, v_x represents the velocity in the x -direction, and a_x represents the acceleration in the x -direction. If the motion model is in one-dimensional space, the y - and z -axes are assumed to be zero. If the motion model is in

two-dimensional space, values along the z-axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second².

Example: [5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]

Data Types: double

frame — Measurement frame

'rectangular' (default) | 'spherical'

Measurement frame, specified as 'rectangular' or 'spherical'. When the frame is 'rectangular', a measurement consists of the x, y, and z Cartesian coordinates of the tracked object. When specified as 'spherical', a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: char

sensorpos — Sensor position

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: double

sensorvel — Sensor velocity

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: double

laxes — Local sensor coordinate axes

[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x-, y-, and z-axes, respectively, with respect to the global coordinate system.

Data Types: double

measurementParameters — Measurement parameters

structure | array of structure

Measurement parameters, specified as a structure or an array of structures. The fields of the structure are:

Field	Description	Example
Frame	Frame used to report measurements, specified as one of these values: <ul style="list-style-type: none"> 'rectangular' — Detections are reported in rectangular coordinates. 'spherical' — Detections are reported in spherical coordinates. 	'spherical'
OriginPosition	Position offset of the origin of the frame relative to the parent frame, specified as an [x y z] real-valued vector.	[0 0 0]
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, specified as a [vx vy vz] real-valued vector.	[0 0 0]
Orientation	Frame rotation matrix, specified as a 3-by-3 real-valued orthonormal matrix.	[1 0 0; 0 1 0; 0 0 1]
HasAzimuth	Logical scalar indicating if azimuth is included in the measurement.	1

Field	Description	Example
HasElevation	Logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the reported measurements assume 0 degrees of elevation.	1
HasRange	Logical scalar indicating if range is included in the measurement.	1
HasVelocity	Logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if HasVelocity is false, the measurements are reported as [x y z]. If HasVelocity is true, measurements are reported as [x y z vx vy vz].	1
IsParentToChild	Logical scalar indicating if Orientation performs a frame rotation from the parent coordinate frame to the child coordinate frame. When IsParentToChild is false, then Orientation performs a frame rotation from the child coordinate frame to the parent coordinate frame.	0

Data Types: struct

Output Arguments

measurement — Measurement vector

N-by-1 column vector

Measurement vector, returned as an *N*-by-1 column vector. The form of the measurement depends upon which syntax you use.

- When the syntax does not use the `measurementParameters` argument, the measurement vector is $[x, y, z]$ when the frame input argument is set to 'rectangular' and $[az;el;r;rr]$ when the frame is set to 'spherical'.
- When the syntax uses the `measurementParameters` argument, the size of the measurement vector depends on the values of the `frame`, `HasVelocity`, and `HasElevation` fields in the `measurementParameters` structure.

frame	measurement			
'spherical'	Specifies the azimuth angle, <i>az</i> , elevation angle, <i>el</i> , range, <i>r</i> , and range rate, <i>rr</i> , of the object with respect to the local ego vehicle coordinate system. Positive values for range rate indicate that an object is moving away from the sensor.			
	Spherical measurements			
		HasElevation		
		false	true	
HasVelocity	false	[az; r]	[az; el; r]	
	true	[az; r; r]	[az; el; r; rr]	
	Angle units are in degrees, range units are in meters, and range rate units are in m/s.			

frame	measurement	
'rectangular'	Specifies the Cartesian position and velocity coordinates of the tracked object with respect to the ego vehicle coordinate system.	
	Rectangular measurements	
	HasVelocit y	false true
Position units are in meters and velocity units are in m/s.		

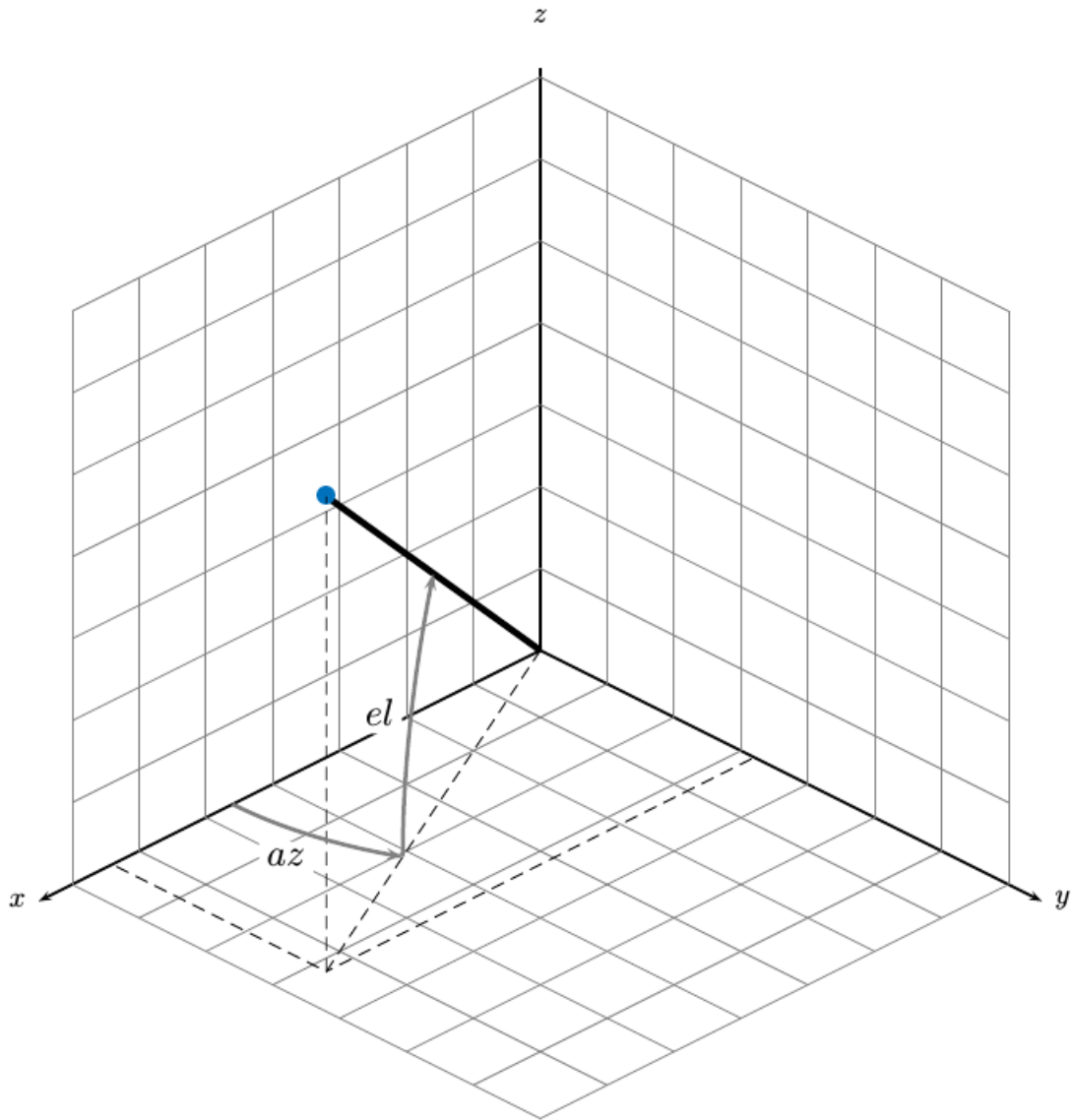
Data Types: double

More About

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Automated Driving Toolbox.

The azimuth angle of a vector is the angle between the x -axis and its orthogonal projection onto the xy plane. The angle is positive in going from the x axis toward the y axis. Azimuth angles lie between -180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the xy -plane. The angle is positive when going toward the positive z -axis from the xy plane.



Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

cameasjac

Jacobian of measurement function for constant-acceleration motion

Syntax

```
measurementjac = cameasjac(state)
measurementjac = cameasjac(state, frame)
measurementjac = cameasjac(state, frame, sensorpos)
measurementjac = cameasjac(state, frame, sensorpos, sensorvel)
measurementjac = cameasjac(state, frame, sensorpos, sensorvel, laxes)
measurementjac = cameasjac(state, measurementParameters)
```

Description

`measurementjac = cameasjac(state)` returns the measurement Jacobian, for constant-acceleration Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the filter.

`measurementjac = cameasjac(state, frame)` also specifies the measurement coordinate system, `frame`.

`measurementjac = cameasjac(state, frame, sensorpos)` also specifies the sensor position, `sensorpos`.

`measurementjac = cameasjac(state, frame, sensorpos, sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurementjac = cameasjac(state, frame, sensorpos, sensorvel, laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurementjac = cameasjac(state, measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Measurement Jacobian of Accelerating Object in Rectangular Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Construct the measurement Jacobian in rectangular coordinates.

```
state = [1,10,3,2,20,5].';
jacobian = cameasjac(state)
```

```
jacobian = 3×6
```

```

     1     0     0     0     0     0
     0     0     0     1     0     0
     0     0     0     0     0     0
```

Measurement Jacobian of Accelerating Object in Spherical Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Compute the measurement Jacobian in spherical coordinates.

```
state = [1;10;3;2;20;5];
measurementjac = cameasjac(state, 'spherical')
```

```
measurementjac = 4×6
```

```

-22.9183     0     0    11.4592     0     0
     0     0     0     0     0     0
  0.4472     0     0    0.8944     0     0
  0.0000    0.4472     0    0.0000    0.8944     0
```

Measurement Jacobian of Accelerating Object in Translated Spherical Frame

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Compute the measurement Jacobian in spherical coordinates with respect to an origin at (5;-20;0) meters.

```
state = [1,10,3,2,20,5].';  
sensorpos = [5,-20,0].';  
measurementjac = cameasjac(state,'spherical',sensorpos)
```

```
measurementjac = 4×6
```

```
-2.5210         0         0    -0.4584         0         0  
         0         0         0         0         0         0  
-0.1789         0         0     0.9839         0         0  
0.5903    -0.1789         0     0.1073     0.9839         0
```

Create Measurement Jacobian of Accelerating Object Using Measurement Parameters

Define the state of an object in 2-D constant-acceleration motion. The state is the position, velocity, and acceleration in both dimensions. Compute the measurement Jacobian in spherical coordinates with respect to an origin at (5;-20;0) meters.

```
state2d = [1,10,3,2,20,5].';  
sensorpos = [5,-20,0].';  
frame = 'spherical';  
sensorvel = [0;8;0];  
laxes = eye(3);  
measurementjac = cameasjac(state2d,frame,sensorpos,sensorvel,laxes)
```

```
measurementjac = 4×6
```

```
-2.5210         0         0    -0.4584         0         0  
         0         0         0         0         0         0  
-0.1789         0         0     0.9839         0         0  
0.5274    -0.1789         0     0.0959     0.9839         0
```

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,  
    'Orientation',laxes);  
measurementjac = cameasjac(state2d,measparm)
```

```
measurementjac = 4×6
```

```

-2.5210      0      0      -0.4584      0      0
      0      0      0      0      0      0
-0.1789      0      0      0.9839      0      0
0.5274     -0.1789      0      0.0959      0.9839      0

```

Input Arguments

state — Kalman filter state vector

real-valued $3N$ -element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued $3N$ -element vector. N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x; vx; ax]
2-D	[x; vx; ax; y; vy; ay]
3-D	[x; vx; ax; y; vy; ay; z; vz; az]

For example, x represents the x -coordinate, vx represents the velocity in the x -direction, and ax represents the acceleration in the x -direction. If the motion model is in one-dimensional space, the y - and z -axes are assumed to be zero. If the motion model is in two-dimensional space, values along the z -axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second².

Example: [5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]

Data Types: double

frame — Measurement frame

'rectangular' (default) | 'spherical'

Measurement frame, specified as 'rectangular' or 'spherical'. When the frame is 'rectangular', a measurement consists of the x , y , and z Cartesian coordinates of the tracked object. When specified as 'spherical', a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: char

sensorpos — Sensor position

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: double

sensorvel — Sensor velocity

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: double

laxes — Local sensor coordinate axes

[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x-, y-, and z-axes, respectively, with respect to the global coordinate system.

Data Types: double

measurementParameters — Measurement parameters

structure | array of structure

Measurement parameters, specified as a structure or an array of structures. The fields of the structure are:

Field	Description	Example
Frame	<p>Frame used to report measurements, specified as one of these values:</p> <ul style="list-style-type: none"> 'rectangular' — Detections are reported in rectangular coordinates. 'spherical' — Detections are reported in spherical coordinates. 	'spherical'
OriginPosition	Position offset of the origin of the frame relative to the parent frame, specified as an [x y z] real-valued vector.	[0 0 0]
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, specified as a [vx vy vz] real-valued vector.	[0 0 0]
Orientation	Frame rotation matrix, specified as a 3-by-3 real-valued orthonormal matrix.	[1 0 0; 0 1 0; 0 0 1]
HasAzimuth	Logical scalar indicating if azimuth is included in the measurement.	1
HasElevation	Logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the reported measurements assume 0 degrees of elevation.	1

Field	Description	Example
HasRange	Logical scalar indicating if range is included in the measurement.	1
HasVelocity	Logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if <code>HasVelocity</code> is false, the measurements are reported as <code>[x y z]</code> . If <code>HasVelocity</code> is true, measurements are reported as <code>[x y z vx vy vz]</code> .	1
IsParentToChild	Logical scalar indicating if <code>Orientation</code> performs a frame rotation from the parent coordinate frame to the child coordinate frame. When <code>IsParentToChild</code> is false, then <code>Orientation</code> performs a frame rotation from the child coordinate frame to the parent coordinate frame.	0

Data Types: struct

Output Arguments

measurementjac — Measurement Jacobian

real-valued 3-by- N matrix | real-valued 4-by- N matrix

Measurement Jacobian, specified as a real-valued 3-by- N or 4-by- N matrix. N is the dimension of the state vector. The interpretation of the rows and columns depends on the frame argument, as described in this table.

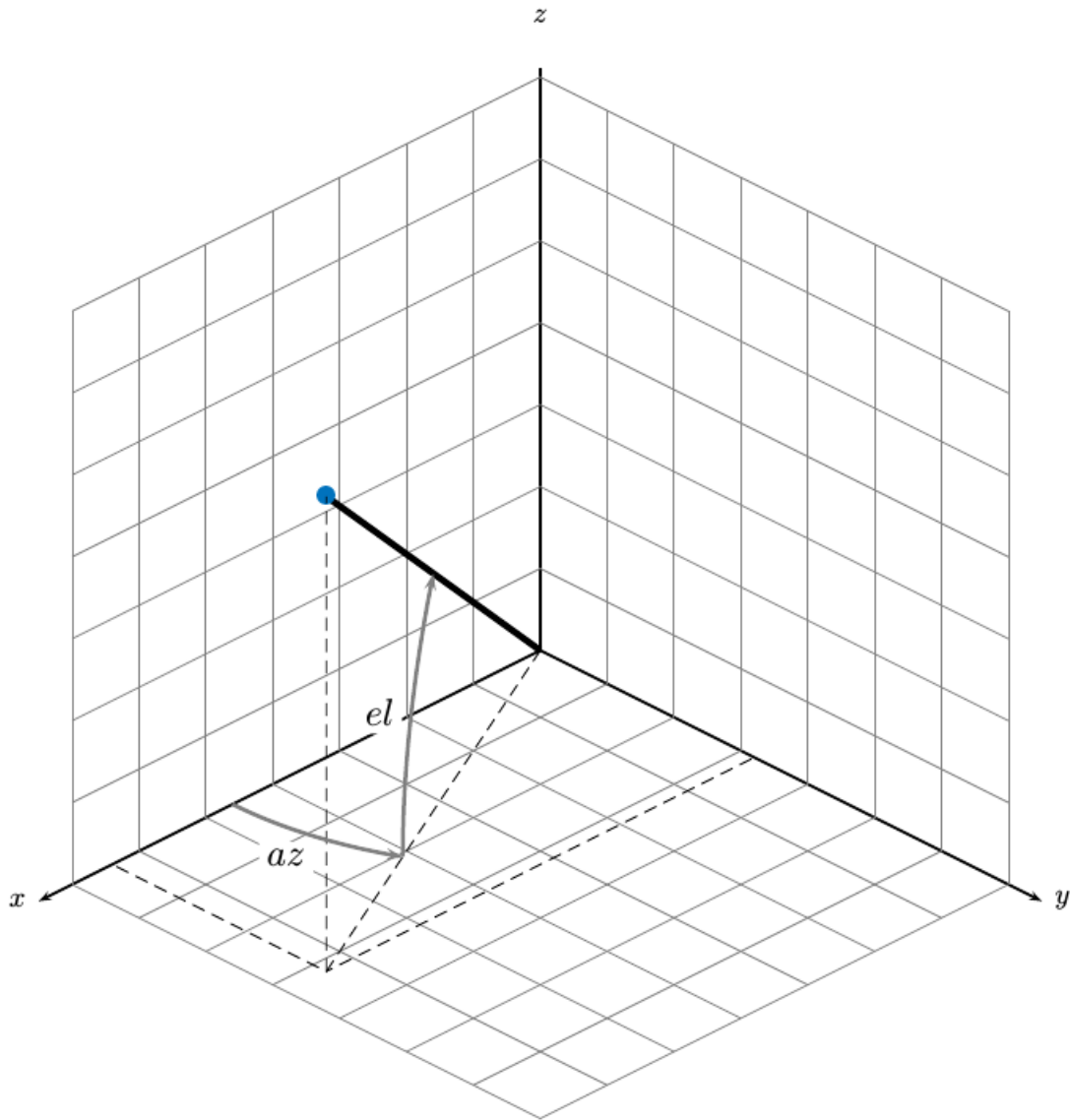
Frame	Measurement Jacobian
'rectangular'	Jacobian of the measurements $[x; y; z]$ with respect to the state vector. The measurement vector is with respect to the local coordinate system. Coordinates are in meters.
'spherical'	Jacobian of the measurement vector $[az; el; r; rr]$ with respect to the state vector. Measurement vector components specify the azimuth angle, elevation angle, range, and range rate of the object with respect to the local sensor coordinate system. Angle units are in degrees. Range units are in meters and range rate units are in meters/second.

More About

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Automated Driving Toolbox.

The azimuth angle of a vector is the angle between the x -axis and its orthogonal projection onto the xy plane. The angle is positive in going from the x axis toward the y axis. Azimuth angles lie between -180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the xy -plane. The angle is positive when going toward the positive z -axis from the xy plane.



Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

checkPathValidity

Check validity of planned vehicle path

Syntax

```
isValid = checkPathValidity(refPath,costmap)  
isValid = checkPathValidity(refPoses,costmap)
```

Description

`isValid = checkPathValidity(refPath,costmap)` checks the validity of a planned vehicle path, `refPath`, against the vehicle costmap. Use this function to test if a path is valid within a changing environment.

A path is valid if the following conditions are true:

- The path has at least one pose.
- The path is collision-free and within the limits of `costmap`.

`isValid = checkPathValidity(refPoses,costmap)` checks the validity of a sequence of vehicle poses, `refPoses`, against the vehicle costmap.

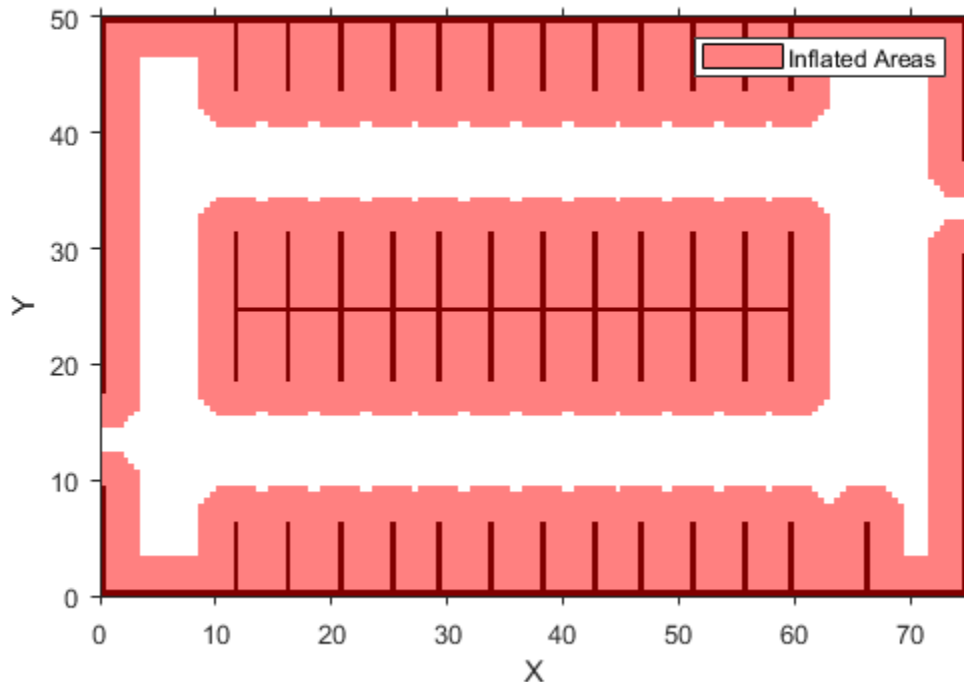
Examples

Plan Path and Check Its Validity

Plan a vehicle path through a parking lot by using the optimal rapidly exploring random tree (RRT*) algorithm. Check that the path is valid, and then plot the transition poses along the path.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmap.mat');
costmap = data.parkingLotCostmap;
plot(costmap)
```



Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x, y) locations are in meters. World units for the θ orientation angles are in degrees.

```
startPose = [4, 4, 90]; % [meters, meters, degrees]
goalPose = [30, 13, 0];
```

Use a `pathPlannerRRT` object to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Check that the path is valid.

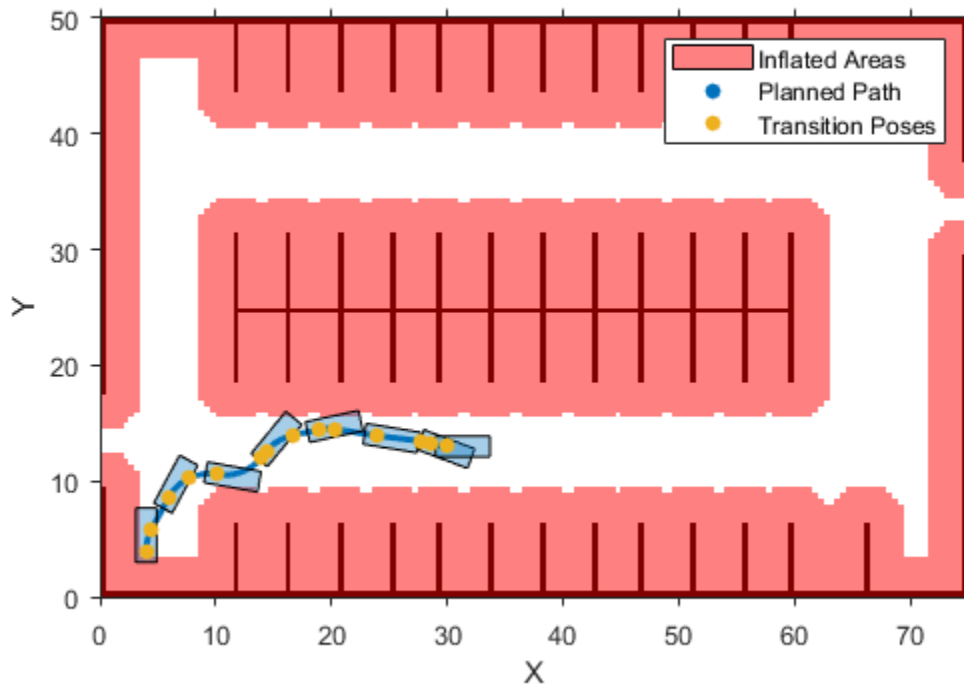
```
isPathValid = checkPathValidity(refPath,costmap)
isPathValid = logical
    1
```

Interpolate the transition poses along the path.

```
transitionPoses = interpolate(refPath);
```

Plot the planned path and the transition poses on the costmap.

```
hold on
plot(refPath,'DisplayName','Planned Path')
scatter(transitionPoses(:,1),transitionPoses(:,2),[],'filled', ...
        'DisplayName','Transition Poses')
hold off
```



Input Arguments

refPath — Planned vehicle path

`driving.Path` object

Planned vehicle path, specified as a `driving.Path` object.

costmap — Costmap used for collision checking

`vehicleCostmap` object

Costmap used for collision checking, specified as a `vehicleCostmap` object.

refPoses — Sequence of vehicle poses

m-by-3 matrix of $[x, y, \theta]$ vectors

Sequence of vehicle poses, specified as an *m*-by-3 matrix of $[x, y, \theta]$ vectors. *m* is the number of specified poses.

x and *y* specify the location of the vehicle. These values must be in the same world units used by `costmap`.

θ specifies the orientation angle of the vehicle in degrees.

Output Arguments

isValid — Indicates validity of path or poses

1 | 0

Indicates validity of the planned vehicle path, `refPath`, or the sequence of vehicle poses, `refPoses`, returned as a logical value of 1 or 0.

A path or sequence of poses is valid (1) if the following conditions are true:

- The path or pose sequence has at least one pose.
- The path or pose sequence is collision-free and within the limits of `costmap`.

Algorithms

To check if a vehicle path is valid, the `checkPathValidity` function discretizes the path. Then, the function checks that the poses at the discretized points are collision-free. The threshold for a collision-free pose depends on the resolution at which `checkPathValidity` discretizes.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

plan | plot

Objects

driving.Path | pathPlannerRRT | vehicleCostmap

Topics

“Automated Parking Valet”

Introduced in R2018a

configureDetectorMonoCamera

Configure object detector for using calibrated monocular camera

Syntax

```
configuredDetector = configureDetectorMonoCamera(detector,sensor,  
objectSize)
```

Description

`configuredDetector = configureDetectorMonoCamera(detector,sensor,objectSize)` configures an ACF (aggregate channel features), Faster R-CNN (regions with convolutional neural networks), Fast R-CNN or YOLO v2 object detector to detect objects of a known size on a ground plane. Specify your trained object detector, `detector`, a camera configuration for transforming image coordinates to world coordinates, `sensor`, and the range of the object widths and lengths, `objectSize`.

Examples

Detect Vehicles Using Monocular Camera and ACF

Configure an ACF object detector for use with a monocular camera mounted on an ego vehicle. Use this detector to detect vehicles within video frames captured by the camera.

Load an `acfObjectDetector` object pretrained to detect vehicles.

```
detector = vehicleDetectorACF;
```

Model a monocular camera sensor by creating a `monoCamera` object. This object contains the camera intrinsics and the location of the camera on the ego vehicle.

```
focalLength = [309.4362 344.2161];    % [fx fy]  
principalPoint = [318.9034 257.5352]; % [cx cy]  
imageSize = [480 640];              % [mrows ncols]
```



```

height = 2.1798; % height of camera above ground, in meters
pitch = 14; % pitch of camera, in degrees
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);

```

```

monCam = monoCamera(intrinsics,height,'Pitch',pitch);

```

Configure the detector for use with the camera. Limit the width of detected objects to a typical range for vehicle widths: 1.5–2.5 meters. The configured detector is an `acfObjectDetectorMonoCamera` object.

```

vehicleWidth = [1.5 2.5];
detectorMonoCam = configureDetectorMonoCamera(detector,monCam,vehicleWidth);

```

Load a video captured from the camera, and create a video reader and player.

```

videoFile = fullfile(toolboxdir('driving'),'drivingdata','caltech_washington1.avi');
reader = vision.VideoFileReader(videoFile,'VideoOutputDataType','uint8');
videoPlayer = vision.VideoPlayer('Position',[29 597 643 386]);

```

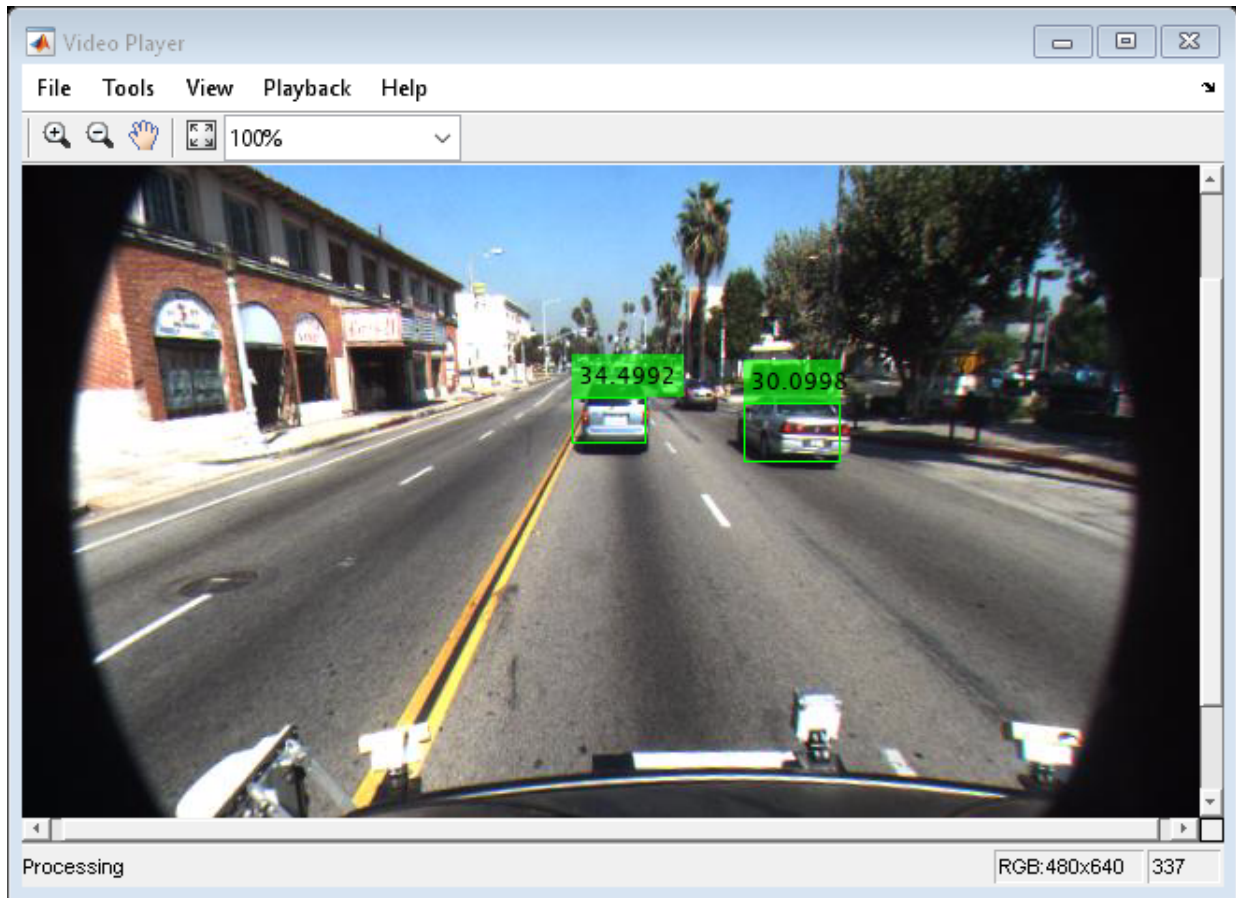
Run the detector in a loop over the video. Annotate the video with the bounding boxes for the detections and the detection confidence scores.

```

cont = ~isDone(reader);
while cont
    I = reader();

    % Run the detector.
    [bboxes,scores] = detect(detectorMonoCam,I);
    if ~isempty(bboxes)
        I = insertObjectAnnotation(I, ...
            'rectangle',bboxes, ...
            scores, ...
            'Color','g');
    end
    videoPlayer(I)
    % Exit the loop if the video player figure is closed.
    cont = ~isDone(reader) && isOpen(videoPlayer);
end

```



Input Arguments

detector — Object detector to configure

acfObjectDetector object | fastRCNNObjectDetector object |
fasterRCNNObjectDetector object | yolov2ObjectDetector object

Object detector to configure, specified as one of these object detector objects:

- acfObjectDetector

- `fastRCNNObjectDetector`
- `fasterRCNNObjectDetector`
- `yolov2ObjectDetector`

Train the object detector before configuring them by using:

- `trainACFObjectDetector`
- `trainFastRCNNObjectDetector`
- `trainFasterRCNNObjectDetector`
- `trainYOLOv2ObjectDetector`

sensor — Camera configuration

`monoCamera object`

Camera configuration, specified as a `monoCamera` object. The object contains the camera intrinsics, the location, the pitch, yaw, and roll placement, and the world units for the parameters. Use the intrinsics to transform the object points in the image to world coordinates, which you can then compare to the `WorldObjectSize` property for detector.

objectSize — Range of object widths and lengths

`[minWidth maxWidth] vector` | `[minWidth maxWidth; minLength maxLength] vector`

Range of object widths and lengths in world units, specified as a `[minWidth maxWidth]` vector or `[minWidth maxWidth; minLength maxLength]` vector. Specifying the range of object lengths is optional.

Output Arguments

configuredDetector — Configured object detector

`acfObjectDetectorMonoCamera object` | `fastRCNNObjectDetectorMonoCamera object` | `fasterRCNNObjectDetectorMonoCamera object` | `yolov2ObjectDetectorMonoCamera`

Configured object detector, returned as one of these object detector objects:

- `acfObjectDetectorMonoCamera`
- `fastRCNNObjectDetectorMonoCamera`

- `fasterRCNNObjectDetectorMonoCamera`
- `yolov2ObjectDetectorMonoCamera`

See Also

`acfObjectDetector` | `acfObjectDetectorMonoCamera` |
`fastRCNNObjectDetector` | `fastRCNNObjectDetectorMonoCamera` |
`fasterRCNNObjectDetector` | `fasterRCNNObjectDetectorMonoCamera` |
`monoCamera` | `yolov2ObjectDetectorMonoCamera`

Introduced in R2017a

constacc

Constant-acceleration motion model

Syntax

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

Description

`updatedstate = constacc(state)` returns the updated state, `state`, of a constant acceleration Kalman filter motion model for a step time of one second.

`updatedstate = constacc(state,dt)` specifies the time step, `dt`.

Examples

Predict State for Constant-Acceleration Motion

Define an initial state for 2-D constant-acceleration motion.

```
state = [1;1;1;2;1;0];
```

Predict the state 1 second later.

```
state = constacc(state)
```

```
state = 6×1
```

```
2.5000
2.0000
1.0000
3.0000
1.0000
```

0

Predict State for Constant-Acceleration Motion With Specified Time Step

Define an initial state for 2-D constant-acceleration motion.

```
state = [1;1;1;2;1;0];
```

Predict the state 0.5 s later.

```
state = constacc(state,0.5)
```

```
state = 6×1
```

```
1.6250  
1.5000  
1.0000  
2.5000  
1.0000  
0
```

Input Arguments

state — Kalman filter state vector

real-valued $3N$ -element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued $3N$ -element vector. N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx;ax]
2-D	[x;vx;ax;y;vy;ay]
3-D	[x;vx;ax;y;vy;ay;z;vz;az]

For example, x represents the x -coordinate, v_x represents the velocity in the x -direction, and a_x represents the acceleration in the x -direction. If the motion model is in one-dimensional space, the y - and z -axes are assumed to be zero. If the motion model is in two-dimensional space, values along the z -axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second².

Example: [5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]

Data Types: double

dt — Time step interval of filter

1.0 (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: 0.5

Data Types: single | double

Output Arguments

updatedstate — Updated state vector

real-valued column or row vector | real-valued matrix

Updated state vector, returned as a real-valued vector or real-valued matrix with same number of elements and dimensions as the input state vector.

Algorithms

For a two-dimensional constant-acceleration process, the state transition matrix after a time step, T , is block diagonal:

$$\begin{bmatrix} x_{k+1} \\ vx_{k+1} \\ ax_{k+1} \\ y_{k+1} \\ vy_{k+1} \\ ay_{k+1} \end{bmatrix} = \begin{bmatrix} 1 & T & \frac{1}{2}T^2 & 0 & 0 & 0 \\ 0 & 1 & T & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & T & \frac{1}{2}T^2 \\ 0 & 0 & 0 & 0 & 1 & T \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_k \\ vx_k \\ ax_k \\ y_k \\ vy_k \\ ay_k \end{bmatrix}$$

The block for each spatial dimension has this form:

$$\begin{bmatrix} 1 & T & \frac{1}{2}T^2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

constaccjac

Jacobian for constant-acceleration motion

Syntax

```
jacobian = constaccjac(state)
jacobian = constaccjac(state,dt)
```

Description

`jacobian = constaccjac(state)` returns the updated Jacobian, `jacobian`, for a constant-acceleration Kalman filter motion model. The step time is one second. The `state` argument specifies the current state of the filter.

`jacobian = constaccjac(state,dt)` also specifies the time step, `dt`.

Examples

Compute State Jacobian for Constant-Acceleration Motion

Compute the state Jacobian for two-dimensional constant-acceleration motion.

Define an initial state and compute the state Jacobian for a one second update time.

```
state = [1,1,1,2,1,0];
jacobian = constaccjac(state)
```

```
jacobian = 6×6
```

```
1.0000    1.0000    0.5000         0         0         0
         0    1.0000    1.0000         0         0         0
         0         0    1.0000         0         0         0
         0         0         0    1.0000    1.0000    0.5000
         0         0         0         0    1.0000    1.0000
```

```
0 0 0 0 0 1.0000
```

Compute State Jacobian for Constant-Acceleration Motion with Specified Time Step

Compute the state Jacobian for two-dimensional constant-acceleration motion. Set the step time to 0.5 seconds.

```
state = [1,1,1,2,1,0].';
jacobian = constaccjac(state,0.5)
```

```
jacobian = 6x6
```

```
1.0000 0.5000 0.1250 0 0 0
0 1.0000 0.5000 0 0 0
0 0 1.0000 0 0 0
0 0 0 1.0000 0.5000 0.1250
0 0 0 0 1.0000 0.5000
0 0 0 0 0 1.0000
```

Input Arguments

state — Kalman filter state vector

real-valued $3N$ -element vector

Kalman filter state vector for constant-acceleration motion, specified as a real-valued $3N$ -element vector. N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x; vx; ax]
2-D	[x; vx; ax; y; vy; ay]
3-D	[x; vx; ax; y; vy; ay; z; vz; az]

For example, x represents the x -coordinate, vx represents the velocity in the x -direction, and ax represents the acceleration in the x -direction. If the motion model is in one-

dimensional space, the y- and z-axes are assumed to be zero. If the motion model is in two-dimensional space, values along the z-axis are assumed to be zero. Position coordinates are in meters. Velocity coordinates are in meters/second. Acceleration coordinates are in meters/second².

Example: [5;0.1;0.01;0;-0.2;-0.01;-3;0.05;0]

Data Types: double

dt — Time step interval of filter

1.0 (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: 0.5

Data Types: single | double

Output Arguments

jacobian — Constant-acceleration motion Jacobian

real-valued $3N$ -by- $3N$ matrix

Constant-acceleration motion Jacobian, returned as a real-valued $3N$ -by- $3N$ matrix.

Algorithms

For a two-dimensional constant-acceleration process, the Jacobian matrix after a time step, T , is block diagonal:

$$\begin{bmatrix} 1 & T & \frac{1}{2}T^2 & 0 & 0 & 0 \\ 0 & 1 & T & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & T & \frac{1}{2}T^2 \\ 0 & 0 & 0 & 0 & 1 & T \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The block for each spatial dimension has this form:

$$\begin{bmatrix} 1 & T & \frac{1}{2}T^2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

[cameas](#) | [cameasjac](#) | [constacc](#) | [constturn](#) | [constturnjac](#) | [constvel](#) | [constveljac](#) | [ctmeas](#) | [ctmeasjac](#) | [cvmeas](#) | [cvmeasjac](#)

Objects

[trackingEKF](#) | [trackingKF](#) | [trackingUKF](#)

Introduced in R2017a

constturn

Constant turn-rate motion model

Syntax

```
updatedstate = constturn(state)
updatedstate = constturn(state,dt)
updatedstate = constturn(state,dt,w)
```

Description

`updatedstate = constturn(state)` returns the updated state, `updatedstate`, obtained from the previous state, `state`, after a one-second step time for motion modelled as constant turn rate. Constant turn rate means that motion in the x - y plane follows a constant angular velocity and motion in the vertical z directions follows a constant velocity model.

`updatedstate = constturn(state,dt)` also specifies the time step, `dt`.

`updatedstate = constturn(state,dt,w)` also specifies noise, `w`.

Examples

Update State for Constant Turn-Rate Motion

Define an initial state for 2-D constant turn-rate motion. The turn rate is 12 degrees per second. Update the state to one second later.

```
state = [500,0,0,100,12].';
state = constturn(state)
```

```
state = 5×1
```

```
489.5662
```

```
-20.7912  
99.2705  
97.8148  
12.0000
```

Update State for Constant Turn-Rate Motion with Specified Time Step

Define an initial state for 2-D constant turn-rate motion. The turn rate is 12 degrees per second. Update the state to 0.1 seconds later.

```
state = [500,0,0,100,12].';  
state = constturn(state,0.1)
```

```
state = 5×1  
  
499.8953  
-2.0942  
9.9993  
99.9781  
12.0000
```

Input Arguments

state — State vector

real-valued 5-element vector | real-valued 7-element vector | 5-by-*N* real-valued matrix | 7-by-*N* real-valued matrix

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector or matrix.

- When specified as a 5-element vector, the state vector describes 2-D motion in the *x*-*y* plane. You can specify the state vector as a row or column vector. The components of the state vector are [*x*; *vx*; *y*; *vy*; *omega*] where *x* represents the *x*-coordinate and *vx* represents the velocity in the *x*-direction. *y* represents the *y*-coordinate and *vy* represents the velocity in the *y*-direction. *omega* represents the turn rate.

When specified as a 5-by- N matrix, each column represents a different state vector N represents the number of states.

- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector are $[x; vx; y; vy; \omega; z; vz]$ where x represents the x -coordinate and vx represents the velocity in the x -direction. y represents the y -coordinate and vy represents the velocity in the y -direction. ω represents the turn rate. z represents the z -coordinate and vz represents the velocity in the z -direction.

When specified as a 7-by- N matrix, each column represents a different state vector. N represents the number of states.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: `[5;0.1;4;-0.2;0.01]`

Data Types: `double`

dt — Time step interval of filter

1.0 (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: `0.5`

Data Types: `single` | `double`

w — State noise

scalar | real-valued $(D+1)$ -by- N matrix

State noise, specified as a scalar or real-valued $(D+1)$ -length -by- N matrix. D is the number of motion dimensions and N is the number of state vectors. The components are each columns are $[ax; ay; \alpha]$ for 2-D motion or $[ax; ay; \alpha; az]$ for 3-D motion. ax , ay , and az are the linear acceleration noise values in the x -, y -, and z -axes, respectively, and α is the angular acceleration noise value. If specified as a scalar, the value expands to a $(D+1)$ -by- N matrix.

Data Types: `single` | `double`

Output Arguments

updatedstate — Updated state vector

real-valued column or row vector | real-valued matrix

Updated state vector, returned as a real-valued vector or real-valued matrix with same number of elements and dimensions as the input state vector.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initctekf | initctukf

Objects

trackingEKF | trackingUKF

Introduced in R2017a

constturnjac

Jacobian for constant turn-rate motion

Syntax

```
jacobian = constturnjac(state)
jacobian = constturnjac(state,dt)
[jacobian,noisejacobian] = constturnjac(state,dt,w)
```

Description

`jacobian = constturnjac(state)` returns the updated Jacobian, `jacobian`, for constant turn-rate Kalman filter motion model for a one-second step time. The `state` argument specifies the current state of the filter. Constant turn rate means that motion in the x-y plane follows a constant angular velocity and motion in the vertical z directions follows a constant velocity model.

`jacobian = constturnjac(state,dt)` specifies the time step, `dt`.

`[jacobian,noisejacobian] = constturnjac(state,dt,w)` also specifies noise, `w`, and returns the Jacobian, `noisejacobian`, of the state with respect to the noise.

Examples

Compute State Jacobian for Constant Turn-Rate Motion

Compute the Jacobian for a constant turn-rate motion state. Assume the turn rate is 12 degrees/second. The time step is one second.

```
state = [500,0,0,100,12];
jacobian = constturnjac(state)
```

```
jacobian = 5×5
```

```
1.0000    0.9927         0   -0.1043   -0.8631
         0    0.9781         0   -0.2079   -1.7072
         0    0.1043    1.0000    0.9927   -0.1213
         0    0.2079         0    0.9781   -0.3629
         0         0         0         0    1.0000
```

Compute State Jacobian for Constant Turn-Rate Motion with Specified Time Step

Compute the Jacobian for a constant turn-rate motion state. Assume the turn rate is 12 degrees/second. The time step is 0.1 second.

```
state = [500,0,0,100,12];
jacobian = constturnjac(state,0.1)
```

```
jacobian = 5x5
```

```
1.0000    0.1000         0   -0.0010   -0.0087
         0    0.9998         0   -0.0209   -0.1745
         0    0.0010    1.0000    0.1000   -0.0001
         0    0.0209         0    0.9998   -0.0037
         0         0         0         0    1.0000
```

Input Arguments

state — State vector

real-valued 5-element vector | real-valued 7-element vector

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector.

- When specified as a 5-element vector, the state vector describes 2-D motion in the x-y plane. You can specify the state vector as a row or column vector. The components of the state vector are `[x; vx; y; vy; omega]` where `x` represents the x-coordinate and `vx` represents the velocity in the x-direction. `y` represents the y-coordinate and `vy` represents the velocity in the y-direction. `omega` represents the turn rate.
- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector

are `[x;vx;y;vy;omega;z;vz]` where `x` represents the `x`-coordinate and `vx` represents the velocity in the `x`-direction. `y` represents the `y`-coordinate and `vy` represents the velocity in the `y`-direction. `omega` represents the turn rate. `z` represents the `z`-coordinate and `vz` represents the velocity in the `z`-direction.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: `[5;0.1;4;-0.2;0.01]`

Data Types: `double`

dt — Time step interval of filter

`1.0` (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: `0.5`

Data Types: `single` | `double`

w — State noise

scalar | real-valued $(D+1)$ vector

State noise, specified as a scalar or real-valued M -by- $(D+1)$ -length vector. D is the number of motion dimensions. D is two for 2-D motion and D is three for 3-D motion. The vector components are `[ax;ay;alpha]` for 2-D motion or `[ax;ay;alpha;az]` for 3-D motion. `ax`, `ay`, and `az` are the linear acceleration noise values in the `x`-, `y`-, and `z`-axes, respectively, and `alpha` is the angular acceleration noise value. If specified as a scalar, the value expands to a $(D+1)$ vector.

Data Types: `single` | `double`

Output Arguments

jacobian — Constant turn-rate motion Jacobian

real-valued 5-by-5 matrix | real-valued 7-by-7 matrix

Constant turn-rate motion Jacobian, returned as a real-valued 5-by-5 matrix or 7-by-7 matrix depending on the size of the `state` vector. The Jacobian is constructed from the partial derivatives of the state at the updated time step with respect to the state at the previous time step.

noisejacobian — Constant turn-rate motion noise Jacobian

real-valued 5-by-5 matrix | real-valued 7-by-7 matrix

Constant turn-rate motion noise Jacobian, returned as a real-valued 5-by- $(D+1)$ matrix where D is two for 2-D motion or a real-valued 7-by- $(D+1)$ matrix where D is three for 3-D motion. The Jacobian is constructed from the partial derivatives of the state at the updated time step with respect to the noise components.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initctekf

Objects

trackingEKF

Introduced in R2017a

constvel

Constant velocity state update

Syntax

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

Description

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

`updatedstate = constvel(state,dt)` specifies the time step, `dt`.

Examples

Update State for Constant-Velocity Motion

Update the state of two-dimensional constant-velocity motion for a time interval of one second.

```
state = [1;1;2;1];
state = constvel(state)
```

```
state = 4×1
```

```
 2
 1
 3
 1
```

Update State for Constant-Velocity Motion with Specified Time Step

Update the state of two-dimensional constant-velocity motion for a time interval of 1.5 seconds.

```
state = [1;1;2;1];
state = constvel(state,1.5)
```

```
state = 4×1
```

```
    2.5000
    1.0000
    3.5000
    1.0000
```

Input Arguments

state — Kalman filter state vector

real-valued $2N$ -element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued $2N$ -element column vector where N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx]
2-D	[x;vx;y;vy]
3-D	[x;vx;y;vy;z;vz]

For example, x represents the x -coordinate and v_x represents the velocity in the x -direction. If the motion model is 1-D, values along the y and z axes are assumed to be zero. If the motion model is 2-D, values along the z axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: [5;.1;0;-.2;-3;.05]

Data Types: single | double

dt — Time step interval of filter

1.0 (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: 0.5

Data Types: `single` | `double`

Output Arguments

updatedstate — Updated state vector

real-valued column or row vector | real-valued matrix

Updated state vector, returned as a real-valued vector or real-valued matrix with same number of elements and dimensions as the input state vector.

Algorithms

For a two-dimensional constant-velocity process, the state transition matrix after a time step, T , is block diagonal as shown here.

$$\begin{bmatrix} x_{k+1} \\ v_{x,k+1} \\ y_{k+1} \\ v_{y,k+1} \end{bmatrix} = \begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_k \\ vx_k \\ y_k \\ vy_k \end{bmatrix}$$

The block for each spatial dimension is:

$$\begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

constveljac

Jacobian for constant-velocity motion

Syntax

```
jacobian = constveljac(state)
jacobian = constveljac(state,dt)
```

Description

`jacobian = constveljac(state)` returns the updated Jacobian , `jacobian`, for a constant-velocity Kalman filter motion model for a step time of one second. The `state` argument specifies the current state of the filter.

`jacobian = constveljac(state,dt)` specifies the time step, `dt`.

Examples

Compute State Jacobian for Constant-Velocity Motion

Compute the state Jacobian for a two-dimensional constant-velocity motion model for a one second update time.

```
state = [1,1,2,1].';
jacobian = constveljac(state)
```

```
jacobian = 4x4
```

```
    1    1    0    0
    0    1    0    0
    0    0    1    1
    0    0    0    1
```

Compute State Jacobian for Constant-Velocity Motion with Specified Time Step

Compute the state Jacobian for a two-dimensional constant-velocity motion model for a half-second update time.

```
state = [1;1;2;1];
```

Compute the state update Jacobian for 0.5 second.

```
jacobian = constveljac(state,0.5)
```

```
jacobian = 4x4
```

```

1.0000    0.5000         0         0
         0    1.0000         0         0
         0         0    1.0000    0.5000
         0         0         0    1.0000

```

Input Arguments

state — Kalman filter state vector

real-valued $2N$ -element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued $2N$ -element column vector where N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx]
2-D	[x;vx;y;vy]
3-D	[x;vx;y;vy;z;vz]

For example, x represents the x -coordinate and vx represents the velocity in the x -direction. If the motion model is 1-D, values along the y and z axes are assumed to be zero. If the motion model is 2-D, values along the z axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: [5;.1;0;-.2;-3;.05]

Data Types: single | double

dt — Time step interval of filter

1.0 (default) | positive scalar

Time step interval of filter, specified as a positive scalar. Time units are in seconds.

Example: 0.5

Data Types: single | double

Output Arguments

jacobian — Constant-velocity motion Jacobian

real-valued $2N$ -by- $2N$ matrix

Constant-velocity motion Jacobian, returned as a real-valued $2N$ -by- $2N$ matrix. N is the number of spatial degrees of motion.

Algorithms

For a two-dimensional constant-velocity motion, the Jacobian matrix for a time step, T , is block diagonal:

$$\begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The block for each spatial dimension has this form:

$$\begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}$$

For each additional spatial dimension, add an identical block.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac |
constvel | ctmeas | ctmeasjac | cvmeas | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

ctmeas

Measurement function for constant turn-rate motion

Syntax

```
measurement = ctmeas(state)
measurement = ctmeas(state, frame)
measurement = ctmeas(state, frame, sensorpos)
measurement = ctmeas(state, frame, sensorpos, sensorvel)
measurement = ctmeas(state, frame, sensorpos, sensorvel, laxes)
measurement = ctmeas(state, measurementParameters)
```

Description

`measurement = ctmeas(state)` returns the measurement for a constant turn-rate Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the filter.

`measurement = ctmeas(state, frame)` also specifies the measurement coordinate system, `frame`.

`measurement = ctmeas(state, frame, sensorpos)` also specifies the sensor position, `sensorpos`.

`measurement = ctmeas(state, frame, sensorpos, sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurement = ctmeas(state, frame, sensorpos, sensorvel, laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurement = ctmeas(state, measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Create Measurement from Constant Turn-Rate Motion in Rectangular Frame

Create a measurement from an object undergoing constant turn-rate motion. The state is the position and velocity in each dimension and the turn-rate. The measurements are in rectangular coordinates.

```
state = [1;10;2;20;5];  
measurement = ctmeas(state)
```

```
measurement = 3×1
```

```
    1  
    2  
    0
```

The z-component of the measurement is zero.

Create Measurement from Constant Turn-Rate Motion in Spherical Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. The measurements are in spherical coordinates.

```
state = [1;10;2;20;5];  
measurement = ctmeas(state, 'spherical')
```

```
measurement = 4×1
```

```
63.4349  
    0  
 2.2361  
22.3607
```

The elevation of the measurement is zero and the range rate is positive indicating that the object is moving away from the sensor.

Create Measurement from Constant Turn-Rate Motion in Translated Spherical Frame

Define the state of an object moving in 2-D constant turn-rate motion. The state consists of position and velocity, and the turn rate. The measurements are in spherical coordinates with respect to a frame located at [20;40;0].

```
state = [1;10;2;20;5];
measurement = ctmeas(state, 'spherical', [20;40;0])
```

```
measurement = 4×1
```

```
-116.5651
      0
   42.4853
  -22.3607
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

Create Measurement from Constant Turn-Rate Motion using Measurement Parameters

Define the state of an object moving in 2-D constant turn-rate motion. The state consists of position and velocity, and the turn rate. The measurements are in spherical coordinates with respect to a frame located at [20;40;0].

```
state2d = [1;10;2;20;5];
frame = 'spherical';
sensorpos = [20;40;0];
sensorvel = [0;5;0];
laxes = eye(3);
measurement = ctmeas(state2d, frame, sensorpos, sensorvel, laxes)
```

```
measurement = 4×1
```

```
-116.5651
      0
   42.4853
  -17.8885
```

The elevation of the measurement is zero and the range rate is negative indicating that the object is moving toward the sensor.

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos, ...  
                'OriginVelocity',sensorvel,'Orientation',laxes);  
measurement = ctmeas(state2d,measparm)
```

```
measurement = 4×1
```

```
-116.5651  
    0  
  42.4853  
 -17.8885
```

Input Arguments

state — State vector

real-valued 5-element vector | real-valued 7-element vector | 5-by- N real-valued matrix | 7-by- N real-valued matrix

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector or matrix.

- When specified as a 5-element vector, the state vector describes 2-D motion in the x - y plane. You can specify the state vector as a row or column vector. The components of the state vector are $[x; vx; y; vy; \omega]$ where x represents the x -coordinate and vx represents the velocity in the x -direction. y represents the y -coordinate and vy represents the velocity in the y -direction. ω represents the turn rate.

When specified as a 5-by- N matrix, each column represents a different state vector N represents the number of states.

- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector are $[x; vx; y; vy; \omega; z; vz]$ where x represents the x -coordinate and vx represents the velocity in the x -direction. y represents the y -coordinate and vy represents the velocity in the y -direction. ω represents the turn rate. z represents the z -coordinate and vz represents the velocity in the z -direction.

When specified as a 7-by- N matrix, each column represents a different state vector. N represents the number of states.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: [5;0.1;4;-0.2;0.01]

Data Types: double

frame — Measurement frame

'rectangular' (default) | 'spherical'

Measurement frame, specified as 'rectangular' or 'spherical'. When the frame is 'rectangular', a measurement consists of the x , y , and z Cartesian coordinates of the tracked object. When specified as 'spherical', a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: char

sensorpos — Sensor position

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: double

sensorvel — Sensor velocity

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: double

laxes — Local sensor coordinate axes

[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x -, y -, and z -axes, respectively, with respect to the global coordinate system.

Data Types: double

measurementParameters — Measurement parameters

structure | array of structure

Measurement parameters, specified as a structure or an array of structures. The fields of the structure are:

Field	Description	Example
Frame	Frame used to report measurements, specified as one of these values: <ul style="list-style-type: none"> 'rectangular' — Detections are reported in rectangular coordinates. 'spherical' — Detections are reported in spherical coordinates. 	'spherical'
OriginPosition	Position offset of the origin of the frame relative to the parent frame, specified as an [x y z] real-valued vector.	[0 0 0]
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, specified as a [vx vy vz] real-valued vector.	[0 0 0]
Orientation	Frame rotation matrix, specified as a 3-by-3 real-valued orthonormal matrix.	[1 0 0; 0 1 0; 0 0 1]
HasAzimuth	Logical scalar indicating if azimuth is included in the measurement.	1

Field	Description	Example
HasElevation	Logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the reported measurements assume 0 degrees of elevation.	1
HasRange	Logical scalar indicating if range is included in the measurement.	1
HasVelocity	Logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if HasVelocity is false, the measurements are reported as [x y z]. If HasVelocity is true, measurements are reported as [x y z vx vy vz].	1
IsParentToChild	Logical scalar indicating if Orientation performs a frame rotation from the parent coordinate frame to the child coordinate frame. When IsParentToChild is false, then Orientation performs a frame rotation from the child coordinate frame to the parent coordinate frame.	0

Data Types: struct

Output Arguments

measurement — Measurement vector

N-by-1 column vector

Measurement vector, returned as an *N*-by-1 column vector. The form of the measurement depends upon which syntax you use.

- When the syntax does not use the `measurementParameters` argument, the measurement vector is $[x, y, z]$ when the frame input argument is set to 'rectangular' and $[az;el;r;rr]$ when the frame is set to 'spherical'.
- When the syntax uses the `measurementParameters` argument, the size of the measurement vector depends on the values of the `frame`, `HasVelocity`, and `HasElevation` fields in the `measurementParameters` structure.

frame	measurement			
'spherical'	Specifies the azimuth angle, <i>az</i> , elevation angle, <i>el</i> , range, <i>r</i> , and range rate, <i>rr</i> , of the object with respect to the local ego vehicle coordinate system. Positive values for range rate indicate that an object is moving away from the sensor.			
	Spherical measurements			
		HasElevation		
		false	true	
HasVelocity	false	[az;r]	[az;el;r]	
	true	[az;r;r]	[az;el;r;rr]	
	Angle units are in degrees, range units are in meters, and range rate units are in m/s.			

frame	measurement	
'rectangular	Specifies the Cartesian position and velocity coordinates of the tracked object with respect to the ego vehicle coordinate system.	
	Rectangular measurements	
	HasVelocit y	false true
Position units are in meters and velocity units are in m/s.		

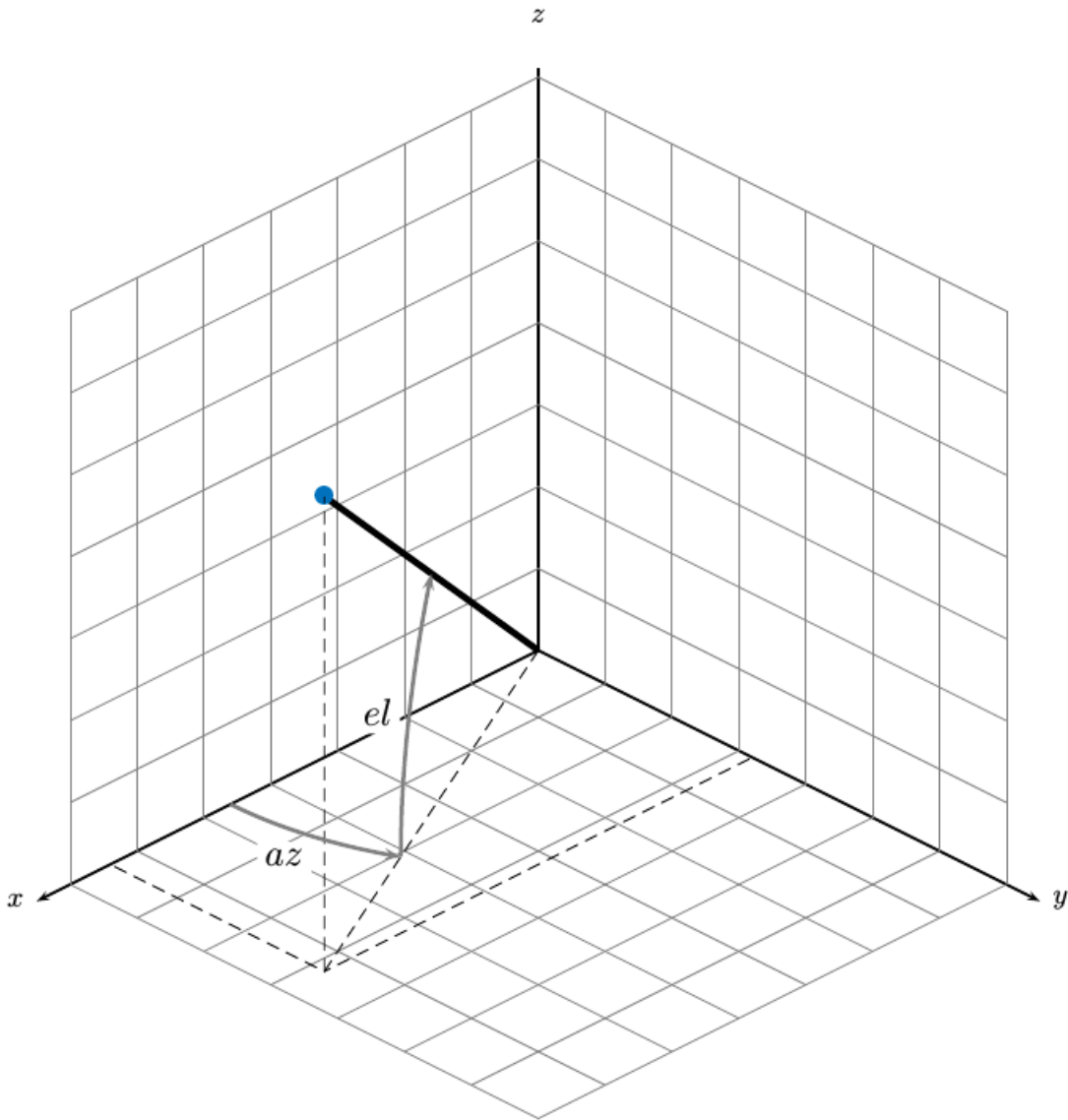
Data Types: double

More About

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Automated Driving Toolbox.

The azimuth angle of a vector is the angle between the x -axis and its orthogonal projection onto the xy plane. The angle is positive in going from the x axis toward the y axis. Azimuth angles lie between -180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the xy -plane. The angle is positive when going toward the positive z -axis from the xy plane.



Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac |
constvel | constveljac | ctmeasjac | cvmeas | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

ctmeasjac

Jacobian of measurement function for constant turn-rate motion

Syntax

```
measurementjac = ctmeasjac(state)
measurementjac = ctmeasjac(state, frame)
measurementjac = ctmeasjac(state, frame, sensorpos)
measurementjac = ctmeasjac(state, frame, sensorpos, sensorvel)
measurementjac = ctmeasjac(state, frame, sensorpos, sensorvel, laxes)
measurementjac = ctmeasjac(state, measurementParameters)
```

Description

`measurementjac = ctmeasjac(state)` returns the measurement Jacobian, `measurementjac`, for a constant turn-rate Kalman filter motion model in rectangular coordinates. `state` specifies the current state of the track.

`measurementjac = ctmeasjac(state, frame)` also specifies the measurement coordinate system, `frame`.

`measurementjac = ctmeasjac(state, frame, sensorpos)` also specifies the sensor position, `sensorpos`.

`measurementjac = ctmeasjac(state, frame, sensorpos, sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurementjac = ctmeasjac(state, frame, sensorpos, sensorvel, laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurementjac = ctmeasjac(state, measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Measurement Jacobian of Constant Turn-Rate Motion in Rectangular Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Construct the measurement Jacobian in rectangular coordinates.

```
state = [1;10;2;20;5];
jacobian = ctmeasjac(state)
```

```
jacobian = 3×5
```

```
    1    0    0    0    0
    0    0    1    0    0
    0    0    0    0    0
```

Measurement Jacobian of Constant Turn-Rate Motion in Spherical Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Compute the measurement Jacobian with respect to spherical coordinates.

```
state = [1;10;2;20;5];
measurementjac = ctmeasjac(state, 'spherical')
```

```
measurementjac = 4×5
```

```
-22.9183    0    11.4592    0    0
         0         0         0         0    0
    0.4472    0    0.8944    0    0
    0.0000    0.4472    0.0000    0.8944    0
```

Measurement Jacobian of Constant Turn-Rate Object in Translated Spherical Frame

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Compute the measurement Jacobian with respect to spherical coordinates centered at [5; -20; 0].

```
state = [1;10;2;20;5];
sensorpos = [5;-20;0];
measurementjac = ctmeasjac(state,'spherical',sensorpos)

measurementjac = 4x5

    -2.5210         0    -0.4584         0         0
         0         0         0         0         0
    -0.1789         0     0.9839         0         0
    0.5903    -0.1789     0.1073     0.9839         0
```

Measurement Jacobian of Constant Turn-Rate Object Using Measurement Parameters

Define the state of an object in 2-D constant turn-rate motion. The state is the position and velocity in each dimension, and the turn rate. Compute the measurement Jacobian with respect to spherical coordinates centered at [25; -40; 0].

```
state2d = [1;10;2;20;5];
sensorpos = [25,-40,0].';
frame = 'spherical';
sensorvel = [0;5;0];
laxes = eye(3);
measurementjac = ctmeasjac(state2d,frame,sensorpos,sensorvel,laxes)

measurementjac = 4x5

    -1.0284         0    -0.5876         0         0
         0         0         0         0         0
    -0.4961         0     0.8682         0         0
    0.2894    -0.4961     0.1654     0.8682         0
```

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurementjac = ctmeasjac(state2d,measparm)

measurementjac = 4x5
```

```

-1.0284      0    -0.5876      0      0
      0      0      0      0      0
-0.4961      0      0.8682      0      0
 0.2894  -0.4961    0.1654    0.8682    0

```

Input Arguments

state — State vector

real-valued 5-element vector | real-valued 7-element vector | 5-by- N real-valued matrix | 7-by- N real-valued matrix

State vector for a constant turn-rate motion model in two or three spatial dimensions, specified as a real-valued vector or matrix.

- When specified as a 5-element vector, the state vector describes 2-D motion in the x - y plane. You can specify the state vector as a row or column vector. The components of the state vector are $[x; vx; y; vy; \omega]$ where x represents the x -coordinate and vx represents the velocity in the x -direction. y represents the y -coordinate and vy represents the velocity in the y -direction. ω represents the turn rate.

When specified as a 5-by- N matrix, each column represents a different state vector. N represents the number of states.

- When specified as a 7-element vector, the state vector describes 3-D motion. You can specify the state vector as a row or column vector. The components of the state vector are $[x; vx; y; vy; \omega; z; vz]$ where x represents the x -coordinate and vx represents the velocity in the x -direction. y represents the y -coordinate and vy represents the velocity in the y -direction. ω represents the turn rate. z represents the z -coordinate and vz represents the velocity in the z -direction.

When specified as a 7-by- N matrix, each column represents a different state vector. N represents the number of states.

Position coordinates are in meters. Velocity coordinates are in meters/second. Turn rate is in degrees/second.

Example: `[5;0.1;4;-0.2;0.01]`

Data Types: `double`

frame — Measurement frame

'rectangular' (default) | 'spherical'

Measurement frame, specified as 'rectangular' or 'spherical'. When the frame is 'rectangular', a measurement consists of the x , y , and z Cartesian coordinates of the tracked object. When specified as 'spherical', a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: char

sensorpos — Sensor position

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: double

sensorvel — Sensor velocity

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: double

laxes — Local sensor coordinate axes

[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x -, y -, and z -axes, respectively, with respect to the global coordinate system.

Data Types: double

measurementParameters — Measurement parameters

structure | array of structure

Measurement parameters, specified as a structure or an array of structures. The fields of the structure are:

Field	Description	Example
Frame	<p>Frame used to report measurements, specified as one of these values:</p> <ul style="list-style-type: none"> 'rectangular' — Detections are reported in rectangular coordinates. 'spherical' — Detections are reported in spherical coordinates. 	'spherical'
OriginPosition	Position offset of the origin of the frame relative to the parent frame, specified as an [x y z] real-valued vector.	[0 0 0]
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, specified as a [vx vy vz] real-valued vector.	[0 0 0]
Orientation	Frame rotation matrix, specified as a 3-by-3 real-valued orthonormal matrix.	[1 0 0; 0 1 0; 0 0 1]
HasAzimuth	Logical scalar indicating if azimuth is included in the measurement.	1
HasElevation	Logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the reported measurements assume 0 degrees of elevation.	1

Field	Description	Example
HasRange	Logical scalar indicating if range is included in the measurement.	1
HasVelocity	Logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if HasVelocity is false, the measurements are reported as [x y z]. If HasVelocity is true, measurements are reported as [x y z vx vy vz].	1
IsParentToChild	Logical scalar indicating if Orientation performs a frame rotation from the parent coordinate frame to the child coordinate frame. When IsParentToChild is false, then Orientation performs a frame rotation from the child coordinate frame to the parent coordinate frame.	0

Data Types: struct

Output Arguments

measurement_jac — Measurement Jacobian

real-valued 3-by-5 matrix | real-valued 4-by-5 matrix

Measurement Jacobian, returned as a real-valued 3-by-5 or 4-by-5 matrix. The row dimension and interpretation depend on value of the frame argument.

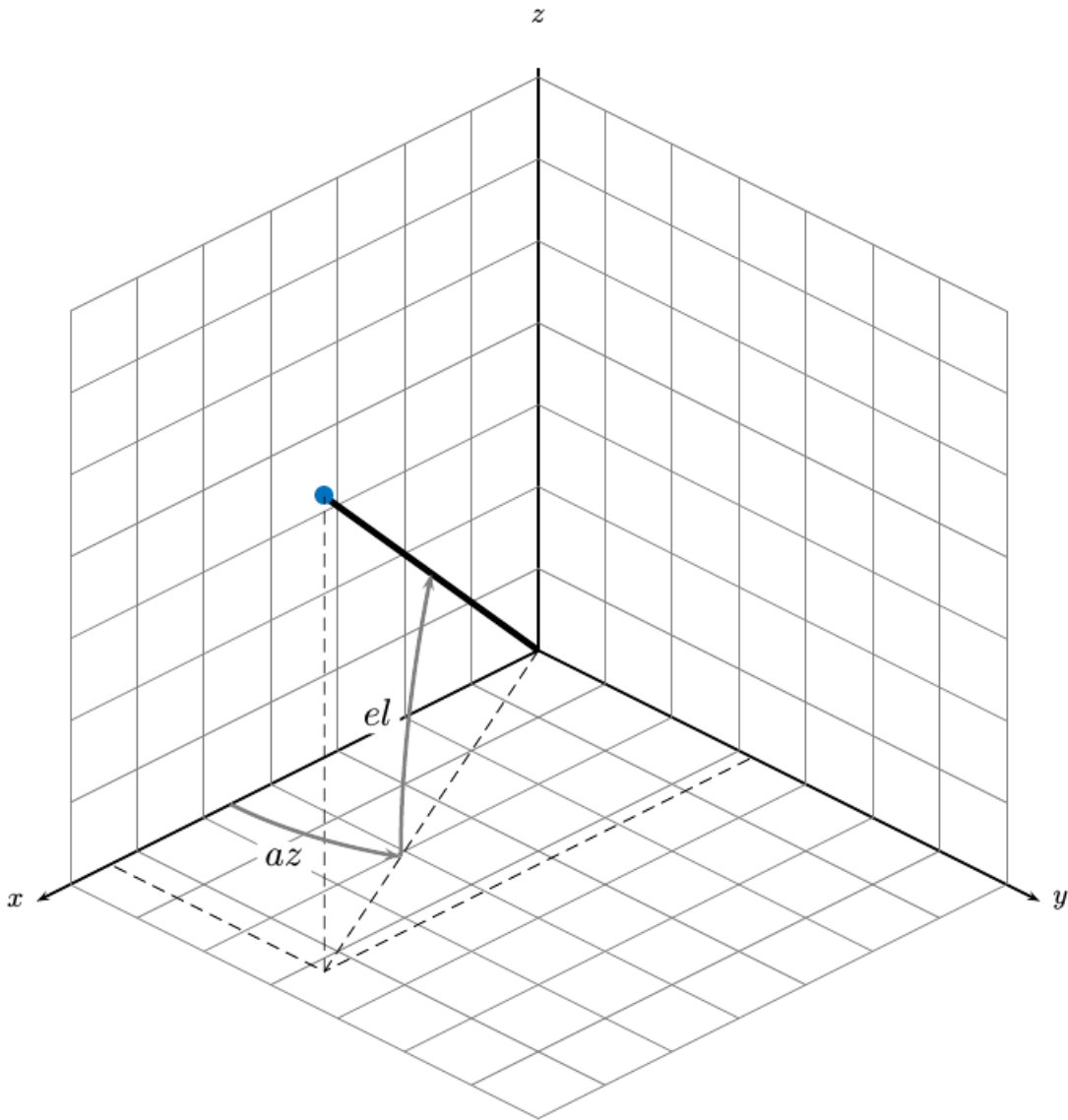
Frame	Measurement Jacobian
'rectangular'	Jacobian of the measurements $[x; y; z]$ with respect to the state vector. The measurement vector is with respect to the local coordinate system. Coordinates are in meters.
'spherical'	Jacobian of the measurement vector $[az; el; r; rr]$ with respect to the state vector. Measurement vector components specify the azimuth angle, elevation angle, range, and range rate of the object with respect to the local sensor coordinate system. Angle units are in degrees. Range units are in meters and range rate units are in meters/second.

More About

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Automated Driving Toolbox.

The azimuth angle of a vector is the angle between the x -axis and its orthogonal projection onto the xy plane. The angle is positive in going from the x axis toward the y axis. Azimuth angles lie between -180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the xy -plane. The angle is positive when going toward the positive z -axis from the xy plane.



Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac |
constvel | constveljac | ctmeas | cvmeas | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

cvmeas

Measurement function for constant velocity motion

Syntax

```
measurement = cvmeas(state)
measurement = cvmeas(state, frame)
measurement = cvmeas(state, frame, sensorpos)
measurement = cvmeas(state, frame, sensorpos, sensorvel)
measurement = cvmeas(state, frame, sensorpos, sensorvel, laxes)
measurement = cvmeas(state, measurementParameters)
```

Description

`measurement = cvmeas(state)` returns the measurement for a constant-velocity Kalman filter motion model in rectangular coordinates. The `state` argument specifies the current state of the tracking filter.

`measurement = cvmeas(state, frame)` also specifies the measurement coordinate system, `frame`.

`measurement = cvmeas(state, frame, sensorpos)` also specifies the sensor position, `sensorpos`.

`measurement = cvmeas(state, frame, sensorpos, sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurement = cvmeas(state, frame, sensorpos, sensorvel, laxes)` specifies the local sensor axes orientation, `laxes`.

`measurement = cvmeas(state, measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Create Measurement from Constant-Velocity Object in Rectangular Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in both dimensions. The measurements are in rectangular coordinates.

```
state = [1;10;2;20];  
measurement = cvmeas(state)
```

```
measurement = 3×1
```

```
    1  
    2  
    0
```

The z-component of the measurement is zero.

Create Measurement from Constant Velocity Object in Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each spatial dimension. The measurements are in spherical coordinates.

```
state = [1;10;2;20];  
measurement = cvmeas(state, 'spherical')
```

```
measurement = 4×1
```

```
63.4349  
    0  
 2.2361  
22.3607
```

The elevation of the measurement is zero and the range rate is positive. These results indicate that the object is moving away from the sensor.

Create Measurement from Constant-Velocity Object in Translated Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state consists of position and velocity in each spatial dimension. The measurements are in spherical coordinates with respect to a frame located at $(20;40;0)$ meters.

```
state = [1;10;2;20];  
measurement = cvmeas(state, 'spherical', [20;40;0])  
  
measurement = 4×1  
  
-116.5651  
      0  
  42.4853  
-22.3607
```

The elevation of the measurement is zero and the range rate is negative. These results indicate that the object is moving toward the sensor.

Create Measurement from Constant-Velocity Object Using Measurement Parameters

Define the state of an object in 2-D constant-velocity motion. The state consists of position and velocity in each spatial dimension. The measurements are in spherical coordinates with respect to a frame located at $(20;40;0)$ meters.

```
state2d = [1;10;2;20];  
frame = 'spherical';  
sensorpos = [20;40;0];  
sensorvel = [0;5;0];  
laxes = eye(3);  
measurement = cvmeas(state2d, frame, sensorpos, sensorvel, laxes)  
  
measurement = 4×1  
  
-116.5651  
      0  
  42.4853  
-17.8885
```

The elevation of the measurement is zero and the range rate is negative. These results indicate that the object is moving toward the sensor.

Put the measurement parameters in a structure and use the alternative syntax.

```
measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurement = cvmeas(state2d,measparm)
```

```
measurement = 4×1
```

```
-116.5651
         0
  42.4853
 -17.8885
```

Input Arguments

state — Kalman filter state vector

real-valued $2N$ -element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued $2N$ -element column vector where N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x;vx]
2-D	[x;vx;y;vy]
3-D	[x;vx;y;vy;z;vz]

For example, x represents the x -coordinate and vx represents the velocity in the x -direction. If the motion model is 1-D, values along the y and z axes are assumed to be zero. If the motion model is 2-D, values along the z axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: [5;.1;0;-.2;-3;.05]

Data Types: single | double

frame — Measurement frame

'rectangular' (default) | 'spherical'

Measurement frame, specified as 'rectangular' or 'spherical'. When the frame is 'rectangular', a measurement consists of the x , y , and z Cartesian coordinates of the tracked object. When specified as 'spherical', a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: char

sensorpos — Sensor position

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: double

sensorvel — Sensor velocity

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: double

laxes — Local sensor coordinate axes

[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x -, y -, and z -axes, respectively, with respect to the global coordinate system.

Data Types: double

measurementParameters — Measurement parameters

structure | array of structure

Measurement parameters, specified as a structure or an array of structures. The fields of the structure are:

Field	Description	Example
Frame	<p>Frame used to report measurements, specified as one of these values:</p> <ul style="list-style-type: none"> 'rectangular' — Detections are reported in rectangular coordinates. 'spherical' — Detections are reported in spherical coordinates. 	'spherical'
OriginPosition	Position offset of the origin of the frame relative to the parent frame, specified as an [x y z] real-valued vector.	[0 0 0]
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, specified as a [vx vy vz] real-valued vector.	[0 0 0]
Orientation	Frame rotation matrix, specified as a 3-by-3 real-valued orthonormal matrix.	[1 0 0; 0 1 0; 0 0 1]
HasAzimuth	Logical scalar indicating if azimuth is included in the measurement.	1
HasElevation	Logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the reported measurements assume 0 degrees of elevation.	1

Field	Description	Example
HasRange	Logical scalar indicating if range is included in the measurement.	1
HasVelocity	Logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if HasVelocity is false, the measurements are reported as [x y z]. If HasVelocity is true, measurements are reported as [x y z vx vy vz].	1
IsParentToChild	Logical scalar indicating if Orientation performs a frame rotation from the parent coordinate frame to the child coordinate frame. When IsParentToChild is false, then Orientation performs a frame rotation from the child coordinate frame to the parent coordinate frame.	0

Data Types: struct

Output Arguments

measurement — Measurement vector

N-by-1 column vector

Measurement vector, returned as an *N*-by-1 column vector. The form of the measurement depends upon which syntax you use.

- When the syntax does not use the `measurementParameters` argument, the measurement vector is $[x, y, z]$ when the frame input argument is set to 'rectangular' and $[az; el; r; rr]$ when the frame is set to 'spherical'.
- When the syntax uses the `measurementParameters` argument, the size of the measurement vector depends on the values of the `frame`, `HasVelocity`, and `HasElevation` fields in the `measurementParameters` structure.

frame	measurement																	
'spherical'	<p>Specifies the azimuth angle, <i>az</i>, elevation angle, <i>el</i>, range, <i>r</i>, and range rate, <i>rr</i>, of the object with respect to the local ego vehicle coordinate system. Positive values for range rate indicate that an object is moving away from the sensor.</p> <p>Spherical measurements</p> <table border="1"> <thead> <tr> <th></th> <th></th> <th colspan="2">HasElevation</th> </tr> <tr> <th></th> <th></th> <th>false</th> <th>true</th> </tr> </thead> <tbody> <tr> <th rowspan="2">HasVelocity</th> <td>false</td> <td>[az; r]</td> <td>[az; el; r]</td> </tr> <tr> <td>true</td> <td>[az; r; r]</td> <td>[az; el; r; rr]</td> </tr> </tbody> </table> <p>Angle units are in degrees, range units are in meters, and range rate units are in m/s.</p>					HasElevation				false	true	HasVelocity	false	[az; r]	[az; el; r]	true	[az; r; r]	[az; el; r; rr]
		HasElevation																
		false	true															
HasVelocity	false	[az; r]	[az; el; r]															
	true	[az; r; r]	[az; el; r; rr]															

frame	measurement					
'rectangular'	Specifies the Cartesian position and velocity coordinates of the tracked object with respect to the ego vehicle coordinate system.					
	Rectangular measurements					
	HasVelocit	<table border="1"> <tr> <td>false</td> <td>[x; y; y]</td> </tr> <tr> <td>true</td> <td>[x; y; z; vx; vy; vz]</td> </tr> </table>	false	[x; y; y]	true	[x; y; z; vx; vy; vz]
false	[x; y; y]					
true	[x; y; z; vx; vy; vz]					
	y					
	Position units are in meters and velocity units are in m/s.					

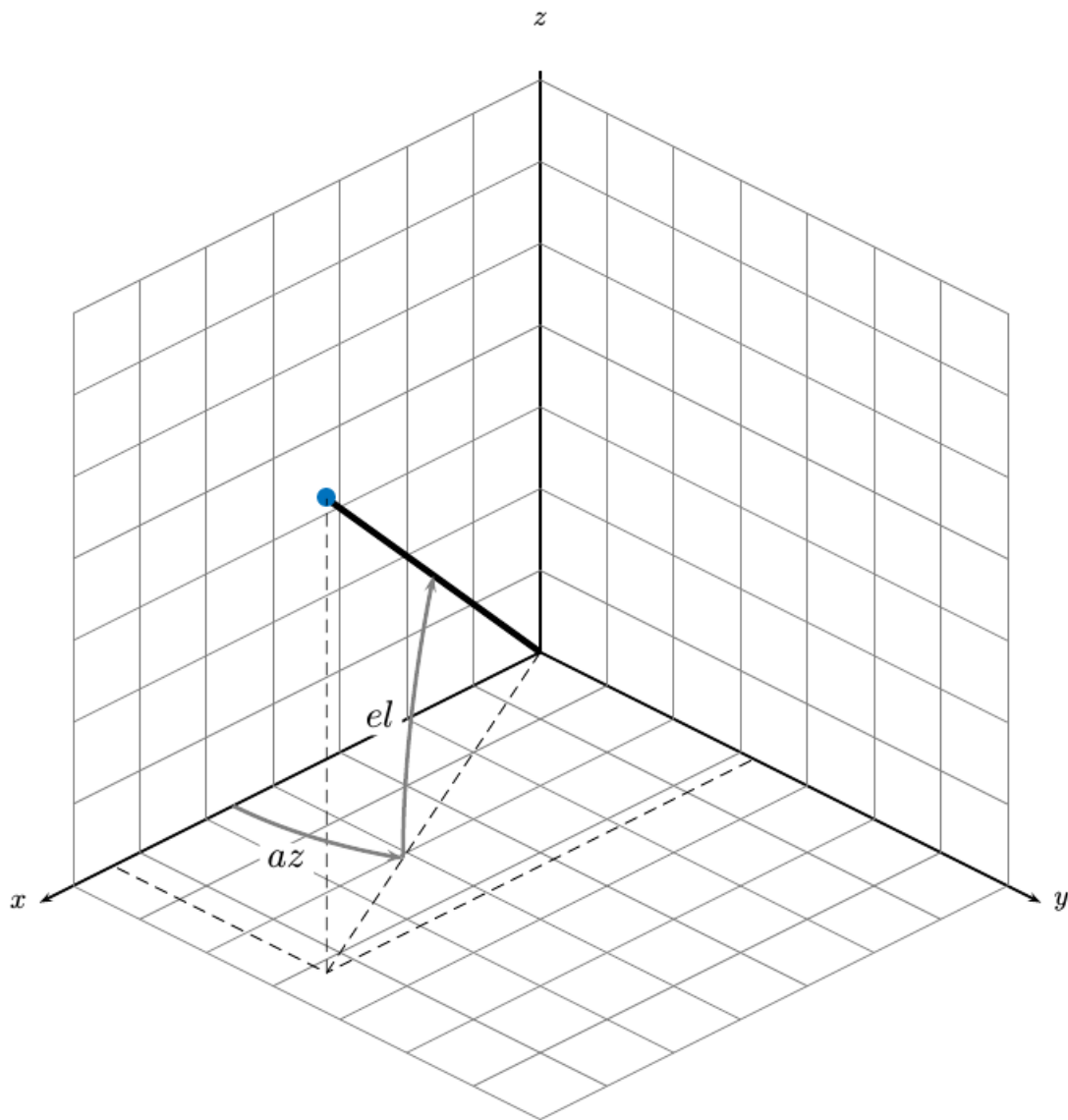
Data Types: double

More About

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Automated Driving Toolbox.

The azimuth angle of a vector is the angle between the x -axis and its orthogonal projection onto the xy plane. The angle is positive in going from the x axis toward the y axis. Azimuth angles lie between -180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the xy -plane. The angle is positive when going toward the positive z -axis from the xy plane.



Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac |
constvel | constveljac | ctmeas | ctmeasjac | cvmeasjac

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

cvmeasjac

Jacobian of measurement function for constant velocity motion

Syntax

```
measurementjac = cvmeasjac(state)
measurementjac = cvmeasjac(state, frame)
measurementjac = cvmeasjac(state, frame, sensorpos)
measurementjac = cvmeasjac(state, frame, sensorpos, sensorvel)
measurementjac = cvmeasjac(state, frame, sensorpos, sensorvel, laxes)
measurementjac = cvmeasjac(state, measurementParameters)
```

Description

`measurementjac = cvmeasjac(state)` returns the measurement Jacobian for constant-velocity Kalman filter motion model in rectangular coordinates. `state` specifies the current state of the tracking filter.

`measurementjac = cvmeasjac(state, frame)` also specifies the measurement coordinate system, `frame`.

`measurementjac = cvmeasjac(state, frame, sensorpos)` also specifies the sensor position, `sensorpos`.

`measurementjac = cvmeasjac(state, frame, sensorpos, sensorvel)` also specifies the sensor velocity, `sensorvel`.

`measurementjac = cvmeasjac(state, frame, sensorpos, sensorvel, laxes)` also specifies the local sensor axes orientation, `laxes`.

`measurementjac = cvmeasjac(state, measurementParameters)` specifies the measurement parameters, `measurementParameters`.

Examples

Measurement Jacobian of Constant-Velocity Object in Rectangular Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each spatial dimension. Construct the measurement Jacobian in rectangular coordinates.

```
state = [1;10;2;20];  
jacobian = cvmeasjac(state)
```

```
jacobian = 3×4
```

```
    1    0    0    0  
    0    0    1    0  
    0    0    0    0
```

Measurement Jacobian of Constant-Velocity Motion in Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each dimension. Compute the measurement Jacobian with respect to spherical coordinates.

```
state = [1;10;2;20];  
measurementjac = cvmeasjac(state, 'spherical')
```

```
measurementjac = 4×4
```

```
-22.9183    0    11.4592    0  
    0    0    0    0  
    0.4472    0    0.8944    0  
    0.0000    0.4472    0.0000    0.8944
```

Measurement Jacobian of Constant-Velocity Object in Translated Spherical Frame

Define the state of an object in 2-D constant-velocity motion. The state is the position and velocity in each spatial dimension. Compute the measurement Jacobian with respect to spherical coordinates centered at (5;-20;0) meters.

```

state = [1;10;2;20];
sensorpos = [5;-20;0];
measurementjac = cvmeasjac(state,'spherical',sensorpos)

measurementjac = 4x4

    -2.5210         0    -0.4584         0
         0         0         0         0
   -0.1789         0    0.9839         0
    0.5903   -0.1789    0.1073    0.9839

```

Create Measurement Jacobian for Constant-Velocity Object Using Measurement Parameters

Define the state of an object in 2-D constant-velocity motion. The state consists of position and velocity in each spatial dimension. The measurements are in spherical coordinates with respect to a frame located at $(20;40;0)$ meters.

```

state2d = [1;10;2;20];
frame = 'spherical';
sensorpos = [20;40;0];
sensorvel = [0;5;0];
laxes = eye(3);
measurementjac = cvmeasjac(state2d,frame,sensorpos,sensorvel,laxes)

measurementjac = 4x4

    1.2062         0    -0.6031         0
         0         0         0         0
   -0.4472         0    -0.8944         0
    0.0471   -0.4472   -0.0235   -0.8944

```

Put the measurement parameters in a structure and use the alternative syntax.

```

measparm = struct('Frame',frame,'OriginPosition',sensorpos,'OriginVelocity',sensorvel,
    'Orientation',laxes);
measurementjac = cvmeasjac(state2d,measparm)

measurementjac = 4x4

```

```

1.2062         0   -0.6031         0
         0         0         0         0
-0.4472         0   -0.8944         0
0.0471   -0.4472   -0.0235   -0.8944

```

Input Arguments

state — Kalman filter state vector

real-valued $2N$ -element vector

Kalman filter state vector for constant-velocity motion, specified as a real-valued $2N$ -element column vector where N is the number of spatial degrees of freedom of motion. For each spatial degree of motion, the state vector takes the form shown in this table.

Spatial Dimensions	State Vector Structure
1-D	[x; vx]
2-D	[x; vx; y; vy]
3-D	[x; vx; y; vy; z; vz]

For example, x represents the x -coordinate and vx represents the velocity in the x -direction. If the motion model is 1-D, values along the y and z axes are assumed to be zero. If the motion model is 2-D, values along the z axis are assumed to be zero. Position coordinates are in meters and velocity coordinates are in meters/sec.

Example: [5; .1; 0; - .2; -3; .05]

Data Types: single | double

frame — Measurement frame

'rectangular' (default) | 'spherical'

Measurement frame, specified as 'rectangular' or 'spherical'. When the frame is 'rectangular', a measurement consists of the x , y , and z Cartesian coordinates of the tracked object. When specified as 'spherical', a measurement consists of the azimuth, elevation, range, and range rate of the tracked object.

Data Types: char

sensorpos — Sensor position

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor position with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters.

Data Types: double

sensorvel — Sensor velocity

[0;0;0] (default) | real-valued 3-by-1 column vector

Sensor velocity with respect to the global coordinate system, specified as a real-valued 3-by-1 column vector. Units are in meters/second.

Data Types: double

laxes — Local sensor coordinate axes

[1,0,0;0,1,0;0,0,1] (default) | 3-by-3 orthogonal matrix

Local sensor coordinate axes, specified as a 3-by-3 orthogonal matrix. Each column specifies the direction of the local x-, y-, and z-axes, respectively, with respect to the global coordinate system.

Data Types: double

measurementParameters — Measurement parameters

structure | array of structure

Measurement parameters, specified as a structure or an array of structures. The fields of the structure are:

Field	Description	Example
Frame	<p>Frame used to report measurements, specified as one of these values:</p> <ul style="list-style-type: none"> 'rectangular' — Detections are reported in rectangular coordinates. 'spherical' — Detections are reported in spherical coordinates. 	'spherical'
OriginPosition	Position offset of the origin of the frame relative to the parent frame, specified as an [x y z] real-valued vector.	[0 0 0]
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, specified as a [vx vy vz] real-valued vector.	[0 0 0]
Orientation	Frame rotation matrix, specified as a 3-by-3 real-valued orthonormal matrix.	[1 0 0; 0 1 0; 0 0 1]
HasAzimuth	Logical scalar indicating if azimuth is included in the measurement.	1
HasElevation	Logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the reported measurements assume 0 degrees of elevation.	1

Field	Description	Example
HasRange	Logical scalar indicating if range is included in the measurement.	1
HasVelocity	Logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if HasVelocity is false, the measurements are reported as [x y z]. If HasVelocity is true, measurements are reported as [x y z vx vy vz].	1
IsParentToChild	Logical scalar indicating if Orientation performs a frame rotation from the parent coordinate frame to the child coordinate frame. When IsParentToChild is false, then Orientation performs a frame rotation from the child coordinate frame to the parent coordinate frame.	0

Data Types: struct

Output Arguments

measurementjac — Measurement Jacobian

real-valued 3-by- N matrix | real-valued 4-by- N matrix

Measurement Jacobian, specified as a real-valued 3-by- N or 4-by- N matrix. N is the dimension of the state vector. The first dimension and meaning depend on value of the frame argument.

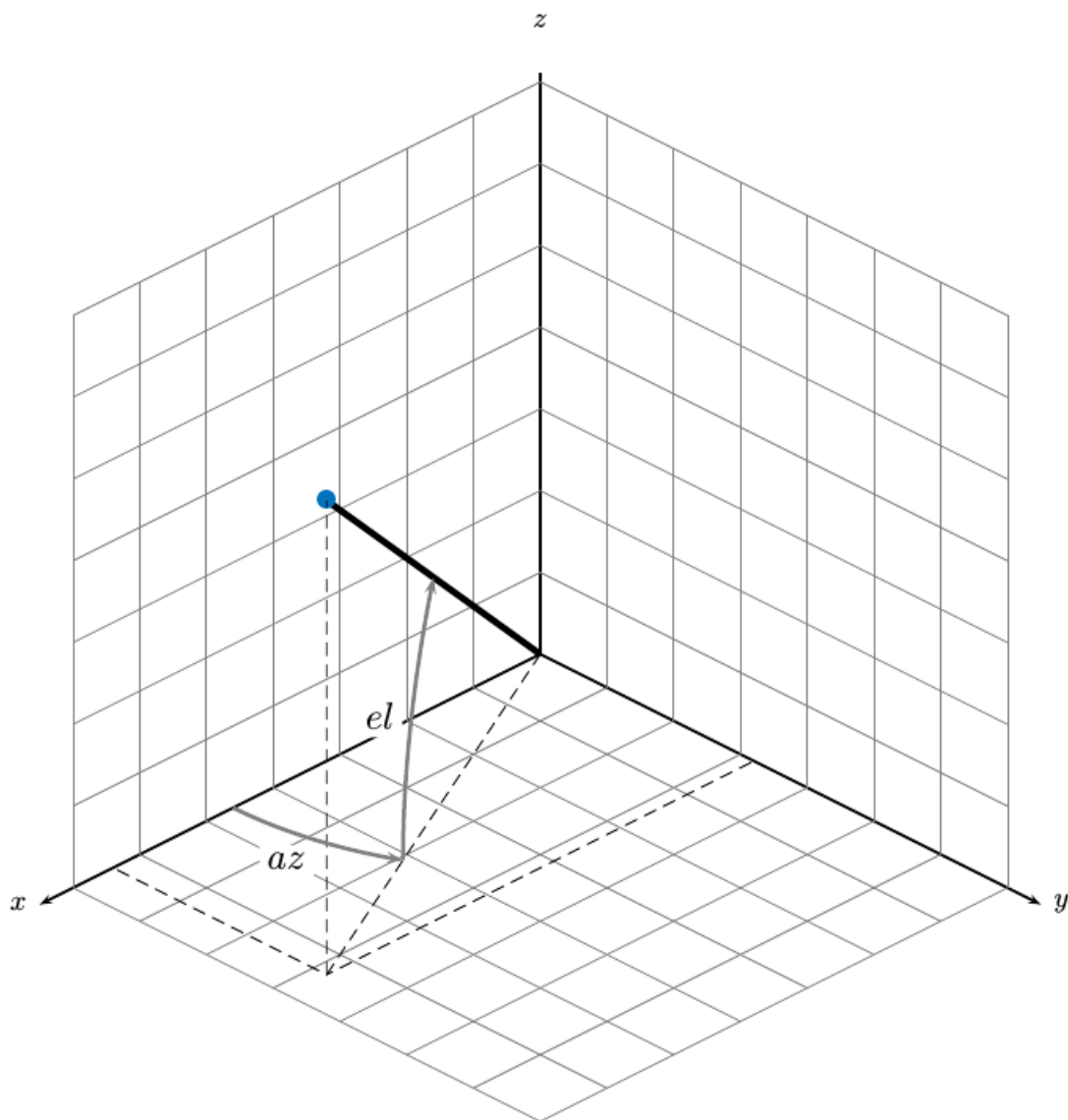
Frame	Measurement Jacobian
'rectangular'	Jacobian of the measurements $[x; y; z]$ with respect to the state vector. The measurement vector is with respect to the local coordinate system. Coordinates are in meters.
'spherical'	Jacobian of the measurement vector $[az; el; r; rr]$ with respect to the state vector. Measurement vector components specify the azimuth angle, elevation angle, range, and range rate of the object with respect to the local sensor coordinate system. Angle units are in degrees. Range units are in meters and range rate units are in meters/second.

More About

Azimuth and Elevation Angle Definitions

Define the azimuth and elevation angles used in Automated Driving Toolbox.

The azimuth angle of a vector is the angle between the x -axis and its orthogonal projection onto the xy plane. The angle is positive in going from the x axis toward the y axis. Azimuth angles lie between -180 and 180 degrees. The elevation angle is the angle between the vector and its orthogonal projection onto the xy -plane. The angle is positive when going toward the positive z -axis from the xy plane.



Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac |
constvel | constveljac | ctmeas | ctmeasjac | cvmeas

Objects

trackingEKF | trackingKF | trackingUKF

Introduced in R2017a

estimateMonoCameraParameters

Estimate extrinsic monocular camera parameters using checkerboard

Syntax

```
[pitch,yaw,roll,height] = estimateMonoCameraParameters(intrinsics,  
imagePoints,worldPoints,patternOriginHeight)  
[pitch,yaw,roll,height] = estimateMonoCameraParameters( ____,  
Name,Value)
```

Description

[pitch,yaw,roll,height] = estimateMonoCameraParameters(intrinsics, imagePoints,worldPoints,patternOriginHeight) estimates the extrinsic parameters of a monocular camera by using the intrinsic parameters of the camera and a checkerboard calibration pattern. The returned extrinsic parameters define the yaw, pitch, and roll rotation angles between the camera coordinate system (Computer Vision Toolbox) and vehicle coordinate system on page 3-123 axes. The function also returns the height of the camera above the ground. Specify the intrinsic parameters, the image and world coordinates of the checkerboard corner points, and the height of the checkerboard pattern's origin above the ground.

By default, the function assumes that the camera is facing forward and that the checkerboard pattern is parallel with the ground. For all possible camera and checkerboard placements, see “Calibrate a Monocular Camera”.

[pitch,yaw,roll,height] = estimateMonoCameraParameters(____, Name,Value) specifies options using one or more name-value pairs, in addition to the inputs and outputs from the previous syntax. For example, you can specify the orientation or position of the checkerboard pattern.

Examples

Configure Monocular Camera Using Checkerboard Pattern

Configure a monocular fisheye camera by removing lens distortion and then estimating the camera's extrinsic parameters. Use an image of a checkerboard as the calibration pattern. For a more detailed look at how to configure a monocular camera that has a fisheye lens, see the “Configure Monocular Fisheye Camera” example.

Load the intrinsic parameters of a monocular camera that has a fisheye lens. `intrinsics` is a `fisheyeIntrinsics` object.

```
ld = load('fisheyeCameraIntrinsics');  
intrinsics = ld.intrinsics;
```

Load an image of a checkerboard pattern that is placed flat on the ground. This image is for illustrative purposes and was not taken from a camera mounted to the vehicle. In a camera mounted to the vehicle, the *X*-axis of the pattern points to the right of the vehicle, and the *Y*-axis of the pattern points to the camera. Display the image.

```
imageFileName = fullfile(toolboxdir('driving'),'drivingdata','checkerboard.png');  
I = imread(imageFileName);  
imshow(I)
```




Warning: Image is too big to fit on screen; displaying at 33%

Detect the coordinates of the checkerboard corners in the image.

```
[imagePoints,boardSize] = detectCheckerboardPoints(I);
```

Generate the corresponding world coordinates of the corners.

```
squareSize = 0.029; % Square size in meters
```

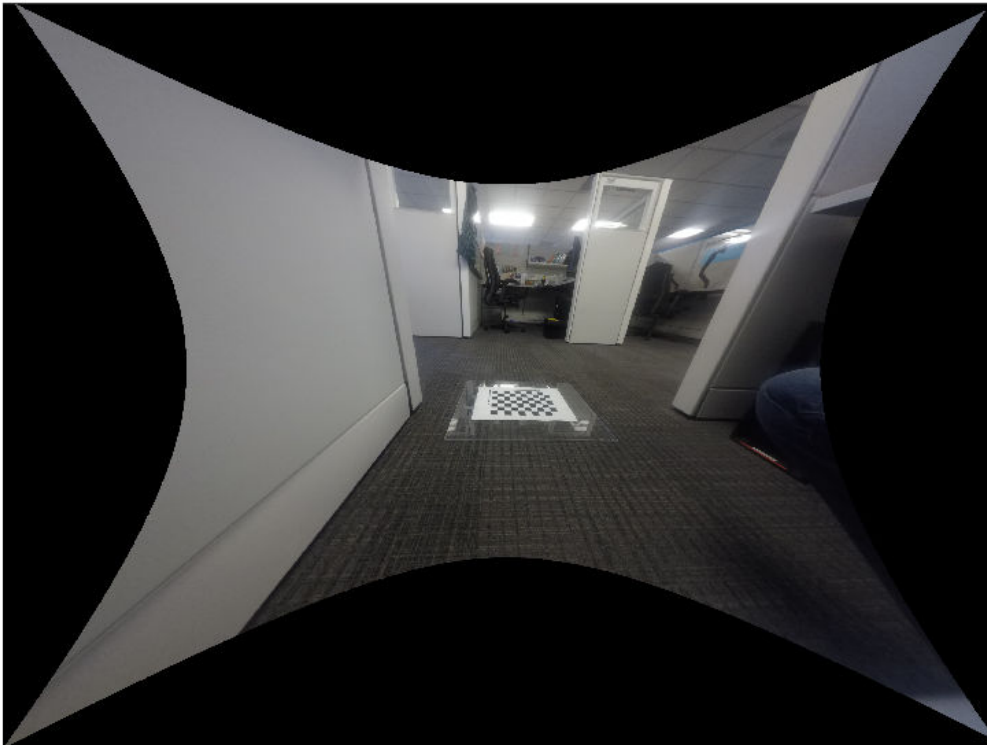
```
worldPoints = generateCheckerboardPoints(boardSize,squareSize);
```

Estimate the extrinsic parameters required to configure the monoCamera object. Because the checkerboard pattern is directly on the ground, set the height of the pattern's origin to 0.

```
patternOriginHeight = 0;  
[pitch,yaw,roll,height] = estimateMonoCameraParameters(intrinsics, ...  
                                                    imagePoints,worldPoints,patternOriginHeight);
```

Because `monoCamera` does not accept `fishEyeIntrinsics` objects, remove distortion from the image and compute new intrinsic parameters from the undistorted image. `camIntrinsics` is an `cameraIntrinsics` object. Display the image to confirm distortion is removed.

```
[undistortedI,camIntrinsics] = undistortFisheyeImage(I,intrinsics,'Output','full');  
imshow(undistortedI)
```



Warning: Image is too big to fit on screen; displaying at 17%

Configure the monocular camera using the estimated parameters.

```
monoCam = monoCamera(camIntrinsics,height,'Pitch',pitch,'Yaw',yaw,'Roll',roll)
```

```
monoCam =
  monoCamera with properties:
    Intrinsic: [1x1 cameraIntrinsics]
    WorldUnits: 'meters'
    Height: 0.4447
    Pitch: 21.8459
    Yaw: -3.6130
    Roll: -3.1707
    SensorLocation: [0 0]
```

Input Arguments

intrinsics — Intrinsic camera parameters

cameraIntrinsics object | fisheyeIntrinsics object

Intrinsic camera parameters, specified as a cameraIntrinsics or fisheyeIntrinsics object.

Checkerboard pattern images produced by these cameras can include lens distortion, which can affect the accuracy of corner point detections. To remove lens distortion and compute new intrinsic parameters, use these functions:

- For cameraIntrinsics objects, use undistortImage.
- For fisheyeIntrinsics objects, use undistortFisheyeImage.

imagePoints — Image coordinates of checkerboard corner points

M -by-2 matrix

Image coordinates of checkerboard corner points, specified as an M -by-2 matrix of M number of $[x\ y]$ vectors. These points must come from an image captured by a monocular camera. To detect these points in an image, use the detectCheckerboardPoints function.

`estimateMonoCameraParameters` assumes that all points in `worldPoints` are in the (X_p, Y_p) plane and that M is greater than or equal to 4. To specify the height of the (X_p, Y_p) plane above the ground, use `patternOriginHeight`.

Data Types: `single` | `double`

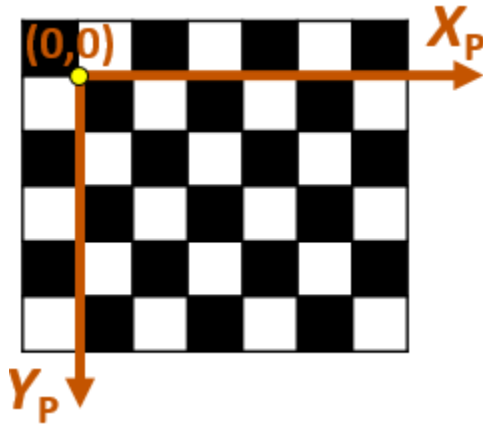
worldPoints — World coordinates of corner points in checkerboard

M -by-2 matrix

World coordinates of the corner points in the checkerboard, specified as an M -by-2 matrix of M number of $[x\ y]$ vectors.

`estimateMonoCameraParameters` assumes that all points in `worldPoints` are in the (X_p, Y_p) plane and that M is greater than or equal to 4. To specify the height of the (X_p, Y_p) plane above the ground, use `patternOriginHeight`.

Point $(0,0)$ corresponds to the bottom-right corner of the top-left square of the checkerboard.



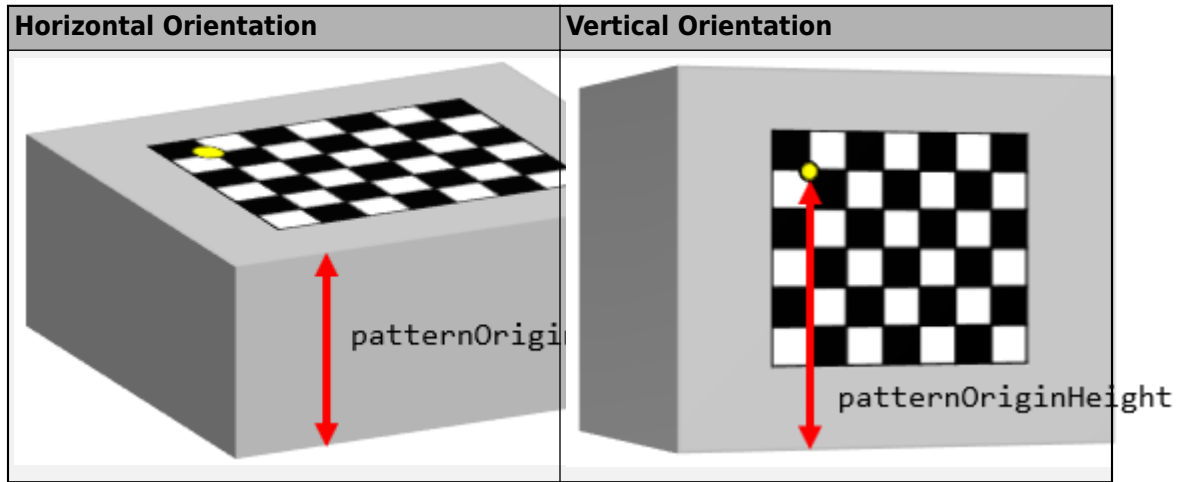
Data Types: `single` | `double`

patternOriginHeight — Height of checkerboard pattern's origin

nonnegative real scalar

Height of the checkerboard pattern's origin above the ground, specified as a nonnegative real scalar. The origin is the bottom-right corner of the top-left square of the checkerboard.

The measurement of `patternOriginHeight` depends on the orientation of the checkerboard pattern, as shown in these diagrams.



To specify the pattern orientation, use the `'PatternOrientation'` name-value pair. If you set `'PatternOrientation'` to `'horizontal'` (default), and the pattern is on the ground, then set `patternOriginHeight` to 0.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'PatternOrientation','vertical','PatternPosition','right'`

PatternOrientation — Orientation of checkerboard pattern

`'horizontal'` (default) | `'vertical'`

Orientation of the checkerboard pattern relative to the ground, specified as the comma-separated pair consisting of `'PatternOrientation'` and one of the following:

- `'horizontal'` — Checkerboard pattern is parallel to the ground.

- 'vertical' — Checkerboard pattern is perpendicular to the ground.

PatternPosition — Position of checkerboard pattern

'front' (default) | 'back' | 'left' | 'right'

Position of the checkerboard pattern relative to the ground, specified as the comma-separated pair consisting of 'PatternPosition' and one of the following:

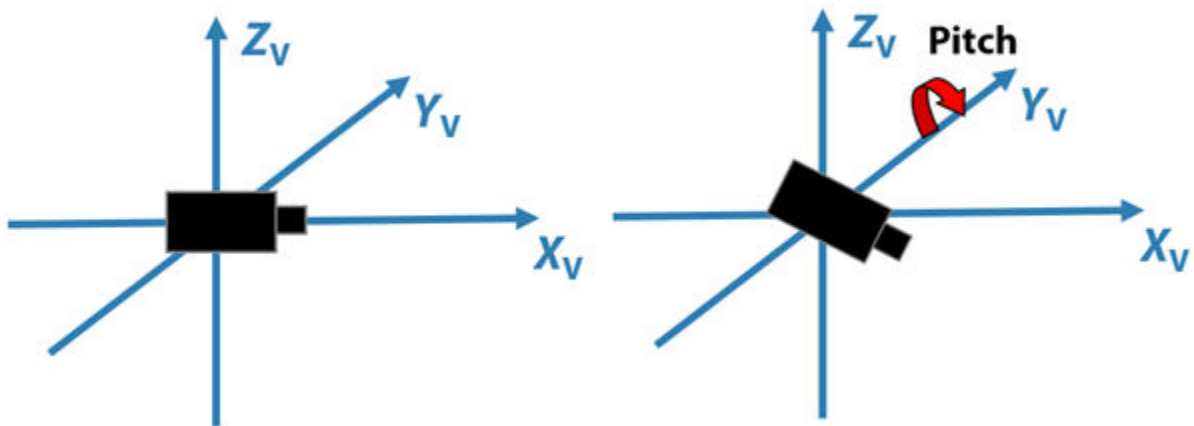
- 'front' — Checkerboard pattern is in front of the vehicle.
- 'back' — Checkerboard pattern is behind the vehicle.
- 'left' — Checkerboard pattern is to the left of the vehicle.
- 'right' — Checkerboard pattern is to the right of the vehicle.

Output Arguments

pitch — Pitch angle

real scalar

Pitch angle between the horizontal plane of the vehicle and the optical axis of the camera, returned as a real scalar in degrees. `pitch` uses the ISO convention for rotation, with a clockwise positive angle direction when looking in the positive direction of the vehicle's Y_v -axis.

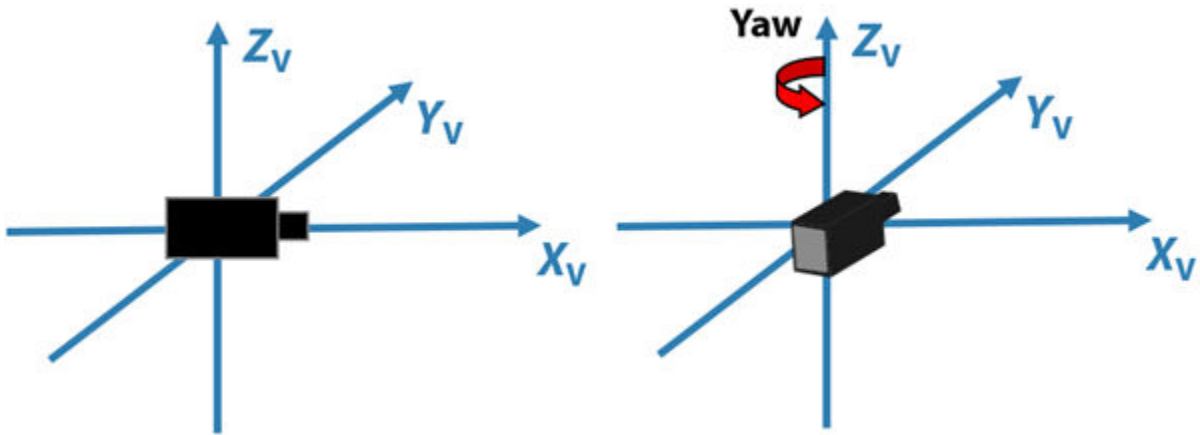


For more details, see “Angle Directions” on page 3-124.

yaw — Yaw angle

real scalar

Yaw angle between the X_V -axis of the vehicle and the optical axis of the camera, returned as a real scalar in degrees. `yaw` uses the ISO convention for rotation, with a clockwise positive angle direction when looking in the positive direction of the vehicle's Z_V -axis.

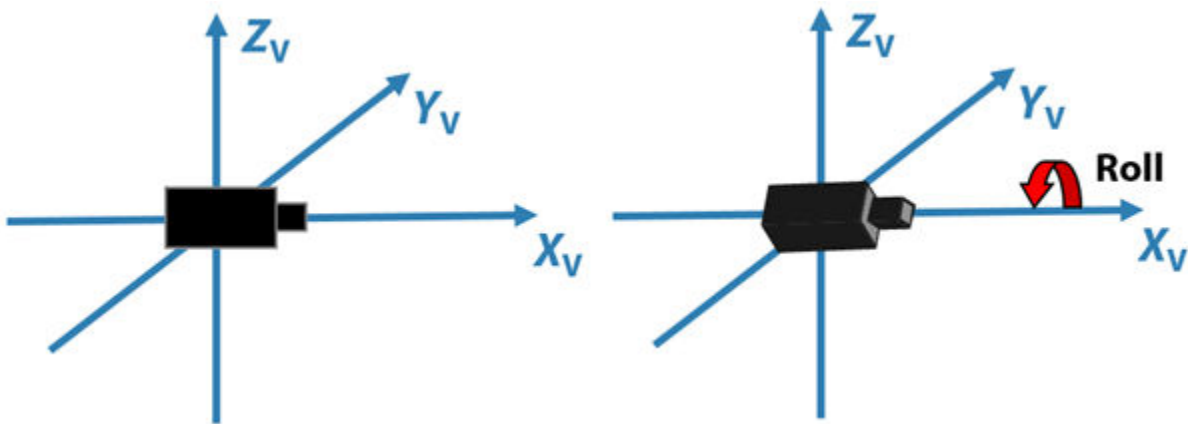


For more details, see “Angle Directions” on page 3-124.

roll — Roll angle

real scalar

Roll angle of the camera around its optical axis, returned as a real scalar in degrees. `roll` uses the ISO convention for rotation, with a clockwise positive angle direction when looking in the positive direction of the vehicle's X_V -axis.



For more details, see “Angle Directions” on page 3-124.

height — Perpendicular height from ground to camera

nonnegative real scalar

Perpendicular height from the ground to the focal point of the camera, returned as a nonnegative real scalar in world units, such as meters.



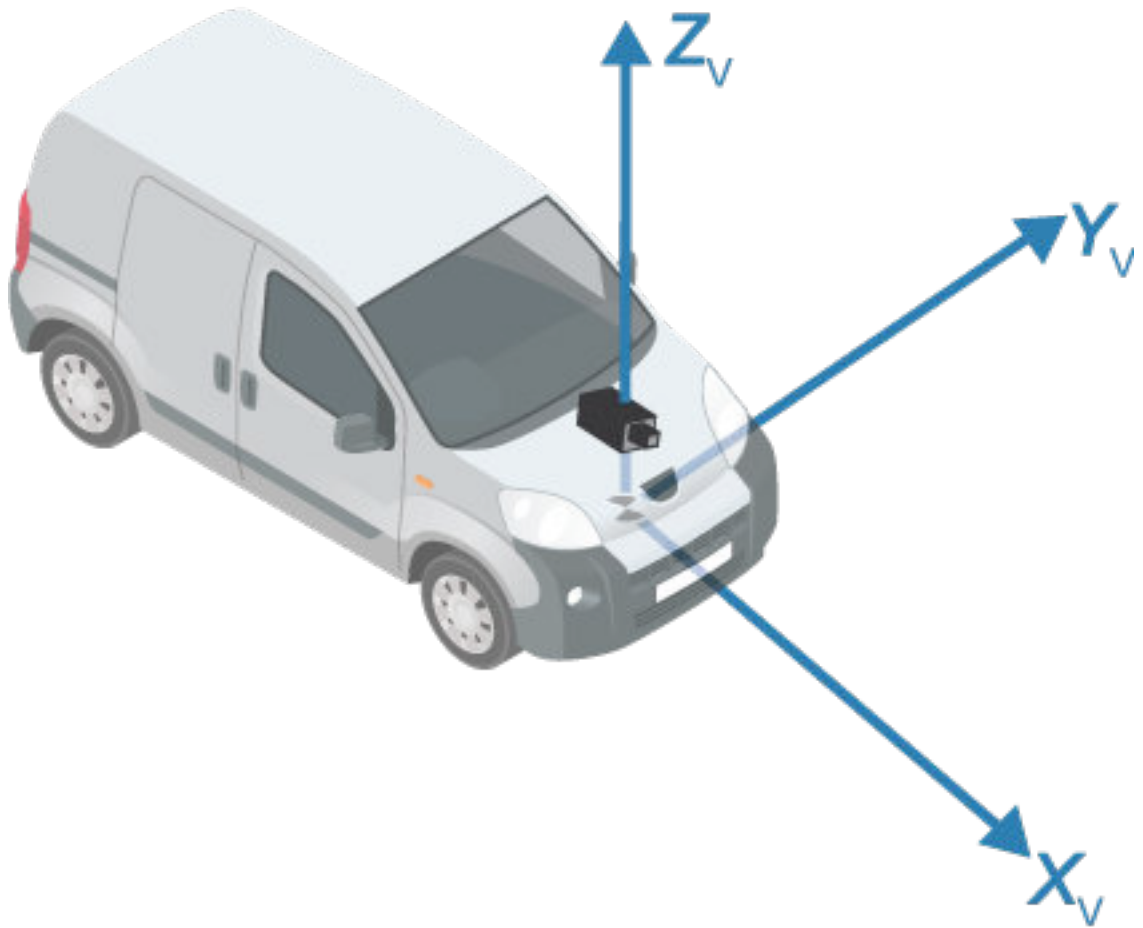
More About

Vehicle Coordinate System

In the vehicle coordinate system (X_V, Y_V, Z_V) defined by a `monoCamera` object:

- The X_V -axis points forward from the vehicle.
- The Y_V -axis points to the left, as viewed when facing forward.
- The Z_V -axis points up from the ground to maintain the right-handed coordinate system.

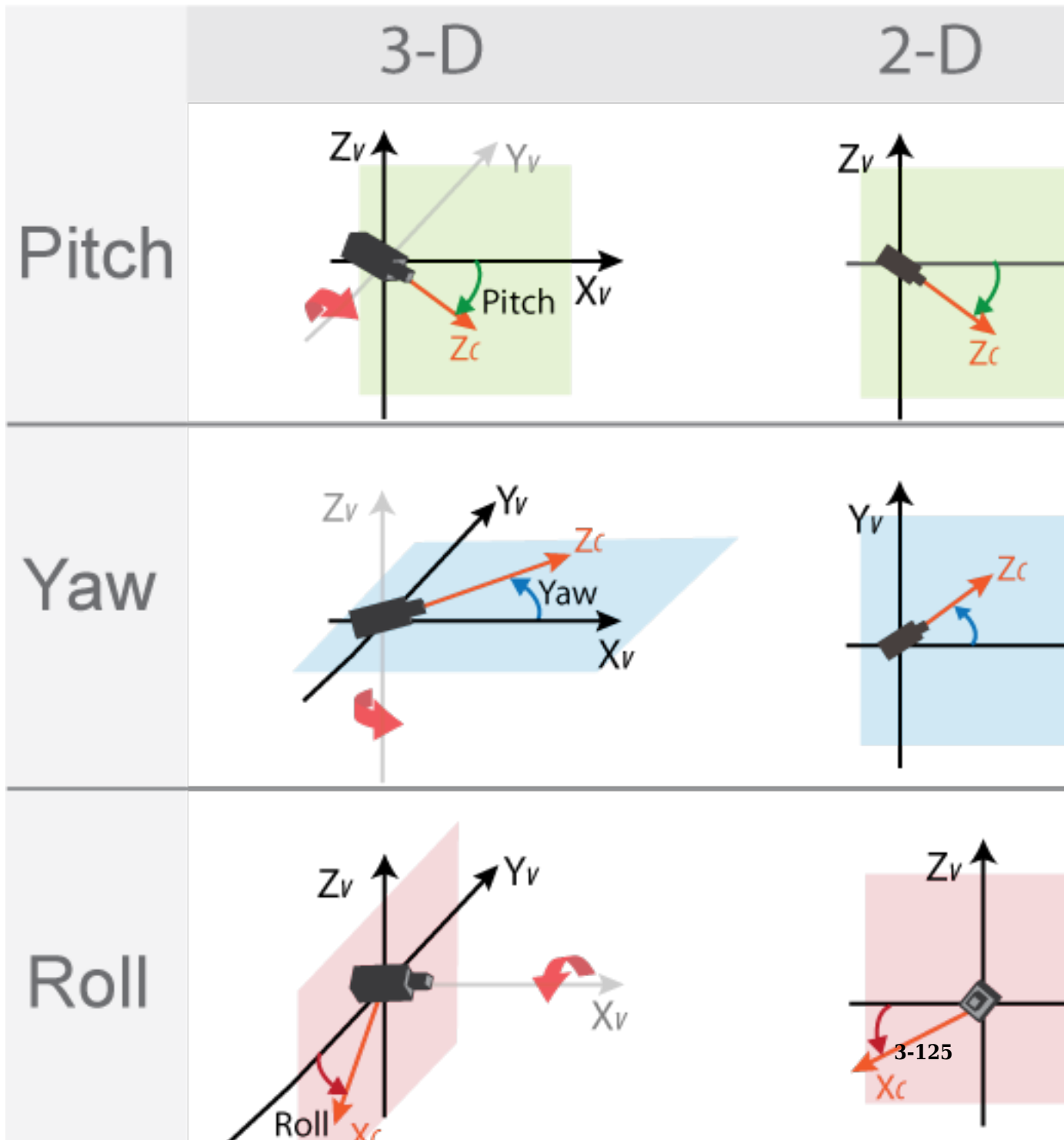
By default, the origin of this coordinate system is on the road surface, directly below the camera center (focal point of camera).



To obtain more reliable results from `estimateMonoCameraParameters`, the checkerboard pattern must be placed in precise locations relative to this coordinate system. For more details, see “Calibrate a Monocular Camera”.

Angle Directions

The monocular camera sensor uses clockwise positive angle directions when looking in the positive direction of the Z -, Y -, and X -axes, respectively.



See Also

Apps

Camera Calibrator

Functions

`detectCheckerboardPoints` | `estimateCameraParameters` |
`estimateFisheyeParameters` | `extrinsics` | `generateCheckerboardPoints`

Objects

`cameraIntrinsics` | `fisheyeIntrinsics` | `monoCamera`

Topics

“Calibrate a Monocular Camera”

“Configure Monocular Fisheye Camera”

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2018b

evaluateLaneBoundaries

Evaluate lane boundary models against ground truth

Syntax

```
numMatches = evaluateLaneBoundaries(boundaries,
worldGroundTruthPoints,threshold)
[numMatches,numMissed,numFalsePositives] = evaluateLaneBoundaries(
___)
[___] = evaluateLaneBoundaries( ___,xWorld)
[___] = evaluateLaneBoundaries(boundaries,groundTruthBoundaries,
threshold)
[___,assignments] = evaluateLaneBoundaries( ___ )
```

Description

`numMatches = evaluateLaneBoundaries(boundaries, worldGroundTruthPoints, threshold)` returns the total number of lane boundary matches (true positives) within the lateral distance threshold by comparing the input boundary models, `boundaries`, against ground truth data.

`[numMatches,numMissed,numFalsePositives] = evaluateLaneBoundaries(___)` also returns the total number of misses (false negatives) and false positives, using the previous inputs.

`[___] = evaluateLaneBoundaries(___,xWorld)` specifies the x-axis points at which to perform the comparisons. Points specified in `worldGroundTruthPoints` are linearly interpolated at the given x-axis locations.

`[___] = evaluateLaneBoundaries(boundaries,groundTruthBoundaries, threshold)` compares the boundaries against ground truth models that are specified in an array of lane boundary objects or a cell array of arrays.

`[___ ,assignments] = evaluateLaneBoundaries(___)` also returns the assignment indices that are specified in `groundTruthBoundaries`. Each boundary is

matched to the corresponding class assignment in `groundTruthBoundaries`. The `k`th boundary in `boundaries` is matched to the `assignments(k)` element of `worldGroundTruthPoints`. Zero indicates a false positive (no match found).

Examples

Compare Lane Boundary Models

Create a set of ground truth points, add noise to simulate actual lane boundary points, and compare the simulated data to the model.

Create a set of points representing ground truth by using parabolic parameters.

```
parabolaParams1 = [-0.001 0.01 0.5];  
parabolaParams2 = [0.001 0.02 0.52];  
x = (0:0.1:20)';  
y1 = polyval(parabolaParams1,x);  
y2 = polyval(parabolaParams1,x);
```

Add noise relative to the offset parameter.

```
y1 = y1 + 0.10*parabolaParams1(3)*(rand(length(y1),1)-0.5);  
y2 = y2 + 0.10*parabolaParams2(3)*(rand(length(y2),1)-0.5);
```

Create a set of test boundary models.

```
testlbs = parabolicLaneBoundary([-0.002 0.01 0.5;  
                                -0.001 0.02 0.45;  
                                -0.001 0.01 0.5;  
                                0.000 0.02 0.52;  
                                -0.001 0.01 0.51]);
```

Compare the boundary models to the ground truth points. Calculate the precision and sensitivity of the models based on the number of matches, misses, and false positives.

```
threshold = 0.1;  
[numMatches,numMisses,numFalsePositives,~] = ...  
    evaluateLaneBoundaries(testlbs,{x y1],[x y2]},threshold);  
  
disp('Precision:');  
  
Precision:
```

```

disp(numMatches/(numMatches+numFalsePositives));
    0.4000
disp('Sensitivity/Recall:');
Sensitivity/Recall:
disp(numMatches/(numMatches+numMisses));
    1

```

Input Arguments

worldGroundTruthPoints — Ground truth points of lane boundaries

[x y] array | cell array of [x y] arrays

Ground truth points of lane boundaries, specified as an [x y] array or cell array of [x y] arrays. The x-axis points must be unique and in the same coordinate system as the boundary models. A lane boundary must contain at least two points, but for a robust comparison, four or more points are recommended. Each element of the cell array represents a separate lane boundary.

threshold — Maximum lateral distance from ground truth

real scalar

Maximum lateral distance between a model and ground truth point in order for that point to be considered a valid match (true positive), specified as a real scalar.

boundaries — Lane boundary models

array of `parabolicLaneBoundary` objects | array of `cubicLaneBoundary` objects

Lane boundary models, specified as an array of `parabolicLaneBoundary` objects or `cubicLaneBoundary` objects. Lane boundary models contain the following properties:

- **Parameters** — A vector corresponding to the coefficients of the boundary model. The size of the vector depends on the degree of polynomial for the model.

Lane Boundary Object	Parameters
parabolicLaneBoundary	[A B C], corresponding to coefficients of a second-degree polynomial equation of the form $y = Ax^2 + Bx + C$
cubicLaneBoundary	[A B C D], corresponding to coefficients of a third-degree polynomial equation of the form $y = Ax^3 + Bx^2 + Cx + D$

- **BoundaryType** — A LaneBoundaryType enumeration of supported lane boundaries:
 - Unmarked
 - Solid
 - Dashed
 - BottsDots
 - DoubleSolid

Specify a lane boundary type as LaneBoundaryType.*BoundaryType*. For example:

```
LaneBoundaryType.BottsDots
```

- **Strength** — The ratio of the number of unique x-axis locations on the boundary to the total number of points along the line based on the XExtent property.
- **XExtent** — A two-element vector describing the minimum and maximum x-axis locations for the boundary points.

xWorld — x-axis locations of boundary

real-valued vector

x-axis locations of boundary, specified as a real-valued vector. Points in worldGroundTruthPoints are linearly interpolated at the given x-axis locations. Boundaries outside of these locations are excluded and count as false negatives.

groundTruthBoundaries — Ground truth boundary models

array of parabolicLaneBoundary or cubicLaneBoundary objects | cell array of parabolicLaneBoundary or cubicLaneBoundary arrays

Ground truth boundary models, specified as an array of parabolicLaneBoundary or cubicLaneBoundary objects or cell array of parabolicLaneBoundary or cubicLaneBoundary arrays.

Output Arguments

numMatches — Number of matches (true positives)

real scalar

Number of matches (true positives), returned as a real scalar.

numMissed — Number of misses (false negatives)

real scalar

Number of misses (false negatives), returned as a real scalar.

numFalsePositives — Number of false positives

real scalar

Number of false positives, returned as a real scalar.

assignments — Assignment indices for ground truth boundaries

cell array of real-valued arrays

Assignment indices for ground truth boundaries, returned as a cell array of real-valued arrays. Each boundary is matched to the corresponding assignment in `groundTruthBoundaries`. The k th boundary in `boundaries` is matched to the `assignments(k)` element of `worldGroundTruthPoints`. Zero indicates a false positive (no match found).

See Also

Functions

`findCubicLaneBoundaries` | `findParabolicLaneBoundaries`

Objects

`cubicLaneBoundary` | `parabolicLaneBoundary`

Apps

`Ground Truth Labeler`

Introduced in R2017a

findCubicLaneBoundaries

Find boundaries using cubic model

Syntax

```
boundaries = findCubicLaneBoundaries(xyBoundaryPoints,  
approxBoundaryWidth)  
[boundaries,boundaryPoints] = findCubicLaneBoundaries(  
xyBoundaryPoints,approxBoundaryWidth)  
[ ___ ] = findCubicLaneBoundaries( ___,Name,Value)
```

Description

`boundaries = findCubicLaneBoundaries(xyBoundaryPoints, approxBoundaryWidth)` uses the random sample consensus (RANSAC) algorithm to find cubic lane boundary models that fit a set of boundary points and an approximate width. Each model in the returned array of `cubicLaneBoundary` objects contains the [A B C D] coefficients of its third-degree polynomial equation and the strength of the boundary estimate.

`[boundaries,boundaryPoints] = findCubicLaneBoundaries(xyBoundaryPoints,approxBoundaryWidth)` also returns a cell array of inlier boundary points for each boundary model found, using the previous input arguments.

`[___] = findCubicLaneBoundaries(___,Name,Value)` uses options specified by one or more `Name,Value` pair arguments, with any of the preceding syntaxes.

Examples

Find Cubic Lane Boundaries in Bird's-Eye-View Image

Find lanes in an image by using cubic lane boundary models. Overlay the identified lanes on the original image and on a bird's-eye-view transformation of the image.

Load an image of a road with lanes. The image was obtained from a camera sensor mounted on the front of a vehicle.

```
I = imread('road.png');
```

Transform the image into a bird's-eye-view image by using a preconfigured sensor object. This object models the sensor that captured the original image.

```
bevSensor = load('birdsEyeConfig');  
birdsEyeImage = transformImage(bevSensor.birdsEyeConfig,I);  
imshow(birdsEyeImage)
```

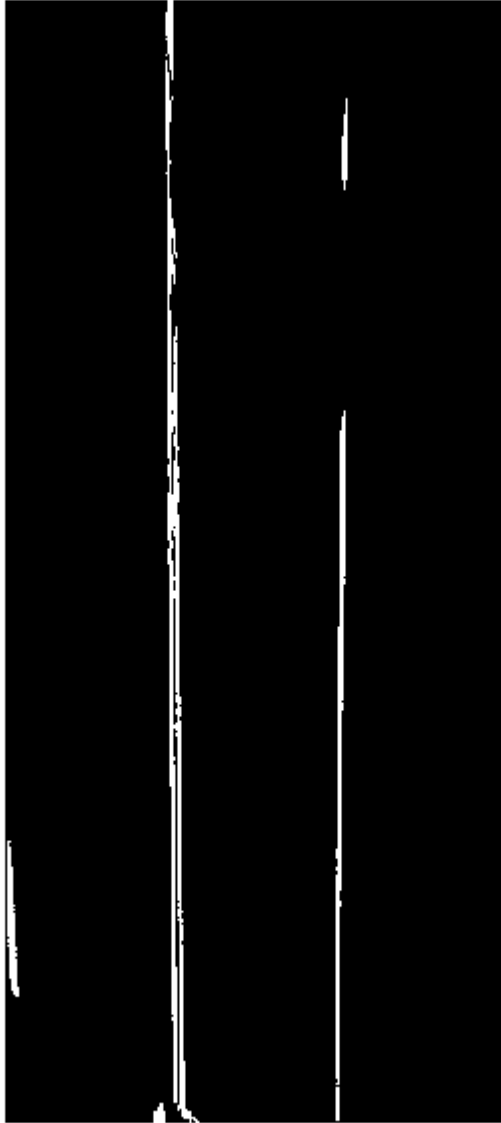


Set the approximate lane marker width in world units (meters).

```
approxBoundaryWidth = 0.25;
```

Detect lane features and display them as a black-and-white image.

```
birdsEyeBW = segmentLaneMarkerRidge(rgb2gray(birdsEyeImage), ...  
    bevSensor.birdsEyeConfig,approxBoundaryWidth);  
imshow(birdsEyeBW)
```



Obtain lane candidate points in world coordinates.

```
[imageX,imageY] = find(birdsEyeBW);  
xyBoundaryPoints = imageToVehicle(bevSensor.birdsEyeConfig,[imageY,imageX]);
```

Find lane boundaries in the image by using the `findCubicLaneBoundaries` function. By default, the function returns a maximum of two lane boundaries. The boundaries are stored in an array of `cubicLaneBoundary` objects.

```
boundaries = findCubicLaneBoundaries(xyBoundaryPoints,approxBoundaryWidth);
```

Use `insertLaneBoundary` to overlay the lanes on the original image. The `XPoints` vector represents the lane points, in meters, that are within range of the ego vehicle's sensor. Specify the lanes in different colors. By default, lanes are yellow.

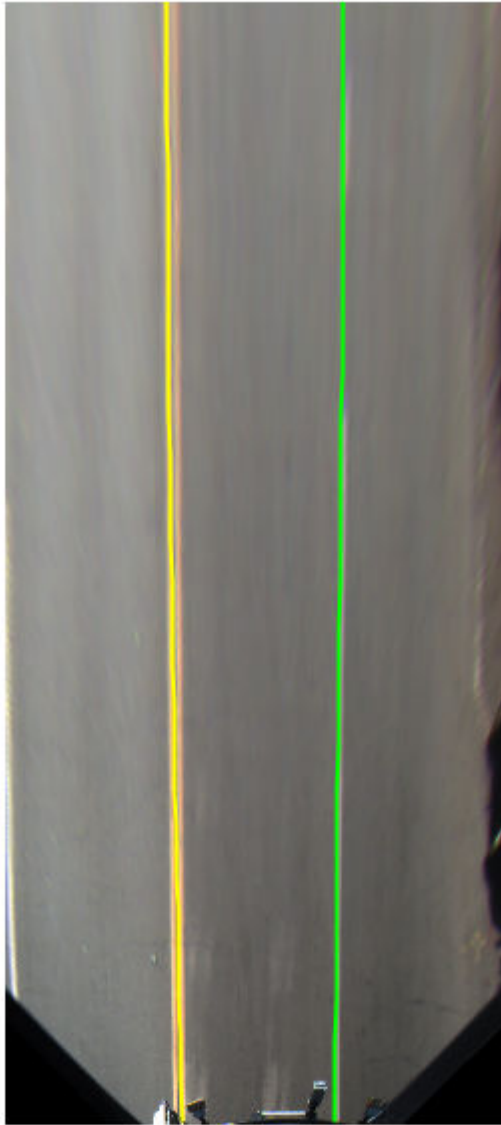
```
XPoints = 3:30;
```

```
figure  
sensor = bevSensor.birdsEyeConfig.Sensor;  
lanesI = insertLaneBoundary(I,boundaries(1),sensor,XPoints);  
lanesI = insertLaneBoundary(lanesI,boundaries(2),sensor,XPoints,'Color','green');  
imshow(lanesI)
```



View the lanes in the bird's-eye-view image.

```
figure  
BEconfig = bevSensor.birdsEyeConfig;  
lanesBEI = insertLaneBoundary(birdsEyeImage,boundaries(1),BEconfig,XPoints);  
lanesBEI = insertLaneBoundary(lanesBEI,boundaries(2),BEconfig,XPoints,'Color','green')  
imshow(lanesBEI)
```

Input Arguments

xyBoundaryPoints — Candidate boundary points

[x y] vector

Candidate boundary points, specified as an [x y] vector in vehicle coordinates. To obtain the vehicle coordinates for points in a `birdsEyeView` image, use the `imageToVehicle` function to convert the bird's-eye-view image coordinates to vehicle coordinates.

approxBoundaryWidth — Approximate boundary width

real scalar

Approximate boundary width, specified as a real scalar in world units. The width is a horizontal y-axis measurement.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'MaxSamplingAttempts', 200`

MaxNumBoundaries — Maximum number of lane boundaries

2 (default) | positive integer

Maximum number of lane boundaries that the function attempts to find, specified as the comma-separated pair consisting of `'MaxNumBoundaries'` and a positive integer.

ValidateBoundaryFcn — Function to validate boundary model

function handle

Function to validate the boundary model, specified as the comma-separated pair consisting of `'ValidateBoundaryFcn'` and a function handle. The specified function returns logical 1 (true) if the boundary model is accepted and logical 0 (false) otherwise. Use this function to reject invalid boundaries. The function must be of the form:

```
isValid = validateBoundaryFcn(parameters)
```

parameters is a vector corresponding to the three parabolic parameters.

The default validation function always returns 1 (true).

MaxSamplingAttempts — Maximum number of sampling attempts

100 (default) | positive integer

Maximum number of attempts to find a sample of points that yields a valid cubic boundary, specified as the comma-separated pair consisting of 'MaxSamplingAttempts' and a function handle. `findCubicLaneBoundaries` uses the `fitPolynomialRANSAC` function to sample from the set of boundary points and fit a cubic boundary line.

Output Arguments

boundaries — Lane boundary models

array of `cubicLaneBoundary` objects

Lane boundary models, returned as an array of `cubicLaneBoundary` objects. Lane boundary objects contain the following properties:

- **Parameters** — A four-element vector, [A B C D], that corresponds to the four coefficients of a third-degree polynomial equation in general form: $y = Ax^3 + Bx^2 + Cx + D$.
- **BoundaryType** — A `LaneBoundaryType` of supported lane boundaries. The supported lane boundary types are:
 - Unmarked
 - Solid
 - Dashed
 - BottsDots
 - DoubleSolid

Specify a lane boundary type as `LaneBoundaryType.BoundaryType`. For example:

```
LaneBoundaryType.BottsDots
```

- **Strength** — A ratio of the number of unique x-axis locations on the boundary to the total number of points along the line, based on the `XExtent` property.

- **XExtent** — A two-element vector describing the minimum and maximum x-axis locations for the boundary points.

boundaryPoints — Inlier boundary points

cell array of [x y] values

Inlier boundary points, returned as a cell array of [x y] values. Each element of the cell array corresponds to the same element in the array of `cubicLaneBoundary` objects.

Tips

- To fit a single boundary model to a double lane marker, set the `approxBoundaryWidth` argument to be large enough to include the width spanning both lane markers.

Algorithms

- This function uses `fitPolynomialRANSAC` to find cubic models. Because this algorithm uses random sampling, the output can vary between runs.
- The `maxDistance` parameter of `fitPolynomialRANSAC` is set to half the width specified in the `approxBoundaryWidth` argument. Points are considered inliers if they are within the boundary width. The function obtains the final boundary model using a least-squares fit on the inlier points.

See Also

`birdsEyePlot` | `birdsEyeView` | `cubicLaneBoundary` | `fitPolynomialRANSAC` | `monoCamera` | `segmentLaneMarkerRidge`

Introduced in R2018a

findParabolicLaneBoundaries

Find boundaries using parabolic model

Syntax

```
boundaries = findParabolicLaneBoundaries(xyBoundaryPoints,
approxBoundaryWidth)
[boundaries,boundaryPoints] = findParabolicLaneBoundaries(
xyBoundaryPoints,approxBoundaryWidth)
[ ___ ] = findParabolicLaneBoundaries( ___ ,Name,Value)
```

Description

`boundaries = findParabolicLaneBoundaries(xyBoundaryPoints, approxBoundaryWidth)` uses the random sample consensus (RANSAC) algorithm to find parabolic lane boundary models that fit a set of boundary points and an approximate width. Each model in the returned array of `parabolicLaneBoundary` objects contains the [A B C] coefficients of its second-degree polynomial equation and the strength of the boundary estimate.

`[boundaries,boundaryPoints] = findParabolicLaneBoundaries(xyBoundaryPoints,approxBoundaryWidth)` also returns a cell array of inlier boundary points for each boundary model found.

`[___] = findParabolicLaneBoundaries(___ ,Name,Value)` uses options specified by one or more `Name,Value` pair arguments, with any of the preceding syntaxes.

Examples

Find Parabolic Lane Boundaries in Bird's-Eye-View Image

Find lanes in an image by using parabolic lane boundary models. Overlay the identified lanes on the original image and on a bird's-eye-view transformation of the image.

Load an image of a road with lanes. The image was obtained from a camera sensor mounted on the front of a vehicle.

```
I = imread('road.png');
```

Transform the image into a bird's-eye-view image by using a preconfigured sensor object. This object models the sensor that captured the original image.

```
bevSensor = load('birdsEyeConfig');  
birdsEyeImage = transformImage(bevSensor.birdsEyeConfig,I);  
imshow(birdsEyeImage)
```

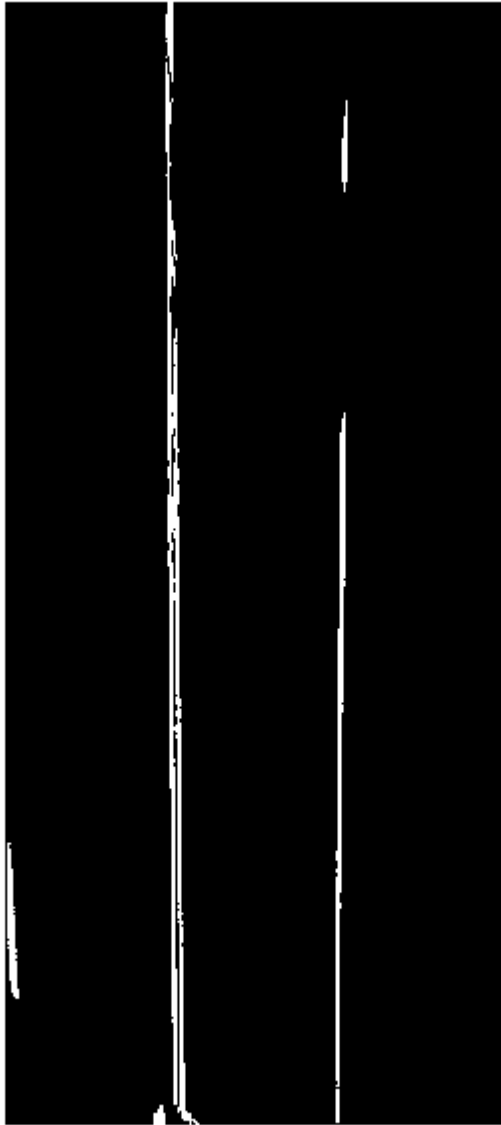


Set the approximate lane marker width in world units (meters).

```
approxBoundaryWidth = 0.25;
```

Detect lane features and display them as a black-and-white image.

```
birdsEyeBW = segmentLaneMarkerRidge(rgb2gray(birdsEyeImage), ...  
    bevSensor.birdsEyeConfig,approxBoundaryWidth);  
imshow(birdsEyeBW)
```

Obtain lane candidate points in world coordinates.

```
[imageX,imageY] = find(birdsEyeBW);  
xyBoundaryPoints = imageToVehicle(bevSensor.birdsEyeConfig,[imageY,imageX]);
```

Find lane boundaries in the image by using the `findParabolicLaneBoundaries` function. By default, the function returns a maximum of two lane boundaries. The boundaries are stored in an array of `parabolicLaneBoundary` objects.

```
boundaries = findParabolicLaneBoundaries(xyBoundaryPoints,approxBoundaryWidth);
```

Use `insertLaneBoundary` to overlay the lanes on the original image. The `XPoints` vector represents the lane points, in meters, that are within range of the ego vehicle's sensor. Specify the lanes in different colors. By default, lanes are yellow.

```
XPoints = 3:30;
```

```
figure  
sensor = bevSensor.birdsEyeConfig.Sensor;  
lanesI = insertLaneBoundary(I,boundaries(1),sensor,XPoints);  
lanesI = insertLaneBoundary(lanesI,boundaries(2),sensor,XPoints,'Color','green');  
imshow(lanesI)
```



View the lanes in the bird's-eye-view image.

```
figure
BEconfig = bevSensor.birdsEyeConfig;
lanesBEI = insertLaneBoundary(birdsEyeImage,boundaries(1),BEconfig,XPoints);
lanesBEI = insertLaneBoundary(lanesBEI,boundaries(2),BEconfig,XPoints,'Color','green');
imshow(lanesBEI)
```



Input Arguments

xyBoundaryPoints — Candidate boundary points

[x y] vector

Candidate boundary points, specified as an [x y] vector in vehicle coordinates. To obtain the vehicle coordinates for points in a `birdsEyeView` image, use the `imageToVehicle` function to convert the bird's-eye-view image coordinates to vehicle coordinates.

approxBoundaryWidth — Approximate boundary width

real scalar

Approximate boundary width, specified as a real scalar in world units. The width is a horizontal y-axis measurement.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'MaxSamplingAttempts', 200`

MaxNumBoundaries — Maximum number of lane boundaries

2 (default) | positive integer

Maximum number of lane boundaries that the function attempts to find, specified as the comma-separated pair consisting of `'MaxNumBoundaries'` and a positive integer.

ValidateBoundaryFcn — Function to validate boundary model

function handle

Function to validate the boundary model, specified as the comma-separated pair consisting of `'ValidateBoundaryFcn'` and a function handle. The specified function returns logical 1 (true) if the boundary model is accepted and logical 0 (false) otherwise. Use this function to reject invalid boundaries. The function must be of the form:

```
isValid = validateBoundaryFcn(parameters)
```

parameters is a vector corresponding to the three parabolic parameters.

The default validation function always returns 1 (true).

MaxSamplingAttempts — Maximum number of sampling attempts

100 (default) | positive integer

Maximum number of attempts to find a sample of points that yields a valid parabolic boundary, specified as the comma-separated pair consisting of 'MaxSamplingAttempts' and a function handle. `findParabolicLaneBoundaries` uses the `fitPolynomialRANSAC` function to sample from the set of boundary points and fit a parabolic boundary line.

Output Arguments

boundaries — Lane boundary models

array of `parabolicLaneBoundary` objects

Lane boundary models, returned as an array of `parabolicLaneBoundary` objects. Lane boundary objects contain the following properties:

- **Parameters** — A three-element vector, [A B C], that corresponds to the three coefficients of a second-degree polynomial equation in general form: $y = Ax^2 + Bx + C$.
- **BoundaryType** — A `LaneBoundaryType` of supported lane boundaries. The supported lane boundary types are:
 - Unmarked
 - Solid
 - Dashed
 - BottsDots
 - DoubleSolid

Specify a lane boundary type as `LaneBoundaryType.BoundaryType`. For example:

`LaneBoundaryType.BottsDots`

- **Strength** — A ratio of the number of unique x-axis locations on the boundary to the total number of points along the line, based on the `XExtent` property.
- **XExtent** — A two-element vector describing the minimum and maximum x-axis locations for the boundary points.

boundaryPoints — Inlier boundary points

cell array of [x y] values

Inlier boundary points, returned as a cell array of [x y] values. Each element of the cell array corresponds to the same element in the array of `parabolicLaneBoundary` objects.

Tips

- To fit a single boundary model to a double lane marker, set the `approxBoundaryWidth` argument to be large enough to include the width spanning both lane markers.

Algorithms

- This function uses `fitPolynomialRANSAC` to find parabolic models. Because this algorithm uses random sampling, the output can vary between runs.
- The `maxDistance` parameter of `fitPolynomialRANSAC` is set to half the width specified in the `approxBoundaryWidth` argument. Points are considered inliers if they are within the boundary width. The function obtains the final boundary model using a least-squares fit on the inlier points.

See Also

`birdsEyePlot` | `birdsEyeView` | `fitPolynomialRANSAC` | `monoCamera` | `parabolicLaneBoundary` | `segmentLaneMarkerRidge`

Introduced in R2017a

getTrackPositions

Returns updated track positions and position covariance matrix

Syntax

```
position = getTrackPositions(tracks,positionSelector)
[position,positionCovariances] = getTrackPositions(tracks,
positionSelector)
```

Description

`position = getTrackPositions(tracks,positionSelector)` returns a matrix of track positions. Each row contains the position of a tracked object.

`[position,positionCovariances] = getTrackPositions(tracks,positionSelector)` returns a matrix of track positions.

Examples

Find Position of 3-D Constant-Acceleration Object

Create an extended Kalman filter tracker for 3-D constant-acceleration motion.

```
tracker = multiObjectTracker('FilterInitializationFcn',@initcaekf);
```

Update the tracker with a single detection and get the tracks output.

```
detection = objectDetection(0,[10;-20;4],'ObjectClassID',3);
tracks = updateTracks(tracker,detection,0)
```

```
tracks = struct with fields:
    TrackID: 1
    Time: 0
    Age: 1
    State: [9x1 double]
```



```

StateCovariance: [9x9 double]
  IsConfirmed: 1
  IsCoasted: 0
  ObjectClassID: 3
  ObjectAttributes: {}

```

Obtain the position vector from the track state.

```

positionSelector = [1 0 0 0 0 0 0 0 0; 0 0 0 1 0 0 0 0 0; 0 0 0 0 0 0 1 0 0];
position = getTrackPositions(tracks, positionSelector)

```

```

position = 1x3
         10    -20     4

```

Find Position and Covariance of 3-D Constant-Velocity Object

Create an extended Kalman filter tracker for 3-D constant-velocity motion.

```

tracker = multiObjectTracker('FilterInitializationFcn',@initcvekf);

```

Update the tracker with a single detection and get the tracks output.

```

detection = objectDetection(0,[10;3;-7],'ObjectClassID',3);
tracks = updateTracks(tracker,detection,0)

```

```

tracks = struct with fields:
  TrackID: 1
  Time: 0
  Age: 1
  State: [6x1 double]
  StateCovariance: [6x6 double]
  IsConfirmed: 1
  IsCoasted: 0
  ObjectClassID: 3
  ObjectAttributes: {}

```

Obtain the position vector and position covariance for that track

```
positionSelector = [1 0 0 0 0 0; 0 0 1 0 0 0; 0 0 0 0 1 0];  
[position,positionCovariance] = getTrackPositions(tracks,positionSelector)
```

```
position = 1×3
```

```
    10     3    -7
```

```
positionCovariance = 3×3
```

```
     1     0     0  
     0     1     0  
     0     0     1
```

Input Arguments

tracks — Track data structure

struct array

Tracked object, specified as a struct array. A track struct array is an array of MATLAB struct types containing sufficient information to obtain the track position vector and, optionally, the position covariance matrix. At a minimum, the struct must contain a State column vector field and a positive-definite StateCovariance matrix field. For an example of a track struct used by Automated Driving Toolbox, examine the output argument, tracks, returned by the updateTracks function when used with a multiObjectTracker System object.

positionSelector — Position selection matrix

D -by- N real-valued matrix.

Position selector, specified as a D -by- N real-valued matrix of ones and zeros. D is the number of dimensions of the tracker. N is the size of the state vector. Using this matrix, the function extracts track positions from the state vector. Multiply the state vector by position selector matrix returns positions. The same selector is applied to all object tracks.

Output Arguments

position — Positions of tracked objects

real-valued M -by- D matrix

Positions of tracked objects at last update time, returned as a real-valued M -by- D matrix. D represents the number of position elements. M represents the number of tracks.

positionCovariances — Position covariance matrices of tracked objects

real-valued D -by- D - M array

Position covariance matrices of tracked objects, returned as a real-valued D -by- D - M array. D represents the number of position elements. M represents the number of tracks. Each D -by- D submatrix is a position covariance matrix for a track.

More About

Position Selector for 2-Dimensional Motion

Show the position selection matrix for two-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Position Selector for 3-Dimensional Motion

Show the position selection matrix for three-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Position Selector for 3-Dimensional Motion with Acceleration

Show the position selection matrix for three-dimensional motion when the state consists of the position, velocity, and acceleration.

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`getTrackVelocities` | `initcaekf` | `initcakf` | `initcaukf` | `initctekf` | `initctukf` | `initcvkf` | `initcvukf`

Objects

`multiObjectTracker` | `objectDetection`

Introduced in R2017a

getTrackVelocities

Obtain updated track velocities and velocity covariance matrix

Syntax

```
velocity = getTrackVelocities(tracks,velocitySelector)
[velocity,velocityCovariances] = getTrackVelocities(tracks,
velocitySelector)
```

Description

`velocity = getTrackVelocities(tracks,velocitySelector)` returns velocities of tracked objects.

`[velocity,velocityCovariances] = getTrackVelocities(tracks,velocitySelector)` also returns the track velocity covariance matrices.

Examples

Find Velocity of 3-D Constant-Acceleration Object

Create an extended Kalman filter tracker for 3-D constant-acceleration motion.

```
tracker = multiObjectTracker('FilterInitializationFcn',@initcaekf);
```

Initialize the tracker with a one detection.

```
detection = objectDetection(0,[10;-20;4],'ObjectClassID',3);
tracks = updateTracks(tracker,detection,0);
```

Add a second detection at a later time and translated position.

```
detection = objectDetection(0.1,[10.3;-20.2;4],'ObjectClassID',3);
tracks = updateTracks(tracker,detection,0.2);
```

Obtain the velocity vector from the track state.

```
velocitySelector = [0 1 0 0 0 0 0 0 0; 0 0 0 0 1 0 0 0 0; 0 0 0 0 0 0 0 0 1 0];  
velocity = getTrackVelocities(tracks,velocitySelector)
```

```
velocity = 1×3
```

```
    1.0093    -0.6728         0
```

Velocity and Covariance of 3-D Constant-Acceleration Object

Create an extended Kalman filter tracker for 3-D constant-acceleration motion.

```
tracker = multiObjectTracker('FilterInitializationFcn',@initcaekf);
```

Initialize the tracker with a one detection.

```
detection = objectDetection(0,[10;-20;4], 'ObjectClassID',3);  
tracks = updateTracks(tracker,detection,0);
```

Add a second detection at a later time and translated position.

```
detection = objectDetection(0.1,[10.3;-20.2;4.3], 'ObjectClassID',3);  
tracks = updateTracks(tracker,detection,0.2);
```

Obtain the velocity vector from the track state.

```
velocitySelector = [0 1 0 0 0 0 0 0 0; 0 0 0 0 1 0 0 0 0; 0 0 0 0 0 0 0 0 1 0];  
[velocity,velocityCovariance] = getTrackVelocities(tracks,velocitySelector)
```

```
velocity = 1×3
```

```
    1.0093    -0.6728    1.0093
```

```
velocityCovariance = 3×3
```

```
    70.0685         0         0  
         0    70.0685         0  
         0         0    70.0685
```

Input Arguments

tracks — Track data structure

struct array

Tracked object, specified as a struct array. A track struct array is an array of MATLAB struct types containing sufficient information to obtain the track position vector and, optionally, the position covariance matrix. At a minimum, the struct must contain a State column vector field and a positive-definite StateCovariance matrix field. For an example of a track struct used by Automated Driving Toolbox, examine the output argument, tracks, returned by the updateTracks function when used with a multiObjectTracker System object.

velocitySelector — Velocity selection matrix

D -by- N real-valued matrix.

Velocity selector, specified as a D -by- N real-valued matrix of ones and zeros. D is the number of dimensions of the tracker. N is the size of the state vector. Using this matrix, the function extracts track velocities from the state vector. Multiply the state vector by velocity selector matrix returns velocities. The same selector is applied to all object tracks.

Output Arguments

velocity — Velocities of tracked objects

real-valued 1 -by- D vector | real-valued M -by- D matrix

Velocities of tracked objects at last update time, returned as a 1 -by- D vector or a real-valued M -by- D matrix. D represents the number of velocity elements. M represents the number of tracks.

velocityCovariances — Velocity covariance matrices of tracked objects

real-valued D -by- D -matrix | real-valued D -by- D -by- M array

Velocity covariance matrices of tracked objects, returned as a real-valued D -by- D -matrix or a real-valued D -by- D -by- M array. D represents the number of velocity elements. M represents the number of tracks. Each D -by- D submatrix is a velocity covariance matrix for a track.

More About

Velocity Selector for 2-Dimensional Motion

Show the velocity selection matrix for two-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Velocity Selector for 3-Dimensional Motion

Show the velocity selection matrix for three-dimensional motion when the state consists of the position and velocity.

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Velocity Selector for 3-Dimensional Motion with Acceleration

Show the velocity selection matrix for three-dimensional motion when the state consists of the position, velocity, and acceleration.

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

getTrackPositions | initcaekf | initcakf | initcaukf | initctekf | initctukf
| initcvkf | initcvukf

Objects

multiObjectTracker | objectDetection

Introduced in R2017a

hereHDLMCredentials

Set up or delete HERE HD Live Map credentials

Syntax

```
hereHDLMCredentials('setup')  
hereHDLMCredentials('delete')
```

Description

`hereHDLMCredentials('setup')` opens a dialog box for specifying the app ID and app code credentials required to access the HERE HD Live Map¹ (HERE HDLM) web service. By default, entered credentials last for the duration of a MATLAB session. To save credentials between sessions, in the HERE HD Live Map Credentials dialog box, select the **Save my credentials between MATLAB sessions** check box .

Simplified form: `hereHDLMCredentials setup`

`hereHDLMCredentials('delete')` deletes saved HERE HDLM credentials. Any subsequent use of HERE HDLM functions and objects, such as `hereHDLMConfiguration` or `hereHDLMReader`, requires entering new credentials.

Simplified form: `hereHDLMCredentials delete`

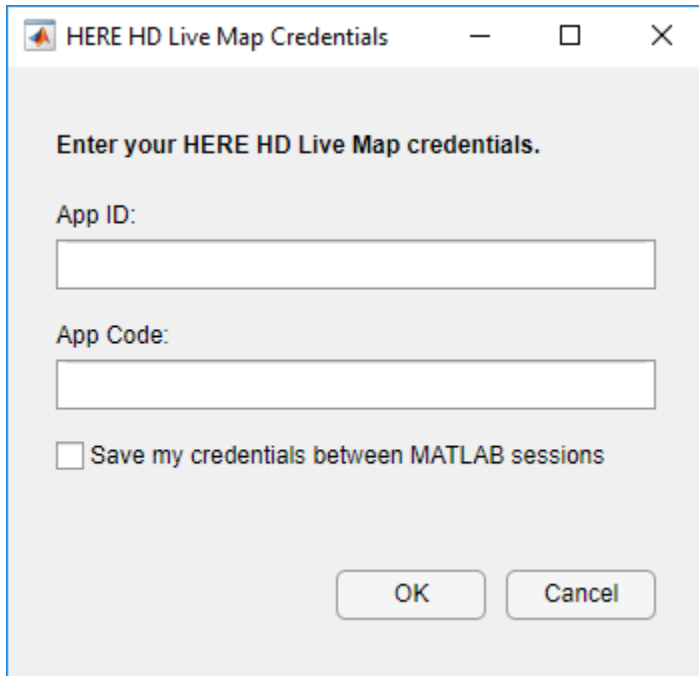
Examples

Manage HERE HD Live Map Credentials

Set up HERE HD Live Map (HERE HDLM) credentials.

```
hereHDLMCredentials setup
```

1. You need to enter into a separate agreement with HERE in order to gain access to the HDLM services and to get the required credentials (app_id and app_code) for using the HERE Service.



Enter a valid **App ID** and **App Code**. You can obtain these credentials by entering into a separate agreement with HERE Technologies. Optionally select **Save my credentials between MATLAB sessions**, and click **OK**.

Load a driving route, and create a HERE HDLM reader using the route coordinates. The HERE HD Live Map Credentials dialog box does not open, because the credentials have already been set up.

```
data = load('geoSequence.mat');  
reader = hereHDLMReader(data.latitude,data.longitude);
```

Delete the HERE HDLM credentials you previously entered. The next time you call `hereHDLMReader`, you are asked to enter your credentials again.

```
hereHDLMCredentials delete
```

See Also

`hereHDLMConfiguration` | `hereHDLMReader`

Topics

“Enter HERE HD Live Map Credentials”

“Access HERE HD Live Map Data”

Introduced in R2019a

initcaekf

Create constant-acceleration extended Kalman filter from detection report

Syntax

```
filter = initcaekf(detection)
```

Description

`filter = initcaekf(detection)` creates and initializes a constant-acceleration extended Kalman filter from information contained in a `detection` report. For more information about the extended Kalman filter, see `trackingEKF`.

Examples

Initialize 3-D Constant-Acceleration Extended Kalman Filter

Create and initialize a 3-D constant-acceleration extended Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, $(-200;30;0)$, of the object position. Assume uncorrelated measurement noise.

```
detection = objectDetection(0,[-200;-30;0],'MeasurementNoise',2.1*eye(3), ...  
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{ 'Car',2});
```

Create the new filter from the detection report and display its properties.

```
filter = initcaekf(detection)
```

```
filter =  
    trackingEKF with properties:
```

```
        State: [9x1 double]  
    StateCovariance: [9x9 double]
```

```
StateTransitionFcn: @constacc
StateTransitionJacobianFcn: @constaccjac
    ProcessNoise: [3x3 double]
HasAdditiveProcessNoise: 0

MeasurementFcn: @cameas
MeasurementJacobianFcn: @cameasjac
    MeasurementNoise: [3x3 double]
HasAdditiveMeasurementNoise: 1
```

Show the filter state.

```
filter.State
```

```
ans = 9x1
```

```
-200
  0
  0
-30
  0
  0
  0
  0
  0
```

Show the state covariance matrix.

```
filter.StateCovariance
```

```
ans = 9x9
```

```
2.1000    0    0    0    0    0    0    0    0
  0 100.0000    0    0    0    0    0    0    0
  0    0 100.0000    0    0    0    0    0    0
  0    0    0 2.1000    0    0    0    0    0
  0    0    0    0 100.0000    0    0    0    0
  0    0    0    0    0 100.0000    0    0    0
  0    0    0    0    0    0 2.1000    0    0
  0    0    0    0    0    0    0 100.0000    0
  0    0    0    0    0    0    0    0 100.0000
```

Create 3D Constant Acceleration EKF from Spherical Measurement

Initialize a 3D constant-acceleration extended Kalman filter from an initial detection report made from an initial measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45° , the elevation to 22° , the range to 1000 meters, and the range rate to -4.0 m/s.

```
frame = 'spherical';
sensorpos = [25,-40,-10].';
sensorvel = [0;5;0];
laxes = eye(3);
```

Create the measurement parameters structure. Set `'HasVelocity'` and `'HasElevation'` to `true`. Then, the measurement vector consists of azimuth, elevation, range, and range rate.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',true, ...
    'HasElevation',true);
meas = [45;22;1000;-4];
measnoise = diag([3.0,2.5,2,1.0].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
  objectDetection with properties:
        Time: 0
    Measurement: [4x1 double]
  MeasurementNoise: [4x4 double]
      SensorIndex: 1
    ObjectClassID: 0
  MeasurementParameters: [1x1 struct]
    ObjectAttributes: {}
```

```
filter = initcaekf(detection);
```

Display the state vector.

```
disp(filter.State)
```

```
680.6180  
-2.6225  
0  
615.6180  
2.3775  
0  
364.6066  
-1.4984  
0
```

Input Arguments

detection — Detection report

objectDetection object

Detection report, specified as an objectDetection object.

Example: `detection = objectDetection(0,[1;4.5;3], 'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Extended Kalman filter

trackingEKF object

Extended Kalman filter, returned as a trackingEKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration-rate standard deviation of 1 m/s³.
- You can use this function as the FilterInitializationFcn property of a multiObjectTracker object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`initcakf` | `initcaukf` | `initctekf` | `initctukf` | `initcvekf` | `initcvkf` | `initcvukf`

Objects

`multiObjectTracker` | `objectDetection` | `trackingEKF` | `trackingKF` | `trackingUKF`

Introduced in R2017a

initcakf

Create constant-acceleration linear Kalman filter from detection report

Syntax

```
filter = initcakf(detection)
```

Description

`filter = initcakf(detection)` creates and initializes a constant-acceleration linear Kalman filter from information contained in a detection report. For more information about the linear Kalman filter, see `trackingKF`.

Examples

Initialize 2-D Constant-Acceleration Linear Kalman Filter

Create and initialize a 2-D constant-acceleration linear Kalman filter object from an initial detection report.

Create the detection report from an initial 2-D measurement, (10,−5), of the object position. Assume uncorrelated measurement noise.

```
detection = objectDetection(0,[10;-5], 'MeasurementNoise', eye(2), ...  
    'SensorIndex', 1, 'ObjectClassID', 1, 'ObjectAttributes', {'Car', 5});
```

Create the new filter from the detection report.

```
filter = initcakf(detection);
```

Show the filter state.

```
filter.State
```

```
ans = 6×1
```

```

10
0
0
-5
0
0

```

Show the state transition model.

```
filter.StateTransitionModel
```

```
ans = 6x6
```

```

1.0000    1.0000    0.5000         0         0         0
0         1.0000    1.0000         0         0         0
0         0         1.0000         0         0         0
0         0         0         1.0000    1.0000    0.5000
0         0         0         0         1.0000    1.0000
0         0         0         0         0         1.0000

```

Input Arguments

detection — Detection report

objectDetection object

Detection report, specified as an objectDetection object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',[1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Linear Kalman filter

trackingKF object

Linear Kalman filter, returned as a trackingKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration rate standard deviation of 1 m/s^3 .
- You can use this function as the `FilterInitializationFcn` property of a `multiObjectTracker` object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`initcaekf` | `initcaukf` | `initctekf` | `initctukf` | `initcvekf` | `initcvkf` | `initcvukf`

Objects

`multiObjectTracker` | `objectDetection` | `trackingEKF` | `trackingKF` | `trackingUKF`

Introduced in R2017a

initcaukf

Create constant-acceleration unscented Kalman filter from detection report

Syntax

```
filter = initcaukf(detection)
```

Description

`filter = initcaukf(detection)` creates and initializes a constant-acceleration unscented Kalman filter from information contained in a `detection` report. For more information about the unscented Kalman filter, see `trackingUKF`.

Examples

Initialize 3-D Constant-Acceleration Unscented Kalman Filter

Create and initialize a 3-D constant-acceleration unscented Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (-200,-30,5), of the object position. Assume uncorrelated measurement noise.

```
detection = objectDetection(0,[-200;-30;5],'MeasurementNoise',2.0*eye(3), ...  
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{ 'Car',2});
```

Create the new filter from the detection report and display the filter properties.

```
filter = initcaukf(detection)
```

```
filter =  
    trackingUKF with properties:
```

```
        State: [9x1 double]  
    StateCovariance: [9x9 double]
```

```
StateTransitionFcn: @constacc
    ProcessNoise: [3x3 double]
HasAdditiveProcessNoise: 0

    MeasurementFcn: @cameas
    MeasurementNoise: [3x3 double]
HasAdditiveMeasurementNoise: 1

    Alpha: 1.0000e-03
    Beta: 2
    Kappa: 0
```

Show the state.

```
filter.State
```

```
ans = 9x1
```

```
-200
  0
  0
-30
  0
  0
  5
  0
  0
```

Show the state covariance matrix.

```
filter.StateCovariance
```

```
ans = 9x9
```

```
  2   0   0   0   0   0   0   0   0
  0  100  0   0   0   0   0   0   0
  0   0  100  0   0   0   0   0   0
  0   0   0   2   0   0   0   0   0
  0   0   0   0  100  0   0   0   0
  0   0   0   0   0  100  0   0   0
  0   0   0   0   0   0   2   0   0
  0   0   0   0   0   0   0  100  0
```

```
0 0 0 0 0 0 0 0 100
```

Create 3D Constant Acceleration UKF from Spherical Measurement

Initialize a 3D constant-acceleration unscented Kalman filter from an initial detection report made from a measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45° , and the range to 1000 meters.

```
frame = 'spherical';
sensorpos = [25, -40, -10].';
sensorvel = [0;5;0];
laxes = eye(3);
```

Create the measurement structure. Set `'HasVelocity'` and `'HasElevation'` to `false`. Then, the measurement vector consists of azimuth angle and range.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',false, ...
    'HasElevation',false);
meas = [45;1000];
measnoise = diag([3.0,2.0].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
    objectDetection with properties:
        Time: 0
        Measurement: [2x1 double]
        MeasurementNoise: [2x2 double]
        SensorIndex: 1
        ObjectClassID: 0
        MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

```
filter = initcaukf(detection);
```

Display the state vector.

```
disp(filter.State)
```

```
732.1068
      0
      0
667.1068
      0
      0
-10.0000
      0
      0
```

Input Arguments

detection — Detection report

objectDetection object

Detection report, specified as an objectDetection object.

Example: `detection = objectDetection(0,[1;4.5;3], 'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Unscented Kalman filter

trackingUKF object

Unscented Kalman filter, returned as a trackingUKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration rate standard deviation of 1 m/s³.
- You can use this function as the `FilterInitializationFcn` property of a `multiObjectTracker` object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`initcaekf` | `initcakf` | `initctekf` | `initctukf` | `initcvekf` | `initcvkf` | `initcvukf`

Objects

`multiObjectTracker` | `objectDetection` | `trackingEKF` | `trackingKF` | `trackingUKF`

Introduced in R2017a

initctekf

Create constant turn-rate extended Kalman filter from detection report

Syntax

```
filter = initctekf(detection)
```

Description

`filter = initctekf(detection)` creates and initializes a constant-turn-rate extended Kalman filter from information contained in a `detection` report. For more information about the extended Kalman filter, see `trackingEKF`.

Examples

Initialize 2-D Constant Turn-Rate Extended Kalman Filter

Create and initialize a 2-D constant turn-rate extended Kalman filter object from an initial detection report.

Create the detection report from an initial 2-D measurement, (-250,-40), of the object position. Assume uncorrelated measurement noise.

Extend the measurement to three dimensions by adding a z-component of zero.

```
detection = objectDetection(0, [-250;-40;0], 'MeasurementNoise', 2.0*eye(3), ...  
    'SensorIndex', 1, 'ObjectClassID', 1, 'ObjectAttributes', {'Car', 2});
```

Create the new filter from the detection report and display the filter properties.

```
filter = initctekf(detection)  
  
filter =  
    trackingEKF with properties:
```

```

                State: [7x1 double]
            StateCovariance: [7x7 double]

            StateTransitionFcn: @constturn
    StateTransitionJacobianFcn: @constturnjac
                ProcessNoise: [4x4 double]
            HasAdditiveProcessNoise: 0

                MeasurementFcn: @ctmeas
            MeasurementJacobianFcn: @ctmeasjac
                MeasurementNoise: [3x3 double]
    HasAdditiveMeasurementNoise: 1

```

Show the state.

```
filter.State
```

```
ans = 7x1
```

```

-250
   0
  -40
   0
   0
   0
   0

```

Show the state covariance matrix.

```
filter.StateCovariance
```

```
ans = 7x7
```

```

   2   0   0   0   0   0   0
   0 100   0   0   0   0   0
   0   0   2   0   0   0   0
   0   0   0 100   0   0   0
   0   0   0   0 100   0   0
   0   0   0   0   0   2   0
   0   0   0   0   0   0 100

```

Create 2-D Constant Turnrate EKF from Spherical Measurement

Initialize a 2-D constant-turnrate extended Kalman filter from an initial detection report made from an initial measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45 degrees, the range to 1000 meters, and the range rate to -4.0 m/s.

```
frame = 'spherical';  
sensorpos = [25,-40,-10].';  
sensorvel = [0;5;0];  
laxes = eye(3);
```

Create the measurement parameters structure. Set `'HasElevation'` to `false`. Then, the measurement consists of azimuth, range, and range rate.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...  
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',true, ...  
    'HasElevation',false);  
meas = [45;1000;-4];  
measnoise = diag([3.0,2,1.0].^2);  
detection = objectDetection(0,meas,'MeasurementNoise', ...  
    measnoise,'MeasurementParameters',measparms)
```

```
detection =  
    objectDetection with properties:  
  
                Time: 0  
        Measurement: [3x1 double]  
    MeasurementNoise: [3x3 double]  
        SensorIndex: 1  
        ObjectClassID: 0  
    MeasurementParameters: [1x1 struct]  
        ObjectAttributes: {}
```

```
filter = initctekf(detection);
```

Filter state vector.

```
disp(filter.State)  
  
    732.1068  
    -2.8284  
    667.1068
```

```
2.1716
0
-10.0000
0
```

Input Arguments

detection — Detection report

objectDetection object

Detection report, specified as an objectDetection object.

Example: `detection = objectDetection(0,[1;4.5;3], 'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Extended Kalman filter

trackingEKF object

Extended Kalman filter, returned as a trackingEKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step. The function assumes an acceleration standard deviation of 1 m/s², and a turn-rate acceleration standard deviation of 1°/s².
- You can use this function as the `FilterInitializationFcn` property of a `multiObjectTracker` object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`initcaekf` | `initcakf` | `initcaukf` | `initctukf` | `initcvekf` | `initcvkf` | `initcvukf`

Objects

`multiObjectTracker` | `objectDetection` | `trackingEKF` | `trackingKF` | `trackingUKF`

Introduced in R2017a

initctukf

Create constant turn-rate unscented Kalman filter from detection report

Syntax

```
filter = initctukf(detection)
```

Description

`filter = initctukf(detection)` creates and initializes a constant-turn-rate unscented Kalman filter from information contained in a `detection` report. For more information about the unscented Kalman filter, see `trackingUKF`.

Examples

Initialize 2-D Constant Turn-Rate Unscented Kalman Filter

Create and initialize a 2-D constant turn-rate unscented Kalman filter object from an initial detection report.

Create the detection report from an initial 2D measurement, (-250,-40), of the object position. Assume uncorrelated measurement noise.

Extend the measurement to three dimensions by adding a z-component of zero.

```
detection = objectDetection(0, [-250;-40;0], 'MeasurementNoise', 2.0*eye(3), ...  
    'SensorIndex', 1, 'ObjectClassID', 1, 'ObjectAttributes', {'Car', 2});
```

Create the new filter from the detection report and display the filter properties.

```
filter = initctukf(detection)  
  
filter =  
    trackingUKF with properties:
```

```
State: [7x1 double]
StateCovariance: [7x7 double]

StateTransitionFcn: @constturn
ProcessNoise: [4x4 double]
HasAdditiveProcessNoise: 0

MeasurementFcn: @ctmeas
MeasurementNoise: [3x3 double]
HasAdditiveMeasurementNoise: 1

Alpha: 1.0000e-03
Beta: 2
Kappa: 0
```

Show the filter state.

```
filter.State
```

```
ans = 7x1
```

```
-250
0
-40
0
0
0
0
```

Show the state covariance matrix.

```
filter.StateCovariance
```

```
ans = 7x7
```

```
2    0    0    0    0    0    0
0   100    0    0    0    0    0
0    0    2    0    0    0    0
0    0    0   100    0    0    0
0    0    0    0   100    0    0
0    0    0    0    0    2    0
0    0    0    0    0    0   100
```


Create 2-D Constant Turnrate UKF from Spherical Measurement

Initialize a 2-D constant-turnrate extended Kalman filter from an initial detection report made from an initial measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45 degrees and the range to 1000 meters.

```
frame = 'spherical';
sensorpos = [25, -40, -10].';
sensorvel = [0;5;0];
laxes = eye(3);
```

Create the measurement parameters structure. Set `'HasVelocity'` and `'HasElevation'` to `false`. Then, the measurement consists of azimuth and range.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',false, ...
    'HasElevation',false);
meas = [45;1000];
measnoise = diag([3.0,2].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
    objectDetection with properties:
        Time: 0
        Measurement: [2x1 double]
        MeasurementNoise: [2x2 double]
        SensorIndex: 1
        ObjectClassID: 0
        MeasurementParameters: [1x1 struct]
        ObjectAttributes: {}
```

```
filter = initctukf(detection);
```

Filter state vector.

```
disp(filter.State)
```

```
732.1068
      0
667.1068
      0
      0
-10.0000
      0
```

Input Arguments

detection — Detection report

`objectDetection` object

Detection report, specified as an `objectDetection` object.

Example: `detection = objectDetection(0,[1;4.5;3], 'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Unscented Kalman filter

`trackingUKF` object

Unscented Kalman filter, returned as a `trackingUKF` object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step. The function assumes an acceleration standard deviation of 1 m/s^2 , and a turn-rate acceleration standard deviation of $1^\circ/\text{s}^2$.
- You can use this function as the `FilterInitializationFcn` property of a `multiObjectTracker` object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`initcaekf` | `initcakf` | `initcaukf` | `initctekf` | `initcvekf` | `initcvkf` | `initcvukf`

Objects

`multiObjectTracker` | `objectDetection` | `trackingEKF` | `trackingKF` | `trackingUKF`

Introduced in R2017a

initcvekf

Create constant-velocity extended Kalman filter from detection report

Syntax

```
filter = initcvekf(detection)
```

Description

`filter = initcvekf(detection)` creates and initializes a constant-velocity extended Kalman filter from information contained in a detection report. For more information about the extended Kalman filter, see `trackingEKF`.

Examples

Initialize 3-D Constant-Velocity Extended Kalman Filter

Create and initialize a 3-D constant-velocity extended Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (10,20,-5), of the object position.

```
detection = objectDetection(0,[10;20;-5],'MeasurementNoise',1.5*eye(3), ...  
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{ 'Sports Car',5});
```

Create the new filter from the detection report.

```
filter = initcvekf(detection)
```

```
filter =  
    trackingEKF with properties:
```

```
        State: [6x1 double]  
    StateCovariance: [6x6 double]
```

```

        StateTransitionFcn: @constvel
StateTransitionJacobianFcn: @constveljac
        ProcessNoise: [3x3 double]
HasAdditiveProcessNoise: 0

        MeasurementFcn: @cvmeas
MeasurementJacobianFcn: @cvmeasjac
        MeasurementNoise: [3x3 double]
HasAdditiveMeasurementNoise: 1

```

Show the filter state.

```
filter.State
```

```
ans = 6x1
```

```

10
 0
20
 0
-5
 0

```

Show the state covariance.

```
filter.StateCovariance
```

```
ans = 6x6
```

```

1.5000    0    0    0    0    0
 0 100.0000    0    0    0    0
 0    0 1.5000    0    0    0
 0    0    0 100.0000    0    0
 0    0    0    0 1.5000    0
 0    0    0    0    0 100.0000

```

Create 3-D Constant Velocity EKF from Spherical Measurement

Initialize a 3-D constant-velocity extended Kalman filter from an initial detection report made from a 3-D measurement in spherical coordinates. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45 degrees, the elevation to -10 degrees, the range to 1000 meters, and the range rate to -4.0 m/s.

```
frame = 'spherical';
sensorpos = [25,-40,0].';
sensorvel = [0;5;0];
laxes = eye(3);
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',true, ...
    'HasElevation',true);
meas = [45;-10;1000;-4];
measnoise = diag([3.0,2.5,2,1.0].^2);
detection = objectDetection(0,meas,'MeasurementNoise', ...
    measnoise,'MeasurementParameters',measparms)
```

```
detection =
  objectDetection with properties:
        Time: 0
    Measurement: [4x1 double]
  MeasurementNoise: [4x4 double]
    SensorIndex: 1
    ObjectClassID: 0
  MeasurementParameters: [1x1 struct]
    ObjectAttributes: {}
```

```
filter = initcvekf(detection);
```

Filter state vector.

```
disp(filter.State)
```

```
721.3642
-2.7855
656.3642
 2.2145
-173.6482
 0.6946
```

Input Arguments

detection — Detection report

objectDetection object

Detection report, specified as an objectDetection object.

Example: `detection = objectDetection(0,[1;4.5;3],'MeasurementNoise',[1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Extended Kalman filter

trackingEKF object

Extended Kalman filter, returned as a trackingEKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration standard deviation of 1 m/s².
- You can use this function as the FilterInitializationFcn property of a multiObjectTracker object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

[initcaekf](#) | [initcakf](#) | [initcaukf](#) | [initctekf](#) | [initctukf](#) | [initcvkf](#) | [initcvukf](#)

Objects

[multiObjectTracker](#) | [objectDetection](#) | [trackingEKF](#) | [trackingKF](#) | [trackingUKF](#)

Introduced in R2017a

initcvkf

Create constant-velocity linear Kalman filter from detection report

Syntax

```
filter = initcvkf(detection)
```

Description

`filter = initcvkf(detection)` creates and initializes a constant-velocity linear Kalman filter from information contained in a detection report. For more information about the linear Kalman filter, see `trackingKF`.

Examples

Initialize 2-D Constant-Velocity Linear Kalman Filter

Create and initialize a 2-D linear Kalman filter object from an initial detection report.

Create the detection report from an initial 2-D measurement, (10,20), of the object position.

```
detection = objectDetection(0,[10;20], 'MeasurementNoise',[1 0.2; 0.2 2], ...  
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{'Yellow Car',5});
```

Create the new track from the detection report.

```
filter = initcvkf(detection)
```

```
filter =  
    trackingKF with properties:
```

```
        State: [4x1 double]  
    StateCovariance: [4x4 double]
```

```
MotionModel: '2D Constant Velocity'  
ControlModel: []  
ProcessNoise: [4x4 double]  
  
MeasurementModel: [2x4 double]  
MeasurementNoise: [2x2 double]
```

Show the state.

```
filter.State
```

```
ans = 4x1
```

```
10  
0  
20  
0
```

Show the state transition model.

```
filter.StateTransitionModel
```

```
ans = 4x4
```

```
1    1    0    0  
0    1    0    0  
0    0    1    1  
0    0    0    1
```

Initialize 3-D Constant-Velocity Linear Kalman Filter

Create and initialize a 3-D linear Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (10,20,-5), of the object position.

```
detection = objectDetection(0,[10;20;-5], 'MeasurementNoise', eye(3), ...  
    'SensorIndex', 1, 'ObjectClassID', 1, 'ObjectAttributes', {'Green Car', 5});
```

Create the new filter from the detection report and display its properties.

```

filter = initcvkf(detection)

filter =
  trackingKF with properties:

      State: [6x1 double]
  StateCovariance: [6x6 double]

      MotionModel: '3D Constant Velocity'
      ControlModel: []
      ProcessNoise: [6x6 double]

  MeasurementModel: [3x6 double]
  MeasurementNoise: [3x3 double]

```

Show the state.

```
filter.State
```

```
ans = 6x1
```

```

10
 0
20
 0
-5
 0

```

Show the state transition model.

```
filter.StateTransitionModel
```

```
ans = 6x6
```

```

 1    1    0    0    0    0
 0    1    0    0    0    0
 0    0    1    1    0    0
 0    0    0    1    0    0
 0    0    0    0    1    1
 0    0    0    0    0    1

```

Input Arguments

detection — Detection report

`objectDetection` object

Detection report, specified as an `objectDetection` object.

Example: `detection = objectDetection(0, [1;4.5;3], 'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Linear Kalman filter

`trackingKF` object

Linear Kalman filter, returned as a `trackingKF` object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration standard deviation of 1 m/s².
- You can use this function as the `FilterInitializationFcn` property of a `multiObjectTracker` object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

[initcaekf](#) | [initcakf](#) | [initcaukf](#) | [initctekf](#) | [initctukf](#) | [initcvekf](#) | [initcvukf](#)

Objects

[multiObjectTracker](#) | [objectDetection](#) | [trackingEKF](#) | [trackingKF](#) | [trackingUKF](#)

Introduced in R2017a

initcvukf

Create constant-velocity unscented Kalman filter from detection report

Syntax

```
filter = initcvukf(detection)
```

Description

`filter = initcvukf(detection)` creates and initializes a constant-velocity unscented Kalman filter from information contained in a detection report. For more information about the unscented Kalman filter, see `trackingUKF`.

Examples

Initialize 3-D Constant-Velocity Unscented Kalman Filter

Create and initialize a 3-D constant-velocity unscented Kalman filter object from an initial detection report.

Create the detection report from an initial 3-D measurement, (10,200,-5), of the object position.

```
detection = objectDetection(0,[10;200;-5],'MeasurementNoise',1.5*eye(3), ...  
    'SensorIndex',1,'ObjectClassID',1,'ObjectAttributes',{ 'Sports Car',5});
```

Create the new filter from the detection report and display the filter properties.

```
filter = initcvukf(detection)
```

```
filter =  
    trackingUKF with properties:
```

```
        State: [6x1 double]  
    StateCovariance: [6x6 double]
```

```

        StateTransitionFcn: @constvel
            ProcessNoise: [3x3 double]
        HasAdditiveProcessNoise: 0

        MeasurementFcn: @cvmeas
            MeasurementNoise: [3x3 double]
        HasAdditiveMeasurementNoise: 1

        Alpha: 1.0000e-03
        Beta: 2
        Kappa: 0

```

Display the state.

```
filter.State
```

```
ans = 6x1
```

```

    10
     0
   200
     0
    -5
     0

```

Show the state covariance.

```
filter.StateCovariance
```

```
ans = 6x6
```

```

   1.5000     0         0         0         0         0
     0  100.0000     0         0         0         0
     0         0   1.5000     0         0         0
     0         0     0  100.0000     0         0
     0         0     0         0   1.5000     0
     0         0     0         0     0  100.0000

```

Create Constant Velocity UKF from Spherical Measurement

Initialize a constant-velocity unscented Kalman filter from an initial detection report made from an initial measurement in spherical coordinates. Because the object lies in the x - y plane, no elevation measurement is made. If you want to use spherical coordinates, then you must supply a measurement parameter structure as part of the detection report with the `Frame` field set to `'spherical'`. Set the azimuth angle of the target to 45 degrees, the range to 1000 meters, and the range rate to -4.0 m/s.

```
frame = 'spherical';  
sensorpos = [25,-40,0].';  
sensorvel = [0;5;0];  
laxes = eye(3);
```

Create the measurement parameters structure. Set `'HasElevation'` to `false`. Then, the measurement consists of azimuth, range, and range rate.

```
measparms = struct('Frame',frame,'OriginPosition',sensorpos, ...  
    'OriginVelocity',sensorvel,'Orientation',laxes,'HasVelocity',true, ...  
    'HasElevation',false);  
meas = [45;1000;-4];  
measnoise = diag([3.0,2,1.0].^2);  
detection = objectDetection(0,meas,'MeasurementNoise', ...  
    measnoise,'MeasurementParameters',measparms)
```

```
detection =  
    objectDetection with properties:  
  
                Time: 0  
        Measurement: [3x1 double]  
    MeasurementNoise: [3x3 double]  
        SensorIndex: 1  
        ObjectClassID: 0  
    MeasurementParameters: [1x1 struct]  
        ObjectAttributes: {}
```

```
filter = initcvukf(detection);
```

Display filter state vector.

```
disp(filter.State)
```

```
732.1068  
-2.8284
```



```
667.1068
 2.1716
 0
 0
```

Input Arguments

detection — Detection report

objectDetection object

Detection report, specified as an objectDetection object.

Example: `detection = objectDetection(0, [1;4.5;3], 'MeasurementNoise', [1.0 0 0; 0 2.0 0; 0 0 1.5])`

Output Arguments

filter — Unscented Kalman filter

trackingUKF object

Unscented Kalman filter, returned as a trackingUKF object.

Algorithms

- The function computes the process noise matrix assuming a one-second time step and an acceleration standard deviation of 1 m/s².
- You can use this function as the FilterInitializationFcn property of a multiObjectTracker object.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

[initcaekf](#) | [initcakf](#) | [initcaukf](#) | [initctekf](#) | [initctukf](#) | [initcvekf](#) | [initcvkf](#)

Objects

[multiObjectTracker](#) | [objectDetection](#) | [trackingEKF](#) | [trackingKF](#) | [trackingUKF](#)

Introduced in R2017a

insertLaneBoundary

Insert lane boundary into image

Syntax

```
rgb = insertLaneBoundary(I, boundaries, sensor, xVehicle)  
rgb = insertLaneBoundary( ____, Name, Value)
```

Description

`rgb = insertLaneBoundary(I, boundaries, sensor, xVehicle)` inserts lane boundary markings into a truecolor image. The lanes are overlaid on the input road image, `I`. This image comes from the sensor specified in the `sensor` object. `xVehicle` specifies the x -coordinates at which to draw the lane markers. The y -coordinates are calculated based on the parameters of the boundary models in `boundaries`.

`rgb = insertLaneBoundary(____, Name, Value)` inserts lane boundary markings with additional options specified by one or more `Name, Value` pair arguments, using the previous input arguments.

Examples

Find Parabolic Lane Boundaries in Bird's-Eye-View Image

Find lanes in an image by using parabolic lane boundary models. Overlay the identified lanes on the original image and on a bird's-eye-view transformation of the image.

Load an image of a road with lanes. The image was obtained from a camera sensor mounted on the front of a vehicle.

```
I = imread('road.png');
```

Transform the image into a bird's-eye-view image by using a preconfigured sensor object. This object models the sensor that captured the original image.

```
bevSensor = load('birdsEyeConfig');  
birdsEyeImage = transformImage(bevSensor.birdsEyeConfig,I);  
imshow(birdsEyeImage)
```

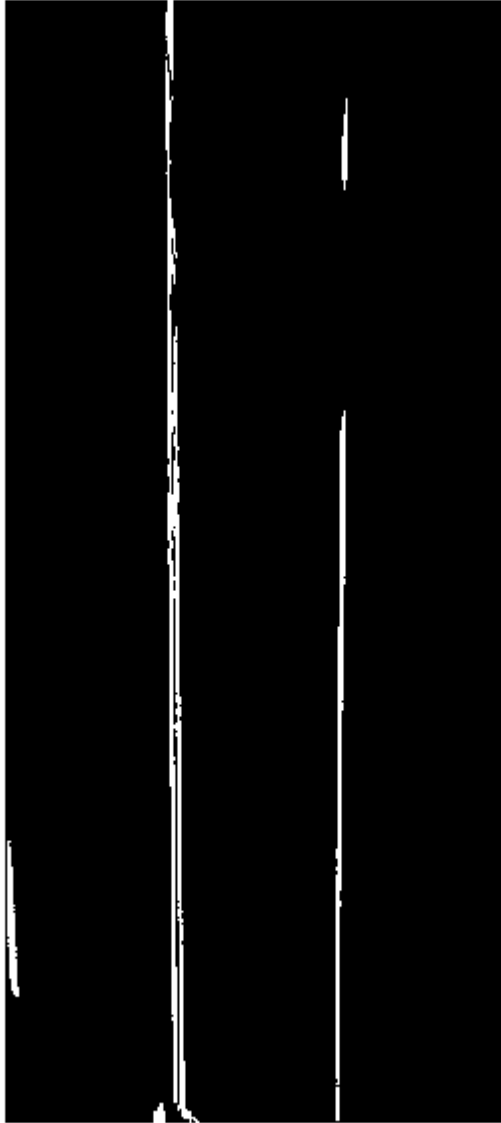


Set the approximate lane marker width in world units (meters).

```
approxBoundaryWidth = 0.25;
```

Detect lane features and display them as a black-and-white image.

```
birdsEyeBW = segmentLaneMarkerRidge(rgb2gray(birdsEyeImage), ...  
    bevSensor.birdsEyeConfig,approxBoundaryWidth);  
imshow(birdsEyeBW)
```



Obtain lane candidate points in world coordinates.

```
[imageX,imageY] = find(birdsEyeBW);  
xyBoundaryPoints = imageToVehicle(bevSensor.birdsEyeConfig,[imageY,imageX]);
```

Find lane boundaries in the image by using the `findParabolicLaneBoundaries` function. By default, the function returns a maximum of two lane boundaries. The boundaries are stored in an array of `parabolicLaneBoundary` objects.

```
boundaries = findParabolicLaneBoundaries(xyBoundaryPoints,approxBoundaryWidth);
```

Use `insertLaneBoundary` to overlay the lanes on the original image. The `XPoints` vector represents the lane points, in meters, that are within range of the ego vehicle's sensor. Specify the lanes in different colors. By default, lanes are yellow.

```
XPoints = 3:30;
```

```
figure  
sensor = bevSensor.birdsEyeConfig.Sensor;  
lanesI = insertLaneBoundary(I,boundaries(1),sensor,XPoints);  
lanesI = insertLaneBoundary(lanesI,boundaries(2),sensor,XPoints,'Color','green');  
imshow(lanesI)
```




View the lanes in the bird's-eye-view image.

```
figure
BEconfig = bevSensor.birdsEyeConfig;
lanesBEI = insertLaneBoundary(birdsEyeImage,boundaries(1),BEconfig,XPoints);
lanesBEI = insertLaneBoundary(lanesBEI,boundaries(2),BEconfig,XPoints,'Color','green')
imshow(lanesBEI)
```



Input Arguments

I — Input road image

truecolor image | grayscale image

Input road image, specified as a truecolor or grayscale image.

Data Types: `single` | `double` | `int8` | `int16` | `uint8` | `uint16`

boundaries — Lane boundary models

array of `parabolicLaneBoundary` objects | array of `cubicLaneBoundary` objects

Lane boundary models, specified as an array of `parabolicLaneBoundary` objects or `cubicLaneBoundary` objects. Lane boundary models contain the following properties:

- **Parameters** — A vector corresponding to the coefficients of the boundary model. The size of the vector depends on the degree of polynomial for the model.

Lane Boundary Object	Parameters
<code>parabolicLaneBoundary</code>	[A B C], corresponding to coefficients of a second-degree polynomial equation of the form $y = Ax^2 + Bx + C$
<code>cubicLaneBoundary</code>	[A B C D], corresponding to coefficients of a third-degree polynomial equation of the form $y = Ax^3 + Bx^2 + Cx + D$

- **BoundaryType** — A `LaneBoundaryType` enumeration of supported lane boundaries:
 - `Unmarked`
 - `Solid`
 - `Dashed`
 - `BottsDots`
 - `DoubleSolid`

Specify a lane boundary type as `LaneBoundaryType.BoundaryType`. For example:

`LaneBoundaryType.BottsDots`

- **Strength** — The ratio of the number of unique x-axis locations on the boundary to the total number of points along the line based on the `XExtent` property.
- **XExtent** — A two-element vector describing the minimum and maximum x-axis locations for the boundary points.

sensor — Sensor that collects images

`birdsEyeView` object | `monoCamera` object

Sensor that collects images, specified as either a `birdsEyeView` or `monoCamera` object.

xVehicle — x-axis locations of boundary

real-valued vector

x-axis locations at which to display the lane boundaries, specified as a real-valued vector in vehicle coordinates. The spacing between points controls the spacing between dashes and dots for the corresponding types of boundaries. To show dashed boundaries clearly, specify at least four points in `xVehicle`. If you specify fewer than four points, the function draws a solid boundary.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Color',[0 1 0]`

Color — Color of lane boundaries

`'yellow'` (default) | character vector | string scalar | `[R,G,B]` vector of RGB values | cell array of character vectors | string array | m -by-3 matrix of RGB values

Color of lane boundaries, specified as a character vector, string scalar, or `[R,G,B]` vector of RGB values. You can specify specific colors for each boundary in `boundaries` with a cell array of character vectors, a string array, or an m -by-3 matrix of RGB values. The colors correspond to the order of the boundary lanes.

RGB values must be in the range of the image data type.

Supported color values are `'blue'`, `'green'`, `'red'`, `'cyan'`, `'magenta'`, `'yellow'`, `'black'`, and `'white'`.

Example: 'red'

Example: [1,0,0]

LineWidth — Line width for boundary lanes

3 (default) | positive integer

Line width for boundary lanes, specified as a positive integer in pixels.

Output Arguments

rgb — Image with boundary lanes

RGB truecolor image

Image with boundary lanes overlaid, returned as an RGB truecolor image. The output image class matches the input image, I.

See Also

[birdsEyeView](#) | [cubicLaneBoundary](#) | [fitPolynomialRANSAC](#) | [monoCamera](#) | [parabolicLaneBoundary](#)

Introduced in R2017a

lateralControllerStanley

Compute steering angle command for path following by using Stanley method

Syntax

```
steerCmd = lateralControllerStanley(refPose,currPose,currVelocity)
steerCmd = lateralControllerStanley(refPose,currPose,currVelocity,
Name,Value)
```

Description

`steerCmd = lateralControllerStanley(refPose,currPose,currVelocity)` computes the steering angle command, in degrees, that adjusts the current pose of a vehicle to match a reference pose, given the current velocity of the vehicle. By default, the function assumes that the vehicle is in forward motion.

The controller computes the steering angle command using the Stanley method [1], whose control law is based on a kinematic bicycle model. Use this controller for path following in low-speed environments, where inertial effects are minimal.

`steerCmd = lateralControllerStanley(refPose,currPose,currVelocity, Name,Value)` specifies options using one or more name-value pairs. For example, `lateralControllerStanley(refPose,currPose,currVelocity, 'Direction', -1)` computes the steering angle command for a vehicle in reverse motion.

Examples

Steering Angle Command for Vehicle in Forward Motion

Compute the steering angle command that adjusts the current pose of a vehicle to a reference pose along a driving path. The vehicle is in forward motion.

In this example, you compute a single steering angle command. In path-following algorithms, compute the steering angle continuously as the pose and velocity of the vehicle change.

Set a reference pose on the path. The pose is at position (4.8 m, 6.5 m) and has an orientation angle of 2 degrees.

```
refPose = [4.8, 6.5, 2]; % [meters, meters, degrees]
```

Set the current pose of the vehicle. The pose is at position (2 m, 6.5 m) and has an orientation angle of 0 degrees. Set the current velocity of the vehicle to 2 meters per second.

```
currPose = [2, 6.5, 0]; % [meters, meters, degrees]  
currVelocity = 2; % meters per second
```

Compute the steering angle command. For the vehicle to match the reference pose, the steering wheel must turn 2 degrees counterclockwise.

```
steerCmd = lateralControllerStanley(refPose,currPose,currVelocity)  
steerCmd = 2.0000
```

Steering Angle Command for Vehicle in Reverse Motion

Compute the steering angle command that adjusts the current pose of a vehicle to a reference pose along a driving path. The vehicle is in reverse motion.

In this example, you compute a single steering angle command. In path-following algorithms, compute the steering angle continuously as the pose and velocity of the vehicle change.

Set a reference pose on the path. The pose is at position (5 m, 9 m) and has an orientation angle of 90 degrees.

```
refPose = [5, 9, 90]; % [meters, meters, degrees]
```

Set the current pose of the vehicle. The pose is at position (5 m, 10 m) and has an orientation angle of 75 degrees.

```
currPose = [5, 10, 75]; % [meters, meters, degrees]
```

Set the current velocity of the vehicle to -2 meters per second. Because the vehicle is in reverse motion, the velocity must be negative.

```
currVelocity = -2; % meters per second
```

Compute the steering angle command. For the vehicle to match the reference pose, the steering wheel must turn 15 degrees clockwise.

```
steerCmd = lateralControllerStanley(refPose,currPose,currVelocity,'Direction',-1)  
steerCmd = -15.0000
```

Input Arguments

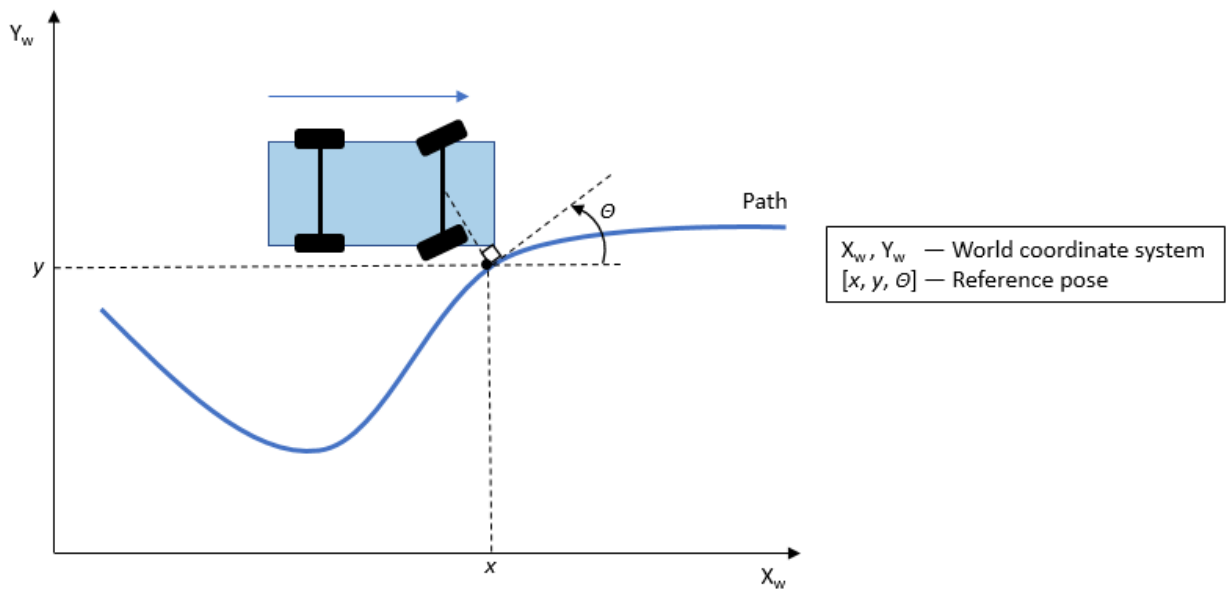
refPose — Reference pose

[x , y , θ] vector

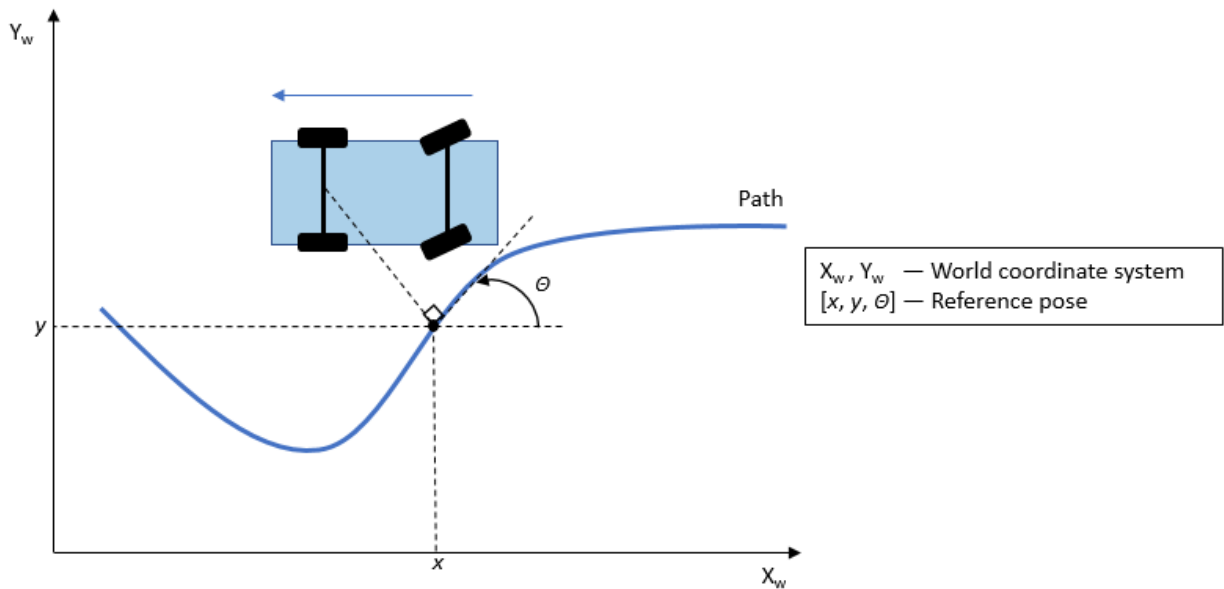
Reference pose, specified as an [x , y , θ] vector. x and y are in meters, and θ is in degrees.

x and y specify the reference point to steer the vehicle toward. θ specifies the orientation angle of the path at this reference point and is positive in the counterclockwise direction.

- For a vehicle in forward motion, the reference point is the point on the path that is closest to the center of the vehicle's front axle.



- For a vehicle in reverse motion, the reference point is the point on the path that is closest to the center of the vehicle's rear axle.



Data Types: single | double

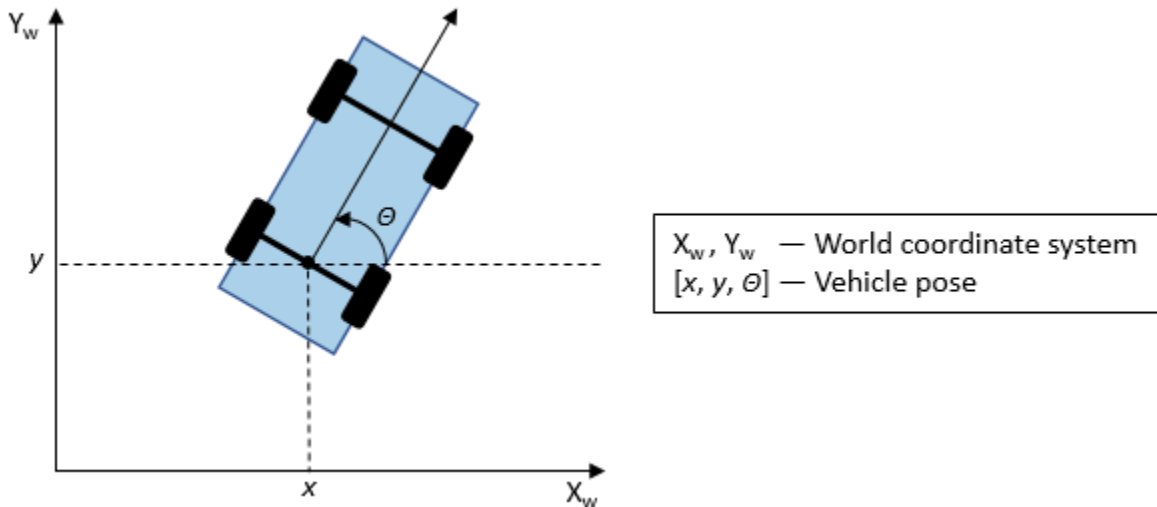
currPose — Current pose

$[x, y, \theta]$ vector

Current pose of the vehicle, specified as an $[x, y, \theta]$ vector. x and y are in meters, and θ is in degrees.

x and y specify the location of the vehicle, which is defined as the center of the vehicle's rear axle.

θ specifies the orientation angle of the vehicle at location (x, y) and is positive in the counterclockwise direction.



For more details on vehicle pose, see “Coordinate Systems in Automated Driving Toolbox”.

Data Types: `single` | `double`

currVelocity — Current longitudinal velocity

real scalar

Current longitudinal velocity of the vehicle, specified as a real scalar. Units are in meters per second.

- If the vehicle is in forward motion, then this value must be greater than 0.
- If the vehicle is in reverse motion, then this value must be less than 0.
- A value of 0 represents a vehicle that is not in motion.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: 'MaxSteeringAngle',25

Direction — Driving direction of vehicle

1 (forward motion) (default) | -1 (reverse motion)

Driving direction of the vehicle, specified as the comma-separated pair consisting of 'Direction' and either 1 for forward motion or -1 for reverse motion. The driving direction determines the position error and angle error used to compute the steering angle command. For more details, see “Algorithms” on page 3-223.

PositionGain — Position gain

2.5 (default) | positive real scalar

Position gain of the vehicle, specified as the comma-separated pair consisting of 'PositionGain' and a positive real scalar. This value determines how much the position error affects the steering angle. Typical values are in the range [1, 5]. Increase this value to increase the magnitude of the steering angle.

Wheelbase — Distance between front and rear axles of vehicle

2.8 (default) | real scalar

Distance between the front and rear axles of the vehicle, in meters, specified as the comma-separated pair consisting of 'Wheelbase' and a real scalar. This value applies only when the vehicle is in forward motion.

MaxSteeringAngle — Maximum allowed steering angle

35 (default) | real scalar in the range (0, 180)

Maximum allowed steering angle of the vehicle, in degrees, specified as the comma-separated pair consisting of 'MaxSteeringAngle' and a real scalar in the range (0, 180).

The steerCmd value is saturated to the range [-MaxSteeringAngle, MaxSteeringAngle].

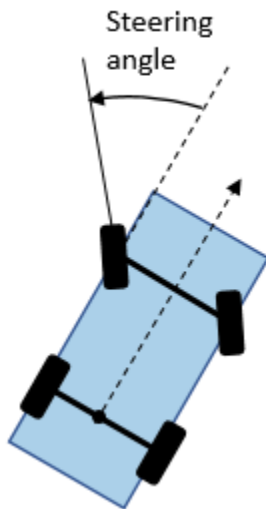
- Values below -MaxSteeringAngle are set to -MaxSteeringAngle.
- Values above MaxSteeringAngle are set to MaxSteeringAngle.

Output Arguments

steerCmd — Steering angle command

real scalar

Steering angle command, in degrees, returned as a real scalar. This value is positive in the counterclockwise direction.



For more details, see “Coordinate Systems in Automated Driving Toolbox”.

Algorithms

To compute the steering angle command, the controller minimizes the position error and the angle error of the current pose with respect to the reference pose. The driving direction of the vehicle determines these error values.

When the vehicle is in forward motion ('Direction' name-value pair is 1):

- The position error is the lateral distance from the center of the front axle to the reference point on the path.

- The angle error is the angle of the front wheel with respect to reference path.

When the vehicle is in reverse motion ('Direction' name-value pair is -1):

- The position error is the lateral distance from the center of the rear axle to the reference point on the path.
- The angle error is the angle of the rear wheel with respect to reference path.

For details on how the controller minimizes these errors, see [1].

References

- [1] Hoffmann, Gabriel M., Claire J. Tomlin, Michael Montemerlo, and Sebastian Thrun. "Autonomous Automobile Trajectory Tracking for Off-Road Driving: Controller Design, Experimental Validation and Racing." *American Control Conference*. 2007, pp. 2296-2301. doi:10.1109/ACC.2007.4282788

Extended Capabilities

C/C++ Code Generation

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

See Also

Blocks

Lateral Controller Stanley | Longitudinal Controller Stanley

Objects

pathPlannerRRT

Topics

"Automated Parking Valet"

"Coordinate Systems in Automated Driving Toolbox"

Introduced in R2018b

removeCustomBasemap

Remove custom basemap

Syntax

```
removeCustomBasemap(basemapName)
```

Description

`removeCustomBasemap(basemapName)` removes the custom basemap specified by `basemapName` from the list of available basemaps.

If the custom basemap specified by `basemapName` has not been previously added using the `addCustomBasemap` function, the `removeCustomBasemap` function returns an error.

Examples

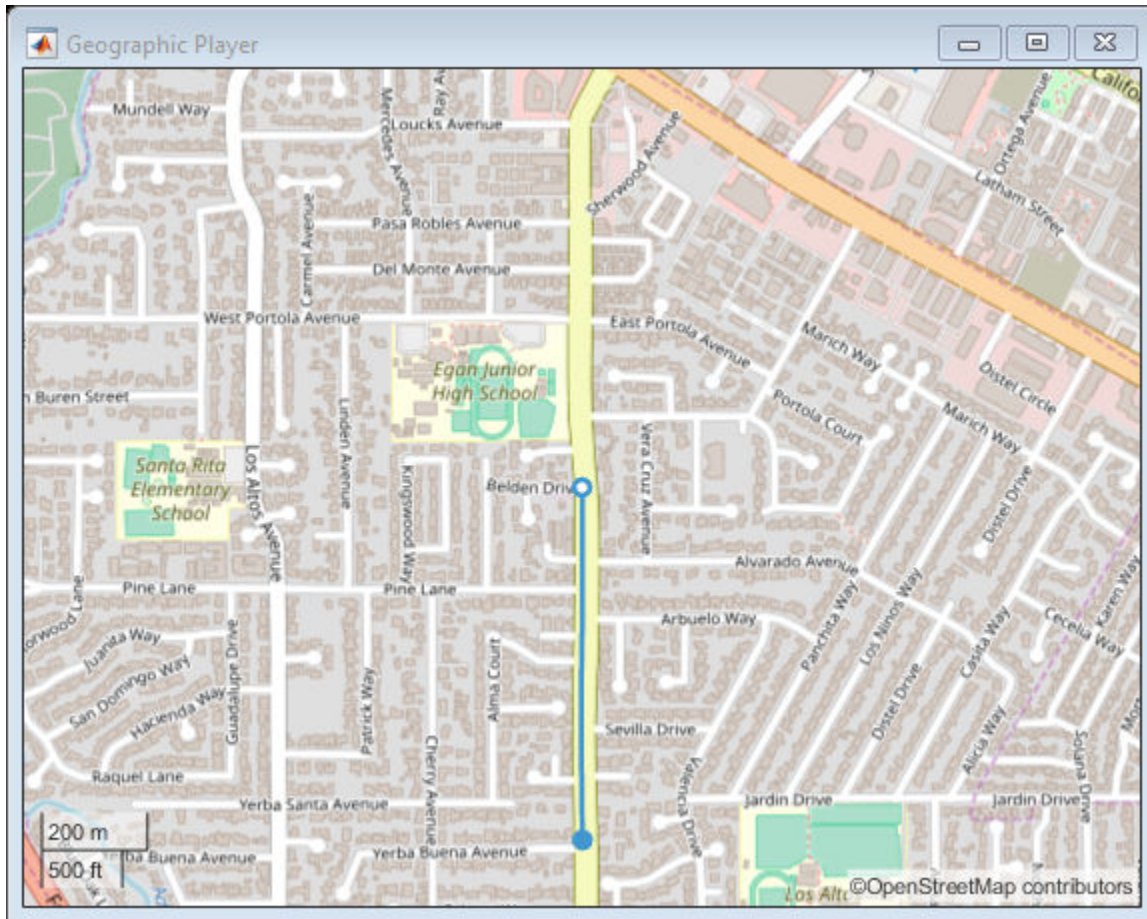
Remove Custom Basemap

Add a custom basemap to view locations on an OpenStreetMap® basemap.

```
name = 'openstreetmap';  
url = 'a.tile.openstreetmap.org';  
copyright = char(uint8(169));  
attribution = copyright + "OpenStreetMap contributors";  
addCustomBasemap(name,url,'Attribution',attribution)
```

Use the custom basemap with a geographic player.

```
data = load('geoSequence.mat');  
player = geoplayer(data.latitude(1),data.longitude(1),'Basemap',name);  
plotRoute(player,data.latitude,data.longitude);
```

Remove the custom basemap. The custom basemap associated with the specified name remains stored in this geographic player. However, this basemap is no longer available for use with new players.

```
removeCustomBasemap(name)
```

Input Arguments

basemapName — Name of custom basemap

string scalar | character vector

Name of the custom basemap to remove, specified as a string scalar or character vector. You define the basemap name when you add the basemap using the `addCustomBasemap` function.

Data Types: `string` | `char`

See Also

`addCustomBasemap` | `geoaxes` | `geobasemap` | `geobubble` | `geodensityplot` | `geoplayer` | `geoplot` | `geoscatter`

Introduced in R2019a

segmentLaneMarkerRidge

Detect lanes in a grayscale intensity image

Syntax

```
birdsEyeBW = segmentLaneMarkerRidge(birdsEyeImage,birdsEyeConfig,  
approxMarkerWidth)  
birdsEyeBW = segmentLaneMarkerRidge( ____,Name,Value)
```

Description

`birdsEyeBW = segmentLaneMarkerRidge(birdsEyeImage,birdsEyeConfig,approxMarkerWidth)` returns a binary image that represents lane features. The function segments the input grayscale intensity image, `birdsEyeImage`, using a lane ridge detector. `birdsEyeConfig` transforms point locations from vehicle coordinates to image coordinates. The `approxMarkerWidth` argument is in world units, and specifies the approximate width of the lane-like features that are detected.

`birdsEyeBW = segmentLaneMarkerRidge(____,Name,Value)` returns a binary image with additional options specified by one or more `Name,Value` pair arguments.

Examples

Detect Lanes in Road Image

Load a bird's-eye-view configuration object.

```
load birdsEyeConfig
```

Load the image captured from the sensor that is defined in the bird's-eye-view configuration object.

```
I = imread('road.png');  
figure
```

```
imshow(I)
title('Original Image')
```

Create a bird's-eye-view image.

```
birdsEyeImage = transformImage(birdsEyeConfig,I);
imshow(birdsEyeImage)
```

Convert bird's-eye-view image to grayscale.

```
birdsEyeImage = rgb2gray(birdsEyeImage);
```

Set the approximate lane marker width to 25 cm, which is in world units.

```
approxMarkerWidth = 0.25;
```

Detect lane features.

```
birdsEyeBW = segmentLaneMarkerRidge(birdsEyeImage,birdsEyeConfig,approxMarkerWidth);
imshow(birdsEyeBW)
```

Input Arguments

birdsEyeImage — Bird's-eye-view image

matrix

Bird's-eye-view image, specified as a nonsparse matrix.

Data Types: `single` | `int16` | `uint16` | `uint8`

birdsEyeConfig — Object to transform point locations

`birdsEyeView` object

Object to transform point locations from vehicle to image coordinates, specified as a `birdsEyeView` object.

approxMarkerWidth — Approximate width of lane-like features

real scalar in world units

Approximate width of lane-like features for the function to detect in the bird's-eye-view image, specified as a real scalar in world units, such as meters.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, . . . , NameN, ValueN`.

Example: 'ROI' []

ROI — Region of interest

[] (default) | world units

Region of interest in world units, specified as the comma-separated pair consisting of 'ROI' and a 1-by-4 vector in the format `[xmin,xmax,ymin,ymax]`. The function searches for lane-like features only within this region of interest. If you do not specify ROI, the function searches the entire image.

Sensitivity — Sensitivity factor

0.25 (default) | real scalar in the range [0, 1]

Sensitivity factor, specified as the comma-separated pair consisting of 'Sensitivity' and a real scalar in the range [0, 1]. You can increase this value to detect more lane-like features. However, the higher sensitivity can increase the risk of false detections.

Output Arguments

birdsEyeBW — Bird's-eye-view image

binary image

Bird's-eye-view image, returned as a binary image that represents lane features.

More About

Vehicle Coordinate System

This function uses a vehicle coordinate system to define point locations, as defined by the sensor in the `birdsEyeView` object. It uses the same world units as defined by the `birdsEyeConfig.Sensor.WorldUnits` property. See "Coordinate Systems in Automated Driving Toolbox".

Algorithms

`segmentLaneMarkerRidge` selects lanes by searching for pixels that are lane-like. Lane-like pixels are groups of pixels with high-intensity contrast compared to neighboring pixels on either side. The function chooses the filter used to threshold the intensity contrast based on the `approxMarkerWidth` value. The filter has high responses for pixels with intensity values higher than those of the left and right neighboring pixels that have a similar intensity at a distance of `approxMarkerWidth`. The function retains only certain values from the filtered image based on the `Sensitivity` factor.

References

- [1] Nieto, M., J. A. Laborda, and L. Salgado. "Road Environment Modeling Using Robust Perspective Analysis and Recursive Bayesian Segmentation." *Machine Vision and Applications*. Volume 22, Issue 6, 2011, pp. 927-945.

Extended Capabilities

C/C++ Code Generation

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

See Also

`birdsEyeView`

Introduced in R2017a

smoothPathSpline

Smooth vehicle path using cubic spline interpolation

Syntax

```
[poses,directions] = smoothPathSpline(refPoses,refDirections,
numSmoothPoses)
[poses,directions] = smoothPathSpline(refPoses,refDirections,
numSmoothPoses,minSeparation)
[ ___,cumLengths,curvatures] = smoothPathSpline( ___ )
```

Description

[poses,directions] = smoothPathSpline(refPoses,refDirections, numSmoothPoses) generates a smooth vehicle path, consisting of numSmoothPoses discretized poses, by fitting the input reference path poses to a cubic spline. Given the input reference path directions, smoothPathSpline also returns the directions that correspond to each pose.

Use this function to convert a C¹-continuous vehicle path to a C²-continuous path. C¹-continuous paths include the `driving.DubinsPathSegment` or `driving.ReedsSheppPathSegment` paths that you can plan using a `pathPlannerRRT` object. For more details on these path types, see “C¹-Continuous and C²-Continuous Paths” on page 3-239.

You can use the returned poses and directions with a vehicle controller, such as the `lateralControllerStanley` function.

[poses,directions] = smoothPathSpline(refPoses,refDirections, numSmoothPoses,minSeparation) specifies a minimum separation threshold between poses. If the distance between two poses is smaller than minSeparation, the function uses only one of the poses for interpolation.

[___,cumLengths,curvatures] = smoothPathSpline(___) also returns the cumulative path length and signed path curvature at each returned pose, using any of the previous syntaxes. Use these values to generate a velocity profile along the path.

Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation angles are in degrees.

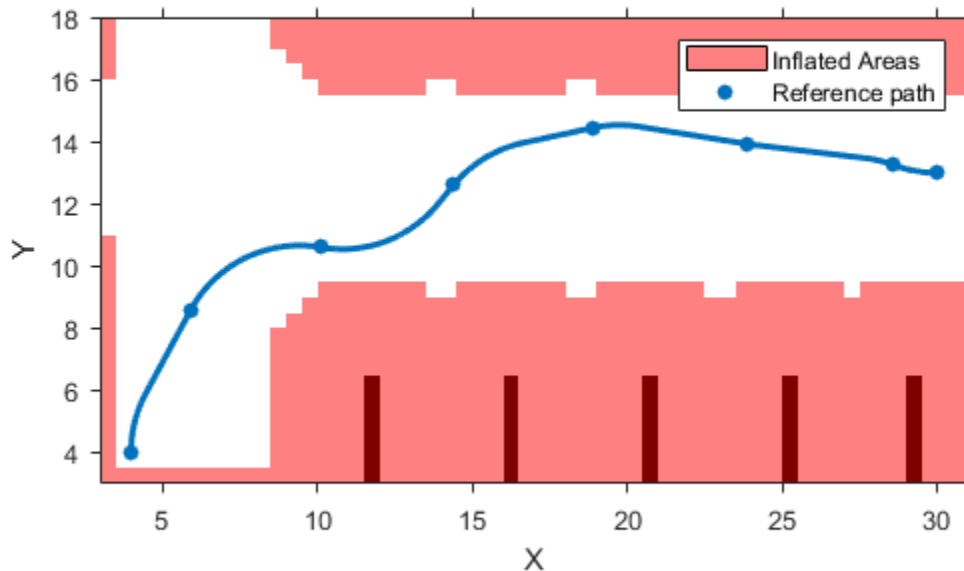
```
startPose = [4,4,90]; % [meters, meters, degrees]
goalPose = [30,13,0];
```

Use a `pathPlannerRRT` object to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);
refPath = plan(planner,startPose,goalPose);
```

Plot and zoom in on the planned path. The path is composed of a sequence of Dubins curves. These curves include abrupt changes in curvature that are not suitable for driving with passengers.

```
hold on
plot(refPath, 'Vehicle', 'off', 'DisplayName', 'Reference path')
xlim([3 31])
ylim([3 18])
```



Interpolate the transition poses of the path. Use these poses as the reference poses for interpolating the smooth path. Also return the motion directions at each pose.

```
[refPoses,refDirections] = interpolate(refPath);
```

Specify the number of poses to return in the smooth path. Return poses spaced about 0.1 meters apart, along the entire length of the path.

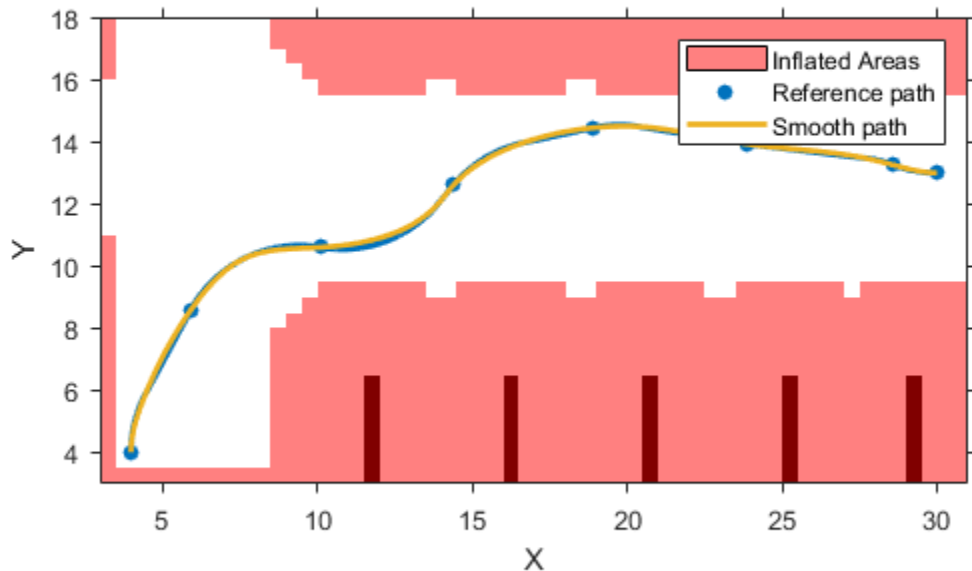
```
approxSeparation = 0.1; % meters
numSmoothPoses = round(refPath.Length / approxSeparation);
```

Generate the smooth path by fitting a cubic spline to the reference poses. `smoothPathSpline` returns the specified number of discretized poses along the smooth path.

```
[poses,directions] = smoothPathSpline(refPoses,refDirections,numSmoothPoses);
```

Plot the smooth path. The more abrupt changes in curvature that were present in the reference path are now smoothed out.

```
plot(poses(:,1),poses(:,2),'LineWidth',2,'DisplayName','Smooth path')
hold off
```



Input Arguments

refPoses — Reference poses

M-by-3 matrix of $[x, y, \theta]$ vectors

Reference poses of the vehicle along the path, specified as an M -by-3 matrix of $[x, y, \theta]$ vectors, where M is the number of poses.

x and y specify the location of the vehicle in meters. θ specifies the orientation angle of the vehicle in degrees.

Data Types: `single` | `double`

refDirections — Reference directions

M -by-1 column vector of 1s (forward motion) and -1s (reverse motion)

Reference directions of the vehicle along the path, specified as an M -by-1 column vector of 1s (forward motion) and -1s (reverse motion). M is the number of reference directions. Each element of `refDirections` corresponds to a pose in the `refPoses` input argument.

Data Types: `single` | `double`

numSmoothPoses — Number of smooth poses to return

positive integer

Number of smooth poses to return in the `poses` output argument, specified as a positive integer. To increase the granularity of the returned poses, increase `numSmoothPoses`.

minSeparation — Minimum separation between poses

$1e-3$ (default) | positive real scalar

Minimum separation between poses, in meters, specified as a positive real scalar. If the Euclidean (x, y) distance between two poses is less than this value, then the function uses only one of these poses for interpolation.

Output Arguments

poses — Discretized poses of smoothed path

`numSmoothPoses`-by-3 matrix of $[x, y, \theta]$ vectors

Discretized poses of the smoothed path, returned as a `numSmoothPoses`-by-3 matrix of $[x, y, \theta]$ vectors.

x and y specify the location of the vehicle in meters. θ specifies the orientation angle of the vehicle in degrees.

The values in `poses` are of the same data type as the values in the `refPoses` input argument.

directions — Motion directions at each output pose

`numSmoothPoses-by-1` column vector of 1s (forward motion) and -1s (reverse motion)

Motion directions at each output pose in `poses`, returned as a `numSmoothPoses-by-1` column vector of 1s (forward motion) and -1s (reverse motion).

The values in `directions` are of the same data type as the values in the `refDirections` input argument.

cumLengths — Cumulative path lengths

`numSmoothPoses-by-1` real-valued column vector

Cumulative path length at each output pose in `poses`, returned as a `numSmoothPoses-by-1` real-valued column vector. Units are in meters.

You can use the `cumLengths` and `curvatures` outputs to generate a velocity profile of the vehicle along the smooth path. For more details, see the “Automated Parking Valet” example.

curvatures — Signed path curvatures

`numSmoothPoses-by-1` real-valued column vector

Signed path curvatures at each output pose in `poses`, returned as a `numSmoothPoses-by-1` real-valued column vector. Units are in radians per meter.

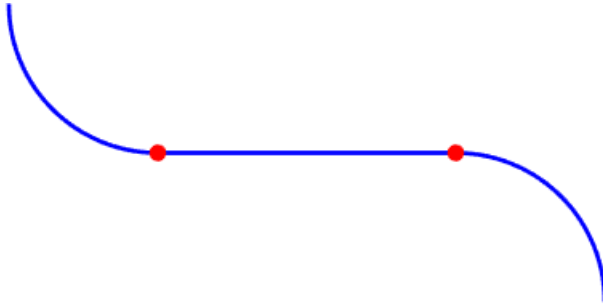
You can use the `curvatures` and `cumLengths` outputs to generate a velocity profile of the vehicle along the smooth path. For more details, see the “Automated Parking Valet” example.

More About

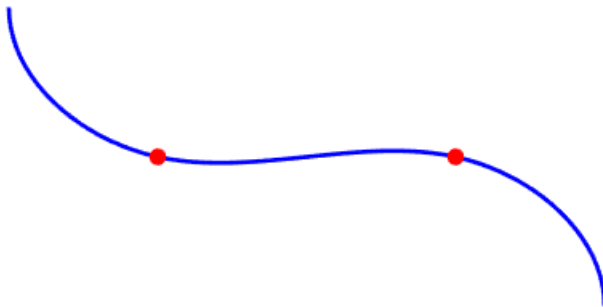
C¹-Continuous and C²-Continuous Paths

A path is C¹-continuous if its derivative exists and is continuous. Paths that are only C¹-continuous have discontinuities in their curvature. For example, a path composed of Dubins or Reeds-Sheep path segments has discontinuities in curvature at the points

where the segments join. These discontinuities result in changes in direction that are not smooth enough for driving with passengers.



A path is also C^2 -continuous if its second derivative exists and is continuous. C^2 -continuous paths have continuous curvature and are smooth enough for driving with passengers.



Tips

- To check if a smooth path is collision-free, specify the smooth poses as an input to the `checkPathValidity` function.

Algorithms

- The path-smoothing algorithm interpolates a parametric cubic spline that passes through all input reference pose points. The parameter of the spline is the cumulative chord length at these points. [1]

- The tangent direction of the smoothed output path approximately matches the orientation angle of the vehicle at the starting and goal poses.

References

- [1] Floater, Michael S. "On the Deviation of a Parametric Cubic Spline Interpolant from Its Data Polygon." *Computer Aided Geometric Design*. Vol. 25, Number 3, 2008, pp. 148-156.
- [2] Lepetic, Marko, Gregor Klančar, Igor Skrjanc, Drago Matko, and Bostjan Potocnik. "Time Optimal Path Planning Considering Acceleration Limits." *Robotics and Autonomous Systems*. Vol. 45, Numbers 3-4, 2003, pp. 199-210.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`checkPathValidity` | `driving.Path` | `interpolate` | `lateralControllerStanley` | `pathPlannerRRT` | `spline`

Blocks

Path Smoother Spline

Topics

"Automated Parking Valet"

Introduced in R2019a

vehicleDetectorACF

Load vehicle detector using aggregate channel features

Syntax

```
detector = vehicleDetectorACF  
detector = vehicleDetectorACF(modelName)
```

Description

`detector = vehicleDetectorACF` returns a pretrained vehicle detector using aggregate channel features (ACF). The returned `acfObjectDetector` object is trained using unoccluded images of the front, rear, left, and right sides of the vehicles.

`detector = vehicleDetectorACF(modelName)` returns a pretrained vehicle detector based on the model specified in `modelName`. A 'full-view' model uses training images that are unoccluded views from the front, rear, left, and right sides of vehicles. A 'front-rear-view' model uses images only from the front and rear sides of the vehicle.

Examples

Detect Vehicles in Image

Load the pre-trained detector for vehicles

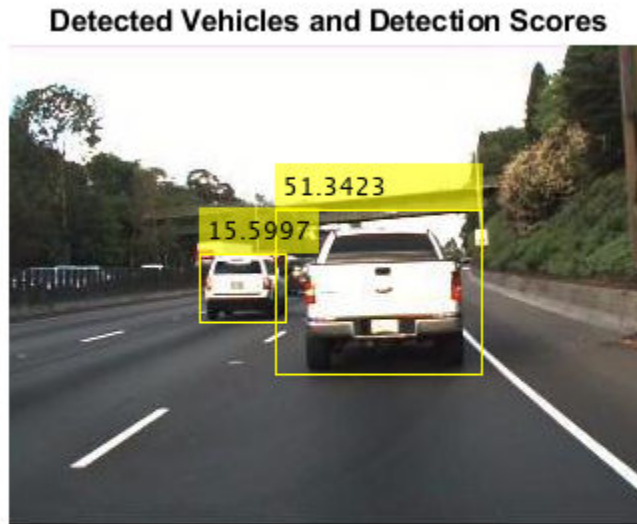
```
detector = vehicleDetectorACF('front-rear-view');
```

Load an image and run the detector.

```
I = imread('highway.png');  
[bboxes,scores] = detect(detector,I);
```

Overlay bounding boxes and scores for vehicles detected in the image.


```
I = insertObjectAnnotation(I, 'rectangle', bboxes, scores);  
figure  
imshow(I)  
title('Detected Vehicles and Detection Scores')
```



Input Arguments

modelName — Type of vehicle detector model

'full-view' (default) | 'front-rear-view'

Type of vehicle detector model, specified as either 'front-rear-view' or 'full-view'. A 'full-view' model uses training images that are unoccluded views from the front, rear, left, and right sides of vehicles. A 'front-rear-view' model uses images only from the front and rear sides of the vehicle.

Data Types: char | string

Output Arguments

detector — Trained ACF-based object detector

acfObjectDetector object

Trained ACF-based object detector, returned as an acfObjectDetector object.

See Also

acfObjectDetector | trainACFObjectDetector

Introduced in R2017a

vehicleDetectorFasterRCNN

Detect vehicles using Faster R-CNN

Syntax

```
detector = vehicleDetectorFasterRCNN  
detector = vehicleDetectorFasterRCNN(modelName)
```

Description

`detector = vehicleDetectorFasterRCNN` returns a trained Faster R-CNN (regions with convolution neural networks) object detector for detecting vehicles. Faster R-CNN is a deep learning object detection framework that uses a convolutional neural network (CNN) for detection.

The function trains the detector using unoccluded images of the front, rear, left, and right sides of vehicles. The CNN used with the vehicle detector uses a modified version of the CIFAR-10 network architecture.

Use of this function requires Deep Learning Toolbox™.

Note The detector is trained using `uint8` images. Before using this detector, rescale the input images to the range `[0, 255]` by using `im2uint8` or `rescale`.

`detector = vehicleDetectorFasterRCNN(modelName)` returns a pretrained vehicle detector based on the model name specified in `modelName`. The default `'full-view'` model uses training images that are unoccluded views from the front, rear, left, and right sides of vehicles. A `'front-rear-view'` model uses images of only the front and rear sides of the vehicles.

Examples

Detect Vehicles on Highway

Detect cars in a single image and annotate the image with the detection scores. To detect cars, use a Faster R-CNN object detector that was trained using images of vehicles.

Load the pretrained detector.

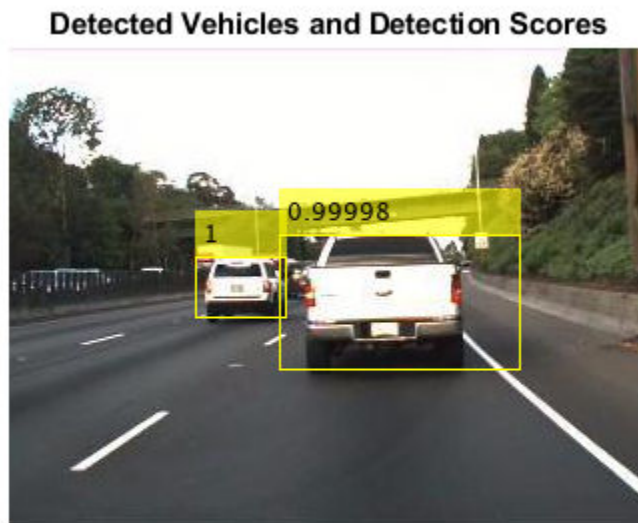
```
fasterRCNN = vehicleDetectorFasterRCNN('full-view');
```

Use the detector on a loaded image. Store the locations of the bounding boxes and their detection scores.

```
I = imread('highway.png');  
[bboxes,scores] = detect(fasterRCNN,I);
```

Annotate the image with the detections and their scores.

```
I = insertObjectAnnotation(I,'rectangle',bboxes,scores);  
figure  
imshow(I)  
title('Detected Vehicles and Detection Scores')
```



Input Arguments

modelName — Type of vehicle detector model

'full-view' (default) | 'front-rear-view'

Type of vehicle detector model, specified as either 'full-view' or 'front-rear-view'. A 'full-view' model uses training images that are unoccluded views from the front, rear, left, and right sides of vehicles. A 'front-rear-view' model uses images of only the front and rear sides of the vehicles.

Data Types: char | string

Output Arguments

detector — Trained Faster R-CNN-based object detector

fasterRCNNObjectDetector object

Trained Faster R-CNN-based object detector, returned as an fasterRCNNObjectDetector object.

See Also

fasterRCNNObjectDetector | trainFasterRCNNObjectDetector |
vehicleDetectorACF

Introduced in R2017a

Objects in Automated Driving Toolbox

birdsEyePlot

Plot detections, tracks, and sensor coverages around vehicle

Description

The `birdsEyePlot` object displays a bird's-eye plot of a 2-D driving scenario in the immediate vicinity of an ego vehicle. You can use this plot with sensors capable of detecting objects and lanes.

To display aspects of a driving scenario on a bird's-eye plot:

- 1 Create a `birdsEyePlot` object.
- 2 Create plotters for the aspects of the driving scenario that you want to plot.
- 3 Use the plotters with their corresponding plot functions to display those aspects on the bird's-eye plot.

This table shows the plotter functions to use based on the driving scenario aspect that you want to plot.

Driving Scenario Aspect to Plot	Plotter Creation Function	Plotter Display Function
Sensor coverage areas	<code>coverageAreaPlotter</code>	<code>plotCoverageArea</code>
Sensor detections	<code>detectionPlotter</code>	<code>plotDetection</code>
Lane boundaries	<code>laneBoundaryPlotter</code>	<code>plotLaneBoundary</code>
Lane markings	<code>laneMarkingPlotter</code>	<code>plotLaneMarking</code>
Object outlines	<code>outlinePlotter</code>	<code>plotOutline</code>
Ego vehicle path	<code>pathPlotter</code>	<code>plotPath</code>
Object tracking results	<code>trackPlotter</code>	<code>plotTrack</code>

For an example of how to configure and use a bird's-eye plot, see “Visualize Sensor Coverage, Detections, and Tracks”.

Creation

Syntax

```
bep = birdsEyePlot  
bep = birdsEyePlot(Name,Value)
```

Description

`bep = birdsEyePlot` creates a bird's-eye plot in a new figure.

`bep = birdsEyePlot(Name,Value)` sets properties on page 4-3 using one or more `Name,Value` pair arguments. For example, `birdsEyePlot('XLimits',[0 60],'YLimits',[-20 20])` displays the area that is 60 meters in front of the ego vehicle and 20 meters to either side of the ego vehicle. Enclose each property name in quotes.

Properties

Parent — Axes on which to plot

axes handle

Axes on which to plot, specified as an axes handle. By default, the `birdsEyePlot` object uses the current axes handle, which is returned by the `gca` function.

Plotters — Plotters created for bird's-eye plot

array of plotter objects

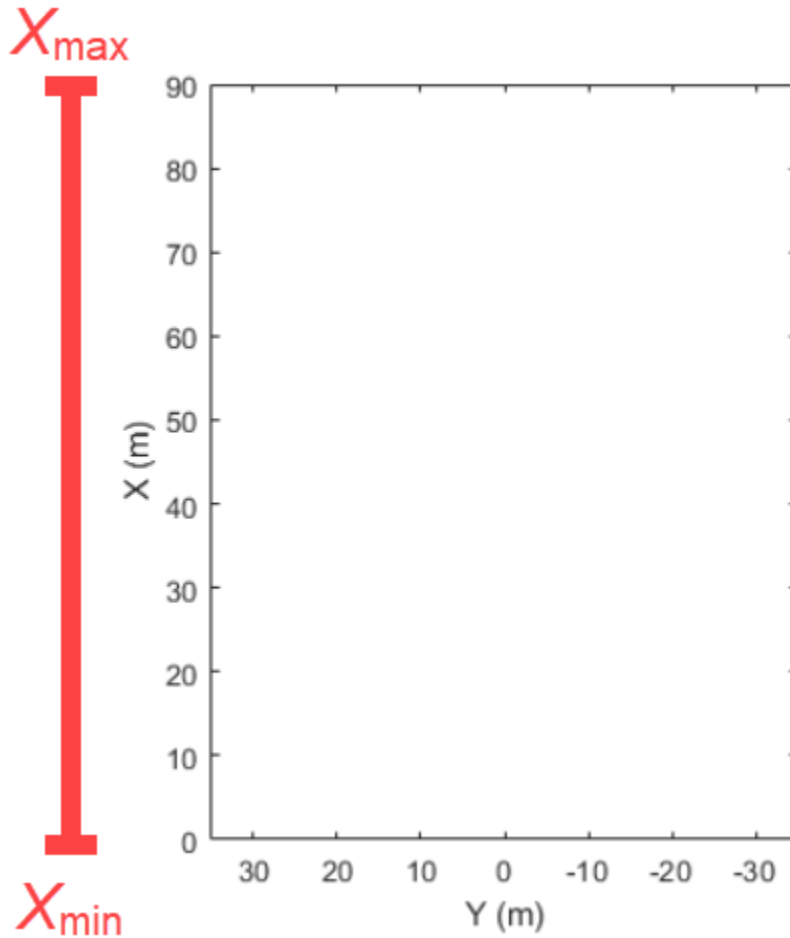
Plotters created for the bird's-eye plot, specified as an array of plotter objects.

XLimits — X-axis range

real-valued vector of the form $[X_{\min} X_{\max}]$

X-axis range of the bird's-eye plot, in vehicle coordinates, specified as a real-valued vector of the form $[X_{\min} X_{\max}]$. Units are in meters. If you do not specify `XLimits`, then the plot uses the default values for the parent axes.

The X-axis is vertical and positive in the forward direction of the ego vehicle. The origin is at the center of the rear axle of the ego vehicle.



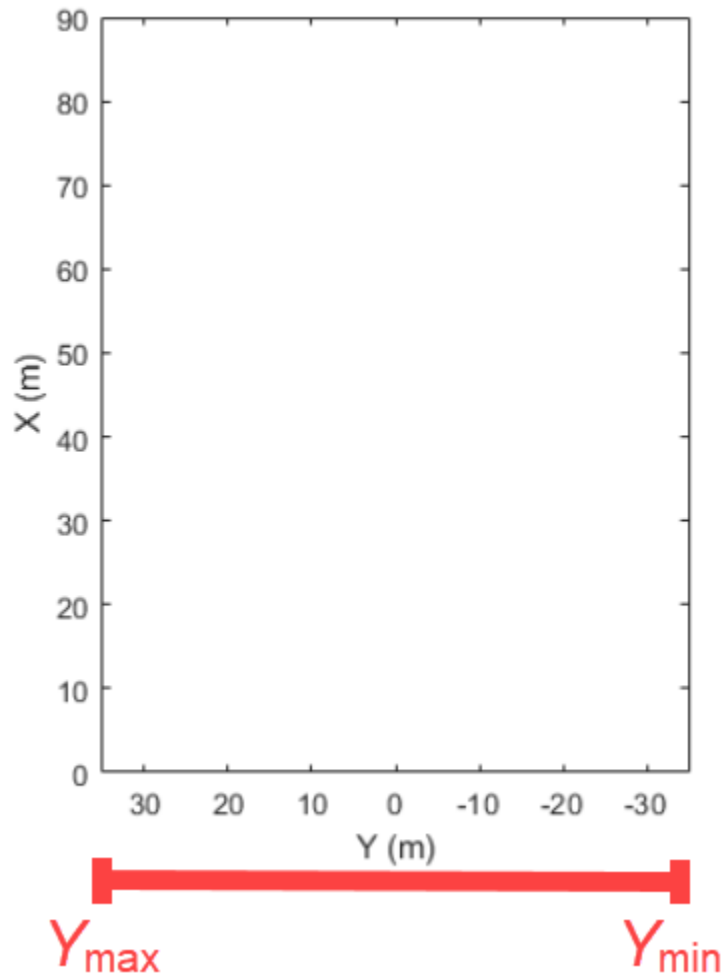
For more details on the coordinate system used in the bird's-eye plot, see “Vehicle Coordinate System” on page 4-13.

YLimits – Y-axis range

real-valued vector of the form $[Y_{\min} \ Y_{\max}]$

Y-axis range of the bird's-eye plot, in vehicle coordinates, specified as a real-valued vector of the form $[Y_{\min} \ Y_{\max}]$. Units are in meters. If you do not specify `YLimits`, then the plot uses the default values for the parent axes.

The Y-axis runs horizontally and is positive to the left of the ego vehicle, as viewed when facing forward. The origin is at the center of the rear axle of the ego vehicle.



For more details on the coordinate system used in the `birdsEyePlot` object, see “Vehicle Coordinate System” on page 4-13.

Object Functions

Plotter Creation

<code>coverageAreaPlotter</code>	Coverage area plotter for bird's-eye plot
<code>detectionPlotter</code>	Detection plotter for bird's-eye plot
<code>laneBoundaryPlotter</code>	Lane boundary plotter for bird's-eye plot
<code>laneMarkingPlotter</code>	Lane marking plotter for bird's-eye plot
<code>outlinePlotter</code>	Outline plotter for bird's-eye plot
<code>pathPlotter</code>	Path plotter for bird's-eye plot
<code>trackPlotter</code>	Track plotter for bird's-eye plot

Plotter Display

<code>plotCoverageArea</code>	Display sensor coverage area on bird's-eye plot
<code>plotDetection</code>	Display object detections on bird's-eye plot
<code>plotLaneBoundary</code>	Display lane boundaries on bird's-eye plot
<code>plotLaneMarking</code>	Display lane markings on bird's-eye plot
<code>plotOutline</code>	Display object outlines on bird's-eye plot
<code>plotPath</code>	Display actor paths on bird's-eye plot
<code>plotTrack</code>	Display object tracks on bird's-eye plot

Plotter Utilities

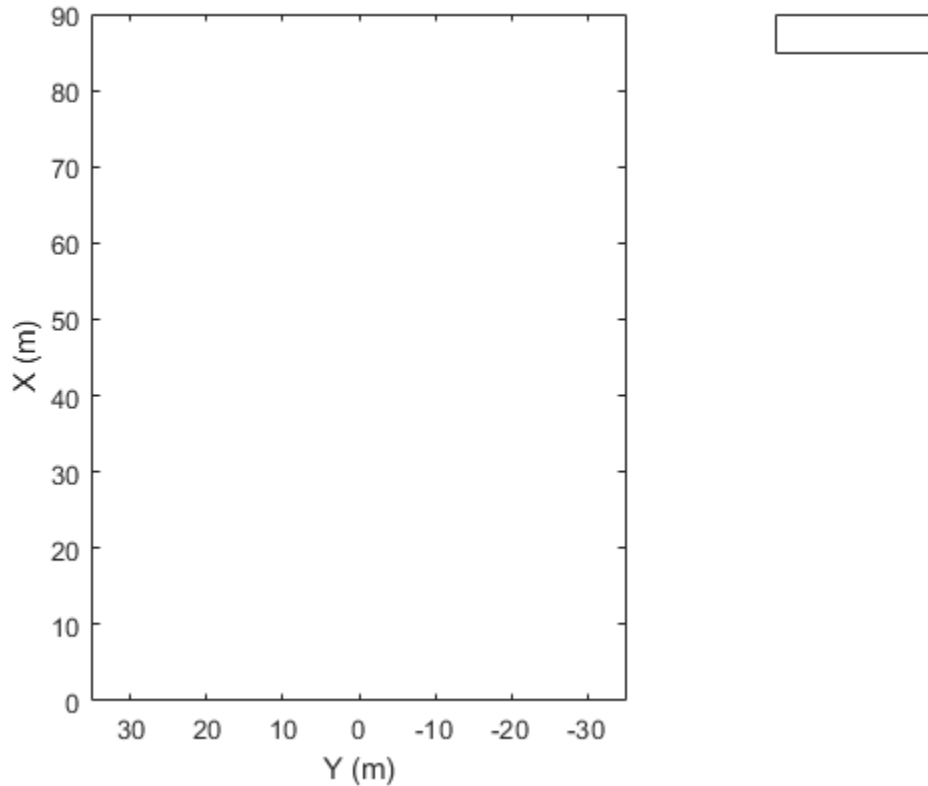
<code>clearData</code>	Clear data from specific plotter of bird's-eye plot
<code>clearPlotterData</code>	Clear data from bird's-eye plot
<code>findPlotter</code>	Find plotters associated with bird's-eye plot

Examples

Create and Display a Bird's-Eye Plot

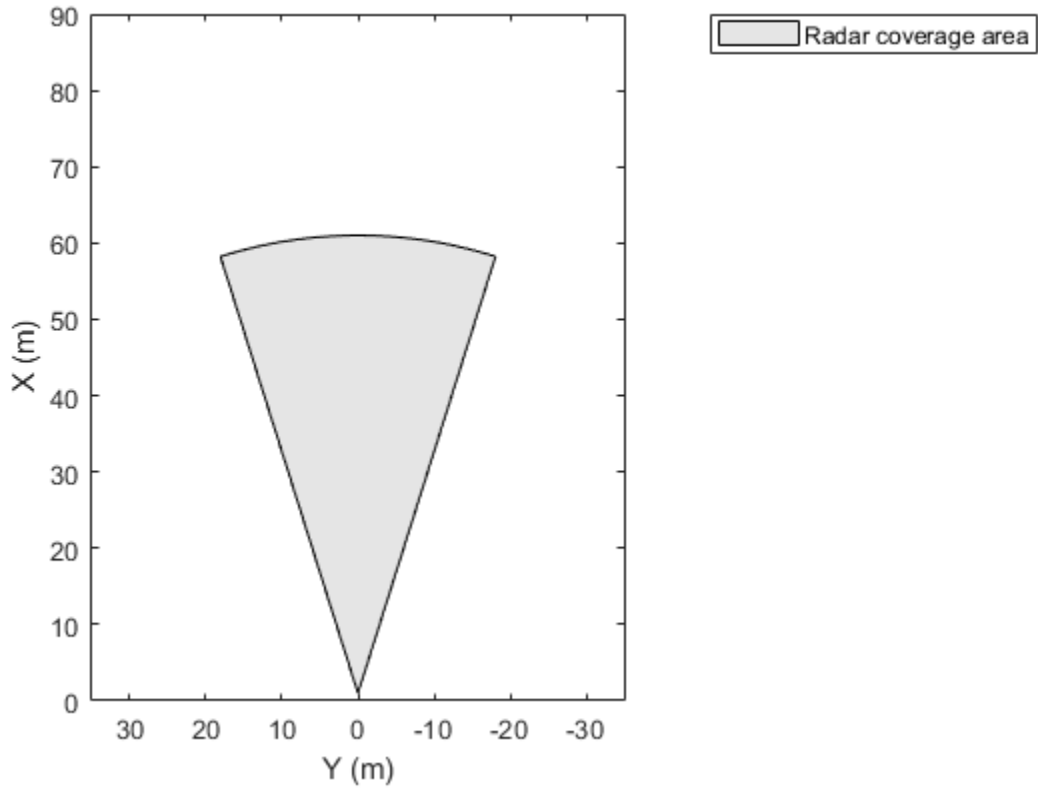
Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);
```



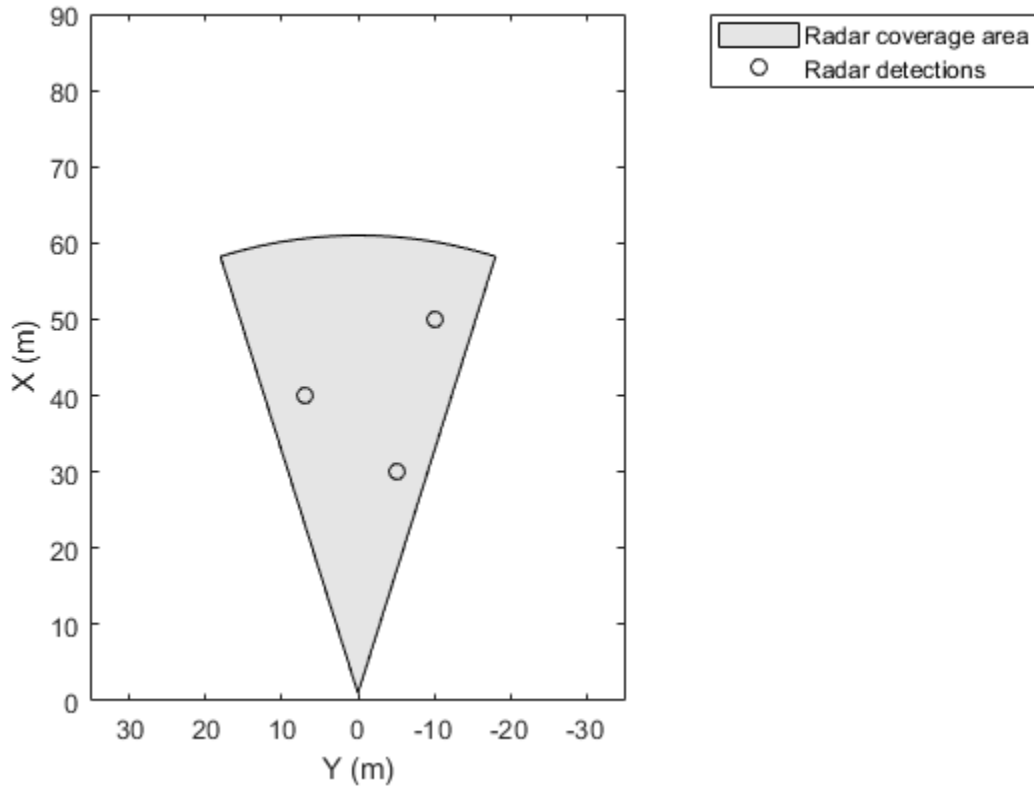
Display a coverage area with a 35-degree field of view and a 60-meter range.

```
caPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Radar coverage area');  
mountPosition = [1 0];  
range = 60;  
orientation = 0;  
fieldOfView = 35;  
plotCoverageArea(caPlotter, mountPosition, range, orientation, fieldOfView);
```



Display radar detections with coordinates at (30, -5), (50, -10), and (40, 7).

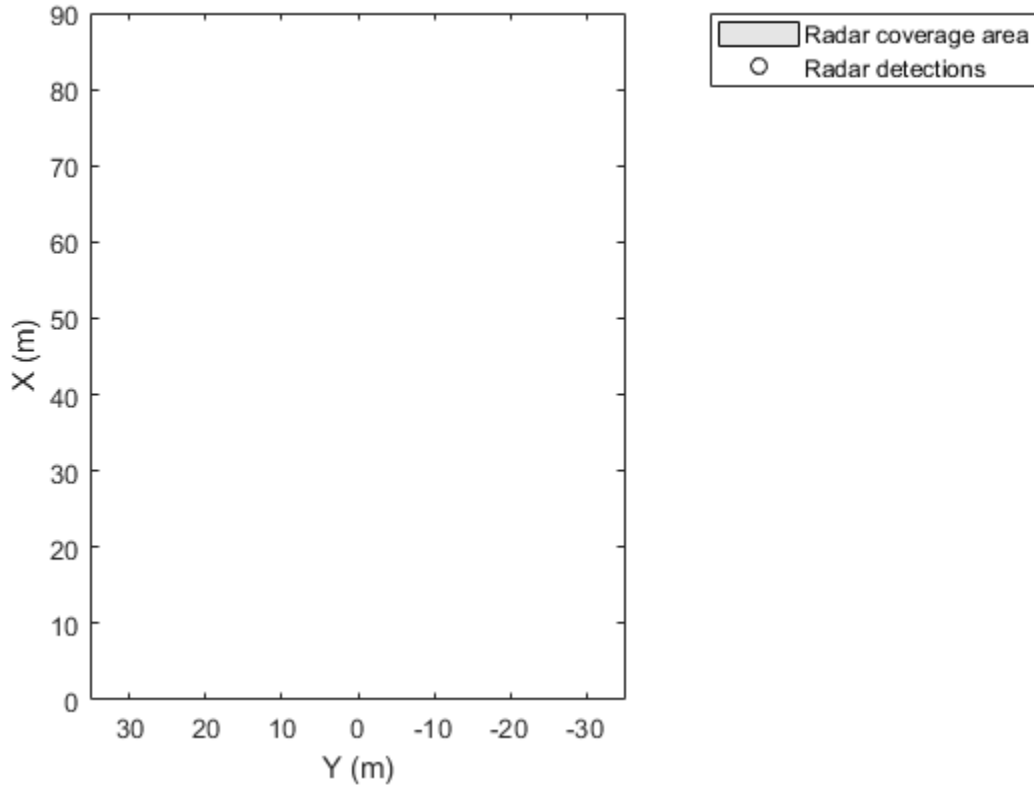
```
radarPlotter = detectionPlotter(bep, 'DisplayName', 'Radar detections');  
plotDetection(radarPlotter, [30 -5; 50 -10; 40 7]);
```



Create Bird's-Eye Plot with Coverage Area and Detection Plotters

Create a bird's-eye plot with an x-axis range of 0 to 90 meters and a y-axis range from -35 to 35 meters. Configure the plot to include a radar coverage area plotter and a detection plotter. Set the display names of these plotters.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);  
coverageAreaPlotter(bep,'DisplayName','Radar coverage area');  
detectionPlotter(bep,'DisplayName','Radar detections');
```

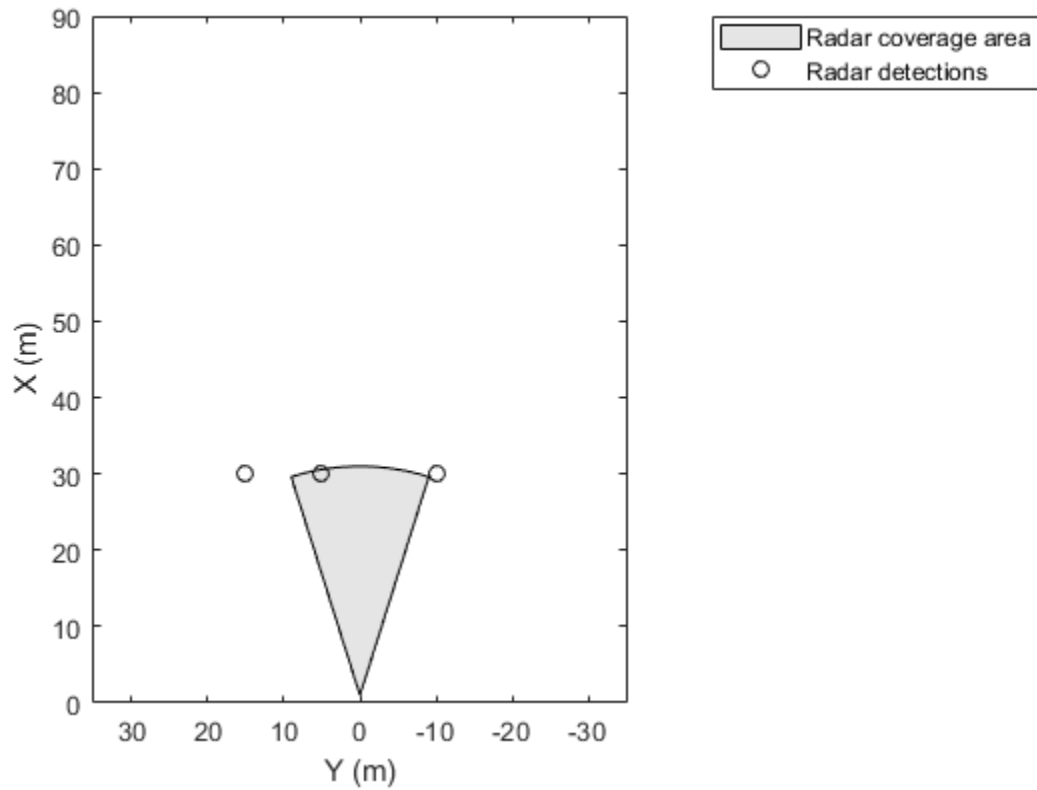


Use `findPlotter` to locate the plotters by their display names.

```
caPlotter = findPlotter(bep, 'DisplayName', 'Radar coverage area');  
radarPlotter = findPlotter(bep, 'DisplayName', 'Radar detections');
```

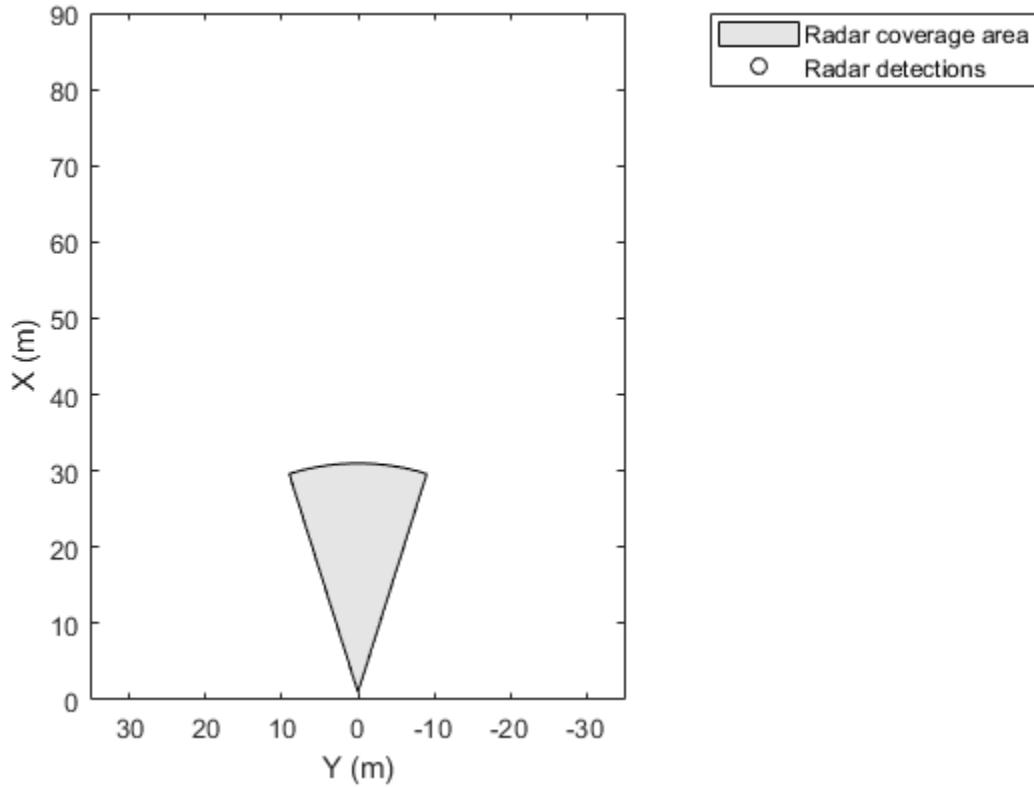
Plot the coverage area and detected objects.

```
plotCoverageArea(caPlotter, [1 0], 30, 0, 35);  
plotDetection(radarPlotter, [30 5; 30 -10; 30 15]);
```

Clear data from the plot.

```
clearPlotterData(bep);
```



Limitations

The rectangle-zoom feature, where you draw a rectangle to zoom in on a section of a figure, does not work in bird's-eye plot figures.

More About

Vehicle Coordinate System

The `birdsEyePlot` uses the vehicle coordinate system (X_V, Y_V) , where:

- The X_V -axis points forward from the ego vehicle.
- The Y_V -axis points to the left, as viewed when facing forward.

The origin is at the center of rotation of the ego vehicle. This point is on the road surface, beneath the center of the rear axle of the ego vehicle.



For more details about the vehicle coordinate system, see “Coordinate Systems in Automated Driving Toolbox”.

See Also

Bird's-Eye Scope | `drivingScenario`

Topics

“Visualize Sensor Coverage, Detections, and Tracks”

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

clearData

Clear data from specific plotter of bird's-eye plot

Syntax

```
clearData(pl)
```

Description

`clearData(pl)` clears data belonging to the plotter `pl` associated with a bird's-eye plot. This function can clear data from these plotters:

- `detectionPlotter`
- `laneBoundaryPlotter`
- `laneMarkingPlotter`
- `outlinePlotter`
- `pathPlotter`
- `trackPlotter`

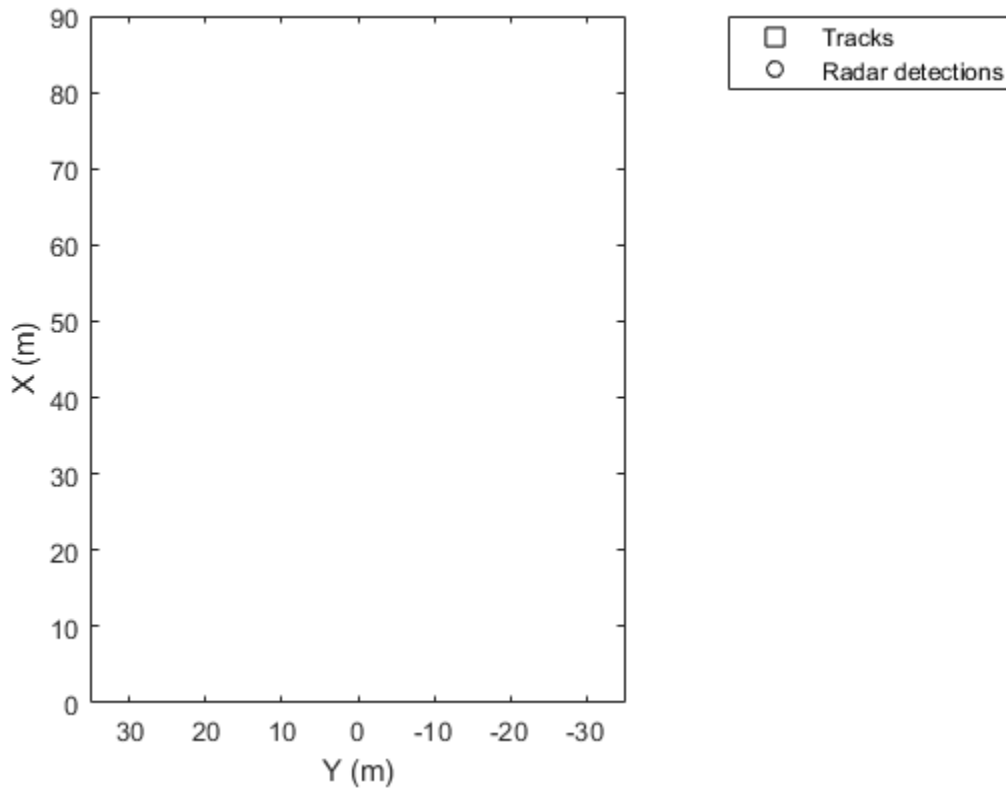
To clear data from all plotters belonging to a bird's-eye plot, use the `clearPlotterData` function.

Examples

Clear Specific Plotter Data from Bird's-Eye Plot

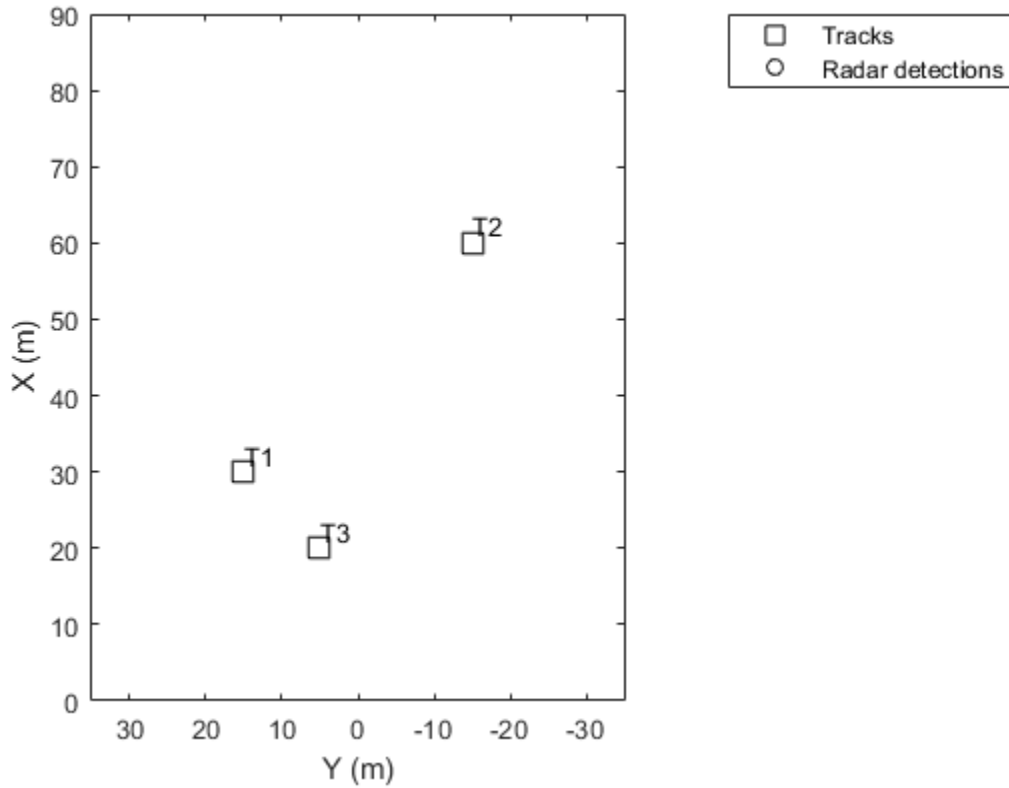
Create a bird's-eye plot. Add a track plotter and detection plotter to the bird's-eye plot.

```
bep = birdsEyePlot('XLim',[0,90],'YLim',[-35,35]);  
tPlotter = trackPlotter(bep,'DisplayName','Tracks');  
detPlotter = detectionPlotter(bep,'DisplayName','Radar detections');
```



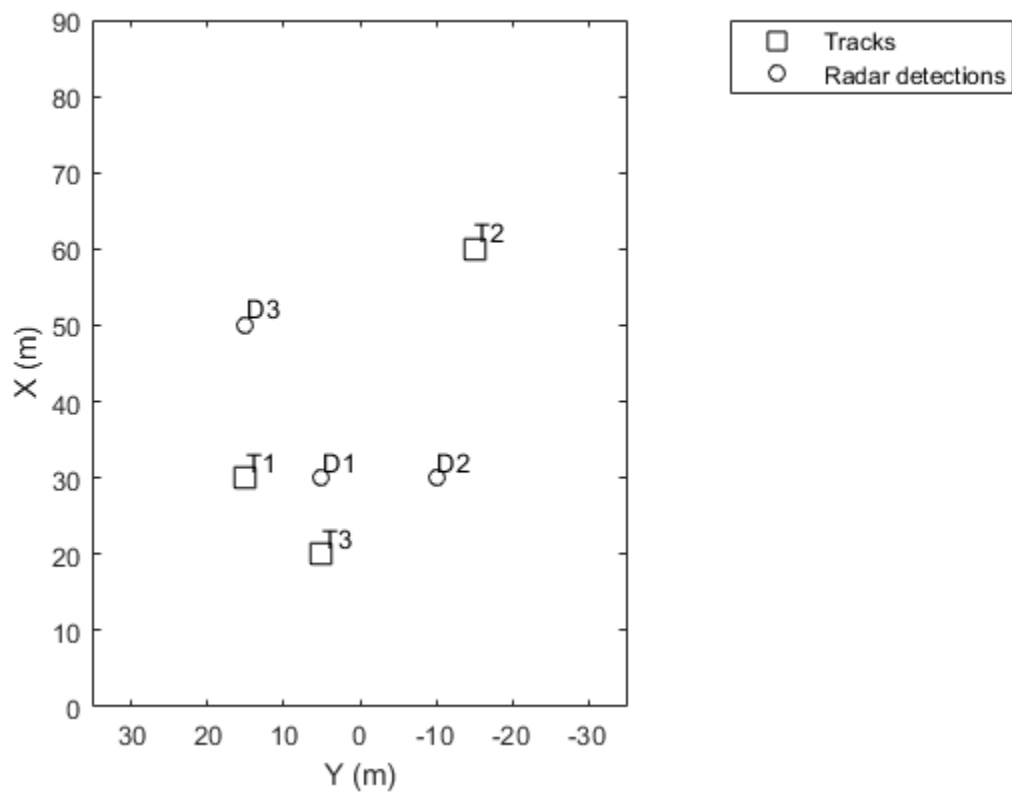
Create and display a set of tracks on the bird's-eye plot.

```
trackPos = [30 15 1; 60 -15 1; 20 5 1];  
trackLabels = {'T1', 'T2', 'T3'};  
plotTrack(tPlotter, trackPos, trackLabels)
```



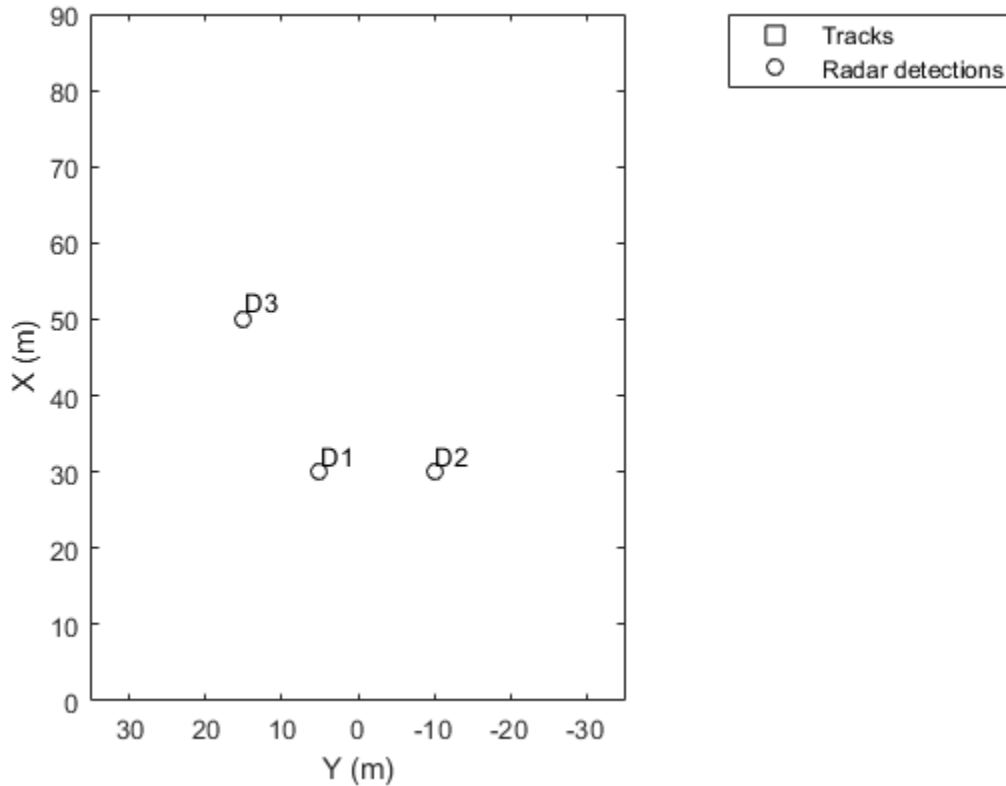
Create and display a set of detections on the bird's-eye plot.

```
detPos = [30 5 4; 30 -10 2; 50 15 1];  
detLabels = {'D1', 'D2', 'D3'};  
plotDetection(detPlotter, detPos, detLabels)
```

Clear the track plotter data from the bird's-eye plot.

```
clearData(tPlotter)
```



Input Arguments

p1 — Plotter belonging to bird's-eye plot

plotter object

Plotter belonging to a `birdsEyePlot` object, specified as a plotter object. You can clear data from any plotter except `coverageAreaPlotter`.

See Also

Objects

`birdsEyePlot` | `clearPlotterData` | `findPlotter`

Introduced in R2017a

clearPlotterData

Clear data from bird's-eye plot

Syntax

```
clearPlotterData(bep)
```

Description

`clearPlotterData(bep)` clears all plotter data displayed in the specified bird's-eye plot. Legend entries and coverage areas are not cleared from the plot.

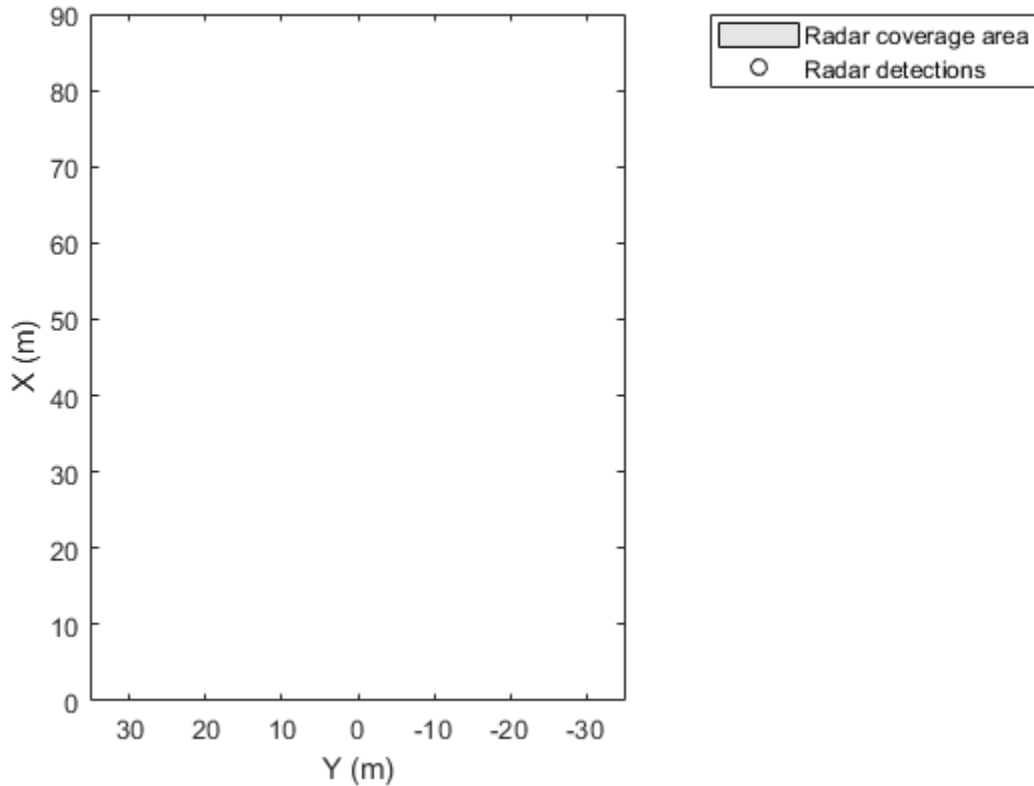
To clear data from a specific plotter, use the `clearData` function.

Examples

Create Bird's-Eye Plot with Coverage Area and Detection Plotters

Create a bird's-eye plot with an x-axis range of 0 to 90 meters and a y-axis range from -35 to 35 meters. Configure the plot to include a radar coverage area plotter and a detection plotter. Set the display names of these plotters.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);  
coverageAreaPlotter(bep,'DisplayName','Radar coverage area');  
detectionPlotter(bep,'DisplayName','Radar detections');
```

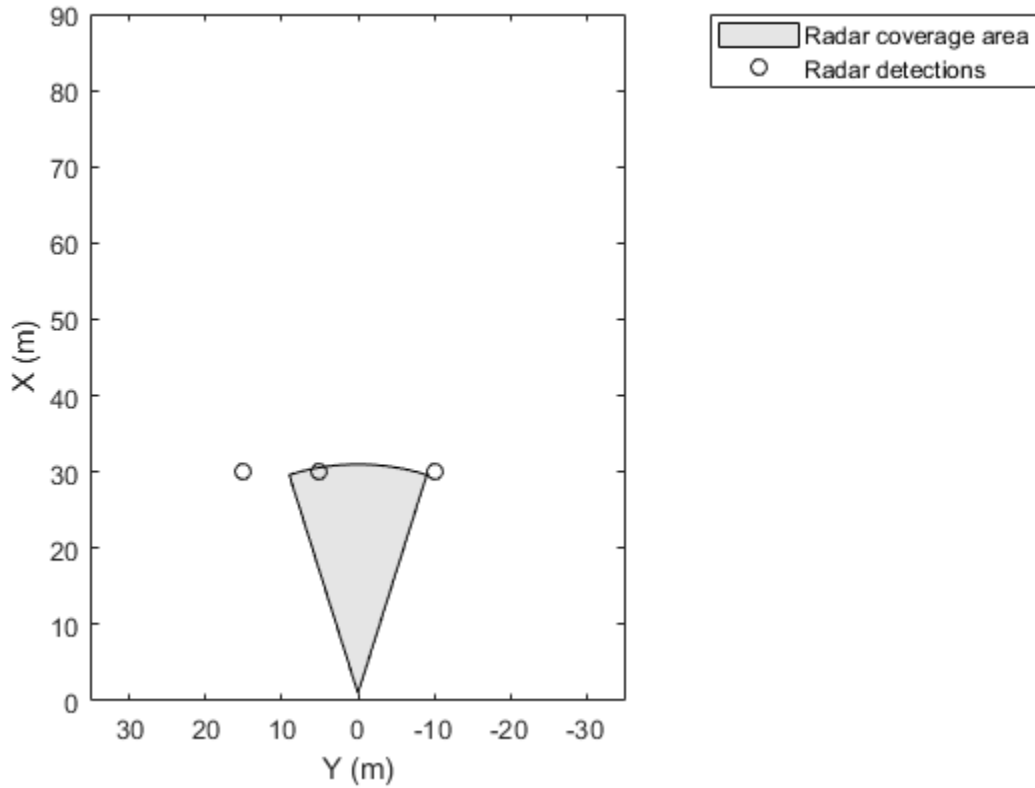


Use `findPlotter` to locate the plotters by their display names.

```
caPlotter = findPlotter(bep, 'DisplayName', 'Radar coverage area');  
radarPlotter = findPlotter(bep, 'DisplayName', 'Radar detections');
```

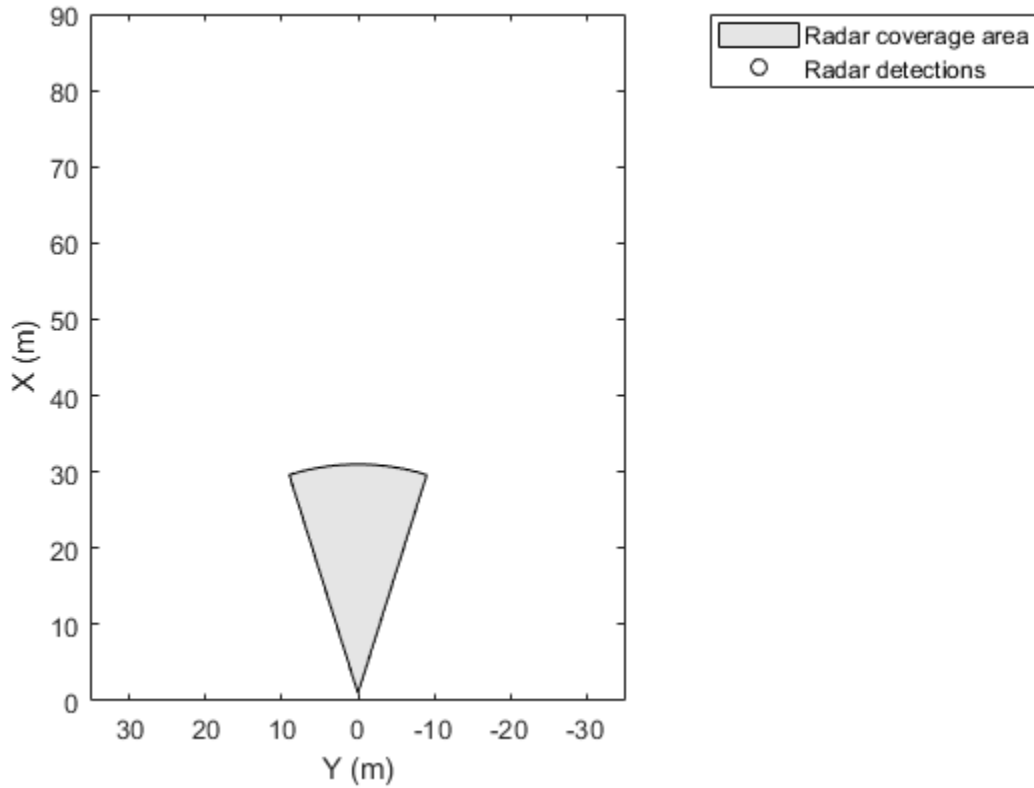
Plot the coverage area and detected objects.

```
plotCoverageArea(caPlotter, [1 0], 30, 0, 35);  
plotDetection(radarPlotter, [30 5; 30 -10; 30 15]);
```



Clear data from the plot.

```
clearPlotterData(bep);
```



Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

See Also

Functions

`birdsEyePlot` | `clearData` | `findPlotter`

Introduced in R2017a

coverageAreaPlotter

Package:

Coverage area plotter for bird's-eye plot

Syntax

```
caPlotter = coverageAreaPlotter(bep)
caPlotter = coverageAreaPlotter(bep, Name, Value)
```

Description

`caPlotter = coverageAreaPlotter(bep)` creates a `CoverageAreaPlotter` object that configures the display of sensor coverage areas on a bird's-eye plot. The `CoverageAreaPlotter` object is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To display the sensor coverage areas, use the `plotCoverageArea` function.

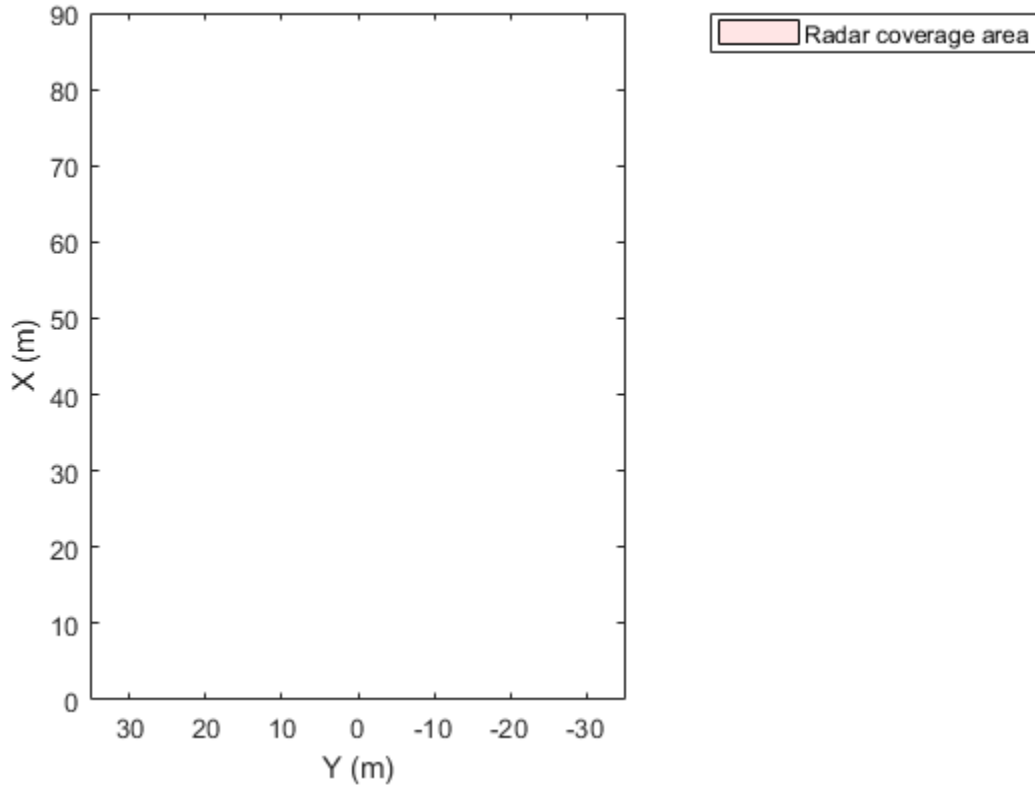
`caPlotter = coverageAreaPlotter(bep, Name, Value)` sets properties using one or more `Name, Value` pair arguments. For example, `coverageAreaPlotter(bep, 'DisplayName', 'Coverage area')` sets the display name that appears in the bird's-eye-plot legend.

Examples

Create and Display Coverage Area on Bird's-Eye Plot

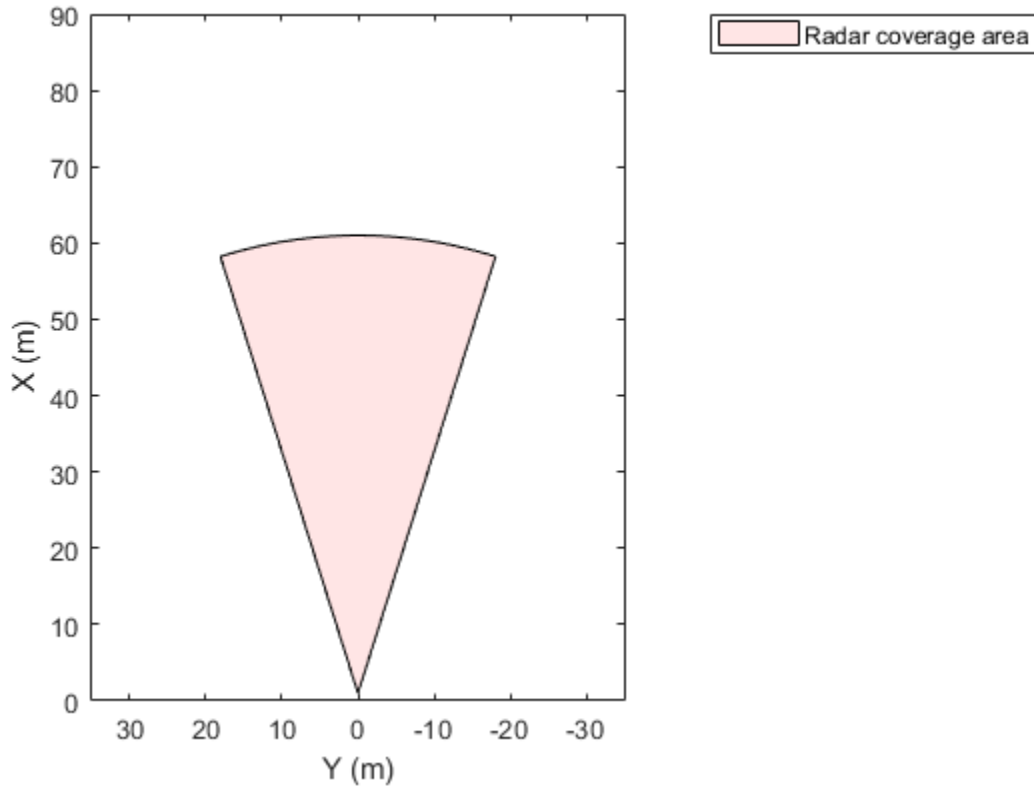
Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters. Create a coverage area plotter that displays coverage areas in red.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);
caPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Radar coverage area', 'FaceColor', 'r');
```



Display a coverage area that has a 35-degree field of view and a 60-meter range. Mount the coverage area sensor 1 meter in front of the origin. Set the orientation angle of the sensor to 0 degrees.

```
mountPosition = [1 0];  
range = 60;  
orientation = 0;  
fieldOfView = 35;  
plotCoverageArea(caPlotter, mountPosition, range, orientation, fieldOfView);
```



Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `coverageAreaPlotter('FaceColor', 'red')` sets the fill color of sensor coverage areas to red.

DisplayName — Plotter name to display in legend

' ' (default) | character vector | string scalar

Plotter name to display in legend, specified as the comma-separated pair consisting of 'DisplayName' and character vector or string scalar. If you do not specify a name, the bird's-eye plot does not display a legend entry for the plotter.

FaceColor — Fill color of coverage areas




[0 0 0] (black) (default) | RGB triplet | hexadecimal color code | color name | short color name






Fill color of coverage areas, specified as the comma-separated pair consisting of 'FaceColor' and an RGB triplet, a hexadecimal color code, a color name, or a short color name.

For a custom color, specify an RGB triplet or a hexadecimal color code.

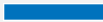






- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].
- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (#) followed by three or six hexadecimal digits, which can range from 0 to F. The values are not case sensitive. Thus, the color codes '#FF8800', '#ff8800', '#F80', and '#f80' are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	
'blue'	'b'	[0 0 1]	'#0000FF'	

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color

Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

EdgeColor — Border color of coverage areas

[0 0 0] (black) (default) | RGB triplet | hexadecimal color code | color name | short color name





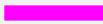



Border color of coverage areas, specified as the comma-separated pair consisting of 'EdgeColor' and an RGB triplet, a hexadecimal color code, a color name, or a short color name.

For a custom color, specify an RGB triplet or a hexadecimal color code.


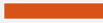





- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].

- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (#) followed by three or six hexadecimal digits, which can range from 0 to F. The values are not case sensitive. Thus, the color codes '#FF8800', '#ff8800', '#F80', and '#f80' are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color

Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

FaceAlpha — Transparency of coverage areas

0.1 (default) | scalar in the range [0, 1]

Transparency of coverage areas, specified as the comma-separated pair consisting of 'FaceAlpha' and a scalar in the range [0, 1]. A value of 0 makes the coverage area fully transparent. A value of 1 makes the coverage area fully opaque.

Tag — Tag associated with plotter object

'Plotter N ' (default) | character vector | string scalar

Tag associated with the plotter object, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar. The default value is 'Plotter N ', where N is an integer that corresponds to the N th plotter associated with the input birdsEyePlot object.

Output Arguments

caPlotter — Coverage area plotter

CoverageAreaPlotter object

Coverage area plotter, returned as a CoverageAreaPlotter object. You can modify this object by changing its property values. The property names correspond to the name-value pair arguments of the coverageAreaPlotter function.

caPlotter is stored in the Plotters property of the input birdsEyePlot object, bep. To plot the coverage areas, use the plotCoverageArea function.

See Also

birdsEyePlot | findPlotter | plotCoverageArea

Introduced in R2017a

detectionPlotter

Package:

Detection plotter for bird's-eye plot

Syntax

```
detPlotter = detectionPlotter(bep)
detPlotter = detectionPlotter(bep,Name,Value)
```

Description

`detPlotter = detectionPlotter(bep)` creates a `DetectionPlotter` object that configures the display of object detections on a bird's-eye plot. The `DetectionPlotter` object is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To plot the object detections, use the `plotDetection` function.

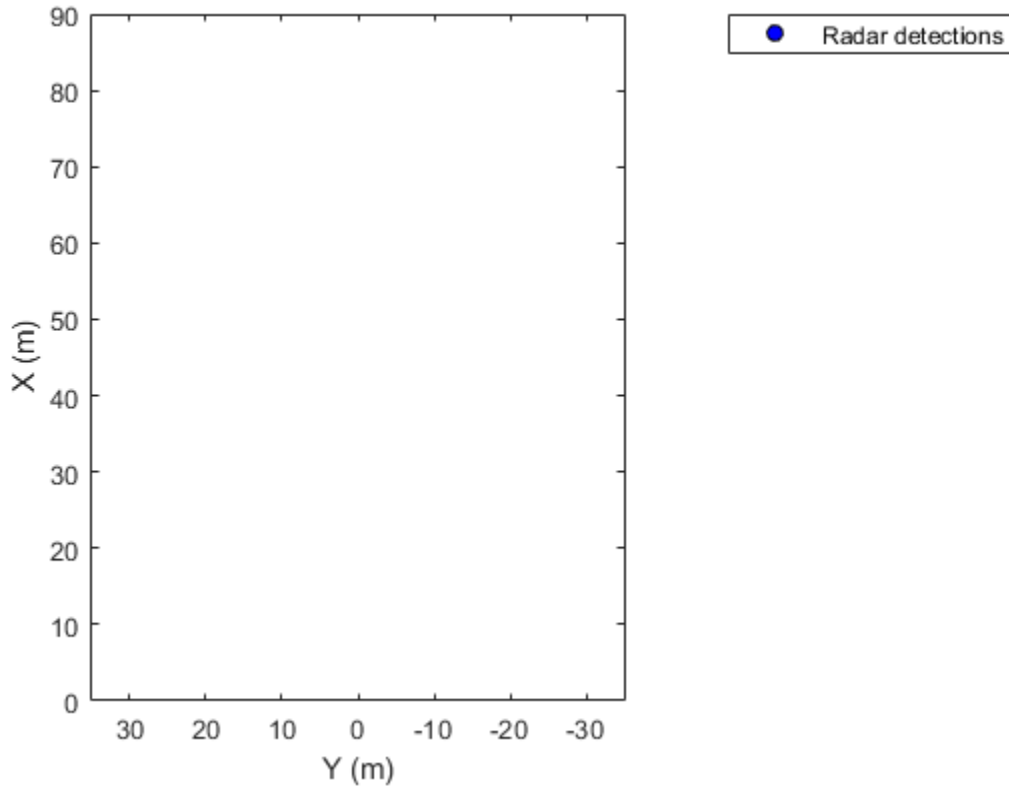
`detPlotter = detectionPlotter(bep,Name,Value)` sets properties using one or more `Name,Value` pair arguments. For example, `detectionPlotter(bep,'DisplayName','Detections')` sets the display name that appears in the bird's-eye-plot legend.

Examples

Create and Display Labeled Detections on Bird's-Eye Plot

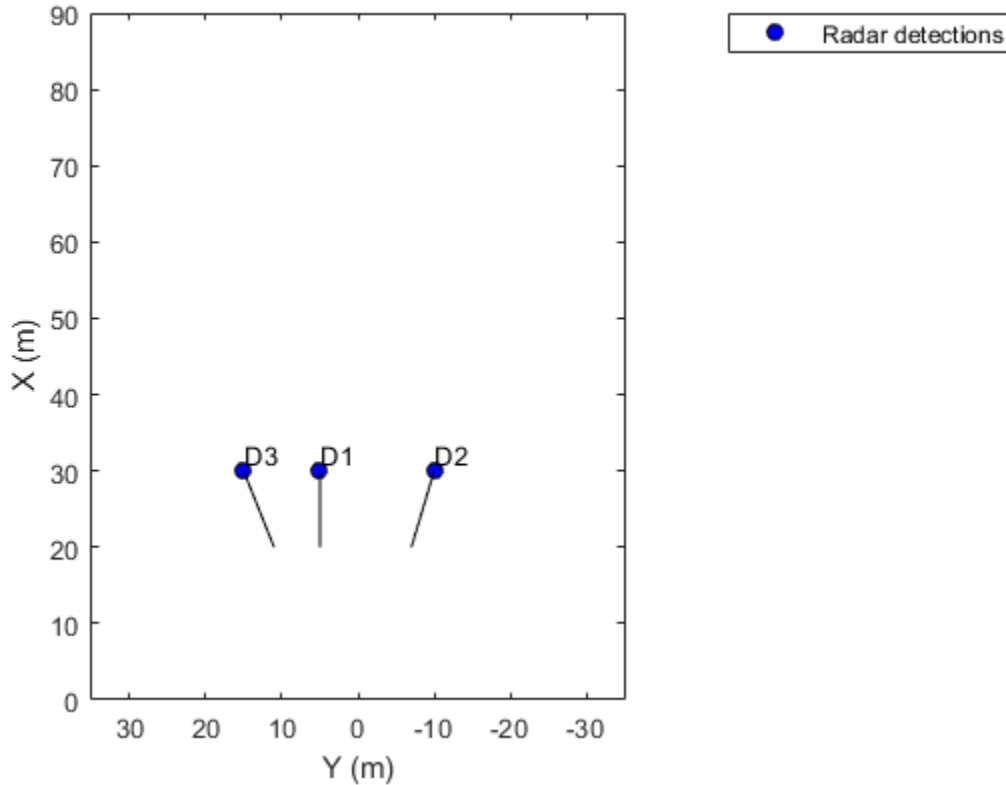
Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters. Create a radar detection plotter that displays detections in blue.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);
detPlotter = detectionPlotter(bep,'DisplayName','Radar detections', ...
    'MarkerFaceColor','b');
```

Display the positions and velocities of three labeled detections.

```
positions = [30 5; 30 -10; 30 15];  
velocities = [-10 0; -10 3; -10 -4];  
labels = {'D1', 'D2', 'D3'};  
plotDetection(detPlotter, positions, velocities, labels);
```



Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `detectionPlotter('Marker', '+')` sets the marker symbol for detections to a plus sign.

DisplayName — Plotter name to display in legend

' ' (default) | character vector | string scalar

Plotter name to display in legend, specified as the comma-separated pair consisting of `'DisplayName'` and character vector or string scalar. If you do not specify a name, the bird's-eye plot does not display a legend entry for the plotter.

Marker — Marker symbol for detections

'o' (default) | '+' | '*' | '.' | 'x' | ...

Marker symbol for detections, specified as the comma-separated pair consisting of `'Marker'` and one of the markers in this table.

Value	Description
'o'	Circle
'+'	Plus sign
'*'	Asterisk
'.'	Point
'x'	Cross
'square' or 's'	Square
'diamond' or 'd'	Diamond
'^'	Upward-pointing triangle
'v'	Downward-pointing triangle
'>'	Right-pointing triangle
'<'	Left-pointing triangle
'pentagram' or 'p'	Five-pointed star (pentagram)
'hexagram' or 'h'	Six-pointed star (hexagram)
'none'	No markers

MarkerSize — Size of marker for detections

6 (default) | positive integer

Size of marker, specified as the comma-separated pair consisting of 'MarkerSize' and a positive integer in points.

MarkerEdgeColor — Marker outline color for detections

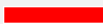






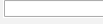
[0 0 0] (black) (default) | RGB triplet | hexadecimal color code | color name | short color name

Marker outline color for detections, specified as the comma-separated pair consisting of 'MarkerEdgeColor' and an RGB triplet, a hexadecimal color code, a color name, or a short color name.








For a custom color, specify an RGB triplet or a hexadecimal color code.

- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].
- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (#) followed by three or six hexadecimal digits, which can range from 0 to F. The values are not case sensitive. Thus, the color codes '#FF8800', '#ff8800', '#F80', and '#f80' are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color

Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

MarkerFaceColor — Marker fill color



'none' (default) | RGB triplet | hexadecimal color code | color name | short color name







Marker fill color, specified as the comma-separated pair consisting of 'MarkerFaceColor' and an RGB triplet, a hexadecimal color code, a color name, or a short color name.

For a custom color, specify an RGB triplet or a hexadecimal color code.








- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].
- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (#) followed by three or six hexadecimal digits, which can range from 0 to F. The values are not case sensitive. Thus, the color codes '#FF8800', '#ff8800', '#F80', and '#f80' are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color

Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

FontSize — Font size for labeling detections

10 points (default) | positive integer

Font size for labeling detections, specified as the comma-separated pair consisting of 'FontSize' and a positive integer in font points.

LabelOffset — Gap between label and positional point

[0 0] (default) | real-valued vector of the form [x y]

Gap between label and positional point, specified as the comma-separated pair consisting of 'LabelOffset' and a real-valued vector of the form [x y]. Units are in meters.

VelocityScaling — Scale factor for magnitude length of velocity vectors

1 (default) | positive real scalar

Scale factor for magnitude length of velocity vectors, specified as the comma-separated pair consisting of 'VelocityScaling' and a positive real scalar. The bird's-eye plot renders the magnitude vector value as $M \times \text{VelocityScaling}$, where M is the magnitude of velocity.

Tag — Tag associated with plotter object'Plotter N ' (default) | character vector | string scalar

Tag associated with the plotter object, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar. The default value is 'Plotter N ', where N is an integer that corresponds to the N th plotter associated with the input `birdsEyePlot` object.

Output Arguments

detPlotter — Detection plotter

DetectionPlotter object

Detection plotter, returned as a `DetectionPlotter` object. You can modify this object by changing its property values. The property names correspond to the name-value pair arguments of the `detectionPlotter` function.

`detPlotter` is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To plot the detections, use the `plotDetection` function.

See Also

`birdsEyePlot` | `clearData` | `clearPlotterData` | `findPlotter` | `plotDetection`**Introduced in R2017a**

findPlotter

Find plotters associated with bird's-eye plot

Syntax

```
p = findPlotter(bep)
p = findPlotter(bep,Name,Value)
```

Description

`p = findPlotter(bep)` returns an array of plotters associated with a bird's-eye plot.

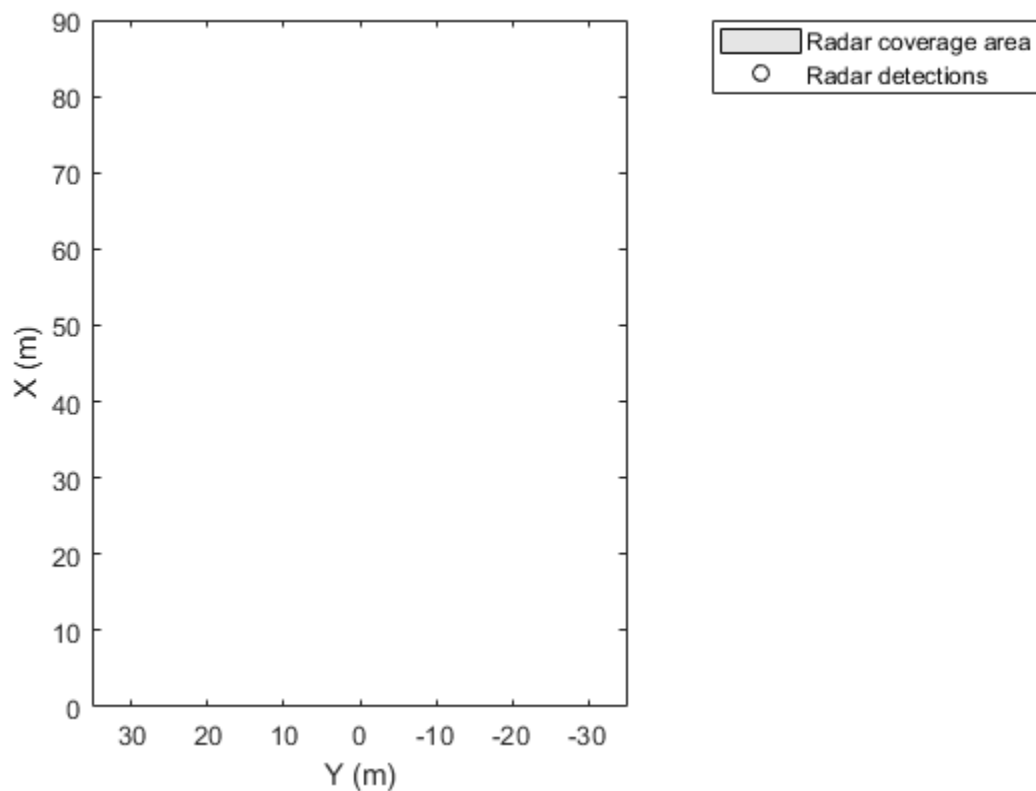
`p = findPlotter(bep,Name,Value)` specifies options using one or more `Name,Value` pair arguments. For example, `findPlotter(bep,'Tag','Plotter1')` returns the plotter object whose `Tag` property value is `'Plotter1'`.

Examples

Create Bird's-Eye Plot with Coverage Area and Detection Plotters

Create a bird's-eye plot with an x-axis range of 0 to 90 meters and a y-axis range from -35 to 35 meters. Configure the plot to include a radar coverage area plotter and a detection plotter. Set the display names of these plotters.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);
coverageAreaPlotter(bep,'DisplayName','Radar coverage area');
detectionPlotter(bep,'DisplayName','Radar detections');
```

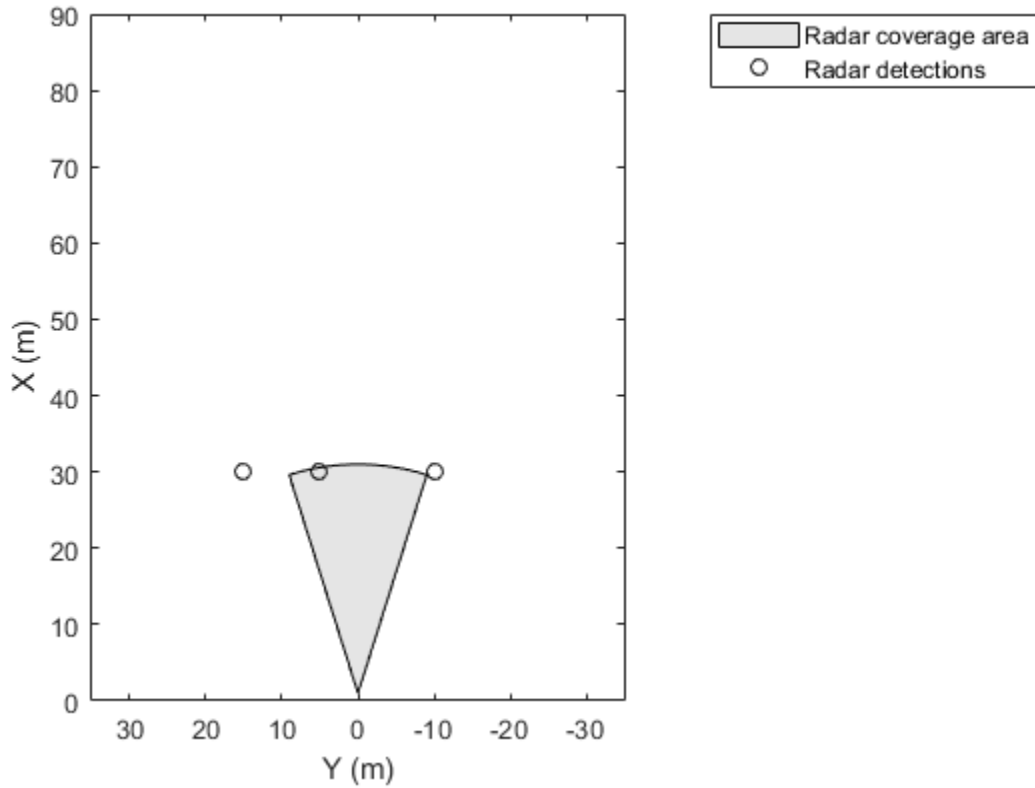



Use `findPlotter` to locate the plotters by their display names.

```
caPlotter = findPlotter(bep, 'DisplayName', 'Radar coverage area');  
radarPlotter = findPlotter(bep, 'DisplayName', 'Radar detections');
```

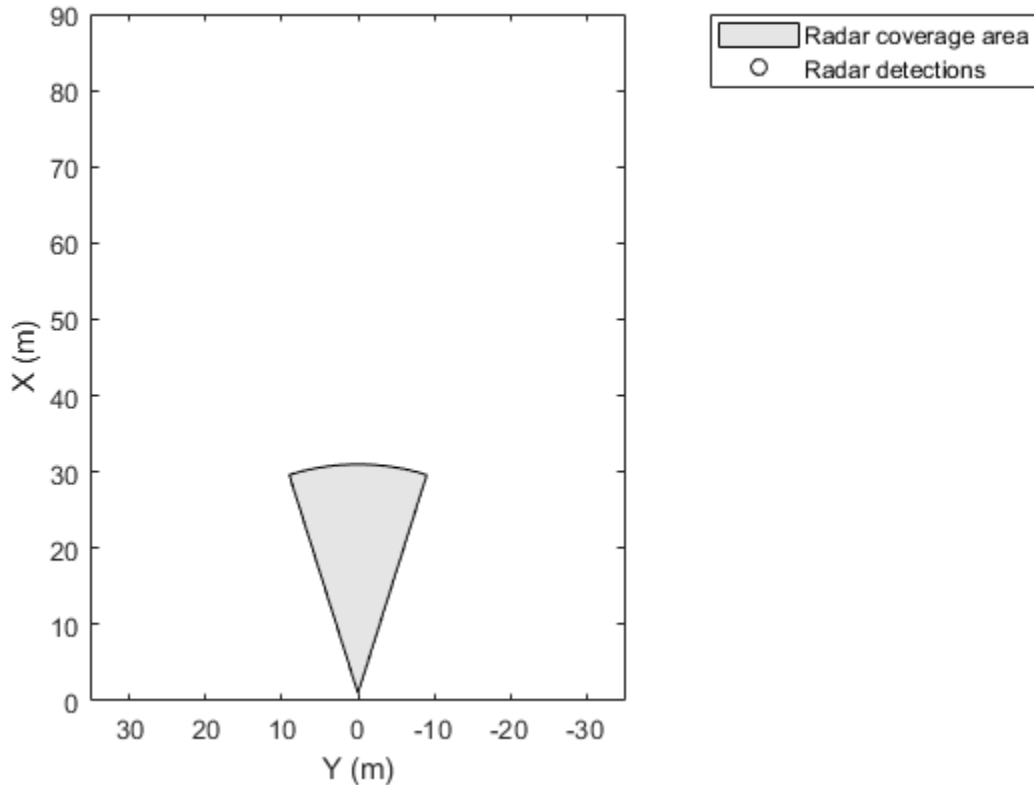
Plot the coverage area and detected objects.

```
plotCoverageArea(caPlotter, [1 0], 30, 0, 35);  
plotDetection(radarPlotter, [30 5; 30 -10; 30 15]);
```



Clear data from the plot.

```
clearPlotterData(bep);
```



Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `'DisplayName', 'MyBirdsEyePlots'`

DisplayName — Display name of plotter to find

character vector | string scalar

Display name of the plotter to find, specified as the comma-separated pair consisting of `'DisplayName'` and a character vector or string scalar. `DisplayName` is the plotter name that appears in the legend of the bird's-eye plot. To match missing legend entries, specify `DisplayName` as `''`.

Tag — Tag of plotter to find

`'PlotterN'` (default) | character vector | string scalar

Tag of plotter to find, specified as the comma-separated pair consisting of `'Tag'` and a character vector or string scalar. By default, plotter objects have a `Tag` property with a default value of `'PlotterN'`. `N` is an integer that corresponds to the `N`th plotter associated with the specified `birdsEyePlot` object, `bep`.

Output Arguments

p — Plotters associated with input bird's-eye plot

array of plotter objects

Plotters associated with the input bird's-eye plot, returned as an array of plotter objects.

See Also

Functions

`birdsEyePlot` | `clearData` | `clearPlotterData`

Introduced in R2017a

laneBoundaryPlotter

Package:

Lane boundary plotter for bird's-eye plot

Syntax

```
lbPlotter = laneBoundaryPlotter(bep)
lbPlotter = laneBoundaryPlotter(bep,Name,Value)
```

Description

`lbPlotter = laneBoundaryPlotter(bep)` creates a `LaneBoundaryPlotter` object that configures the display of lane boundaries on a bird's-eye plot. The `LaneBoundaryPlotter` object is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To display the lane boundaries, use the `plotLaneBoundary` function.

`lbPlotter = laneBoundaryPlotter(bep,Name,Value)` sets properties using one or more `Name,Value` pair arguments. For example, `laneBoundaryPlotter(bep,'DisplayName','Lane boundaries')` sets the display name that appears in the bird's-eye-plot legend.

Examples

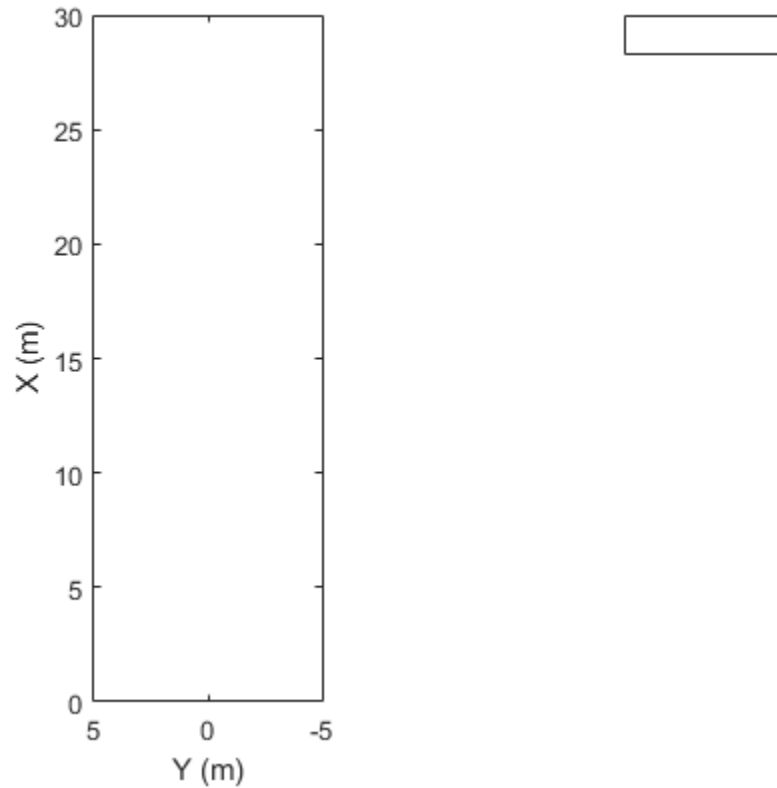
Create and Display Lane Boundaries on Bird's-Eye Plot

Create left-lane and right-lane boundaries.

```
leftlb = parabolicLaneBoundary([-0.001,0.01,-1.8]);
rightlb = parabolicLaneBoundary([-0.001,0.01,1.8]);
```

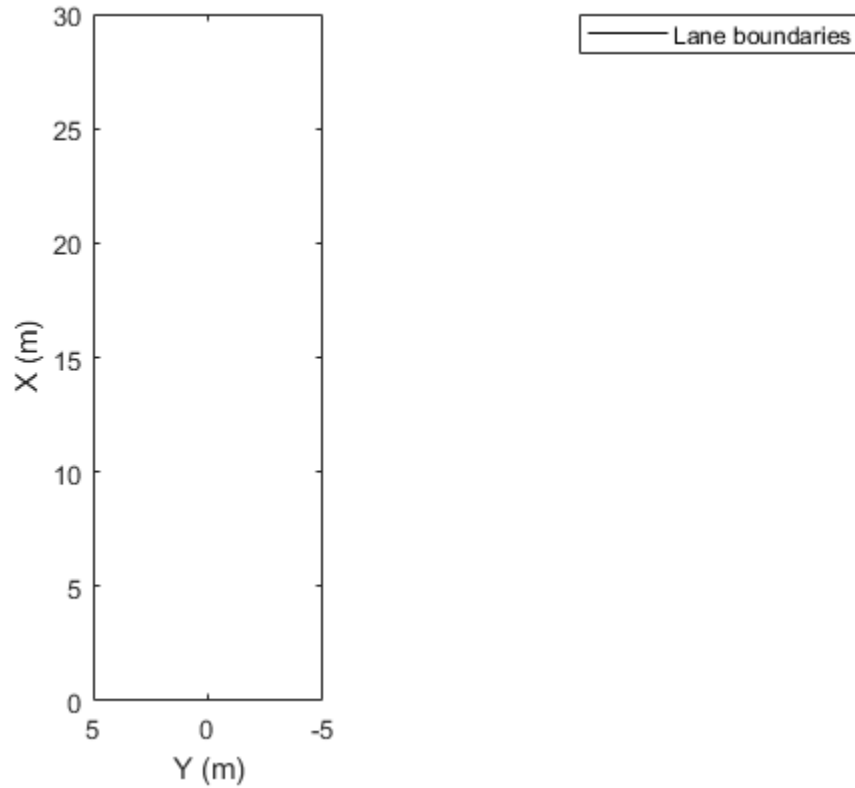
Create a bird's-eye plot with an x-axis range from 0 to 30 meters and a y-axis range from -5 to 5 meters.

```
bep = birdsEyePlot('XLimits',[0 30],'YLimits',[-5 5]);
```



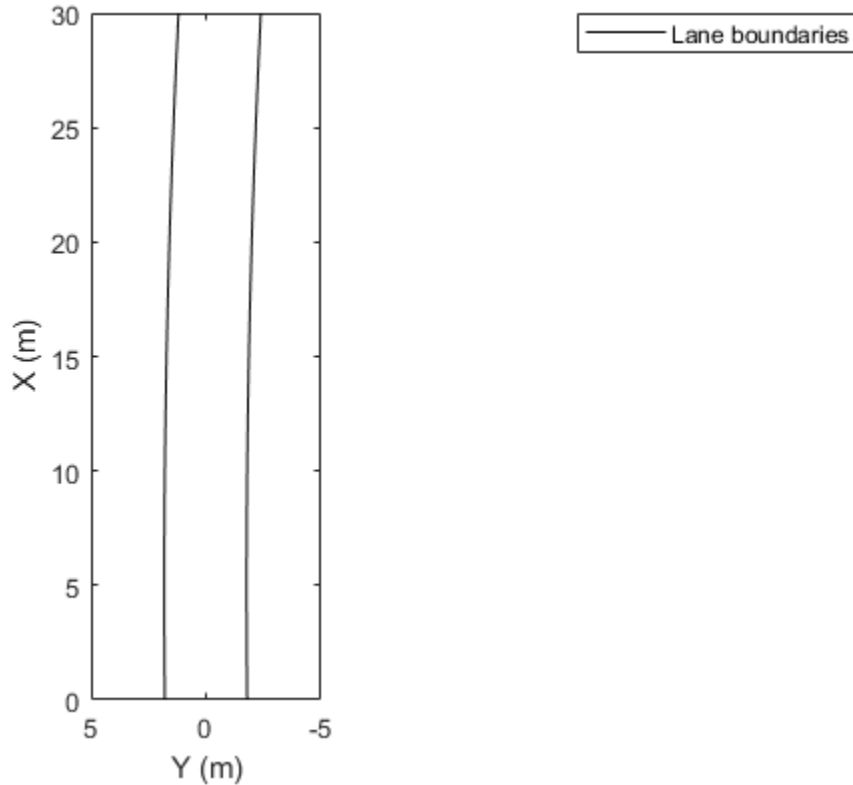
Create a lane boundary plotter.

```
lbPlotter = laneBoundaryPlotter(bep,'DisplayName','Lane boundaries');
```



Display the lane boundaries on the bird's-eye plot.

```
plotLaneBoundary(lbPlotter,[leftlb rightlb]);
```



Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `laneBoundaryPlotter('Color', 'red')` sets the color of lane boundaries to red.

DisplayName — Plotter name to display in legend

`''` (default) | character vector | string scalar

Plotter name to display in legend, specified as the comma-separated pair consisting of `'DisplayName'` and character vector or string scalar. If you do not specify a name, the bird's-eye plot does not display a legend entry for the plotter.

Color — Lane boundary color




`[0 0 0]` (black) (default) | RGB triplet | hexadecimal color code | color name | short color name





Lane boundary color, specified as the comma-separated pair consisting of `'Color'` and an RGB triplet, a hexadecimal color code, a color name, or a short color name.

For a custom color, specify an RGB triplet or a hexadecimal color code.








- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range `[0, 1]`; for example, `[0.4 0.6 0.7]`.
- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (`#`) followed by three or six hexadecimal digits, which can range from `0` to `F`. The values are not case sensitive. Thus, the color codes `'#FF8800'`, `'#ff8800'`, `'#F80'`, and `'#f80'` are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color

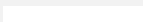


Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

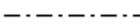
RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

LineStyle – Lane boundary line style

'-' (default) | '- -' | ':' | '- .' | 'none'

Lane boundary line style, specified as the comma-separated pair consisting of 'LineStyle' and one of the options listed in this table.

Line Style	Description	Resulting Line
'-'	Solid line	
'- -'	Dashed line	
':'	Dotted line	

Line Style	Description	Resulting Line
'-.'	Dash-dotted line	
'none'	No line	No line

Tag — Tag associated with plotter object

'Plotter N ' (default) | character vector | string scalar

Tag associated with the plotter object, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar. The default value is 'Plotter N ', where N is an integer that corresponds to the N th plotter associated with the input `birdsEyePlot` object.

Output Arguments

lbPlotter — Lane boundary plotter

LaneBoundaryPlotter object

Lane boundary plotter, returned as a LaneBoundaryPlotter object. You can modify this object by changing its property values. The property names correspond to the name-value pair arguments of the `laneBoundaryPlotter` function.

`lbPlotter` is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To plot the lane boundaries, use the `plotLaneBoundary` function.

See Also

`birdsEyePlot` | `clearData` | `clearPlotterData` | `findPlotter` | `plotLaneBoundary`

Introduced in R2017a

laneMarkingPlotter

Package:

Lane marking plotter for bird's-eye plot

Syntax

```
lmPlotter = laneMarkingPlotter(bep)
lmPlotter = laneMarkingPlotter(bep,Name,Value)
```

Description

`lmPlotter = laneMarkingPlotter(bep)` creates a `LaneMarkingPlotter` object that configures the display of lane markings on a bird's-eye plot. The `LaneMarkingPlotter` object is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To display the lane markings, use the `plotLaneMarking` function.

`lmPlotter = laneMarkingPlotter(bep,Name,Value)` sets properties using one or more `Name,Value` pair arguments. For example, `laneMarkingPlotter(bep,'DisplayName','Lane markings')` sets the display name that appears in the bird's-eye-plot legend.

Examples

Generate Object and Lane Boundary Detections

Create a driving scenario containing an ego vehicle and a target vehicle traveling along a three-lane road. Detect the lane boundaries by using a vision detection generator.

```
scenario = drivingScenario;
```

Create a three-lane road by using lane specifications.

```
roadCenters = [0 0 0; 60 0 0; 120 30 0];  
lspc = lanespec(3);  
road(scenario,roadCenters,'Lanes',lspc);
```

Specify that the ego vehicle follows the center lane at 30 m/s.

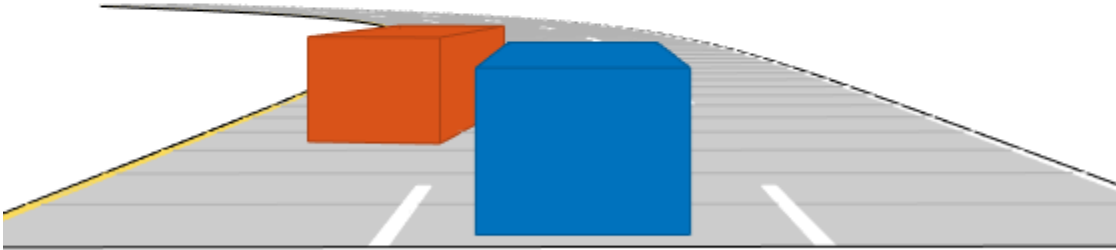
```
egovehicle = vehicle(scenario);  
egopath = [1.5 0 0; 60 0 0; 111 25 0];  
egospeed = 30;  
trajectory(egovehicle,egopath,egospeed);
```

Specify that the target vehicle travels ahead of the ego vehicle at 40 m/s and changes lanes close to the ego vehicle.

```
targetcar = vehicle(scenario,'ClassID',2);  
targetpath = [8 2; 60 -3.2; 120 33];  
targetspeed = 40;  
trajectory(targetcar,targetpath,targetspeed);
```

Display a chase plot for a 3-D view of the scenario from behind the ego vehicle.

```
chasePlot(egovehicle)
```



Create a vision detection generator that detects lanes and objects. The pitch of the sensor points one degree downward.

```
visionSensor = visionDetectionGenerator('Pitch',1.0);  
visionSensor.DetectorOutput = 'Lanes and objects';  
visionSensor.ActorProfiles = actorProfiles(scenario);
```

Run the simulation.

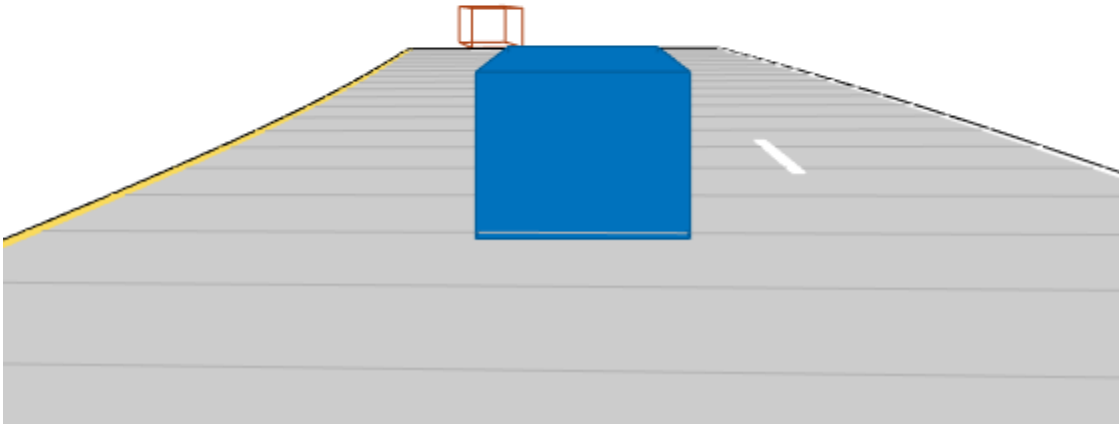
- 1 Create a bird's-eye plot and the associated plotters.
- 2 Display the sensor coverage area.
- 3 Display the lane markings.

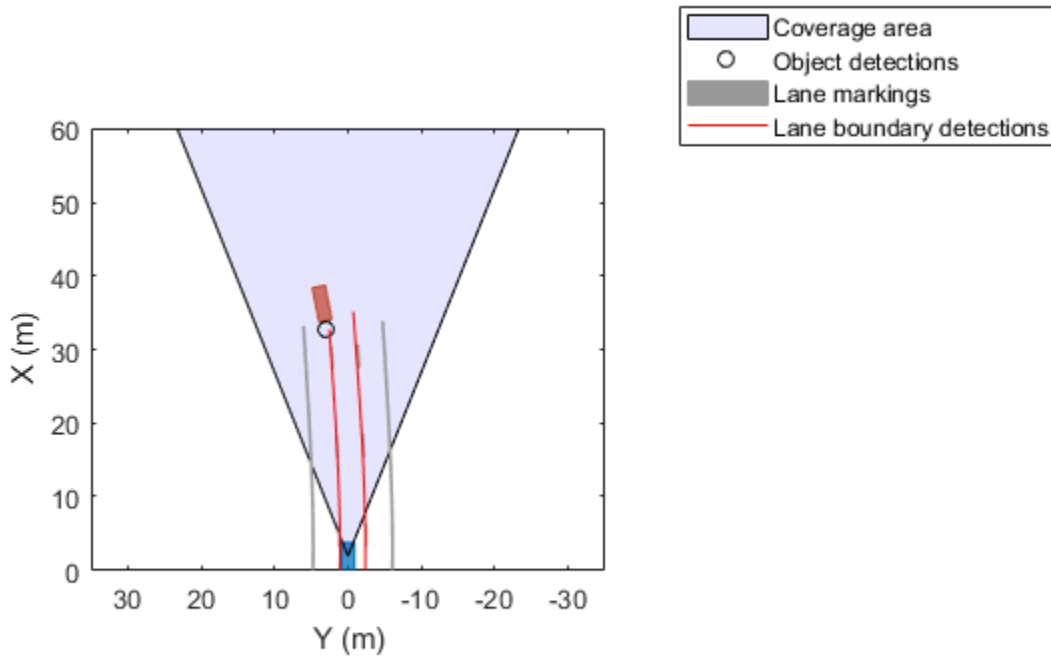
- 4 Obtain ground truth poses of targets on the road.
- 5 Obtain ideal lane boundary points up to 60 m ahead.
- 6 Generate detections from the ideal target poses and lane boundaries.
- 7 Display the outline of the target.
- 8 Display object detections when the object detection is valid.
- 9 Display the lane boundary when the lane detection is valid.

```

bep = birdsEyePlot('XLim',[0 60],'YLim',[-35 35]);
caPlotter = coverageAreaPlotter(bep,'DisplayName','Coverage area', ...
    'FaceColor','blue');
detPlotter = detectionPlotter(bep,'DisplayName','Object detections');
lmPlotter = laneMarkingPlotter(bep,'DisplayName','Lane markings');
lbPlotter = laneBoundaryPlotter(bep,'DisplayName', ...
    'Lane boundary detections','Color','red');
olPlotter = outlinePlotter(bep);
plotCoverageArea(caPlotter,visionSensor.SensorLocation,...
    visionSensor.MaxRange,visionSensor.Yaw, ...
    visionSensor.FieldOfView(1));
while advance(scenario)
    [lmv,lmf] = laneMarkingVertices(egovehicle);
    plotLaneMarking(lmPlotter,lmv,lmf)
    tgtpose = targetPoses(egovehicle);
    lookaheadDistance = 0:0.5:60;
    lb = laneBoundaries(egovehicle,'XDistance',lookaheadDistance,'LocationType','inner
    [obdets,nobdets,obValid,lb_dets,nlb_dets,lbValid] = ...
        visionSensor(tgtpose,lb,scenario.SimulationTime);
    [objjposition,objyaw,objlength,objwidth,objoriginOffset,color] = targetOutlines(egovehicle);
    plotOutline(olPlotter,objjposition,objyaw,objlength,objwidth, ...
        'OriginOffset',objoriginOffset,'Color',color)
    if obValid
        detPos = cellfun(@(d)d.Measurement(1:2),obdets,'UniformOutput',false);
        detPos = vertcat(zeros(0,2),cell2mat(detPos)');
        plotDetection(detPlotter,detPos)
    end
    if lbValid
        plotLaneBoundary(lbPlotter,vertcat(lb_dets.LaneBoundaries))
    end
end
end

```





Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `laneBoundaryPlotter('Color', 'red')` sets the color of lane markings to red.

DisplayName — Plotter name to display in legend

' ' (default) | character vector | string scalar









Plotter name to display in legend, specified as the comma-separated pair consisting of 'DisplayName' and character vector or string scalar. If you do not specify a name, the bird's-eye plot does not display a legend entry for the plotter.

FaceColor — Face color of lane marking patches

[0.6 0.6 0.6] (gray) (default) | RGB triplet | color name

Face color of lane marking patches, specified as the comma-separated pair consisting of 'FaceColor' and an RGB triplet or one of the color names listed in the table.

For a custom color, specify an RGB triplet. An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7]. Alternatively, you can specify some common colors by name. This table lists the named color options and the equivalent RGB triplet values.

Color Name	RGB Triplet	Appearance
'red'	[1 0 0]	
'green'	[0 1 0]	
'blue'	[0 0 1]	
'cyan'	[0 1 1]	
'magenta'	[1 0 1]	
'yellow'	[1 1 0]	
'black'	[0 0 0]	
'white'	[1 1 1]	

Tag — Tag associated with plotter object

'PlotterN' (default) | character vector | string scalar

Tag associated with the plotter object, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar. The default value is 'Plotter N ', where N is an integer that corresponds to the N th plotter associated with the input `birdsEyePlot` object.

Output Arguments

lmPlotter — Lane marking plotter

LaneMarkingPlotter object

Lane marking plotter, returned as a `LaneMarkingPlotter` object. You can modify this object by changing its property values. The property names correspond to the name-value pair arguments of the `laneMarkingPlotter` function.

`lmPlotter` is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To plot the lane markings, use the `plotLaneMarking` function.

See Also

`birdsEyePlot` | `clearData` | `clearPlotterData` | `findPlotter` | `plotLaneMarking`

Introduced in R2018a

outlinePlotter

Package:

Outline plotter for bird's-eye plot

Syntax

```
olPlotter = outlinePlotter(bep)  
olPlotter = outlinePlotter(bep,Name,Value)
```

Description

`olPlotter = outlinePlotter(bep)` creates an `OutlinePlotter` object that configures the display of object outlines on a bird's-eye plot. The `OutlinePlotter` object is stored in the `Plotters` property of the `birdsEyePlot` object, `bep`. To display the outlines of actors that are in a driving scenario, first use `targetOutlines` to get the dimensions of the actors. Then, after creating an outline plotter object, use the `plotOutline` function to display the outlines of all the actors in the bird's-eye plot.

`olPlotter = outlinePlotter(bep,Name,Value)` sets properties using one or more `Name,Value` pair arguments. For example, `outlinePlotter(bep,'FaceAlpha',0)` sets the areas within each outline to be fully transparent.

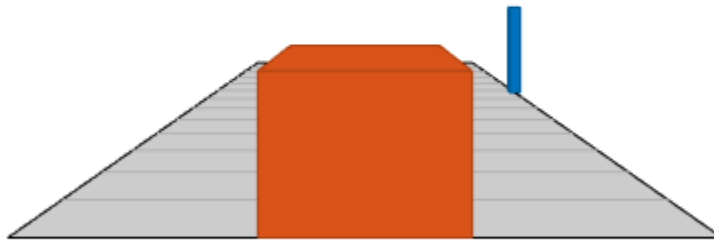
Examples

Plot Outlines of Targets on Bird's-Eye Plot

Create a driving scenario. Create a 25 m road segment, add a pedestrian and a vehicle, and specify their trajectories to follow. The pedestrian crosses the road at 1 m/s. The vehicle drives along the road at 10 m/s.

```
scenario = drivingScenario;  
road(scenario,[0 0 0; 25 0 0]);
```

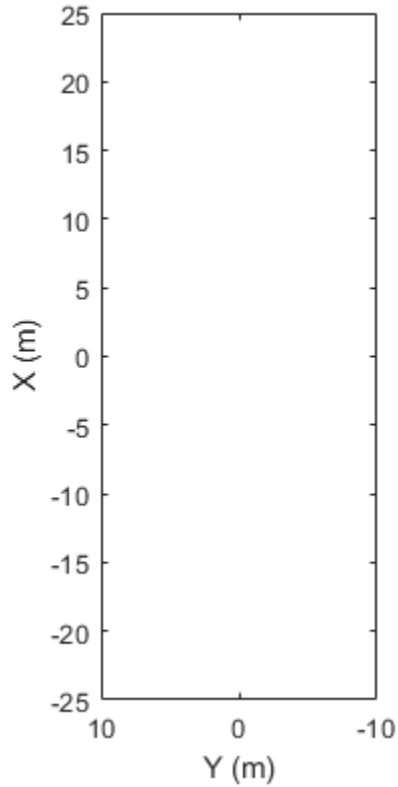
```
p = actor(scenario, 'Length',0.2, 'Width',0.4, 'Height',1.7);  
v = vehicle(scenario);  
  
trajectory(p,[15 -3 0; 15 3 0],1);  
trajectory(v,[v.RearOverhang 0 0; 25-v.Length+v.RearOverhang 0 0], 10);  
  
Use a chase plot to display the scenario from the perspective of the vehicle.  
chasePlot(v, 'Centerline', 'on')
```



Create a bird's-eye plot, outline plotter, and lane boundary plotter.

```
bep = birdsEyePlot('XLim',[-25 25], 'YLim',[-10 10]);  
olPlotter = outlinePlotter(bep);
```

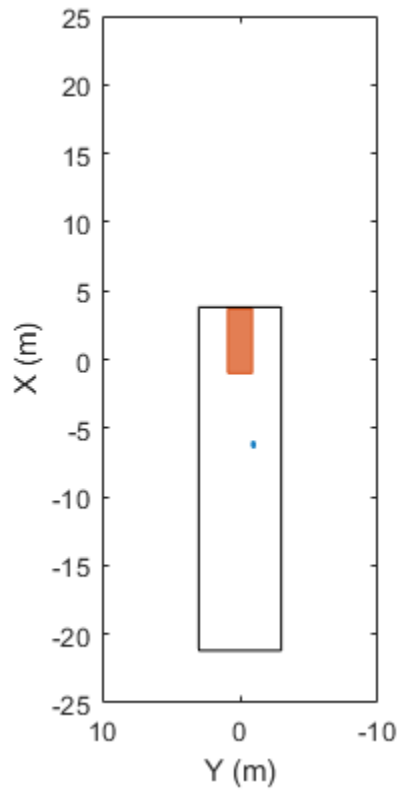
```
lbPlotter = laneBoundaryPlotter(bep);  
legend('off')
```

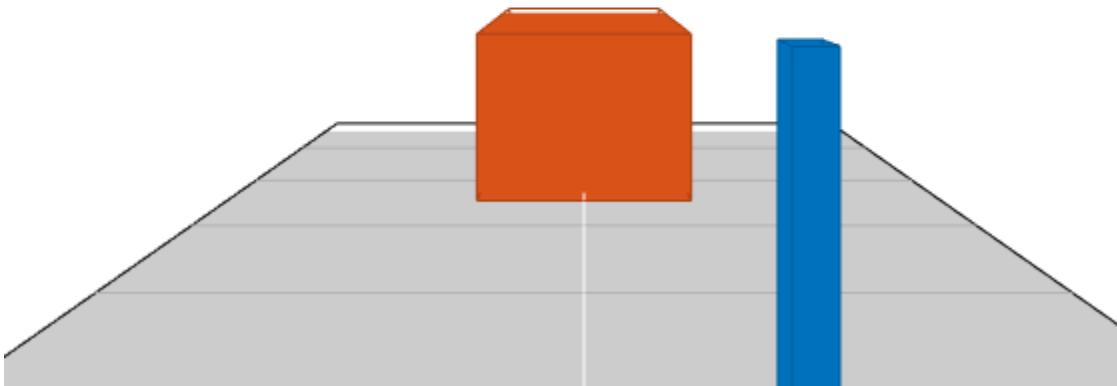


Run the simulation loop. Update the plotter with outlines for the targets.

```
while advance(scenario)  
    % Obtain the road boundaries and rectangular outlines.  
    rb = roadBoundaries(v);  
    [position,yaw,length,width,originOffset,color] = targetOutlines(v);  
  
    % Update the bird's-eye plotters with the road and actors.  
    plotLaneBoundary(lbPlotter,rb);  
    plotOutline(olPlotter,position,yaw,length,width, ...  
        'OriginOffset',originOffset,'Color',color);  
end
```

```
% Allow time for plot to update.  
pause(0.01)  
end
```





Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `outlinePlotter('FaceAlpha', 1)` sets the areas within each outline to be fully opaque.

FaceAlpha — Transparency of area within each outline

0.75 (default) | real scalar

Transparency of the area within each outline, specified as the comma-separated pair consisting of 'FaceAlpha' and a real scalar in the range [0, 1]. A value of 0 makes the areas fully transparent. A value of 1 makes the areas fully opaque.

Tag — Tag associated with plotter object

'PlotterN' (default) | character vector | string scalar

Tag associated with the plotter object, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar. The default value is 'PlotterN', where *N* is an integer that corresponds to the *N*th plotter associated with the input `birdsEyePlot` object.

Output Arguments

olPlotter — Outline plotter

OutlinePlotter object

Outline plotter, returned as an `OutlinePlotter` object. You can modify this object by changing its property values. The property names correspond to the name-value pair arguments of the `outlinePlotter` function.

`olPlotter` is stored in the `Plotters` property of a `birdsEyePlot` object. To plot the outlines of actors that are in a driving scenario, first use `targetOutlines` to get the dimensions of the actors. Then, after calling `outlinePlotter` to create a plotter object, use `plotOutline` to plot the outlines of all the actors in a bird's-eye plot.

See Also

`birdsEyePlot` | `clearData` | `clearPlotterData` | `findPlotter` | `plotOutline`

Introduced in R2017b

pathPlotter

Package:

Path plotter for bird's-eye plot

Syntax

```
pPlotter = pathPlotter(bep)
pPlotter = pathPlotter(bep, Name, Value)
```

Description

`pPlotter = pathPlotter(bep)` creates a `PathPlotter` object that configures the display of actor paths on a bird's-eye plot. The `PathPlotter` object is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To display the paths, use the `plotPath` function.

`pPlotter = pathPlotter(bep, Name, Value)` sets properties using one or more `Name, Value` pair arguments. For example, `pathPlotter(bep, 'DisplayName', 'Actor paths')` sets the display name that appears in the bird's-eye-plot legend.

Examples

Plot Path of Ego Vehicle

Create a 3-meter-wide lane.

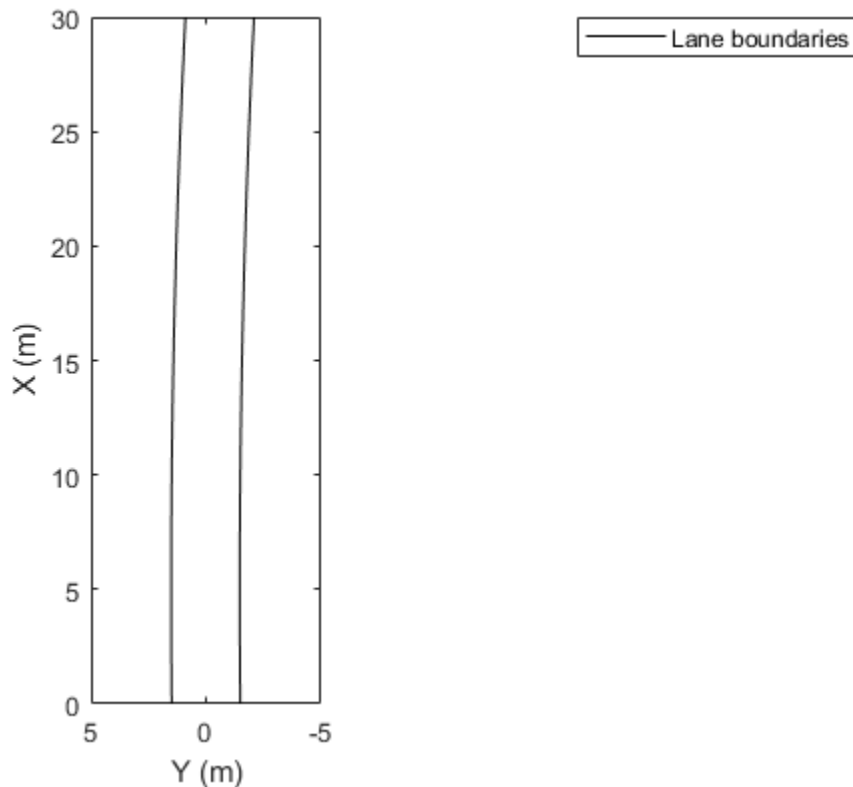
```
lb = parabolicLaneBoundary([-0.001, 0.01, 1.5]);
rb = parabolicLaneBoundary([-0.001, 0.01, -1.5]);
```

Compute the lane boundary model manually from 0 to 30 meters along the x-axis.

```
xWorld = (0:30)';  
yLeft = computeBoundaryModel(lb,xWorld);  
yRight = computeBoundaryModel(rb,xWorld);
```

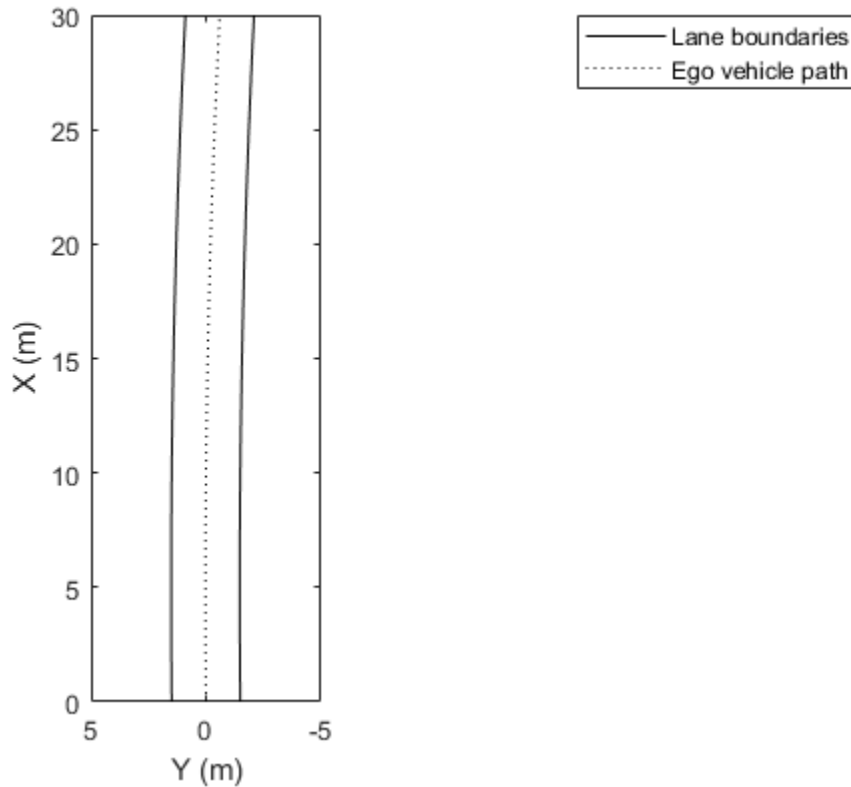
Create a bird's-eye plot and lane boundary plotter. Display the lane information on the bird's-eye plot.

```
bep = birdsEyePlot('XLimits',[0 30],'YLimits',[-5 5]);  
lanePlotter = laneBoundaryPlotter(bep,'DisplayName','Lane boundaries');  
plotLaneBoundary(lanePlotter,{xWorld,yLeft},{xWorld,yRight});
```



Create a path plotter. Create and display the path of an ego vehicle that travels through the center of the lane.

```
yCenter = (yLeft + yRight)/2;  
egoPathPlotter = pathPlotter(bep, 'DisplayName', 'Ego vehicle path');  
plotPath(egoPathPlotter, {[xWorld, yCenter]});
```



Input Arguments

bep — Bird's-eye plot

birdsEyePlot object

Bird's-eye plot, specified as a birdsEyePlot object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `pathPlotter('Color', 'red')` sets the color of the path to red.

Display Name — Plotter name to display in legend

' ' (default) | character vector | string scalar

Plotter name to display in legend, specified as the comma-separated pair consisting of 'Display Name' and character vector or string scalar. If you do not specify a name, the bird's-eye plot does not display a legend entry for the plotter.

Color — Path color



[0 0 0] (black) (default) | RGB triplet | hexadecimal color code | color name | short color name







Path color, specified as the comma-separated pair consisting of 'Color' and an RGB triplet, a hexadecimal color code, a color name, or a short color name.

For a custom color, specify an RGB triplet or a hexadecimal color code.








- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].
- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (#) followed by three or six hexadecimal digits, which can range from 0 to F. The values are not case sensitive. Thus, the color codes '#FF8800', '#ff8800', '#F80', and '#f80' are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color



Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

LineStyle – Path line style

' : ' (default) | ' - ' | ' - - ' | ' - . ' | ' none '

Path line style, specified as the comma-separated pair consisting of 'LineStyle' and one of the options listed in this table.

Line Style	Description	Resulting Line
' - '	Solid line	
' - - '	Dashed line	

Line Style	Description	Resulting Line
' : '	Dotted line
' - . '	Dash-dotted line	- . - . - .
' none '	No line	No line

Tag — Tag associated with plotter object

'Plotter*N*' (default) | character vector | string scalar

Tag associated with the plotter object, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar. The default value is 'Plotter*N*', where *N* is an integer that corresponds to the *N*th plotter associated with the input `birdsEyePlot` object.

Output Arguments

pPlotter — Path plotter

PathPlotter object

Path plotter, returned as a `PathPlotter` object. You can modify this object by changing its property values. The property names correspond to the name-value pair arguments of the `pathPlotter` function.

`pPlotter` is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To plot the paths, use the `plotPath` function.

See Also

`birdsEyePlot` | `clearData` | `clearPlotterData` | `findPlotter` | `plotPath`

Introduced in R2017a

plotCoverageArea

Display sensor coverage area on bird's-eye plot

Syntax

```
plotCoverageArea(caPlotter,position,range,orientation,fieldOfView)
```

Description

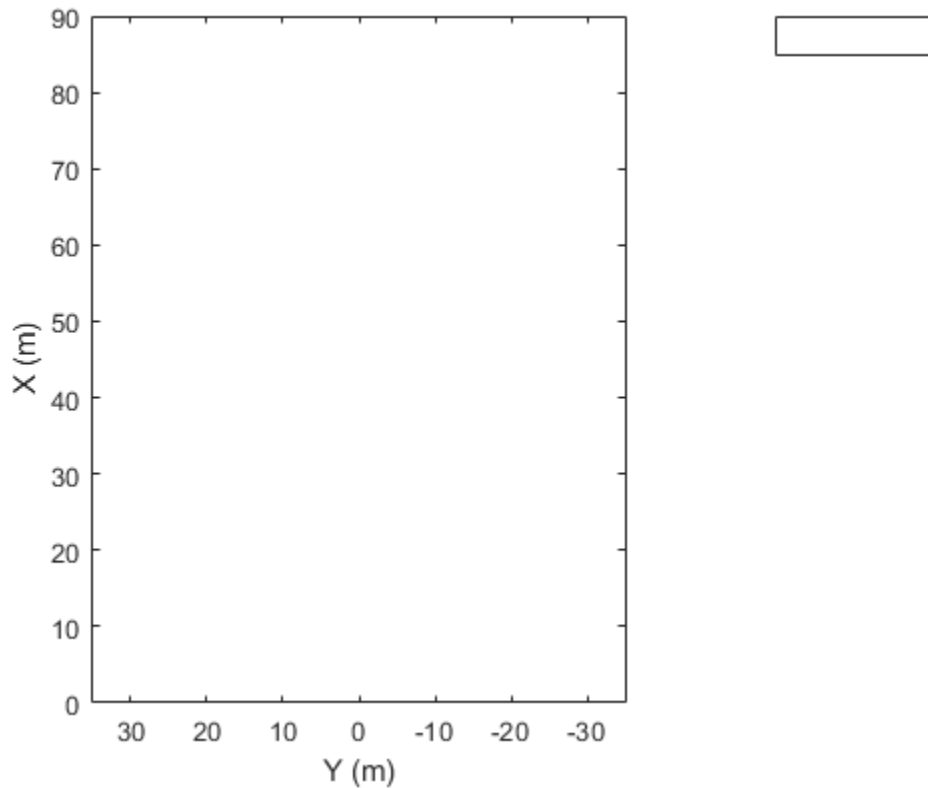
`plotCoverageArea(caPlotter,position,range,orientation,fieldOfView)` displays the coverage area of an ego vehicle sensor on a bird's-eye plot. Specify the position, range, orientation angle, and field of view of the sensor. The coverage area plotter, `caPlotter`, is associated with a `birdsEyePlot` object and configures the display of sensor coverage areas.

Examples

Display Coverage Area for Radar Sensor

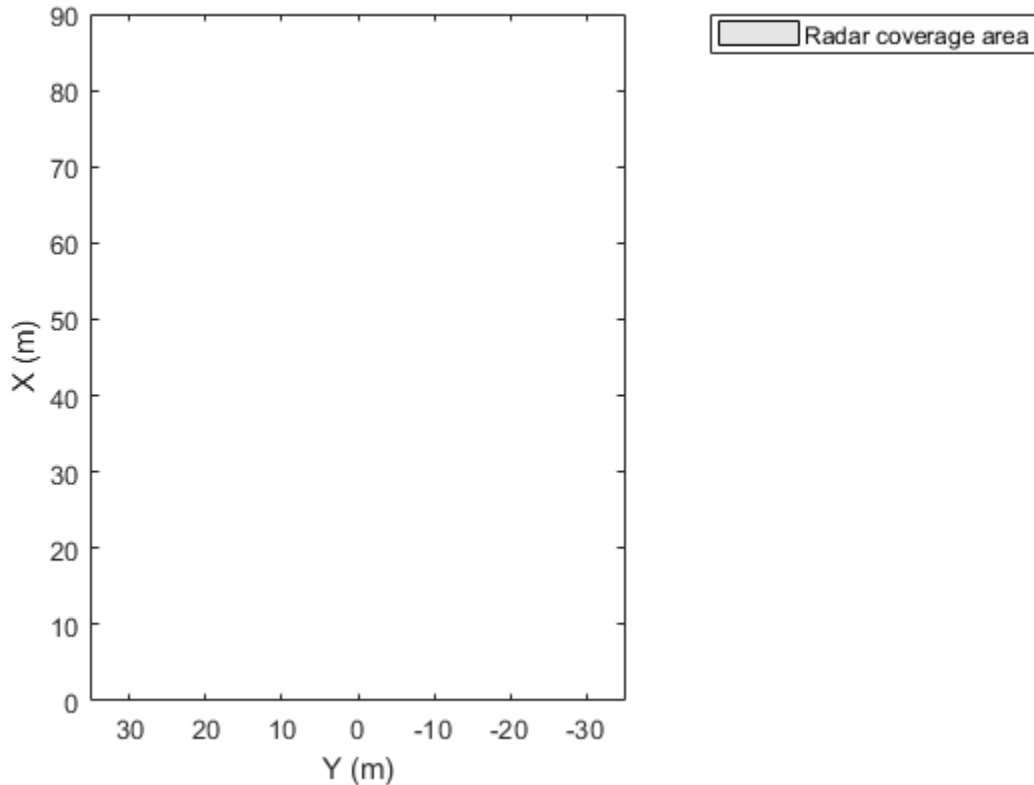
Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);
```



Create a coverage area plotter for the bird's-eye plot.

```
caPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Radar coverage area');
```

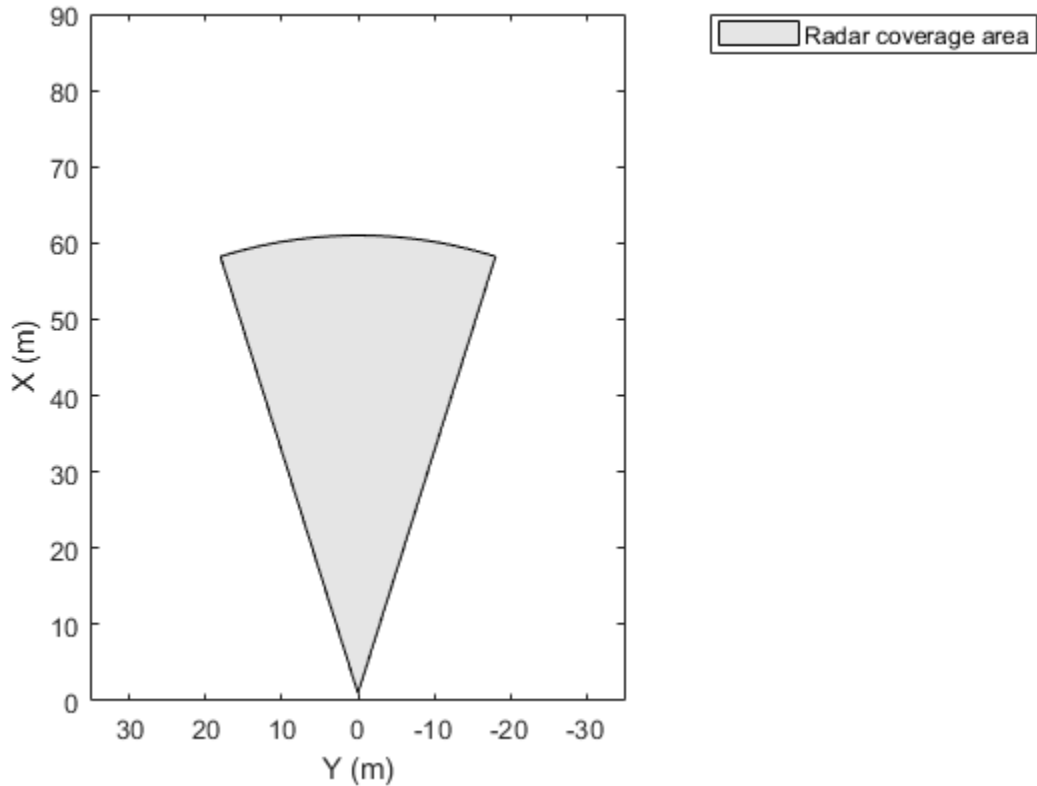


Display a coverage area that has a 35-degree field of view and a 60-meter range. Mount the coverage area sensor 1 meter in front of the origin. Set the orientation angle of the sensor to 0 degrees.

```
mountPosition = [1 0];  
range = 60;  
orientation = 0;  
fieldOfView = 35;
```

Plot the coverage area.

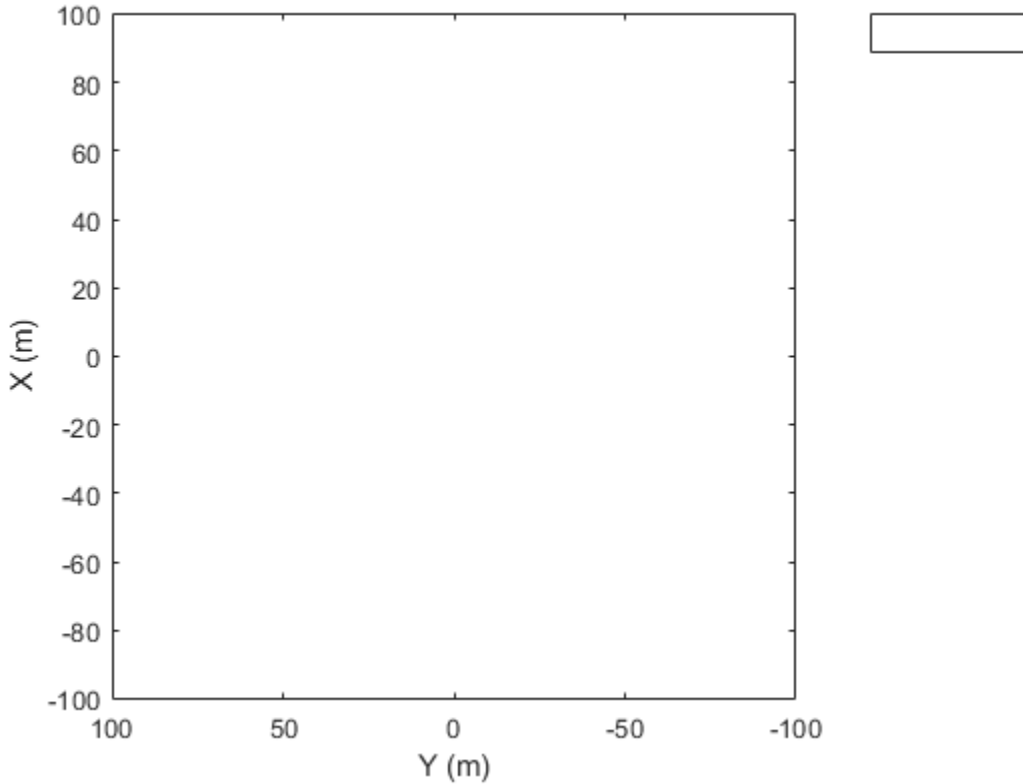
```
plotCoverageArea(caPlotter, mountPosition, range, orientation, fieldOfView);
```



Display Sensor Coverage Areas from Four Corners of Vehicle

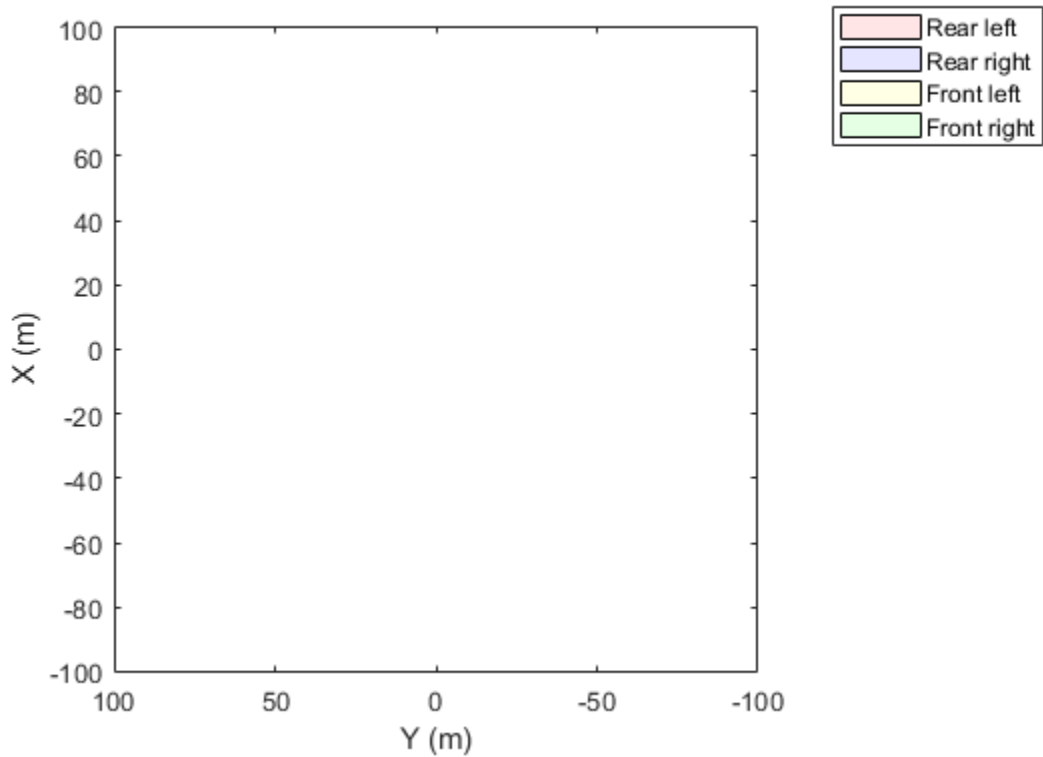
Create a bird's-eye plot with an x-axis range from -100 to 100 meters and a y-axis range from -100 to 100 meters

```
bep = birdsEyePlot('XLim',[-100 100], 'YLim',[-100 100]);
```



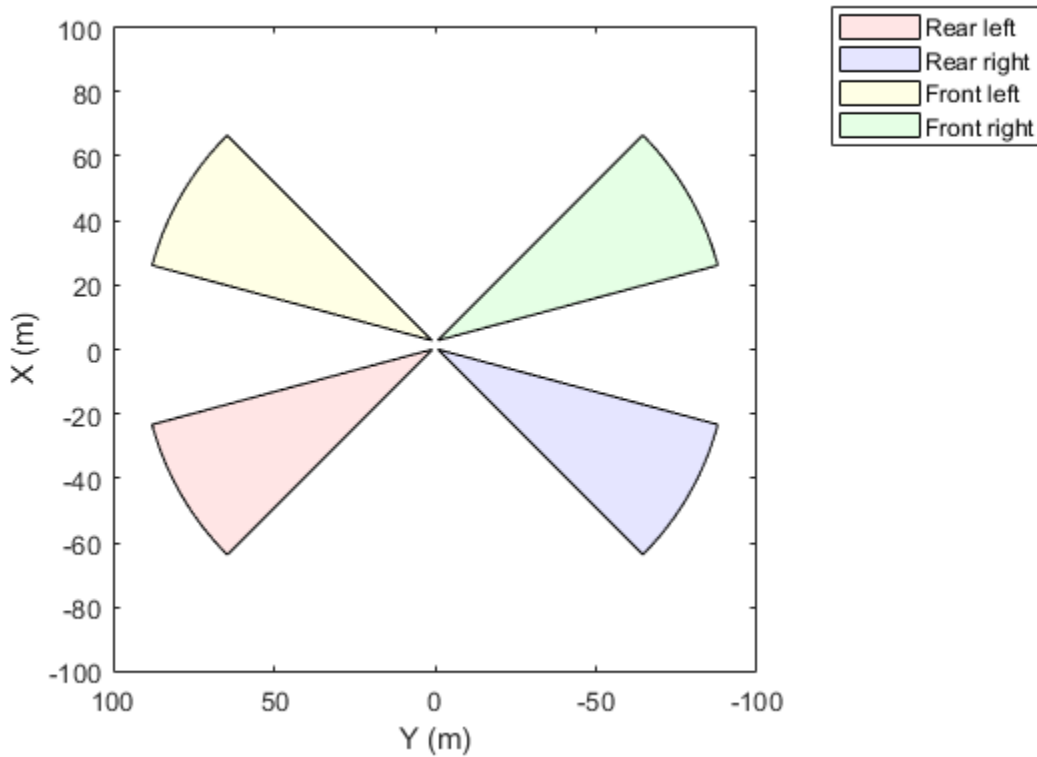
Create coverage area plotters with unique display names and fill colors for each sensor location on the vehicle.

```
rearLeftPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Rear left', 'FaceColor', 'r');  
rearRightPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Rear right', 'FaceColor', 'b');  
frontLeftPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Front left', 'FaceColor', 'y');  
frontRightPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Front right', 'FaceColor', 'g');
```



Set the positions, ranges, orientations, and fields of view for the sensors. The sensors have a maximum range of 90 meters and a field of view of 30 degrees. Plot the coverage areas.

```
plotCoverageArea(rearLeftPlotter, [0 0.9], 90, 120, 30);  
plotCoverageArea(rearRightPlotter, [0 -0.9], 90, -120, 30);  
plotCoverageArea(frontLeftPlotter, [2.8 0.9], 90, 60, 30);  
plotCoverageArea(frontRightPlotter, [2.8 -0.9], 90, -60, 30);
```



Input Arguments

caPlotter — Coverage area plotter

CoverageAreaPlotter object

Coverage area plotter, specified as a CoverageAreaPlotter object. This object is stored in the Plotters property of a birdsEyePlot object and configures the display of coverage areas in the bird's-eye plot. To create this object, use the coverageAreaPlotter function.

position — Position of sensor

real-valued vector of the form $[X_{\text{OriginOffset}} \ Y_{\text{OriginOffset}}]$

Position of the sensor in vehicle coordinates, specified as a real-valued vector of the form $[X_{\text{OriginOffset}} \ Y_{\text{OriginOffset}}]$. Units are in meters.

- $X_{\text{OriginOffset}}$ specifies the distance that the sensor is in front of the origin.
- $Y_{\text{OriginOffset}}$ specifies the distance that the sensor is to the left of the origin.

The origin is located at the center of the rear axle, as shown in this figure of the vehicle coordinate system.

**range — Range of sensor**

positive real scalar

Range of sensor, specified as a positive real scalar. Units are in meters.

orientation — Orientation angle of sensor

real scalar

Orientation angle of the sensor relative to the X -axis of the ego vehicle, specified as a real scalar. Units are in degrees. `orientation` is positive in the counterclockwise direction (to the left).

fieldOfView — Field of view of sensor

positive real scalar

Field of view of the sensor coverage area, specified as a positive real scalar. Units are in degrees.

See Also

`birdsEyePlot` | `coverageAreaPlotter`

Introduced in R2017a

plotDetection

Display object detections on bird's-eye plot

Syntax

```
plotDetection(detPlotter,positions)
plotDetection(detPlotter,positions,velocities)
plotDetection(detPlotter,positions,labels)
plotDetection(detPlotter,positions,velocities,labels)
```

Description

`plotDetection(detPlotter,positions)` displays object detections from a list of object positions on a bird's-eye plot. The detection plotter, `detPlotter`, is associated with a `birdsEyePlot` object and configures the display of the specified detections.

To remove all detections associated with detection plotter `detPlotter`, call the `clearData` function and specify `detPlotter` as the input argument.

`plotDetection(detPlotter,positions,velocities)` displays detections and their velocities on a bird's-eye plot.

`plotDetection(detPlotter,positions,labels)` displays detections and their labels on a bird's-eye plot.

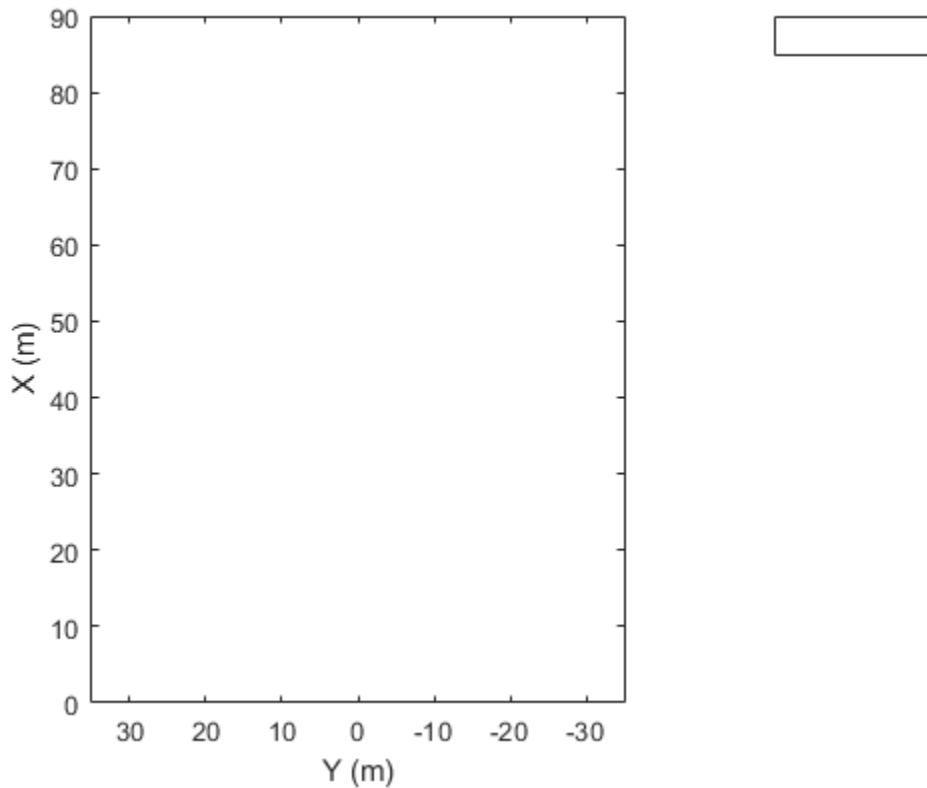
`plotDetection(detPlotter,positions,velocities,labels)` displays detections and their velocities and labels on a bird's-eye plot. `velocities` and `labels` can appear in either order but must come after `detPlotter` and `positions`.

Examples

Create and Display a Bird's-Eye Plot

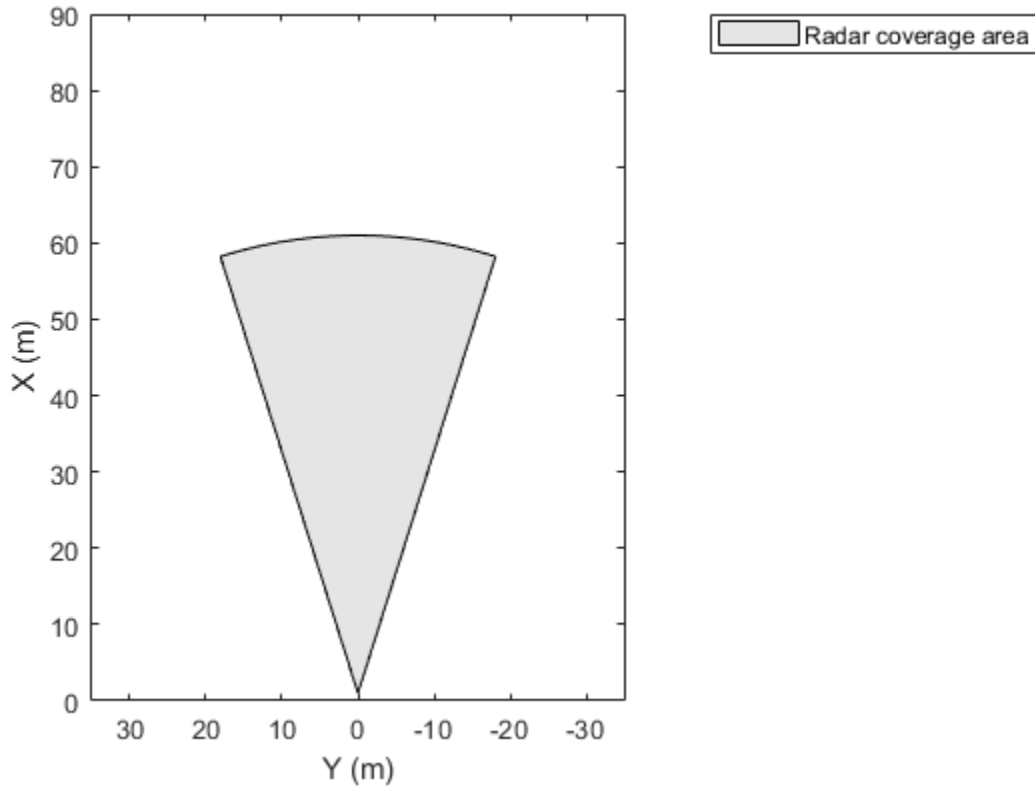
Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);
```



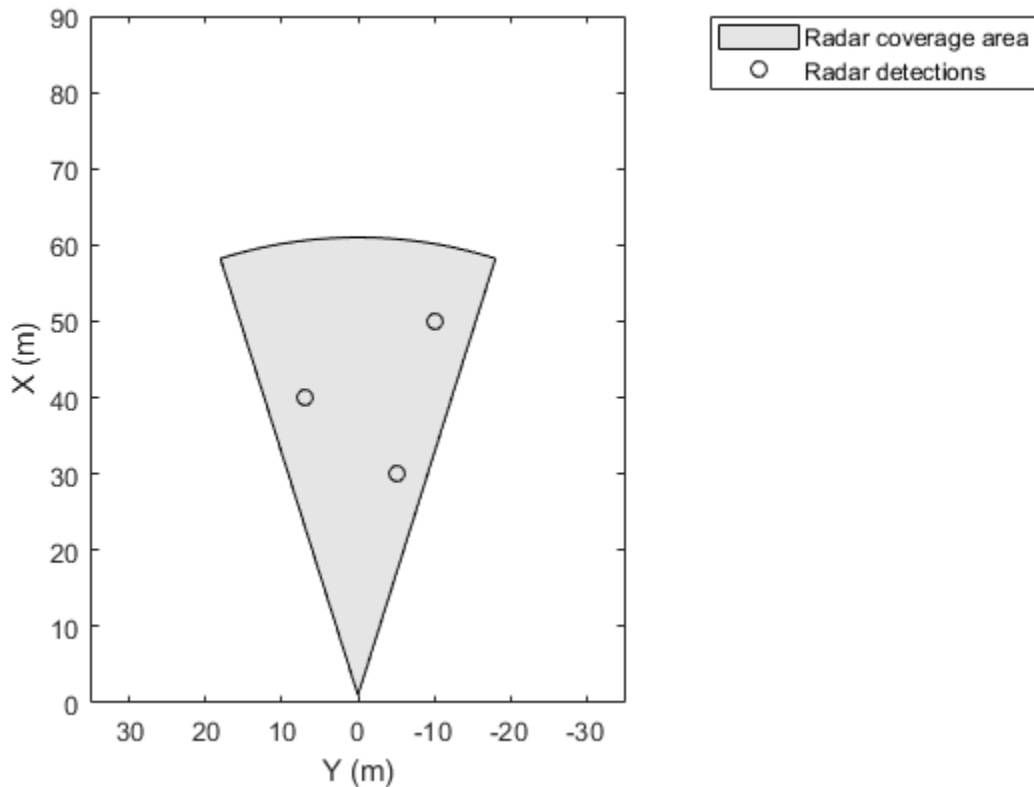
Display a coverage area with a 35-degree field of view and a 60-meter range.

```
caPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Radar coverage area');  
mountPosition = [1 0];  
range = 60;  
orientation = 0;  
fieldOfView = 35;  
plotCoverageArea(caPlotter, mountPosition, range, orientation, fieldOfView);
```



Display radar detections with coordinates at (30, -5), (50, -10), and (40, 7).

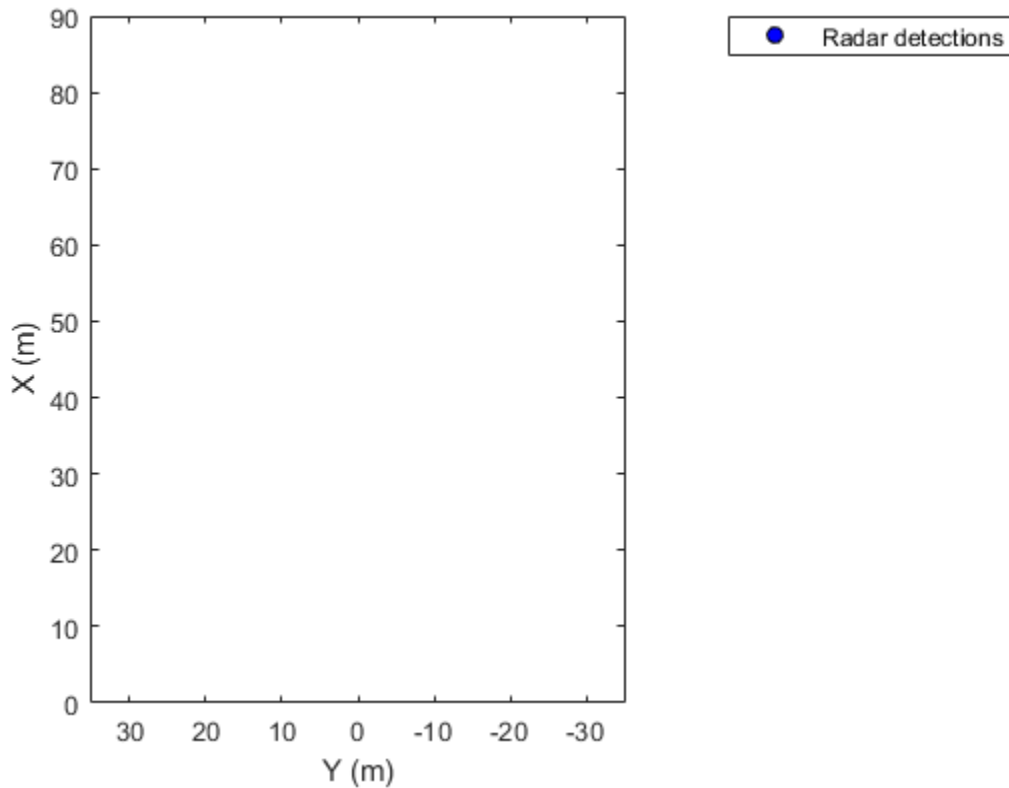
```
radarPlotter = detectionPlotter(bep, 'DisplayName', 'Radar detections');  
plotDetection(radarPlotter, [30 -5; 50 -10; 40 7]);
```



Create and Display Labeled Detections on Bird's-Eye Plot

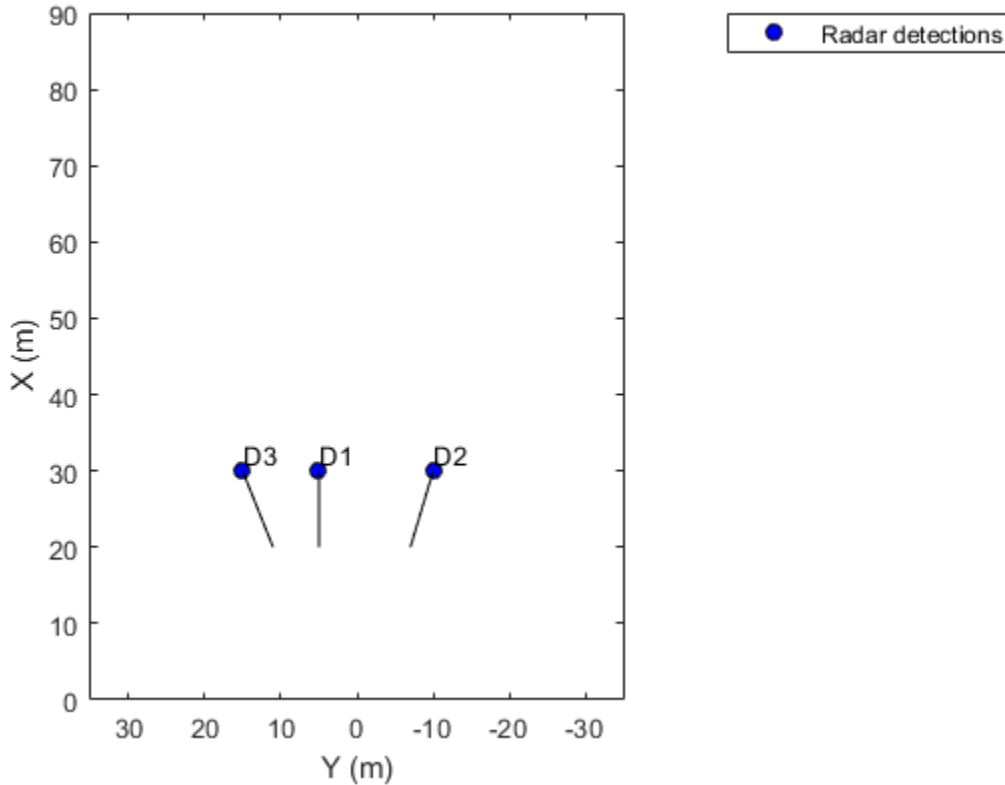
Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters. Create a radar detection plotter that displays detections in blue.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);  
detPlotter = detectionPlotter(bep,'DisplayName','Radar detections', ...  
    'MarkerFaceColor','b');
```



Display the positions and velocities of three labeled detections.

```
positions = [30 5; 30 -10; 30 15];  
velocities = [-10 0; -10 3; -10 -4];  
labels = {'D1', 'D2', 'D3'};  
plotDetection(detPlotter, positions, velocities, labels);
```



Input Arguments

detPlotter — Detection plotter

DetectionPlotter object

Detection plotter, specified as a `DetectionPlotter` object. This object is stored in the `Plotters` property of a `birdsEyePlot` object and configures the display of the specified detections in the bird's-eye plot. To create this object, use the `detectionPlotter` function.

positions — Positions of detected objects

M -by-2 real-valued matrix

Positions of detected objects in vehicle coordinates, specified as an M -by-2 real-valued matrix of (X, Y) positions. M is the number of detected objects. The positive X -direction points ahead of the center of the vehicle. The positive Y -direction points to the left of the origin of the vehicle, which is the center of the rear axle, as shown in this figure of the vehicle coordinate system.



velocities — Velocities of detected objects

M-by-2 real-valued matrix

Velocities of detected objects, specified as an *M*-by-2 real-valued matrix of velocities in the (*X*, *Y*) direction. *M* is the number of detected objects. The velocities are plotted as line vectors that originate from the center positions of the detections as they are tracked.

labels — Detection labels

M-length string array | *M*-length cell array of character vectors

Detection labels, specified as an *M*-length string array or *M*-length cell array of character vectors. *M* is the number of detected objects. The labels correspond to the locations in the `positions` matrix. By default, detections do not have labels. To remove all annotations and labels associated with the detection plotter, use the `clearData` function.

See Also

`birdsEyePlot` | `detectionPlotter`

Introduced in R2017a

plotLaneBoundary

Display lane boundaries on bird's-eye plot

Syntax

```
plotLaneBoundary(lbPlotter, boundaryCoords)  
plotLaneBoundary(lbPlotter, boundaries)
```

Description

`plotLaneBoundary(lbPlotter, boundaryCoords)` displays lane boundaries from a list of boundary coordinates on a bird's-eye plot. The lane boundary plotter, `lbPlotter`, is associated with a `birdsEyePlot` object and configures the display of the specified lane boundaries.

To remove all lane boundaries associated with lane boundary plotter `lbPlotter`, call the `clearData` function and specify `lbPlotter` as the input argument.

`plotLaneBoundary(lbPlotter, boundaries)` displays lane boundaries from a lane boundary object or an array of lane boundary objects, `boundaries`.

Examples

Create and Display Road Boundaries

Create a driving scenario containing a figure-8 road specified in the world coordinates of the scenario. Convert the world coordinates of the scenario to the coordinate system of the ego vehicle.

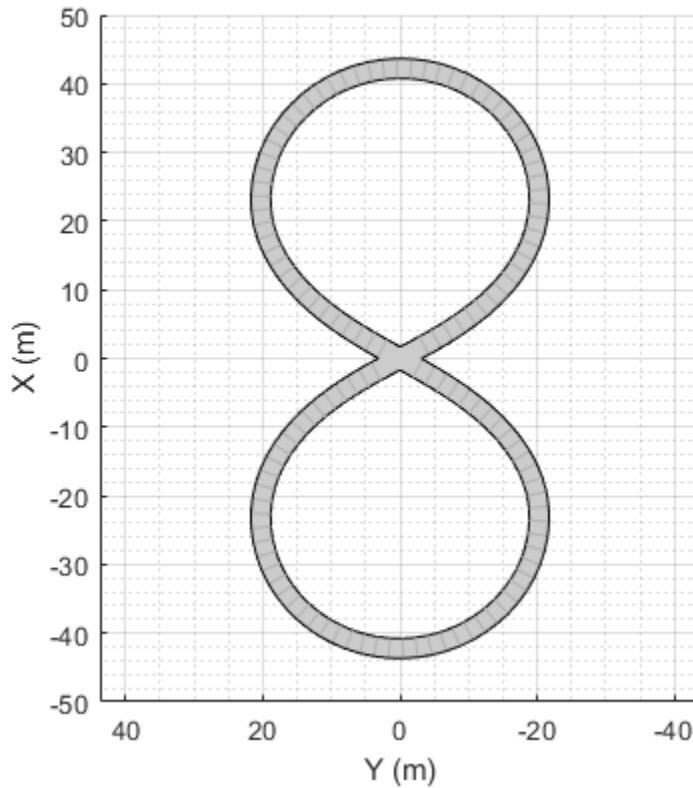
Create an empty driving scenario.

```
scenario = drivingScenario;
```

Add a figure-8 road to the scenario. Display the scenario.

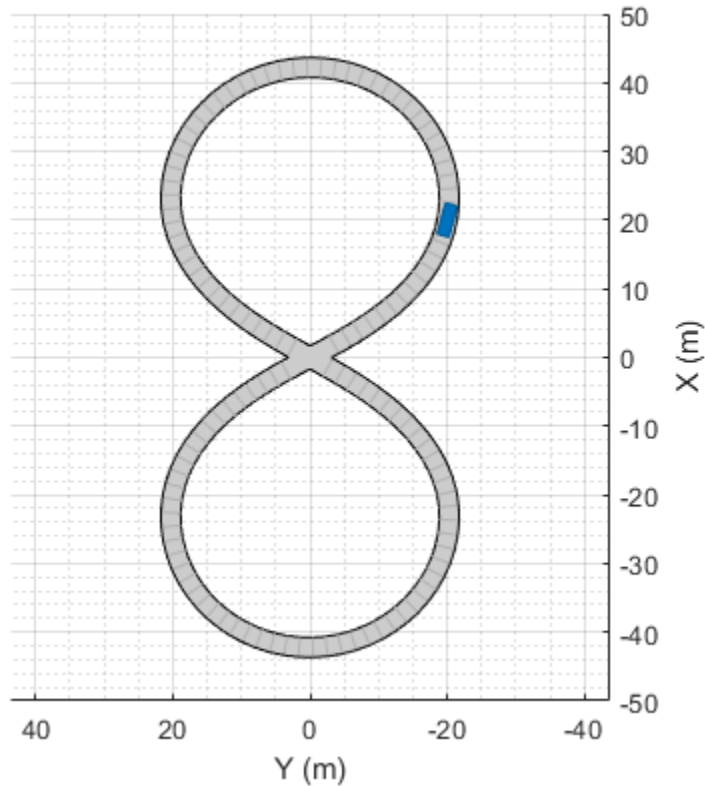
```
roadCenters = [0  0  1
               20 -20 1
               20  20 1
               -20 -20 1
               -20  20 1
               0  0  1];

roadWidth = 3;
bankAngle = [0 15 15 -15 -15 0];
road(scenario,roadCenters,roadWidth,bankAngle);
plot(scenario)
```



Add an ego vehicle to the scenario. Position the vehicle at world coordinates (20, -20) and orient it at a -15 degree yaw angle.

```
ego = actor(scenario, 'Position', [20 -20 0], 'Yaw', -15);
```

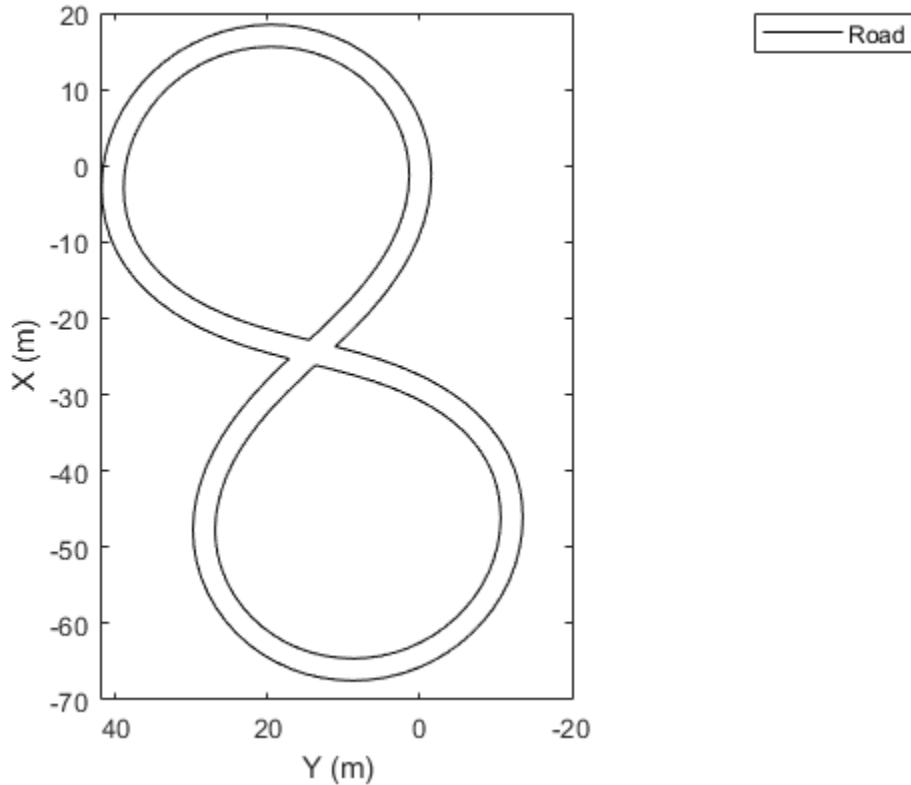


Obtain the road boundaries in ego vehicle coordinates by using the `roadBoundaries` function. Specify the ego vehicle as the input argument.

```
rbEgo1 = roadBoundaries(ego);
```

Display the result on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road');  
plotLaneBoundary(lbp, rbEgo1)
```



Obtain the road boundaries in world coordinates by using the `roadBoundaries` function. Specify the scenario as the input argument.

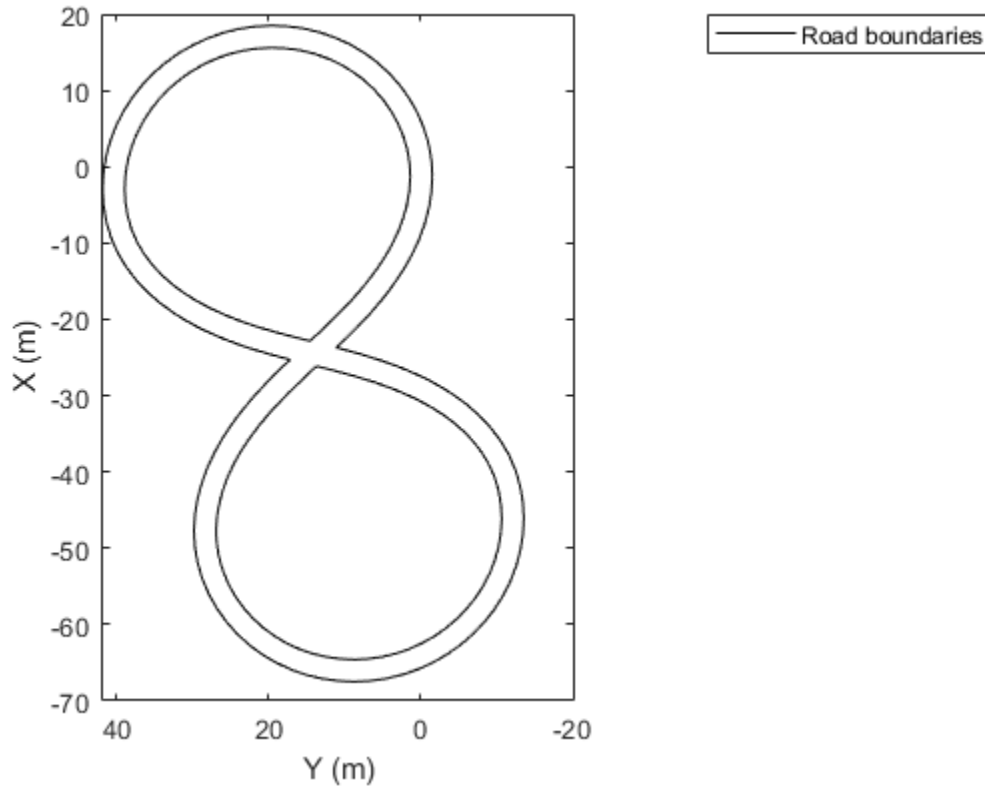
```
rbScenario = roadBoundaries(scenario);
```

Obtain the road boundaries in ego vehicle coordinates by using the `driving.scenario.roadBoundariesToEgo` function.

```
rbEgo2 = driving.scenario.roadBoundariesToEgo(rbScenario,ego);
```

Display the road boundaries on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road boundaries');  
plotLaneBoundary(lbp, {rbEgo2})
```



Input Arguments

lbPlotter — Lane boundary plotter

LaneBoundaryPlotter object

Lane boundary plotter, specified as a LaneBoundaryPlotter object. This object is stored in the `Plotters` property of a `birdsEyePlot` object and configures the display of the specified lane boundaries in the bird's-eye plot. To create this object, use the `laneBoundaryPlotter` function.

boundaryCoords — Lane boundary coordinates

cell array of M -by-2 real-valued matrices

Lane boundary coordinates, specified as a cell array of M -by-2 real-valued matrices. Each matrix represents the coordinates for a different lane boundary. M is the number of coordinates in a lane boundary and can be different for each lane boundary. Each row represents the (X, Y) positions of a curve. The positive X -direction points ahead of the center of the vehicle. The positive Y -direction points to the left of the origin of the vehicle, which is the center of the rear axle, as shown in this figure of the vehicle coordinate system.



boundaries – Lane boundaries

lane boundary object | array of lane boundary objects

Lane boundaries, specified as a lane boundary object or an array of lane boundary objects. Valid lane boundary objects are `parabolicLaneBoundary`, `cubicLaneBoundary`, and `clothoidLaneBoundary`. If you specify an array of lane boundary objects, all objects must be of the same type. Z-data, which represents height, is ignored.

See Also

`birdsEyePlot` | `laneBoundaryPlotter`

Introduced in R2017a

plotLaneMarking

Display lane markings on bird's-eye plot

Syntax

```
plotLaneMarking(lmPlotter, lmv, lmf)
```

Description

`plotLaneMarking(lmPlotter, lmv, lmf)` displays lane marking vertices, `lmv`, and lane marking faces, `lmf`, on a bird's-eye plot. The lane marking plotter, `lmPlotter`, is associated with a `birdsEyePlot` object and configures the display of the specified lane markings.

To remove all lane markings associated with the lane marking plotter `lmPlotter`, call the `clearData` function and specify `lmPlotter` as the input argument.

Examples

Display Lane Markings in Car and Pedestrian Scenario

Create a driving scenario containing a car and pedestrian on a straight road. Then, create and display the lane markings of the road on a bird's-eye plot.

Create an empty driving scenario.

```
scenario = drivingScenario;
```

Create a straight, 25-meter road segment with two travel lanes in one direction.

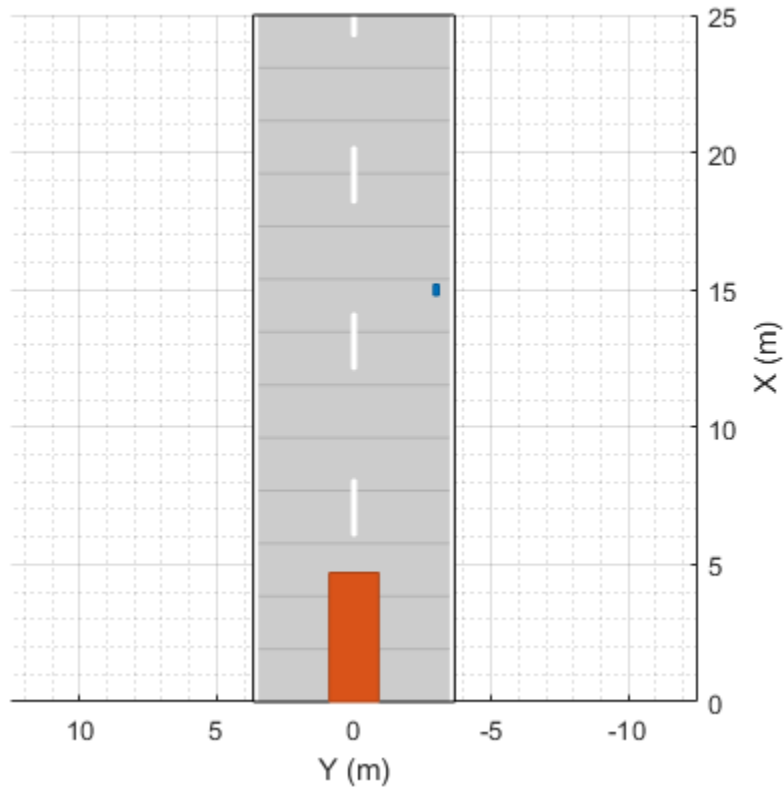
```
lm = [laneMarking('Solid')  
      laneMarking('Dashed', 'Length', 2, 'Space', 4)  
      laneMarking('Solid')];  
l = lanespec(2, 'Marking', lm);  
road(scenario, [0 0 0; 25 0 0], 'Lanes', l);
```

Add to the driving scenario a pedestrian crossing the road at 1 meter per second and a car following the road at 10 meters per second.

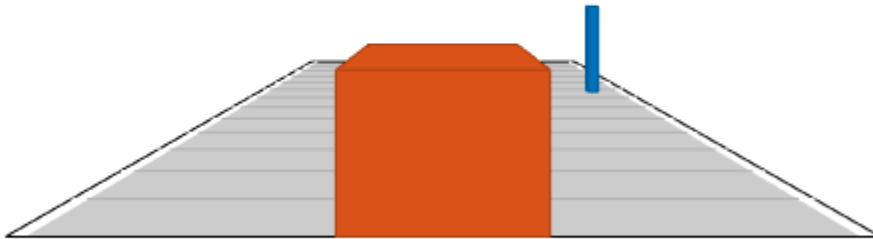
```
ped = actor(scenario, 'Length',0.2, 'Width',0.4, 'Height',1.7);  
car = vehicle(scenario);  
trajectory(ped,[15 -3 0; 15 3 0],1);  
trajectory(car,[car.RearOverhang 0 0; 25-car.Length+car.RearOverhang 0 0],10);
```

Display the scenario and corresponding chase plot.

```
plot(scenario)
```



```
chasePlot(car)
```

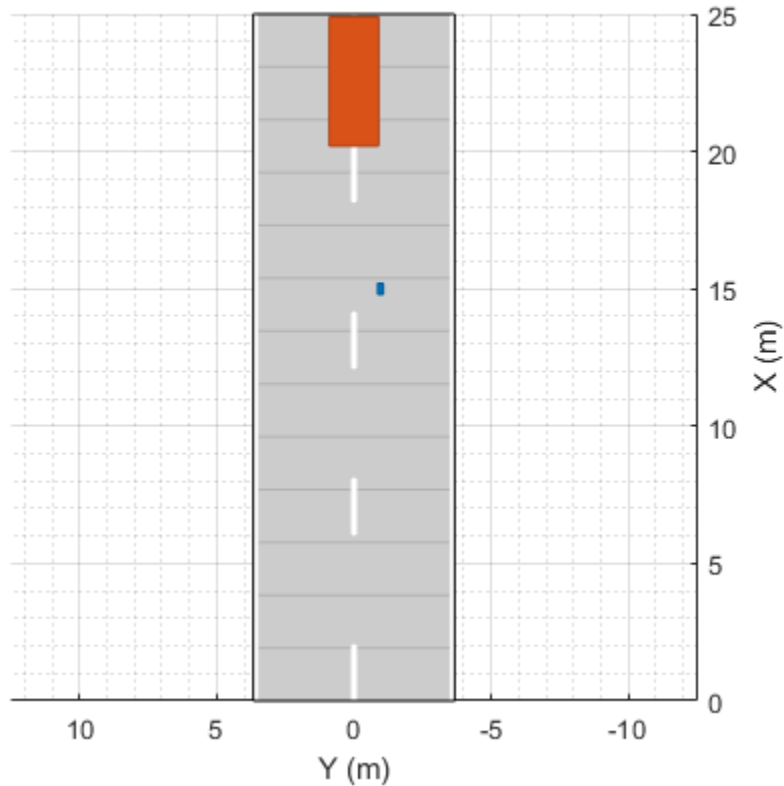


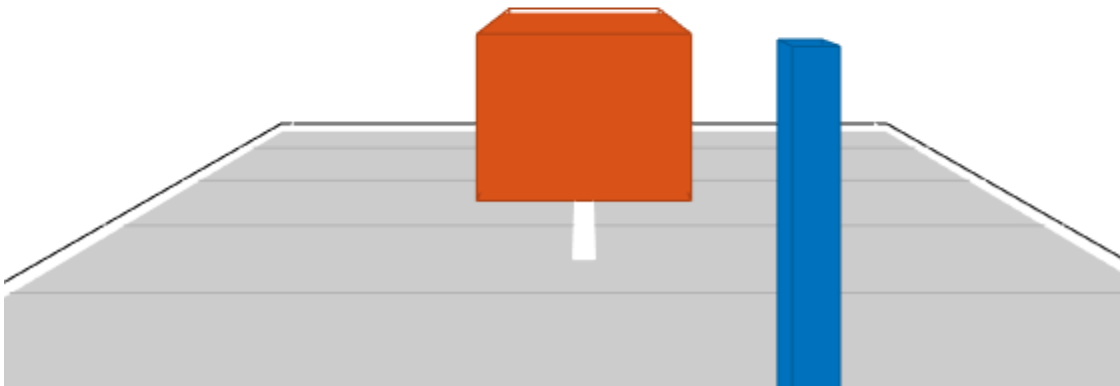
Run the simulation.

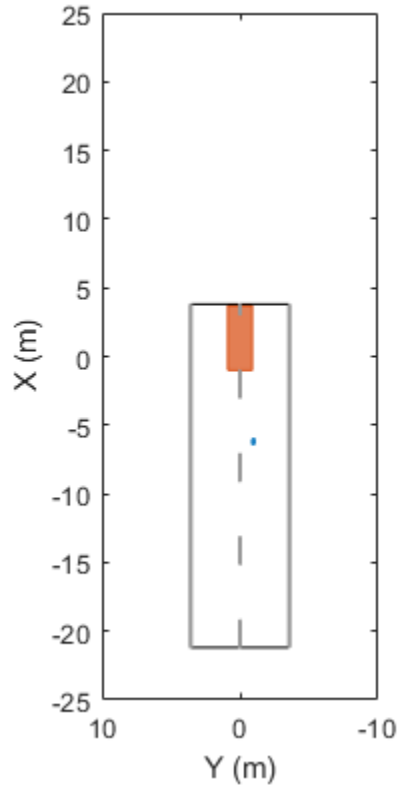
- 1 Create a bird's-eye plot.
- 2 Create an outline plotter, lane boundary plotter, and lane marking plotter for the bird's-eye plot.
- 3 Obtain the road boundaries and target outlines.
- 4 Obtain the lane marking vertices and faces.
- 5 Display the lane boundaries and lane markers.
- 6 Run the simulation loop.

```
bep = birdsEyePlot('XLim',[-25 25], 'YLim',[-10 10]);  
olPlotter = outlinePlotter(bep);
```

```
lbPlotter = laneBoundaryPlotter(bep);  
lmPlotter = laneMarkingPlotter(bep, 'DisplayName', 'Lanes');  
legend('off');  
while advance(scenario)  
    rb = roadBoundaries(car);  
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);  
    [lmv,lmf] = laneMarkingVertices(car);  
    plotLaneBoundary(lbPlotter,rb);  
    plotLaneMarking(lmPlotter,lmv,lmf);  
    plotOutline(olPlotter,position,yaw,length,width, ...  
        'OriginOffset',originOffset,'Color',color);  
end
```







Input Arguments

lmPlotter – Lane marking plotter

LaneMarkingPlotter object

Lane marking plotter, specified as a LaneMarkingPlotter object. This object is stored in the `Plotters` property of a `birdsEyePlot` object and configures the display of the specified lane markings in the bird's-eye plot. To create this object, use the `laneMarkingPlotter` function.

lmv – Lane marking vertices

L -by-3 real-valued matrix

Lane marking vertices, specified as an L -by-3 real-valued matrix. Each row of `lmv` represents the x , y , and z coordinates of one vertex. The plotter uses only the x and y coordinates. To obtain lane marking vertices and faces from a driving scenario, use the `laneMarkingVertices` function.

lmf — Lane marking faces

real-valued matrix

Lane marking faces, specified as a real-valued matrix. Each row of `lmf` is a face that defines the connection between vertices for one lane marking. To obtain lane marking vertices and faces from a driving scenario, use the `laneMarkingVertices` function.

See Also

`birdsEyePlot` | `laneMarkingPlotter` | `laneMarkingVertices`

Introduced in R2018a

plotOutline

Display object outlines on bird's-eye plot

Syntax

```
plotOutline(olPlotter,positions,yaw,length,width)  
plotOutline( ____,Name,Value)
```

Description

`plotOutline(olPlotter,positions,yaw,length,width)` displays the rectangular outlines of cuboid objects on a bird's-eye plot. Specify the position, yaw angle of rotation, length, and width of each cuboid. The outline plotter, `olPlotter`, is associated with a `birdsEyePlot` object and configures the display of the specified outlines.

To remove all outlines associated with outline plotter `olPlotter`, call the `clearData` function and specify `olPlotter` as the input argument.

To display the outlines of actors that are in a driving scenario, first use `targetOutlines` to get the dimensions of the actors. Then, after calling `outlinePlotter` to create a plotter object, use the `plotOutline` function to display the outlines of all the actors in a bird's-eye plot.

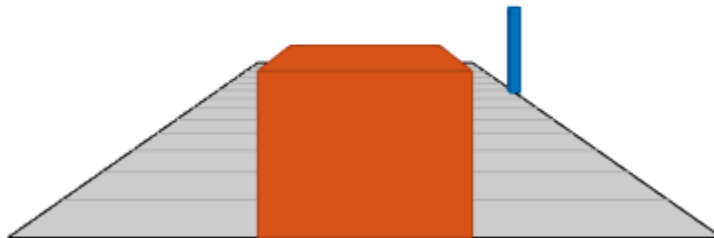
`plotOutline(____,Name,Value)` specifies options using one or more `Name,Value` pair arguments and the input arguments from the previous syntax.

Examples

Plot Outlines of Targets on Bird's-Eye Plot

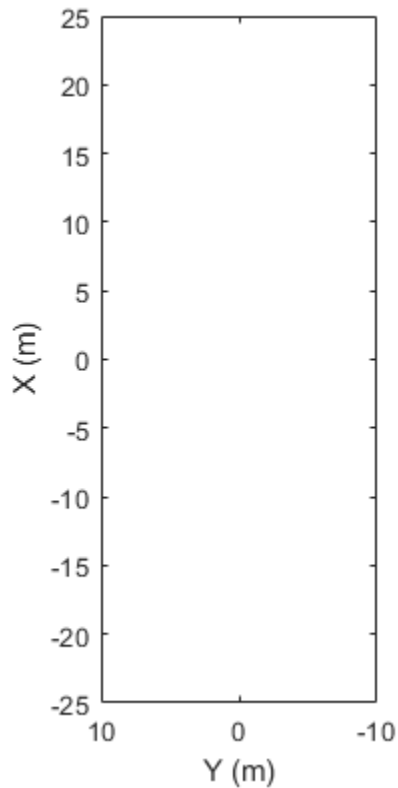
Create a driving scenario. Create a 25 m road segment, add a pedestrian and a vehicle, and specify their trajectories to follow. The pedestrian crosses the road at 1 m/s. The vehicle drives along the road at 10 m/s.

```
scenario = drivingScenario;  
road(scenario,[0 0 0; 25 0 0]);  
p = actor(scenario,'Length',0.2,'Width',0.4,'Height',1.7);  
v = vehicle(scenario);  
trajectory(p,[15 -3 0; 15 3 0],1);  
trajectory(v,[v.RearOverhang 0 0; 25-v.Length+v.RearOverhang 0 0], 10);  
Use a chase plot to display the scenario from the perspective of the vehicle.  
chasePlot(v,'Centerline','on')
```



Create a bird's-eye plot, outline plotter, and lane boundary plotter.

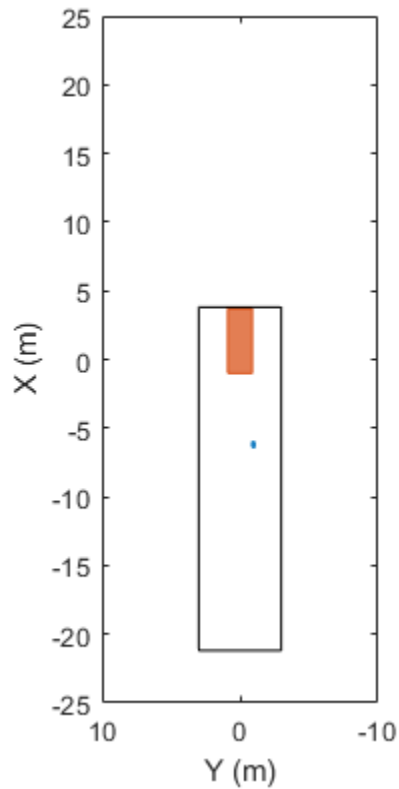
```
bep = birdsEyePlot('XLim',[-25 25], 'YLim',[-10 10]);  
olPlotter = outlinePlotter(bep);  
lbPlotter = laneBoundaryPlotter(bep);  
legend('off')
```

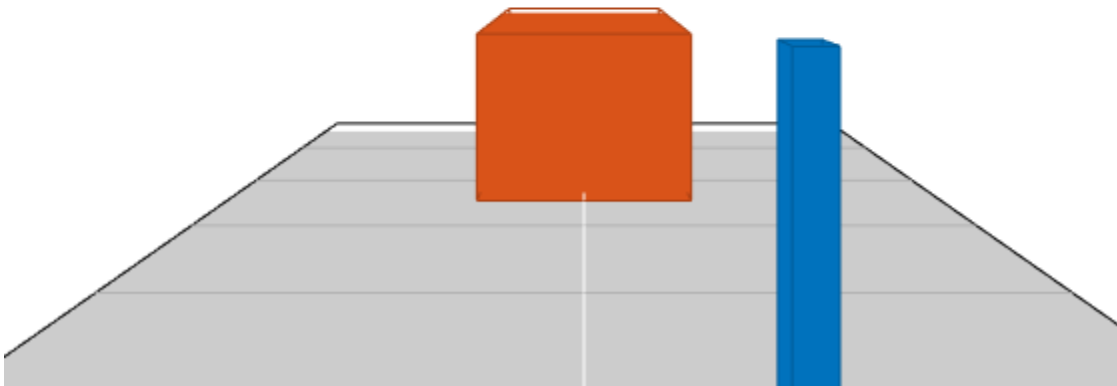


Run the simulation loop. Update the plotter with outlines for the targets.

```
while advance(scenario)  
    % Obtain the road boundaries and rectangular outlines.  
    rb = roadBoundaries(v);  
    [position,yaw,length,width,originOffset,color] = targetOutlines(v);
```

```
% Update the bird's-eye plotters with the road and actors.  
plotLaneBoundary(lbPlotter,rb);  
plotOutline(olPlotter,position,yaw,length,width, ...  
            'OriginOffset',originOffset,'Color',color);  
  
% Allow time for plot to update.  
pause(0.01)  
end
```





Input Arguments

olPlotter — Outline plotter

OutlinePlotter object

Outline plotter, specified as an `OutlinePlotter` object. This object is stored in the `Plotters` property of a `birdsEyePlot` object and configures the display of the specified outlines in the bird's-eye plot. To create this object, use the `outlinePlotter` function.

positions — Positions of detected objects

M -by-2 real-valued matrix

Positions of detected objects in vehicle coordinates, specified as an M -by-2 real-valued matrix of (X, Y) positions. M is the number of detected objects. The positive X -direction points ahead of the center of the vehicle. The positive Y -direction points to the left of the origin of the vehicle, which is the center of the rear axle, as shown in this figure of the vehicle coordinate system.



yaw — Angles of rotation

M -element real-valued vector

Angles of rotation for object outlines, specified as an M -element real-valued vector, where M is the number of objects.

Length — Lengths of outlines

M -element real-valued vector

Lengths of object outlines, specified as an M -element real-valued vector, where M is the number of objects.

width — Widths of outlines

M -element real-valued vector

Widths of object outlines, specified as an M -element real-valued vector, where M is the number of objects.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'Marker', 'x'`

OriginOffset — Rotational centers of rectangles relative to origin

M -by-2 real-valued matrix

Rotational centers of rectangles relative to origin, specified as the comma-separated pair consisting of `'OriginOffset'` and an M -by-2 real-valued matrix. M is the number of objects. Each row corresponds to the rotational center about which to rotate the corresponding rectangle, specified as an (X,Y) displacement from the geometrical center of that rectangle.

Color — Outline color

M -by-3 matrix of RGB triplets

Outline color, specified as the comma-separated pair consisting of `'Color'` and an M -by-3 matrix of RGB triplets. M is the number of objects. If you do not specify this argument, the function uses the default colormap for each object.

Example: `'Color',[0 0.5 0.75; 0.8 0.3 0.1]`

See Also

`birdsEyePlot` | `outlinePlotter`

Introduced in R2017b

plotPath

Display actor paths on bird's-eye plot

Syntax

```
plotPath(pPlotter,pathCoords)
```

Description

`plotPath(pPlotter,pathCoords)` displays the paths of actors from a list of path coordinates on a bird's-eye plot. The path plotter object, `pPlotter`, is associated with a `birdsEyePlot` object and configures the display of the specified path.

To remove all paths associated with the path plotter `pPlotter`, call the `clearData` function and specify `pPlotter` as the input argument.

Examples

Plot Path of Ego Vehicle

Create a 3-meter-wide lane.

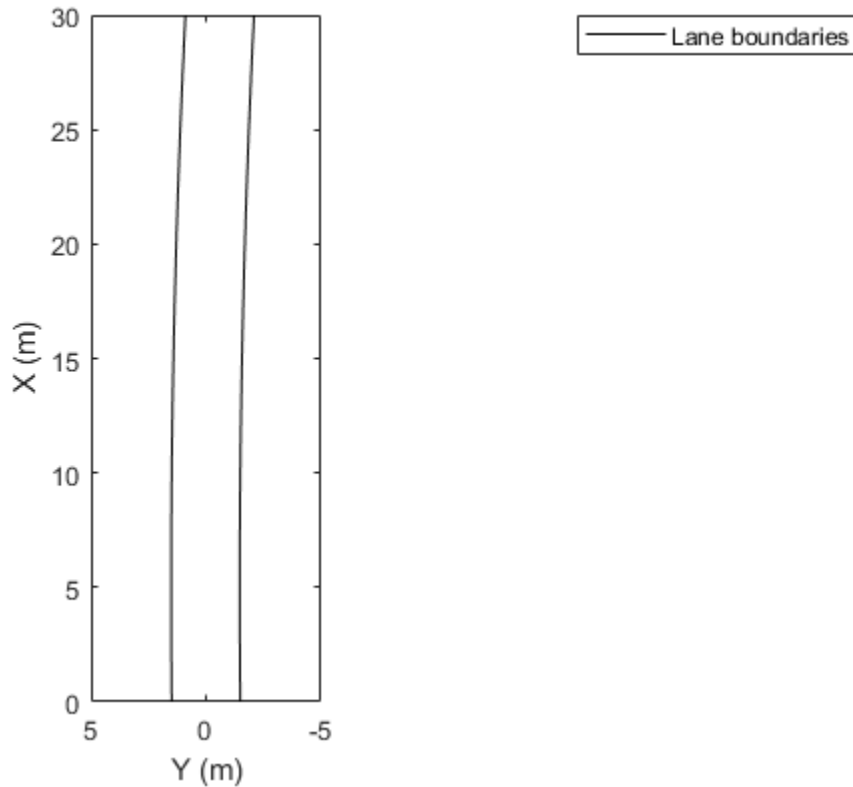
```
lb = parabolicLaneBoundary([-0.001,0.01,1.5]);  
rb = parabolicLaneBoundary([-0.001,0.01,-1.5]);
```

Compute the lane boundary model manually from 0 to 30 meters along the x-axis.

```
xWorld = (0:30)';  
yLeft = computeBoundaryModel(lb,xWorld);  
yRight = computeBoundaryModel(rb,xWorld);
```

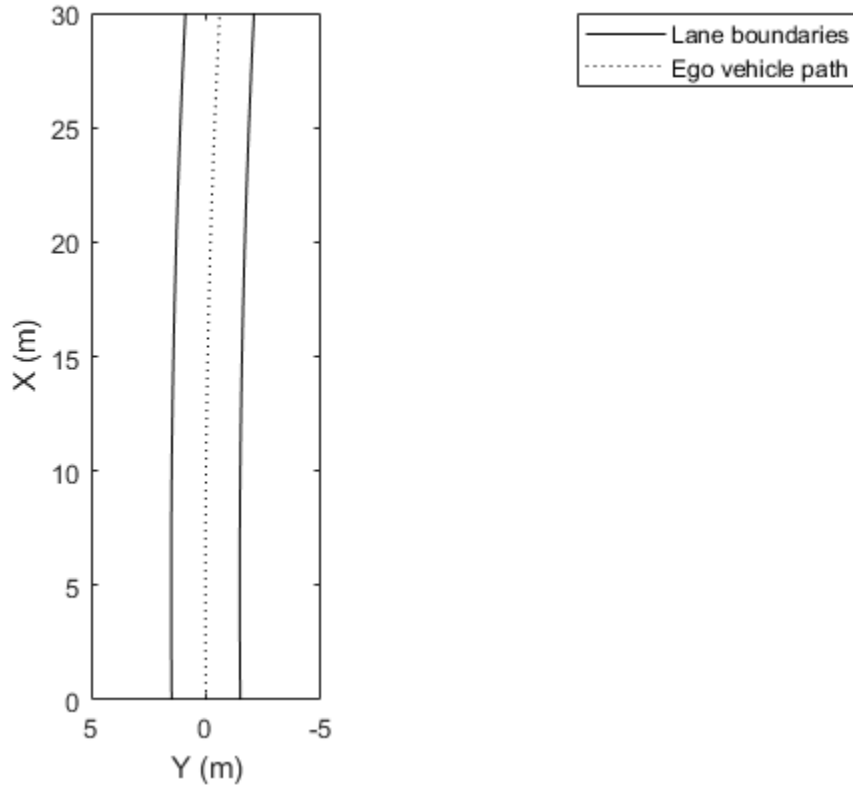
Create a bird's-eye plot and lane boundary plotter. Display the lane information on the bird's-eye plot.

```
bep = birdsEyePlot('XLimits',[0 30],'YLimits',[-5 5]);  
lanePlotter = laneBoundaryPlotter(bep,'DisplayName','Lane boundaries');  
plotLaneBoundary(lanePlotter,{[xWorld,yLeft],[xWorld,yRight]});
```



Create a path plotter. Create and display the path of an ego vehicle that travels through the center of the lane.

```
yCenter = (yLeft + yRight)/2;  
egoPathPlotter = pathPlotter(bep,'DisplayName','Ego vehicle path');  
plotPath(egoPathPlotter,{[xWorld,yCenter]});
```



Input Arguments

pPlotter — Path plotter

PathPlotter object

Path plotter, specified as a `PathPlotter` object. This object is stored in the `Plotters` property of a `birdsEyePlot` object and configures the display of the specified actor paths in the bird's-eye plot. To create this object, use the `pathPlotter` function.

pathCoords — Path coordinates

cell array of M -by-2 real-valued matrices

Path coordinates, specified as a cell array of M -by-2 real-valued matrices. Each matrix represents the coordinates for a different path. M is the number of coordinates in a path and can be different for each path. The first and second columns of each matrix represent the (X, Y) positions of the path curve. The positive X -direction points ahead of the center of the vehicle. The positive Y -direction points to the left of the origin of the vehicle, which is the center of the rear axle, as shown in this figure of the vehicle coordinate system..



Path coordinates are relative to the ego vehicle.

See Also

`birdsEyePlot` | `pathPlotter`

Introduced in R2017a

plotTrack

Display object tracks on bird's-eye plot

Syntax

```
plotTrack(tPlotter, positions)
plotTrack(tPlotter, positions, velocities)
plotTrack(tPlotter, positions, labels)
plotTrack(tPlotter, positions, covariances)
plotTrack(tPlotter, positions, velocities, labels, covariances)
```

Description

`plotTrack(tPlotter, positions)` displays object tracks from a list of object positions on a bird's-eye plot. The track plotter, `tPlotter`, is associated with a `birdsEyePlot` object and configures the display of the object tracks.

To remove all tracks associated with track plotter `tPlotter`, call the `clearData` function and specify `tPlotter` as the input argument.

`plotTrack(tPlotter, positions, velocities)` displays tracks and their velocities on a bird's-eye plot.

`plotTrack(tPlotter, positions, labels)` displays tracks and their labels on a bird's-eye plot.

`plotTrack(tPlotter, positions, covariances)` displays tracks and the covariances of track uncertainties on a bird's-eye plot.

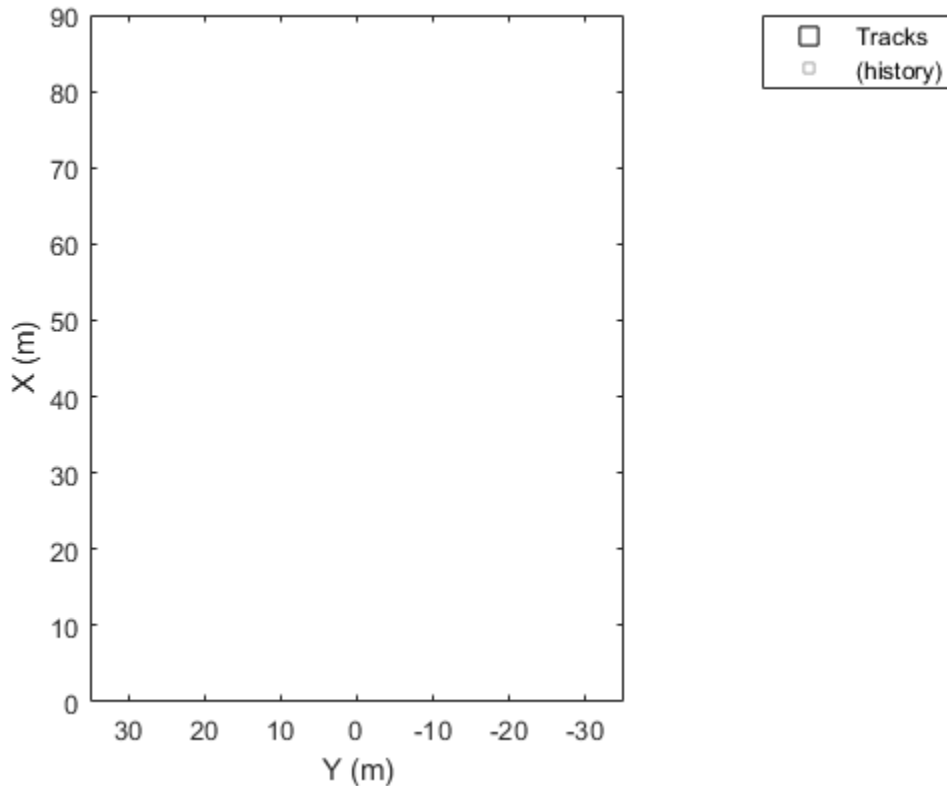
`plotTrack(tPlotter, positions, velocities, labels, covariances)` displays tracks and their velocities, labels, and covariances on a bird's-eye plot. You can specify one or more of `velocities`, `labels`, and `covariances`. These arguments can appear in any order but they must come after `tPlotter` and `positions`.

Examples

Create and Display Labeled Tracks on Bird's-Eye Plot

Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters. Create a track plotter that displays up to seven history values for each track and offsets labels by 3 meters in front of the tracks.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);  
tPlotter = trackPlotter(bep,'DisplayName','Tracks','HistoryDepth',7,'LabelOffset',[3 0]);
```

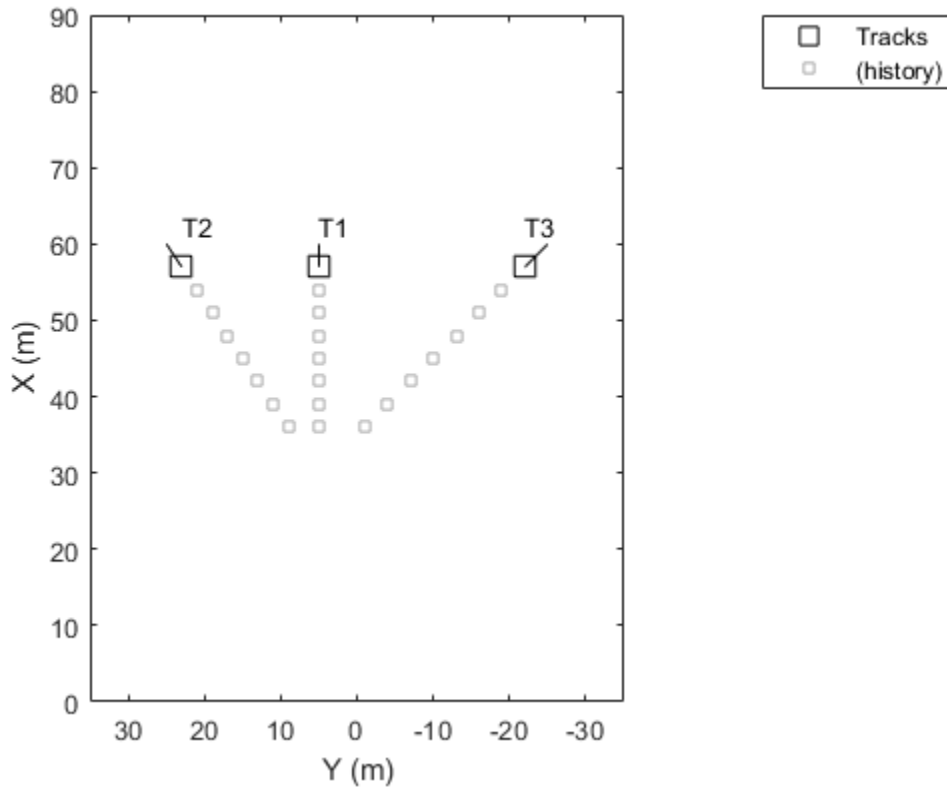


Set the positions and velocities of three labeled tracks.


```
positions = [30, 5; 30, 5; 30, 5];  
velocities = [3, 0; 3, 2; 3, -3];  
labels = {'T1', 'T2', 'T3'};
```

Display the tracks for 10 trials. The bird's-eye plot shows the seven history values specified previously.

```
for i=1:10  
    plotTrack(tPlotter,positions,velocities,labels);  
    positions = positions + velocities;  
end
```



Input Arguments

tPlotter — Track plotter

TrackPlotter object

Track plotter, specified as a `TrackPlotter` object. This object is stored in the `Plotters` property of a `birdsEyePlot` object and configures the display of the specified tracks in the bird's-eye plot. To create this object, use the `trackPlotter` function.

positions — Positions of tracked objects

M -by-2 real-valued matrix

Positions of tracked objects in vehicle coordinates, specified as an M -by-2 real-valued matrix of (X, Y) positions. M is the number of tracked objects. The positive X -direction points ahead of the center of the vehicle. The positive y -direction points to the left of the origin of the vehicle, which is the center of the rear axle, as shown in this figure of the vehicle coordinate system.

**velocities – Velocities of tracked objects**

M-by-2 real-valued matrix

Velocities of tracked objects, specified as an *M*-by-2 real-valued matrix of velocities in the (*X*, *Y*) direction. *M* is the number of tracked objects. The velocities are plotted as line vectors that originate from the center positions of the tracked objects.

labels – Track labels

M-length string array | *M*-length cell array of character vectors

Track labels, specified as an M -length string array or an M -length cell array of character vectors. M is the number of tracked objects. The labels correspond to the locations in the `positions` matrix. By default, tracks do not have labels. To remove all annotations and labels associated with the track plotter, use the `clearData` function.

covariances — Covariances of track uncertainties

2-by-2-by- M real-valued array

Covariances of track uncertainties centered at the track positions, specified as a 2-by-2-by- M real-valued array. The uncertainties are plotted as an ellipse.

See Also

`birdsEyePlot` | `trackPlotter`

Introduced in R2017a

trackPlotter

Package:

Track plotter for bird's-eye plot

Syntax

```
tPlotter = trackPlotter(bep)
tPlotter = trackPlotter(bep,Name,Value)
```

Description

`tPlotter = trackPlotter(bep)` creates a `TrackPlotter` object that configures the display of tracks on a bird's-eye plot. The `TrackPlotter` object is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To display the tracks, use the `plotTrack` function.

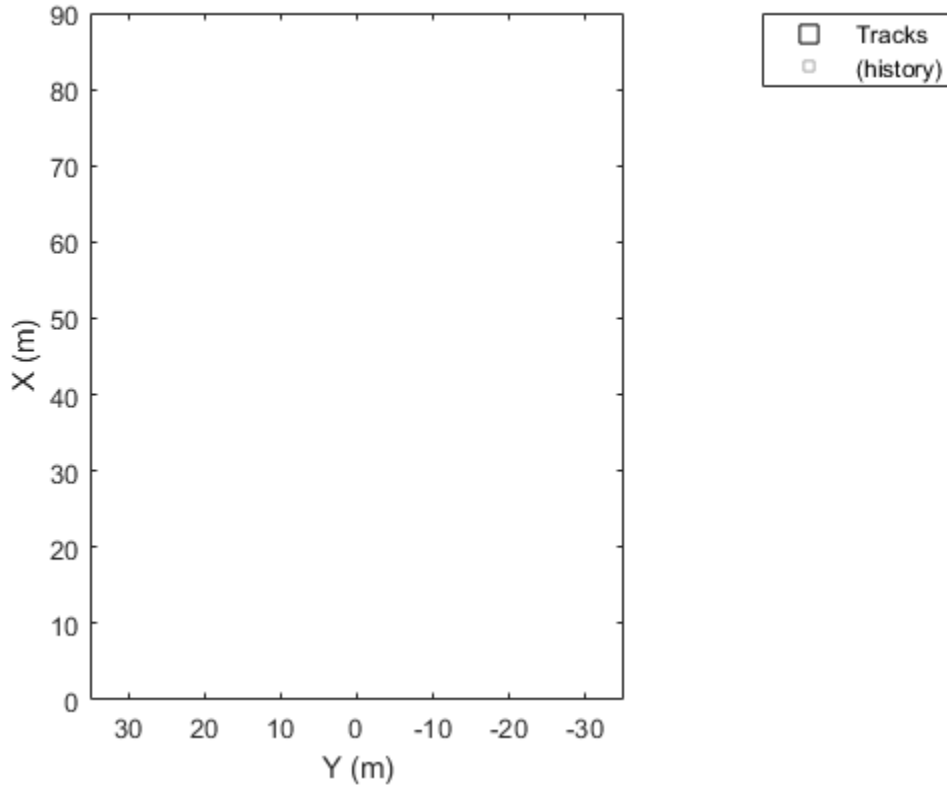
`tPlotter = trackPlotter(bep,Name,Value)` sets properties using one or more `Name,Value` pair arguments. For example, `trackPlotter(bep,'DisplayName','Tracks')` sets the display name that appears in the bird's-eye-plot legend.

Examples

Create and Display Labeled Tracks on Bird's-Eye Plot

Create a bird's-eye plot with an x-axis range from 0 to 90 meters and a y-axis range from -35 to 35 meters. Create a track plotter that displays up to seven history values for each track and offsets labels by 3 meters in front of the tracks.

```
bep = birdsEyePlot('XLim',[0 90],'YLim',[-35 35]);
tPlotter = trackPlotter(bep,'DisplayName','Tracks','HistoryDepth',7,'LabelOffset',[3 0]);
```

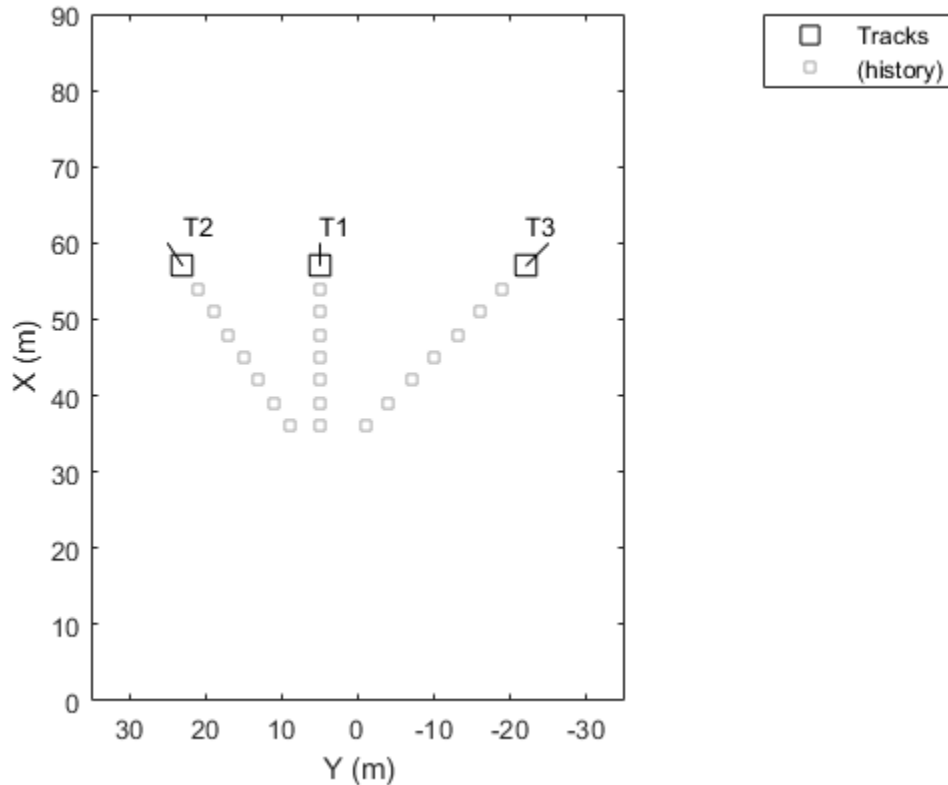


Set the positions and velocities of three labeled tracks.

```
positions = [30, 5; 30, 5; 30, 5];  
velocities = [3, 0; 3, 2; 3, -3];  
labels = {'T1', 'T2', 'T3'};
```

Display the tracks for 10 trials. The bird's-eye plot shows the seven history values specified previously.

```
for i=1:10  
    plotTrack(tPlotter,positions,velocities,labels);  
    positions = positions + velocities;  
end
```



Input Arguments

bep — Bird's-eye plot

`birdsEyePlot` object

Bird's-eye plot, specified as a `birdsEyePlot` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `trackPlotter('Marker','*')` sets the marker symbol for tracks to an asterisk.

DisplayName — Plotter name to display in legend

' ' (default) | character vector | string scalar

Plotter name to display in legend, specified as the comma-separated pair consisting of 'DisplayName' and character vector or string scalar. If you do not specify a name, the bird's-eye plot does not display a legend entry for the plotter.

HistoryDepth — Number of previous track updates to display

0 (default) | integer in the range [0, 100]

Number of previous track updates to display, specified as the comma-separated pair consisting of 'HistoryDepth' and an integer in the range [0, 100]. When you set this value to 0, the bird's-eye plot displays no previous updates.

Marker — Marker symbol for tracks

'square' (default) | '+' | '*' | '.' | 'x' | ...

Marker symbol for tracks, specified as the comma-separated pair consisting of 'Marker' and one of the markers in this table.

Value	Description
'o'	Circle
'+'	Plus sign
'*'	Asterisk
'.'	Point
'x'	Cross
'square' or 's'	Square
'diamond' or 'd'	Diamond
'^'	Upward-pointing triangle
'v'	Downward-pointing triangle
'>'	Right-pointing triangle

Value	Description
'<'	Left-pointing triangle
'pentagram' or 'p'	Five-pointed star (pentagram)
'hexagram' or 'h'	Six-pointed star (hexagram)
'none'	No markers

MarkerSize — Size of marker for tracks

10 (default) | positive integer

Size of marker for tracks, specified as the comma-separated pair consisting of 'MarkerSize' and a positive integer in points.

MarkerEdgeColor — Marker outline color for tracks

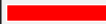

[0 0 0] (black) (default) | RGB triplet | hexadecimal color code | color name | short color name







Marker outline color for tracks, specified as the comma-separated pair consisting of 'MarkerEdgeColor' and an RGB triplet, a hexadecimal color code, a color name, or a short color name.

For a custom color, specify an RGB triplet or a hexadecimal color code.








- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].
- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (#) followed by three or six hexadecimal digits, which can range from 0 to F. The values are not case sensitive. Thus, the color codes '#FF8800', '#ff8800', '#F80', and '#f80' are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color

Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

MarkerFaceColor — Marker fill color for tracks

'none' (default) | RGB triplet | hexadecimal color code | color name | short color name





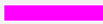



Marker fill color for tracks, specified as the comma-separated pair consisting of 'MarkerFaceColor' and an RGB triplet, a hexadecimal color code, a color name, or a short color name.

For a custom color, specify an RGB triplet or a hexadecimal color code.


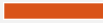





- An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].

- A hexadecimal color code is a character vector or a string scalar that starts with a hash symbol (#) followed by three or six hexadecimal digits, which can range from 0 to F. The values are not case sensitive. Thus, the color codes '#FF8800', '#ff8800', '#F80', and '#f80' are equivalent.

Alternatively, you can specify some common colors by name. This table lists the named color options, the equivalent RGB triplets, and hexadecimal color codes.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	
'none'	Not applicable	Not applicable	Not applicable	No color

Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

FontSize – Font size for labeling tracks

10 points (default) | positive integer

Font size for labeling tracks, specified as the comma-separated pair consisting of 'FontSize' and a positive integer in font points.

LabelOffset — Gap between label and positional point

[0 0] (default) | real-valued vector of the form [x y]

Gap between label and positional point, specified as the comma-separated pair consisting of 'LabelOffset' and a real-valued vector of the form [x y]. Units are in meters.

VelocityScaling — Scale factor for magnitude length of velocity vectors

1 (default) | positive real scalar

Scale factor for magnitude length of velocity vectors, specified as the comma-separated pair consisting of 'VelocityScaling' and a positive real scalar. The bird's-eye plot renders the magnitude vector value as $M \times \text{VelocityScaling}$, where M is the magnitude of velocity.

Tag — Tag associated with plotter object

'PlotterN' (default) | character vector | string scalar

Tag associated with the plotter object, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar. The default value is 'PlotterN', where N is an integer that corresponds to the N th plotter associated with the input `birdsEyePlot` object.

Output Arguments

tPlotter — Track plotter

`TrackPlotter` object

Track plotter, returned as a `TrackPlotter` object. You can modify this object by changing its property values. The property names correspond to the name-value pair arguments of the `trackPlotter` function.

`tPlotter` is stored in the `Plotters` property of the input `birdsEyePlot` object, `bep`. To plot the tracks, use the `plotTrack` function.

See Also

`birdsEyePlot` | `clearData` | `clearPlotterData` | `findPlotter` | `plotTrack`

Introduced in R2017a

birdsEyeView

Create bird's-eye view using inverse perspective mapping

Description

Use the `birdsEyeView` object to create a bird's-eye view of a 2-D scene using inverse perspective mapping. To transform an image into a bird's-eye view, pass a `birdsEyeView` object and that image to the `transformImage` function. To convert the bird's-eye-view image coordinates to or from vehicle coordinates, use the `imageToVehicle` and `vehicleToImage` functions. All of these functions assume that the input image does not have lens distortion. To remove lens distortion, use the `undistortImage` function.

Creation

Syntax

```
birdsEye = birdsEyeView(sensor,outView,outImageSize)
```

Description

`birdsEye = birdsEyeView(sensor,outView,outImageSize)` creates a `birdsEyeView` object for transforming an image to a bird's-eye-view.

- `sensor` is a `monoCamera` object that defines the configuration of the camera sensor. This input sets the `Sensor` property.
- `outView` defines the portion of the camera view, in vehicle coordinates, that is transformed into a bird's-eye view. This input sets the `OutputView` property.
- `outImageSize` defines the size, in pixels, of the output bird's-eye-view image. This input sets the `ImageSize` property.

Properties

Sensor — Camera sensor configuration

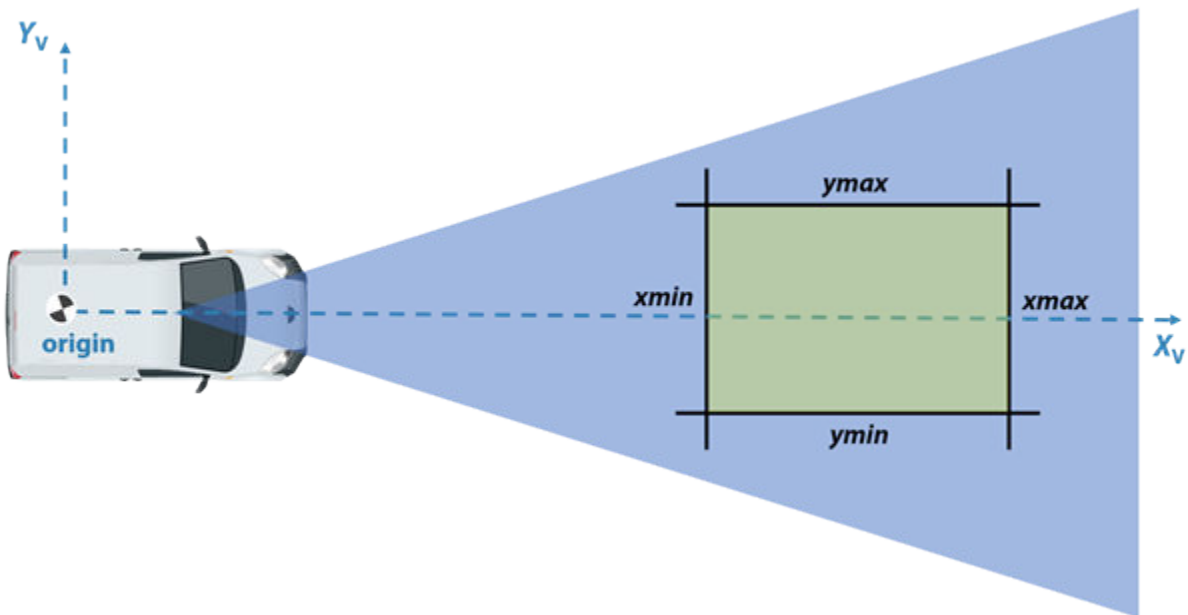
monoCamera object

Camera sensor configuration, specified as a `monoCamera` object. The object contains the intrinsic camera parameters, the mounting height, and the camera mounting angles. This configuration defines the vehicle coordinate system of the `birdsEyeView` object. For more details, see “Vehicle Coordinate System” on page 4-145.

OutputView — Coordinates of region to transform

four-element vector of form $[xmin\ xmax\ ymin\ ymax]$

Coordinates of the region to transform into a bird's-eye-view image, specified as a four-element vector of the form $[xmin\ xmax\ ymin\ ymax]$. The units are in world coordinates, such as meters or feet, as determined by the `Sensor` property. The four coordinates define the output space in the vehicle coordinate system (X_V, Y_V) .



You can set this property when you create the object. After you create the object, this property is read-only.

ImageSize — Size of output bird's-eye-view images

two-element vector

Size of output bird's-eye-view images, in pixels, specified as a two-element vector of the form $[m \ n]$, where m and n specify the number of rows and columns of pixels for the output image, respectively. If you specify a value for one dimension, you can set the other dimension to NaN and `birdsEyeView` calculates this value automatically. Setting one dimension to NaN maintains the same pixel to world-unit ratio along the X_V -axis and Y_V -axis.

You can set this property when you create the object. After you create the object, this property is read-only.

Object Functions

<code>transformImage</code>	Transform image to bird's-eye view
<code>imageToVehicle</code>	Convert bird's-eye-view image coordinates to vehicle coordinates
<code>vehicleToImage</code>	Convert vehicle coordinates to bird's-eye-view image coordinates

Examples

Transform Road Image to Bird's-Eye-View Image

Create a bird's-eye-view image from an image obtained by a front-facing camera mounted on a vehicle. Display points within the bird's-eye view using the vehicle and image coordinate systems.

Define the camera intrinsics and create an object containing these intrinsics.

```
focalLength = [309.4362 344.2161];  
principalPoint = [318.9034 257.5352];  
imageSize = [480 640];
```

```
camIntrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

Set the height of the camera to be about 2 meters above the ground. Set the pitch of the camera to 14 degrees toward the ground.

```
height = 2.1798;  
pitch = 14;
```


Create an object containing the camera configuration.

```
sensor = monoCamera(camIntrinsics,height, 'Pitch',pitch);
```

Define the area in front of the camera that you want to transform into a bird's-eye view. Set an area from 3 to 30 meters in front of the camera, with 6 meters to either side of the camera.

```
distAhead = 30;  
spaceToOneSide = 6;  
bottomOffset = 3;
```

```
outView = [bottomOffset,distAhead,-spaceToOneSide,spaceToOneSide];
```

Set the output image width to 250 pixels. Compute the output length automatically from the width by setting the length to NaN.

```
outImageSize = [NaN,250];
```

Create an object for performing bird's-eye-view transforms, using the previously defined parameters.

```
birdsEye = birdsEyeView(sensor,outView,outImageSize);
```

Load an image that was captured by the sensor.

```
I = imread('road.png');  
figure  
imshow(I)  
title('Original Image')
```

Original Image



Transform the input image into a bird's-eye-view image.

```
BEV = transformImage(birdsEye,I);
```

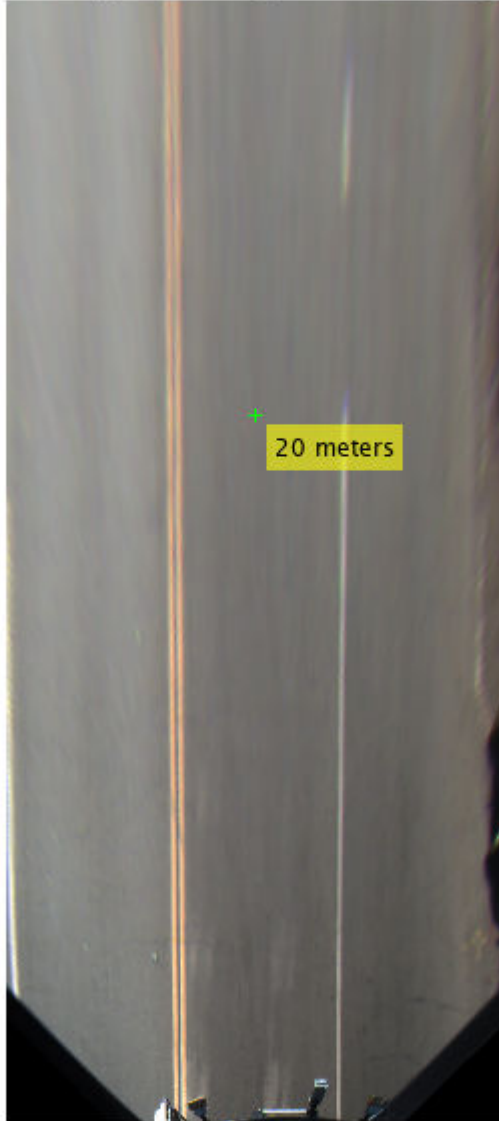
In the bird's-eye-view image, place a 20-meter marker directly in front of the sensor. Use the `vehicleToImage` function to specify the location of the marker in vehicle coordinates. Display the marker on the bird's-eye-view image.

```
imagePoint = vehicleToImage(birdsEye,[20 0]);  
annotatedBEV = insertMarker(BEV,imagePoint);  
annotatedBEV = insertText(annotatedBEV,imagePoint + 5,'20 meters');
```

```
figure
```

```
imshow(annotatedBEV)  
title('Bird's-Eye-View Image: vehicleToImage')
```

Bird's-Eye-View Image: vehicleToImage



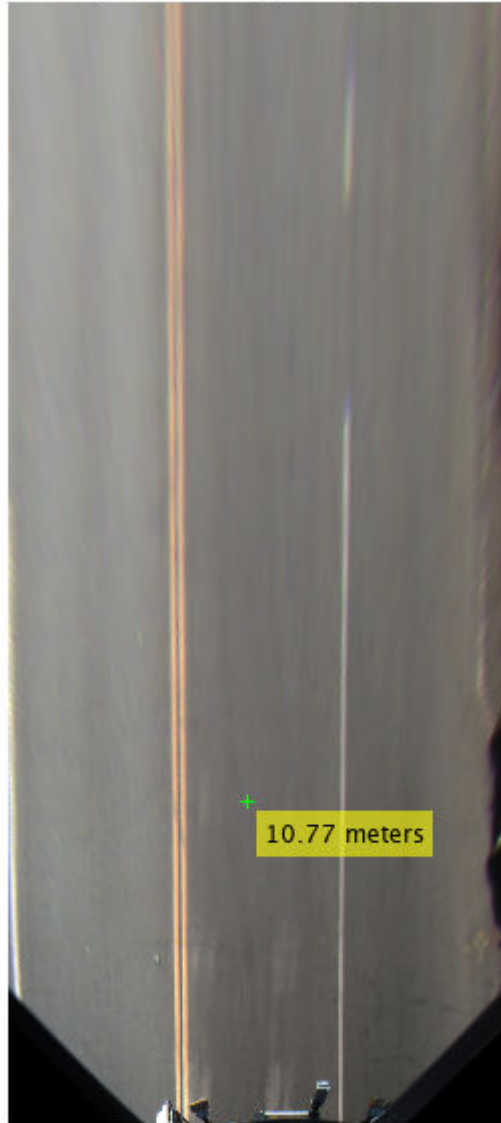
Define a location in the original bird's-eye-view image, this time in image coordinates. Use the `imageToVehicle` function to convert the image coordinates to vehicle coordinates. Display the distance between the marker and the front of the vehicle.

```
imagePoint2 = [120 400];
annotatedBEV = insertMarker(BEV,imagePoint2);

vehiclePoint = imageToVehicle(birdsEye,imagePoint2);
xAhead = vehiclePoint(1);
displayText = sprintf('%.2f meters',xAhead);
annotatedBEV = insertText(annotatedBEV,imagePoint2 + 5,displayText);

figure
imshow(annotatedBEV)
title('Bird's-Eye-View Image: imageToVehicle')
```

Bird's-Eye-View Image: imageToVehicle



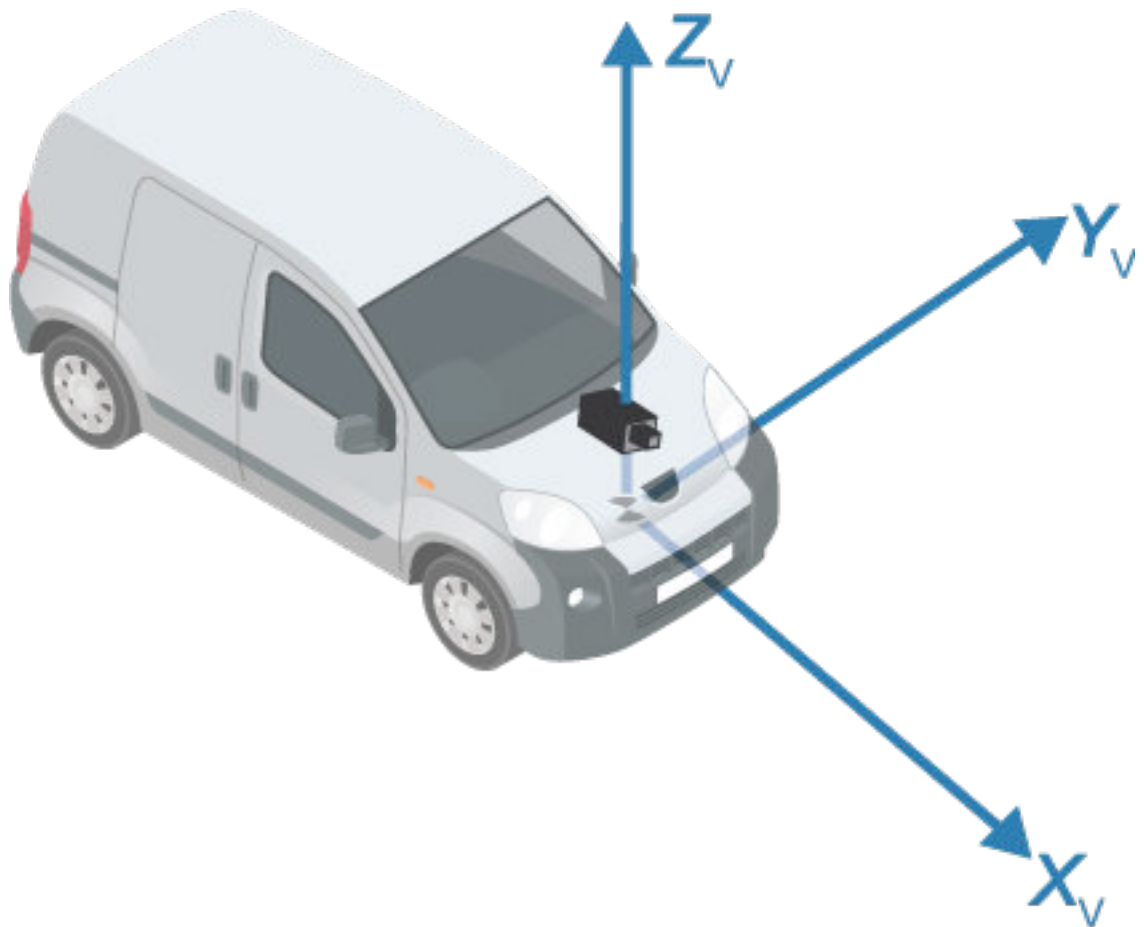
More About

Vehicle Coordinate System

In the vehicle coordinate system (X_v , Y_v , Z_v) defined by the input `monoCamera` object:

- The X_v -axis points forward from the vehicle.
- The Y_v -axis points to the left, as viewed when facing forward.
- The Z_v -axis points up from the ground to maintain the right-handed coordinate system.

The default origin of this coordinate system is on the road surface, directly below the camera center. The focal point of the camera defines this center point.



To change the placement of the origin within the vehicle coordinate system, update the `SensorLocation` property of the input `monoCamera` object.

For more details about the vehicle coordinate system, see “Coordinate Systems in Automated Driving Toolbox”.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

monoCamera

Topics

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

imageToVehicle

Convert bird's-eye-view image coordinates to vehicle coordinates

Syntax

```
vehiclePoints = imageToVehicle(birdsEye,imagePoints)
```

Description

`vehiclePoints = imageToVehicle(birdsEye,imagePoints)` converts bird's-eye-view image coordinates to [x y] vehicle coordinates.

Examples

Transform Road Image to Bird's-Eye-View Image

Create a bird's-eye-view image from an image obtained by a front-facing camera mounted on a vehicle. Display points within the bird's-eye view using the vehicle and image coordinate systems.

Define the camera intrinsics and create an object containing these intrinsics.

```
focalLength = [309.4362 344.2161];  
principalPoint = [318.9034 257.5352];  
imageSize = [480 640];
```

```
camIntrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

Set the height of the camera to be about 2 meters above the ground. Set the pitch of the camera to 14 degrees toward the ground.

```
height = 2.1798;  
pitch = 14;
```

Create an object containing the camera configuration.

```
sensor = monoCamera(camIntrinsics,height,'Pitch',pitch);
```

Define the area in front of the camera that you want to transform into a bird's-eye view. Set an area from 3 to 30 meters in front of the camera, with 6 meters to either side of the camera.

```
distAhead = 30;  
spaceToOneSide = 6;  
bottomOffset = 3;
```

```
outView = [bottomOffset,distAhead,-spaceToOneSide,spaceToOneSide];
```

Set the output image width to 250 pixels. Compute the output length automatically from the width by setting the length to NaN.

```
outImageSize = [NaN,250];
```

Create an object for performing bird's-eye-view transforms, using the previously defined parameters.

```
birdsEye = birdsEyeView(sensor,outView,outImageSize);
```

Load an image that was captured by the sensor.

```
I = imread('road.png');  
figure  
imshow(I)  
title('Original Image')
```

Original Image



Transform the input image into a bird's-eye-view image.

```
BEV = transformImage(birdsEye,I);
```

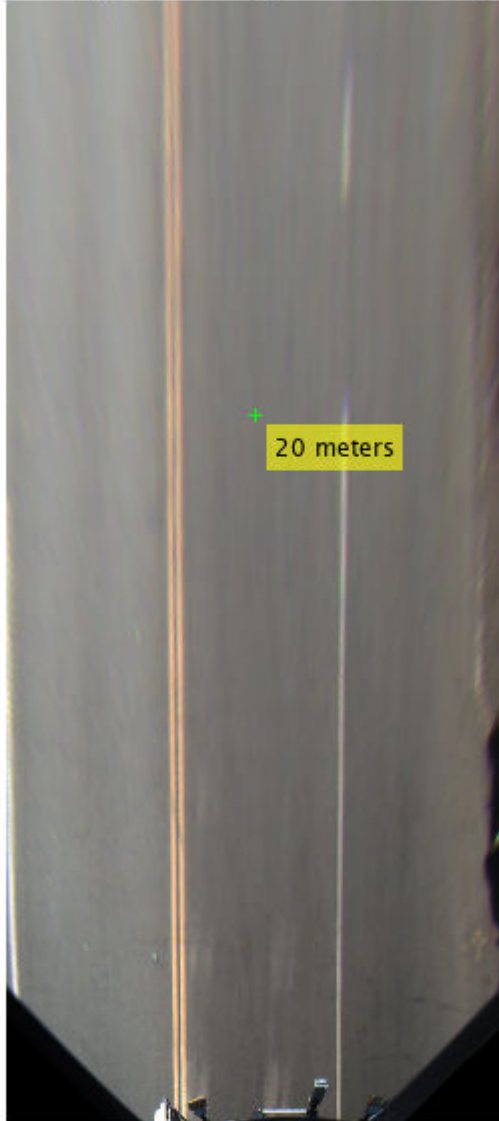
In the bird's-eye-view image, place a 20-meter marker directly in front of the sensor. Use the `vehicleToImage` function to specify the location of the marker in vehicle coordinates. Display the marker on the bird's-eye-view image.

```
imagePoint = vehicleToImage(birdsEye,[20 0]);  
annotatedBEV = insertMarker(BEV,imagePoint);  
annotatedBEV = insertText(annotatedBEV,imagePoint + 5,'20 meters');
```

```
figure
```

```
imshow(annotatedBEV)
title('Bird''s-Eye-View Image: vehicleToImage')
```

Bird's-Eye-View Image: vehicleToImage



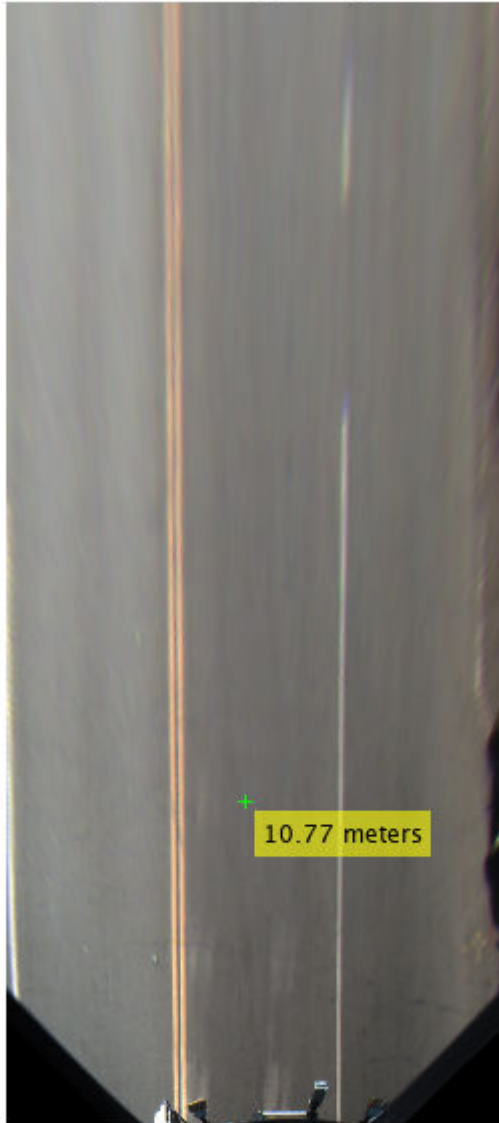
Define a location in the original bird's-eye-view image, this time in image coordinates. Use the `imageToVehicle` function to convert the image coordinates to vehicle coordinates. Display the distance between the marker and the front of the vehicle.

```
imagePoint2 = [120 400];
annotatedBEV = insertMarker(BEV,imagePoint2);

vehiclePoint = imageToVehicle(birdsEye,imagePoint2);
xAhead = vehiclePoint(1);
displayText = sprintf('%.2f meters',xAhead);
annotatedBEV = insertText(annotatedBEV,imagePoint2 + 5,displayText);

figure
imshow(annotatedBEV)
title('Bird's-Eye-View Image: imageToVehicle')
```

Bird's-Eye-View Image: imageToVehicle



Input Arguments

birdsEye — Object for transforming image to bird's-eye view

`birdsEyeView` object

Object for transforming image to bird's-eye view, specified as a `birdsEyeView` object.

imagePoints — Image points

M -by-2 matrix

Image points, specified as an M -by-2 matrix containing M number of $[x\ y]$ image coordinates.

Output Arguments

vehiclePoints — Vehicle points

M -by-2 matrix

Vehicle points, returned as an M -by-2 matrix containing M number of $[x\ y]$ vehicle coordinates.

Extended Capabilities

C/C++ Code Generation

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

See Also

Objects

`birdsEyeView`

Functions

`vehicleToImage`

Topics

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

transformImage

Transform image to bird's-eye view

Syntax

```
J = transformImage(birdsEye,I)
```

Description

`J = transformImage(birdsEye,I)` transforms the input image, `I`, to a bird's-eye-view image, `J`. The `OutputView` and `ImageSize` properties of the `birdsEyeView` object, `birdsEye`, determine the portion of `I` to transform and the size of `J`, respectively.

Examples

Transform Road Image to Bird's-Eye-View Image

Create a bird's-eye-view image from an image obtained by a front-facing camera mounted on a vehicle. Display points within the bird's-eye view using the vehicle and image coordinate systems.

Define the camera intrinsics and create an object containing these intrinsics.

```
focalLength = [309.4362 344.2161];  
principalPoint = [318.9034 257.5352];  
imageSize = [480 640];
```

```
camIntrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

Set the height of the camera to be about 2 meters above the ground. Set the pitch of the camera to 14 degrees toward the ground.

```
height = 2.1798;  
pitch = 14;
```

Create an object containing the camera configuration.

```
sensor = monoCamera(camIntrinsics,height,'Pitch',pitch);
```

Define the area in front of the camera that you want to transform into a bird's-eye view. Set an area from 3 to 30 meters in front of the camera, with 6 meters to either side of the camera.

```
distAhead = 30;  
spaceToOneSide = 6;  
bottomOffset = 3;
```

```
outView = [bottomOffset,distAhead,-spaceToOneSide,spaceToOneSide];
```

Set the output image width to 250 pixels. Compute the output length automatically from the width by setting the length to NaN.

```
outImageSize = [NaN,250];
```

Create an object for performing bird's-eye-view transforms, using the previously defined parameters.

```
birdsEye = birdsEyeView(sensor,outView,outImageSize);
```

Load an image that was captured by the sensor.

```
I = imread('road.png');  
figure  
imshow(I)  
title('Original Image')
```

Original Image



Transform the input image into a bird's-eye-view image.

```
BEV = transformImage(birdsEye,I);
```

In the bird's-eye-view image, place a 20-meter marker directly in front of the sensor. Use the `vehicleToImage` function to specify the location of the marker in vehicle coordinates. Display the marker on the bird's-eye-view image.

```
imagePoint = vehicleToImage(birdsEye,[20 0]);  
annotatedBEV = insertMarker(BEV,imagePoint);  
annotatedBEV = insertText(annotatedBEV,imagePoint + 5,'20 meters');
```

```
figure
```

```
imshow(annotatedBEV)
title('Bird''s-Eye-View Image: vehicleToImage')
```

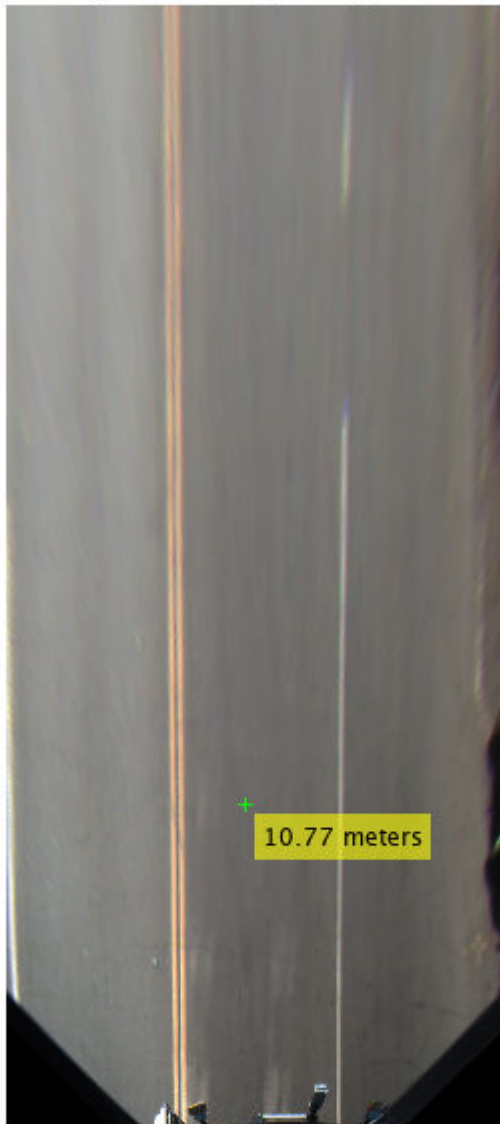
Bird's-Eye-View Image: vehicleToImage



Define a location in the original bird's-eye-view image, this time in image coordinates. Use the `imageToVehicle` function to convert the image coordinates to vehicle coordinates. Display the distance between the marker and the front of the vehicle.

```
imagePoint2 = [120 400];  
annotatedBEV = insertMarker(BEV,imagePoint2);  
  
vehiclePoint = imageToVehicle(birdsEye,imagePoint2);  
xAhead = vehiclePoint(1);  
displayText = sprintf('%.2f meters',xAhead);  
annotatedBEV = insertText(annotatedBEV,imagePoint2 + 5,displayText);  
  
figure  
imshow(annotatedBEV)  
title('Bird''s-Eye-View Image: imageToVehicle')
```


Bird's-Eye-View Image: imageToVehicle



Input Arguments

birdsEye — Object for transforming image to bird's-eye view

birdsEyeView object

Object for transforming image to bird's-eye view, specified as a `birdsEyeView` object.

I — Input image

truecolor image | grayscale image

Input image, specified as a truecolor or grayscale image. The `OutputView` property of `birdsEye` determines the portion of `I` to transform to a bird's-eye view.

`I` must not contain lens distortion. You can remove lens distortion by using the `undistortImage` function. In high-end optics, you can ignore distortion.

Output Arguments

J — Bird's-eye-view image

truecolor image | grayscale image

Bird's-eye-view image, returned as a truecolor or grayscale image. The `ImageSize` property of `birdsEye` determines the size of `J`.

Extended Capabilities

C/C++ Code Generation

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

See Also

Objects

`birdsEyeView`

Functions

imageToVehicle | vehicleToImage

Introduced in R2017a

vehicleToImage

Convert vehicle coordinates to bird's-eye-view image coordinates

Syntax

```
imagePoints = vehicleToImage(birdsEye,vehiclePoints)
```

Description

`imagePoints = vehicleToImage(birdsEye,vehiclePoints)` converts vehicle coordinates to $[x\ y]$ bird's-eye-view image coordinates.

Examples

Transform Road Image to Bird's-Eye-View Image

Create a bird's-eye-view image from an image obtained by a front-facing camera mounted on a vehicle. Display points within the bird's-eye view using the vehicle and image coordinate systems.

Define the camera intrinsics and create an object containing these intrinsics.

```
focalLength = [309.4362 344.2161];  
principalPoint = [318.9034 257.5352];  
imageSize = [480 640];
```

```
camIntrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

Set the height of the camera to be about 2 meters above the ground. Set the pitch of the camera to 14 degrees toward the ground.

```
height = 2.1798;  
pitch = 14;
```

Create an object containing the camera configuration.

```
sensor = monoCamera(camIntrinsics,height,'Pitch',pitch);
```

Define the area in front of the camera that you want to transform into a bird's-eye view. Set an area from 3 to 30 meters in front of the camera, with 6 meters to either side of the camera.

```
distAhead = 30;  
spaceToOneSide = 6;  
bottomOffset = 3;
```

```
outView = [bottomOffset,distAhead,-spaceToOneSide,spaceToOneSide];
```

Set the output image width to 250 pixels. Compute the output length automatically from the width by setting the length to NaN.

```
outImageSize = [NaN,250];
```

Create an object for performing bird's-eye-view transforms, using the previously defined parameters.

```
birdsEye = birdsEyeView(sensor,outView,outImageSize);
```

Load an image that was captured by the sensor.

```
I = imread('road.png');  
figure  
imshow(I)  
title('Original Image')
```

Original Image



Transform the input image into a bird's-eye-view image.

```
BEV = transformImage(birdsEye,I);
```

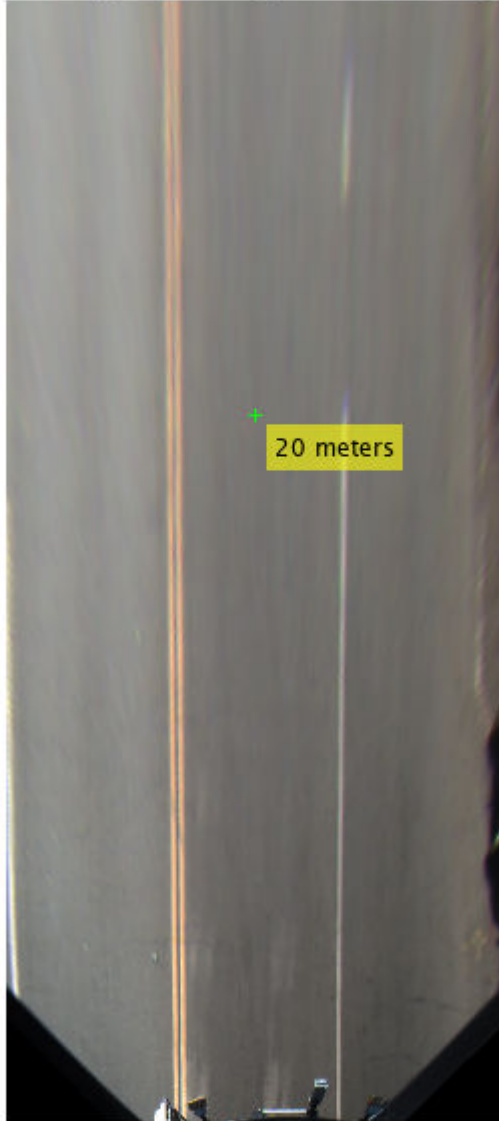
In the bird's-eye-view image, place a 20-meter marker directly in front of the sensor. Use the `vehicleToImage` function to specify the location of the marker in vehicle coordinates. Display the marker on the bird's-eye-view image.

```
imagePoint = vehicleToImage(birdsEye,[20 0]);  
annotatedBEV = insertMarker(BEV,imagePoint);  
annotatedBEV = insertText(annotatedBEV,imagePoint + 5,'20 meters');
```

```
figure
```

```
imshow(annotatedBEV)
title('Bird''s-Eye-View Image: vehicleToImage')
```

Bird's-Eye-View Image: vehicleToImage



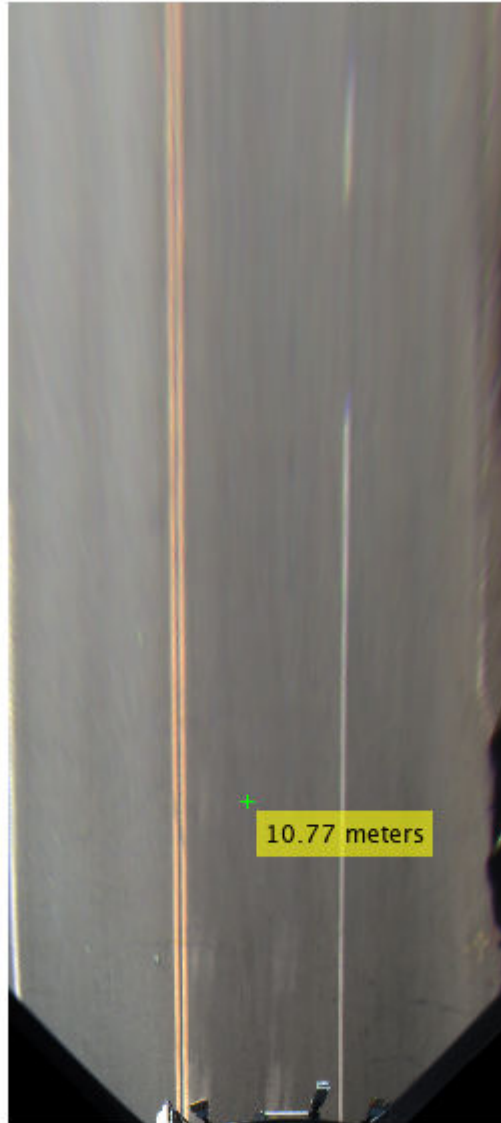
Define a location in the original bird's-eye-view image, this time in image coordinates. Use the `imageToVehicle` function to convert the image coordinates to vehicle coordinates. Display the distance between the marker and the front of the vehicle.

```
imagePoint2 = [120 400];
annotatedBEV = insertMarker(BEV,imagePoint2);

vehiclePoint = imageToVehicle(birdsEye,imagePoint2);
xAhead = vehiclePoint(1);
displayText = sprintf('%.2f meters',xAhead);
annotatedBEV = insertText(annotatedBEV,imagePoint2 + 5,displayText);

figure
imshow(annotatedBEV)
title('Bird's-Eye-View Image: imageToVehicle')
```

Bird's-Eye-View Image: imageToVehicle



Input Arguments

birdsEye — Object for transforming image to bird's-eye view

`birdsEyeView` object

Object for transforming image to bird's-eye view, specified as a `birdsEyeView` object.

vehiclePoints — Vehicle points

M -by-2 matrix

Vehicle points, specified as an M -by-2 matrix containing M number of $[x\ y]$ vehicle coordinates.

Output Arguments

imagePoints — Image points

M -by-2 matrix

Image points, returned as an M -by-2 matrix containing M number of $[x\ y]$ image coordinates.

Extended Capabilities

C/C++ Code Generation

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

See Also

Objects

`birdsEyeView`

Functions

`imageToVehicle`

Topics

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

driving.connector.Connector class

Package: driving.connector

Interface to connect external tool to Ground Truth Labeler app

Description

The `driving.connector.Connector` class creates an interface between a custom visualization or analysis tool and the **Ground Truth Labeler** app.

The `driving.connector.Connector` class is a `handle` class.

Creation

The `Connector` class that is inherited from the `Connector` interface is called a client.

The client can:

- Sync an external tool to each frame change event in the **Ground Truth Labeler**. Syncing allows you to control the external tool through the range slider and playback controls of the app.
- Control the current time in the external tool and the corresponding display in the app.
- Export custom labeled data from an external tool via the app.

To connect an external tool to the **Ground Truth Labeler** app, follow these steps:

- 1 Define a client class that inherits from `driving.connector.Connector`. You can use the `Connector` class template to define a class and implement your custom visualization or analysis tool. At the MATLAB command prompt, enter:

```
driving.connector.Connector.openTemplateInEditor
```

Follow the steps found in the template.

- 2 Save the file to any folder on the MATLAB path. Alternatively, save the file to a folder and add the folder to MATLAB path by using the `addpath` function.

Properties

VideoStartTime — Start time of source video file

real scalar in seconds

Start time of the source video file, specified as a real scalar in seconds.

Attributes:

GetAccess	public
SetAccess	private

VideoEndTime — End time of source video file

real scalar in seconds

End time of the source video file, specified as a real scalar in seconds.

Attributes:

GetAccess	public
SetAccess	private

StartTime — Start time of video interval in app

real scalar in seconds

Start time of the video interval in the app, specified as a real scalar in seconds. To set the start time, use the start flag interval in the app.

Attributes:

GetAccess	public
SetAccess	private

CurrentTime — Time of video frame currently displaying in app

real scalar in seconds

Time of the video frame currently displaying in the app, specified as a real scalar in seconds.

Attributes:

GetAccess	public
SetAccess	private

EndTime — End time of video in app

real scalar in seconds

End time of the video in the app, specified as a real scalar in seconds. To set the end time, use the end flag interval in the app.

Attributes:

GetAccess	public
SetAccess	private

TimeVector — Time stamps for loaded video

array

Timestamps for the loaded video, specified as an array.

Attributes:

GetAccess	public
SetAccess	private

LabelData — Label data imported from external tool

two-column table

Label data imported from the external tool, specified as a two-column table. The first column contains the timestamps and the second column contains the label information that you specify for the corresponding timestamp.

Attributes:

GetAccess	public
SetAccess	private

LabelName — Names of labels

character vector | string scalar | cell array of character vectors | string array

Names of labels, specified as a character vector, a string scalar, a cell array of character vectors, or a string array. These names must be valid MATLAB variables that correspond to the label names specified in the second column of LabelData.

Attributes:

GetAccess	public
SetAccess	public
Dependent	true

LabelDescription — Descriptions of labels

' ' (default) | character vector | string scalar | cell array of character vectors | string array

Descriptions of labels, specified as a character vector, a string scalar, a cell array of character vectors, or a string array. Each description of `LabelDescription` corresponds to a label specified in `LabelName`.

Attributes:

GetAccess	public
SetAccess	public

Methods

Public Methods

<code>frameChangeListener</code>	Update external tool when new frame is displayed in Ground Truth Labeler app
<code>labelDefinitionLoadListener</code>	Update external tool for new label definitions in Ground Truth Labeler app
<code>labelLoadListener</code>	Update external tool for new label data in Ground Truth Labeler app
<code>addLabelData</code>	Add custom label data at current time
<code>queryLabelData</code>	Query for custom label data at current time
<code>updateLabelerCurrentTime</code>	Update current time in Ground Truth Labeler app
<code>close</code>	Close external tool connected to Ground Truth Labeler app
<code>disconnect</code>	Disconnect external tool from Ground Truth Labeler app
<code>dataSourceChangeListener</code>	Update external tool when you add data sources to Ground Truth Labeler app

Examples

Connect Lidar Display to Ground Truth Labeler

Connect a lidar data visualization tool to the Ground Truth Labeler app. Use the app and tool to display synchronized lidar and video data. To use another set of data, modify the MATLAB code in this example.

Specify the video name to display in the Ground Truth Labeler.

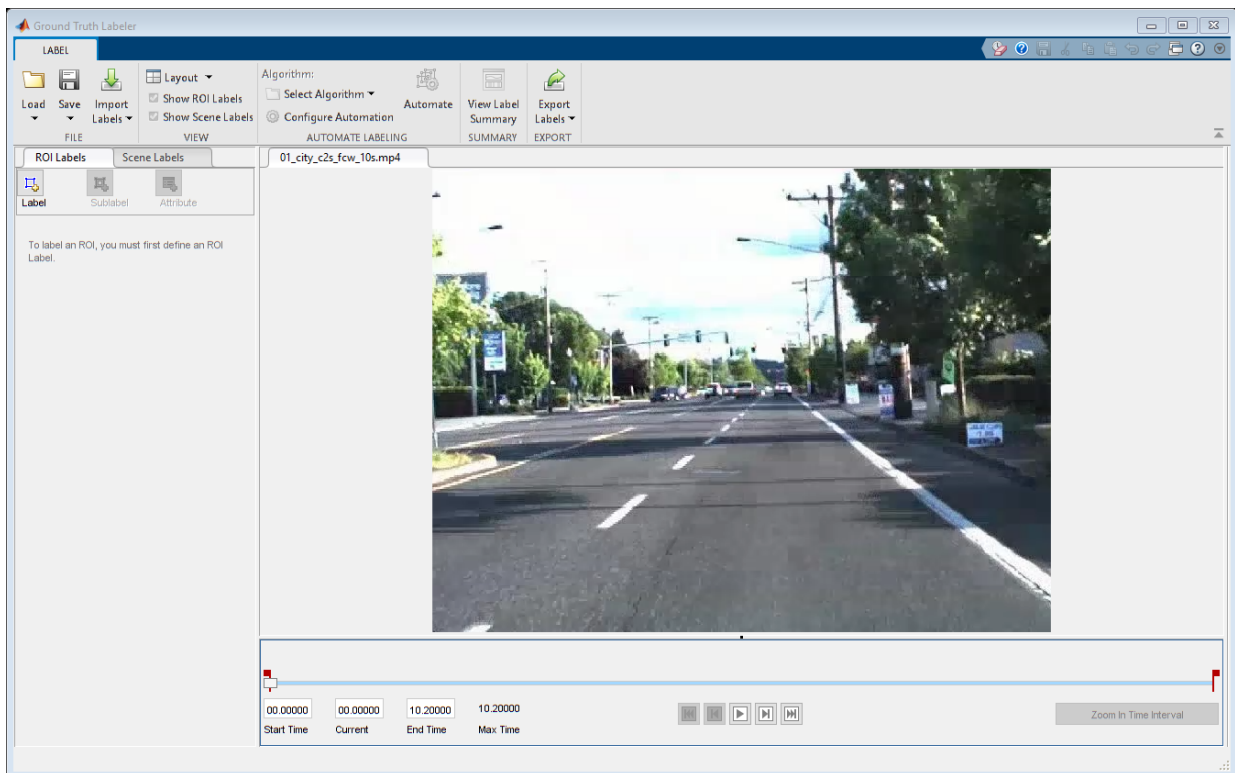
```
videoName = '01_city_c2s_fcw_10s.mp4';
```

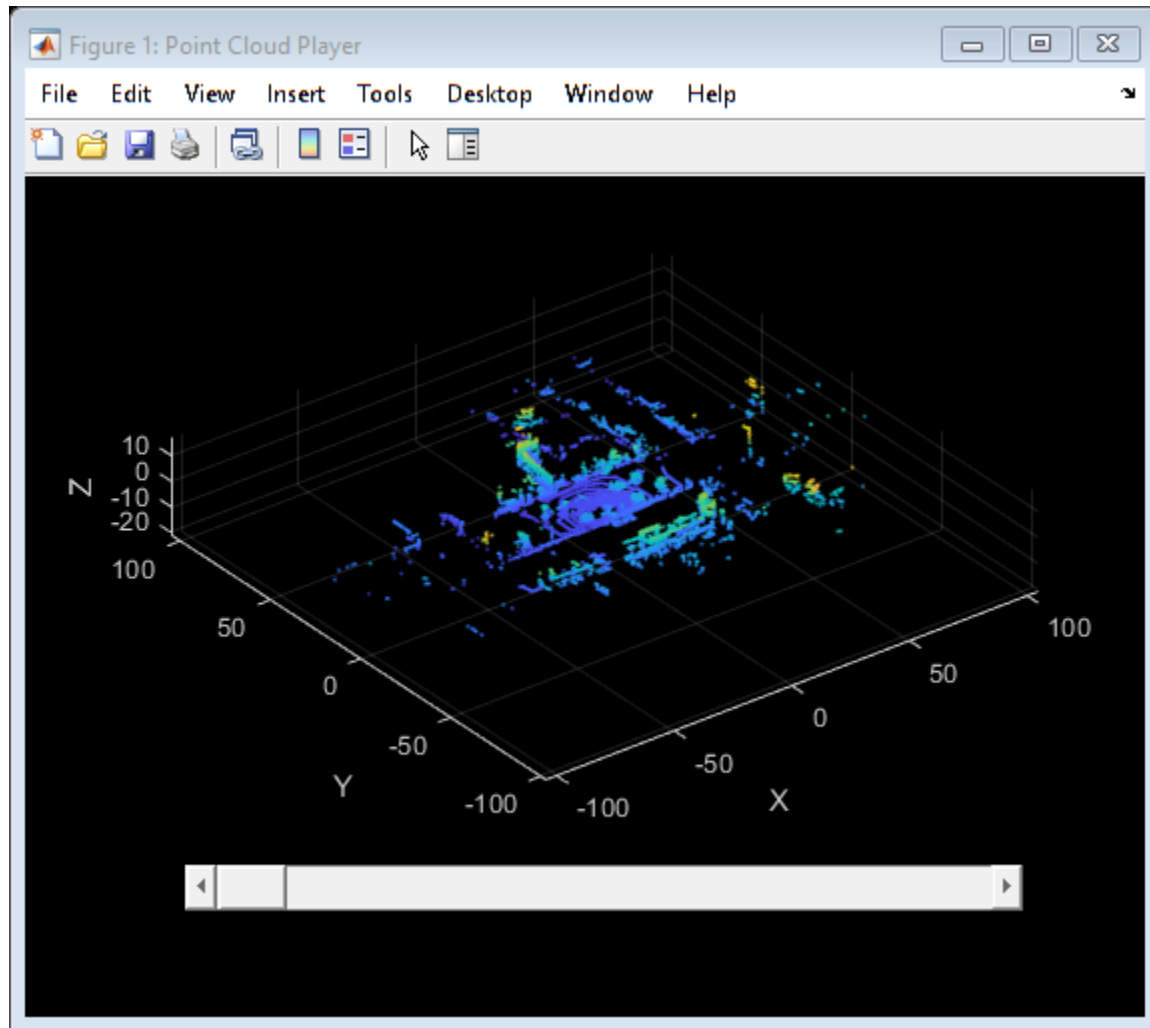
Add the path to the lidar display data.

```
addpath(fullfile(matlabroot, 'toolbox', 'driving', 'drivingdemos'));
```

Connect the lidar display to the Ground Truth Labeler.

```
groundTruthLabeler(videoName, 'ConnectorTargetHandle', @LidarDisplay);
```





See Also

Apps
Ground Truth Labeler

Introduced in R2017a

addLabelData

Class: `driving.connector.Connector`

Package: `driving.connector`

Add custom label data at current time

Syntax

```
addLabelData(connectorObj, labelData)
```

Description

`addLabelData(connectorObj, labelData)` adds the custom label data related to the current time that is shown in the **Ground Truth Labeler** app. The client calls this method using the `connectorObj` object.

Note The client class can call this method.

Input Arguments

connectorObj — Connector object

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

labelData — Label data

cell array of character vectors | string array

Label data, specified as a cell array of character vectors or as a string array. Each element of `labelData` must correspond to a label stored in the `labelData` property of the input `driving.connector.Connector` object, `connectorObj`.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

close

Class: `driving.connector.Connector`

Package: `driving.connector`

Close external tool connected to Ground Truth Labeler app

Syntax

```
close(connectorObj)
```

Description

`close(connectorObj)` provides the option to close the external tool that is connected to the **Ground Truth Labeler** app when the app closes. The app calls this method using the `connectorObj` object.

Note The client class can optionally implement this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

dataSourceChangeListener

Class: `driving.connector.Connector`

Package: `driving.connector`

Update external tool when you add data sources to Ground Truth Labeler app

Syntax

```
dataSourceChangeListener(connectorObj)
```

Description

`dataSourceChangeListener(connectorObj)` provides the option to update the external tool when a new data source is loaded into the **Ground Truth Labeler** app. The app calls this method using the `connectorObj` object. You can optionally use this method to react to a new data source being connected to the app.

A new data source can be a video, image sequence, or custom reader. You can load a new data source while loading a new session.

Note The client class can optionally implement this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

disconnect

Class: `driving.connector.Connector`

Package: `driving.connector`

Disconnect external tool from Ground Truth Labeler app

Syntax

```
disconnect(connectorObj)
```

Description

`disconnect(connectorObj)` disconnects the interface between an external tool and the **Ground Truth Labeler** app. The client calls this method using the `connectorObj` object. After the external tool is disconnected, the **Ground Truth Labeler** app no longer calls the `frameChangeListener` method in the client class.

Note The client class can call this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

frameChangeListener

Class: `driving.connector.Connector`

Package: `driving.connector`

Update external tool when new frame is displayed in Ground Truth Labeler app

Syntax

```
frameChangeListener(connectorObj)
```

Description

`frameChangeListener(connectorObj)` provides an option to synchronize an external tool with the frame changes in the **Ground Truth Labeler** app. The app calls this method when a new frame is displayed in the app.

Note The client class must implement this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

labelDefinitionLoadListener

Class: `driving.connector.Connector`

Package: `driving.connector`

Update external tool for new label definitions in Ground Truth Labeler app

Syntax

```
labelDefinitionLoadListener(connectorObj)
```

Description

`labelDefinitionLoadListener(connectorObj)` provides an option to update the external tool that is connected to the **Ground Truth Labeler** app when new set of label definitions is imported into the app. The app calls this method using the `connectorObj` object. You can optionally use this method to react to the event of connecting a new data source to the app.

Note The client class can optionally implement this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

labelLoadListener

Class: `driving.connector.Connector`

Package: `driving.connector`

Update external tool for new label data in Ground Truth Labeler app

Syntax

```
labelLoadListener(connectorObj)
```

Description

`labelLoadListener(connectorObj)` provides the option to update the external tool that is connected to the **Ground Truth Labeler** app when a new set of label data or new session with label data is imported into the app. The app calls this method using the `connectorObj` object. Use this method to react to the event of loading a new label data into the app.

Note The client class can optionally implement this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

queryLabelData

Class: `driving.connector.Connector`

Package: `driving.connector`

Query for custom label data at current time

Syntax

```
queryLabelData(connectorObj)
```

Description

`queryLabelData(connectorObj)` queries for label data related to the current time in the **Ground Truth Labeler** app. The client calls this method using the `connectorObj`.

Note The client class can call this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

updateLabelerCurrentTime

Class: `driving.connector.Connector`

Package: `driving.connector`

Update current time in Ground Truth Labeler app

Syntax

```
updateLabelerCurrentTime(connectorObj, newTime)
```

Description

`updateLabelerCurrentTime(connectorObj, newTime)` updates the current time in the **Ground Truth Labeler** app to `newTime`. The client calls this method using the `connectorObj` object.

Note The client class can call this method.

Input Arguments

connectorObj — **Connector object**

`driving.connector.Connector` object

Connector object, specified as a `driving.connector.Connector` object.

newTime — **Current time for app**

real scalar in seconds

Current time for app, specified as a real scalar in seconds. The `newTime` value sets the current time in the **Ground Truth Labeler** app.

See Also

Ground Truth Labeler | `driving.connector.Connector`

Introduced in R2017a

radarDetectionGenerator

Generate radar detections for driving scenario

Description

The `radarDetectionGenerator` System object generates detections from a radar sensor mounted on an ego vehicle. All detections are referenced to the coordinate system of the ego vehicle. You can use the `radarDetectionGenerator` object in a scenario containing actors and trajectories, which you can create by using a `drivingScenario` object. The object can simulate real detections with added random noise and also generate false alarm detections. In addition, you can use the `radarDetectionGenerator` object to create input to a `multiObjectTracker`. When building scenarios using the **Driving Scenario Designer** app, the radar sensors mounted on the ego vehicle are output as `radarDetectionGenerator` objects.

To generate radar detections:

- 1 Create the `radarDetectionGenerator` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects? \(MATLAB\)](#).

Creation

Syntax

```
sensor = radarDetectionGenerator  
sensor = radarDetectionGenerator(Name,Value)
```

Description

`sensor = radarDetectionGenerator` creates a radar detection generator object with default property values.

`sensor = radarDetectionGenerator(Name, Value)` sets properties on page 4-195 using one or more name-value pairs. For example, `radarDetectionGenerator('DetectionCoordinates', 'SensorCartesian', 'MaxRange', 200)` creates a radar detection generator that reports detections in the sensor Cartesian coordinate system and has a maximum detection range of 200 meters. Enclose each property name in quotes.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects (MATLAB).

SensorIndex — Unique sensor identifier

positive integer

Unique sensor identifier, specified as a positive integer. This property distinguishes detections that come from different sensors in a multisensor system.

Example: 5

Data Types: double

UpdateInterval — Required time interval between sensor updates

0.1 (default) | positive real scalar

Required time interval between sensor updates, specified as a positive real scalar. The `drivingScenario` object calls the radar detection generator at regular time intervals. The radar detector generates new detections at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Example: 5

Data Types: double

SensorLocation — Sensor location

[3.4 0] (default) | [x y] vector

Location of the radar sensor center, specified as an [x y] vector. The `SensorLocation` and `Height` properties define the coordinates of the radar sensor with respect to the ego vehicle coordinate system. The default value corresponds to a radar mounted at the center of the front grill of a sedan. Units are in meters.

Example: [4 0.1]

Data Types: double

Height — Radar sensor height above ground plane

0.2 (default) | positive real scalar

Radar sensor height above the ground plane, specified as a positive real scalar. The height is defined with respect to the vehicle ground plane. The `SensorLocation` and `Height` properties define the coordinates of the radar sensor with respect to the ego vehicle coordinate system. The default value corresponds to a radar mounted at the center of the front grill of a sedan. Units are in meters.

Example: 0.3

Data Types: double

Yaw — Yaw angle of sensor

0 (default) | real scalar

Yaw angle of radar sensor, specified as a real scalar. The yaw angle is the angle between the center line of the ego vehicle and the downrange axis of the radar sensor. A positive yaw angle corresponds to a clockwise rotation when looking in the positive direction of the z-axis of the ego vehicle coordinate system. Units are in degrees.

Example: -4

Data Types: double

Pitch — Pitch angle of sensor

0 (default) | real scalar

Pitch angle of sensor, specified as a real scalar. The pitch angle is the angle between the downrange axis of the radar sensor and the x-y plane of the ego vehicle coordinate system. A positive pitch angle corresponds to a clockwise rotation when looking in the positive direction of the y-axis of the ego vehicle coordinate system. Units are in degrees.

Example: 3

Data Types: double

Roll — Roll angle of sensor

0 (default) | real scalar

Roll angle of the radar sensor, specified as a real scalar. The roll angle is the angle of rotation of the downrange axis of the radar around the x-axis of the ego vehicle coordinate system. A positive roll angle corresponds to a clockwise rotation when looking in the positive direction of the x-axis of the coordinate system. Units are in degrees.

Example: -4

Data Types: double

FieldOfView — Azimuth and elevation fields of view of radar sensor

[20 5] | real-valued 1-by-2 vector of positive values

Azimuth and elevation fields of view of radar sensor, specified as a real-valued 1-by-2 vector of positive values, [azfov elfov]. The field of view defines the angular extent spanned by the sensor. Each component must lie in the interval (0,180]. Targets outside of the field of view of the radar are not detected. Units are in degrees.

Example: [14 7]

Data Types: double

MaxRange — Maximum detection range

150 | positive real scalar

Maximum detection range, specified as a positive real scalar. The radar cannot detect a target beyond this range. Units are in meters.

Example: 200

Data Types: double

RangeRateLimits — Minimum and maximum detection range rates

[-100 100] | real-valued 1-by-2 vector

Minimum and maximum detection range rates, specified as a real-valued 1-by-2 vector. The radar cannot detect a target out this range rate interval. Units are in meters per second.

Example: [-20 100]

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

DetectionProbability — Probability of detecting a target

0.9 | positive real scalar less than or equal to 1

Probability of detecting a target, specified as a positive real scalar less than or equal to one. This quantity defines the probability of detecting target that has a radar cross-section, `ReferenceRCS`, at the reference detection range, `ReferenceRange`.

FalseAlarmRate — False alarm rate

1e-6 (default) | positive real scalar

False alarm rate within a radar resolution cell, specified as a positive real scalar in the range $[10^{-7}, 10^{-3}]$. Units are dimensionless.

Example: `1e-5`

Data Types: `double`

ReferenceRange — Reference range for given probability of detection

100 (default) | positive real scalar

Reference range for a given probability of detection, specified as a positive real scalar. The reference range is the range when a target having a radar cross-section specified by `ReferenceRCS` is detected with a probability of specified by `DetectionProbability`. Units are in meters.

Data Types: `double`

ReferenceRCS — Reference radar cross-section for given probability of detection

0 (default) | nonnegative real scalar

Reference radar cross-section (RCS) for given probability of detection, specified as a nonnegative real scalar. The reference RCS is the value at which a target is detected with probability specified by `DetectionProbability`. Units are in dBsm.

Data Types: `double`

RadarLoopGain — Radar loop gain

real scalar

This property is read-only.

Radar loop gain, specified as a real scalar. Radar loop gain is related to the reported signal-to-noise ratio of the radar, *SNR*, the target radar cross section, *RCS*, and target range, *R* by

$$\text{SNR} = \text{RadarLoopGain} + \text{RCS} - 40 \cdot \log_{10}(R)$$

SNR and *RCS* units are in dB and dBsm, respectively and range units are in meters. *RadarLoopGain* depends on the *DetectionProbability*, *ReferenceRange*, *ReferenceRCS*, and *FalseAlarmRate* property values. Units are in dB.

Data Types: double

AzimuthResolution — Azimuth resolution of radar

4 (default) | positive real scalar

Azimuth resolution of the radar, specified as a positive real scalar. The azimuth resolution defines the minimum separation in azimuth angle at which the radar can distinguish two targets. The azimuth resolution is typically the 3dB-downpoint in azimuth angle beamwidth of the radar. Units are in degrees.

Data Types: double

ElevationResolution — Elevation resolution of radar

10 (default) | positive real scalar

Elevation resolution of the radar, specified as a positive real scalar. The elevation resolution defines the minimum separation in elevation angle at which the radar can distinguish two targets. The elevation resolution is typically the 3dB-downpoint in elevation angle beamwidth of the radar. Units are in degrees.

Dependencies

To enable this property, set the *HasElevation* property to true.

Data Types: double

RangeResolution — Range resolution of radar

2.5 (default) | positive real scalar

Range resolution of the radar, specified as a positive real scalar. The range resolution defines the minimum separation in range at which the radar can distinguish between two targets. Units are in meters.

Data Types: double

RangeRateResolution — Range rate resolution of radar

0.5 (default) | positive real scalar

Range rate resolution of the radar, specified as a positive real scalar. The range rate resolution defines the minimum separation in range rate at which the radar can distinguish between two targets. Units are in meters per second.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: double

AzimuthBiasFraction — Azimuth bias fraction

0.1 (default) | nonnegative real scalar

Azimuth bias fraction of the radar, specified as a nonnegative real scalar. The azimuth bias is expressed as a fraction of the azimuth resolution specified in `AzimuthResolution`. Units are dimensionless.

Data Types: double

ElevationBiasFraction — Elevation bias fraction

0.1 (default) | nonnegative real scalar

Elevation bias fraction of the radar, specified as a nonnegative real scalar. Elevation bias is expressed as a fraction of the elevation resolution specified in `ElevationResolution`. Units are dimensionless.

Dependencies

To enable this property, set the `HasElevation` property to `true`.

Data Types: double

RangeBiasFraction — Range bias fraction

0.05 (default) | nonnegative real scalar

Range bias fraction of the radar, specified as a nonnegative real scalar. Range bias is expressed as a fraction of the range resolution specified in `RangeResolution`. Units are dimensionless.

Data Types: double

RangeRateBiasFraction — Range rate bias fraction

0.05 (default) | nonnegative real scalar

Range rate bias fraction of the radar, specified as a nonnegative real scalar. Range rate bias is expressed as a fraction of the range rate resolution specified in `RangeRateResolution`. Units are dimensionless.

Dependencies

To enable this property, set the `HasRangeRate` property to `true`.

Data Types: `double`

HasElevation — Enable radar to measure elevation

`false` (default) | `true`

Enable the radar to measure target elevation angles, specified as `false` or `true`. Set this property to `true` to model a radar sensor that can estimate target elevation. Set this property to `false` to model a radar sensor that cannot measure elevation.

Data Types: `logical`

HasRangeRate — Enable radar to measure range rate

`false` (default) | `true`

Enable the radar to measure target range rates, specified as `false` or `true`. Set this property to `true` to model a radar sensor which can estimate target range rate. Set this property to `false` to model a radar sensor that cannot measure range rate.

Data Types: `logical`

HasNoise — Enable adding noise to radar sensor measurements

`true` (default) | `false`

Enable adding noise to radar sensor measurements, specified as `true` or `false`. Set this property to `true` to add noise to the radar measurements. Otherwise, the measurements have no noise. Even if you set `HasNoise` to `false`, the object still computes the `MeasurementNoise` property of each detection.

Data Types: `logical`

HasFalseAlarms — Enable creating false alarm radar detections

`true` (default) | `false`

Enable reporting false alarm radar measurements, specified as `true` or `false`. Set this property to `true` to report false alarms. Otherwise, only actual detections are reported.

Data Types: `logical`

HasOcclusion — Enable line-of-sight occlusion

`true` (default) | `false`

Enable line-of-sight occlusion, specified as `true` or `false`. To generate detections only from objects for which the radar has a direct line of sight, set this property to `true`. For example, with this property enabled, the radar does not generate a detection for a vehicle that is behind another vehicle and blocked from view.

Data Types: `logical`

MaxNumDetectionsSource — Source of maximum number of detections reported

`'Auto'` (default) | `'Property'`

Source of maximum number of detections reported by the sensor, specified as `'Auto'` or `'Property'`. When this property is set to `'Auto'`, the sensor reports all detections. When this property is set to `'Property'`, the sensor reports no more than the number of detections specified by the `MaxNumDetections` property.

Data Types: `char` | `string`

MaxNumDetections — Maximum number of reported detections

50 (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. Detections are reported in order of distance to the sensor until the maximum number is reached.

Dependencies

To enable this property, set the `MaxNumDetectionsSource` property to `'Property'`.

Data Types: `double`

DetectionCoordinates — Coordinate system of reported detections

`'Ego Cartesian'` (default) | `'Sensor Cartesian'` | `'Sensor Spherical'`

Coordinate system of reported detections, specified as one of these values:

- `'Ego Cartesian'` — Detections are reported in the ego vehicle Cartesian coordinate system.

- 'Sensor Cartesian' — Detections are reported in the sensor Cartesian coordinate system.
- 'Sensor Spherical' — Detections are reported in a spherical coordinate system. This coordinate system is centered at the radar and aligned with the orientation of the radar on the ego vehicle.

Data Types: char | string

ActorProfiles — Actor profiles

structure | array of structures

Actor profiles, specified as structure or as an array of structures. Each structure contains the physical and radar characteristics of an actor.

- If ActorProfiles is a single structure, all actors passed into the radarDetectionGenerator object use this profile.
- If ActorProfiles is an array, each actor passed into the object must have a unique actor profile.

To generate an array of structures for your driving scenario, use the actorProfiles function. The table shows the valid structure fields. If you do not specify a field, the fields are set to their default values. If no actors are passed into the object, then the ActorID field is not included.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
ClassID	Classification identifier, specified as a nonnegative integer. 0 is reserved for an object of an unknown or unassigned class.
Length	Length of actor, specified as a positive real scalar. The default is 4.7. Units are in meters.
Width	Width of actor, specified as a positive real scalar. The default is 1.8. Units are in meters.

Field	Description
Height	Height of actor, specified as a positive real scalar. The default is 1.4. Units are in meters.
OriginOffset	Offset of actor's rotational center from its geometric center, specified as an $[x,y,z]$ real-valued vector. The rotational center, or origin, is located at the bottom center of the actor. For vehicles, the rotational center is the point on the ground beneath the center of the rear axle. The default is $[0\ 0\ 0]$. Units are in meters.
RCSPattern	Radar cross-section pattern of actor, specified as a <code>numel(RCSElevationAngles)-by-numel(RCSAzimuthAngles)</code> real-valued matrix. The default is $[10\ 10; 10\ 10]$. Units are in decibels per square meter.
RCSAzimuthAngles	Azimuth angles corresponding to rows of <code>RCSPattern</code> , specified as a vector of real values in the range $[-180, 180]$. The default is $[-180\ 180]$. Units are in degrees.
RCSElevationAngles	Elevation angles corresponding to rows of <code>RCSPattern</code> , specified as a vector of real values in the range $[-90, 90]$. The default is $[-90\ 90]$. Units are in degrees.

For full definitions of the structure fields, see the `actor` and `vehicle` functions.

Usage

Syntax

```
dets = sensor(actors,time)
[dets,numValidDets] = sensor(actors,time)
```

```
[dets,numValidDets,isValidTime] = sensor(actors,time)
```

Description

`dets = sensor(actors,time)` creates radar detections, `dets`, from sensor measurements taken of `actors` at the current simulation time. The object can generate sensor detections for multiple actors simultaneously. Do not include the ego vehicle as one of the actors.

`[dets,numValidDets] = sensor(actors,time)` also returns the number of valid detections reported, `numValidDets`.

`[dets,numValidDets,isValidTime] = sensor(actors,time)` also returns a logical value, `isValidTime`, indicating that the `UpdateInterval` time has elapsed.

Input Arguments

actors — Scenario actor poses

structure | structure array

Scenario actor poses, specified as a structure or structure array. Each structure corresponds to an actor. You can generate these structures using the `actorPoses` function. You can also create these structures manually.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an $[x\ y\ z]$ real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x -, y -, and z -directions, specified as a $[v_x\ v_y\ v_z]$ real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.

Field	Description
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x -, y -, and z -directions, specified as an $[\omega_x \ \omega_y \ \omega_z]$ real-valued vector. Units are in degrees per second.

For full definitions of the structure fields, see the `actor` and `vehicle` functions.

time — Current simulation time

nonnegative real scalar

Current simulation time, specified as a nonnegative real scalar. The `drivingScenario` object calls the radar detection generator at regular time intervals. The radar detector generates new detections at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Example: 10.5

Data Types: double

Output Arguments

dets — Radar sensor detections

cell array of `objectDetection` objects

Radar sensor detections, returned as a cell array of `objectDetection` objects. Each object contains these fields:

Property	Definition
Time	Measurement time
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor
ObjectClassID	Object classification

Property	Definition
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

For Cartesian coordinates, Measurement, MeasurementNoise, and MeasurementParameters are reported in the coordinate system specified by the DetectionCoordinates property of the radarDetectionGenerator.

For spherical coordinates, Measurement and MeasurementNoise are reported in the spherical coordinate system based on the sensor Cartesian coordinate system. MeasurementParameters are reported in sensor Cartesian coordinates.

Measurement

DetectionCoordinates Property	Measurement and Measurement Noise Coordinates		
'Ego Cartesian'	Coordinate Dependence on HasRangeRate		
'Sensor Cartesian'	HasRangeRate	Coordinates	
	true		[x;y;z;vx;vy;vz]
	false		[x;y;z]
'Sensor Spherical'	Coordinate Dependence on HasRangeRate and HasElevation		
	HasRangeRate	HasElevation	Coordinates
	true	true	[az;el;rng;rr]
	true	false	[az;rng;rr]
	false	true	[az;el;rng]
	false	false	[az;rng]

MeasurementParameters

Parameter	Definition
Frame	Enumerated type indicating the frame used to report measurements. When Frame is set to 'rectangular', detections are reported in Cartesian coordinates. When Frame is set 'spherical', detections are reported in spherical coordinates.
OriginPosition	3-D vector offset of the sensor origin from the ego vehicle origin. The vector is derived from the SensorLocation and Height properties specified in the radarDetectionGenerator.
Orientation	Orientation of the vision sensor coordinate system with respect to the ego vehicle coordinate system. The orientation is derived from the Yaw, Pitch, and Roll properties of the radarDetectionGenerator.
HasVelocity	Indicates whether measurements contain velocity or range rate components.
HasElevation	Indicates whether measurements contain elevation components.

ObjectAttributes

Attribute	Definition
TargetIndex	Identifier of the actor, ActorID, that generated the detection. For false alarms, this value is negative.
SNR	Detection signal-to-noise ratio in dB.

numValidDets – Number of detections

nonnegative integer

Number of detections, returned as a nonnegative integer.

- When the `MaxNumDetectionsSource` property is set to 'Auto', `numValidDets` is set to the length of `dets`.
- When the `MaxNumDetectionsSource` property is set to 'Property', `dets` is a cell array with length determined by the `MaxNumDetections` property. No more than `MaxNumDetections` number of detections are returned. If the number of detections is fewer than `MaxNumDetections`, the first `numValidDets` elements of `dets` hold valid detections. The remaining elements of `dets` are set to the default value.

Data Types: `double`

isValidTime — Valid detection time

0 | 1

Valid detection time, returned as 0 or 1. `isValidTime` is 0 when detection updates are requested at times that are between update intervals specified by `UpdateInterval`.

Data Types: `logical`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to radarDetectionGenerator

`isLocked` Determine if System object is in use

Common to All System Objects

`step` Run System object algorithm

`release` Release resources and allow changes to System object property values and input characteristics

`reset` Reset internal states of System object

Examples

Generate Radar Detections of Multiple Vehicles

Generate detections using a forward-facing automotive radar mounted on an ego vehicle. Assume that there are three targets:

- Vehicle 1 is in the center lane, directly in front of the ego vehicle, and driving at the same speed.
- Vehicle 2 is in the left lane and driving faster than the ego vehicle by 12 kilometers per hour.
- Vehicle 3 is in the right lane and driving slower than the ego vehicle by 5 kilometers per hour.

All positions, velocities, and measurements are relative to the ego vehicle. Run the simulation for ten steps.

```
dt = 0.1;
pos1 = [150 0 0];
pos2 = [160 10 0];
pos3 = [130 -10 0];
vel1 = [0 0 0];
vel2 = [12*1000/3600 0 0];
vel3 = [-5*1000/3600 0 0];
car1 = struct('ActorID',1,'Position',pos1,'Velocity',vel1);
car2 = struct('ActorID',2,'Position',pos2,'Velocity',vel2);
car3 = struct('ActorID',3,'Position',pos3,'Velocity',vel3);
```

Create an automotive radar sensor that is offset from the ego vehicle. By default, the sensor location is at (3.4,0) meters from the vehicle center and 0.2 meters above the ground plane. Turn off the range rate computation so that the radar sensor measures position only.

```
radar = radarDetectionGenerator('DetectionCoordinates','Sensor Cartesian', ...
    'MaxRange',200,'RangeResolution',10,'AzimuthResolution',10, ...
    'FieldOfView',[40 15],'UpdateInterval',dt,'HasRangeRate',false);
tracker = multiObjectTracker('FilterInitializationFcn',@initcvkf, ...
    'ConfirmationParameters',[3 4],'NumCoastingUpdates',6);
```

Generate detections with the radar from the non-ego vehicles. The output detections form a cell array and can be passed directly in to the `multiObjectTracker`.

```
simTime = 0;
nsteps = 10;
for k = 1:nsteps
```



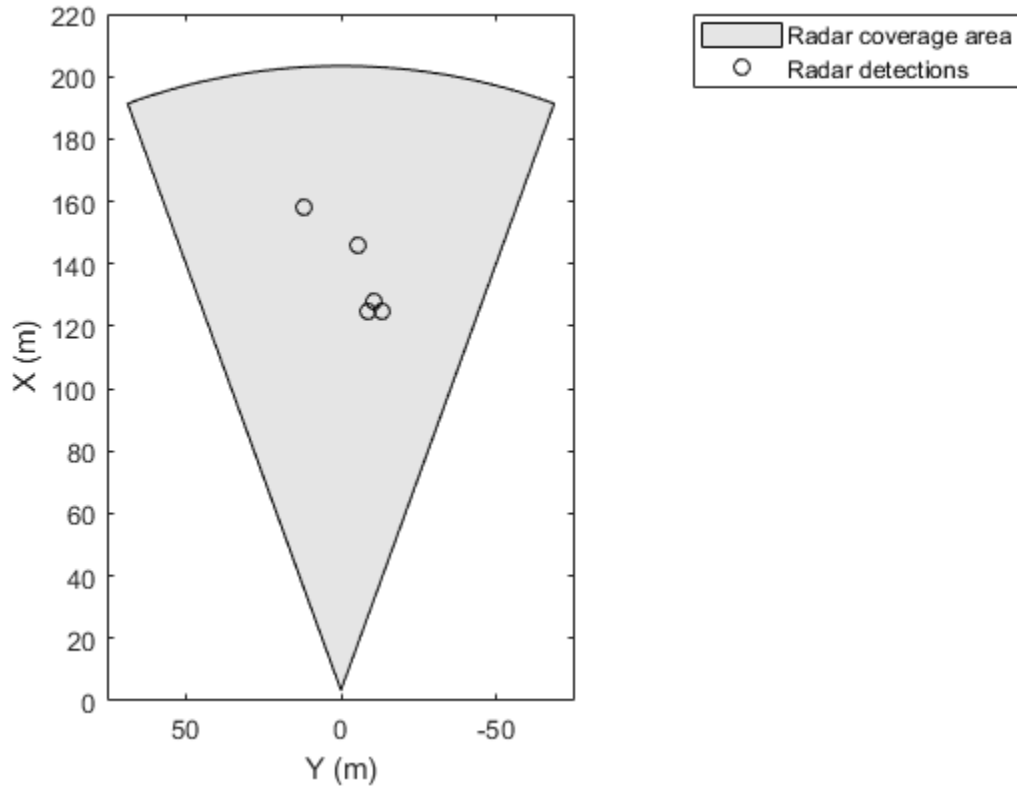
```
dets = radar([car1 car2 car3],simTime);
[confirmedTracks,tentativeTracks,allTracks] = updateTracks(tracker,dets,simTime);
```

Move the cars one time step and update the multi-object tracker.

```
simTime = simTime + dt;
car1.Position = car1.Position + dt*car1.Velocity;
car2.Position = car2.Position + dt*car2.Velocity;
car3.Position = car3.Position + dt*car3.Velocity;
end
```

Use `birdsEyePlot` to create an overhead view of the detections. Plot the sensor coverage area. Extract the X and Y positions of the targets by converting the Measurement fields of the cell array into a MATLAB array. Display the detections on the bird's-eye plot.

```
BEplot = birdsEyePlot('XLim',[0 220],'YLim',[-75 75]);
caPlotter = coverageAreaPlotter(BEplot,'DisplayName','Radar coverage area');
plotCoverageArea(caPlotter,radar.SensorLocation,radar.MaxRange, ...
    radar.Yaw,radar.FieldOfView(1))
detPlotter = detectionPlotter(BEplot,'DisplayName','Radar detections');
detPos = cellfun(@(d)d.Measurement(1:2),dets,'UniformOutput',false);
detPos = cell2mat(detPos)';
if ~isempty(detPos)
    plotDetection(detPlotter,detPos)
end
```



Generate Radar Detections of Occluded Targets

Model the effects of occlusion when generating radar detections from a `radarDetectionGenerator` System object™.

Create two cars. Position the first car 40 meters away from the sensor. Position the second car 10 meters directly behind the first car.

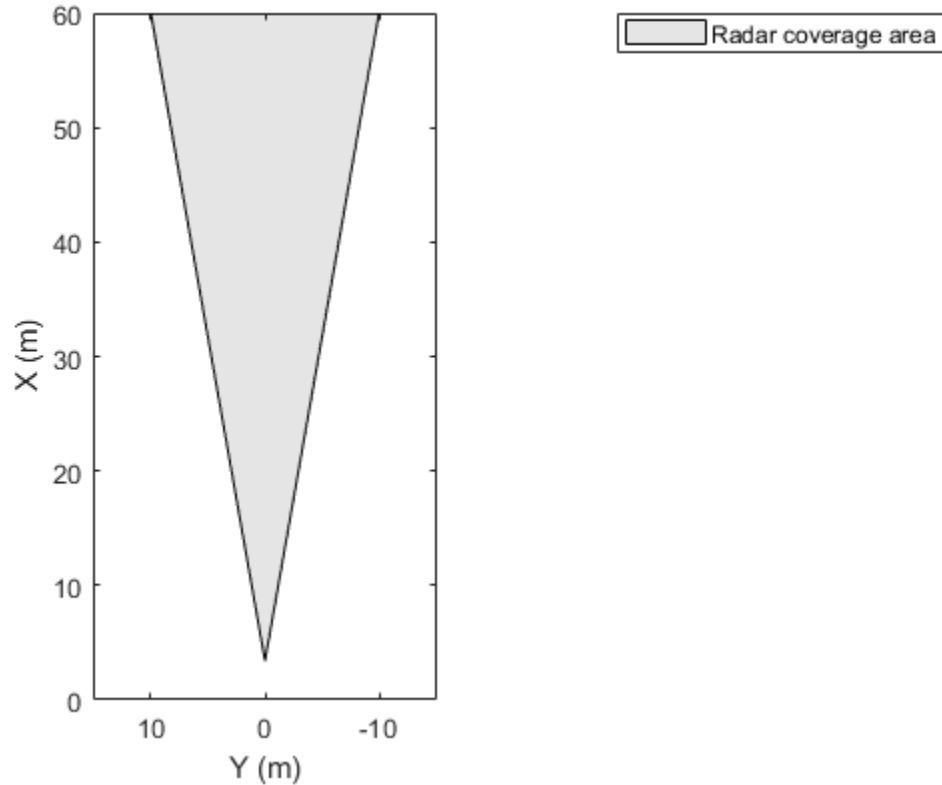
```
car1 = struct('ActorID',1,'Position',[40 0 0]);  
car2 = struct('ActorID',2,'Position',[50 0 0]);
```

Create a radar detection generator System object, `radarSensor`, with default values. Use the System object to generate detections.

```
radarSensor = radarDetectionGenerator;  
simTime = 0; % start of simulation  
[dets,numValidDets] = radarSensor([car1 car2],simTime);
```

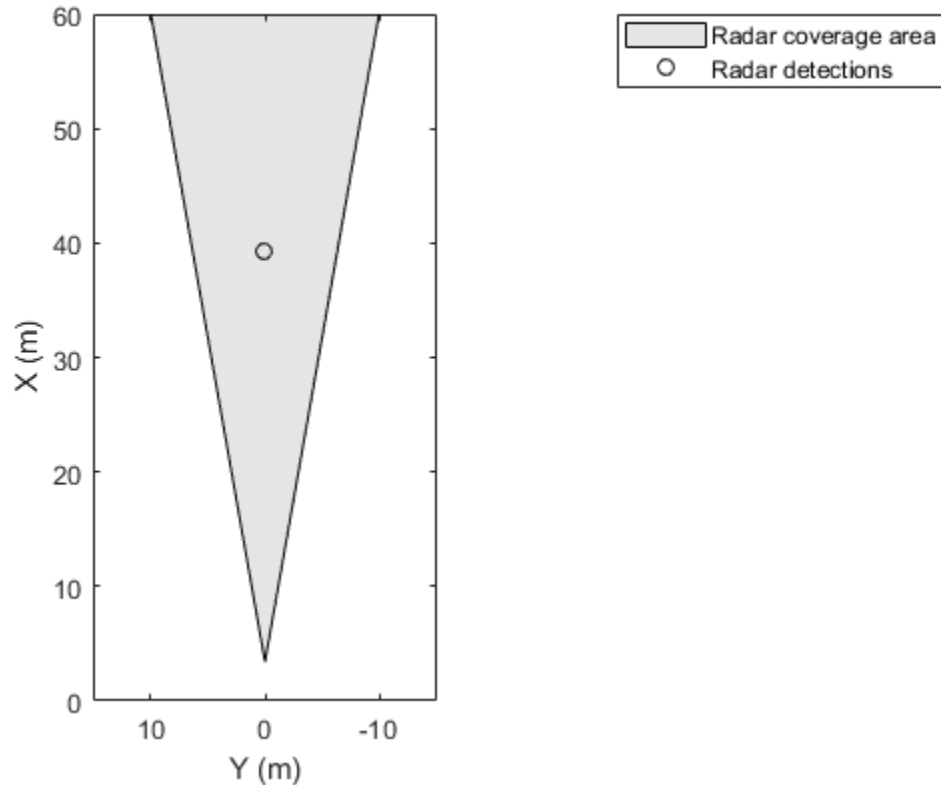
Display the coverage area of the radar detection generator on a bird's-eye plot.

```
bep = birdsEyePlot('XLim',[0 60],'YLim',[-15 15]);  
caPlotter = coverageAreaPlotter(bep,'DisplayName', ...  
    'Radar coverage area');  
plotCoverageArea(caPlotter,radarSensor.SensorLocation, ...  
    radarSensor.MaxRange,radarSensor.Yaw, ...  
    radarSensor.FieldOfView(1));
```



Extract the (X,Y) positions of the targets by converting the (X,Y) values of the Measurement field of the cell array into a MATLAB array. Then, display the detections.

```
if numValidDets > 0
    detPlotter = detectionPlotter(bep, 'DisplayName', 'Radar detections');
    detPos = cellfun(@(d)d.Measurement(1:2),dets, 'UniformOutput', false);
    detPos = cell2mat(detPos)';
    plotDetection(detPlotter, detPos)
end
```

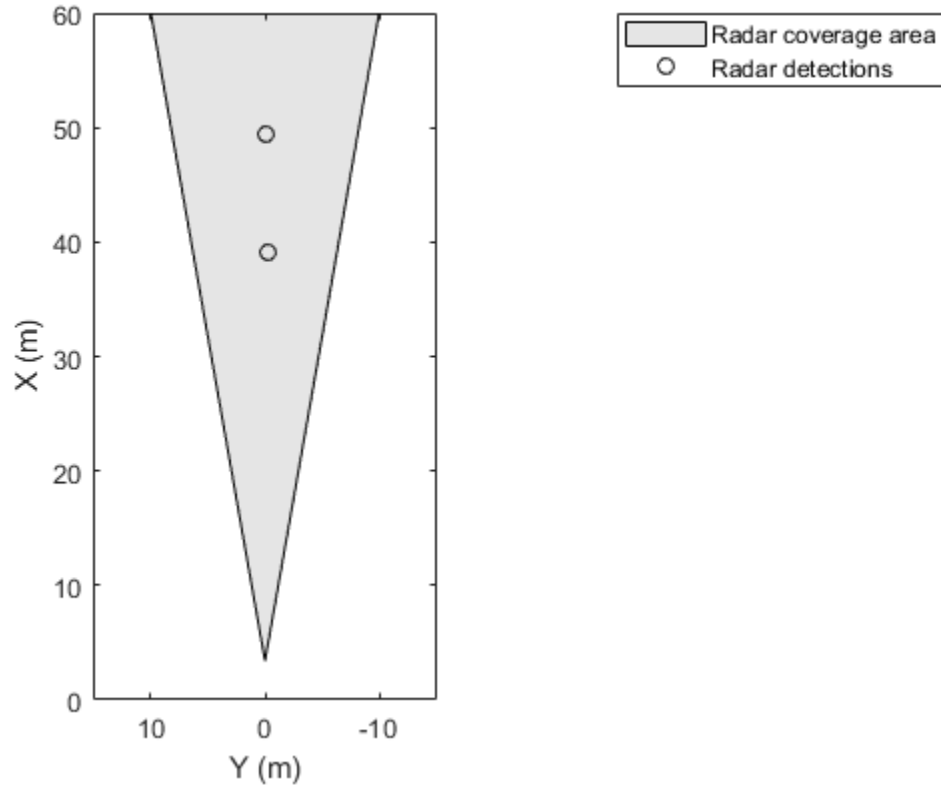


By default, the radar detection generator excludes targets that are occluded by other objects. Therefore, the radar detects the nearest target but not the target directly behind it. To include the occluded target in the detections, release the radar detection generator, disable line-of-sight occlusion, and generate detections again. Display the detections.

```

release(radarSensor)
radarSensor.HasOcclusion = false;
[detsNoOcclusion,numValidDets] = radarSensor([car1 car2],simTime);
if numValidDets > 0
    detPos = cellfun(@(d)d.Measurement(1:2),detsNoOcclusion,'UniformOutput',false);
    detPos = cell2mat(detPos)';
    plotDetection(detPlotter, detPos)
end

```



Release the radar detection generator.

```
release(radarSensor)
```

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

See “System Objects in MATLAB Code Generation” (MATLAB Coder).

See Also

Objects

[drivingScenario](#) | [multiObjectTracker](#) | [objectDetection](#) | [visionDetectionGenerator](#)

Functions

[actorPoses](#) | [actorProfiles](#)

Apps

[Driving Scenario Designer](#)

Topics

[“Model Radar Sensor Detections”](#)

[“Coordinate Systems in Automated Driving Toolbox”](#)

Introduced in R2017a

visionDetectionGenerator

Generate vision detections for driving scenario

Description

The `visionDetectionGenerator` System object generates detections from a monocular camera sensor mounted on an ego vehicle. All detections are referenced to the coordinate system of the ego vehicle or the vehicle-mounted sensor. You can use the `visionDetectionGenerator` object in a scenario containing actors and trajectories, which you can create by using a `drivingScenario` object. Using a statistical mode, the generator can simulate real detections with added random noise and also generate false alarm detections. In addition, you can use the `visionDetectionGenerator` object to create input to a `multiObjectTracker`. When building scenarios using the **Driving Scenario Designer** app, the camera sensors mounted on the ego vehicle are output as `visionDetectionGenerator` objects.

To generate visual detections:

- 1 Create the `visionDetectionGenerator` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects? \(MATLAB\)](#).

Creation

Syntax

```
sensor = visionDetectionGenerator
sensor = visionDetectionGenerator(cameraConfig)
sensor = visionDetectionGenerator(Name,Value)
```


Description

`sensor = visionDetectionGenerator` creates a vision detection generator object with default property values.

`sensor = visionDetectionGenerator(cameraConfig)` creates a vision detection generator object using the `monoCamera` configuration object, `cameraConfig`.

`sensor = visionDetectionGenerator(Name,Value)` sets properties on page 4-219 using one or more name-value pairs. For example, `visionDetectionGenerator('DetectionCoordinates','SensorCartesian','MaxRange',200)` creates a vision detection generator that reports detections in the sensor Cartesian coordinate system and has a maximum detection range of 200 meters. Enclose each property name in quotes.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects (MATLAB)*.

DetectorOutput — Types of detections generated by sensor

'Objects only' (default) | 'Lanes only' | 'Lanes with occlusion' | 'Lanes and objects'

Types of detections generated by the sensor, specified as 'Objects only', 'Lanes only', 'Lanes with occlusion', or 'Lanes and objects'.

- When set to 'Objects only', only actors are detected.
- When set to 'Lanes only', only lanes are detected.
- When set to 'Lanes with occlusion', only lanes are detected but actors in the camera field of view can impair the sensor ability to detect lanes.
- When set to 'Lanes and objects', the sensor generates both object detections and occluded lane detections.

Example: 'Lanes with occlusion'

Data Types: char | string

SensorIndex — Unique sensor identifier

positive integer

Unique sensor identifier, specified as a positive integer. This property distinguishes detections that come from different sensors in a multi-sensor system.

Example: 5

Data Types: double

UpdateInterval — Required time interval between sensor updates

0.1 | positive real scalar

Required time interval between sensor updates, specified as a positive real scalar. The `drivingScenario` object calls the vision detection generator at regular time intervals. The vision detector generates new detections at intervals defined by the `UpdateInterval` property. The value of the `UpdateInterval` property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Example: 5

Data Types: double

SensorLocation — Sensor location

[3.4 0] | [x y] vector

Location of the vision sensor center, specified as an [x y]. The `SensorLocation` and `Height` properties define the coordinates of the vision sensor with respect to the ego vehicle coordinate system. The default value corresponds to a forward-facing sensor mounted on a vehicle dashboard. Units are in meters.

Example: [4 0.1]

Data Types: double

Height — Sensor height above ground plane

1.1 | positive real scalar

Sensor height above the vehicle ground plane, specified as a positive real scalar. The default value corresponds to a forward-facing vision sensor mounted on the dashboard of a sedan. Units are in meters.

Example: 1.5

Data Types: double

Yaw — Yaw angle of vision sensor

θ | real scalar

Yaw angle of vision sensor, specified as a real scalar. The yaw angle is the angle between the center line of the ego vehicle and the down-range axis of the vision sensor. A positive yaw angle corresponds to a clockwise rotation when looking in the positive direction of the z-axis of the ego vehicle coordinate system. Units are in degrees.

Example: -4

Data Types: double

Pitch — Pitch angle of vision sensor

θ | real scalar

Pitch angle of vision sensor, specified as a real scalar. The pitch angle is the angle between the down-range axis of the vision sensor and the x-y plane of the ego vehicle coordinate system. A positive pitch angle corresponds to a clockwise rotation when looking in the positive direction of the y-axis of the ego vehicle coordinate system. Units are in degrees.

Example: 3

Data Types: double

Roll — Roll angle of vision sensor

θ | real scalar

Roll angle of the vision sensor, specified as a real scalar. The roll angle is the angle of rotation of the down-range axis of the vision sensor around the x-axis of the ego vehicle coordinate system. A positive roll angle corresponds to a clockwise rotation when looking in the positive direction of the x-axis of the coordinate system. Units are in degrees.

Example: -4

Data Types: double

Intrinsics — Intrinsic calibration parameters of vision sensor

`cameraIntrinsics([800 800],[320 240],[480 640])` (default) |
`cameraIntrinsics` object

Intrinsic calibration parameters of vision sensor, specified as a `cameraIntrinsics` object.

FieldOfView — Angular field of view of vision sensor

real-valued 1-by-2 vector of positive values

This property is read-only.

Angular field of view of vision sensor, specified as a real-valued 1-by-2 vector of positive values, `[azfov, elfov]`. The field of view defines the azimuth and elevation extents of the sensor image. Each component must lie in the interval from 0 degrees to 180 degrees. The field of view is derived from the intrinsic parameters of the vision sensor. Targets outside of the angular field of view of the sensor are not detected. Units are in degrees.

Data Types: `double`

MaxRange — Maximum detection range

150 | positive real scalar

Maximum detection range, specified as a positive real scalar. The sensor cannot detect a target beyond this range. Units are in meters.

Example: 200

Data Types: `double`

MaxSpeed — Maximum detectable object speed

50 (default) | nonnegative real scalar

Maximum detectable object speed, specified as a nonnegative real scalar. Units are in meters per second.

Example: 10.0

Data Types: `double`

MaxAllowedOcclusion — Maximum allowed occlusion of an object

0.5 (default) | real scalar in the range [0 1]

Maximum allowed occlusion of an object, specified as a real scalar in the range [0 1]. Occlusion is the fraction of the total surface area of an object not visible to the sensor. A value of one indicates that the object is fully occluded. Units are dimensionless.

Example: 0.2

Data Types: double

DetectionProbability — Probability of detection

0.9 (default) | positive real scalar less than or equal to 1

Probability of detecting a target, specified as a positive real scalar less than or equal to 1. This quantity defines the probability that the sensor detects a detectable object. A detectable object is an object that satisfies the minimum detectable size, maximum range, maximum speed, and maximum allowed occlusion constraints.

Example: 0.95

Data Types: double

FalsePositivesPerImage — Number of false detections per image

0.1 (default) | nonnegative real scalar

Number of false detections that the vision sensor generates for each image, specified as a nonnegative real scalar.

Example: 2

Data Types: double

MinObjectImageSize — Minimum image size of detectable object

[15 15] (default) | 1-by-2 vector of positive values

Minimum height and width of an object that the vision sensor detects within an image, specified as a [minHeight, minWidth] vector of positive values. The 2-D projected height of an object must be greater than or equal to minHeight. The projected width of an object must be greater than or equal to minWidth. Units are in pixels.

Example: [30 20]

Data Types: double

BoundingBoxAccuracy — Bounding box accuracy

5 (default) | positive real scalar

Bounding box accuracy, specified as a positive real scalar. This quantity defines the accuracy with which the detector can match a bounding box to a target. Units are in pixels.

Example: 4

Data Types: double

ProcessNoiseIntensity — Noise intensity used for filtering position and velocity measurements

5 (default) | positive real scalar

Noise intensity used for filtering position and velocity measurements, specified as a positive real scalar. Noise intensity defines the standard deviation of the process noise of the internal constant-velocity Kalman filter used in a vision sensor. The filter models the process noise using a piecewise-constant white noise acceleration model. Noise intensity is typically of the order of the maximum acceleration magnitude expected for a target. Units are in m/s^2 .

Example: 2.5

Data Types: double

HasNoise — Enable adding noise to vision sensor measurements

true (default) | false

Enable adding noise to vision sensor measurements, specified as true or false. Set this property to true to add noise to the sensor measurements. Otherwise, the measurements have no noise. Even if you set HasNoise to false, the object still computes the MeasurementNoise property of each detection.

Data Types: logical

MaxNumDetectionsSource — Source of maximum number of detections reported

'Auto' (default) | 'Property'

Source of maximum number of detections reported by the sensor, specified as 'Auto' or 'Property'. When this property is set to 'Auto', the sensor reports all detections. When this property is set to 'Property', the sensor reports no more than the number of detections specified by the MaxNumDetections property.

Data Types: char | string

MaxNumDetections — Maximum number of reported detections

50 (default) | positive integer

Maximum number of detections reported by the sensor, specified as a positive integer. The detections closest to the sensor are reported.

Dependencies

To enable this property, set the MaxNumDetectionsSource property to 'Property'.

Data Types: double

DetectionCoordinates — Coordinate system of reported detections

'Ego Cartesian' (default) | 'Sensor Cartesian'

Coordinate system of reported detections, specified as one of these values:

- 'Ego Cartesian' — Detections are reported in the ego vehicle Cartesian coordinate system.
- 'Sensor Cartesian' — Detections are reported in the sensor Cartesian coordinate system.

Data Types: char | string

LaneUpdateInterval — Required time interval between lane detection updates

0.1 (default) | positive real scalar

Required time interval between lane detection updates, specified as a positive real scalar. The `drivingScenario` object calls the vision detection generator at regular time intervals. The vision detector generates new lane detections at intervals defined by this property which must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no lane detections. Units are in seconds.

Example: 0.4

Data Types: double

MinLaneImageSize — Minimum lane size in image

[20 5] (default) | 1-by-2 real-valued vector

Minimum size of a projected lane marking that can be detected by the sensor after accounting for curvature, specified as a 1-by-2 real-valued vector, [`minHeight` `minWidth`]. Lane markings must exceed both of these values to be detected. This property is used only when detecting lanes. Units are in pixels.

Example: [5,7]

Data Types: double

LaneBoundaryAccuracy — Accuracy of lane boundaries

3 | positive real scalar

Accuracy of lane boundaries, specified as a positive real scalar. This property defines the accuracy with which the lane sensor can place a lane boundary. Units are in pixels. This property is used only when detecting lanes.

MaxNumLanesSource — Source of maximum number of reported lanes

'Property' (default) | 'Auto'

Source of maximum number of reported lanes, specified as 'Auto' or 'Property'. When specified as 'Auto', the maximum number of lanes is computed automatically. When specified as 'Property', use the MaxNumLanes property to set the maximum number of lanes.

Data Types: char | string

MaxNumLanes — Maximum number of reported lanes

30 (default) | positive integer

Maximum number of reported lanes, specified as a positive integer.

Dependencies

To enable this property, set the MaxNumLanesSource property to 'Property'.

Data Types: char | string

ActorProfiles — Actor profiles

structure | array of structures

Actor profiles, specified as structure or as an array of structures. Each structure contains the physical and radar characteristics of an actor.

- If ActorProfiles is a single structure, all actors passed into the visionDetectionGenerator object use this profile.
- If ActorProfiles is an array, each actor passed into the object must have a unique actor profile.

To generate an array of structures for your driving scenario, use the actorProfiles function. The table shows the valid structure fields. If you do not specify a field, the fields are set to their default values. If no actors are passed into the object, then the ActorID field is not included.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
ClassID	Classification identifier, specified as a nonnegative integer. 0 is reserved for an object of an unknown or unassigned class.
Length	Length of actor, specified as a positive real scalar. The default is 4.7. Units are in meters.
Width	Width of actor, specified as a positive real scalar. The default is 1.8. Units are in meters.
Height	Height of actor, specified as a positive real scalar. The default is 1.4. Units are in meters.
OriginOffset	Offset of actor's rotational center from its geometric center, specified as an $[x,y,z]$ real-valued vector. The rotational center, or origin, is located at the bottom center of the actor. For vehicles, the rotational center is the point on the ground beneath the center of the rear axle. The default is $[0\ 0\ 0]$. Units are in meters.
RCSPattern	Radar cross-section pattern of actor, specified as a $\text{numel}(\text{RCSElevationAngles})$ -by- $\text{numel}(\text{RCSAzimuthAngles})$ real-valued matrix. The default is $[10\ 10; 10\ 10]$. Units are in decibels per square meter.
RCSAzimuthAngles	Azimuth angles corresponding to rows of RCSPattern, specified as a vector of real values in the range $[-180, 180]$. The default is $[-180\ 180]$. Units are in degrees.

Field	Description
RCSElevationAngles	Elevation angles corresponding to rows of RCSPattern, specified as a vector of real values in the range [-90, 90]. The default is [-90 90]. Units are in degrees.

For full definitions of the structure fields, see the `actor` and `vehicle` functions.

Usage

Syntax

```
dets = sensor(actors,time)
lanedets = sensor(laneboundaries,time)
lanedets = sensor(actors,laneboundaries,time)
[___,numValidDets] = sensor(___ )
[___,numValidDets,isValidTime] = sensor(___ )
[dets,numValidDets,isValidTime,lanedets,numValidLaneDets,
isValidLaneTime] = sensor(actors,laneboundaries,time)
```

Description

`dets = sensor(actors,time)` creates visual detections, `dets`, from sensor measurements taken of `actors` at the current simulation time. The object can generate sensor detections for multiple actors simultaneously. Do not include the ego vehicle as one of the actors.

To enable this syntax, set `DetectionOutput` to 'Objects only'.

`lanedets = sensor(laneboundaries,time)` generates lane detections, `lanedets`, from lane boundary structures, `laneboundaries`.

To enable this syntax set `DetectionOutput` to 'Lanes only'. The lane detector generates lane boundaries at intervals specified by the `LaneUpdateInterval` property.

`lanedets = sensor(actors,laneboundaries,time)` generates lane detections, `lanedets`, from lane boundary structures, `laneboundaries`.

To enable this syntax, set `DetectionOutput` to 'Lanes with occlusion'. The lane detector generates lane boundaries at intervals specified by the `LaneUpdateInterval` property.

`[____, numValidDets] = sensor(____)` also returns the number of valid detections reported, `numValidDets`.

`[____, numValidDetsisValidTime] = sensor(____)` also returns a logical value, `isValidTime`, indicating that the `UpdateInterval` time to generate detections has elapsed.

`[dets, numValidDets, isValidTime, lanedets, numValidLaneDets, isValidLaneTime] = sensor(actors, laneboundaries, time)` returns both object detections, `dets`, and lane detections `lanedets`. This syntax also returns the number of valid lane detections reported, `numValidLaneDets`, and a flag, `isValidLaneTime`, indicating whether the required simulation time to generate lane detections has elapsed.

To enable this syntax, set `DetectionOutput` to 'Lanes and objects'.

Input Arguments

actors — Scenario actor poses

structure | structure array

Scenario actor poses, specified as a structure or structure array. Each structure corresponds to an actor. You can generate this structure using the `actorPoses` function. You can also create these structures manually. The table shows the fields that the object uses to generate detections. All other fields are ignored.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x -, y -, and z -directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.

Field	Description
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x-, y-, and z-directions, specified as an $[\omega_x \ \omega_y \ \omega_z]$ real-valued vector. Units are in degrees per second.

For full definitions of the structure fields, see the `actor` and `vehicle` functions.

Dependencies

To enable this argument, set the `DetectorOutput` property to 'Objects only', 'Lanes with occlusion', or 'Lanes and objects'.

laneboundaries — Lane boundaries

array of lane boundary structures

Lane boundaries, specified as an array of lane boundary structures. The table shows the fields for each structure.

Field	Description
Coordinates	Lane boundary coordinates, specified as a real-valued N -by-3 matrix, where N is the number of lane boundaries. Lane boundary coordinates define the position of points on the boundary at distances specified by the 'XDistance' name-value pair argument of the <code>laneBoundaries</code> function. In addition, a set of boundary coordinates are inserted into the matrix at zero distance. Units are in meters.

Curvature	Lane boundary curvature at each row of the <code>Coordinates</code> matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per meter.
CurvatureDerivative	Derivative of lane boundary curvature at each row of the <code>Coordinates</code> matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per square meter.
HeadingAngle	Initial lane boundary heading angle, specified as a real scalar. The heading angle of the lane boundary is relative to the ego vehicle heading. Units are in degrees.
LateralOffset	Distance of the lane boundary from the ego vehicle position, specified as a real scalar. An offset to a lane boundary to the left of the ego vehicle is positive. An offset to the right of the ego vehicle is negative. Units are in meters.
BoundaryType	Type of lane boundary marking, specified as one of these values: <ul style="list-style-type: none"> • 'Unmarked' — No physical lane marker exists • 'Solid' — Single unbroken line • 'Dashed' — Single line of dashed lane markers • 'DoubleSolid' — Two unbroken lines • 'DoubleDashed' — Two dashed lines • 'SolidDashed' — Solid line on the left and a dashed line on the right • 'DashedSolid' — Dashed line on the left and a solid line on the right

Strength	Saturation strength of the lane boundary marking, specified as a real scalar from 0 to 1. A value of 0 corresponds to a marking whose color is fully unsaturated. The marking appears gray. A value of 1 corresponds to a marking whose color is fully saturated.
Width	Lane boundary width, specified as a positive real scalar. In a double-line lane marker, the same width is used for both lines and for the space between lines. Units are in meters.
Length	Length of dash in dashed lines, specified as a positive real scalar. In a double-line lane marker, the same length is used for both lines.
Space	Length of space between dashes in dashed lines, specified as a positive real scalar. In a dashed double-line lane marker, the same space is used for both lines.

Dependencies

To enable this argument, set the `DetectorOutput` property to 'Lanes only', 'Lanes with occlusion', or 'Lanes and objects'.

Data Types: `struct`

time – Current simulation time

positive real scalar

Current simulation time, specified as a positive real scalar. The `drivingScenario` object calls the vision detection generator at regular time intervals. The vision detector generates new detections at intervals defined by the `UpdateInterval` property. The values of the `UpdateInterval` and `LanesUpdateInterval` properties must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals contain no detections. Units are in seconds.

Example: 10.5

Data Types: `double`

Output Arguments

dets — Object detections

cell array of `objectDetection` objects

Object detections, returned as a cell array of `objectDetection` objects. Each object contains these fields:

Property	Definition
Time	Measurement time
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor
ObjectClassID	Object classification
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

Measurement, MeasurementNoise, and MeasurementParameters are reported in the coordinate system specified by the `DetectionCoordinates` property of the `visionDetectionGenerator`.

Measurement

DetectionCoordinates Property	Measurement and Measurement Noise Coordinates
'Ego Cartesian'	[x;y;z;vx;vy;vz]
'Sensor Cartesian'	

MeasurementParameters

Parameter	Definition
Frame	Enumerated type indicating the frame used to report measurements. When Frame is set to 'rectangular', detections are reported in Cartesian coordinates. When Frame is set 'spherical', detections are reported in spherical coordinates.
OriginPosition	3-D vector offset of the sensor origin from the ego vehicle origin. The vector is derived from the SensorLocation and Height properties specified in the visionDetectionGenerator.
Orientation	Orientation of the vision sensor coordinate system with respect to the ego vehicle coordinate system. The orientation is derived from the Yaw, Pitch, and Roll properties of the visionDetectionGenerator.
HasVelocity	Indicates whether measurements contain velocity or range rate components.

ObjectAttributes

Attribute	Definition
TargetIndex	Identifier of the actor, ActorID, that generated the detection. For false alarms, this value is negative.

numValidDets – Number of detections

nonnegative integer

Number of detections returned, defined as a nonnegative integer.

- When the MaxNumDetectionsSource property is set to 'Auto', numValidDets is set to the length of dets.
- When the MaxNumDetectionsSource is set to 'Property', dets is a cell array with length determined by the MaxNumDetections property. No more than

MaxNumDetections number of detections are returned. If the number of detections is fewer than **MaxNumDetections**, the first **numValidDets** elements of **dets** hold valid detections. The remaining elements of **dets** are set to the default value.

Data Types: `double`

isValidTime – Valid detection time

0 | 1

Valid detection time, returned as 0 or 1. **isValidTime** is 0 when detection updates are requested at times that are between update intervals specified by **UpdateInterval**.

Data Types: `logical`

lanedets – Lane boundary detections

lane boundary detection structure

Lane boundary detections, returned as an array structures. The fields of the structure are:

Lane Boundary Detection Structure

Field	Description
Time	Lane detection time
SensorIndex	Unique identifier of sensor
LaneBoundaries	Array of <code>clothoidLaneBoundary</code> objects.

numValidLaneDets – Number of detections

nonnegative integer

Number of lane detections returned, defined as a nonnegative integer.

- When the **MaxNumLanesSource** property is set to 'Auto', **numValidLaneDets** is set to the length of **lanedets**.
- When the **MaxNumLanesSource** is set to 'Property', **lanedets** is a cell array with length determined by the **MaxNumLanes** property. No more than **MaxNumLanes** number of lane detections are returned. If the number of detections is fewer than **MaxNumLanes**, the first **numValidLaneDetections** elements of **lanedets** hold valid lane detections. The remaining elements of **lanedets** are set to the default value.

Data Types: `double`

isValidLaneTime — Valid lane detection time

0 | 1

Valid lane detection time, returned as 0 or 1. `isValidLaneTime` is 0 when lane detection updates are requested at times that are between update intervals specified by `LaneUpdateInterval`.

Data Types: `logical`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to visionDetectionGenerator

`isLocked` Determine if System object is in use

Common to All System Objects

`step` Run System object algorithm

`release` Release resources and allow changes to System object property values and input characteristics

`reset` Reset internal states of System object

Examples

Generate Visual Detections of Multiple Vehicles

Generate detections using a forward-facing automotive vision sensor mounted on an ego vehicle. Assume that there are two target vehicles:

- Vehicle 1 is directly in front of the ego vehicle and moving at the same speed.

- Vehicle 2 vehicle is driving faster than the ego vehicle by 12 kph in the left lane.

All positions, velocities, and measurements are relative to the ego vehicle. Run the simulation for ten steps.

```
dt = 0.1;
car1 = struct('ActorID',1,'Position',[100 0 0],'Velocity',[5*1000/3600 0 0]);
car2 = struct('ActorID',2,'Position',[150 10 0],'Velocity',[12*1000/3600 0 0]);
```

Create an automotive vision sensor having a location offset from the ego vehicle. By default, the sensor location is at (3.4,0) meters from the vehicle center and 1.1 meters above the ground plane..

```
sensor = visionDetectionGenerator('DetectionProbability',1, ...
    'MinObjectImageSize',[5 5],'MaxRange',200,'DetectionCoordinates','Sensor Cartesian
tracker = multiObjectTracker('FilterInitializationFcn',@initcvkf, ...
    'ConfirmationParameters',[3 4],'NumCoastingUpdates',6);
```

Generate visual detections for the non-ego actors as they move. The output detections form a cell array. Extract only position information from the detections to pass to the multiObjectTracker, which expects only position information. The Update the tracker for each new set of detections.

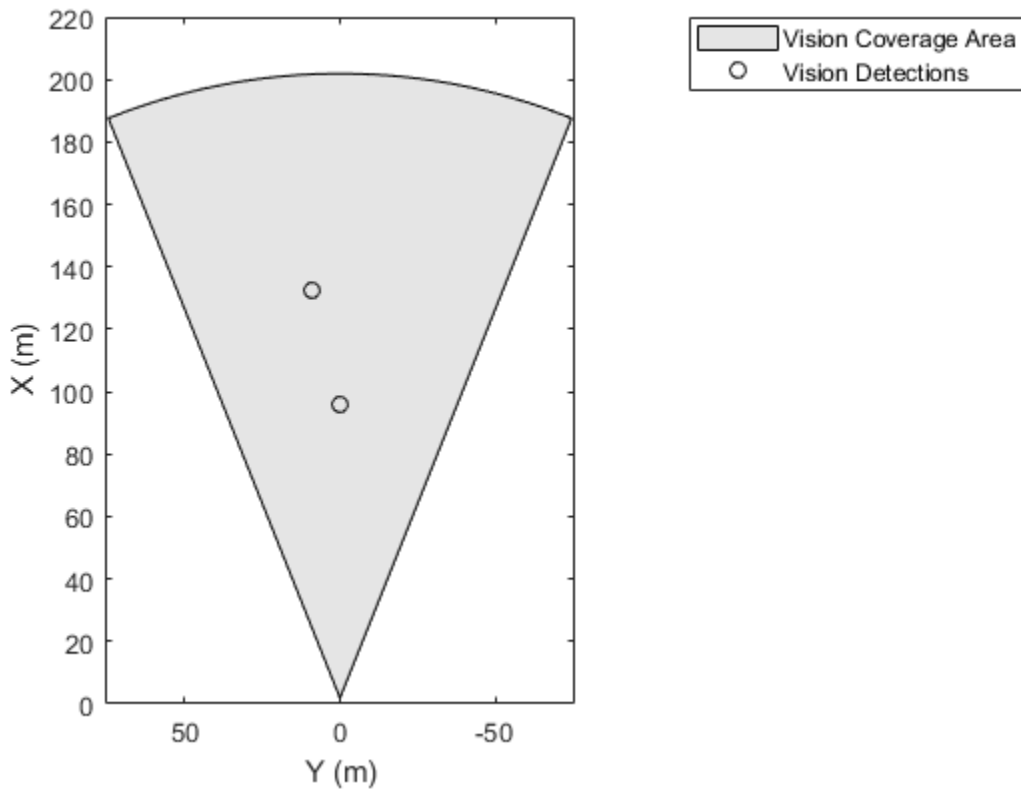
```
simTime = 0;
nsteps = 10;
for k = 1:nsteps
    dets = sensor([car1 car2],simTime);
    n = size(dets,1);
    for k = 1:n
        meas = dets{k}.Measurement(1:3);
        dets{k}.Measurement = meas;
        measmtx = dets{k}.MeasurementNoise(1:3,1:3);
        dets{k}.MeasurementNoise = measmtx;
    end
    [confirmedTracks,tentativeTracks,allTracks] = updateTracks(tracker,dets,simTime);
    simTime = simTime + dt;
    car1.Position = car1.Position + dt*car1.Velocity;
    car2.Position = car2.Position + dt*car2.Velocity;
end
```

Use `birdsEyePlot` to create an overhead view of the detections. Plot the sensor coverage area. Extract the x and y positions of the targets by converting the Measurement fields of the cell into a MATLAB® array. Then, plot the detections using `birdsEyePlot` functions.

```

BEplot = birdsEyePlot('XLim',[0 220],'YLim',[-75 75]);
caPlotter = coverageAreaPlotter(BEplot,'DisplayName','Vision Coverage Area');
plotCoverageArea(caPlotter,sensor.SensorLocation,sensor.MaxRange, ...
    sensor.Yaw,sensor.FieldOfView(1))
detPlotter = detectionPlotter(BEplot,'DisplayName','Vision Detections');
detPos = cellfun(@(d)d.Measurement(1:2),dets,'UniformOutput',false);
detPos = cell2mat(detPos)';
if ~isempty(detPos)
    plotDetection(detPlotter,detPos)
end

```



Generate Visual Detections from Monocular Camera

Create a vision sensor by using a monocular camera configuration, and generate detections from that sensor.

Specify the intrinsic parameters of the camera and create a `monoCamera` object from these parameters. The camera is mounted on top of an ego vehicle at a height of 1.5 meters above the ground and a pitch of 1 degree toward the ground.

```
focalLength = [800 800];
principalPoint = [320 240];
imageSize = [480 640];
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);

height = 1.5;
pitch = 1;
monoCamConfig = monoCamera(intrinsics,height,'Pitch',pitch);
```

Create a vision detection generator using the monocular camera configuration.

```
visionSensor = visionDetectionGenerator(monoCamConfig);
```

Generate a driving scenario with an ego vehicle and two target cars. Position the first target car 30 meters directly in front of the ego vehicle. Position the second target car 20 meters in front of the ego vehicle but offset to the left by 3 meters.

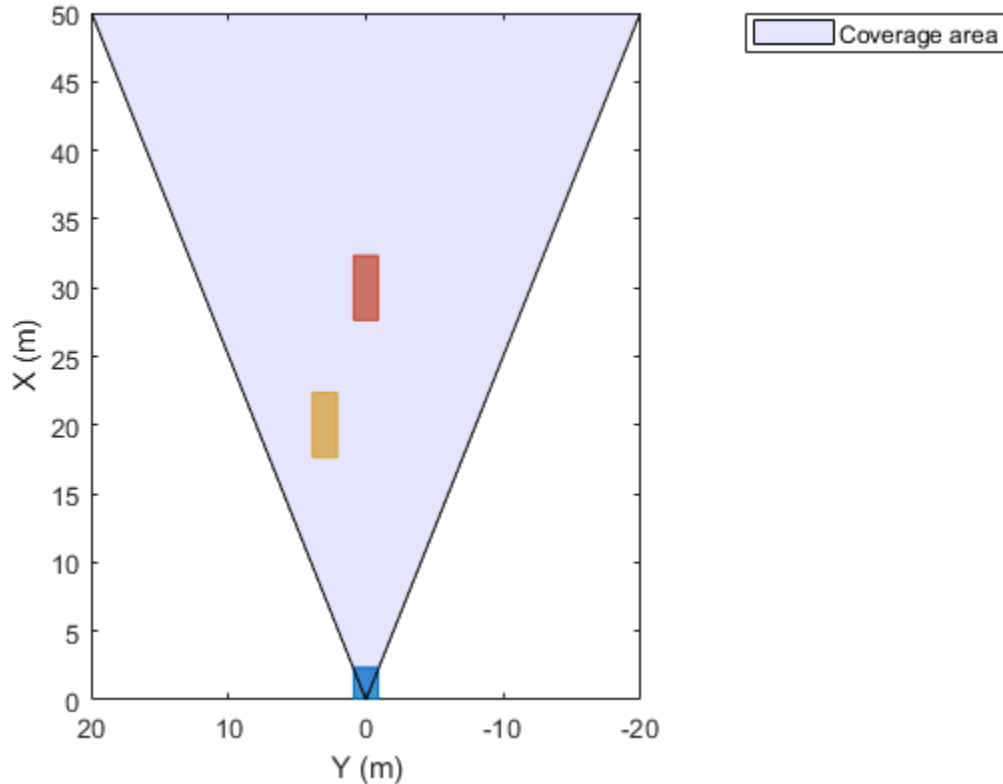
```
scenario = drivingScenario;
egoVehicle = vehicle(scenario);
targetCar1 = vehicle(scenario,'Position',[30 0 0]);
targetCar2 = vehicle(scenario,'Position',[20 3 0]);
```

Use a bird's-eye plot to display the vehicle outlines and sensor coverage area.

```
figure
bep = birdsEyePlot('XLim',[0 50],'YLim',[-20 20]);

olPlotter = outlinePlotter(bep);
[position,yaw,length,width,originOffset,color] = targetOutlines(egoVehicle);
plotOutline(olPlotter,position,yaw,length,width);

caPlotter = coverageAreaPlotter(bep,'DisplayName','Coverage area','FaceColor','blue');
plotCoverageArea(caPlotter,visionSensor.SensorLocation,visionSensor.MaxRange, ...
    visionSensor.Yaw,visionSensor.FieldOfView(1))
```



Obtain the poses of the target cars from the perspective of the ego vehicle. Use these poses to generate detections from the sensor.

```
poses = targetPoses(egoVehicle);
[dets,numValidDets] = visionSensor(poses,scenario.SimulationTime);
```

Display the (X,Y) positions of the valid detections. For each detection, the (X,Y) positions are the first two values of the Measurement field.

```
for i = 1:numValidDets
    XY = dets{i}.Measurement(1:2);
    detXY = sprintf('Detection %d: X = %.2f meters, Y = %.2f meters',i,XY);
    disp(detXY)
end
```

Detection 1: X = 19.09 meters, Y = 2.79 meters
Detection 2: X = 27.81 meters, Y = 0.08 meters

Generate Object and Lane Boundary Detections

Create a driving scenario containing an ego vehicle and a target vehicle traveling along a three-lane road. Detect the lane boundaries by using a vision detection generator.

```
scenario = drivingScenario;
```

Create a three-lane road by using lane specifications.

```
roadCenters = [0 0 0; 60 0 0; 120 30 0];  
lspc = lanespec(3);  
road(scenario, roadCenters, 'Lanes', lspc);
```

Specify that the ego vehicle follows the center lane at 30 m/s.

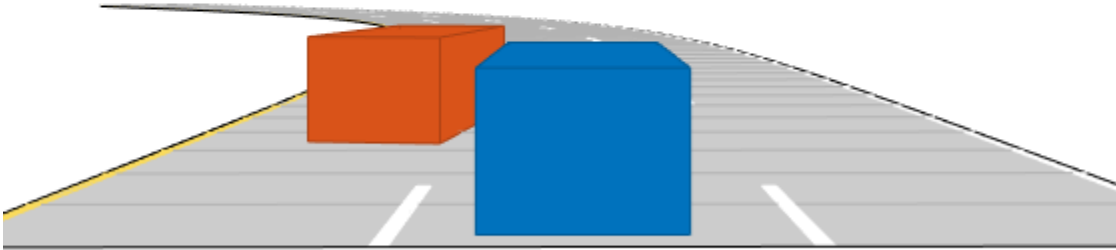
```
egovehicle = vehicle(scenario);  
egopath = [1.5 0 0; 60 0 0; 111 25 0];  
egospeed = 30;  
trajectory(egovehicle, egopath, egospeed);
```

Specify that the target vehicle travels ahead of the ego vehicle at 40 m/s and changes lanes close to the ego vehicle.

```
targetcar = vehicle(scenario, 'ClassID', 2);  
targetpath = [8 2; 60 -3.2; 120 33];  
targetspeed = 40;  
trajectory(targetcar, targetpath, targetspeed);
```

Display a chase plot for a 3-D view of the scenario from behind the ego vehicle.

```
chasePlot(egovehicle)
```



Create a vision detection generator that detects lanes and objects. The pitch of the sensor points one degree downward.

```
visionSensor = visionDetectionGenerator('Pitch',1.0);  
visionSensor.DetectorOutput = 'Lanes and objects';  
visionSensor.ActorProfiles = actorProfiles(scenario);
```

Run the simulation.

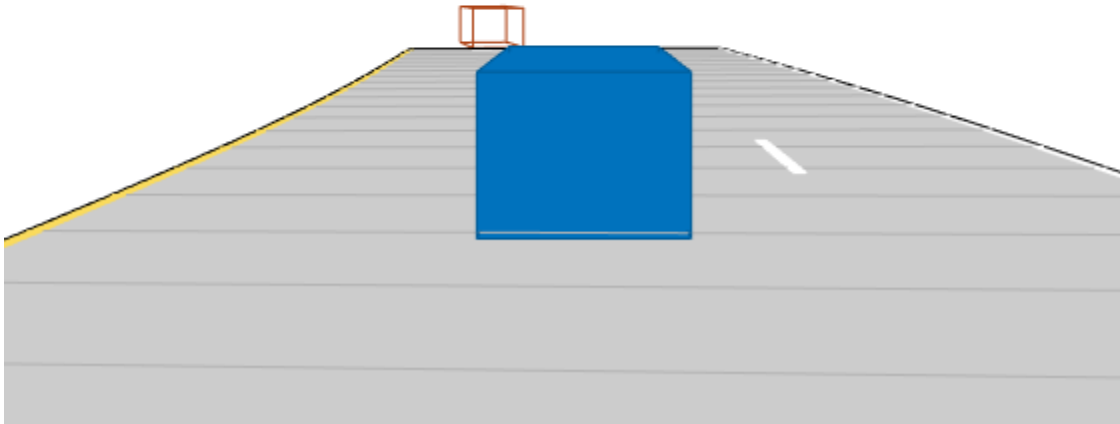
- 1 Create a bird's-eye plot and the associated plotters.
- 2 Display the sensor coverage area.
- 3 Display the lane markings.

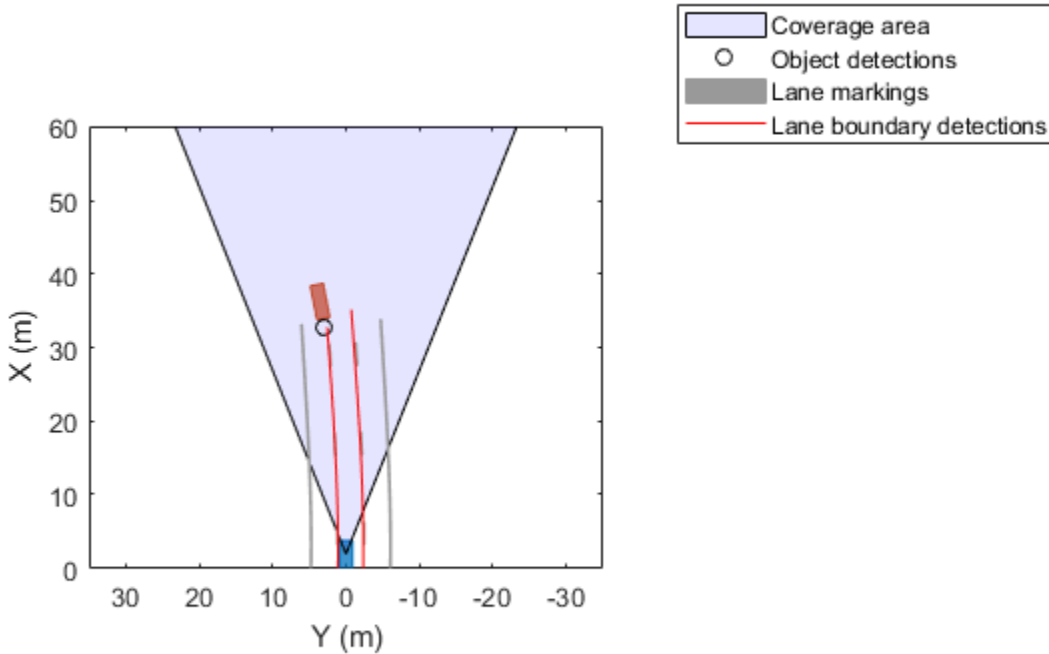
- 4 Obtain ground truth poses of targets on the road.
- 5 Obtain ideal lane boundary points up to 60 m ahead.
- 6 Generate detections from the ideal target poses and lane boundaries.
- 7 Display the outline of the target.
- 8 Display object detections when the object detection is valid.
- 9 Display the lane boundary when the lane detection is valid.

```

bep = birdsEyePlot('XLim',[0 60],'YLim',[-35 35]);
caPlotter = coverageAreaPlotter(bep,'DisplayName','Coverage area', ...
    'FaceColor','blue');
detPlotter = detectionPlotter(bep,'DisplayName','Object detections');
lmPlotter = laneMarkingPlotter(bep,'DisplayName','Lane markings');
lbPlotter = laneBoundaryPlotter(bep,'DisplayName', ...
    'Lane boundary detections','Color','red');
olPlotter = outlinePlotter(bep);
plotCoverageArea(caPlotter,visionSensor.SensorLocation,...
    visionSensor.MaxRange,visionSensor.Yaw, ...
    visionSensor.FieldOfView(1));
while advance(scenario)
    [lmv,lmf] = laneMarkingVertices(egovehicle);
    plotLaneMarking(lmPlotter,lmv,lmf)
    tgtpose = targetPoses(egovehicle);
    lookaheadDistance = 0:0.5:60;
    lb = laneBoundaries(egovehicle,'XDistance',lookaheadDistance,'LocationType','inner
    [obdets,nobdets,obValid,lb_dets,nlb_dets,lbValid] = ...
        visionSensor(tgtpose,lb,scenario.SimulationTime);
    [objjposition,objyaw,objlength,objwidth,objoriginOffset,color] = targetOutlines(egovehicle);
    plotOutline(olPlotter,objjposition,objyaw,objlength,objwidth, ...
        'OriginOffset',objoriginOffset,'Color',color)
    if obValid
        detPos = cellfun(@(d)d.Measurement(1:2),obdets,'UniformOutput',false);
        detPos = vertcat(zeros(0,2),cell2mat(detPos)');
        plotDetection(detPlotter,detPos)
    end
    if lbValid
        plotLaneBoundary(lbPlotter,vertcat(lb_dets.LaneBoundaries))
    end
end
end

```





Configure Ideal Vision Sensor

Generate detections from an ideal vision sensor and compare these detections to ones from a noisy sensor. An *ideal sensor* is one that always generates detections, with no false positives and no added random noise.

Create a Driving Scenario

Create a driving scenario in which the ego vehicle is positioned in front of a diagonal array of target cars. With this configuration, you can later plot the measurement noise covariances of the detected targets without having the target cars occlude one another.

```
scenario = drivingScenario;
egoVehicle = vehicle(scenario);

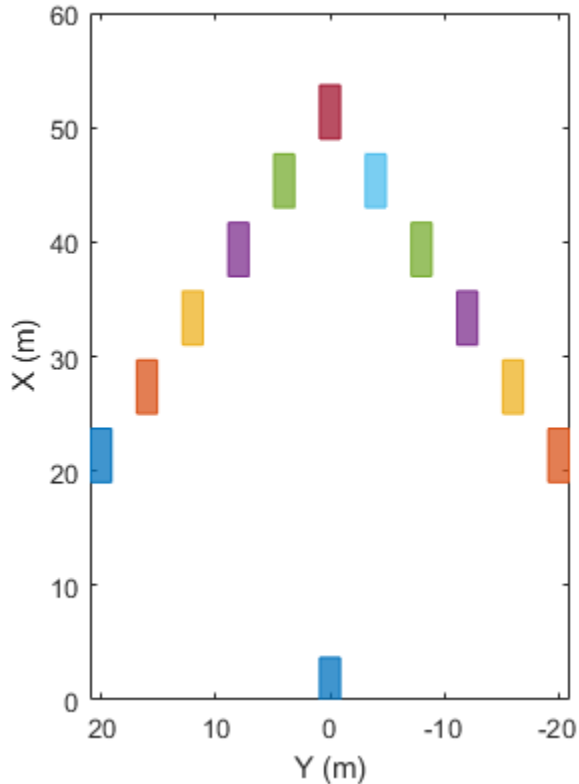
numTgts = 6;
x = linspace(20,50,numTgts)';
y = linspace(-20,0,numTgts)';
x = [x;x(1:end-1)];
y = [y;-y(1:end-1)];
numTgts = numel(x);

for m = 1:numTgts
    vehicle(scenario, 'Position', [x(m) y(m) 0]);
end
```

Plot the driving scenario in a bird's-eye plot.

```
bep = birdsEyePlot('XLim', [0 60]);
legend('hide')

olPlotter = outlinePlotter(bep);
[position, yaw, length, width, originOffset, color] = targetOutlines(egoVehicle);
plotOutline(olPlotter, position, yaw, length, width, ...
    'OriginOffset', originOffset, 'Color', color)
```



Create an Ideal Vision Sensor

Create a vision sensor by using the `visionDetectionGenerator System` object™. To generate ideal detections, set `DetectionProbability` to 1, `FalsePositivesPerImage` to 0, and `HasNoise` to false.

- `DetectionProbability = 1` — The sensor always generates detections for a target, as long as the target is not occluded and meets the range, speed, and image size constraints.
- `FalsePositivesPerImage = 0` — The sensor generates detections from only real targets in the driving scenario.
- `HasNoise = false` — The sensor does not add random noise to the reported position and velocity of the target. However, the `objectDetection` objects returned

by the sensor have measurement noise values set to the noise variance that would have been added if `HasNoise` were `true`. With these noise values, you can process ideal detections using the `multiObjectTracker`. This technique is useful for analyzing maneuver lag without needing to run time-consuming Monte Carlo simulations.

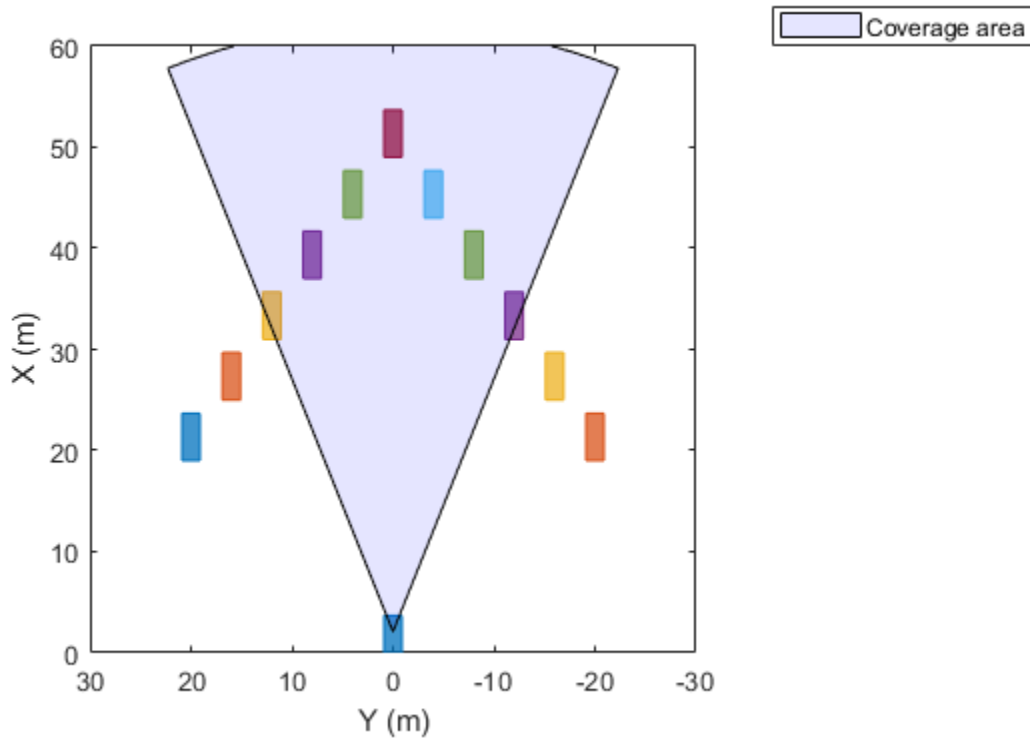
```
idealSensor = visionDetectionGenerator( ...  
    'SensorIndex',1, ...  
    'UpdateInterval',scenario.SampleTime, ...  
    'SensorLocation',[0.75*egoVehicle.Wheelbase 0], ...  
    'Height',1.1, ...  
    'Pitch',0, ...  
    'Intrinsics',cameraIntrinsics(800,[320 240],[480 640]), ...  
    'BoundingBoxAccuracy',50, ... % Make the noise large for illustrative purposes  
    'ProcessNoiseIntensity',5, ...  
    'MaxRange',60, ...  
    'DetectionProbability',1, ...  
    'FalsePositivesPerImage',0, ...  
    'HasNoise',false, ...  
    'ActorProfiles',actorProfiles(scenario))
```

```
idealSensor =  
    visionDetectionGenerator with properties:  
  
        SensorIndex: 1  
        UpdateInterval: 0.0100  
  
        SensorLocation: [2.1000 0]  
            Height: 1.1000  
            Yaw: 0  
            Pitch: 0  
            Roll: 0  
        Intrinsics: [1x1 cameraIntrinsics]  
  
        DetectorOutput: 'Objects only'  
        FieldOfView: [43.6028 33.3985]  
        MaxRange: 60  
        MaxSpeed: 50  
        MaxAllowedOcclusion: 0.5000  
        MinObjectImageSize: [15 15]  
  
        DetectionProbability: 1  
        FalsePositivesPerImage: 0
```

Show all properties

Plot the coverage area of the ideal vision sensor.

```
legend('show')
caPlotter = coverageAreaPlotter(bep, 'DisplayName', 'Coverage area', 'FaceColor', 'blue');
mountPosition = idealSensor.SensorLocation;
range = idealSensor.MaxRange;
orientation = idealSensor.Yaw;
fieldOfView = idealSensor.FieldOfView(1);
plotCoverageArea(caPlotter, mountPosition, range, orientation, fieldOfView);
```



Simulate Ideal Vision Detections

Obtain the positions of the targets. The positions are in ego vehicle coordinates.

```
gTruth = targetPoses(egoVehicle);
```

Generate timestamped vision detections. These detections are returned as a cell array of `objectDetection` objects.

```
time = scenario.SimulationTime;  
dets = idealSensor(gTruth,time);
```

Inspect the measurement and measurement noise variance of the first (leftmost) detection. Even though the detection is ideal and therefore has no added random noise, the `MeasurementNoise` property shows the values as if the detection did have noise.

```
dets{1}.Measurement
```

```
ans = 6×1
```

```
31.0000  
-11.2237  
0  
0  
0  
0
```

```
dets{1}.MeasurementNoise
```

```
ans = 6×6
```

```
1.5427    -0.5958         0         0         0         0  
-0.5958     0.2422         0         0         0         0  
0           0    100.0000         0         0         0  
0           0         0     0.5398    -0.1675         0  
0           0         0    -0.1675     0.1741         0  
0           0         0         0         0    100.0000
```

Plot the ideal detections and ellipses for the 2-sigma contour of the measurement noise covariance.

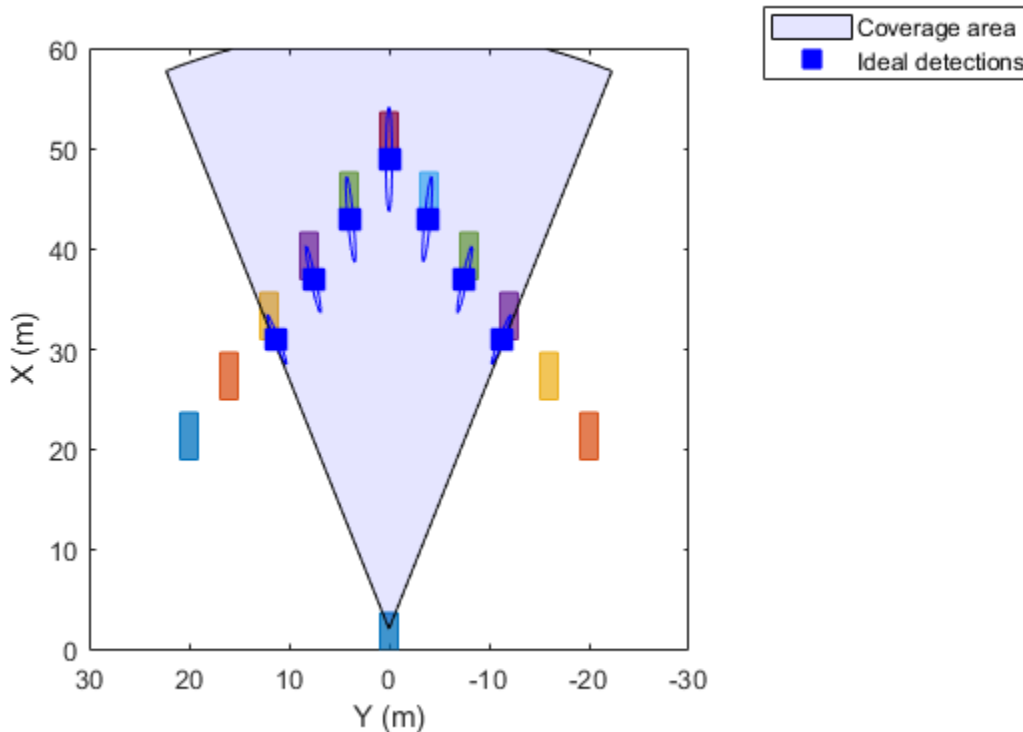
```
pos = cell2mat(cellfun(@(d)d.Measurement(1:2)',dets, ...  
    'UniformOutput',false));
```



```

cov = reshape(cell2mat(cellfun(@(d)d.MeasurementNoise(1:2,1:2),dets, ...
    'UniformOutput',false)),2,2,[]);
plotter = trackPlotter(bep,'DisplayName','Ideal detections', ...
    'MarkerEdgeColor','blue','MarkerFaceColor','blue');
sigma = 2;
plotTrack(plotter,pos,sigma^2*cov)

```



Simulate Noisy Detections for Comparison

Create a noisy sensor based on the properties of the ideal sensor.

```

noisySensor = clone(idealSensor);
release(noisySensor)
noisySensor.HasNoise = true;

```

Reset the driving scenario back to its original state.

```
restart(scenario)
```

Collect statistics from the noisy detections.

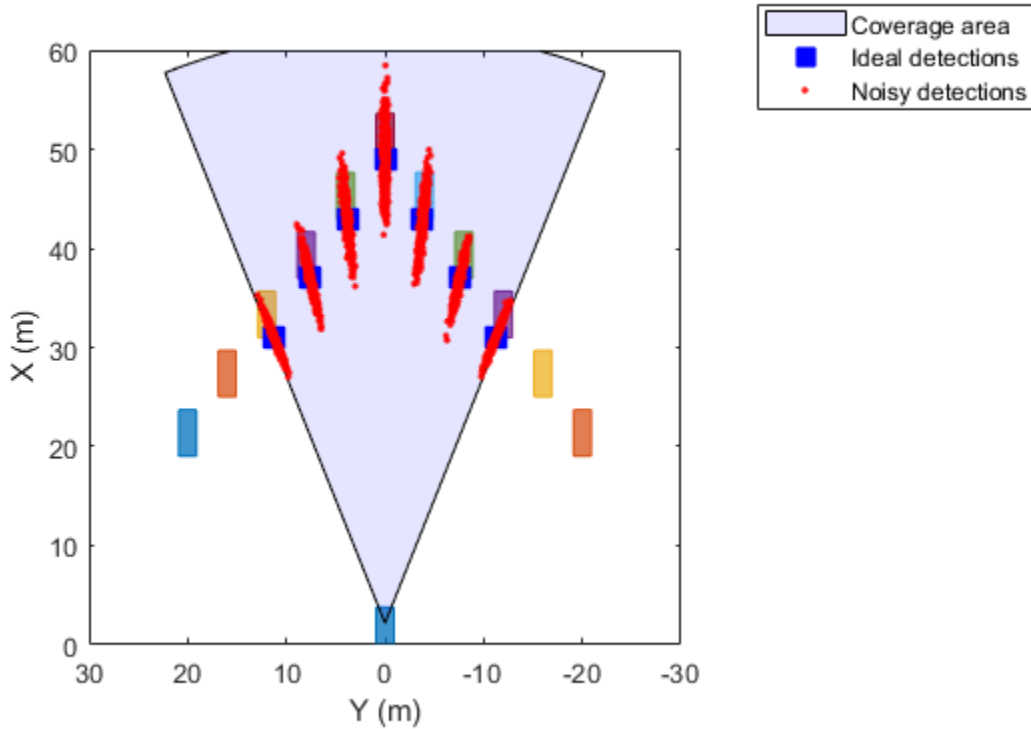
```
numMonte = 1e3;
pos = [];
for itr = 1:numMonte
    time = scenario.SimulationTime;
    dets = noisySensor(gTruth,time);

    % Save noisy measurements
    pos = [pos;cell2mat(cellfun(@(d)d.Measurement(1:2)',dets,'UniformOutput',false))];

    advance(scenario);
end
```

Plot the noisy detections.

```
plotter = detectionPlotter(bep,'DisplayName','Noisy detections', ...
    'Marker','.', 'MarkerEdgeColor','red', 'MarkerFaceColor','red');
plotDetection(plotter,pos)
```



Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

See “System Objects in MATLAB Code Generation” (MATLAB Coder).

See Also

Objects

drivingScenario | laneMarking | lanespec | monoCamera | multiObjectTracker
| objectDetection | radarDetectionGenerator

Functions

actorPoses | actorProfiles | laneBoundaries | road

Apps

Driving Scenario Designer

Topics

“Model Vision Sensor Detections”

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

driving.Path

Planned vehicle path

Description

The `driving.Path` object represents a vehicle path composed of a sequence of path segments. These segments can be either `driving.DubinsPathSegment` objects or `driving.ReedsSheppPathSegment` objects and are stored in the `PathSegments` property of `driving.Path`.

To check the validity of the path against a `vehicleCostmap` object, use the `checkPathValidity` function. To interpolate poses along the length of the path, use the `interpolate` function.

Creation

To create a `driving.Path` object, use the `plan` function, specifying a `pathPlannerRRT` object as input.

Properties

StartPose — Initial pose of vehicle

$[x, y, \theta]$ vector

This property is read-only.

Initial pose of the vehicle, specified as an $[x, y, \theta]$ vector. x and y are in world units, such as meters. θ is in degrees.

GoalPose — Goal pose of vehicle

$[x, y, \theta]$ vector

This property is read-only.

Goal pose of the vehicle, specified as an $[x, y, \theta]$ vector. x and y are in world units, such as meters. θ is in degrees.

PathSegments — Segments along path

array of `driving.DubinsPathSegment` objects | array of `driving.ReedsSheppPathSegment` objects

This property is read-only.

Segments along the path, specified as an array of `driving.DubinsPathSegment` objects or `driving.ReedsSheppPathSegment` objects.

Length — Length of path

positive real scalar

This property is read-only.

Length of the path, in world units, specified as a positive real scalar.

Object Functions

`interpolate` Interpolate poses along planned vehicle path
`plot` Plot planned vehicle path

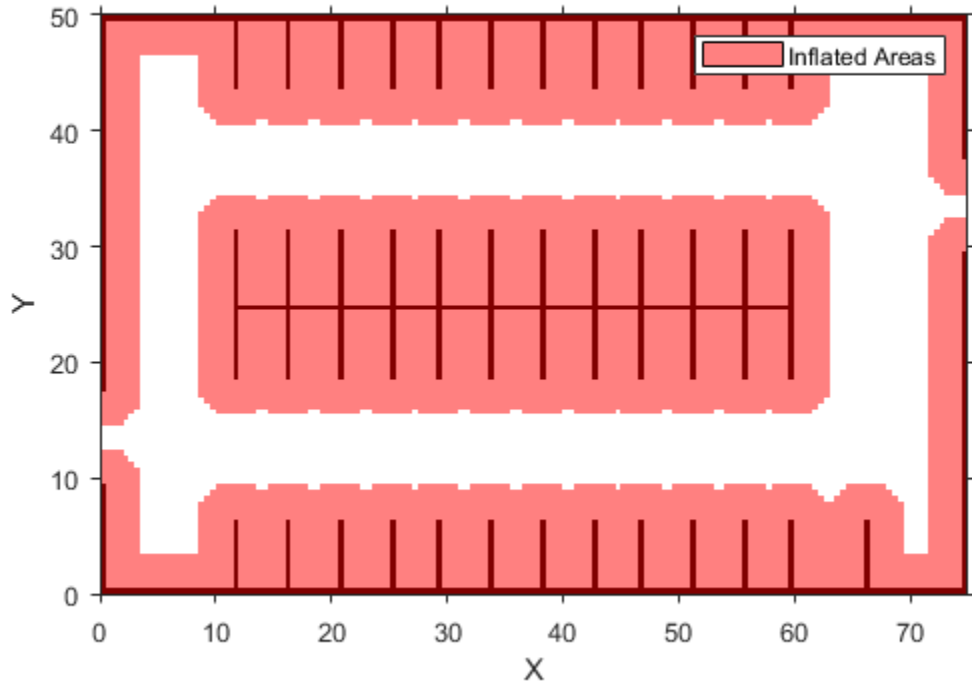
Examples

Plan Path and Check Its Validity

Plan a vehicle path through a parking lot by using the optimal rapidly exploring random tree (RRT*) algorithm. Check that the path is valid, and then plot the transition poses along the path.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmap.mat');  
costmap = data.parkingLotCostmap;  
plot(costmap)
```



Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation angles are in degrees.

```
startPose = [4, 4, 90]; % [meters, meters, degrees]
goalPose = [30, 13, 0];
```

Use a `pathPlannerRRT` object to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Check that the path is valid.

```
isPathValid = checkPathValidity(refPath, costmap)
```

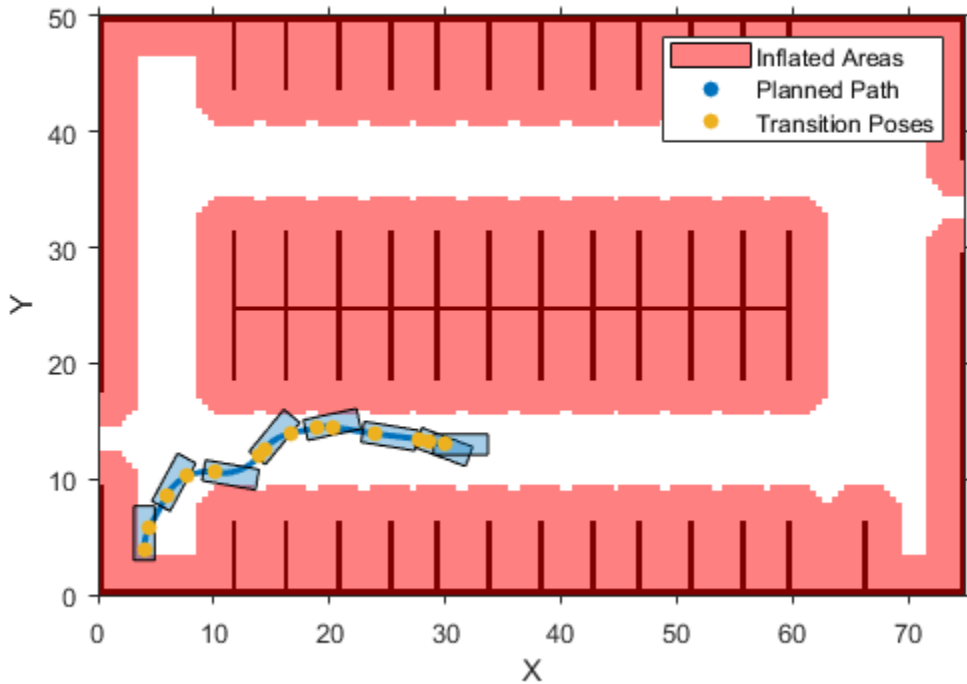
```
isPathValid = logical  
1
```

Interpolate the transition poses along the path.

```
transitionPoses = interpolate(refPath);
```

Plot the planned path and the transition poses on the costmap.

```
hold on  
plot(refPath,'DisplayName','Planned Path')  
scatter(transitionPoses(:,1),transitionPoses(:,2),[],'filled', ...  
        'DisplayName','Transition Poses')  
hold off
```

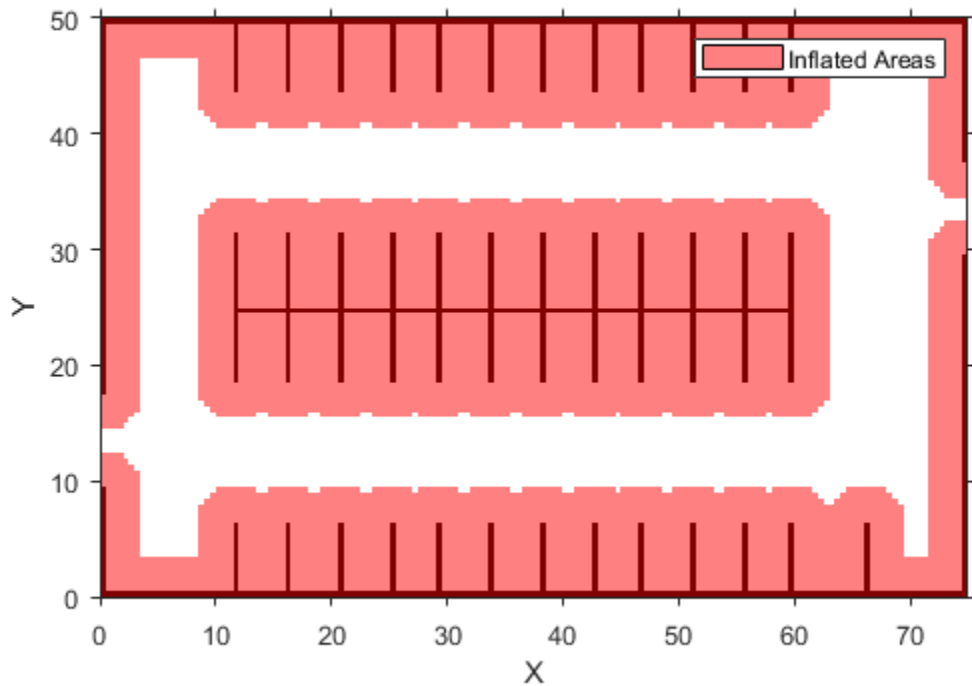


Plan Path and Interpolate Along Path

Plan a vehicle path through a parking lot by using the rapidly exploring random tree (RRT*) algorithm. Interpolate the poses of the vehicle at points along the path.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmap.mat');  
costmap = data.parkingLotCostmap;  
plot(costmap)
```



Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation angles are in degrees.

```
startPose = [4, 4, 90]; % [meters, meters, degrees]
goalPose = [30, 13, 0];
```

Use a `pathPlannerRRT` object to plan a path from the start pose to the goal pose.

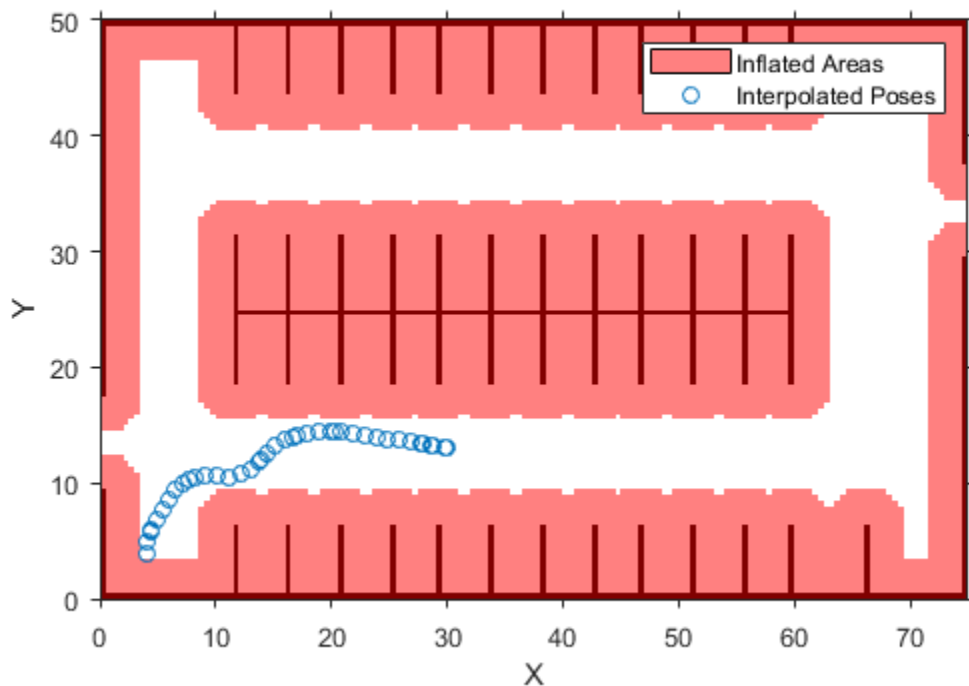
```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Interpolate the vehicle poses every 1 meter along the entire path.

```
lengths = 0 : 1 : refPath.Length;
poses = interpolate(refPath, lengths);
```

Plot the interpolated poses on the costmap.

```
plot(costmap)
hold on
scatter(poses(:,1), poses(:,2), 'DisplayName', 'Interpolated Poses')
hold off
```



Compatibility Considerations

connectingPoses function and driving.Path object properties KeyPoses and NumSegments are not recommended

Not recommended starting in R2018b

The `connectingPoses` function and the `KeyPoses` and `NumSegments` properties of the `driving.Path` object are not recommended. Instead, use the `interpolate` function, which returns key poses, connecting poses, transition poses, and direction changes. The

KeyPoses and NumSegments properties are no longer relevant. KeyPoses, NumSegments, and connectingPoses will be removed in a future release.

In R2018a, connectingPoses enabled you to obtain intermediate poses either along the entire path or along the path segments that are between key poses (as specified by KeyPoses). Using the interpolate function, you can now obtain intermediate poses at any specified point along the path. The interpolate function also provides transition poses at which changes in direction occur.

Update Code

Remove all instances of KeyPoses and NumSegments and replace all instances of connectingPoses with interpolate. The table shows typical usages of connectingPoses and how to update your code to use interpolate instead. Here, path is a driving.Path object returned by pathPlannerRRT.

Discouraged Usage	Recommended Replacement
<code>poses = connectingPoses(path);</code>	<code>poses = interpolate(path);</code>
<code>segID = 1; posesSegment = connectingPoses(path, segID);</code>	<p>interpolate does not have a direct syntax for obtaining segment poses. However, you can sample poses of a segment using a specified step time. For example:</p> <pre>step = 0.1; samples = 0 : step : path.PathSegments(1).Length; segmentPoses = interpolate(path, samples);</pre>

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

checkPathValidity | interpolate | plan | plot | smoothPathSpline

Objects

driving.DubinsPathSegment | driving.ReedsSheppPathSegment |
pathPlannerRRT | vehicleCostmap

Topics

“Automated Parking Valet”

Introduced in R2018a

connectingPoses

Package: driving

(Not recommended) Obtain connecting poses along vehicle path

Note `connectingPoses` is not recommended. Use `interpolate` instead. For more information, see “Compatibility Considerations”

Syntax

```
poses = connectingPoses(path)
poses = connectingPoses(path,segID)
poses = connectingPoses( ____, 'NumSamples', numSamples)
```

Description

`poses = connectingPoses(path)` returns the connecting poses that are between the key poses of a vehicle path.

`poses = connectingPoses(path,segID)` returns the connecting poses that are along the path segment specified by `segID`.

`poses = connectingPoses(____, 'NumSamples', numSamples)` specifies the number of connecting poses to compute between successive key poses, using either of the preceding syntaxes.

Input Arguments

path — Planned vehicle path

`driving.Path` object

Planned vehicle path from which to obtain connecting poses, specified as a `driving.Path` object.

segID — ID of path segment

positive integer

ID of the path segment from which to obtain connecting poses, specified as a positive integer. Each path segment has two successive key poses as its endpoints. `segID` must be less than the number of segments in the input path.

numSamples — Number of connecting poses to sample

100 (default) | integer greater than 1

Number of connecting poses to sample from each segment, specified as an integer greater than 1.

Example: 'NumSamples', 50

Output Arguments

poses — Connecting poses m -by-3 matrix of $[x, y, \theta]$ poses

Connecting poses, returned as an m -by-3 matrix of $[x, y, \theta]$ poses. Each row corresponds to a separate pose. x and y are specified in world coordinates and θ is in degrees. `poses` includes all key poses.

Compatibility Considerations

connectingPoses function and driving.Path object properties KeyPoses and NumSegments are not recommended*Not recommended starting in R2018b*

The `connectingPoses` function and the `KeyPoses` and `NumSegments` properties of the `driving.Path` object are not recommended. Instead, use the `interpolate` function, which returns key poses, connecting poses, transition poses, and direction changes. The `KeyPoses` and `NumSegments` properties are no longer relevant. `KeyPoses`, `NumSegments`, and `connectingPoses` will be removed in a future release.

In R2018a, `connectingPoses` enabled you to obtain intermediate poses either along the entire path or along the path segments that are between key poses (as specified by

KeyPoses). Using the `interpolate` function, you can now obtain intermediate poses at any specified point along the path. The `interpolate` function also provides transition poses at which changes in direction occur.

Update Code

Remove all instances of `KeyPoses` and `NumSegments` and replace all instances of `connectingPoses` with `interpolate`. The table shows typical usages of `connectingPoses` and how to update your code to use `interpolate` instead. Here, `path` is a `driving.Path` object returned by `pathPlannerRRT`.

Discouraged Usage	Recommended Replacement
<code>poses = connectingPoses(path);</code>	<code>poses = interpolate(path);</code>
<code>segID = 1;</code> <code>posesSegment = connectingPoses(path, segID);</code>	<code>interpolate</code> does not have a direct syntax for obtaining segment poses. However, you can sample poses of a segment using a specified step time. For example: <code>step = 0.1;</code> <code>samples = 0 : step : path.PathSegments(1).Length;</code> <code>segmentPoses = interpolate(path, samples);</code>

See Also

Functions

`checkPathValidity` | `interpolate` | `plan`

Objects

`driving.Path` | `pathPlannerRRT`

Topics

“Automated Parking Valet”

Introduced in R2018a

plot

Package: driving

Plot planned vehicle path

Syntax

```
plot(refPath)
plot(refPath,Name,Value)
```

Description

`plot(refPath)` plots the planned vehicle path.

`plot(refPath,Name,Value)` specifies options using one or more name-value pair arguments. For example, `plot(path,'Vehicle','off')` plots the path without displaying the vehicle.

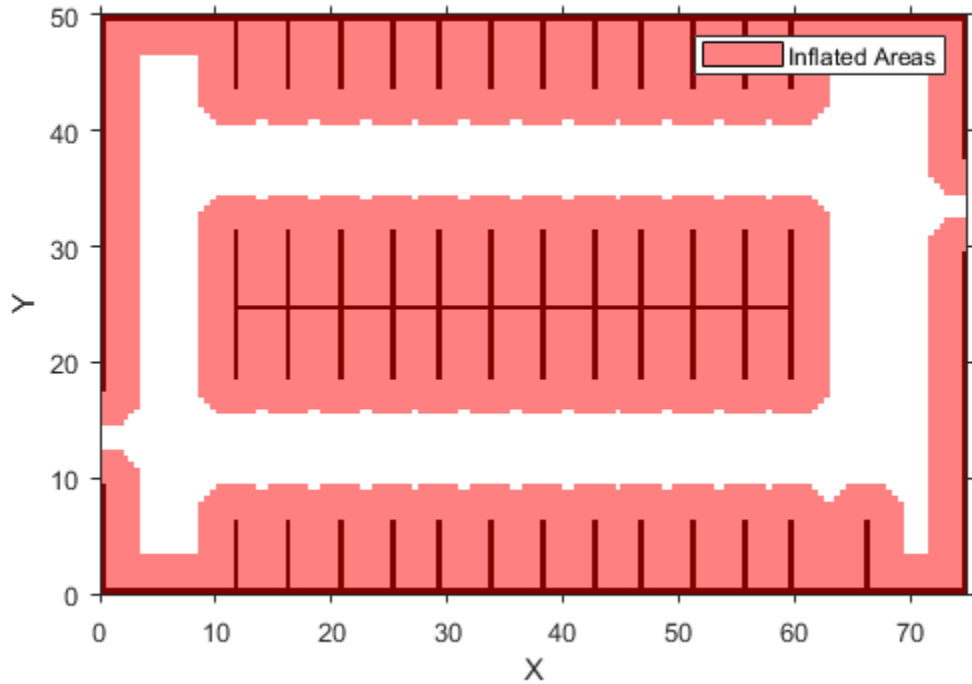
Examples

Plan Path and Check Its Validity

Plan a vehicle path through a parking lot by using the optimal rapidly exploring random tree (RRT*) algorithm. Check that the path is valid, and then plot the transition poses along the path.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmap.mat');
costmap = data.parkingLotCostmap;
plot(costmap)
```



Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation angles are in degrees.

```
startPose = [4, 4, 90]; % [meters, meters, degrees]
goalPose = [30, 13, 0];
```

Use a `pathPlannerRRT` object to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Check that the path is valid.

```
isPathValid = checkPathValidity(refPath, costmap)
```

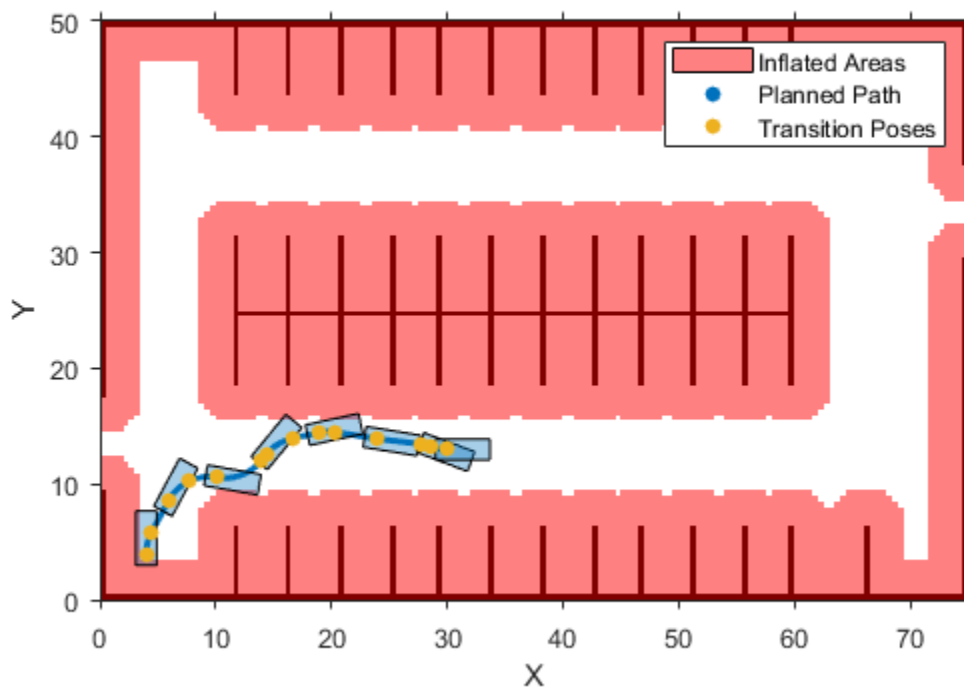
```
isPathValid = logical  
1
```

Interpolate the transition poses along the path.

```
transitionPoses = interpolate(refPath);
```

Plot the planned path and the transition poses on the costmap.

```
hold on  
plot(refPath,'DisplayName','Planned Path')  
scatter(transitionPoses(:,1),transitionPoses(:,2),[],'filled', ...  
        'DisplayName','Transition Poses')  
hold off
```



Input Arguments

refPath — Planned vehicle path

`driving.Path` object

Planned vehicle path, specified as a `driving.Path` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'Inflation', 'off'`

Parent — Axes object

`axes` object

Axes object in which to draw the plot, specified as the comma-separated pair consisting of `'Parent'` and an axes object. If you do not specify `Parent`, a new figure is created.

Vehicle — Display vehicle

`'on'` (default) | `'off'`

Display vehicle, specified as the comma-separated pair consisting of `'Vehicle'` and `'on'` or `'off'`. Setting this argument to `'on'` displays the vehicle along the path.

VehicleDimensions — Dimensions of vehicle

`vehicleDimensions` object

Dimensions of the vehicle, specified as the comma-separated pair consisting of `'VehicleDimensions'` and a `vehicleDimensions` object.

DisplayName — Name of entry in legend

`''` (default) | character vector | string scalar

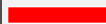




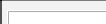
Name of the entry in the legend, specified as the comma-separated pair consisting of `'DisplayName'` and a character vector or string scalar.

Color — Path color

color name | short color name | RGB triplet

Path color, specified as the comma-separated pair consisting of 'Color' and a color name, short color name, or RGB triplet.

For a custom color, specify an RGB triplet. An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range $[0, 1]$; for example, $[0.4 \ 0.6 \ 0.7]$. Alternatively, you can specify some common colors by name. This table lists the named color options and the equivalent RGB triplet values.

Color Name	Color Short Name	RGB Triplet	Appearance
'red'	'r'	[1 0 0]	
'green'	'g'	[0 1 0]	
'blue'	'b'	[0 0 1]	
'cyan'	'c'	[0 1 1]	
'magenta'	'm'	[1 0 1]	
'yellow'	'y'	[1 1 0]	
'black'	'k'	[0 0 0]	
'white'	'w'	[1 1 1]	

Example: 'Color',[1 0 1]

Example: 'Color','m'

Example: 'Color','magenta'

Tag — Tag to identify path

' ' (default) | character vector | string scalar

Tag to identify path, specified as the comma-separated pair consisting of 'Tag' and a character vector or string scalar.

See Also**Functions**

checkPathValidity | interpolate | plan

Objects

`driving.Path` | `pathPlannerRRT` | `vehicleDimensions`

Topics

“Automated Parking Valet”

Introduced in R2018a

interpolate

Package: driving

Interpolate poses along planned vehicle path

Syntax

```
poses = interpolate(refPath)
poses = interpolate(refPath, lengths)
[poses, directions] = interpolate( ___ )
```

Description

`poses = interpolate(refPath)` interpolates along the length of a reference path, returning transition poses. For more information, see Transition Poses on page 4-280.

`poses = interpolate(refPath, lengths)` interpolates poses at specified points along the length of the path. In addition to including poses corresponding to specified lengths, `poses` also includes the transition poses.

`[poses, directions] = interpolate(___)` also returns the motion directions of the vehicle at each pose, using inputs from any of the preceding syntaxes.

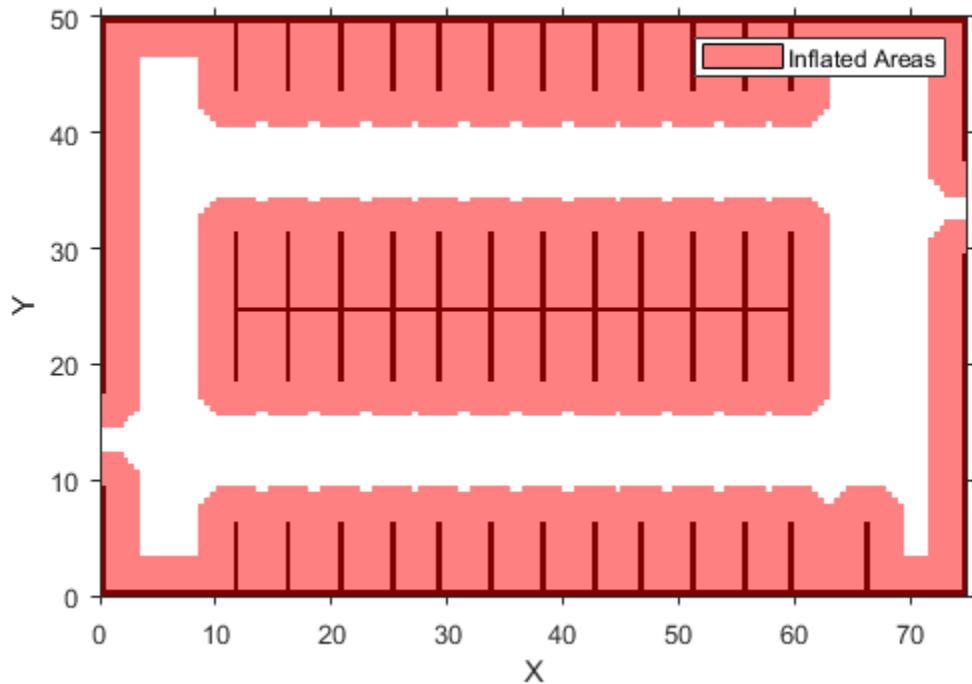
Examples

Plan Path and Check Its Validity

Plan a vehicle path through a parking lot by using the optimal rapidly exploring random tree (RRT*) algorithm. Check that the path is valid, and then plot the transition poses along the path.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmap.mat');  
costmap = data.parkingLotCostmap;  
plot(costmap)
```



Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation angles are in degrees.

```
startPose = [4, 4, 90]; % [meters, meters, degrees]  
goalPose = [30, 13, 0];
```

Use a `pathPlannerRRT` object to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);  
refPath = plan(planner, startPose, goalPose);
```


Check that the path is valid.

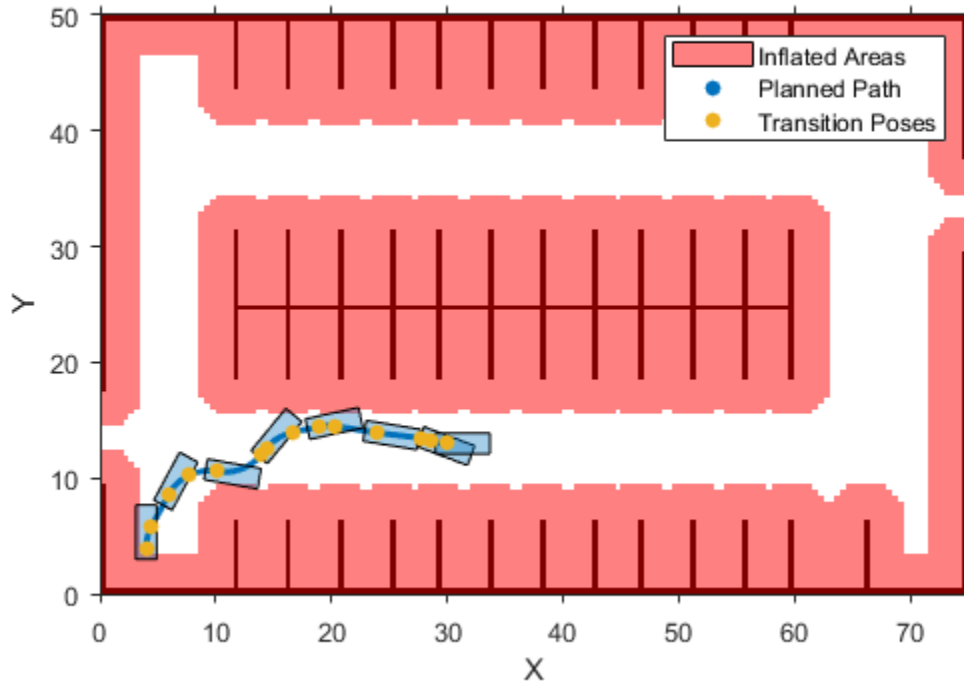
```
isPathValid = checkPathValidity(refPath,costmap)
isPathValid = logical
    1
```

Interpolate the transition poses along the path.

```
transitionPoses = interpolate(refPath);
```

Plot the planned path and the transition poses on the costmap.

```
hold on
plot(refPath,'DisplayName','Planned Path')
scatter(transitionPoses(:,1),transitionPoses(:,2),[],'filled', ...
        'DisplayName','Transition Poses')
hold off
```

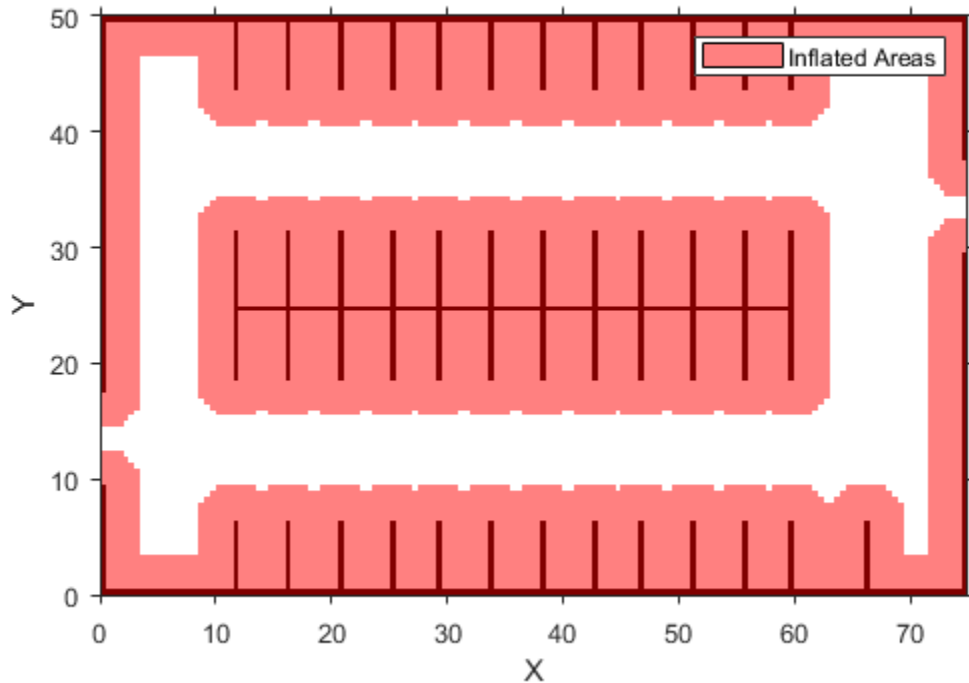


Plan Path and Interpolate Along Path

Plan a vehicle path through a parking lot by using the rapidly exploring random tree (RRT*) algorithm. Interpolate the poses of the vehicle at points along the path.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmap.mat');  
costmap = data.parkingLotCostmap;  
plot(costmap)
```



Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation angles are in degrees.

```
startPose = [4, 4, 90]; % [meters, meters, degrees]
goalPose = [30, 13, 0];
```

Use a pathPlannerRRT object to plan a path from the start pose to the goal pose.

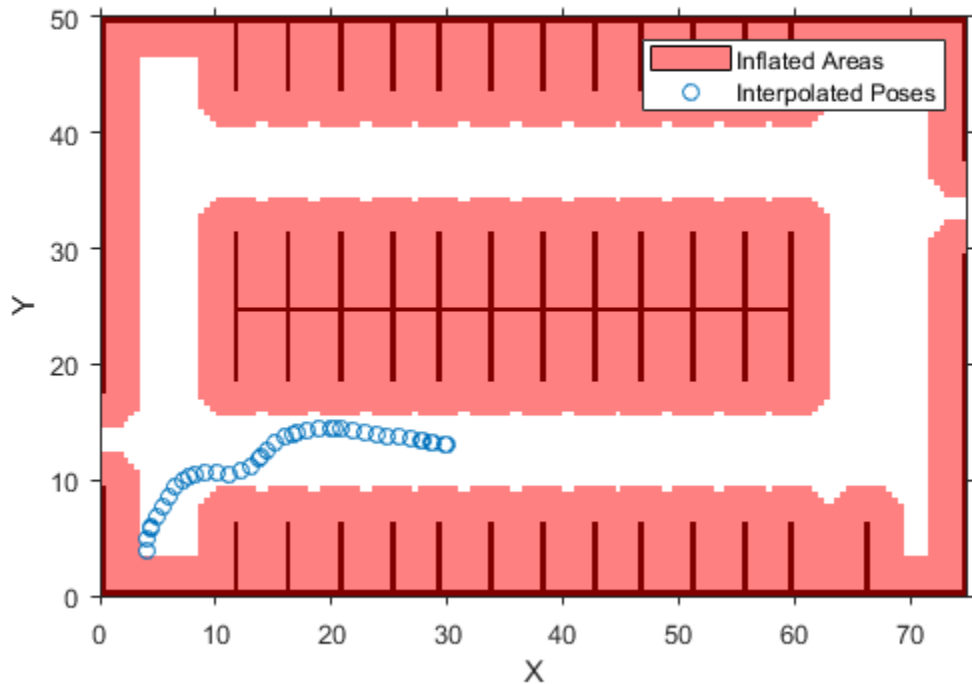
```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Interpolate the vehicle poses every 1 meter along the entire path.

```
lengths = 0 : 1 : refPath.Length;
poses = interpolate(refPath, lengths);
```

Plot the interpolated poses on the costmap.

```
plot(costmap)
hold on
scatter(poses(:,1),poses(:,2),'DisplayName','Interpolated Poses')
hold off
```



Input Arguments

refPath — Planned vehicle path

driving.Path object

Planned vehicle path, specified as a `driving.Path` object.

lengths — Points along length of path

real-valued vector

Points along the length of the path, specified as a real-valued vector. Values must be in the range from 0 to the length of the path, as determined by the `Length` property of `refPath`. The `interpolate` function interpolates poses at these specified points. `lengths` is in world units, such as meters.

Example: `poses = interpolate(refPath,0:0.1:refPath.Length)` interpolates poses every 0.1 meter along the entire length of the path.

Output Arguments

poses — Vehicle poses

m -by-3 matrix of $[x, y, \theta]$ vectors

Vehicle poses along the path, returned as an m -by-3 matrix of $[x, y, \theta]$ vectors. m is the number of returned poses.

x and y specify the location of the vehicle in world units, such as meters. θ specifies the orientation angle of the vehicle in degrees.

`poses` always includes the transition poses, even if you interpolate only at specified points along the path. If you do not specify the `lengths` input argument, then `poses` includes only the transition poses.

directions — Motion directions

m -by-1 vector of 1s (forward motion) and -1s (reverse motion)

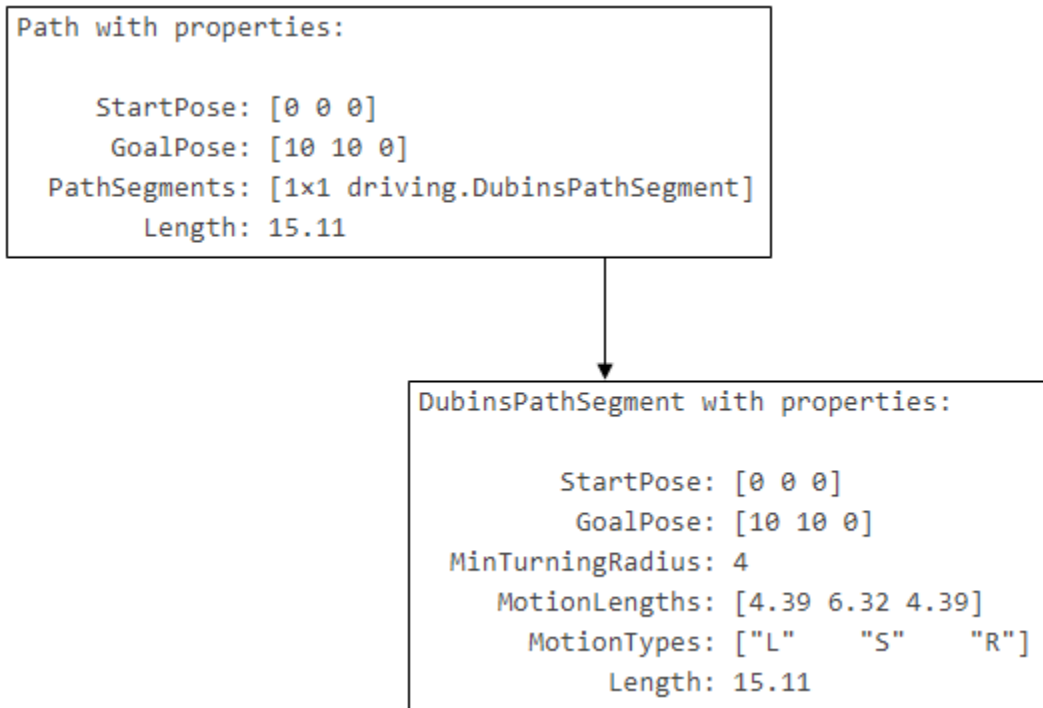
Motion directions of vehicle poses, returned as an m -by-1 vector of 1s (forward motion) and -1s (reverse motion). m is the number of returned poses. Each element of `directions` corresponds to a row of `poses`.

More About

Transition Poses

A path is composed of multiple segments that are combinations of motions (for example, left turn, straight, and right turn). Transition poses are vehicle poses corresponding to the end of one motion and the beginning of another motion. They represent points along the path corresponding to a change in the direction or orientation of the vehicle. The `interpolate` function always returns transition poses, even if you interpolate only at specified points along the path.

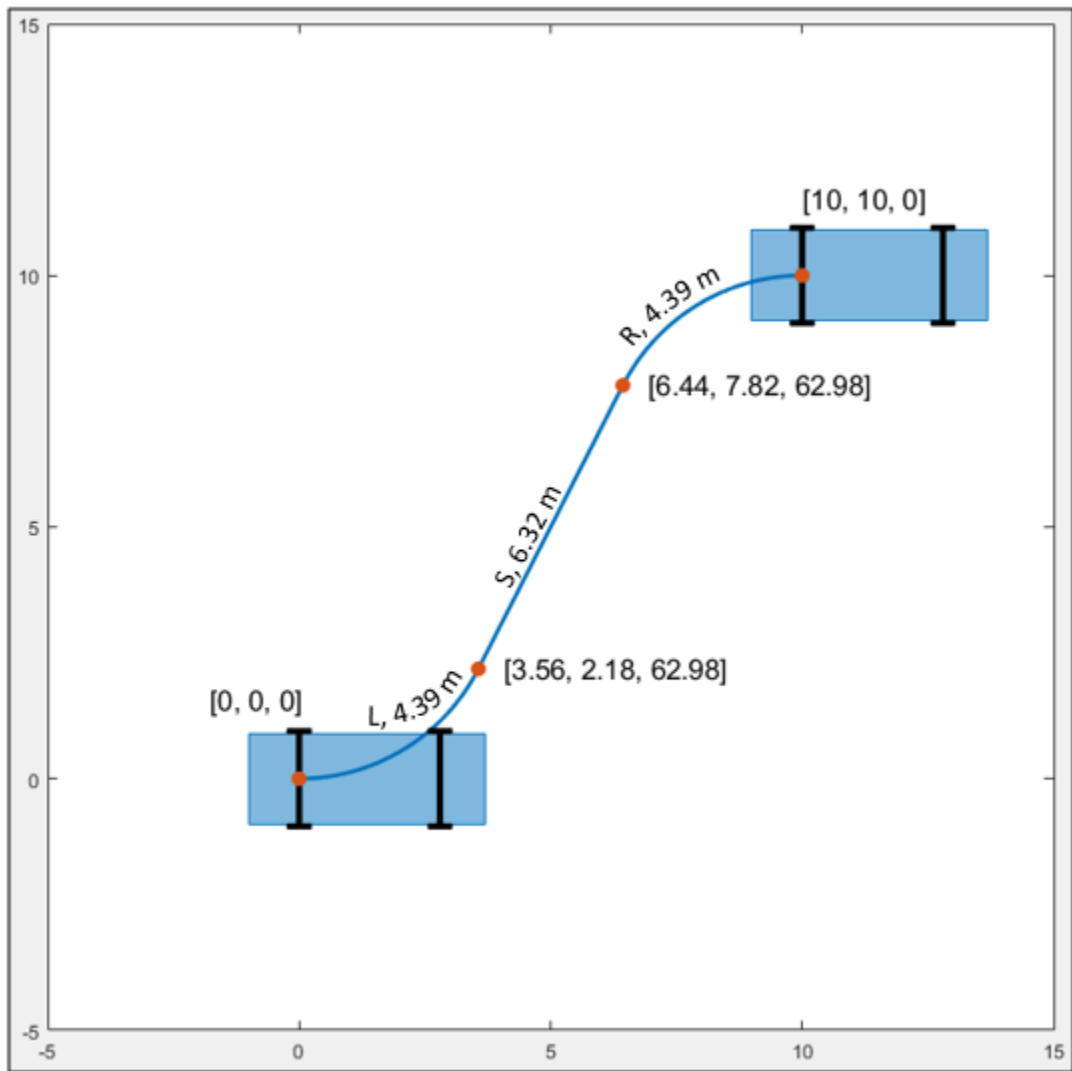
The path length between transition poses is given by the `MotionLengths` property of the path segments. For example, consider the following path, which is a `driving.Path` object composed of a single Dubins path segment. This segment consists of three motions, as described by the `MotionLengths` and `MotionTypes` properties of the segment.



The `interpolate` function interpolates the following transition poses in this order:

- 1** The initial pose of the vehicle, `StartPose`.
- 2** The pose after the vehicle turns left ("L") for 4.39 meters at its maximum steering angle.
- 3** The pose after the vehicle goes straight ("S") for 6.32 meters.
- 4** The pose after the vehicle turns right ("R") for 4.39 meters at its maximum steering angle. This pose is also the goal pose, because it is the last pose of the entire path.

The plot shows these transition poses, which are $[x, y, \theta]$ vectors. x and y specify the location of the vehicle in world units, such as meters. θ specifies the orientation angle of the vehicle in degrees.



Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`checkPathValidity` | `smoothPathSpline`

Objects

`driving.Path` | `pathPlannerRRT`

Topics

“Automated Parking Valet”

Introduced in R2018b

driving.DubinsPathSegment

Dubins path segment

Description

A `driving.DubinsPathSegment` object represents a segment of a planned vehicle path that was connected using the Dubins connection method [1]. A Dubins path segment is composed of a sequence of three motions. Each motion is one of these types:

- Straight
- Left turn at the maximum steering angle of the vehicle
- Right turn at the maximum steering angle of the vehicle

A vehicle path composed of Dubins path segments allows motion in the forward direction only.

The `driving.DubinsPathSegment` objects that represent a path are stored in the `PathSegments` property of a `driving.Path` object. These paths are planned by a `pathPlannerRRT` object whose `ConnectionMethod` property is set to 'Dubins'.

Properties

StartPose — Initial pose of vehicle

$[x, y, \theta]$ vector

This property is read-only.

Initial pose of the vehicle at the start of the path segment, specified as an $[x, y, \theta]$ vector. x and y are in world units, such as meters. θ is in degrees.

GoalPose — Goal pose of vehicle

$[x, y, \theta]$ vector

This property is read-only.

Goal pose of the vehicle at the end of the path segment, specified as an $[x, y, \theta]$ vector. x and y are in world units, such as meters. θ is in degrees.

MinTurningRadius — Minimum turning radius of vehicle

positive real scalar

This property is read-only.

Minimum turning radius of the vehicle, in world units, specified as a positive real scalar. This value corresponds to the radius of the turning circle at the maximum steering angle of the vehicle.

MotionLengths — Length of each motion

three-element real-valued vector

This property is read-only.

Length of each motion in the path segment, in world units, specified as a three-element real-valued vector. Each motion length corresponds to a motion type specified in `MotionTypes`.

MotionTypes — Type of each motion

three-element string array

This property is read-only.

Type of each motion in the path segment, specified as a three-element string array. Valid values are shown in this table.

Motion Type	Description
"S"	Straight
"L"	Left turn at the maximum steering angle of the vehicle
"R"	Right turn at the maximum steering angle of the vehicle

Each motion type corresponds to a motion length specified in `MotionLengths`.

Example: ["R" "S" "R"]

Length — Length of path segment

positive real scalar

This property is read-only.

Length of the path segment, in world units, specified as a positive real scalar.

References

[1] Shkel, Andrei M., and Vladimir Lumelsky. "Classification of the Dubins Set." *Robotics and Autonomous Systems*. Vol. 34, Number 4, 2001, pp. 179-202.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- Only one-dimensional indexing is supported.

See Also

Objects

`driving.Path` | `driving.ReedsSheppPathSegment` | `pathPlannerRRT`

Topics

"Automated Parking Valet"

Introduced in R2018b

driving.ReedsSheppPathSegment

Reeds-Shepp path segment

Description

A `driving.ReedsSheppPathSegment` object represents a segment of a planned vehicle path that was connected using the Reeds-Shepp connection method [1]. A Reeds-Shepp path segment is composed of a sequence of three to five motions. Each motion is one of these types:

- Straight (forward or reverse)
- Left turn at the maximum steering angle of the vehicle (forward or reverse)
- Right turn at the maximum steering angle of the vehicle (forward or reverse)

The `driving.ReedsSheppPathSegment` objects that represent a path are stored in the `PathSegments` property of a `driving.Path` object. These paths are planned by a `pathPlannerRRT` object whose `ConnectionMethod` property is set to `'Dubins'`.

Properties

StartPose — Initial pose of vehicle

$[x, y, \theta]$ vector

This property is read-only.

Initial pose of the vehicle at the start of the path segment, specified as an $[x, y, \theta]$ vector. x and y are in world units, such as meters. θ is in degrees.

GoalPose — Goal pose of vehicle

$[x, y, \theta]$ vector

This property is read-only.

Goal pose of the vehicle at the end of the path segment, specified as an $[x, y, \theta]$ vector. x and y are in world units, such as meters. θ is in degrees.

MinTurningRadius — Minimum turning radius of vehicle

positive real scalar

This property is read-only.

Minimum turning radius of the vehicle, in world units, specified as a positive real scalar. This value corresponds to the radius of the turning circle at the maximum steering angle of the vehicle.

MotionLengths — Length of each motion

five-element real-valued vector

This property is read-only.

Length of each motion in the path segment, in world units, specified as a five-element real-valued vector. Each motion length corresponds to a motion type specified in `MotionTypes` and a motion direction specified in `MotionDirections`.

When a path segment requires fewer than five motions, the remaining `MotionLengths` elements are set to 0. The remaining `MotionTypes` elements are set to "N" (no motion).

MotionTypes — Type of each motion

five-element string array

This property is read-only.

Type of each motion in the path segment, specified as a five-element string array. Valid values are shown in this table.

Motion Type	Description
"S"	Straight (forward or reverse)
"L"	Left turn at the maximum steering angle of the vehicle (forward or reverse)
"R"	Right turn at the maximum steering angle of the vehicle (forward or reverse)
"N"	No motion

`MotionTypes` contains a minimum of three motions, specified as a combination of "S", "L", and "R" elements. If a path segment has fewer than five motions, the remaining elements of `MotionTypes` are "N" (no motion).

Each motion type corresponds to a motion length specified in `MotionLengths` and a motion direction specified in `MotionDirections`.

Example: ["R" "S" "R" "L" "N"]

MotionDirections — Direction of each motion

five-element vector of 1s (forward motion) and -1s (reverse motion)

This property is read-only.

Direction of each motion in the path segment, specified as a five-element vector of 1s (forward motion) and -1s (reverse motion). Each motion direction corresponds to a motion length specified in `MotionLengths` and a motion type specified in `MotionTypes`.

When no motion occurs, that is, when a `MotionTypes` value is "N", then the corresponding `MotionDirections` element is 1.

Example: [-1 1 -1 1 1]

Length — Length of path segment

positive real scalar

This property is read-only.

Length of the path segment, in world units, specified as a positive real scalar.

References

- [1] Reeds, J. A., and L. A. Shepp. "Optimal Paths for a Car That Goes Both Forwards and Backwards." *Pacific Journal of Mathematics*. Vol. 145, Number 2, 1990, pp. 367-393.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- Only one-dimensional indexing is supported.

See Also

Objects

`driving.DubinsPathSegment` | `driving.Path` | `pathPlannerRRT`

Topics

“Automated Parking Valet”

Introduced in R2018b

drivingScenario

Create driving scenario

Description

The `drivingScenario` object represents a 3-D arena containing roads, vehicles, pedestrians, and other aspects of a driving scenario. Use this object to model realistic traffic scenarios and to generate synthetic detections for testing controllers or sensor fusion algorithms.

- To add roads, use the `road` function. To specify lanes in the roads, create a `lanespec` object.
- To add actors (cars, pedestrians, bicycles, and so on), use the `actor` function. To add actors with properties designed specifically for vehicles, use the `vehicle` function. All actors, including vehicles, are modeled as cuboids (box shapes).
- To simulate a scenario, call the `advance` function in a loop, which advances the simulation one time step at a time.

You can also create driving scenarios interactively by using the **Driving Scenario Designer** app. In addition, you can export `drivingScenario` objects from the app to produce scenario variations for use in either the app or in Simulink. For more details, see “Create Driving Scenario Variations Programmatically”.

Creation

Syntax

```
scenario = drivingScenario  
scenario = drivingScenario(Name,Value)
```

Description

`scenario = drivingScenario` creates an empty driving scenario.

`scenario = drivingScenario(Name, Value)` sets the `SampleTime` and `StopTime` properties using name-value pairs. For example, `drivingScenario('SampleTime', 0.1, 'StopTime', 10)` samples the scenario every 0.1 seconds for 10 seconds. Enclose each property name in quotes.

Properties

SampleTime — Time interval between scenario simulation steps

0.01 (default) | positive real scalar

Time interval between scenario simulation steps, specified as a positive real scalar. Units are in seconds.

Example: 1.5

StopTime — End time of simulation

Inf (default) | positive real scalar

End time of simulation, specified as a positive real scalar. Units are in seconds. The default `StopTime` of `Inf` causes the simulation to end when the first actor reaches the end of its trajectory.

Example: 60.0

SimulationTime — Current time of simulation

positive real scalar

This property is read-only.

Current time of the simulation, specified as a positive real scalar. To reset the time to zero, call the `restart` function. Units are in seconds.

IsRunning — Simulation state

true | false

This property is read-only.

Simulation state, specified as `true` or `false`. If the simulation is running, `IsRunning` is `true`.

Actors — Actors and vehicles contained in scenario

heterogeneous array of `Actor` and `Vehicle` objects

This property is read-only.

Actors and vehicles contained in the scenario, specified as a heterogeneous array of Actor and Vehicle objects. To add actors and vehicles to a driving scenario, use the actor and vehicle functions.

Object Functions

Scenarios

advance	Advance driving scenario simulation by one time step
plot	Create driving scenario plot
record	Run driving scenario and record actor states
restart	Restart driving scenario simulation from beginning
updatePlots	Update driving scenario plots

Actors

actor	Add actor to driving scenario
actorPoses	Positions, velocities, and orientations of actors in driving scenario
actorProfiles	Physical and radar characteristics of actors in driving scenario
vehicle	Add vehicle to driving scenario
chasePlot	Ego-centric projective perspective plot
trajectory	Create actor or vehicle trajectory in driving scenario
targetPoses	Target positions and orientations relative to ego vehicle
targetOutlines	Outlines of targets viewed by actor
driving.scenario.targetsToEgo	Convert actor poses to ego vehicle coordinates

Roads

road	Add road to driving scenario
roadNetwork	Add road network to driving scenario
roadBoundaries	Get road boundaries
driving.scenario.roadBoundariesToEgo	Convert road boundaries to ego vehicle coordinates

Lanes

currentLane	Get current lane of actor
lanespec	Create road lane specifications
laneMarking	Create road lane marking object
laneMarkingVertices	Lane marking vertices and faces in driving scenario
laneBoundaries	Get lane boundaries of actor lane
clothoidLaneBoundary	Clothoid-shaped lane boundary model
computeBoundaryModel	Compute lane boundary points from clothoid lane boundary model
laneType	Create road lane type object

Examples

Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```

Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0°, ends at 90°, and is sampled at 5° increments.

```
angs = [0:5:90]';  
R = 800;  
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];  
roadwidth = 10;  
road(scenario,roadcenters,roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];  
road(scenario,roadcenters)  
roadcenters = [400 400 0; 0 0 0];  
road(scenario,roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

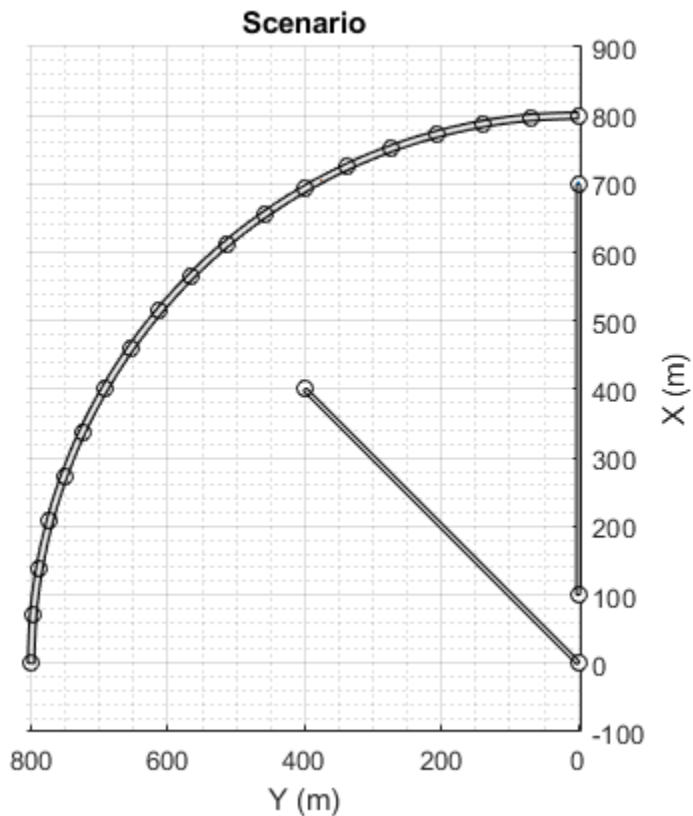
```
car = vehicle(scenario, 'Position', [700 0 0], 'Length', 3, 'Width', 2, 'Height', 1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario, 'Position', [706 376 0]', 'Length', 2, 'Width', 0.45, 'Height', 1.5)
```

Plot the scenario.

```
plot(scenario, 'Centerline', 'on', 'RoadCenters', 'on');  
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct
  ActorID
  Position
  Velocity
  Roll
  Pitch
  Yaw
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```

```
profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles
```

Show Target Outlines in Driving Scenario Simulation

Create a driving scenario and show how target outlines change as the simulation advances.

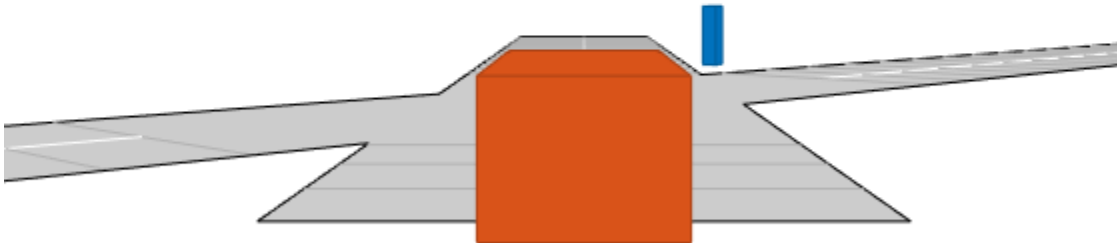
Create a driving scenario consisting of two intersecting straight roads. The first road segment is 45 meters long. The second straight road is 32 meters long and intersects the first road. A car traveling at 12.0 meters per second along the first road approaches a running pedestrian crossing the intersection at 2.0 meters per second.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',1);
road(scenario,[-10 0 0; 45 -20 0]);
road(scenario,[-10 -10 0; 35 10 0]);
ped = actor(scenario,'Length',0.4,'Width',0.6,'Height',1.7);
car = vehicle(scenario);
pedspeed = 2.0;
```

```
carspeed = 12.0;  
trajectory(ped,[15 -3 0; 15 3 0],pedspeed);  
trajectory(car,[-10 -10 0; 35 10 0],carspeed);
```

Create an ego-centric chase plot for the vehicle.

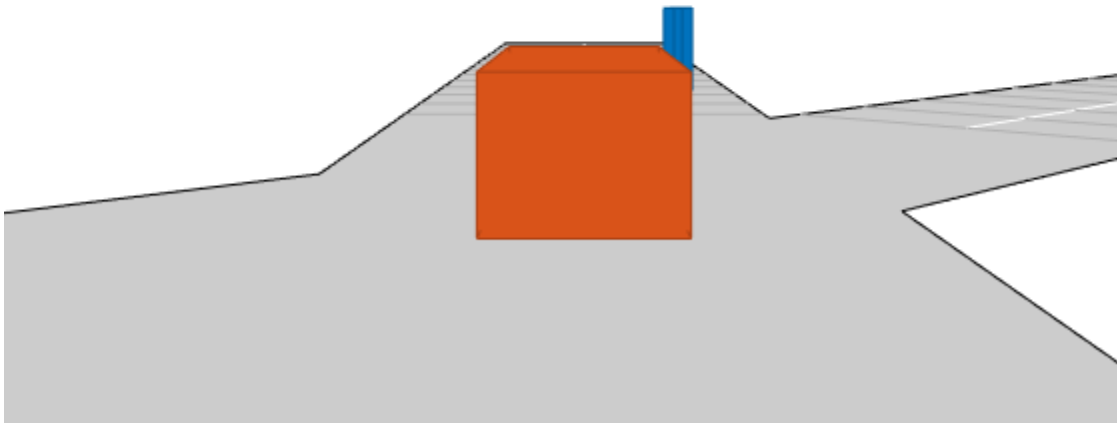
```
chasePlot(car, 'Centerline', 'on')
```

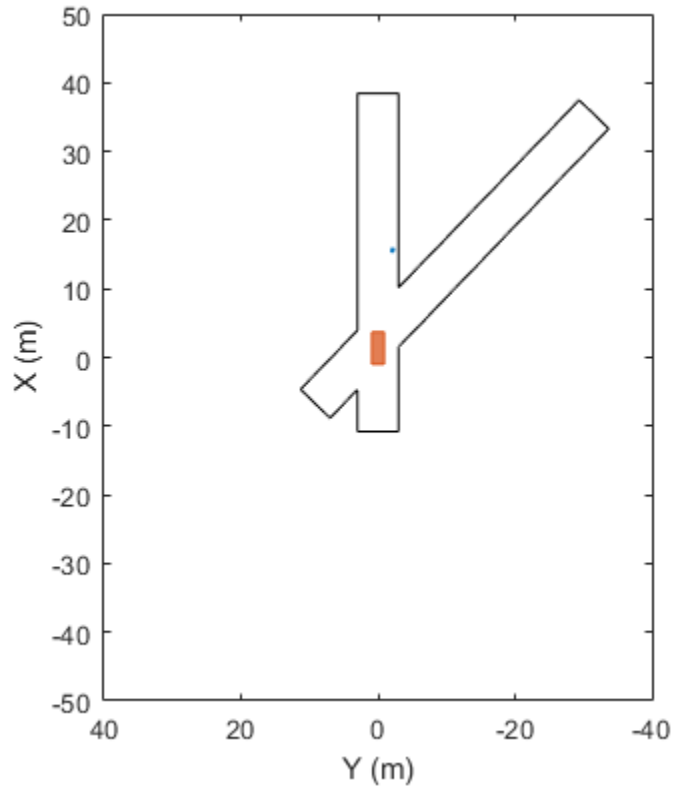


Create an empty bird's-eye plot and add an outline plotter and lane boundary plotter. Then, run the simulation. At each simulation step:

- Update the chase plot to display the road boundaries and target outlines.
- Update the bird's-eye plot to display the updated road boundaries and target outlines. The plot perspective is always with respect to the ego vehicle.

```
bepPlot = birdsEyePlot('XLim',[-50 50],'YLim',[-40 40]);  
outlineplotter = outlinePlotter(bepPlot);  
laneplotter = laneBoundaryPlotter(bepPlot);  
legend('off')  
  
while advance(scenario)  
    rb = roadBoundaries(car);  
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);  
    plotLaneBoundary(laneplotter,rb)  
    plotOutline(outlineplotter,position,yaw,length,width, ...  
        'OriginOffset',originOffset,'Color',color)  
    pause(0.01)  
end
```





Generate Object and Lane Boundary Detections

Create a driving scenario containing an ego vehicle and a target vehicle traveling along a three-lane road. Detect the lane boundaries by using a vision detection generator.

```
scenario = drivingScenario;
```

Create a three-lane road by using lane specifications.

```
roadCenters = [0 0 0; 60 0 0; 120 30 0];  
lspc = lanespec(3);  
road(scenario, roadCenters, 'Lanes', lspc);
```

Specify that the ego vehicle follows the center lane at 30 m/s.

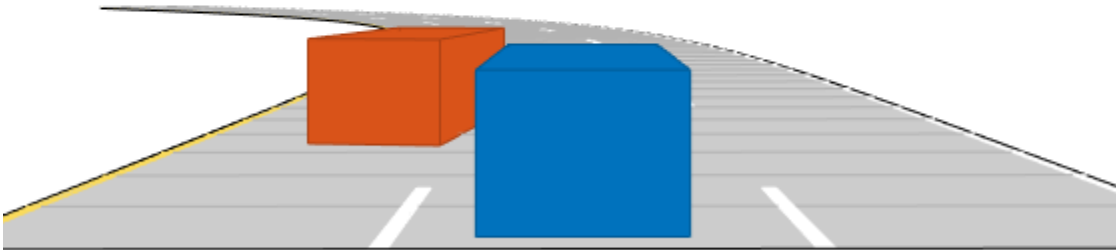
```
egovehicle = vehicle(scenario);  
egopath = [1.5 0 0; 60 0 0; 111 25 0];  
egospeed = 30;  
trajectory(egovehicle, egopath, egospeed);
```

Specify that the target vehicle travels ahead of the ego vehicle at 40 m/s and changes lanes close to the ego vehicle.

```
targetcar = vehicle(scenario, 'ClassID', 2);  
targetpath = [8 2; 60 -3.2; 120 33];  
targetspeed = 40;  
trajectory(targetcar, targetpath, targetspeed);
```

Display a chase plot for a 3-D view of the scenario from behind the ego vehicle.

```
chasePlot(egovehicle)
```



Create a vision detection generator that detects lanes and objects. The pitch of the sensor points one degree downward.

```
visionSensor = visionDetectionGenerator('Pitch',1.0);  
visionSensor.DetectorOutput = 'Lanes and objects';  
visionSensor.ActorProfiles = actorProfiles(scenario);
```

Run the simulation.

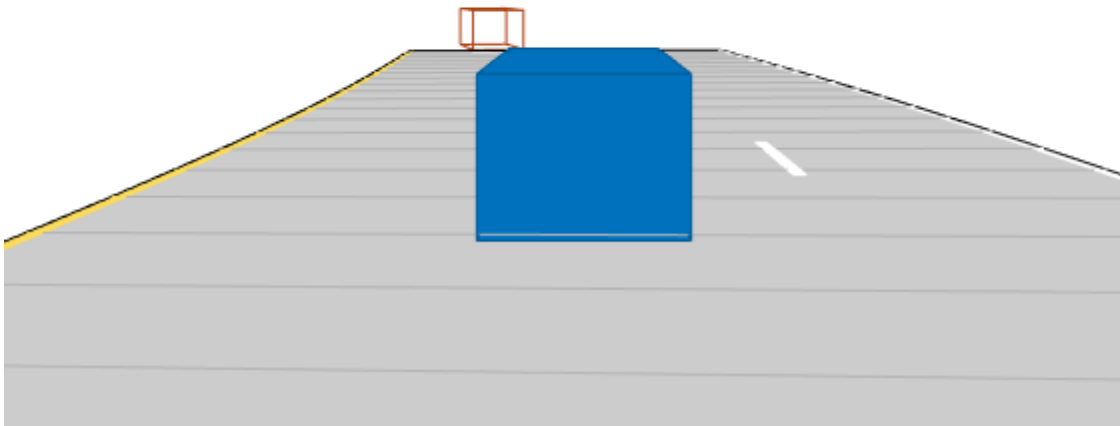
- 1 Create a bird's-eye plot and the associated plotters.
- 2 Display the sensor coverage area.
- 3 Display the lane markings.

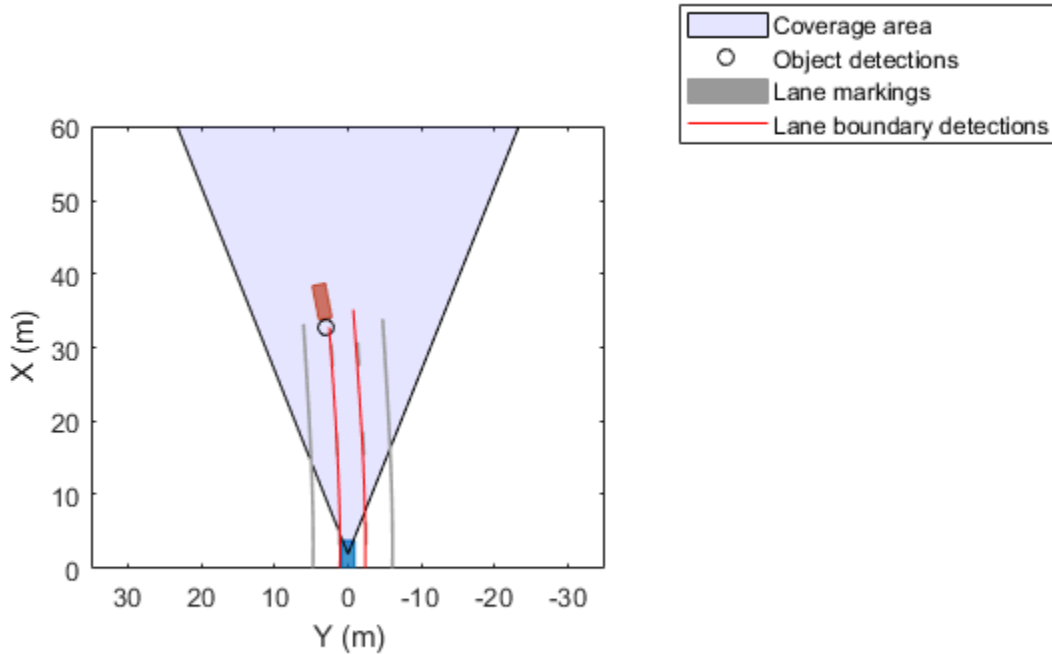
- 4 Obtain ground truth poses of targets on the road.
- 5 Obtain ideal lane boundary points up to 60 m ahead.
- 6 Generate detections from the ideal target poses and lane boundaries.
- 7 Display the outline of the target.
- 8 Display object detections when the object detection is valid.
- 9 Display the lane boundary when the lane detection is valid.

```

bep = birdsEyePlot('XLim',[0 60],'YLim',[-35 35]);
caPlotter = coverageAreaPlotter(bep,'DisplayName','Coverage area', ...
    'FaceColor','blue');
detPlotter = detectionPlotter(bep,'DisplayName','Object detections');
lmPlotter = laneMarkingPlotter(bep,'DisplayName','Lane markings');
lbPlotter = laneBoundaryPlotter(bep,'DisplayName', ...
    'Lane boundary detections','Color','red');
olPlotter = outlinePlotter(bep);
plotCoverageArea(caPlotter,visionSensor.SensorLocation,...
    visionSensor.MaxRange,visionSensor.Yaw, ...
    visionSensor.FieldOfView(1));
while advance(scenario)
    [lmv,lmf] = laneMarkingVertices(egovehicle);
    plotLaneMarking(lmPlotter,lmv,lmf)
    tgtpose = targetPoses(egovehicle);
    lookaheadDistance = 0:0.5:60;
    lb = laneBoundaries(egovehicle,'XDistance',lookaheadDistance,'LocationType','inner
    [obdets,nobdets,obValid,lb_dets,nlb_dets,lbValid] = ...
        visionSensor(tgtpose,lb,scenario.SimulationTime);
    [objjposition,objyaw,objlength,objwidth,objoriginOffset,color] = targetOutlines(egovehicle);
    plotOutline(olPlotter,objjposition,objyaw,objlength,objwidth, ...
        'OriginOffset',objoriginOffset,'Color',color)
    if obValid
        detPos = cellfun(@(d)d.Measurement(1:2),obdets,'UniformOutput',false);
        detPos = vertcat(zeros(0,2),cell2mat(detPos)');
        plotDetection(detPlotter,detPos)
    end
    if lbValid
        plotLaneBoundary(lbPlotter,vertcat(lb_dets.LaneBoundaries))
    end
end
end

```





Algorithms

Specify Actor Motion in Driving Scenarios

To specify the motion of actors in a driving scenario, you can either define trajectories for the actors or specify their motion manually.

Specify Motion Using Trajectory

The trajectory function determines actor pose properties based on a set of waypoints and the speeds at which the actor travels between those waypoints. Actor pose properties

are position, velocity, roll, pitch, yaw, and angular velocity. With this approach, motion is defined by speed, not velocity, because the trajectory determines the direction of motion.

The actor moves along the trajectory each time the `advance` function is called. You can manually update actor pose properties at any time during a simulation. However, these properties are overwritten with updated values at the next call to `advance`.

Specify Motion Manually

When you specify actor motion manually, setting the velocity or angular velocity properties does not automatically move the actor in successive calls to the `advance` function. Therefore, you must use your own motion model to update the position, velocity, and other pose parameters at each simulation time step.

See Also

Apps

Driving Scenario Designer

Objects

`multiObjectTracker` | `radarDetectionGenerator` | `visionDetectionGenerator`

Topics

“Create Driving Scenario Variations Programmatically”

“Driving Scenario Tutorial”

“Define Road Layouts”

“Create Actor and Vehicle Trajectories”

“Scenario Generation from Recorded Vehicle Data”

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

advance

Advance driving scenario simulation by one time step

Syntax

```
isRunning = advance(scenario)
```

Description

`isRunning = advance(scenario)` advances a driving scenario simulation by one time step. To specify the step time, use the `SampleTime` property of the input `drivingScenario` object, `scenario`. The function returns the status, `isRunning`, of the simulation.

Examples

Advance Driving Scenario Simulation

Create a driving scenario. Use the default sample time of 0.01 second.

```
scenario = drivingScenario;
```

Add a straight, 30-meter road to the scenario. The road has two lanes.

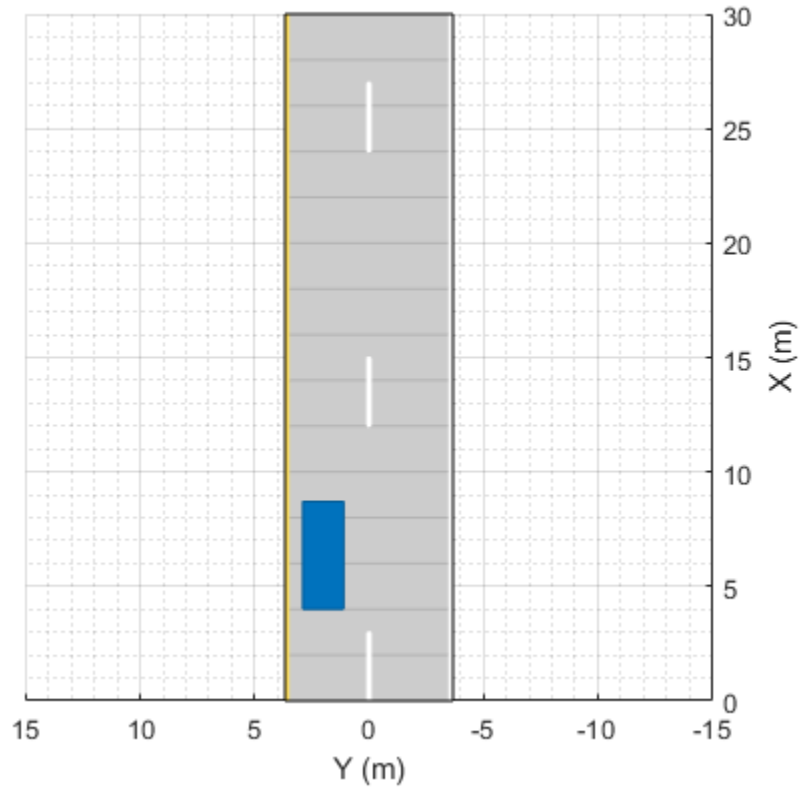
```
roadCenters = [0 0; 30 0];  
road(scenario, roadCenters, 'Lanes', lanespec(2));
```

Add a vehicle that travels in the left lane at a constant speed of 30 meters per second. Plot the scenario before running the simulation.

```
v = vehicle(scenario);  
waypoints = [5 2; 25 2];  
speed = 30; % m/s  
trajectory(v, waypoints, speed)
```

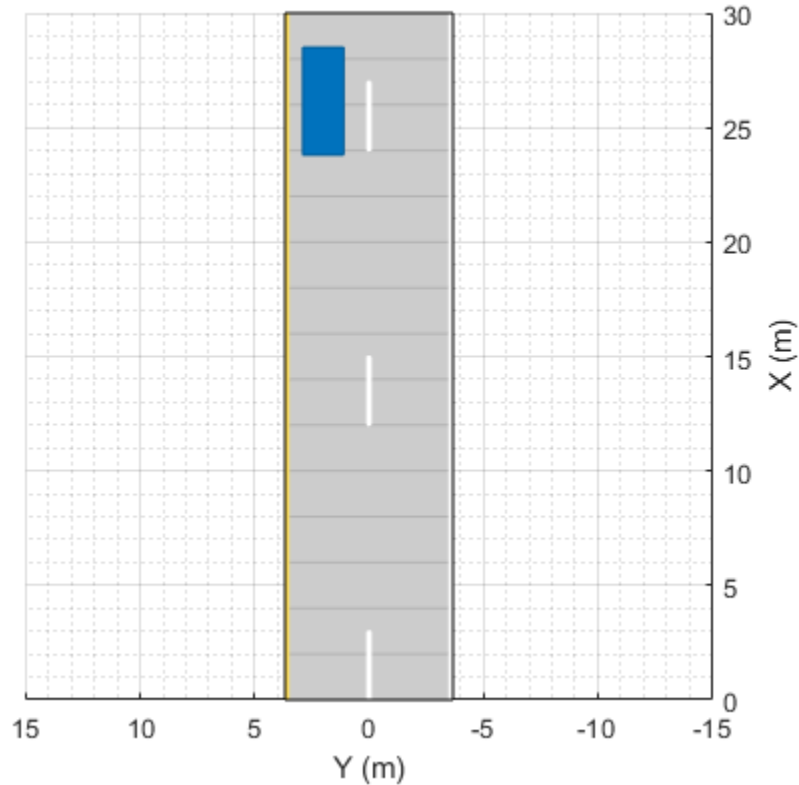


```
plot(scenario)
```



Call the `advance` function in a loop to advance the simulation one time step at a time. Pause every 0.01 second to observe the motion of the vehicle on the plot.

```
while advance(scenario)
    pause(0.01)
end
```



Show Target Outlines in Driving Scenario Simulation

Create a driving scenario and show how target outlines change as the simulation advances.

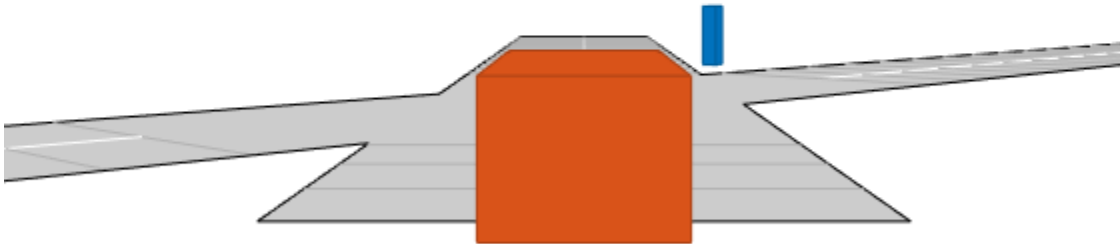
Create a driving scenario consisting of two intersecting straight roads. The first road segment is 45 meters long. The second straight road is 32 meters long and intersects the first road. A car traveling at 12.0 meters per second along the first road approaches a running pedestrian crossing the intersection at 2.0 meters per second.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',1);  
road(scenario,[-10 0 0; 45 -20 0]);
```

```
road(scenario,[-10 -10 0; 35 10 0]);  
ped = actor(scenario,'Length',0.4,'Width',0.6,'Height',1.7);  
car = vehicle(scenario);  
pedspeed = 2.0;  
carspeed = 12.0;  
trajectory(ped,[15 -3 0; 15 3 0],pedspeed);  
trajectory(car,[-10 -10 0; 35 10 0],carspeed);
```

Create an ego-centric chase plot for the vehicle.

```
chasePlot(car,'Centerline','on')
```

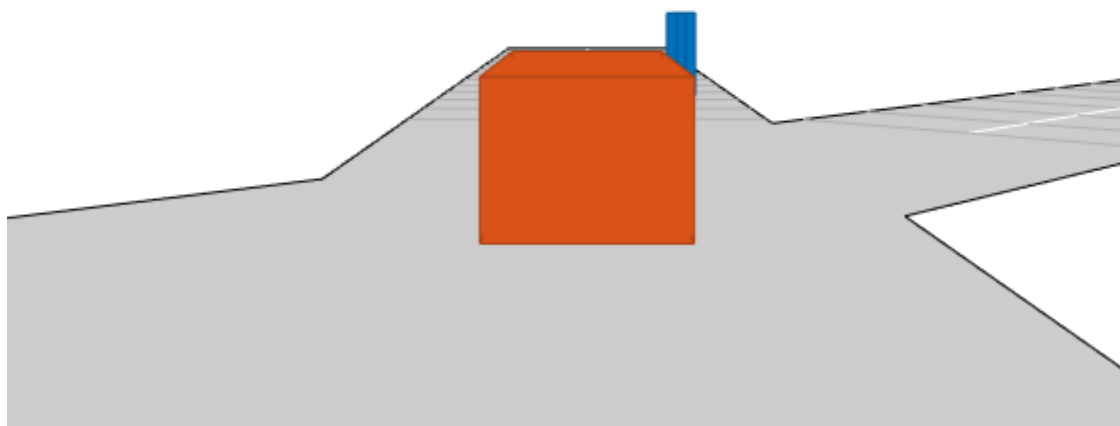


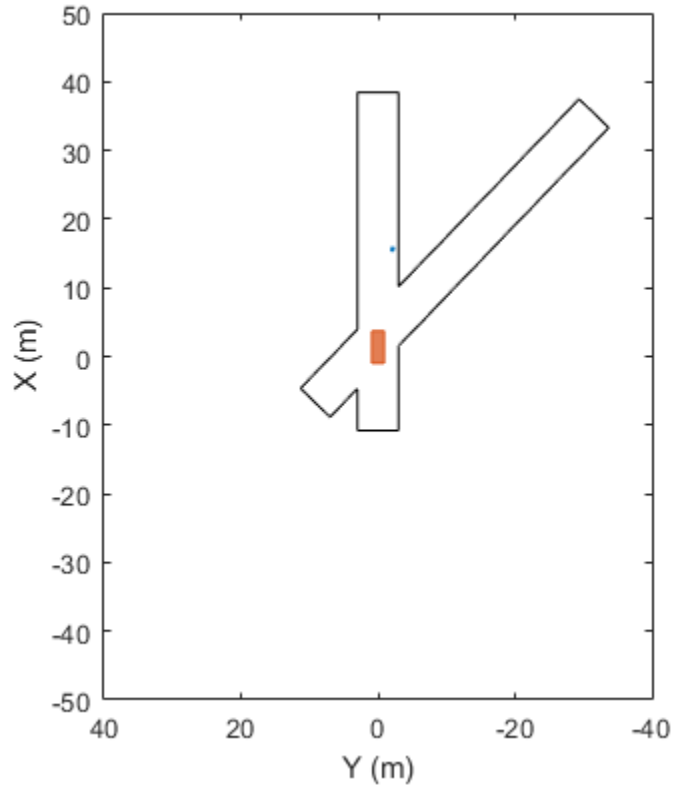
Create an empty bird's-eye plot and add an outline plotter and lane boundary plotter. Then, run the simulation. At each simulation step:

- Update the chase plot to display the road boundaries and target outlines.
- Update the bird's-eye plot to display the updated road boundaries and target outlines. The plot perspective is always with respect to the ego vehicle.

```
bepPlot = birdsEyePlot('XLim',[-50 50],'YLim',[-40 40]);
outlineplotter = outlinePlotter(bepPlot);
laneplotter = laneBoundaryPlotter(bepPlot);
legend('off')

while advance(scenario)
    rb = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    plotLaneBoundary(laneplotter,rb)
    plotOutline(outlineplotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
    pause(0.01)
end
```





Simulate Car Traveling on S-Curve

Simulate a driving scenario with one car traveling on an S-curve. Create and plot the lane boundaries.

Create the driving scenario with one road having an S-curve.

```
scenario = drivingScenario('StopTime',3);  
roadcenters = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];
```

Create the lanes and add them to the road.

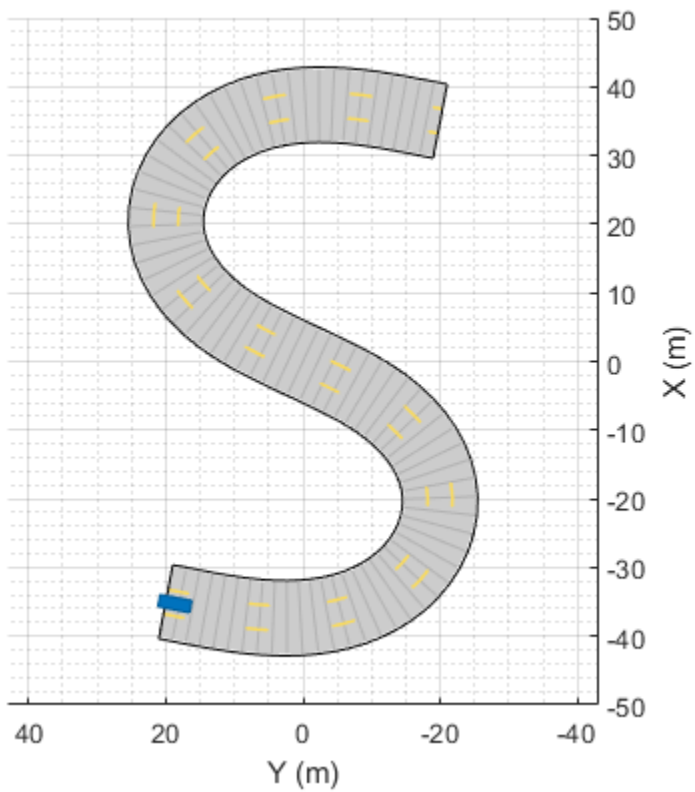
```
lm = [laneMarking('Solid','Color','w'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Solid','Color','w')];  
ls = lanespec(3,'Marking',lm);  
road(scenario,roadcenters,'Lanes',ls);
```

Add an ego vehicle and specify its trajectory from its speed and waypoints. The car travels at 30 meters per second.

```
car = vehicle(scenario, ...  
             'ClassID',1, ...  
             'Position',[-35 20 0]);  
waypoints = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];  
speed = 30;  
trajectory(car,waypoints,speed);
```

Plot the scenario and corresponding chase plot.

```
plot(scenario)
```



`chasePlot(car)`



Run the simulation loop.

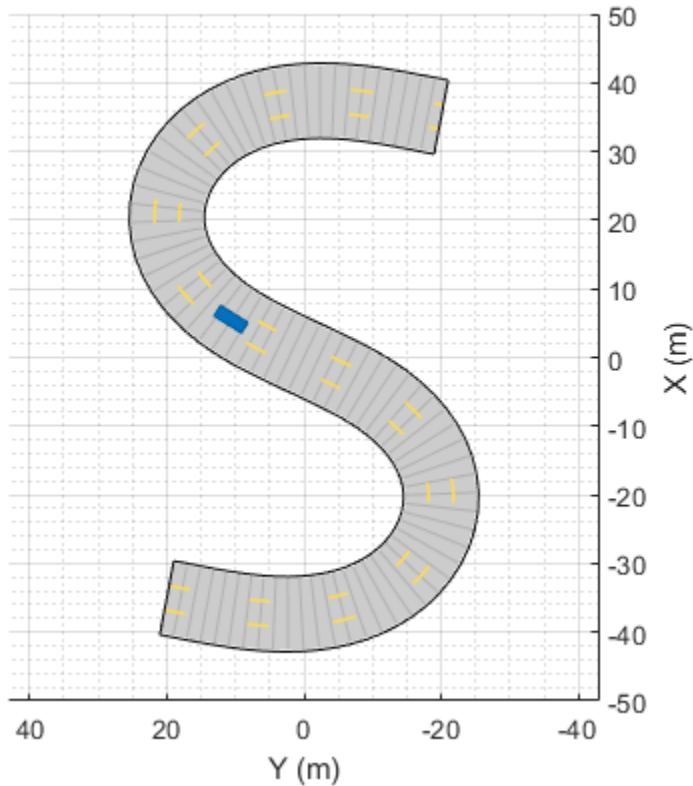
- 1 Initialize a bird's-eye plot and create an outline plotter, left-lane and right-lane boundary plotters, and a road boundary plotter.
- 2 Obtain the road boundaries and rectangular outlines.
- 3 Obtain the lane boundaries to the left and right of the vehicle.
- 4 Advance the simulation and update the plotters.

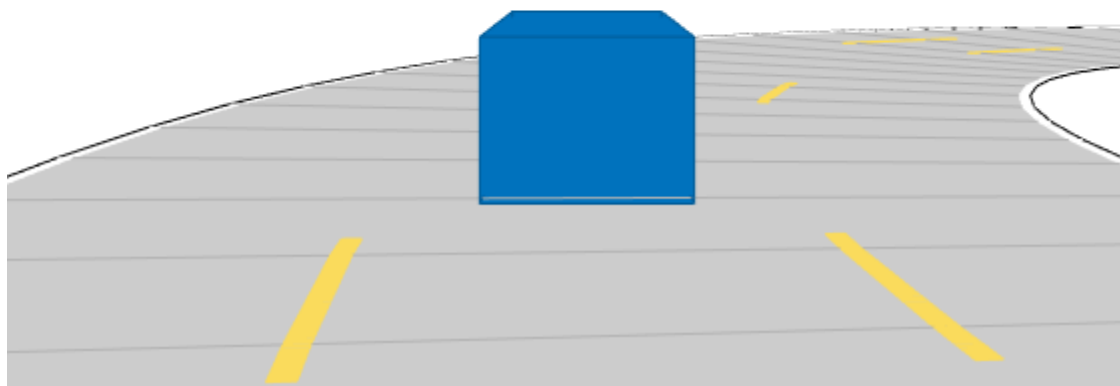
```
bep = birdsEyePlot('XLim',[-40 40], 'YLim',[-30 30]);  
olPlotter = outlinePlotter(bep);  
lblPlotter = laneBoundaryPlotter(bep, 'Color', 'r', 'LineStyle', '-');  
lbrPlotter = laneBoundaryPlotter(bep, 'Color', 'g', 'LineStyle', '-');  
rbsEdgePlotter = laneBoundaryPlotter(bep);
```

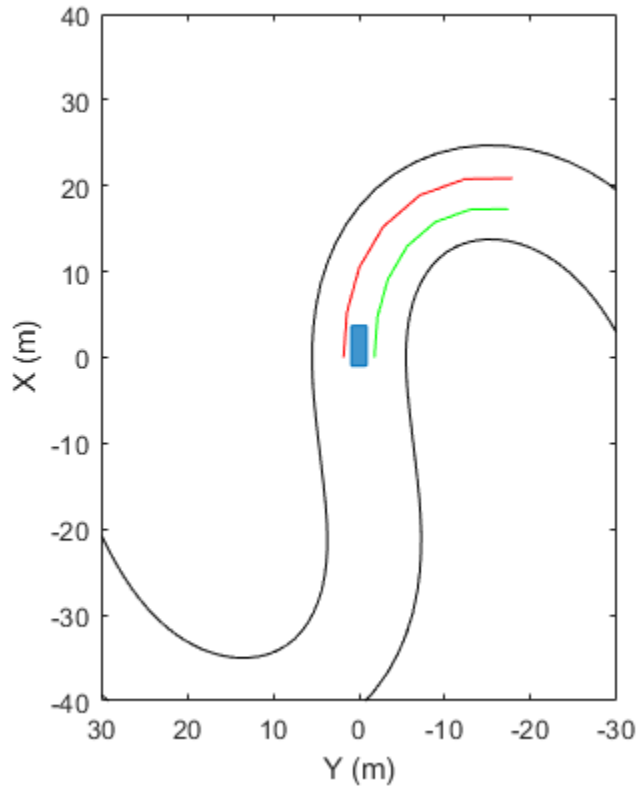
```

legend('off');
while advance(scenario)
    rbs = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    lb = laneBoundaries(car,'XDistance',0:5:30,'LocationType','Center', ...
        'AllBoundaries',false);
    plotLaneBoundary(rbsEdgePlotter,rbs)
    plotLaneBoundary(lblPlotter,{lb(1).Coordinates})
    plotLaneBoundary(lbrPlotter,{lb(2).Coordinates})
    plotOutline(olPlotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
end

```







Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

Output Arguments

isRunning — Run state of simulation

1 | 0

Run state of the simulation, returned as logical 1 (true) or 0 (false).

- If `isRunning` is 1, the simulation is running.
- If `isRunning` is 0, the simulation has stopped running.

A simulation runs until at least one of these conditions are met:

- The simulation time exceeds the simulation stop time. To specify the stop time, use the `StopTime` property of `scenario`.
- Any actor or vehicle reaches the end of its assigned trajectory. The assigned trajectory is specified by the most recent call to the `trajectory` function.

The `advance` function updates actors and vehicles only if they have an assigned trajectory. To update actors and vehicles that have no assigned trajectories, you can set the `Position`, `Velocity`, `Roll`, `Pitch`, `Yaw`, or `AngularVelocity` properties at any time during simulation.

See Also

Objects

`drivingScenario`

Functions

`chasePlot` | `plot` | `record` | `restart` | `trajectory`

Topics

“Driving Scenario Tutorial”

“Create Actor and Vehicle Trajectories”

Introduced in R2017a

plot

Create driving scenario plot

Syntax

```
plot(scenario)  
plot(scenario,Name,Value)
```

Description

`plot(scenario)` creates a 3-D plot with orthonormal perspective, as seen from immediately above the driving scenario, `scenario`.

`plot(scenario,Name,Value)` specifies options using one or more name-value pairs. For example, you can use these options to display road centers and actor waypoints on the plot.

Examples

Create and Display Road Boundaries

Create a driving scenario containing a figure-8 road specified in the world coordinates of the scenario. Convert the world coordinates of the scenario to the coordinate system of the ego vehicle.

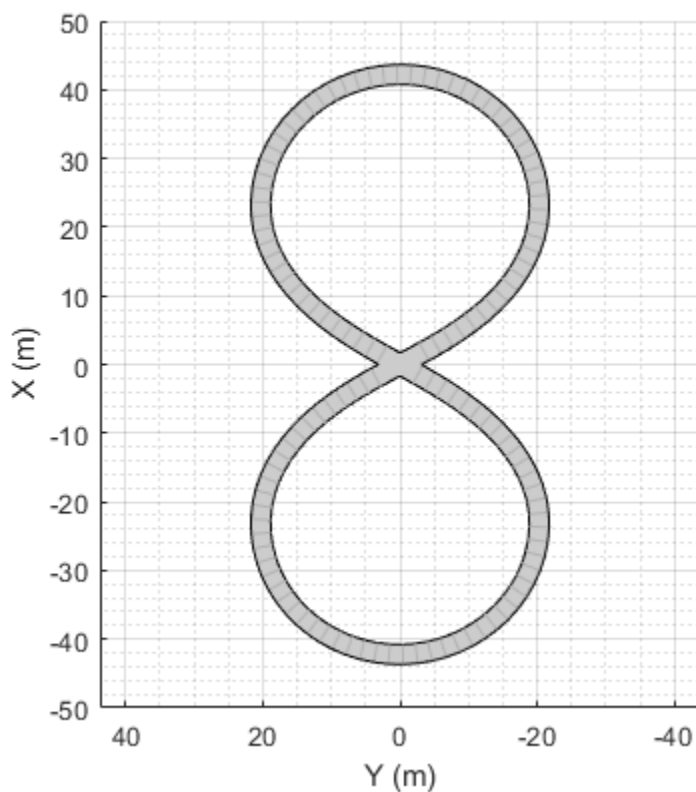
Create an empty driving scenario.

```
scenario = drivingScenario;
```

Add a figure-8 road to the scenario. Display the scenario.

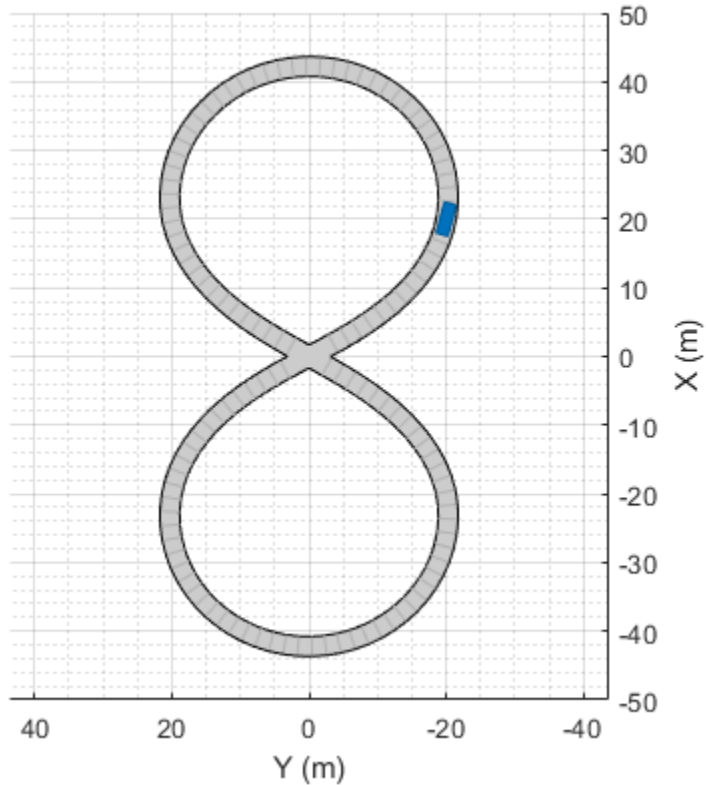
```
roadCenters = [0  0  1  
               20 -20 1  
               20  20 1
```

```
-20 -20 1  
-20 20 1  
0 0 1];  
  
roadWidth = 3;  
bankAngle = [0 15 15 -15 -15 0];  
road(scenario,roadCenters,roadWidth,bankAngle);  
plot(scenario)
```



Add an ego vehicle to the scenario. Position the vehicle at world coordinates (20, -20) and orient it at a -15 degree yaw angle.

```
ego = actor(scenario,'Position',[20 -20 0],'Yaw',-15);
```

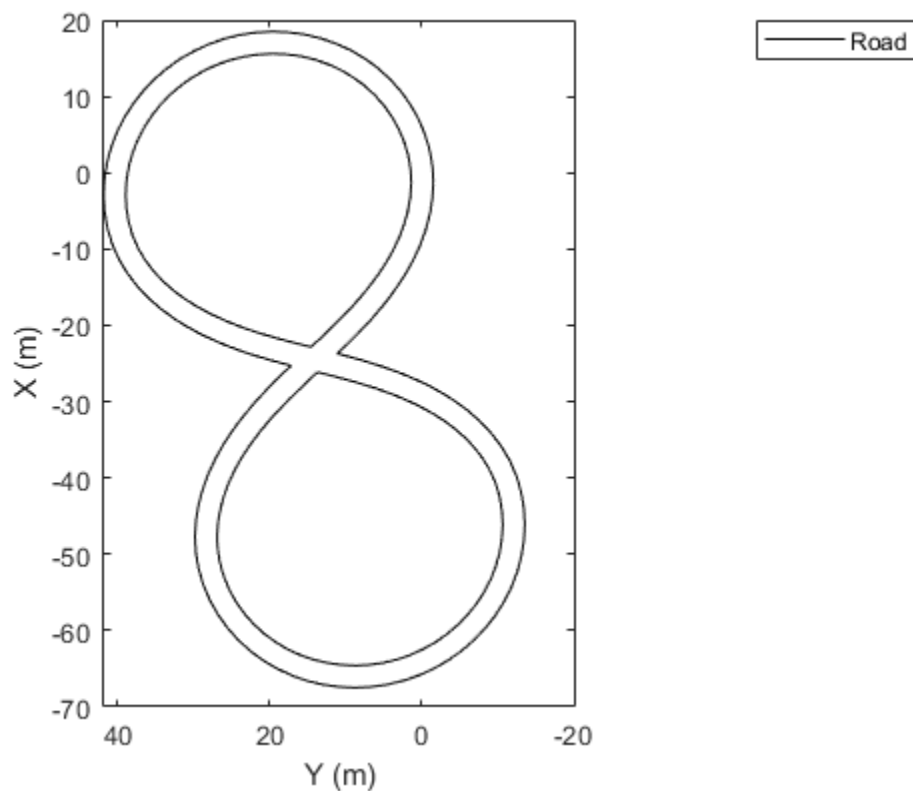


Obtain the road boundaries in ego vehicle coordinates by using the `roadBoundaries` function. Specify the ego vehicle as the input argument.

```
rbEgo1 = roadBoundaries(ego);
```

Display the result on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road');  
plotLaneBoundary(lbp, rbEgo1)
```

Obtain the road boundaries in world coordinates by using the `roadBoundaries` function. Specify the scenario as the input argument.

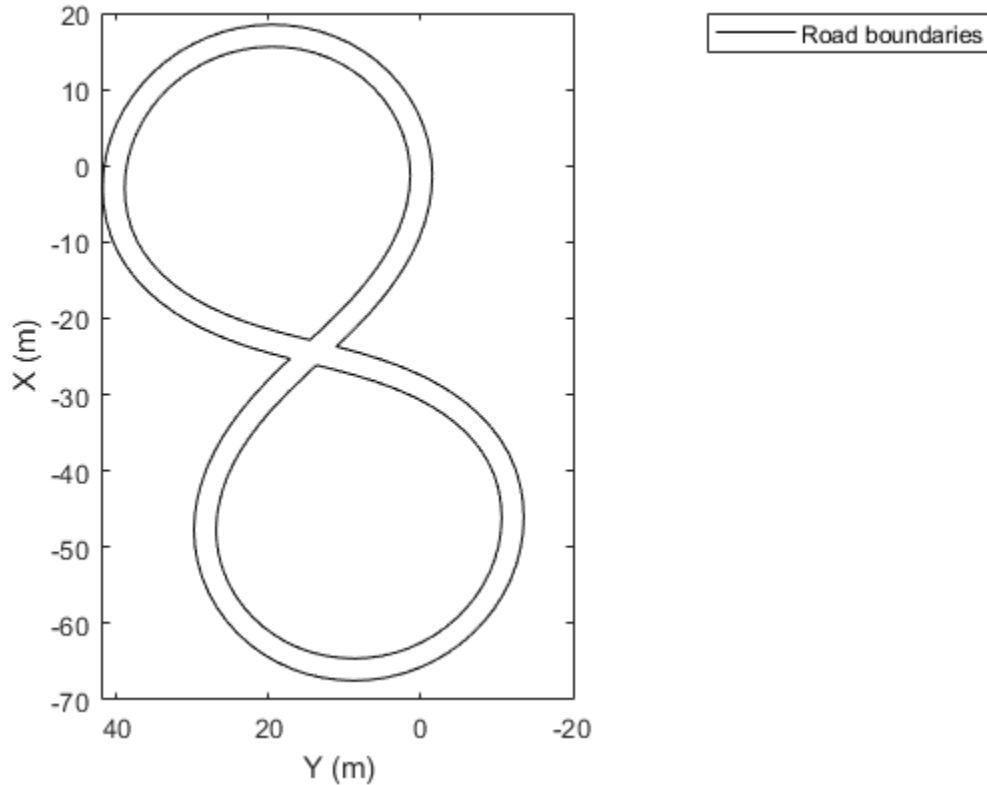
```
rbScenario = roadBoundaries(scenario);
```

Obtain the road boundaries in ego vehicle coordinates by using the `driving.scenario.roadBoundariesToEgo` function.

```
rbEgo2 = driving.scenario.roadBoundariesToEgo(rbScenario,ego);
```

Display the road boundaries on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road boundaries');  
plotLaneBoundary(lbp, {rbEgo2})
```



Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```

Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0° , ends at 90° , and is sampled at 5° increments.

```
angs = [0:5:90]';  
R = 800;  
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];  
roadwidth = 10;  
road(scenario,roadcenters,roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];  
road(scenario,roadcenters)  
roadcenters = [400 400 0; 0 0 0];  
road(scenario,roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

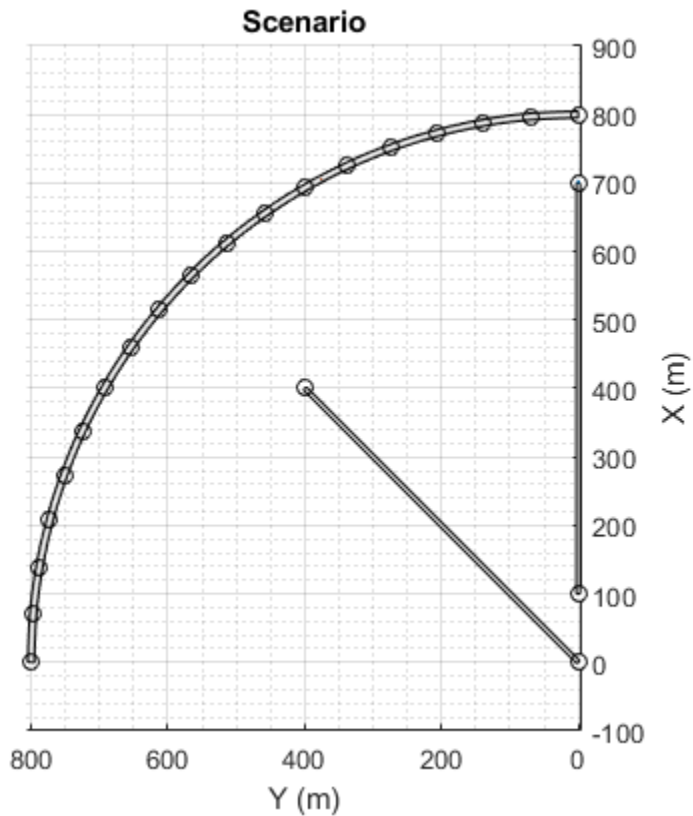
```
car = vehicle(scenario,'Position',[700 0 0],'Length',3,'Width',2,'Height',1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario,'Position',[706 376 0]','Length',2,'Width',0.45,'Height',1.5)
```

Plot the scenario.

```
plot(scenario,'Centerline','on','RoadCenters','on');  
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct
  ActorID
  Position
  Velocity
  Roll
  Pitch
  Yaw
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```

```
profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles
```

Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `plot(sc, 'Centerline', 'on', 'RoadCenters', 'on')` displays the center line and road centers of each road segment.

Parent — Axes in which to draw plot

Axes object

Axes in which to draw the plot, specified as the comma-separated pair consisting of `'Parent'` and an Axes object. If you do not specify `Parent`, a new figure is created.

Centerline — Display center line of roads

`'off'` (default) | `'on'`

Display the center line of roads, specified as the comma-separated pair consisting of `'Centerline'` and `'off'` or `'on'`. The center line follows the middle of each road

segment. Center lines are discontinuous through areas such as intersections or road splits.

RoadCenters — Display road centers

'off' (default) | 'on'

Display road centers, specified as the comma-separated pair consisting of 'RoadCenters' and 'off' or 'on'. The road centers define the roads shown in the plot.

Waypoints — Display actor waypoints

'off' (default) | 'on'

Display actor waypoints, specified as the comma-separated pair consisting of 'Waypoints' and 'off' or 'on'. Waypoints define the trajectory of the actor.

Tips

- To rotate any plot, in the figure window, select **View > Camera Toolbar**.

See Also

Objects

drivingScenario

Functions

actor | chasePlot | road | trajectory | vehicle

Topics

“Driving Scenario Tutorial”

“Create Actor and Vehicle Trajectories”

“Define Road Layouts”

Introduced in R2017a

record

Run driving scenario and record actor states

Syntax

```
rec = record(scenario)
```

Description

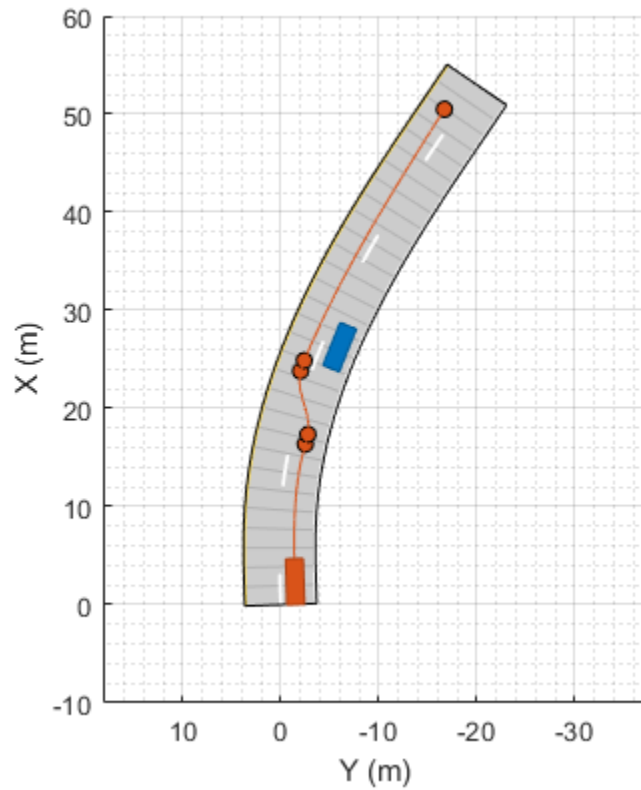
`rec = record(scenario)` returns a recording, `rec`, of the states of actors in a driving scenario simulation, `scenario`. To record a scenario, you must define the trajectory of at least one actor.

Examples

Record Actor Poses from Driving Scenario

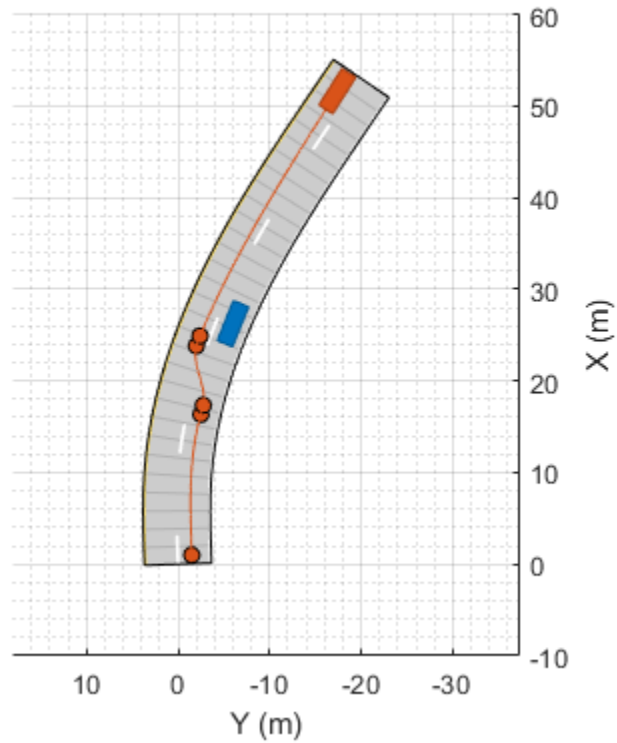
Create a driving scenario in which one car passes a stationary car on a two-lane road.

```
scenario = drivingScenario;  
road(scenario,[0 0; 10 0; 53 -20], 'lanes',lanespec(2));  
plot(scenario,'Waypoints','on');  
stationaryCar = vehicle(scenario,'Position',[25 -5.5 0], 'Yaw',-22);  
  
passingCar = vehicle(scenario);  
waypoints = [1 -1.5; 16.36 -2.5; 17.35 -2.765; ...  
            23.83 -2.01; 24.9 -2.4; 50.5 -16.7];  
speed = 15; % m/s  
trajectory(passingCar,waypoints,speed);
```



Record the driving scenario simulation.

```
rec = record(scenario);
```

Compare the recorded poses of the passing car at the start and end of the simulation.

```
rec(1).ActorPoses(2)
```

```
ans = struct with fields:
```

```
    ActorID: 2  
    Position: [1 -1.5000 0]  
    Velocity: [14.9940 0.4240 0]  
    Roll: 0  
    Pitch: 0  
    Yaw: 1.6198  
    AngularVelocity: [0 0 3.2795]
```

```
rec(end).ActorPoses(2)
```

```
ans = struct with fields:
    ActorID: 2
    Position: [50.4733 -16.6831 0]
    Velocity: [12.6764 -8.0193 0]
    Roll: 0
    Pitch: 0
    Yaw: -32.3183
    AngularVelocity: [0 0 0.2089]
```

Input Arguments

scenario — Driving scenario

drivingScenario object

Driving scenario, specified as a drivingScenario object.

Output Arguments

rec — Recording of actor states during simulation

M-by-1 vector of structures

Recording of actor states during simulation, returned as an *M*-by-1 vector of structures. *M* is the number of time steps in the simulation. Each structure corresponds to a simulation time step.

The rec structure has these fields:

Field	Description	Type
SimulationTime	Simulation time at each time step	Real scalar
ActorPoses	Actor poses in scenario coordinates	<i>N</i> -by-1 vector of ActorPoses structures, where <i>N</i> is the number of actors, including vehicles.

Each ActorPoses structure has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x-, y-, and z-directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x-, y-, and z-directions, specified as an [ω_x ω_y ω_z] real-valued vector. Units are in degrees per second.

For full definitions of these structure fields, see the `actor` and `vehicle` functions.

Data Types: `struct`

See Also

Objects

`drivingScenario`

Functions

`actor` | `actorPoses` | `advance` | `restart` | `vehicle`

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

restart

Restart driving scenario simulation from beginning

Syntax

```
restart(scenario)
```

Description

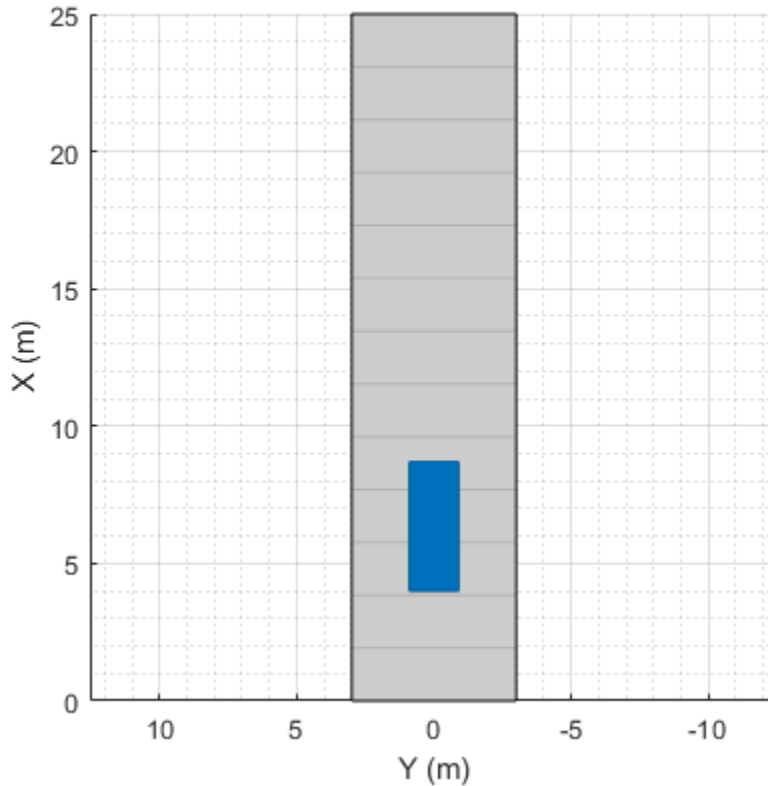
`restart(scenario)` restarts the simulation of the driving scenario, `scenario`, from the beginning. The function sets the `SimulationTime` property of the driving scenario to 0.

Examples

Restart Driving Scenario Simulation

Create a driving scenario in which a vehicle travels down a straight, 25-meter road at 20 meters per second. Plot the scenario.

```
scenario = drivingScenario('SampleTime',0.1);  
  
roadcenters= [0 0 0; 25 0 0];  
road(scenario,roadcenters)  
  
v = vehicle(scenario);  
  
waypoints = [5 0 0; 20 0 0];  
speed = 20; % m/s  
trajectory(v,waypoints,speed)  
  
plot(scenario)
```



Run the simulation and display the location of the vehicle at each time step.

```
while advance(scenario)
    fprintf('Vehicle location: %0.2f meters at t = %0.0f ms\n', ...
        v.Position(1), ...
        scenario.SimulationTime * 1000)
end
```

```
Vehicle location: 7.00 meters at t = 100 ms
```

```
Vehicle location: 9.00 meters at t = 200 ms
```

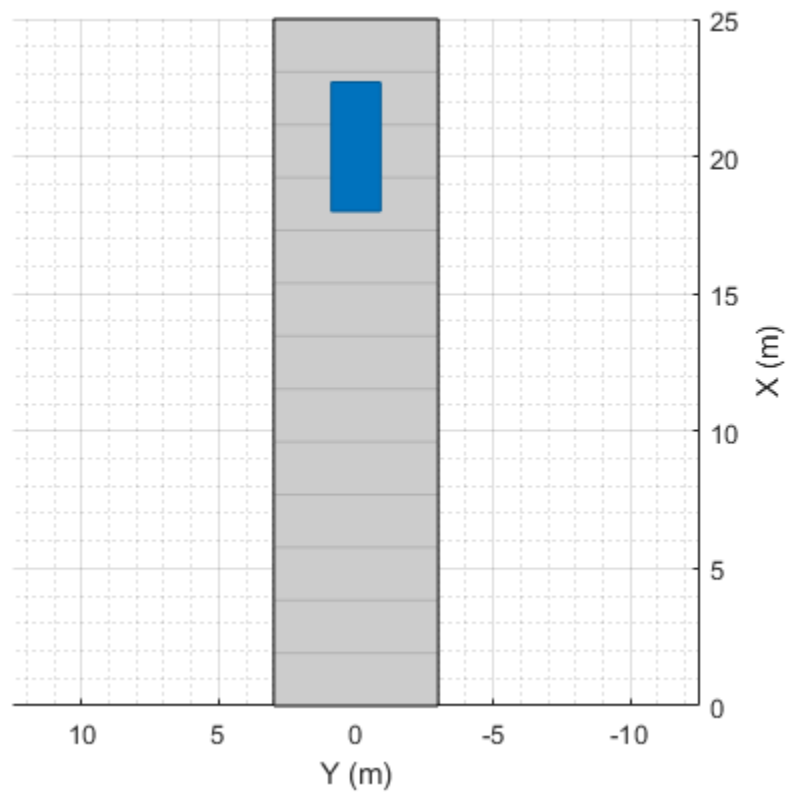
```
Vehicle location: 11.00 meters at t = 300 ms
```

```
Vehicle location: 13.00 meters at t = 400 ms
```

Vehicle location: 15.00 meters at t = 500 ms

Vehicle location: 17.00 meters at t = 600 ms

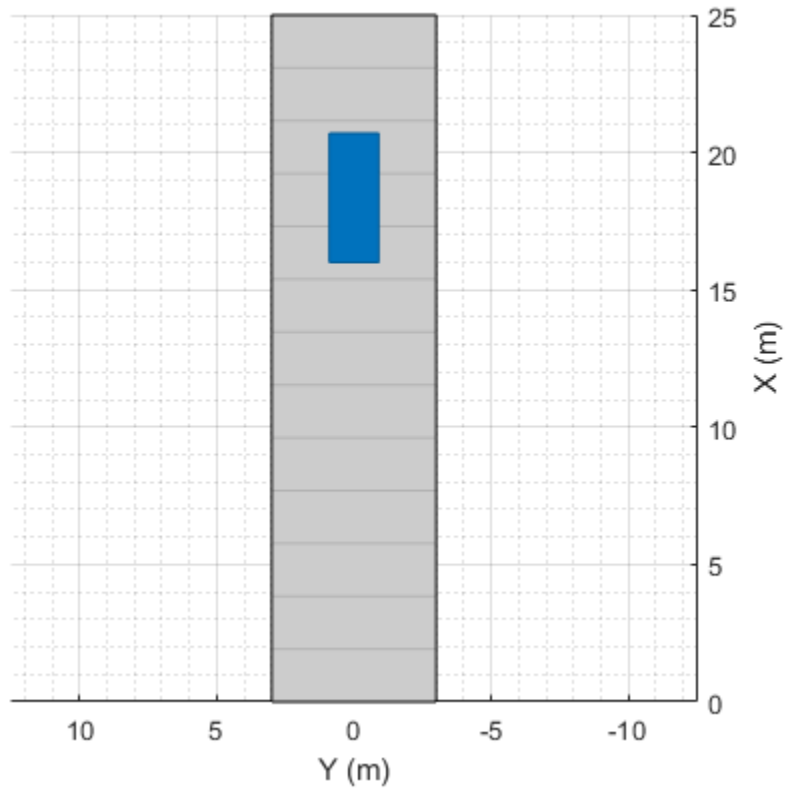
Vehicle location: 19.00 meters at t = 700 ms



Restart the simulation. Increase the sample time and rerun the simulation.

```
restart(scenario);
scenario.SampleTime = 0.2;
while advance(scenario)
    fprintf('Vehicle location: %0.2f meters at t = %0.0f ms\n', ...
        v.Position(1), ...
```

```
        scenario.SimulationTime * 1000)  
end  
Vehicle location: 9.00 meters at t = 200 ms  
Vehicle location: 13.00 meters at t = 400 ms  
Vehicle location: 17.00 meters at t = 600 ms
```



Input Arguments

scenario — Driving scenario
drivingScenario object

Driving scenario, specified as a `drivingScenario` object.

See Also

Objects

`drivingScenario`

Functions

`advance` | `record`

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

updatePlots

Update driving scenario plots

Syntax

```
updatePlots(scenario)
```

Description

`updatePlots(scenario)` updates the display of all existing plots for the driving scenario, `scenario`. Driving scenario plots are automatically updated every time you call the `advance` function to advance the simulation. Use `updatePlots` after you update any actor properties and want to refresh the plot without having to call `advance`.

Examples

Update Driving Scenario Plots

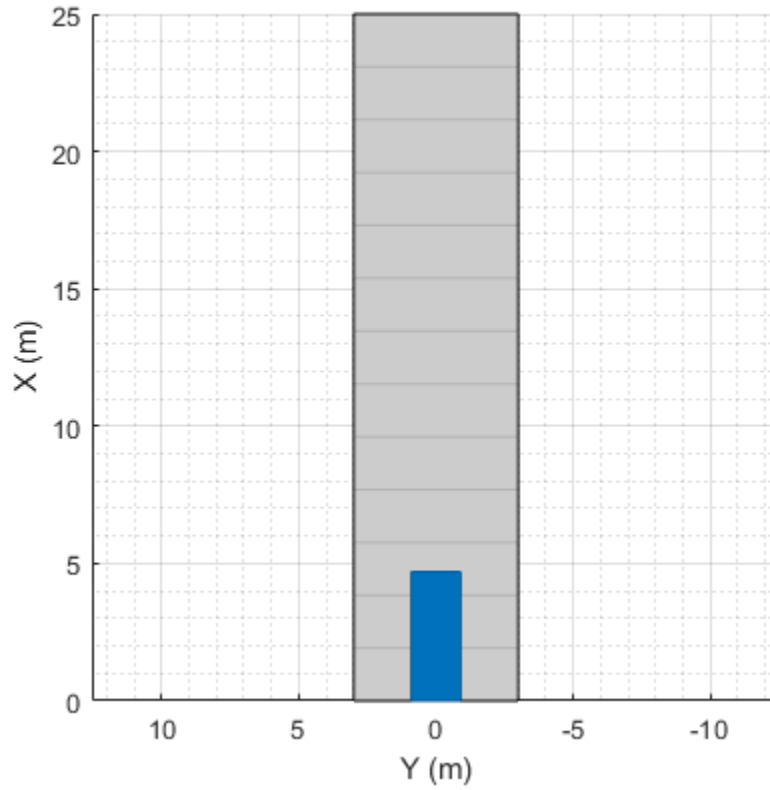
Update driving scenario plots after changing aspects of the scenario.

Create a driving scenario containing a vehicle on a straight, 25-meter road segment. Plot the scenario.

```
scenario = drivingScenario;  
roadcenters = [0 0 0; 25 0 0];  
road(scenario, roadcenters);
```

```
v = vehicle(scenario);  
v.Position = [1 0 0];
```

```
plot(scenario)
```



Use a chase plot to plot the scenario from the perspective of the vehicle.

```
chasePlot(v)
```

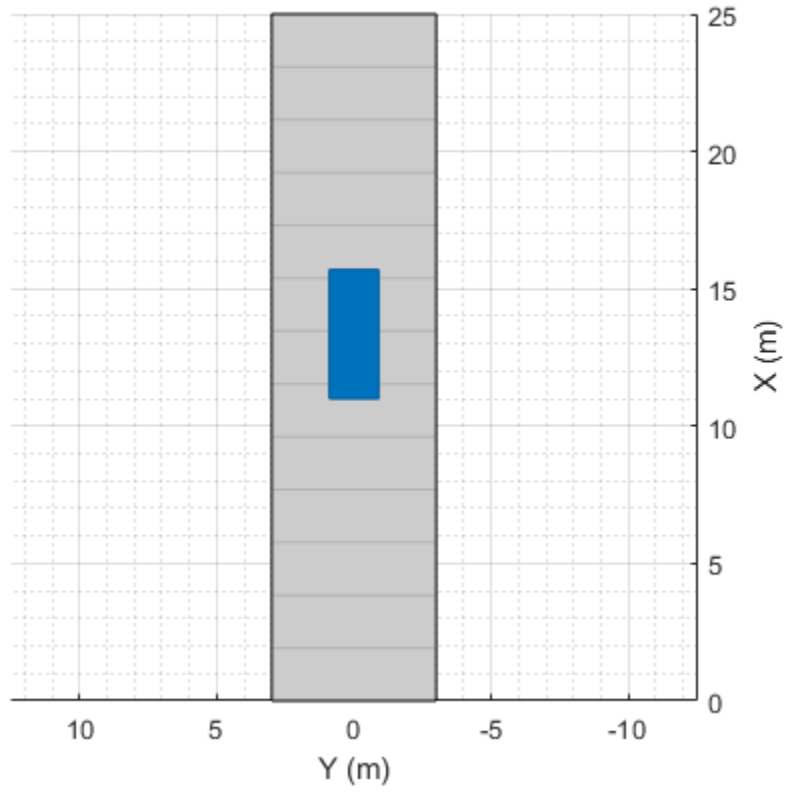


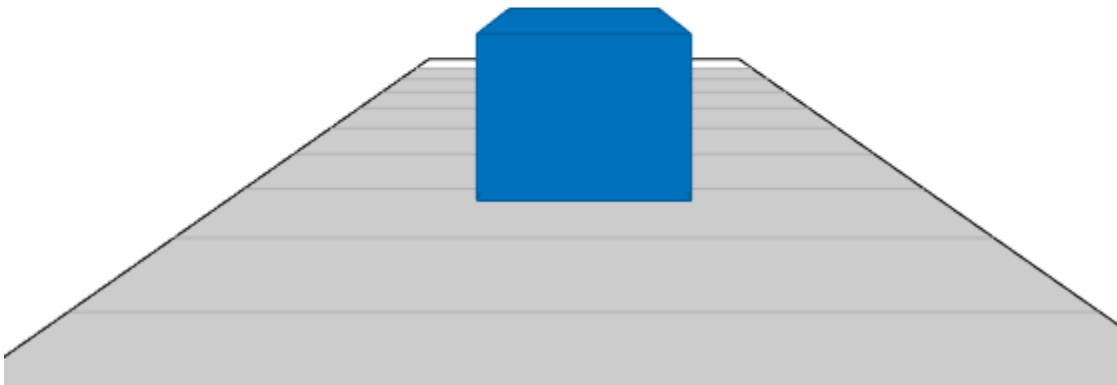
Set a new position for the vehicle.

```
v.Position = [12 0 0];
```

Update both plots to show the new position of the vehicle.

```
updatePlots(scenario)
```





Input Arguments

scenario – Driving scenario
`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

See Also

Objects

drivingScenario

Functions

advance | chasePlot | plot

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

actor

Package:

Add actor to driving scenario

Syntax

```
ac = actor(scenario)
ac = actor(scenario,Name,Value)
```

Description

`ac = actor(scenario)` adds an Actor object, `ac`, to the driving scenario, `scenario`. The actor has default property values.

Actors are cuboids (box shapes) that represent objects in motion, such as cars, pedestrians, and bicycles. Actors can also represent stationary obstacles that can influence the motion of other actors, such as barriers. For more details about how actors are defined, see “Actors and Vehicles” on page 4-354.

`ac = actor(scenario,Name,Value)` sets actor properties using one or more name-value pair arguments. For example, you can set the position, velocity, dimensions, and orientation of the actor.

Examples

Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```


Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0°, ends at 90°, and is sampled at 5° increments.

```
angs = [0:5:90]';  
R = 800;  
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];  
roadwidth = 10;  
road(scenario, roadcenters, roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];  
road(scenario, roadcenters)  
roadcenters = [400 400 0; 0 0 0];  
road(scenario, roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

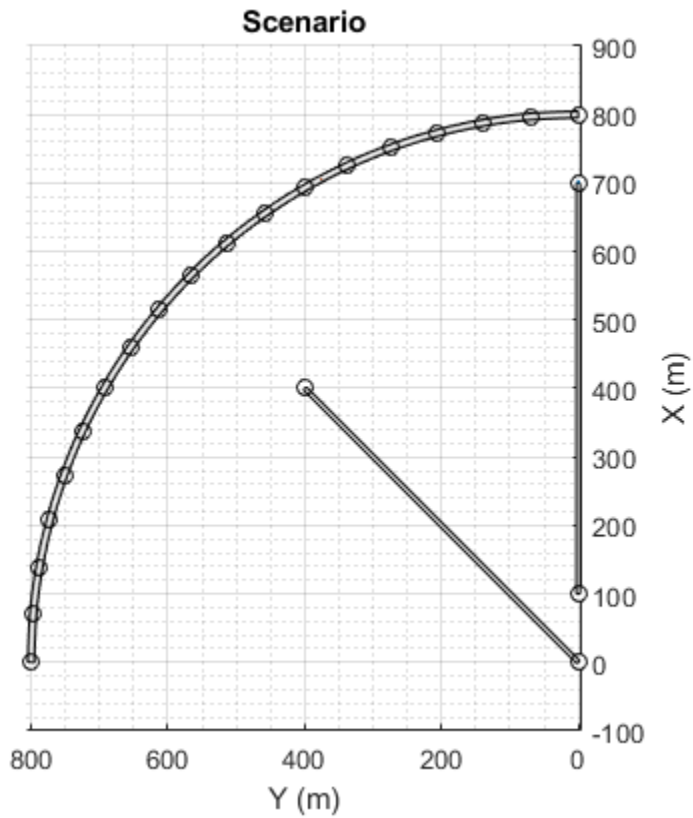
```
car = vehicle(scenario, 'Position', [700 0 0], 'Length', 3, 'Width', 2, 'Height', 1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario, 'Position', [706 376 0]', 'Length', 2, 'Width', 0.45, 'Height', 1.5)
```

Plot the scenario.

```
plot(scenario, 'Centerline', 'on', 'RoadCenters', 'on');  
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct  
  ActorID  
  Position  
  Velocity  
  Roll  
  Pitch  
  Yaw  
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```

```
profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles
```

Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `actor('Length',0.24,'Width',0.45,'Height',1.7)` creates an actor with the dimensions of a pedestrian. Units are in meters.

ClassID — Classification identifier

0 (default) | nonnegative integer

Classification identifier of actor, specified as the comma-separated pair consisting of `'ClassID'` and a nonnegative integer.

Specify `ClassID` values to group together actors that have similar dimensions, radar cross-section (RCS) patterns, or other properties. As a best practice, before adding actors to a `drivingScenario` object, determine the actor classification scheme you want to use. Then, when creating the actors, specify the `ClassID` name-value pair to set classification identifiers according to the scheme.

Suppose you want to create a scenario containing these actors:

- Two cars, one of which is the ego vehicle
- A truck
- A bicycle

The code shows a sample classification scheme for this scenario, where 1 refers to cars, 2 refers to trucks, and 3 refers to bicycles. The cars have default vehicle properties. The truck and bicycle have the dimensions of a typical truck and bicycle, respectively.

```
scenario = drivingScenario;
ego = vehicle(scenario, 'ClassID', 1);
car = vehicle(scenario, 'ClassID', 1);
truck = vehicle(scenario, 'ClassID', 2, 'Length', 8.2, 'Width', 2.5, 'Height', 3.5);
bicycle = actor(scenario, 'ClassID', 3, 'Length', 1.7, 'Width', 0.45, 'Height', 1.7);
```

The default ClassID of 0 is reserved for an object of an unknown or unassigned class. If you plan to import drivingScenario objects into the **Driving Scenario Designer** app, do not leave the ClassID property of actors set to 0. The app does not recognize a ClassID of 0 for actors and returns an error. Instead, set ClassID values of actors according to the actor classification scheme used in the app.

ClassID	Class Name
1	Car
2	Truck
3	Bicycle
4	Pedestrian
5	Barrier

Position — Position of actor center

[0 0 0] (default) | [x y z] real-valued vector

Position of the actor center, specified as the comma-separated pair consisting of 'Position' and an [x y z] real-valued vector.

The center of the actor is [L/2 W/2 b], where:

- L/2 is the midpoint of actor length L.
- W/2 is the midpoint of actor width W.

- b is the bottom of the cuboid.

Units are in meters.

Example: [10;50;0]

Velocity — Velocity of actor center

[0 0 0] (default) | [v_x v_y v_z] real-valued vector

Velocity (v) of the actor center in the x -, y - and z -directions, specified as the comma-separated pair consisting of 'Velocity' and a [v_x v_y v_z] real-valued vector. The 'Position' name-value pair specifies the actor center. Units are in meters per second.

Example: [-4;7;10]

Yaw — Yaw angle of actor

0 (default) | real scalar

Yaw angle of the actor, specified as the comma-separated pair consisting of 'Yaw' and a real scalar. Yaw is the angle of rotation of the actor around the z -axis and is positive in the clockwise direction. Angle values are wrapped to the range [-180, 180]. Units are in degrees.

Example: -0.4

Pitch — Pitch angle of actor

0 (default) | real scalar

Pitch angle of the actor, specified as the comma-separated pair consisting of 'Pitch' and a real scalar. Pitch is the angle of rotation of the actor around the y -axis and is positive in the clockwise direction. Angle values are wrapped to the range [-180, 180]. Units are in degrees.

Example: 5.8

Roll — Roll angle of actor

0 (default) | real scalar

Roll angle of the actor, specified as the comma-separated pair consisting of 'Roll' and a real scalar. Roll is the angle of rotation of the actor around the x -axis and is positive in the clockwise direction. Angle values are wrapped to the range [-180, 180]. Units are in degrees.

Example: -10

AngularVelocity — Angular velocity of actor

[0 0 0] (default) | [$\omega_x \omega_y \omega_z$] real-valued vector

Angular velocity (ω) of the actor, in world coordinates, specified as the comma-separated pair consisting of 'AngularVelocity' and a [$\omega_x \omega_y \omega_z$] real-valued vector. Units are in degrees per second.

Example: [20 40 20]

Length — Length of actor

4.7 (default) | positive real scalar

Length of the actor, specified as the comma-separated pair consisting of 'Length' and a positive real scalar. Units are in meters.

Example: 5.5

Width — Width of actor

1.8 (default) | positive real scalar

Width of the actor, specified as the comma-separated pair consisting of 'Width' and a positive real scalar. Units are in meters.

Example: 3.0

Height — Height of actor

1.4 (default) | positive real scalar

Height of the actor, specified as the comma-separated pair consisting of 'Height' and a positive real scalar. Units are meters.

Example: 2.1

RCSPattern — Radar cross-section pattern of actor

[10 10; 10 10] (default) | Q -by- P real-valued matrix

Radar cross-section (RCS) pattern of actor, specified as the comma-separated pair consisting of 'RCSPattern' and a Q -by- P real-valued matrix. RCS is a function of the azimuth and elevation angles, where:

- Q is the number of elevation angles specified by the 'RCSElevationAngles' name-value pair.
- P is the number of azimuth angles specified by the 'RCSAzimuthAngles' name-value pair.

Units are in decibels per square meter (dBsm).

Example: 5.8

RCSAzimuthAngles — Azimuth angles of actor's RCS pattern

[-180 180] (default) | *P*-element real-valued vector

Azimuth angles of the actor's RCS pattern, specified as the comma-separated pair consisting of 'RCSAzimuthAngles' and a *P*-element real-valued vector. *P* is the number of azimuth angles. Values are in the range $[-180^\circ, 180^\circ]$.

Each element of `RCSAzimuthAngles` defines the azimuth angle of the corresponding column of the 'RCSPattern' name-value pair. Units are in degrees.

Example: [-90:90]

RCSElevationAngles — Elevation angles of actor's RCS pattern

[-90 90] (default) | *Q*-element real-valued vector

Elevation angles of the actor's RCS pattern, specified as the comma-separated pair consisting of 'RCSElevationAngles' and a *Q*-element real-valued vector. *Q* is the number of elevation angles. Values are in the range $[-90^\circ, 90^\circ]$.

Each element of `RCSElevationAngles` defines the elevation angle of the corresponding row of the `RCSPattern` property. Units are in degrees.

Example: [0:90]

Output Arguments

ac — Driving scenario actor

Actor object

Driving scenario actor, returned as an Actor object belonging to the driving scenario specified by `scenario`.

You can modify the Actor object by changing its property values. The property names correspond to the name-value pair arguments used to create the object. The only property that you cannot modify is `ActorID`, which is a positive integer indicating the unique, scenario-defined ID of the actor.

To specify or visualize actor motion, use these functions:

<code>trajectory</code>	Create actor or vehicle trajectory in driving scenario
<code>chasePlot</code>	Ego-centric projective perspective plot

To get information about actor characteristics, use these functions:

<code>actorPoses</code>	Positions, velocities, and orientations of actors in driving scenario
<code>actorProfiles</code>	Physical and radar characteristics of actors in driving scenario
<code>targetOutlines</code>	Outlines of targets viewed by actor
<code>targetPoses</code>	Target positions and orientations relative to ego vehicle
<code>driving.scenario.targetsToEgo</code>	Convert actor poses to ego vehicle coordinates

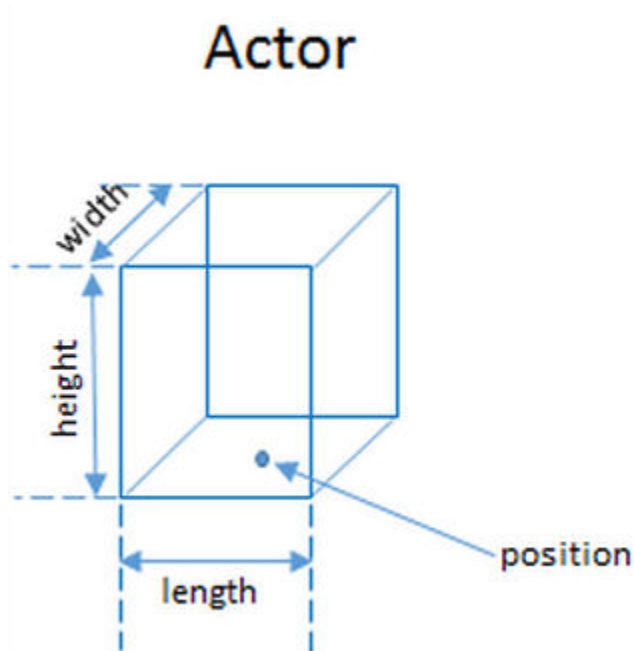
To get information about the roads and lanes that the actor is on, use these functions:

<code>roadBoundaries</code>	Get road boundaries
<code>driving.scenario.roadBoundariesToEgo</code>	Convert road boundaries to ego vehicle coordinates
<code>currentLane</code>	Get current lane of actor
<code>laneBoundaries</code>	Get lane boundaries of actor lane
<code>laneMarkingVertices</code>	Lane marking vertices and faces in driving scenario

More About

Actors and Vehicles

In driving scenarios, an actor is a cuboid (box-shaped) object with a specific length, width, and height. Actors also have a radar cross-section (RCS) pattern, specified in dBsm, which you can refine by setting angular azimuth and elevation coordinates. An actor's position is defined as the center of its bottom face. This center point is used as the actor's rotational center and point of contact with the ground.

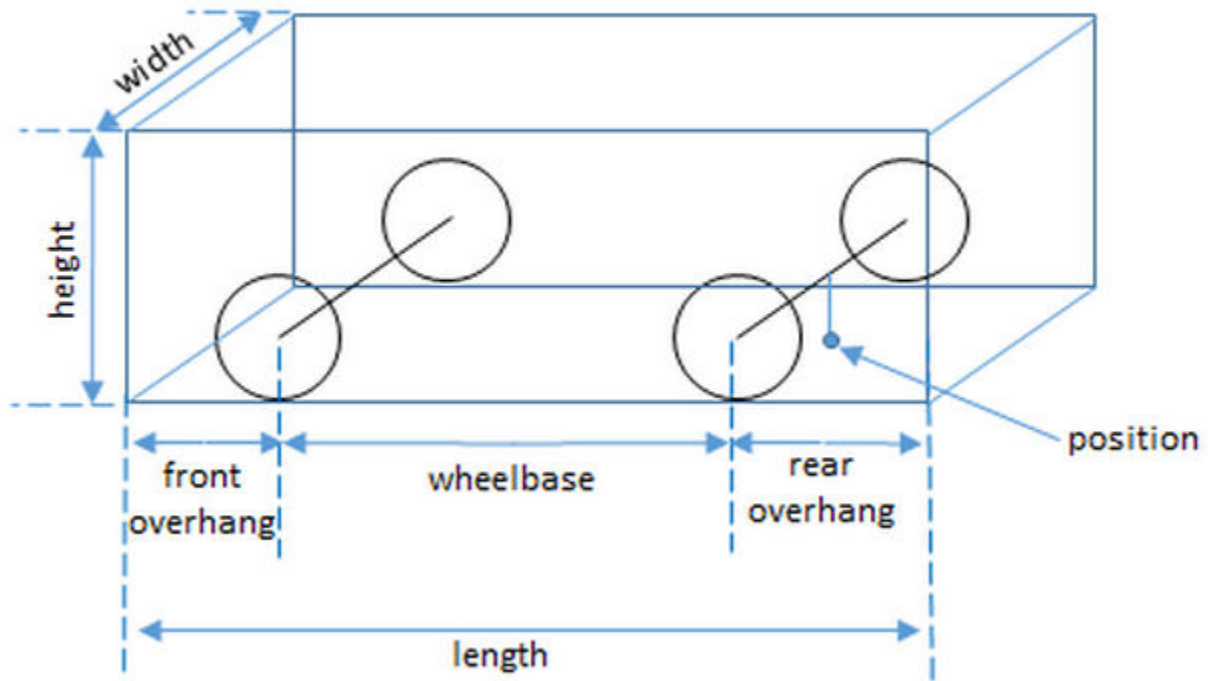


A vehicle is a special kind of actor that moves on wheels. Vehicles have three extra properties that govern the placement of the front and rear axle.

- Wheelbase — Distance between the front and rear axles
- Front overhang — Distance between the front of the vehicle and the front axle.
- Rear overhang — Distance between the rear axle and the rear of the vehicle.

Unlike other types of actors, the vehicle's position is defined by the point on the ground that is below the center of its rear axle. This point corresponds to the vehicle's natural center of rotation.

Vehicle



This table shows a list of common actors and their dimensions. To specify these values in Actor and Vehicle objects, set the corresponding properties shown.

Actor Classification	Actor Object	Actor Properties						
		Length	Width	Height	FrontOverhang	RearOverhang	Wheelbase	RCSPattern
Pedestrian	Actor	0.24 m	0.45 m	1.7 m	N/A	N/A	N/A	-8 dBsm
Car	Vehicle	4.7 m	1.8 m	1.4 m	0.9 m	1.0 m	2.8 m	10 dBsm

Actor Classification	Actor Object	Actor Properties						
		Length	Width	Height	FrontOverhang	RearOverhang	Wheelbase	RCSPattern
Motorcycle	Vehicle	2.2 m	0.6 m	1.5 m	0.37 m	0.32 m	1.51 m	0 dBsm

See Also

[drivingScenario](#) | [vehicle](#)

Topics

[“Driving Scenario Tutorial”](#)

[“Create Actor and Vehicle Trajectories”](#)

Introduced in R2017a

actorPoses

Positions, velocities, and orientations of actors in driving scenario

Syntax

```
poses = actorPoses(scenario)
```

Description

`poses = actorPoses(scenario)` returns the current poses (positions, velocities, and orientations) for all actors in the driving scenario, `scenario`. Actors include `Actor` and `Vehicle` objects, which you can create using the `actor` and `vehicle` functions, respectively. Actor poses are in scenario coordinates.

Examples

Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```

Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0°, ends at 90°, and is sampled at 5° increments.

```
angs = [0:5:90]';  
R = 800;  
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];  
roadwidth = 10;  
road(scenario,roadcenters,roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];  
road(scenario,roadcenters)  
roadcenters = [400 400 0; 0 0 0];  
road(scenario,roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

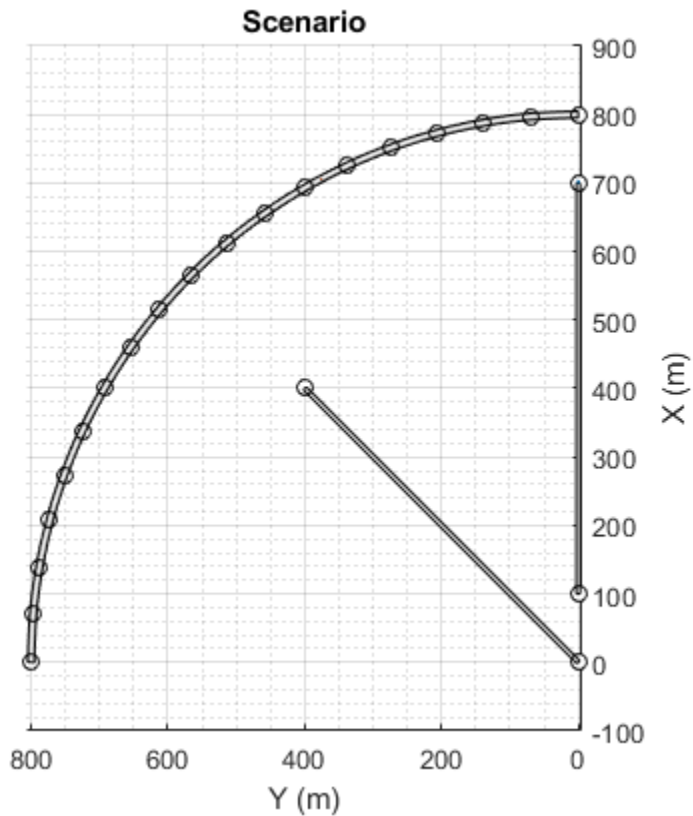
```
car = vehicle(scenario,'Position',[700 0 0],'Length',3,'Width',2,'Height',1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario,'Position',[706 376 0]','Length',2,'Width',0.45,'Height',1.5)
```

Plot the scenario.

```
plot(scenario,'Centerline','on','RoadCenters','on');  
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct
  ActorID
  Position
  Velocity
  Roll
  Pitch
  Yaw
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```

```

profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles

```

Obtain Target Poses in Ego Vehicle Coordinates

Create a driving scenario containing three vehicles. Find the target poses of two of the vehicles as viewed by the third vehicle. Target poses are returned in the ego-centric coordinate system of the third vehicle.

Create a driving scenario.

```
scenario = drivingScenario;
```

Create the target actors.

```

actor(scenario, 'Position', [10 20 30], ...
  'Velocity', [12 113 14], ...
  'Yaw', 54, ...
  'Pitch', 25, ...
  'Roll', 22, ...
  'AngularVelocity', [24 42 27]);

```

```

actor(scenario, 'Position', [17 22 12], ...
  'Velocity', [19 13 15], ...
  'Yaw', 45, ...
  'Pitch', 52, ...
  'Roll', 2, ...
  'AngularVelocity', [42 24 29]);

```

Add the ego vehicle actor.

```

ego = actor(scenario, 'Position', [1 2 3], ...
  'Velocity', [1.2 1.3 1.4], ...

```

```
'Yaw',4, ...  
'Pitch',5, ...  
'Roll',2, ...  
'AngularVelocity',[4 2 7]);
```

Use `actorPoses` to return the poses of all the actors. Pose properties (position, velocity, and orientation) are in scenario coordinates.

```
allposes = actorPoses(scenario);
```

Use `driving.scenario.targetsToEgo` to convert only the target poses to the ego-centric coordinates of the ego actor. Examine the pose of the first actor.

```
targetposes1 = driving.scenario.targetsToEgo(allposes(1:2),ego);  
disp(targetposes1(1))
```

```
ActorID: 1  
Position: [7.8415 18.2876 27.1675]  
Velocity: [18.6826 112.0403 9.2960]  
Roll: 16.4327  
Pitch: 23.2186  
Yaw: 47.8114  
AngularVelocity: [-3.3744 47.3021 18.2569]
```

Alternatively, use `targetPoses` to obtain all non-ego actor poses in ego vehicle coordinates. Compare these poses to the previously calculated poses.

```
targetposes2 = targetPoses(ego);  
disp(targetposes2(1))
```

```
ActorID: 1  
ClassID: 0  
Position: [7.8415 18.2876 27.1675]  
Velocity: [18.6826 112.0403 9.2960]  
Roll: 16.4327  
Pitch: 23.2186  
Yaw: 47.8114  
AngularVelocity: [-3.3744 47.3021 18.2569]
```

Input Arguments

scenario — Driving scenario

drivingScenario object

Driving scenario, specified as a `drivingScenario` object.

Output Arguments

poses — Actor poses

structures | array of structures

Actor poses, in scenario coordinates, returned as a structure or an array of structures. Poses are the positions, velocities, and orientations of actors.

Each structure in `poses` has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an $[x \ y \ z]$ real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x -, y -, and z -directions, specified as a $[v_x \ v_y \ v_z]$ real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x -, y -, and z -directions, specified as an $[\omega_x \ \omega_y \ \omega_z]$ real-valued vector. Units are in degrees per second.

For full definitions of these structure fields, see the `actor` and `vehicle` functions.

See Also

Objects

drivingScenario | radarDetectionGenerator | visionDetectionGenerator

Functions

actor | actorProfiles | targetOutlines | targetPoses | vehicle

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

actorProfiles

Physical and radar characteristics of actors in driving scenario

Syntax

```
profiles = actorProfiles(scenario)
```

Description

`profiles = actorProfiles(scenario)` returns the physical and radar characteristics, `profiles`, for all actors in a driving scenario, `scenario`. Actors include `Actor` and `Vehicle` objects, which you can create using the `actor` and `vehicle` functions, respectively.

You can use actor profiles as inputs to radar and vision sensors, such as `radarDetectionGenerator` and `visionDetectionGenerator` objects.

Examples

Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```

Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0°, ends at 90°, and is sampled at 5° increments.

```
angs = [0:5:90]';  
R = 800;  
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];
```

```
roadwidth = 10;  
road(scenario, roadcenters, roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];  
road(scenario, roadcenters)  
roadcenters = [400 400 0; 0 0 0];  
road(scenario, roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

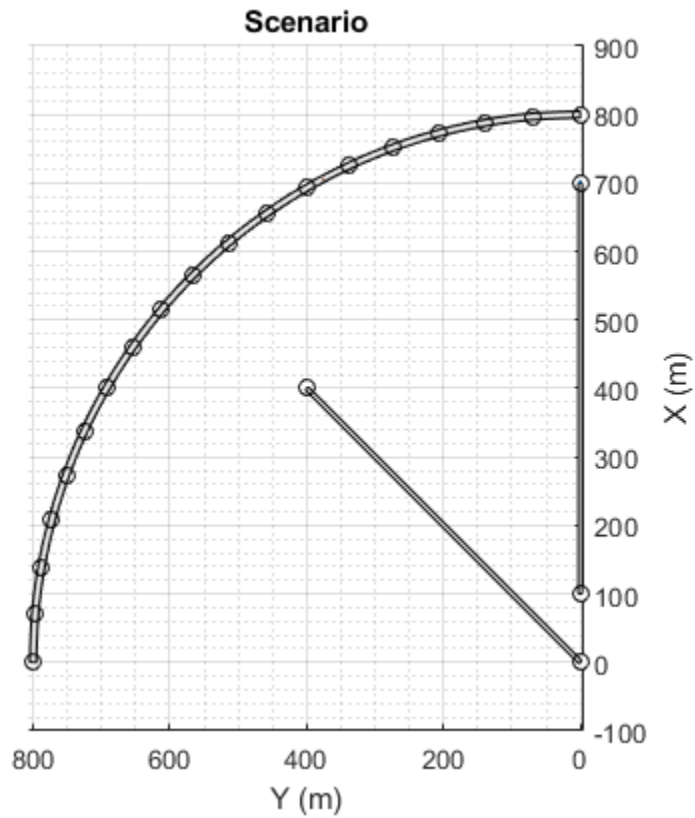
```
car = vehicle(scenario, 'Position', [700 0 0], 'Length', 3, 'Width', 2, 'Height', 1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario, 'Position', [706 376 0], 'Length', 2, 'Width', 0.45, 'Height', 1.5);
```

Plot the scenario.

```
plot(scenario, 'Centerline', 'on', 'RoadCenters', 'on');  
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct  
  ActorID  
  Position  
  Velocity  
  Roll  
  Pitch  
  Yaw  
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```

```
profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles
```

Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

Output Arguments

profiles — Actor profiles

structure | array of structures

Actor profiles, returned as a structure or as an array of structures. Each structure contains the physical and radar characteristics of an actor.

The actor profile structures have these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
ClassID	Classification identifier, specified as a nonnegative integer. 0 is reserved for an object of an unknown or unassigned class.
Length	Length of actor, specified as a positive real scalar. Units are in meters.

Field	Description
Width	Width of actor, specified as a positive real scalar. Units are in meters.
Height	Height of actor, specified as a positive real scalar. Units are in meters.
OriginOffset	Offset of actor's rotational center from its geometric center, specified as an $[x,y,z]$ real-valued vector. The rotational center, or origin, is located at the bottom center of the actor. For vehicles, the rotational center is the point on the ground beneath the center of the rear axle. Units are in meters.
RCSPattern	Radar cross-section (RCS) pattern of actor, specified as a $\text{numel}(\text{RCSElevationAngles})$ -by- $\text{numel}(\text{RCSAzimuthAngles})$ real-valued matrix. Units are in decibels per square meter.
RCSAzimuthAngles	Azimuth angles corresponding to rows of <code>RCSPattern</code> , specified as a vector of real values in the range $[-180, 180]$. Units are in degrees.
RCSElevationAngles	Elevation angles corresponding to rows of <code>RCSPattern</code> , specified as a vector of real values in the range $[-90, 90]$. Units are in degrees.

For full definitions of these structure fields, see the `actor` and `vehicle` functions.

See Also

Objects

`drivingScenario` | `radarDetectionGenerator` | `visionDetectionGenerator`

Functions

`actor` | `actorPoses` | `targetOutlines` | `targetPoses` | `vehicle`

Introduced in R2017a

vehicle

Package:

Add vehicle to driving scenario

Syntax

```
vc = vehicle(scenario)
vc = vehicle(scenario,Name,Value)
```

Description

`vc = vehicle(scenario)` adds a `Vehicle` object, `vc`, to the driving scenario, `scenario`. The vehicle has default property values.

Vehicles are a specialized type of actor cuboid (box-shaped) object that has four wheels. For more details about how vehicles are defined, see “Actors and Vehicles” on page 4-380.

`vc = vehicle(scenario,Name,Value)` sets vehicle properties using one or more name-value pairs. For example, you can set the position, velocity, dimensions, orientation, and wheelbase of the vehicle.

Examples

Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```

Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0°, ends at 90°, and is sampled at 5° increments.

```
angs = [0:5:90]';  
R = 800;  
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];  
roadwidth = 10;  
road(scenario, roadcenters, roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];  
road(scenario, roadcenters)  
roadcenters = [400 400 0; 0 0 0];  
road(scenario, roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

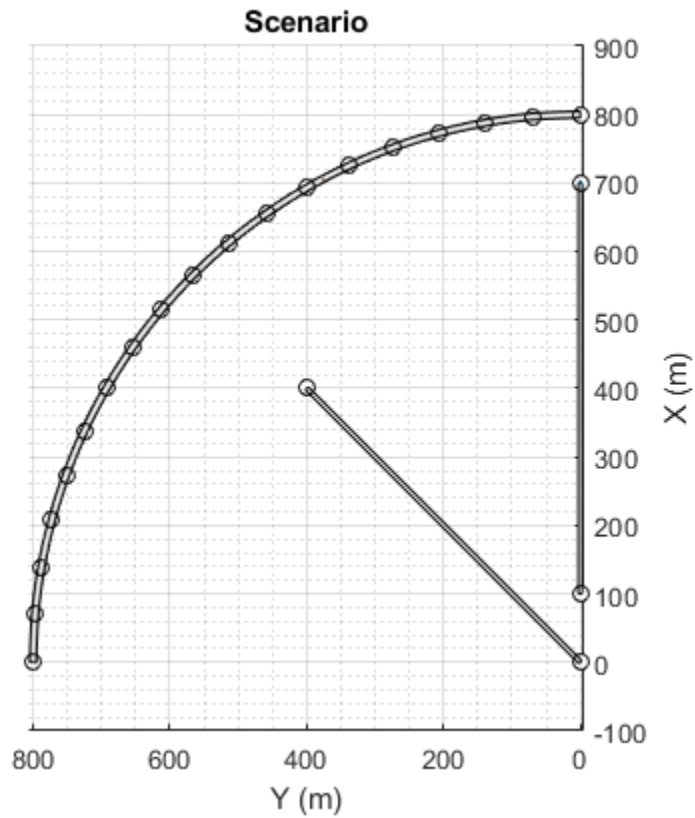
```
car = vehicle(scenario, 'Position', [700 0 0], 'Length', 3, 'Width', 2, 'Height', 1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario, 'Position', [706 376 0], 'Length', 2, 'Width', 0.45, 'Height', 1.5)
```

Plot the scenario.

```
plot(scenario, 'Centerline', 'on', 'RoadCenters', 'on');  
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct  
  ActorID  
  Position  
  Velocity  
  Roll  
  Pitch  
  Yaw  
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```

```
profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles
```

Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `vehicle('Length',2.2,'Width',0.6,'Height',1.5)` creates a vehicle with the dimensions of a motorcycle. Units are in meters.

ClassID — Classification identifier

0 (default) | nonnegative integer

Classification identifier of actor, specified as the comma-separated pair consisting of `'ClassID'` and a nonnegative integer.

Specify `ClassID` values to group together actors that have similar dimensions, radar cross-section (RCS) patterns, or other properties. As a best practice, before adding actors to a `drivingScenario` object, determine the actor classification scheme you want to use. Then, when creating the actors, specify the `ClassID` name-value pair to set classification identifiers according to the scheme.

Suppose you want to create a scenario containing these actors:

- Two cars, one of which is the ego vehicle
- A truck
- A bicycle

The code shows a sample classification scheme for this scenario, where 1 refers to cars, 2 refers to trucks, and 3 refers to bicycles. The cars have default vehicle properties. The truck and bicycle have the dimensions of a typical truck and bicycle, respectively.

```
scenario = drivingScenario;
ego = vehicle(scenario, 'ClassID', 1);
car = vehicle(scenario, 'ClassID', 1);
truck = vehicle(scenario, 'ClassID', 2, 'Length', 8.2, 'Width', 2.5, 'Height', 3.5);
bicycle = actor(scenario, 'ClassID', 3, 'Length', 1.7, 'Width', 0.45, 'Height', 1.7);
```

The default ClassID of 0 is reserved for an object of an unknown or unassigned class. If you plan to import drivingScenario objects into the **Driving Scenario Designer** app, do not leave the ClassID property of actors set to 0. The app does not recognize a ClassID of 0 for actors and returns an error. Instead, set ClassID values of actors according to the actor classification scheme used in the app.

ClassID	Class Name
1	Car
2	Truck
3	Bicycle
4	Pedestrian
5	Barrier

Position — Position of vehicle center

[0 0 0] (default) | [x y z] real-valued vector

Position of the rotational center of the vehicle, specified as the comma-separated pair consisting of 'Position' and an [x y z] real-valued vector.

The rotational center of a vehicle is the midpoint of its rear axle. The vehicle extends rearward by a distance equal to the rear overhang. The vehicle extends forward a distance equal to the sum of the wheelbase and forward overhang. Units are in meters.

Example: [10;50;0]

Velocity — Velocity of vehicle center

[0 0 0] (default) | [v_x v_y v_z] real-valued vector

Velocity (v) of the vehicle center in the x -, y - and z -directions, specified as the comma-separated pair consisting of 'Velocity' and a [v_x v_y v_z] real-valued vector. The 'Position' name-value pair specifies the vehicle center. Units are in meters per second.

Example: [-4;7;10]

Yaw — Yaw angle of vehicle

θ (default) | real scalar

Yaw angle of the vehicle, specified as the comma-separated pair consisting of 'Yaw' and a real scalar. Yaw is the angle of rotation of the vehicle around the z -axis and is positive in the clockwise direction. Angle values are wrapped to the range [-180, 180]. Units are in degrees.

Example: -0.4

Pitch — Pitch angle of vehicle

θ (default) | real scalar

Pitch angle of the vehicle, specified as the comma-separated pair consisting of 'Pitch' and a real scalar. Pitch is the angle of rotation of the vehicle around the y -axis and is positive in the clockwise direction. Angle values are wrapped to the range [-180, 180]. Units are in degrees.

Example: 5.8

Roll — Roll angle of vehicle

θ (default) | real scalar

Roll angle of the vehicle, specified as the comma-separated pair consisting of 'Roll' and a real scalar. Roll is the angle of rotation of the vehicle around the x -axis and is positive in the clockwise direction. Angle values are wrapped to the range [-180, 180]. Units are in degrees.

Example: -10

AngularVelocity — Angular velocity of vehicle

[0 0 0] (default) | [ω_x ω_y ω_z] real-valued vector

Angular velocity (ω) of the vehicle, in world coordinates, specified as the comma-separated pair consisting of 'AngularVelocity' and a $[\omega_x \ \omega_y \ \omega_z]$ real-valued vector. Units are in degrees per second.

Example: [20 40 20]

Length — Length of vehicle

4.7 (default) | positive real scalar

Length of the vehicle, specified as the comma-separated pair consisting of 'Length' and a positive real scalar. Units are in meters.

Example: 5.5

Width — Width of vehicle

1.8 (default) | positive real scalar

Width of the vehicle, specified as the comma-separated pair consisting of 'Width' and a positive real scalar. Units are in meters.

Example: 2.0

Height — Height of vehicle

1.4 (default) | positive real scalar

Height of the vehicle, specified as the comma-separated pair consisting of 'Height' and a positive real scalar. Units are in meters.

Example: 2.1

RCSPattern — Radar cross-section pattern of vehicle

[10 10; 10 10] (default) | Q -by- P real-valued matrix

Radar cross-section (RCS) pattern of the vehicle, specified as the comma-separated pair consisting of 'RCSPattern' and a Q -by- P real-valued matrix. RCS is a function of the azimuth and elevation angles, where:

- Q is the number of elevation angles specified by the 'RCSElevationAngles' name-value pair.
- P is the number of azimuth angles specified by the 'RCSAzimuthAngles' name-value pair.

Units are in decibels per square meter (dBsm).

Example: 5.8

RCSAzimuthAngles — Azimuth angles of vehicle's RCS pattern

`[-180 180]` (default) | P -element real-valued vector

Azimuth angles of the vehicle's RCS pattern, specified as the comma-separated pair consisting of 'RCSAzimuthAngles' and a P -element real-valued vector. P is the number of azimuth angles. Values are in the range $[-180^\circ, 180^\circ]$.

Each element of `RCSAzimuthAngles` defines the azimuth angle of the corresponding column of the 'RCSPattern' name-value pair. Units are in degrees.

Example: `[-90:90]`

RCSElevationAngles — Elevation angles of vehicle's RCS pattern

`[-90 90]` (default) | Q -element real-valued vector

Elevation angles of the vehicle's RCS pattern, specified as the comma-separated pair consisting of 'RCSElevationAngles' and a Q -element real-valued vector. Q is the number of elevation angles. Values are in the range $[-90^\circ, 90^\circ]$.

Each element of `RCSElevationAngles` defines the elevation angle of the corresponding row of the 'RCSPattern' name-value pair. Units are in degrees.

Example: `[0:90]`

FrontOverhang — Front overhang of vehicle

`0.9` (default) | real scalar

Front overhang of the vehicle, specified as the comma-separated pair consisting of 'FrontOverhang' and a real scalar. The front overhang is the distance that the vehicle extends beyond the front axle. If the vehicle does not extend past the front axle, then the front overhang is negative. Units are in meters.

Example: `0.37`

RearOverhang — Rear overhang of vehicle

`1.0` (default) | real scalar

Rear overhang of the vehicle, specified as the comma-separated pair consisting of 'RearOverhang' and a real scalar. The rear overhang is the distance that the vehicle extends beyond the rear axle. If the vehicle does not extend past the rear axle, then the rear overhang is negative. Negative rear overhang is common in semitrailer trucks, where the cab of the truck does not overhang the rear wheel. Units are in meters.

Example: 0.32

Wheelbase — Distance between vehicle axes

2.8 (default) | positive real scalar

Distance between the front and rear axles of a vehicle, specified as the comma-separated pair consisting of 'Wheelbase' and a positive real scalar. Units are in meters.

Example: 1.51

Output Arguments

vc — Driving scenario vehicle

Vehicle object

Driving scenario vehicle, returned as a `Vehicle` object belonging to the driving scenario specified in `scenario`.

You can modify the `Vehicle` object by changing its property values. The property names correspond to the name-value pair arguments used to create the object.

The only property that you cannot modify is `ActorID`, which is a positive integer indicating the unique, scenario-defined ID of the vehicle.

To specify and visualize vehicle motion, use these functions:

<code>trajectory</code>	Create actor or vehicle trajectory in driving scenario
<code>chasePlot</code>	Ego-centric projective perspective plot

To get information about vehicle characteristics, use these functions:

<code>actorPoses</code>	Positions, velocities, and orientations of actors in driving scenario
<code>actorProfiles</code>	Physical and radar characteristics of actors in driving scenario
<code>targetOutlines</code>	Outlines of targets viewed by actor

<code>targetPoses</code>	Target positions and orientations relative to ego vehicle
<code>driving.scenario.targetsToEgo</code>	Convert actor poses to ego vehicle coordinates

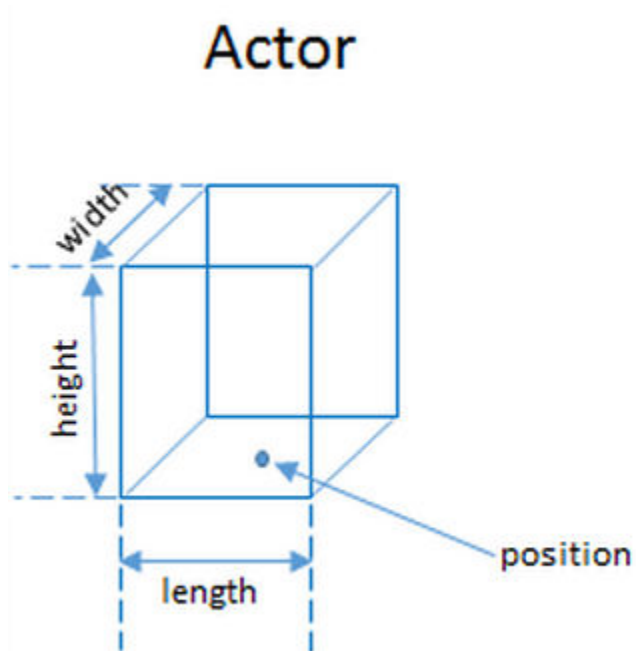
To get information about the roads and lanes that the vehicle is on, use these functions:

<code>roadBoundaries</code>	Get road boundaries
<code>driving.scenario.roadBoundariesToEgo</code>	Convert road boundaries to ego vehicle coordinates
<code>currentLane</code>	Get current lane of actor
<code>laneBoundaries</code>	Get lane boundaries of actor lane
<code>laneMarkingVertices</code>	Lane marking vertices and faces in driving scenario

More About

Actors and Vehicles

In driving scenarios, an actor is a cuboid (box-shaped) object with a specific length, width, and height. Actors also have a radar cross-section (RCS) pattern, specified in dBsm, which you can refine by setting angular azimuth and elevation coordinates. An actor's position is defined as the center of its bottom face. This center point is used as the actor's rotational center and point of contact with the ground.

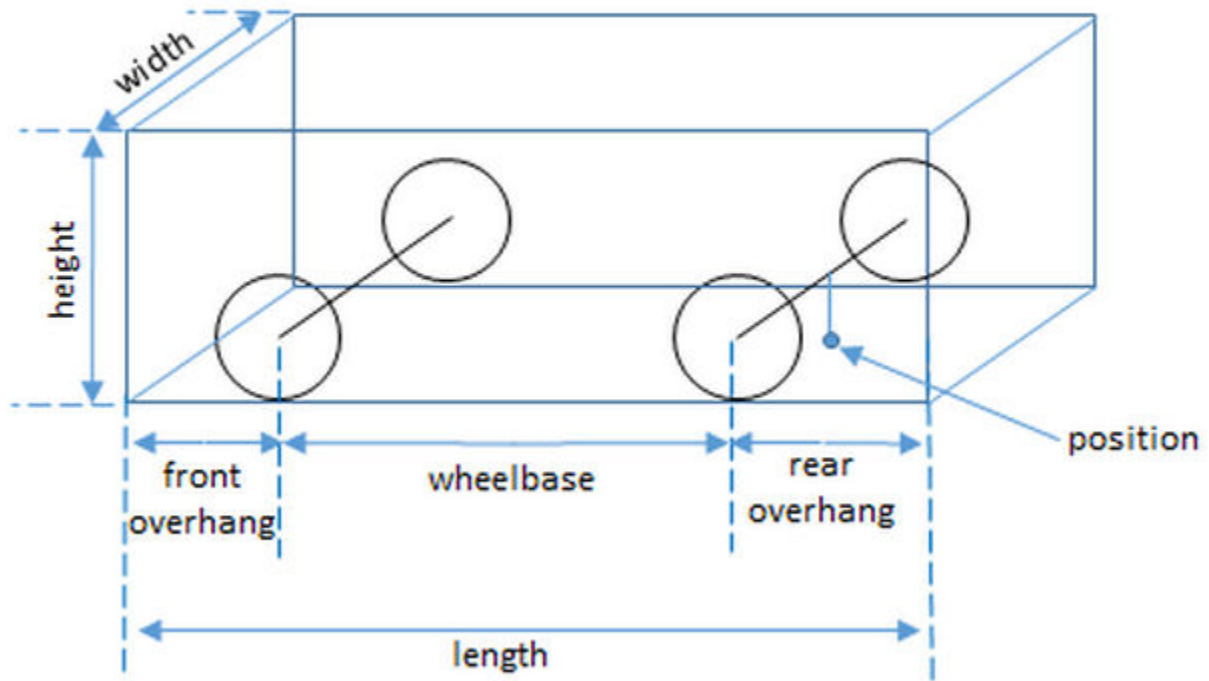


A vehicle is a special kind of actor that moves on wheels. Vehicles have three extra properties that govern the placement of the front and rear axle.

- Wheelbase — Distance between the front and rear axles
- Front overhang — Distance between the front of the vehicle and the front axle.
- Rear overhang — Distance between the rear axle and the rear of the vehicle.

Unlike other types of actors, the vehicle's position is defined by the point on the ground that is below the center of its rear axle. This point corresponds to the vehicle's natural center of rotation.

Vehicle



This table shows a list of common actors and their dimensions. To specify these values in Actor and Vehicle objects, set the corresponding properties shown.

Actor Classification	Actor Object	Actor Properties						
		Length	Width	Height	FrontOverhang	RearOverhang	Wheelbase	RCSPattern
Pedestrian	Actor	0.24 m	0.45 m	1.7 m	N/A	N/A	N/A	-8 dBsm
Car	Vehicle	4.7 m	1.8 m	1.4 m	0.9 m	1.0 m	2.8 m	10 dBsm

Actor Classification	Actor Object	Actor Properties						
		Length	Width	Height	FrontOverhang	RearOverhang	Wheelbase	RCSPattern
Motorcycle	Vehicle	2.2 m	0.6 m	1.5 m	0.37 m	0.32 m	1.51 m	0 dBsm

See Also

actor | drivingScenario

Topics

“Driving Scenario Tutorial”

“Create Actor and Vehicle Trajectories”

Introduced in R2017a

chasePlot

Package:

Ego-centric projective perspective plot

Syntax

```
chasePlot(ac)  
chasePlot(ac,Name,Value)
```

Description

`chasePlot(ac)` plots a driving scenario from the perspective of actor `ac`. This plot is called a chase plot and has an ego-centric projective perspective, where the view is positioned immediately behind the actor.

`chasePlot(ac,Name,Value)` specifies options using one or more name-value pairs. For example, you can display road centers and actor waypoints on the plot.

Examples

Simulate Car Traveling on S-Curve

Simulate a driving scenario with one car traveling on an S-curve. Create and plot the lane boundaries.

Create the driving scenario with one road having an S-curve.

```
scenario = drivingScenario('StopTime',3);  
roadcenters = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];
```

Create the lanes and add them to the road.

```
lm = [laneMarking('Solid','Color','w'); ...  
      laneMarking('Dashed','Color','y'); ...
```

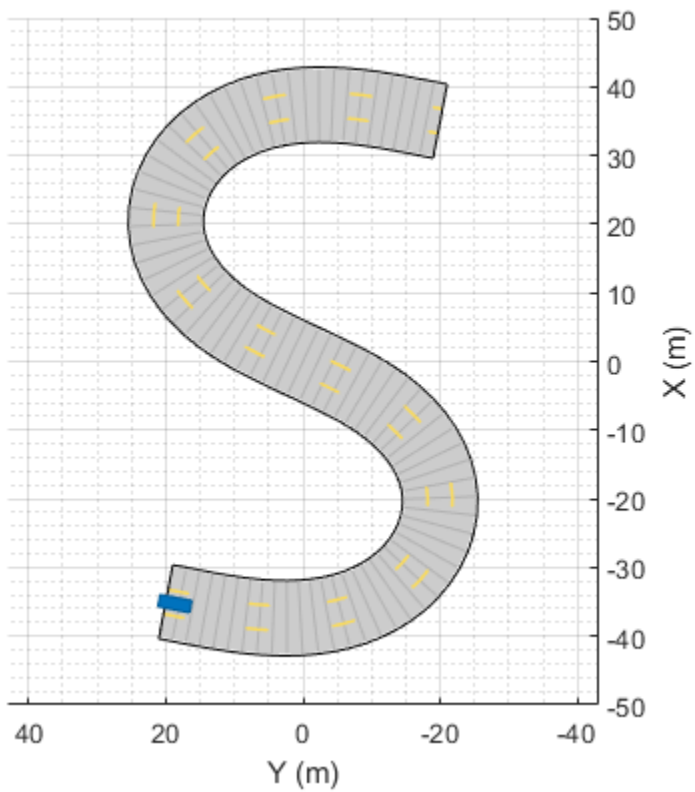
```
    laneMarking('Dashed','Color','y'); ...  
    laneMarking('Solid','Color','w')];  
ls = lanespec(3,'Marking',lm);  
road(scenario,roadcenters,'Lanes',ls);
```

Add an ego vehicle and specify its trajectory from its speed and waypoints. The car travels at 30 meters per second.

```
car = vehicle(scenario, ...  
    'ClassID',1, ...  
    'Position',[-35 20 0]);  
waypoints = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];  
speed = 30;  
trajectory(car,waypoints,speed);
```

Plot the scenario and corresponding chase plot.

```
plot(scenario)
```



`chasePlot(car)`



Run the simulation loop.

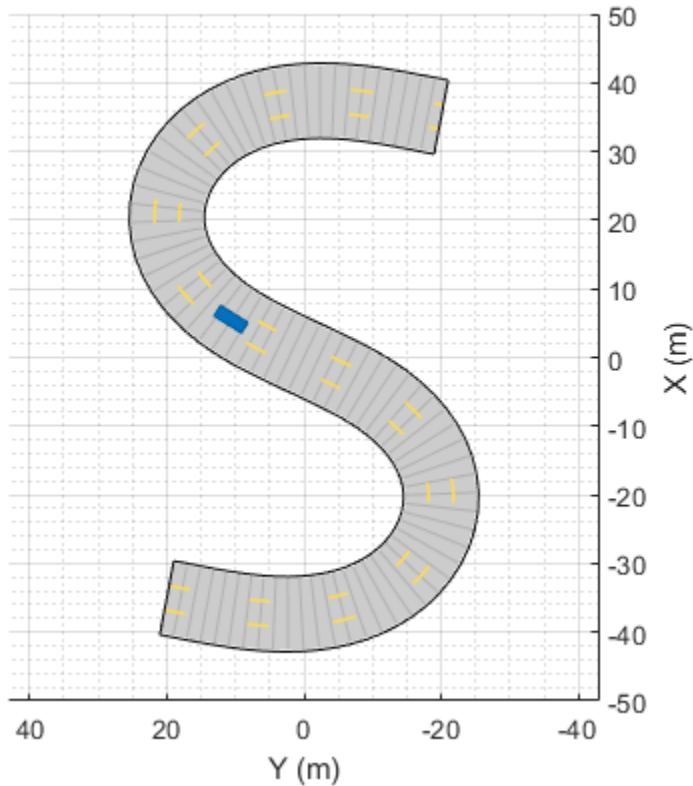
- 1 Initialize a bird's-eye plot and create an outline plotter, left-lane and right-lane boundary plotters, and a road boundary plotter.
- 2 Obtain the road boundaries and rectangular outlines.
- 3 Obtain the lane boundaries to the left and right of the vehicle.
- 4 Advance the simulation and update the plotters.

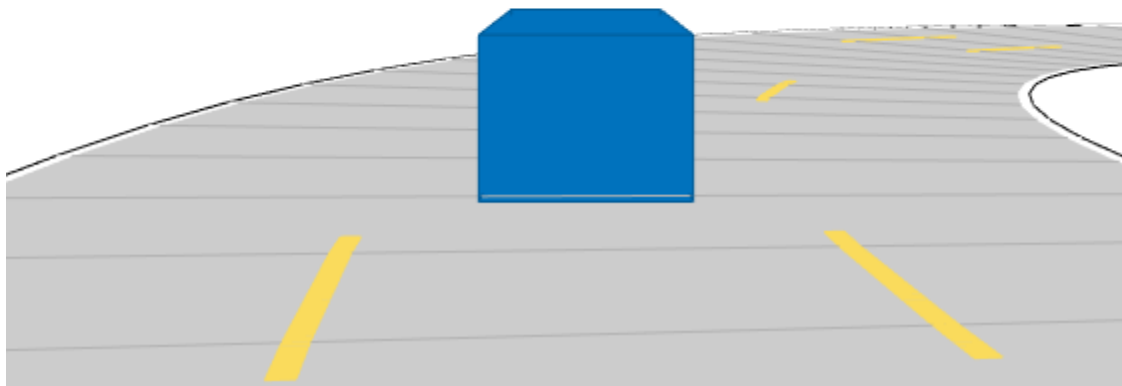
```
bep = birdsEyePlot('XLim',[-40 40], 'YLim',[-30 30]);  
olPlotter = outlinePlotter(bep);  
lblPlotter = laneBoundaryPlotter(bep, 'Color', 'r', 'LineStyle', '-');  
lbrPlotter = laneBoundaryPlotter(bep, 'Color', 'g', 'LineStyle', '-');  
rbsEdgePlotter = laneBoundaryPlotter(bep);
```

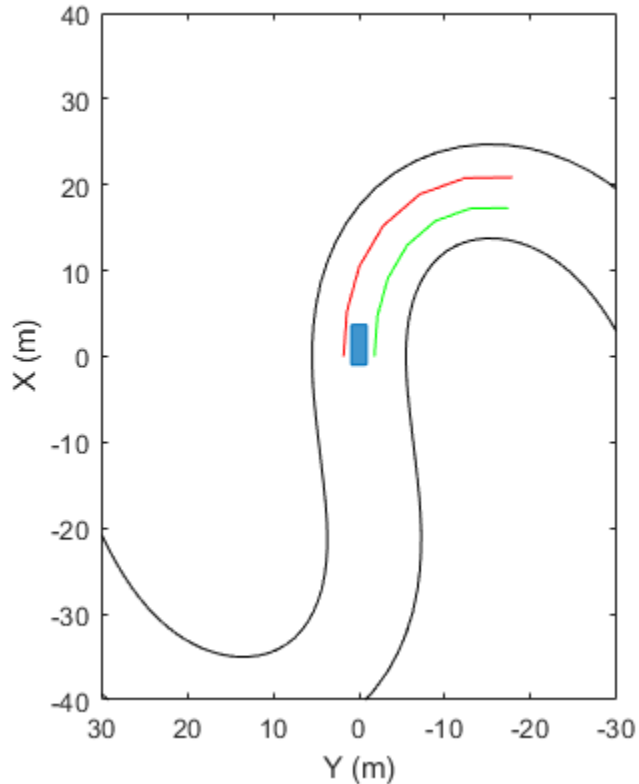
```

legend('off');
while advance(scenario)
    rbs = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    lb = laneBoundaries(car,'XDistance',0:5:30,'LocationType','Center', ...
        'AllBoundaries',false);
    plotLaneBoundary(rbsEdgePlotter,rbs)
    plotLaneBoundary(lblPlotter,{lb(1).Coordinates})
    plotLaneBoundary(lbrPlotter,{lb(2).Coordinates})
    plotOutline(olPlotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
end

```







Show Target Outlines in Driving Scenario Simulation

Create a driving scenario and show how target outlines change as the simulation advances.

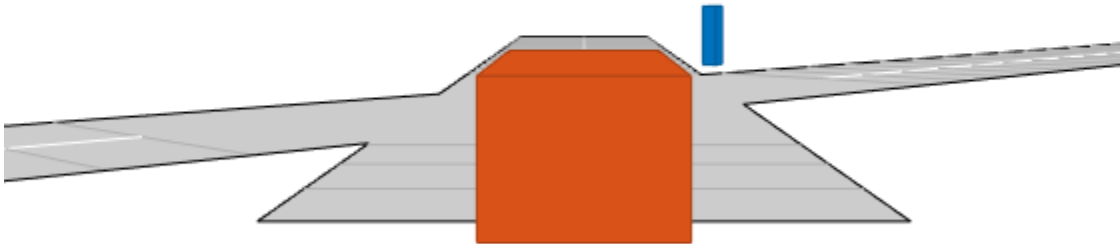
Create a driving scenario consisting of two intersecting straight roads. The first road segment is 45 meters long. The second straight road is 32 meters long and intersects the first road. A car traveling at 12.0 meters per second along the first road approaches a running pedestrian crossing the intersection at 2.0 meters per second.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',1);  
road(scenario,[-10 0 0; 45 -20 0]);
```

```
road(scenario,[-10 -10 0; 35 10 0]);  
ped = actor(scenario,'Length',0.4,'Width',0.6,'Height',1.7);  
car = vehicle(scenario);  
pedspeed = 2.0;  
carspeed = 12.0;  
trajectory(ped,[15 -3 0; 15 3 0],pedspeed);  
trajectory(car,[-10 -10 0; 35 10 0],carspeed);
```

Create an ego-centric chase plot for the vehicle.

```
chasePlot(car,'Centerline','on')
```

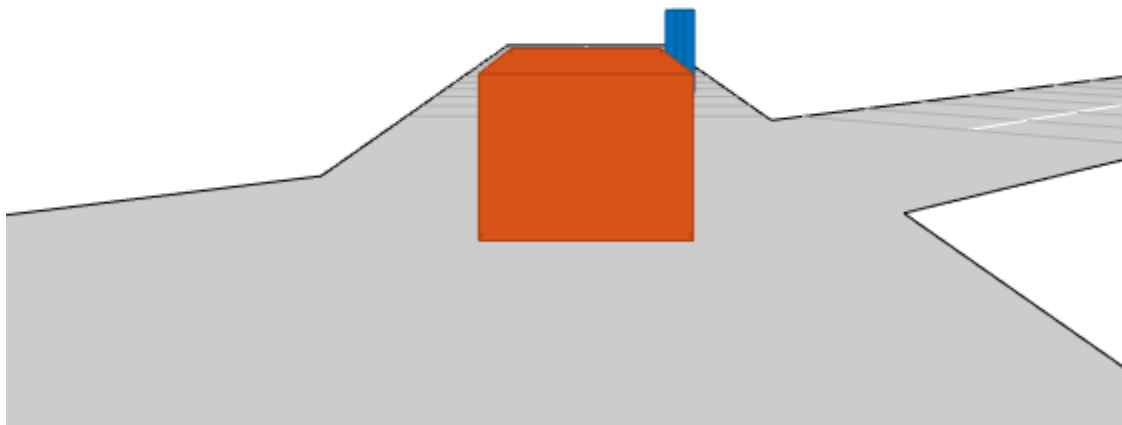


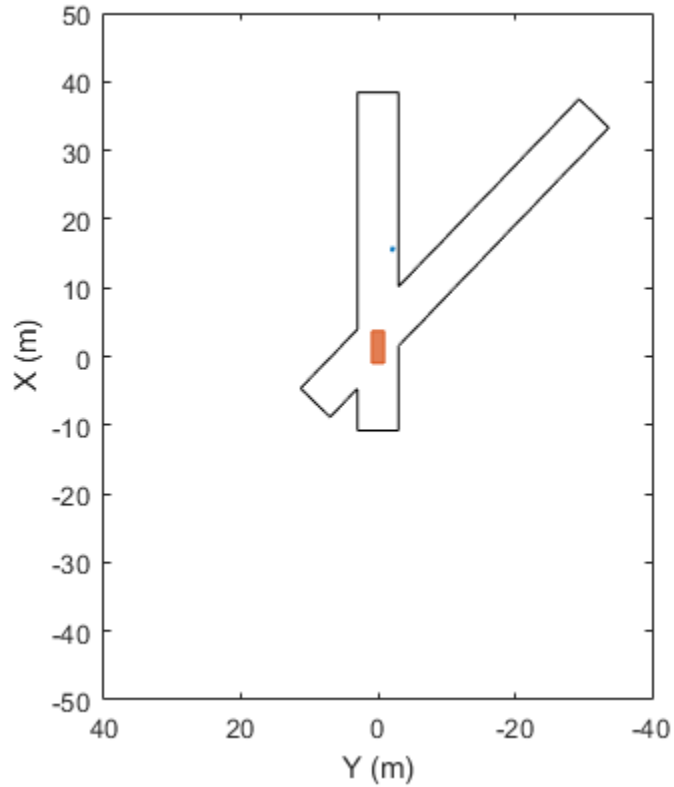
Create an empty bird's-eye plot and add an outline plotter and lane boundary plotter. Then, run the simulation. At each simulation step:

- Update the chase plot to display the road boundaries and target outlines.
- Update the bird's-eye plot to display the updated road boundaries and target outlines. The plot perspective is always with respect to the ego vehicle.

```
bepPlot = birdsEyePlot('XLim',[-50 50],'YLim',[-40 40]);
outlineplotter = outlinePlotter(bepPlot);
laneplotter = laneBoundaryPlotter(bepPlot);
legend('off')

while advance(scenario)
    rb = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    plotLaneBoundary(laneplotter,rb)
    plotOutline(outlineplotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
    pause(0.01)
end
```





Input Arguments

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `chasePlot(ac, 'Centerline', 'on', 'RoadCenters', 'on')` displays the center line and road centers of each road segment.

Parent — Axes in which to draw plot

Axes object

Axes in which to draw the plot, specified as the comma-separated pair consisting of `'Parent'` and an Axes object. If you do not specify `Parent`, a new figure is created.

Centerline — Display center line of roads

`'off'` (default) | `'on'`

Display the center line of roads, specified as the comma-separated pair consisting of `'Centerline'` and `'off'` or `'on'`. The center line follows the middle of each road segment. Center lines are discontinuous through areas such as intersections or road splits.

RoadCenters — Display road centers

`'off'` (default) | `'on'`

Display road centers, specified as the comma-separated pair consisting of `'RoadCenters'` and `'off'` or `'on'`. The road centers define the roads shown in the plot.

Waypoints — Display actor waypoints

`'off'` (default) | `'on'`

Display actor waypoints, specified as the comma-separated pair consisting of `'Waypoints'` and `'off'` or `'on'`. Waypoints define the trajectory of the actor.

ViewHeight — Height of plot viewpoint

$1.5 \times$ actor height (default) | positive real scalar

Height of the plot viewpoint, specified as the comma-separated pair consisting of `'ViewHeight'` and a positive real scalar. The height is with respect to the bottom of the actor. Units are in meters.

ViewLocation — Location of plot viewpoint

2.5 × actor length (default) | [x, y] real-valued vector

Location of the plot viewpoint, specified as the comma-separated pair consisting of 'ViewLocation' and an [x, y] real-valued vector. The location is with respect to the cuboid center in the coordinate system of the actor. The default location of the viewpoint is behind the cuboid center, [2.5*actor.Length 0]. Units are in meters.

ViewRoll — Roll angle orientation of plot viewpoint

0 (default) | real scalar

Roll angle orientation of the plot viewpoint, specified as the comma-separated pair consisting of 'ViewRoll' and a real scalar. Units are in degrees.

ViewPitch — Pitch angle orientation of plot viewpoint

0 (default) | real scalar

Pitch angle orientation of the plot viewpoint, specified as the comma-separated pair consisting of 'ViewPitch' and a real scalar. Units are in degrees.

ViewYaw — Yaw angle orientation of plot viewpoint

0 (default) | real scalar

Yaw angle orientation of the plot viewpoint, specified as the comma-separated pair consisting of 'ViewYaw' and a real scalar. Units are in degrees.

See Also

Objects

drivingScenario

Functions

actor | plot | road | trajectory | vehicle

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

trajectory

Package:

Create actor or vehicle trajectory in driving scenario

Syntax

```
trajectory(ac,waypoints,speed)
```

Description

`trajectory(ac,waypoints,speed)` creates a trajectory for an actor or vehicle, `ac`, from a set of waypoints. The actor follows the trajectory at the specified speed.

Examples

Simulate Vehicle with Varied Trajectory

Create a driving scenario and add a curved two-lane road to it.

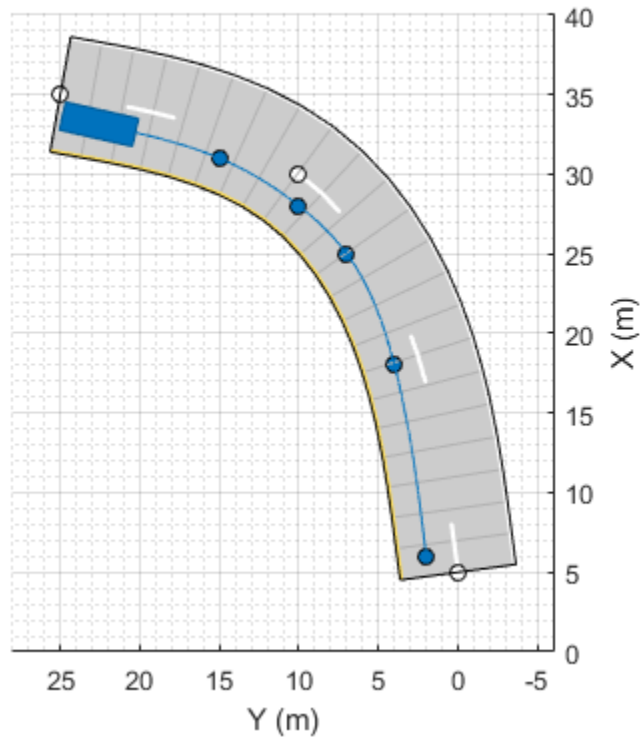
```
scenario = drivingScenario('SampleTime',0.05);  
roadcenters = [5 0; 30 10; 35 25];  
lspec = lanespec(2);  
road(scenario,roadcenters,'Lanes',lspec);
```

Add a vehicle to the scenario. Set a trajectory in which the vehicle drives around the curve at varying speeds.

```
v = vehicle(scenario);  
waypoints = [6 2; 18 4; 25 7; 28 10; 31 15; 33 22];  
speeds = [30 10 5 5 10 30];  
trajectory(v,waypoints,speeds)
```

Plot the scenario and run the simulation. Observe how the vehicle slows down as it drives along the curve.

```
plot(scenario, 'Waypoints', 'on', 'RoadCenters', 'on')  
while advance(scenario)  
    pause(0.1)  
end
```



Show Target Outlines in Driving Scenario Simulation

Create a driving scenario and show how target outlines change as the simulation advances.

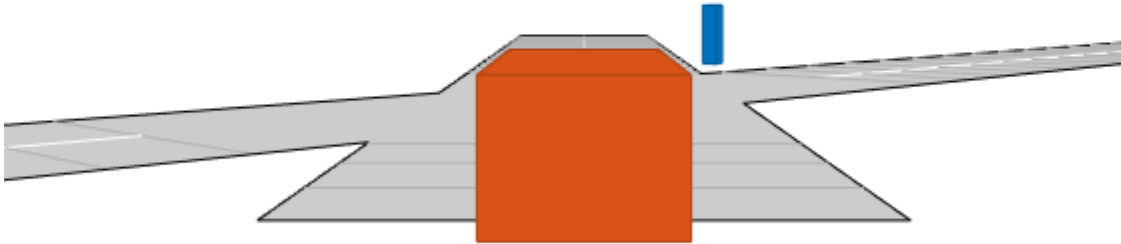
Create a driving scenario consisting of two intersecting straight roads. The first road segment is 45 meters long. The second straight road is 32 meters long and intersects the

first road. A car traveling at 12.0 meters per second along the first road approaches a running pedestrian crossing the intersection at 2.0 meters per second.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',1);
road(scenario,[-10 0 0; 45 -20 0]);
road(scenario,[-10 -10 0; 35 10 0]);
ped = actor(scenario,'Length',0.4,'Width',0.6,'Height',1.7);
car = vehicle(scenario);
pedspeed = 2.0;
carspeed = 12.0;
trajectory(ped,[15 -3 0; 15 3 0],pedspeed);
trajectory(car,[-10 -10 0; 35 10 0],carspeed);
```

Create an ego-centric chase plot for the vehicle.

```
chasePlot(car,'Centerline','on')
```



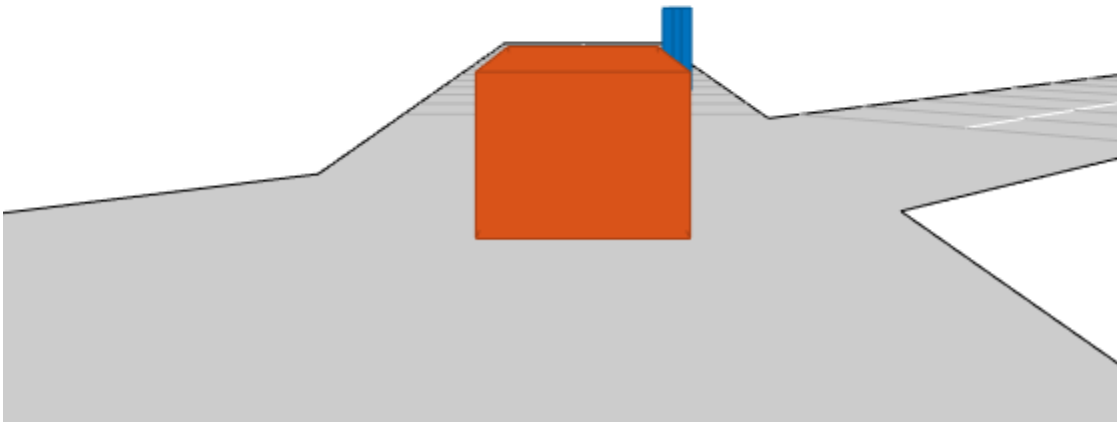
Create an empty bird's-eye plot and add an outline plotter and lane boundary plotter. Then, run the simulation. At each simulation step:

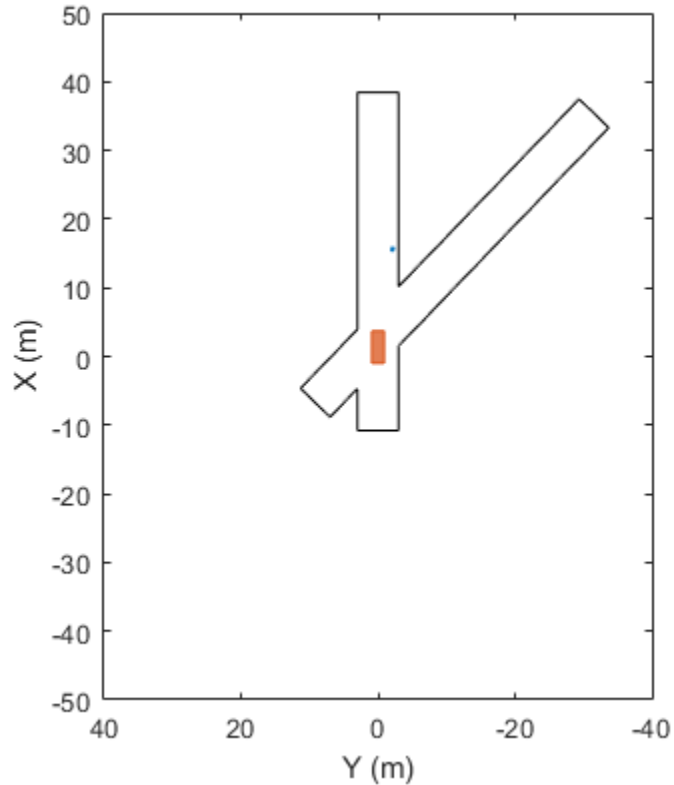
- Update the chase plot to display the road boundaries and target outlines.
- Update the bird's-eye plot to display the updated road boundaries and target outlines. The plot perspective is always with respect to the ego vehicle.

```
bepPlot = birdsEyePlot('XLim',[-50 50],'YLim',[-40 40]);  
outlineplotter = outlinePlotter(bepPlot);  
laneplotter = laneBoundaryPlotter(bepPlot);  
legend('off')
```

```
while advance(scenario)  
    rb = roadBoundaries(car);
```

```
[position,yaw,length,width,originOffset,color] = targetOutlines(car);  
plotLaneBoundary(laneplotter,rb)  
plotOutline(outlineplotter,position,yaw,length,width, ...  
    'OriginOffset',originOffset,'Color',color)  
pause(0.01)  
end
```





Simulate Car Traveling on S-Curve

Simulate a driving scenario with one car traveling on an S-curve. Create and plot the lane boundaries.

Create the driving scenario with one road having an S-curve.

```
scenario = drivingScenario('StopTime',3);  
roadcenters = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];
```

Create the lanes and add them to the road.

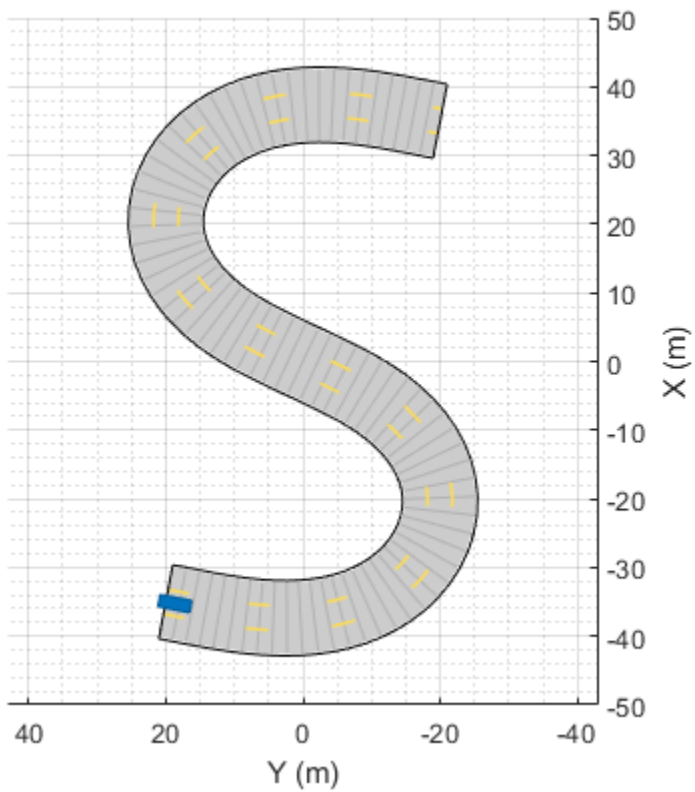

```
lm = [laneMarking('Solid','Color','w'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Solid','Color','w')];  
ls = lanespec(3,'Marking',lm);  
road(scenario,roadcenters,'Lanes',ls);
```

Add an ego vehicle and specify its trajectory from its speed and waypoints. The car travels at 30 meters per second.

```
car = vehicle(scenario, ...  
             'ClassID',1, ...  
             'Position',[-35 20 0]);  
waypoints = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];  
speed = 30;  
trajectory(car,waypoints,speed);
```

Plot the scenario and corresponding chase plot.

```
plot(scenario)
```



`chasePlot(car)`



Run the simulation loop.

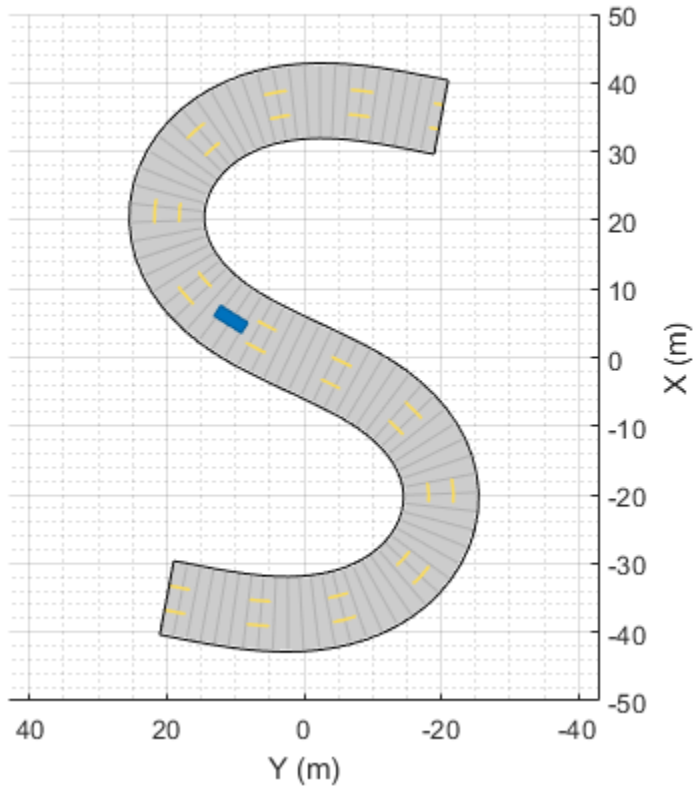
- 1 Initialize a bird's-eye plot and create an outline plotter, left-lane and right-lane boundary plotters, and a road boundary plotter.
- 2 Obtain the road boundaries and rectangular outlines.
- 3 Obtain the lane boundaries to the left and right of the vehicle.
- 4 Advance the simulation and update the plotters.

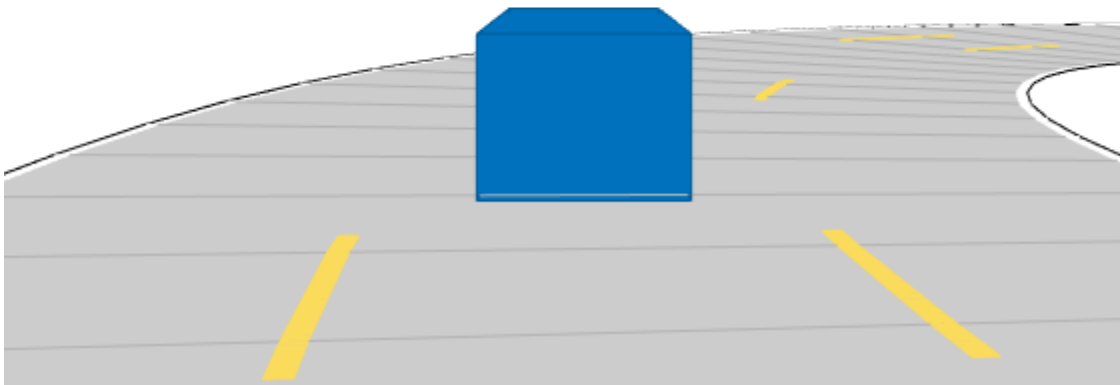
```
bep = birdsEyePlot('XLim',[-40 40], 'YLim',[-30 30]);  
olPlotter = outlinePlotter(bep);  
lblPlotter = laneBoundaryPlotter(bep, 'Color', 'r', 'LineStyle', '-');  
lbrPlotter = laneBoundaryPlotter(bep, 'Color', 'g', 'LineStyle', '-');  
rbsEdgePlotter = laneBoundaryPlotter(bep);
```

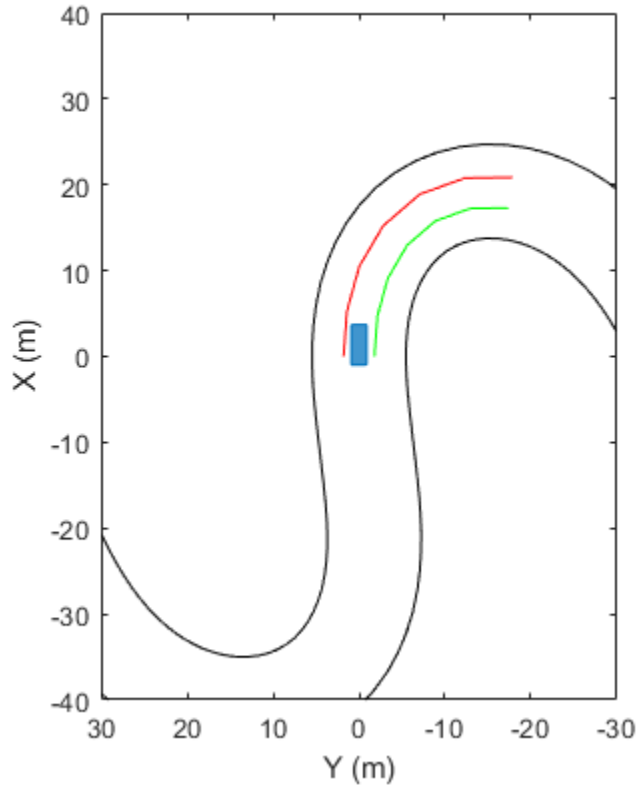
```

legend('off');
while advance(scenario)
    rbs = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    lb = laneBoundaries(car,'XDistance',0:5:30,'LocationType','Center', ...
        'AllBoundaries',false);
    plotLaneBoundary(rbsEdgePlotter,rbs)
    plotLaneBoundary(lblPlotter,{lb(1).Coordinates})
    plotLaneBoundary(lbrPlotter,{lb(2).Coordinates})
    plotOutline(olPlotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
end

```







Input Arguments

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

waypoints — Trajectory waypoints

real-valued N -by-2 matrix | real-valued N -by-3 matrix

Trajectory waypoints, specified as a real-valued N -by-2 or N -by-3 matrix, where N is the number of waypoints.

- If `waypoints` is an N -by-2 matrix, then each matrix row represents the (x, y) coordinates of a waypoint. The z -coordinate of each waypoint is zero.
- If `waypoints` is an N -by-3 matrix, then each matrix row represents the (x, y, z) coordinates of a waypoint.

Waypoints are in the world coordinate system. Units are in meters.

Example: [1 0 0; 2 7 7; 3 8 8]

Data Types: double

speed — Actor speed

30.0 | positive real scalar | N -element vector of nonnegative values

Actor speed at each waypoint in `waypoints`, specified as a positive real scalar or N -element vector of nonnegative values. N is the number of waypoints.

- When `speed` is a scalar, the speed is constant throughout the actor motion.
- When `speed` is a vector, the vector values specify the speed at each waypoint.

Speeds are interpolated between waypoints. `speed` can be zero at any waypoint but cannot be zero at two consecutive waypoints. Units are in meters per second.

Example: [10,8,9]

Algorithms

The `trajectory` function creates a trajectory for an actor to follow in a scenario. A trajectory consists of the path followed by an object and its speed along the path. You specify the path using N two-dimensional or three-dimensional waypoints. Each of the $N - 1$ segments between waypoints defines a curve whose curvature varies linearly with distance along the segment. The function fits a piecewise clothoid curve to the (x, y) coordinates of the waypoints by matching the curvature on both sides of the waypoint. For a nonclosed curve, the curvature at the first and last waypoint is zero. If the first and last waypoints coincide, then the curvatures before and after the endpoints are matched. The z -coordinates of the trajectory are interpolated using a shape-preserving piecewise cubic curve.

You can specify speed as a scalar or a vector. When speed is a scalar, the actor follows the trajectory with constant speed. When speed is an N -element vector, speed is linearly interpolated between waypoints. Setting the speed to zero at two consecutive waypoints creates a stationary actor.

See Also

Objects

`drivingScenario`

Functions

`actor` | `road` | `vehicle`

Topics

“Scenario Generation from Recorded Vehicle Data”

“Create Actor and Vehicle Trajectories”

“Driving Scenario Tutorial”

Introduced in R2018a

targetPoses

Package:

Target positions and orientations relative to ego vehicle

Syntax

```
poses = targetPoses(ac)
```

Description

`poses = targetPoses(ac)` returns the poses of all targets in a driving scenario with respect to the ego vehicle actor, `ac`. See “Ego Vehicle and Targets” on page 4-414 for more details.

Examples

Obtain Target Poses in Ego Vehicle Coordinates

Create a driving scenario containing three vehicles. Find the target poses of two of the vehicles as viewed by the third vehicle. Target poses are returned in the ego-centric coordinate system of the third vehicle.

Create a driving scenario.

```
scenario = drivingScenario;
```

Create the target actors.

```
actor(scenario, 'Position', [10 20 30], ...  
      'Velocity', [12 113 14], ...  
      'Yaw', 54, ...  
      'Pitch', 25, ...  
      'Roll', 22, ...
```

```
    'AngularVelocity',[24 42 27]);  
actor(scenario,'Position',[17 22 12], ...  
    'Velocity',[19 13 15], ...  
    'Yaw',45, ...  
    'Pitch',52, ...  
    'Roll',2, ...  
    'AngularVelocity',[42 24 29]);
```

Add the ego vehicle actor.

```
ego = actor(scenario,'Position',[1 2 3], ...  
    'Velocity',[1.2 1.3 1.4], ...  
    'Yaw',4, ...  
    'Pitch',5, ...  
    'Roll',2, ...  
    'AngularVelocity',[4 2 7]);
```

Use `actorPoses` to return the poses of all the actors. Pose properties (position, velocity, and orientation) are in scenario coordinates.

```
allposes = actorPoses(scenario);
```

Use `driving.scenario.targetsToEgo` to convert only the target poses to the ego-centric coordinates of the ego actor. Examine the pose of the first actor.

```
targetposes1 = driving.scenario.targetsToEgo(allposes(1:2),ego);  
disp(targetposes1(1))
```

```
    ActorID: 1  
    Position: [7.8415 18.2876 27.1675]  
    Velocity: [18.6826 112.0403 9.2960]  
           Roll: 16.4327  
           Pitch: 23.2186  
           Yaw: 47.8114  
    AngularVelocity: [-3.3744 47.3021 18.2569]
```

Alternatively, use `targetPoses` to obtain all non-ego actor poses in ego vehicle coordinates. Compare these poses to the previously calculated poses.

```
targetposes2 = targetPoses(ego);  
disp(targetposes2(1))
```

```
    ActorID: 1  
    ClassID: 0
```

```

Position: [7.8415 18.2876 27.1675]
Velocity: [18.6826 112.0403 9.2960]
  Roll: 16.4327
  Pitch: 23.2186
  Yaw: 47.8114
AngularVelocity: [-3.3744 47.3021 18.2569]

```

Input Arguments

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

Output Arguments

poses — Target poses

structure | array of structures

Target poses, in ego vehicle coordinates, returned as a structure or as an array of structures. The pose of the ego vehicle actor, `ac`, is not included.

A target pose defines the position, velocity, and orientation of a target in ego vehicle coordinates. Target poses also include the rates of change in actor position and orientation.

Each pose structure has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
ClassID	Classification identifier, specified as a nonnegative integer. 0 is reserved for an object of an unknown or unassigned class.

Field	Description
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x -, y -, and z -directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x -, y -, and z -directions, specified as an [ω_x ω_y ω_z] real-valued vector. Units are in degrees per second.

For full definitions of these structure fields, see the `actor` and `vehicle` functions.

More About

Ego Vehicle and Targets

In a driving scenario, you can specify one actor as the observer of all other actors, similar to how the driver of a car observes all other cars. The observer actor is called the ego actor, or more specifically, the ego vehicle. From the perspective of the ego vehicle, all other actors (vehicles, pedestrians, and so on) are the observed actors, or targets. Ego vehicle coordinates are centered and oriented with reference to the ego vehicle. The coordinates of the driving scenario are world coordinates.

See Also

Objects
`drivingScenario`

Functions

actor | actorPoses | actorProfiles | vehicle

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

targetOutlines

Package:

Outlines of targets viewed by actor

Syntax

```
[position,yaw,length,width,originOffset,color] = targetOutlines(ac)
```

Description

```
[position,yaw,length,width,originOffset,color] = targetOutlines(ac)
```

returns the oriented rectangular outlines of all non-ego target actors in a driving scenario. The outlines are as viewed from a designated ego vehicle actor, `ac`. See “Ego Vehicle and Targets” on page 4-422 for more details.

A target outline is the projection of the target actor cuboid into the (x,y) plane of the local coordinate system of the ego vehicle. The target outline components are the `position`, `yaw`, `length`, `width`, `originOffset`, and `color` output arguments.

You can use the returned outlines as input arguments to the outline plotter of a `birdsEyePlot`. First, call the `outlinePlotter` function to create the plotter object. Then, use the `plotOutline` function to plot the outlines of all the actors in a bird's-eye plot.

Examples

Show Target Outlines in Driving Scenario Simulation

Create a driving scenario and show how target outlines change as the simulation advances.

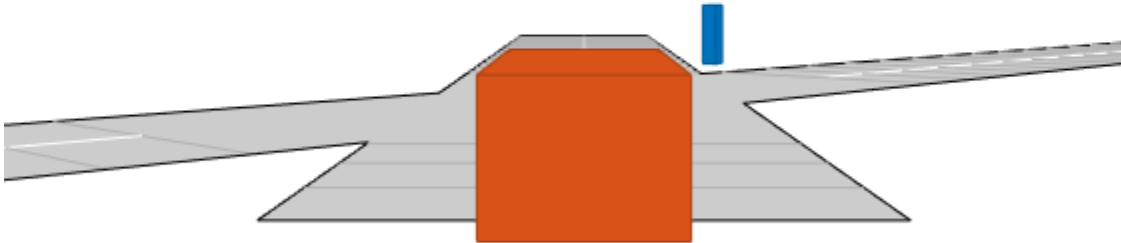
Create a driving scenario consisting of two intersecting straight roads. The first road segment is 45 meters long. The second straight road is 32 meters long and intersects the

first road. A car traveling at 12.0 meters per second along the first road approaches a running pedestrian crossing the intersection at 2.0 meters per second.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',1);
road(scenario,[-10 0 0; 45 -20 0]);
road(scenario,[-10 -10 0; 35 10 0]);
ped = actor(scenario,'Length',0.4,'Width',0.6,'Height',1.7);
car = vehicle(scenario);
pedspeed = 2.0;
carspeed = 12.0;
trajectory(ped,[15 -3 0; 15 3 0],pedspeed);
trajectory(car,[-10 -10 0; 35 10 0],carspeed);
```

Create an ego-centric chase plot for the vehicle.

```
chasePlot(car,'Centerline','on')
```



Create an empty bird's-eye plot and add an outline plotter and lane boundary plotter. Then, run the simulation. At each simulation step:

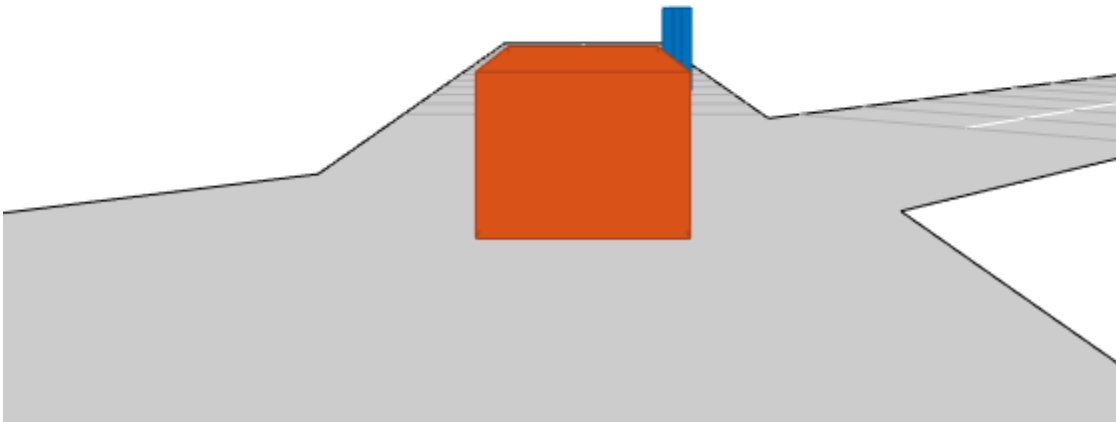
- Update the chase plot to display the road boundaries and target outlines.
- Update the bird's-eye plot to display the updated road boundaries and target outlines. The plot perspective is always with respect to the ego vehicle.

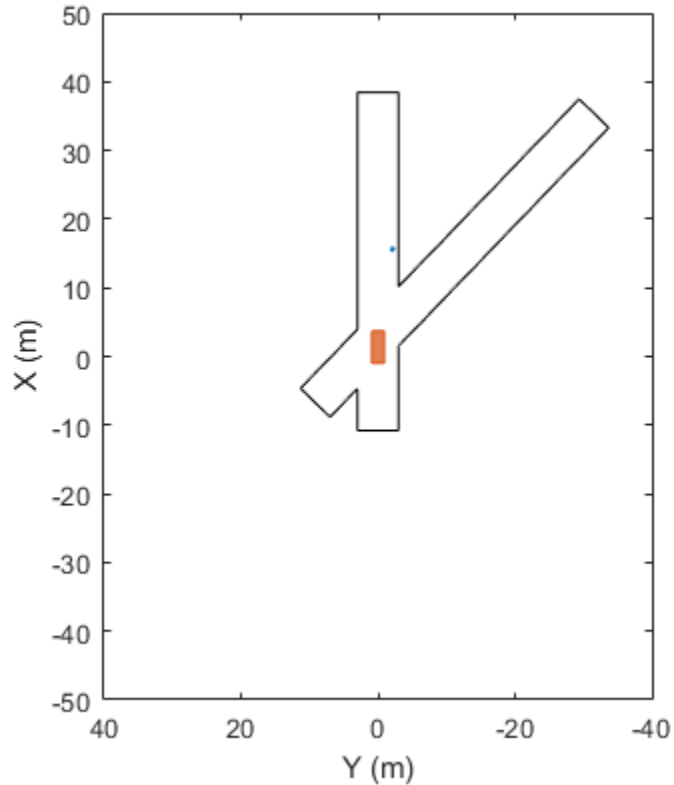
```
bepPlot = birdsEyePlot('XLim',[-50 50],'YLim',[-40 40]);  
outlineplotter = outlinePlotter(bepPlot);  
laneplotter = laneBoundaryPlotter(bepPlot);  
legend('off')
```

```
while advance(scenario)  
    rb = roadBoundaries(car);
```



```
[position,yaw,length,width,originOffset,color] = targetOutlines(car);  
plotLaneBoundary(laneplotter,rb)  
plotOutline(outlineplotter,position,yaw,length,width, ...  
    'OriginOffset',originOffset,'Color',color)  
pause(0.01)  
end
```





Input Arguments

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

Output Arguments

position — Rotational centers of targets

real-valued N -by-2 matrix

Rotational centers of targets, returned as a real-valued N -by-2 matrix. N is the number of targets. Each row contains the x - and y -coordinates of the rotational center of a target. Units are in meters.

yaw — Yaw angles of targets

real-valued N -element vector

Yaw angles of targets about the rotational center, returned as a real-valued N -element vector. N is the number of targets. Yaw angles are measured in the counterclockwise direction, as seen from above. Units are in degrees.

length — Lengths of rectangular outlines of targets

positive, real-valued N -element vector

Lengths of rectangular outlines of targets, returned as a positive, real-valued N -element vector. N is the number of targets. Units are in meters.

width — Widths of rectangular outlines of targets

positive, real-valued N -element vector

Widths of rectangular outline of targets, returned as a positive, real-valued N -element vector. N is the number of targets. Units are in meters.

originOffset — Offsets of rotational centers from geometric centers

real-valued N -by-2 matrix

Offset of the rotational centers of targets from their geometric centers, returned as a real-valued N -by-2 matrix. N is the number of targets. Each row contains the x - and y -coordinates defining this offset. In vehicle targets, the rotational center, or origin, is located on the ground, directly beneath the center of the rear axle. Units are in meters.

color — RGB representation of target colors

nonnegative, real-valued N -by-3 matrix

RGB representation of target colors, returned as a nonnegative, real-valued N -by-3 matrix. N is the number of target actors.

More About

Ego Vehicle and Targets

In a driving scenario, you can specify one actor as the observer of all other actors, similar to how the driver of a car observes all other cars. The observer actor is called the ego actor, or more specifically, the ego vehicle. From the perspective of the ego vehicle, all other actors (vehicles, pedestrians, and so on) are the observed actors, or targets. Ego vehicle coordinates are centered and oriented with reference to the ego vehicle. The coordinates of the driving scenario are world coordinates.

See Also

Objects

`birdsEyePlot` | `drivingScenario`

Functions

`actor` | `actorPoses` | `outlinePlotter` | `plotOutline` | `targetPoses` | `vehicle`

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

driving.scenario.targetsToEgo

Convert actor poses to ego vehicle coordinates

Syntax

```
targetPoses = driving.scenario.targetsToEgo(actorPoses, egoPose)
```

Description

`targetPoses = driving.scenario.targetsToEgo(actorPoses, egoPose)` converts the poses of target actors from the world coordinates of a driving scenario to the coordinate system of an ego vehicle with pose `egoPose`. See “Ego Vehicle and Targets” on page 4-427 for more details.

Examples

Obtain Target Poses in Ego Vehicle Coordinates

Create a driving scenario containing three vehicles. Find the target poses of two of the vehicles as viewed by the third vehicle. Target poses are returned in the ego-centric coordinate system of the third vehicle.

Create a driving scenario.

```
scenario = drivingScenario;
```

Create the target actors.

```
actor(scenario, 'Position', [10 20 30], ...  
      'Velocity', [12 113 14], ...  
      'Yaw', 54, ...  
      'Pitch', 25, ...  
      'Roll', 22, ...  
      'AngularVelocity', [24 42 27]);
```

```
actor(scenario, 'Position', [17 22 12], ...
      'Velocity', [19 13 15], ...
      'Yaw', 45, ...
      'Pitch', 52, ...
      'Roll', 2, ...
      'AngularVelocity', [42 24 29]);
```

Add the ego vehicle actor.

```
ego = actor(scenario, 'Position', [1 2 3], ...
           'Velocity', [1.2 1.3 1.4], ...
           'Yaw', 4, ...
           'Pitch', 5, ...
           'Roll', 2, ...
           'AngularVelocity', [4 2 7]);
```

Use `actorPoses` to return the poses of all the actors. Pose properties (position, velocity, and orientation) are in scenario coordinates.

```
allposes = actorPoses(scenario);
```

Use `driving.scenario.targetsToEgo` to convert only the target poses to the ego-centric coordinates of the ego actor. Examine the pose of the first actor.

```
targetposes1 = driving.scenario.targetsToEgo(allposes(1:2), ego);
disp(targetposes1(1))
```

```
ActorID: 1
Position: [7.8415 18.2876 27.1675]
Velocity: [18.6826 112.0403 9.2960]
Roll: 16.4327
Pitch: 23.2186
Yaw: 47.8114
AngularVelocity: [-3.3744 47.3021 18.2569]
```

Alternatively, use `targetPoses` to obtain all non-ego actor poses in ego vehicle coordinates. Compare these poses to the previously calculated poses.

```
targetposes2 = targetPoses(ego);
disp(targetposes2(1))
```

```
ActorID: 1
ClassID: 0
Position: [7.8415 18.2876 27.1675]
```

```

Velocity: [18.6826 112.0403 9.2960]
Roll: 16.4327
Pitch: 23.2186
Yaw: 47.8114
AngularVelocity: [-3.3744 47.3021 18.2569]

```

Input Arguments

actorPoses — Actor poses in world coordinates

structure | array of structures

Actor poses in world coordinates, specified as a structure or an array of structures. Poses are the positions, velocities, and orientations of actors.

Each actor pose structure has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an $[x\ y\ z]$ real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x -, y -, and z -directions, specified as a $[v_x\ v_y\ v_z]$ real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x -, y -, and z -directions, specified as an $[\omega_x\ \omega_y\ \omega_z]$ real-valued vector. Units are in degrees per second.

For full definitions of these structure fields, see the `actor` and `vehicle` functions.

egoPose — Ego vehicle pose in world coordinates

structure

Ego vehicle pose in world coordinates, specified as a structure. A pose is the position, velocity, and orientation of an actor.

The ego vehicle pose structure has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x-, y-, and z-directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x-, y-, and z-directions, specified as an [ω_x ω_y ω_z] real-valued vector. Units are in degrees per second.

For full definitions of these structure fields, see the actor and vehicle functions.

Output Arguments

targetPoses — Target poses in ego vehicle coordinates

structure | array of structures

Target poses in ego vehicle coordinates, specified as a structure or an array of structures. Poses are the positions, velocities, and orientations of actors.

Each target pose structure has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
ClassID	Classification identifier, specified as a nonnegative integer. 0 is reserved for an object of an unknown or unassigned class.
Position	Position of actor, specified as an $[x\ y\ z]$ real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x -, y -, and z -directions, specified as a $[v_x\ v_y\ v_z]$ real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x -, y -, and z -directions, specified as an $[\omega_x\ \omega_y\ \omega_z]$ real-valued vector. Units are in degrees per second.

For full definitions of these structure fields, see the `actor` and `vehicle` functions.

More About

Ego Vehicle and Targets

In a driving scenario, you can specify one actor as the observer of all other actors, similar to how the driver of a car observes all other cars. The observer actor is called the ego actor, or more specifically, the ego vehicle. From the perspective of the ego vehicle, all other actors (vehicles, pedestrians, and so on) are the observed actors, or targets. Ego

vehicle coordinates are centered and oriented with reference to the ego vehicle. The coordinates of the driving scenario are world coordinates.

See Also

Objects

`drivingScenario`

Functions

`actor` | `actorPoses` | `driving.scenario.roadBoundariesToEgo` | `road` | `roadBoundaries` | `targetPoses` | `vehicle`

Introduced in R2017a

path

(To be removed) Create actor or vehicle path in driving scenario

Note path will be removed in a future release. Use `trajectory` instead.

Syntax

```
path(ac, waypoints)
path(ac, waypoints, speed)
```

Description

`path(ac, waypoints)` creates a path for an actor or vehicle, `ac`, using a set of waypoints. The actor follows the path at 30 m/s.

`path(ac, waypoints, speed)` also specifies the actor speed.

Input Arguments

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

waypoints — Path waypoints

real-valued N -by-2 matrix | real-valued N -by-3 matrix

Path waypoints, specified as a real-valued N -by-2 or N -by-3 matrix, where N is the number of waypoints.

- If you specify the waypoints as an N -by-2 matrix, then each matrix row represents the (x,y) coordinates of a waypoint. The z -coordinate of each waypoint is zero.

- If you specify the waypoints as an N -by-3 matrix, then each matrix row represents the (x,y,z) coordinates of a waypoint.

All coordinates belong to the scenario coordinate system. Units are in meters.

Example: [1 0 0; 2 7 7]

speed – Actor speed

30.0 | positive real scalar | N -element vector of nonnegative values

Actor speed, specified as a positive real scalar or N -element vector of nonnegative values. N is the number of waypoints.

- When **speed** is a scalar, the speed is constant throughout the actor motion.
- When **speed** is a vector, the vector values specify the speed at each waypoint.

Speeds are interpolated between waypoints. **speed** can be zero at any waypoint but cannot be zero at two consecutive waypoints. Units are in meters per second.

Example: [10,8,10,11]

Algorithms

The **path** function creates a path for an actor to follow in a scenario. You specify the path using N two-dimensional or three-dimensional waypoints. Each of the $N - 1$ segments between waypoints defines a curve whose curvature varies linearly with distance along the segment. The function fits a piecewise clothoid curve to the (x,y) coordinates of the waypoints by matching the curvature on both sides of the waypoint. For a nonclosed curve, the curvature at the first and last waypoint is zero. If the first and last waypoints coincide, then the curvatures before and after the endpoints are matched. The z -coordinates of the path are interpolated using a shape-preserving piecewise cubic curve.

You can specify **speed** as a scalar or a vector. When **speed** is a scalar, the actor follows the path with constant speed. When **speed** is an N -element vector, **speed** is linearly interpolated between waypoints. Setting the speed to zero at two consecutive waypoints creates a stationary actor.

Compatibility Considerations

path is not recommended

Not recommended starting in R2018a

path will be removed in a future release. Use trajectory instead.

Update Code

Replace all instances of path with trajectory. If you used path without specifying a speed, you must now specify one. The trajectory function does not include a syntax that assumes a default speed.

Discouraged Usage	Recommended Replacement
<pre>scenario = drivingScenario; road(scenario,[-10 0 0; 45 -20 0]); car = vehicle(scenario); waypoints = [-10 -10 0; 35 10 0]; path(car,waypoints) % default speed = 30</pre>	<pre>scenario = drivingScenario; road(scenario,[-10 0 0; 45 -20 0]); car = vehicle(scenario); waypoints = [-10 -10 0; 35 10 0]; speeds = 30; trajectory(car,waypoints,speed)</pre>

See Also

trajectory

Introduced in R2017a

road

Add road to driving scenario

Syntax

```
road(scenario, roadcenters)
road(scenario, roadcenters, roadwidth)
road(scenario, roadcenters, roadwidth, bankingangle)

road(scenario, roadcenters, 'Lanes', lspec)
road(scenario, roadcenters, bankingangle, 'Lanes', lspec)
```

Description

`road(scenario, roadcenters)` adds a road to a driving scenario, `scenario`. You specify the road shape using a set of road centers, `roadcenters`, at discrete points.

`road(scenario, roadcenters, roadwidth)` adds a road with the specified width, `roadwidth`.

`road(scenario, roadcenters, roadwidth, bankingangle)` adds a road with the specified width and banking angle, `bankingangle`.

`road(scenario, roadcenters, 'Lanes', lspec)` adds a road with the specified lanes, `lspec`.

`road(scenario, roadcenters, bankingangle, 'Lanes', lspec)` adds a road with the specified banking angle and lanes.

Examples

Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```

Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0°, ends at 90°, and is sampled at 5° increments.

```
angs = [0:5:90]';
R = 800;
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];
roadwidth = 10;
road(scenario,roadcenters,roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];
road(scenario,roadcenters)
roadcenters = [400 400 0; 0 0 0];
road(scenario,roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

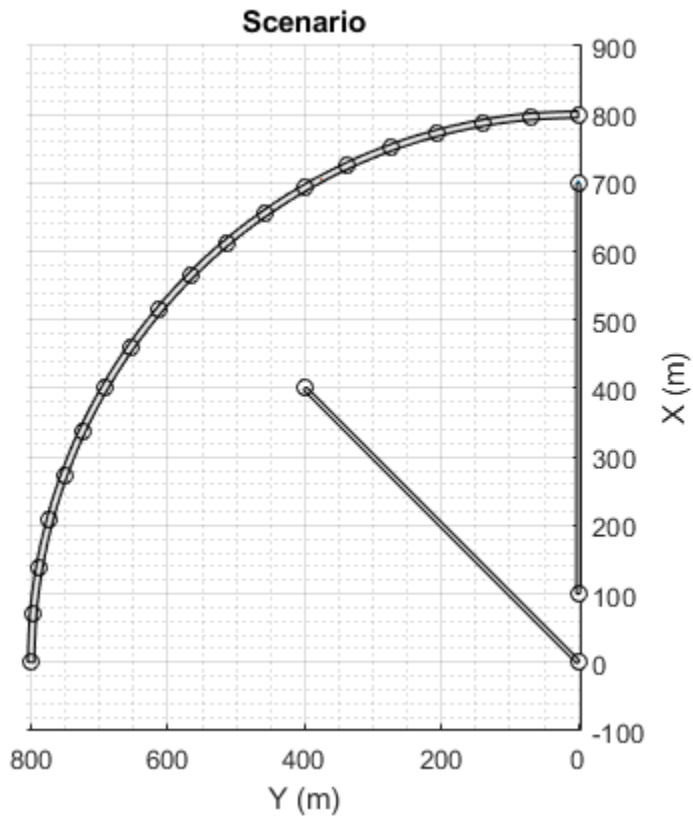
```
car = vehicle(scenario,'Position',[700 0 0],'Length',3,'Width',2,'Height',1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario,'Position',[706 376 0],'Length',2,'Width',0.45,'Height',1.5)
```

Plot the scenario.

```
plot(scenario,'Centerline','on','RoadCenters','on');
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct  
  ActorID  
  Position  
  Velocity  
  Roll  
  Pitch  
  Yaw  
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```



```
profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles
```

Create and Display Road Boundaries

Create a driving scenario containing a figure-8 road specified in the world coordinates of the scenario. Convert the world coordinates of the scenario to the coordinate system of the ego vehicle.

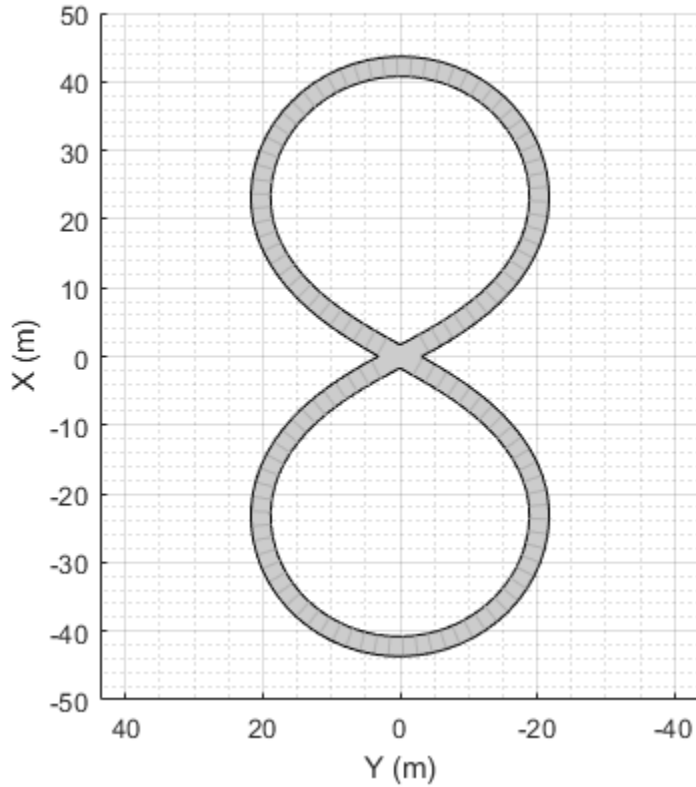
Create an empty driving scenario.

```
scenario = drivingScenario;
```

Add a figure-8 road to the scenario. Display the scenario.

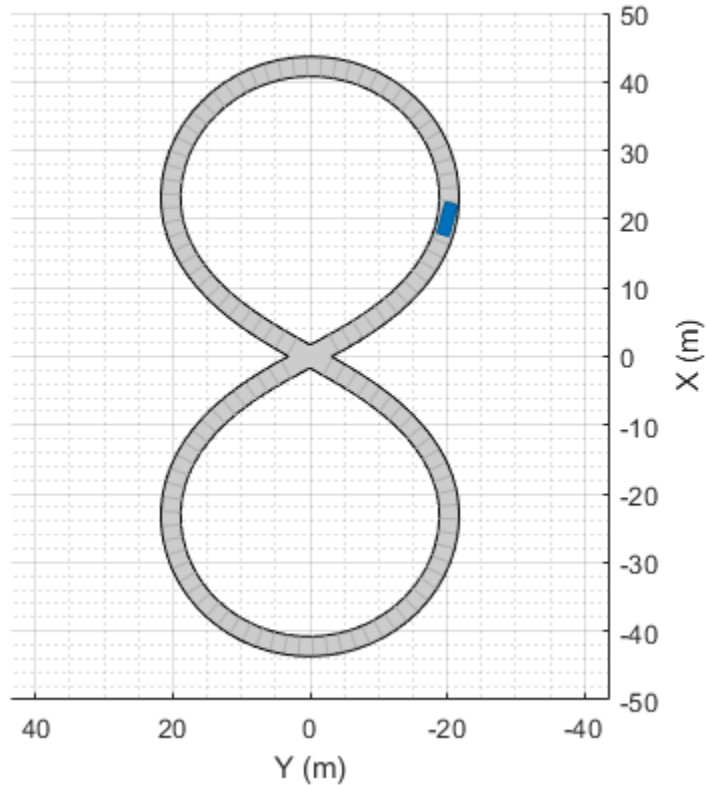
```
roadCenters = [0  0  1
               20 -20 1
               20  20 1
               -20 -20 1
               -20  20 1
               0  0  1];

roadWidth = 3;
bankAngle = [0 15 15 -15 -15 0];
road(scenario, roadCenters, roadWidth, bankAngle);
plot(scenario)
```



Add an ego vehicle to the scenario. Position the vehicle at world coordinates (20, -20) and orient it at a -15 degree yaw angle.

```
ego = actor(scenario, 'Position', [20 -20 0], 'Yaw', -15);
```

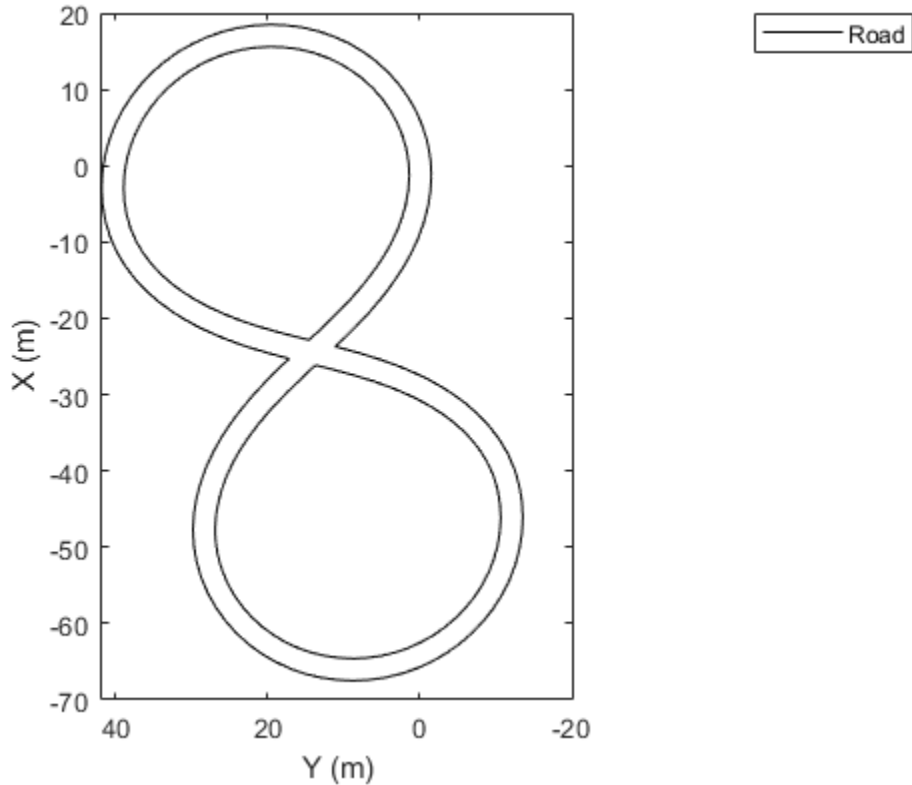


Obtain the road boundaries in ego vehicle coordinates by using the `roadBoundaries` function. Specify the ego vehicle as the input argument.

```
rbEgo1 = roadBoundaries(ego);
```

Display the result on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road');  
plotLaneBoundary(lbp, rbEgo1)
```



Obtain the road boundaries in world coordinates by using the `roadBoundaries` function. Specify the scenario as the input argument.

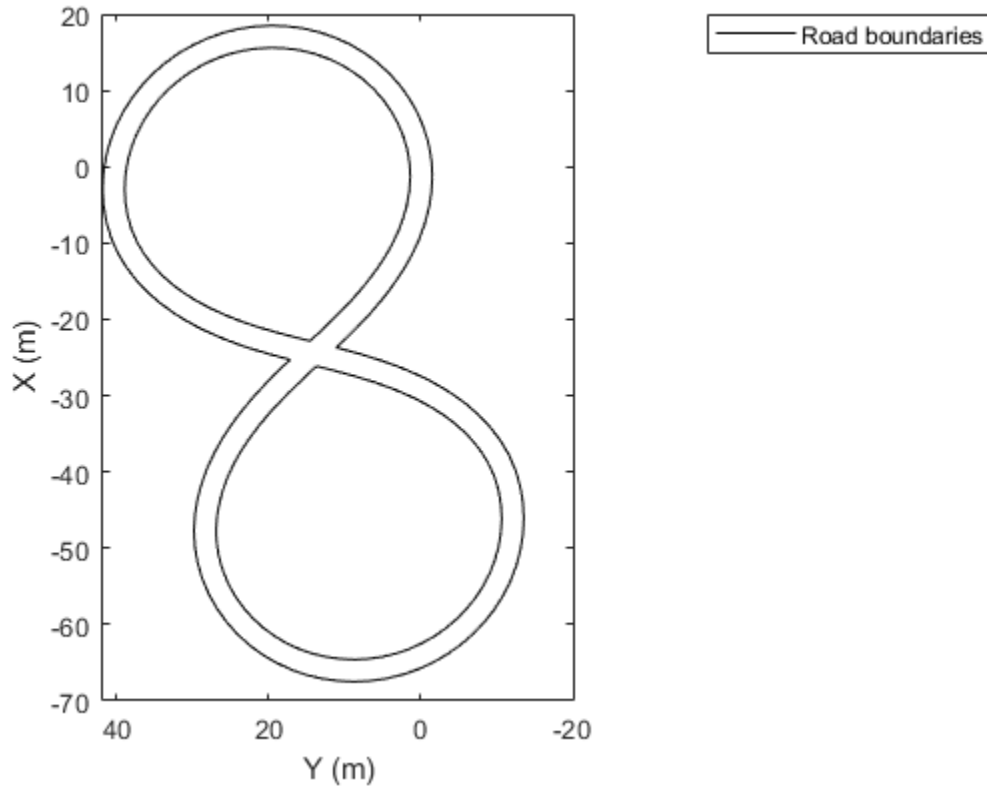
```
rbScenario = roadBoundaries(scenario);
```

Obtain the road boundaries in ego vehicle coordinates by using the `driving.scenario.roadBoundariesToEgo` function.

```
rbEgo2 = driving.scenario.roadBoundariesToEgo(rbScenario,ego);
```

Display the road boundaries on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road boundaries');  
plotLaneBoundary(lbp, {rbEgo2})
```



Display Lane Markings in Car and Pedestrian Scenario

Create a driving scenario containing a car and pedestrian on a straight road. Then, create and display the lane markings of the road on a bird's-eye plot.

Create an empty driving scenario.

```
scenario = drivingScenario;
```

Create a straight, 25-meter road segment with two travel lanes in one direction.

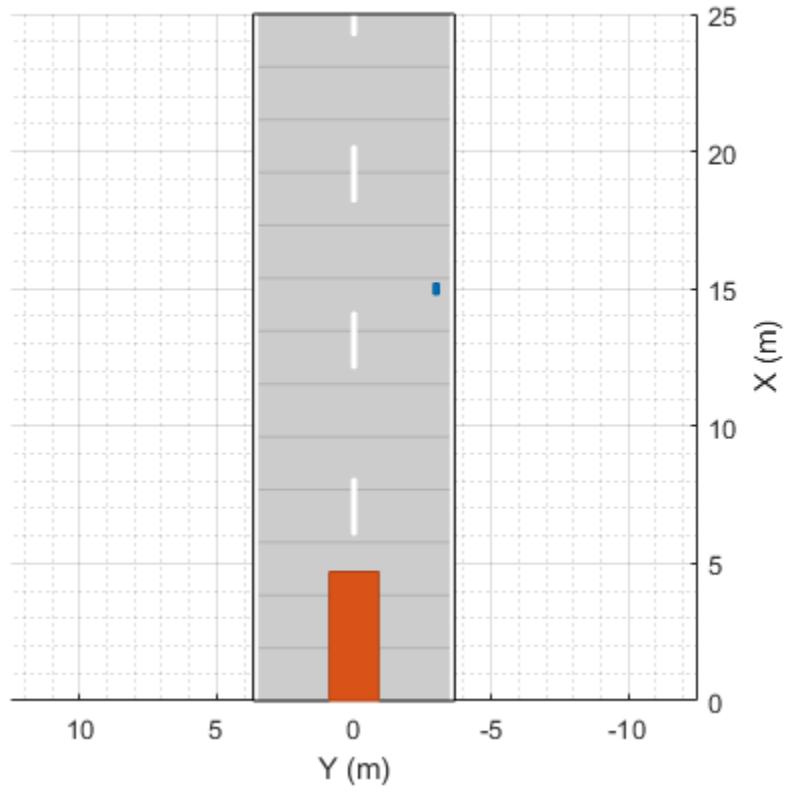
```
lm = [laneMarking('Solid')
      laneMarking('Dashed', 'Length', 2, 'Space', 4)
      laneMarking('Solid')];
l = lanespec(2, 'Marking', lm);
road(scenario, [0 0 0; 25 0 0], 'Lanes', l);
```

Add to the driving scenario a pedestrian crossing the road at 1 meter per second and a car following the road at 10 meters per second.

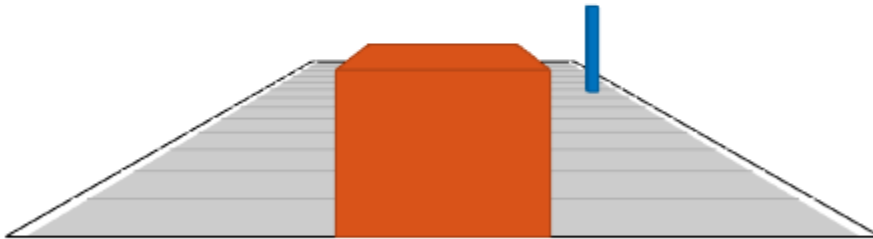
```
ped = actor(scenario, 'Length', 0.2, 'Width', 0.4, 'Height', 1.7);
car = vehicle(scenario);
trajectory(ped, [15 -3 0; 15 3 0], 1);
trajectory(car, [car.RearOverhang 0 0; 25-car.Length+car.RearOverhang 0 0], 10);
```

Display the scenario and corresponding chase plot.

```
plot(scenario)
```



```
chasePlot(car)
```



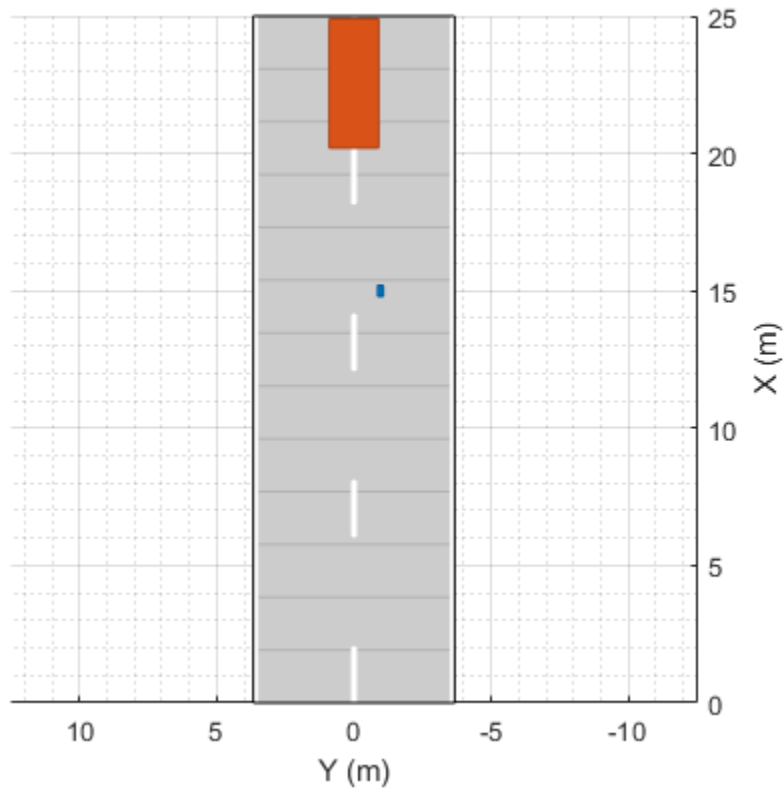
Run the simulation.

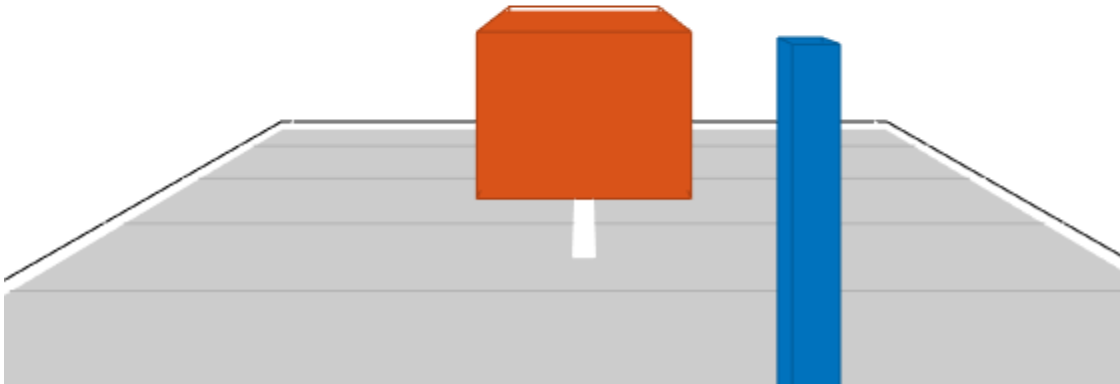
- 1 Create a bird's-eye plot.
- 2 Create an outline plotter, lane boundary plotter, and lane marking plotter for the bird's-eye plot.
- 3 Obtain the road boundaries and target outlines.
- 4 Obtain the lane marking vertices and faces.
- 5 Display the lane boundaries and lane markers.
- 6 Run the simulation loop.

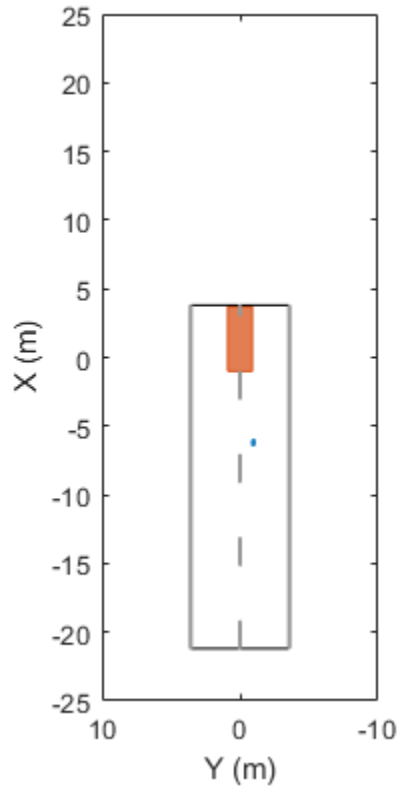
```
bep = birdsEyePlot('XLim',[-25 25], 'YLim',[-10 10]);  
olPlotter = outlinePlotter(bep);
```



```
lbPlotter = laneBoundaryPlotter(bep);  
lmPlotter = laneMarkingPlotter(bep, 'DisplayName', 'Lanes');  
legend('off');  
while advance(scenario)  
    rb = roadBoundaries(car);  
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);  
    [lmv,lmf] = laneMarkingVertices(car);  
    plotLaneBoundary(lbPlotter,rb);  
    plotLaneMarking(lmPlotter,lmv,lmf);  
    plotOutline(olPlotter,position,yaw,length,width, ...  
        'OriginOffset',originOffset,'Color',color);  
end
```







Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

roadcenters — Road centers used to define road

real-valued N -by-2 matrix | real-valued N -by-3 matrix

Road centers used to define a road, specified as a real-valued N -by-2 or N -by-3 matrix. Road centers determine the center line of the road at discrete points.

- If `roadcenters` is an N -by-2 matrix, then each matrix row represents the (x, y) coordinates of a road center. The z -coordinate of each road center is zero.
- If `roadcenters` is an N -by-3 matrix, then each matrix row represents the (x, y, z) coordinates of a road center.

If the first row of the matrix is the same as the last row, the road is a loop. Units are in meters.

Data Types: `double`

roadwidth — Width of road

6.0 (default) | positive real scalar | []

Width of road, specified as a positive real scalar. The width is constant along the entire road. Units are in meters.

To specify the `bankingangle` input but not `roadwidth`, specify `roadwidth` as an empty argument, [].

If you specify `roadwidth`, then you cannot specify the `lspec` input.

Data Types: `double`

bankingangle — Banking angle of road

0 (default) | real-valued N -by-1 vector

Banking angle of road, specified as a real-valued N -by-1 vector. N is the number of road centers. The banking angle is the roll angle of the road along the direction of the road. Units are in degrees.

lspec — Lane specification

`lanespec` object

Lane specification, specified as a `lanespec` object. Use `lanespec` to specify the number of lanes, the width of each lane, and the type of lane markings. To specify the lane markings within `lanespec`, use the `laneMarking` function.

If you specify `lspec`, then you cannot specify the `roadwidth` input.

Example: `'Lane'`, `lanespec(3)` specifies a three-lane road with default lane widths and lane markings.

Algorithms

The `road` function creates a road for an actor to follow in a driving scenario. You specify the road using N two-dimensional or three-dimensional waypoints. Each of the $N - 1$ segments between waypoints defines a curve whose curvature varies linearly with distance along the segment. The function fits a piecewise clothoid curve to the (x, y) coordinates of the waypoints by matching the curvature on both sides of the waypoint. For a nonclosed curve, the curvature at the first and last waypoint is zero. If the first and last waypoints coincide, then the curvatures before and after the endpoints are matched. The z -coordinates of the road are interpolated using a shape-preserving piecewise cubic curve.

See Also

Objects

`drivingScenario` | `lanespec`

Functions

`laneMarking` | `roadBoundaries` | `roadNetwork`

Topics

“Define Road Layouts”

“Driving Scenario Tutorial”

Introduced in R2017a

roadNetwork

Add road network to driving scenario

Syntax

```
roadNetwork(scenario, 'OpenDRIVE', filePath)
roadNetwork( ____, 'ShowLaneTypes', lanetype)
```

Description

`roadNetwork(scenario, 'OpenDRIVE', filePath)` imports roads and lanes from an OpenDRIVE road network file into a driving scenario. This function supports OpenDRIVE format specification version 1.4H [1].

`roadNetwork(____, 'ShowLaneTypes', lanetype)` uses the name-value pair 'ShowLaneTypes' to specify importing lane type information from an OpenDRIVE road network file and render into the driving scenario.

Examples

Import OpenDRIVE Road Network into Driving Scenario

Create an empty driving scenario.

```
scenario = drivingScenario;
```

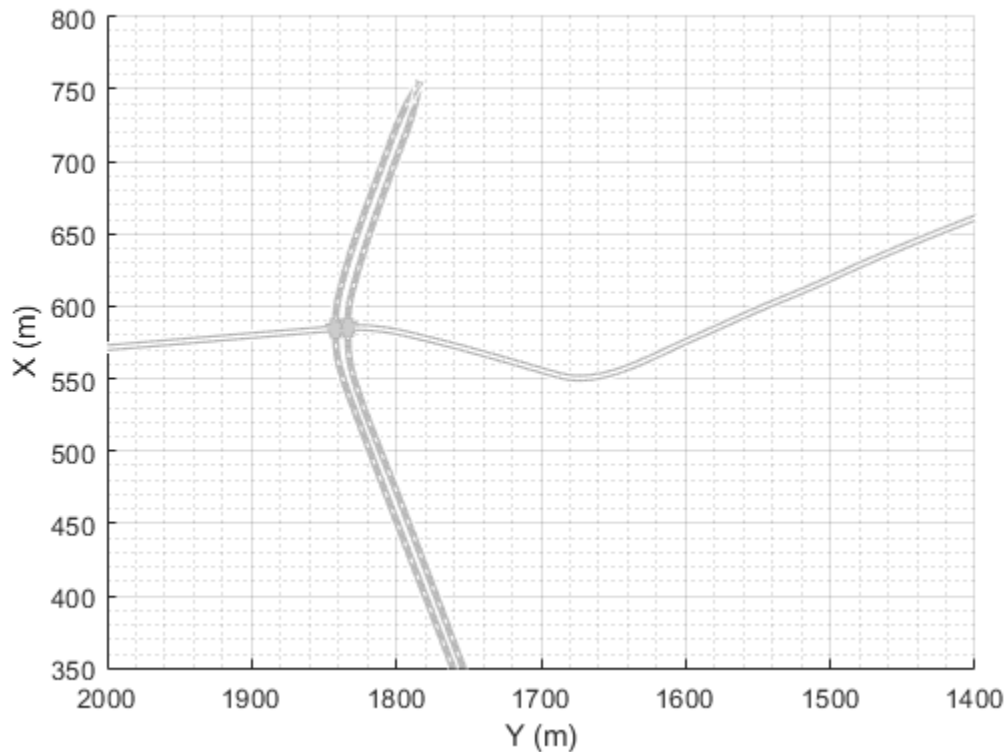
Import an OpenDRIVE road network into the scenario.

```
filePath = fullfile(matlabroot, 'examples', 'driving', 'intersection.xodr');
roadNetwork(scenario, 'OpenDRIVE', filePath);
```

Plot the scenario and zoom in on the road network by setting the axes limits.

```
plot(scenario)
xlim([350 800])
```

```
ylim([1400 2000])  
zlim([0.00 10.00])
```



Import OpenDRIVE Road with Multiple Lane Types into Driving Scenario

Create an empty driving scenario.

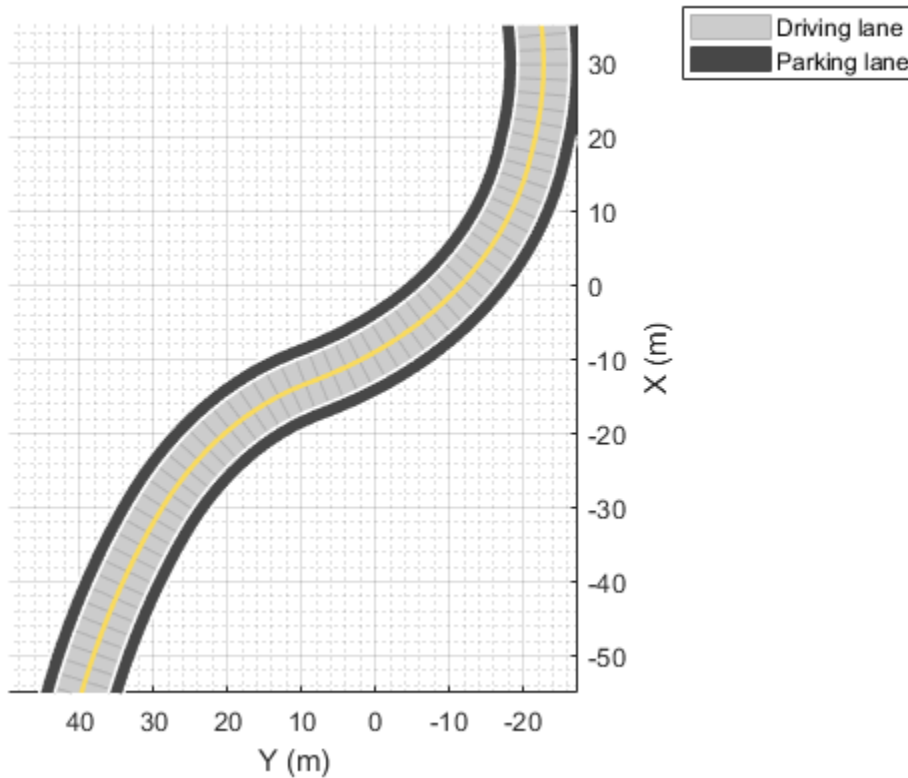
```
scenario = drivingScenario;
```

Import an OpenDRIVE road composed of driving and parking lanes into the scenario. By default, the function interprets the lane type information and imports the lanes into driving scenario without altering the lane type.

```
filePath = 'parking.xodr';  
roadNetwork(scenario, 'OpenDRIVE', filePath);
```

Plot the scenario.

```
plot(scenario)  
zoom(2)  
legend('Driving lane', 'Parking lane')
```

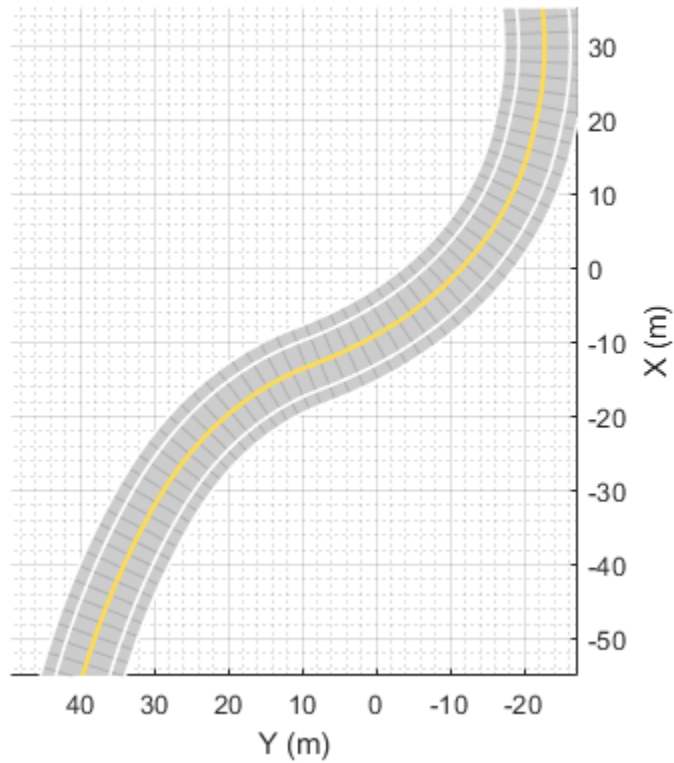


Import the OpenDRIVE road into the scenario. Set the 'ShowLaneTypes' value to false to suppress multiple lane types. The function ignores the lane type information and imports all the lanes as driving lanes.

```
scenario = drivingScenario;  
roadNetwork(scenario, 'OpenDRIVE', filePath, 'ShowLaneTypes', false);
```



```
plot(scenario)
zoom(2)
```



Input Arguments

scenario – Driving scenario

drivingScenario object

Driving scenario, specified as a drivingScenario object. scenario must contain no roads and no other OpenDRIVE road network.

filePath — Path to valid OpenDRIVE file

character vector | string scalar

Path to a valid OpenDRIVE file of type `.xml` or `.xodr`, specified as a character vector or string scalar.

Example: `'OpenDRIVE', 'C:\Desktop\myRoadNetwork.xodr'`




lanetype — Import lane type information



true or 1 (default) | false or 0

Import lane type information, specified as a comma-separated pair consisting of `'ShowLaneTypes'` and one of these values

- `true` or `1` - To import lane type information from an OpenDRIVE road network file into the driving scenario and render lane types.
- `false` or `0` - To ignore lane type information and import all lanes as driving lanes in the driving scenario.

The default value is `true`. The function can import only the lane types listed in this table into the driving scenario. The table summarizes the supported lane types and their default appearance on importing into the driving scenario.

Supported Lane Types	Description	Default Appearance
Driving lanes	Lanes for driving	
Border lanes	Lanes at the road borders	
Restricted lanes	Lanes reserved for high-occupancy vehicles	

Shoulder lanes	Lanes reserved for emergency stopping	
Parking lanes	Lanes alongside driving lanes, intended for parking vehicles	

Any other unsupported lane types are rendered as border lanes.

Example: `'ShowLaneTypes', false`

Limitations

- You can import only lanes, lane type information, and roads. The import of road objects and traffic signals is not supported.
- OpenDRIVE files containing large road networks can take up to several minutes to load. Examples of large road networks include ones that model the roads of a city or ones with roads that are thousands of meters long.
- Lanes with variable widths are not supported. The width is set to the highest width found within that lane. For example, if a lane has a width that varies from 2 meters to 4 meters, the function sets the lane width to 4 meters throughout.
- Roads with lane type information specified as `driving`, `border`, `restricted`, `shoulder`, and `parking` are supported. Lanes with any other lane type information are imported as border lanes.
- Roads with multiple lane marking styles are not supported. The function applies the first found marking style to all lanes in the road. For example, if a road has `Dashed` and `Solid` lane markings, the function applies `Dashed` lane markings throughout.
- Lane marking styles `Bott Dots`, `Curbs`, and `Grass` are not supported. Lanes with these marking styles are imported as unmarked.

References

- [1] Dupuis, Marius, et al. *OpenDRIVE Format Specification*. Revision 1.4, Issue H, Document No. VI2014.106. Bad Aibling, Germany: VIRES Simulationstechnologie GmbH, November 4, 2015.

See Also

Objects

drivingScenario

Functions

actor | trajectory | vehicle

Topics

“Scenario Generation from Recorded Vehicle Data”

External Websites

opendrive.org

Introduced in R2018b

roadBoundaries

Package:

Get road boundaries

Syntax

```
rbdry = roadBoundaries(scenario)
rbdry = roadBoundaries(ac)
```

Description

`rbdry = roadBoundaries(scenario)` returns the road boundaries, `rbdry`, of a driving scenario, `scenario`.

`rbdry = roadBoundaries(ac)` returns the road boundaries that the actor, `ac`, follows in a driving scenario.

Examples

Create Driving Scenario with Multiple Actors and Roads

Create a driving scenario containing a curved road, two straight roads, and two actors: a car and a bicycle. Both actors move along the road for 60 seconds.

Create the driving scenario object.

```
scenario = drivingScenario('SampleTime',0.1,'StopTime',60);
```

Create the curved road using road center points following the arc of a circle with an 800-meter radius. The arc starts at 0°, ends at 90°, and is sampled at 5° increments.

```
angs = [0:5:90]';
R = 800;
```

```
roadcenters = R*[cosd(angs) sind(angs) zeros(size(angs))];  
roadwidth = 10;  
road(scenario, roadcenters, roadwidth);
```

Add two straight roads with the default width, using road center points at each end.

```
roadcenters = [700 0 0; 100 0 0];  
road(scenario, roadcenters)  
roadcenters = [400 400 0; 0 0 0];  
road(scenario, roadcenters)
```

Get the road boundaries.

```
rbdry = roadBoundaries(scenario);
```

Add a car and a bicycle to the scenario. Position the car at the beginning of the first straight road.

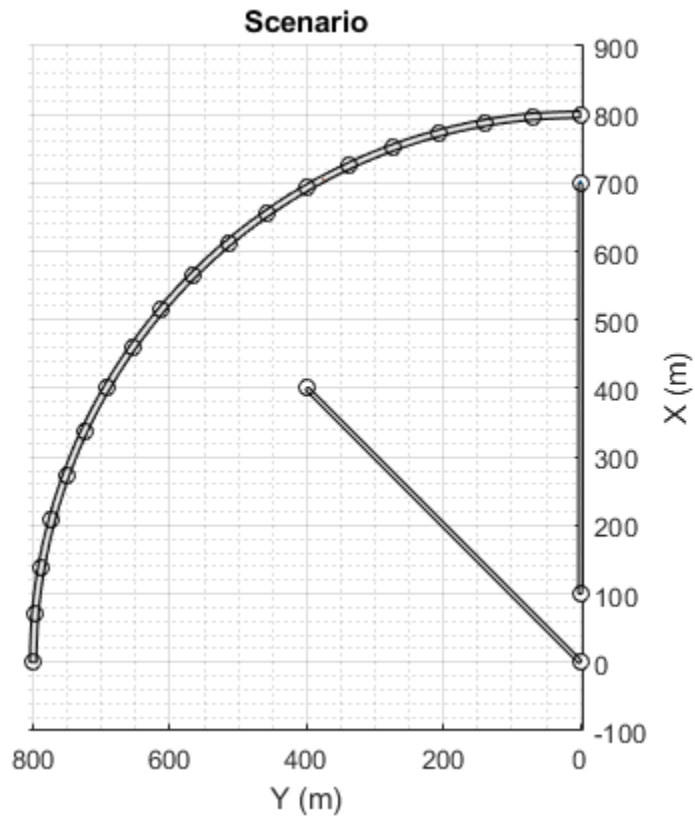
```
car = vehicle(scenario, 'Position', [700 0 0], 'Length', 3, 'Width', 2, 'Height', 1.6);
```

Position the bicycle farther down the road.

```
bicycle = actor(scenario, 'Position', [706 376 0]', 'Length', 2, 'Width', 0.45, 'Height', 1.5)
```

Plot the scenario.

```
plot(scenario, 'Centerline', 'on', 'RoadCenters', 'on');  
title('Scenario');
```



Display the actor poses and profiles.

```
poses = actorPoses(scenario)
```

```
poses=2x7 struct
  ActorID
  Position
  Velocity
  Roll
  Pitch
  Yaw
  AngularVelocity
```

```
profiles = actorProfiles(scenario)
```

```
profiles=2x9 struct
  ActorID
  ClassID
  Length
  Width
  Height
  OriginOffset
  RCSPattern
  RCSAzimuthAngles
  RCSElevationAngles
```

Create and Display Road Boundaries

Create a driving scenario containing a figure-8 road specified in the world coordinates of the scenario. Convert the world coordinates of the scenario to the coordinate system of the ego vehicle.

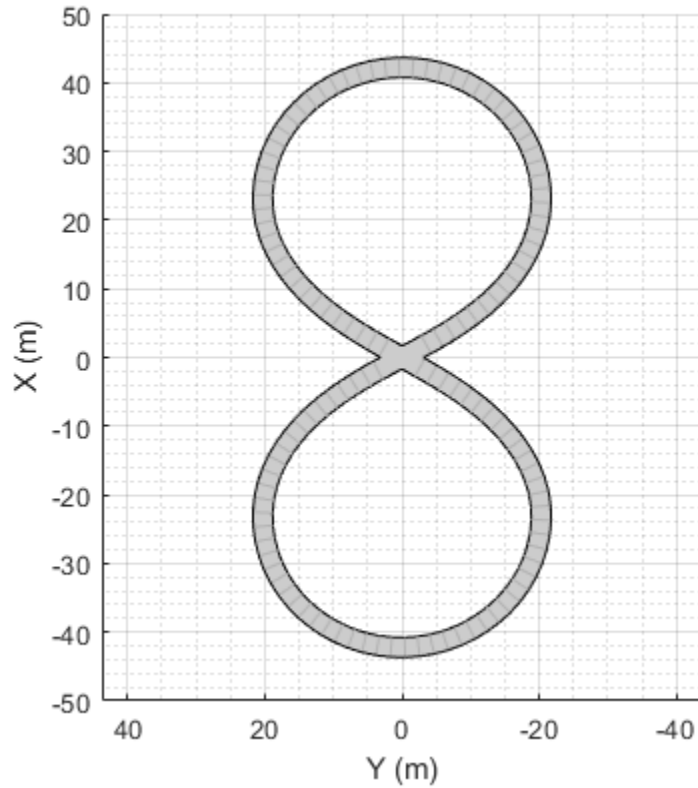
Create an empty driving scenario.

```
scenario = drivingScenario;
```

Add a figure-8 road to the scenario. Display the scenario.

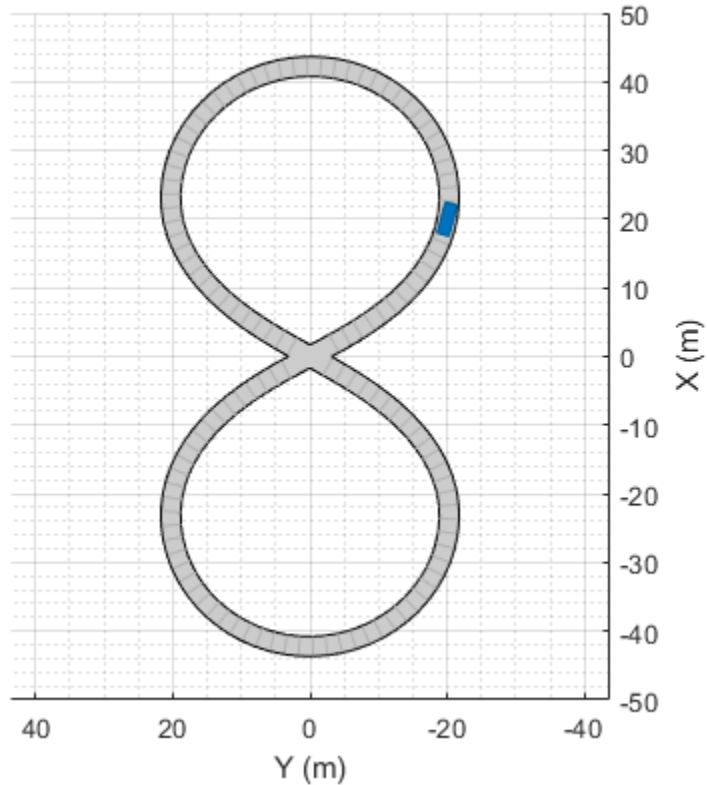
```
roadCenters = [0  0  1
               20 -20 1
               20  20 1
               -20 -20 1
               -20  20 1
               0  0  1];

roadWidth = 3;
bankAngle = [0 15 15 -15 -15 0];
road(scenario,roadCenters,roadWidth,bankAngle);
plot(scenario)
```

Add an ego vehicle to the scenario. Position the vehicle at world coordinates (20, -20) and orient it at a -15 degree yaw angle.

```
ego = actor(scenario, 'Position', [20 -20 0], 'Yaw', -15);
```

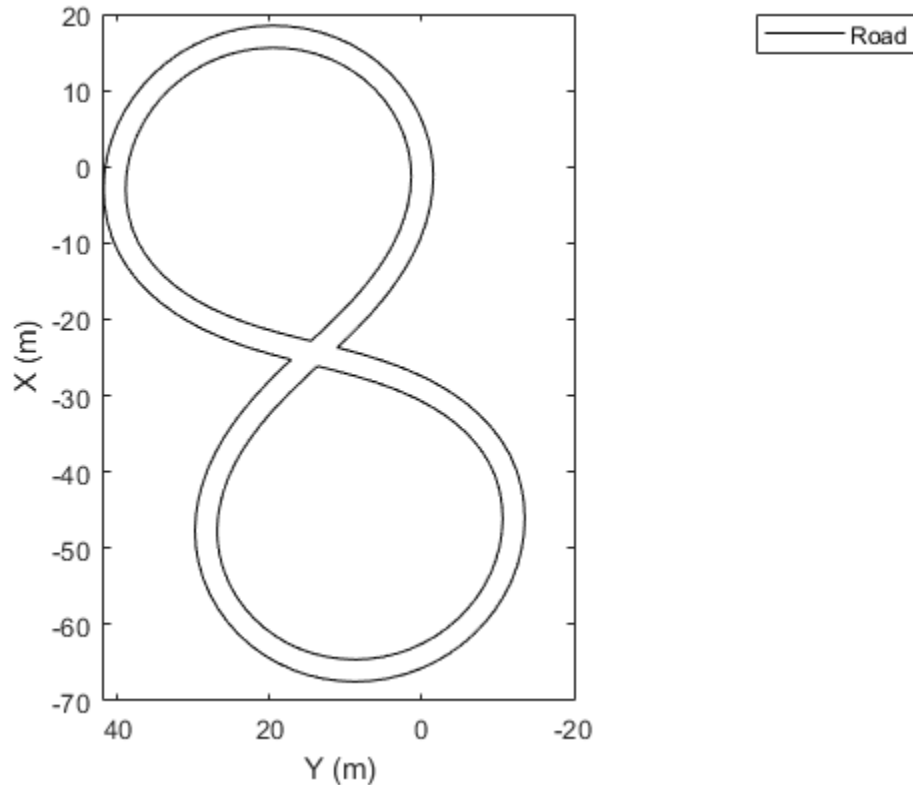


Obtain the road boundaries in ego vehicle coordinates by using the `roadBoundaries` function. Specify the ego vehicle as the input argument.

```
rbEgo1 = roadBoundaries(ego);
```

Display the result on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road');  
plotLaneBoundary(lbp, rbEgo1)
```



Obtain the road boundaries in world coordinates by using the `roadBoundaries` function. Specify the scenario as the input argument.

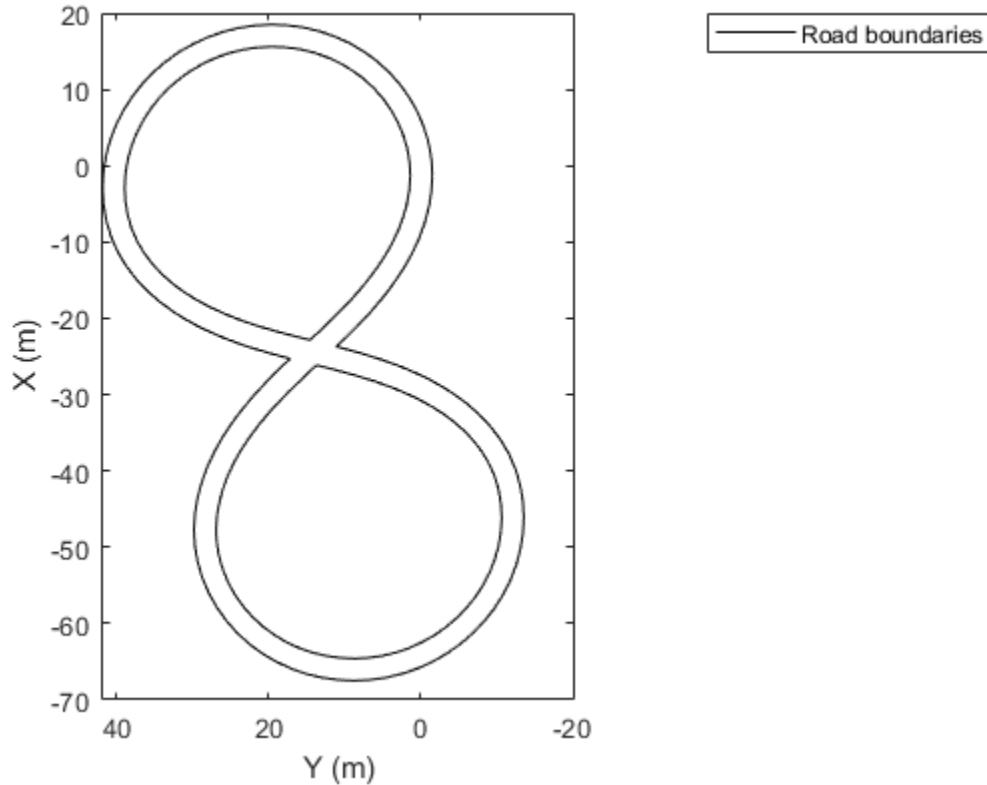
```
rbScenario = roadBoundaries(scenario);
```

Obtain the road boundaries in ego vehicle coordinates by using the `driving.scenario.roadBoundariesToEgo` function.

```
rbEgo2 = driving.scenario.roadBoundariesToEgo(rbScenario,ego);
```

Display the road boundaries on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road boundaries');  
plotLaneBoundary(lbp, {rbEgo2})
```



Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

Output Arguments

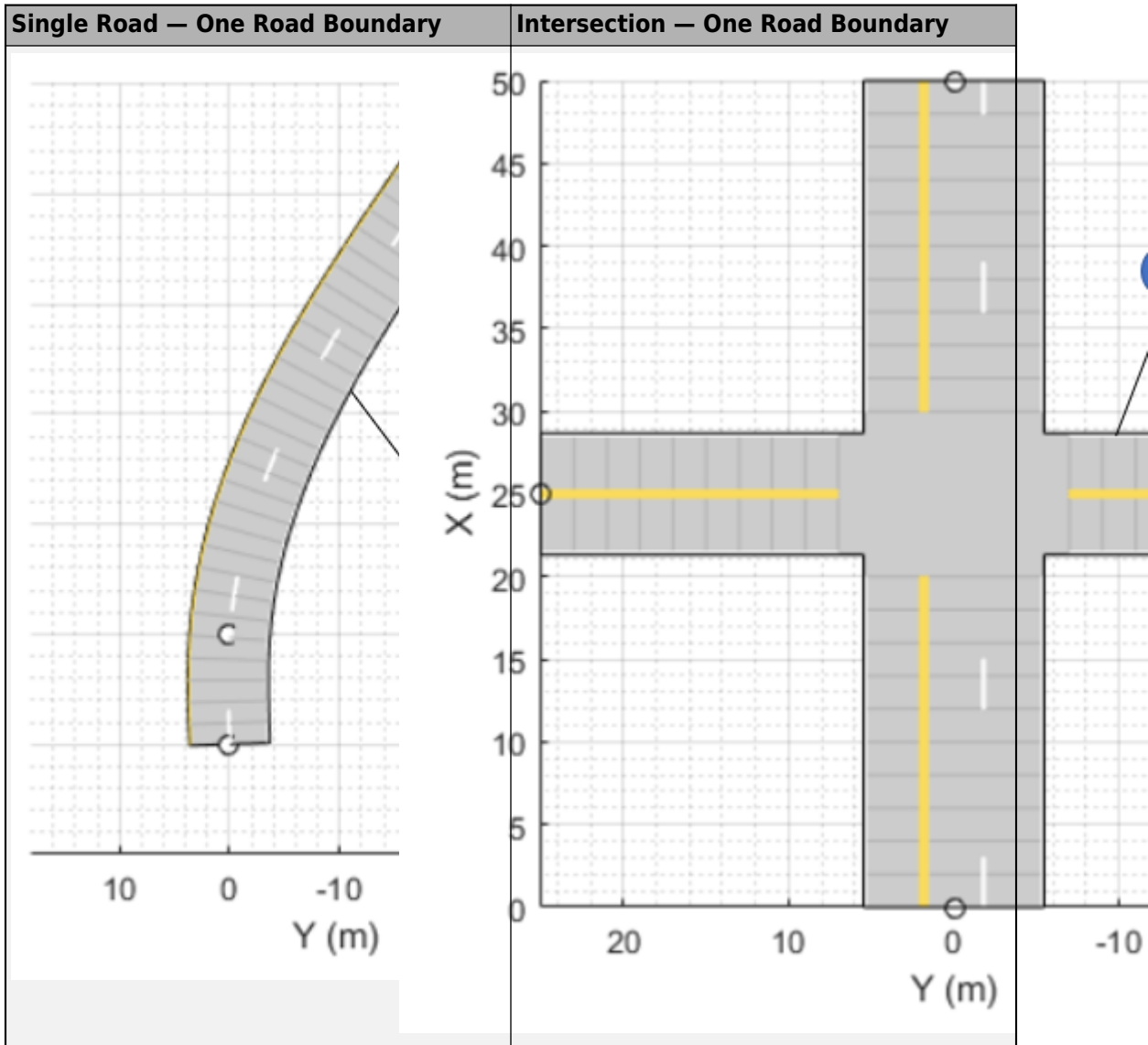
rbdry — Road boundaries

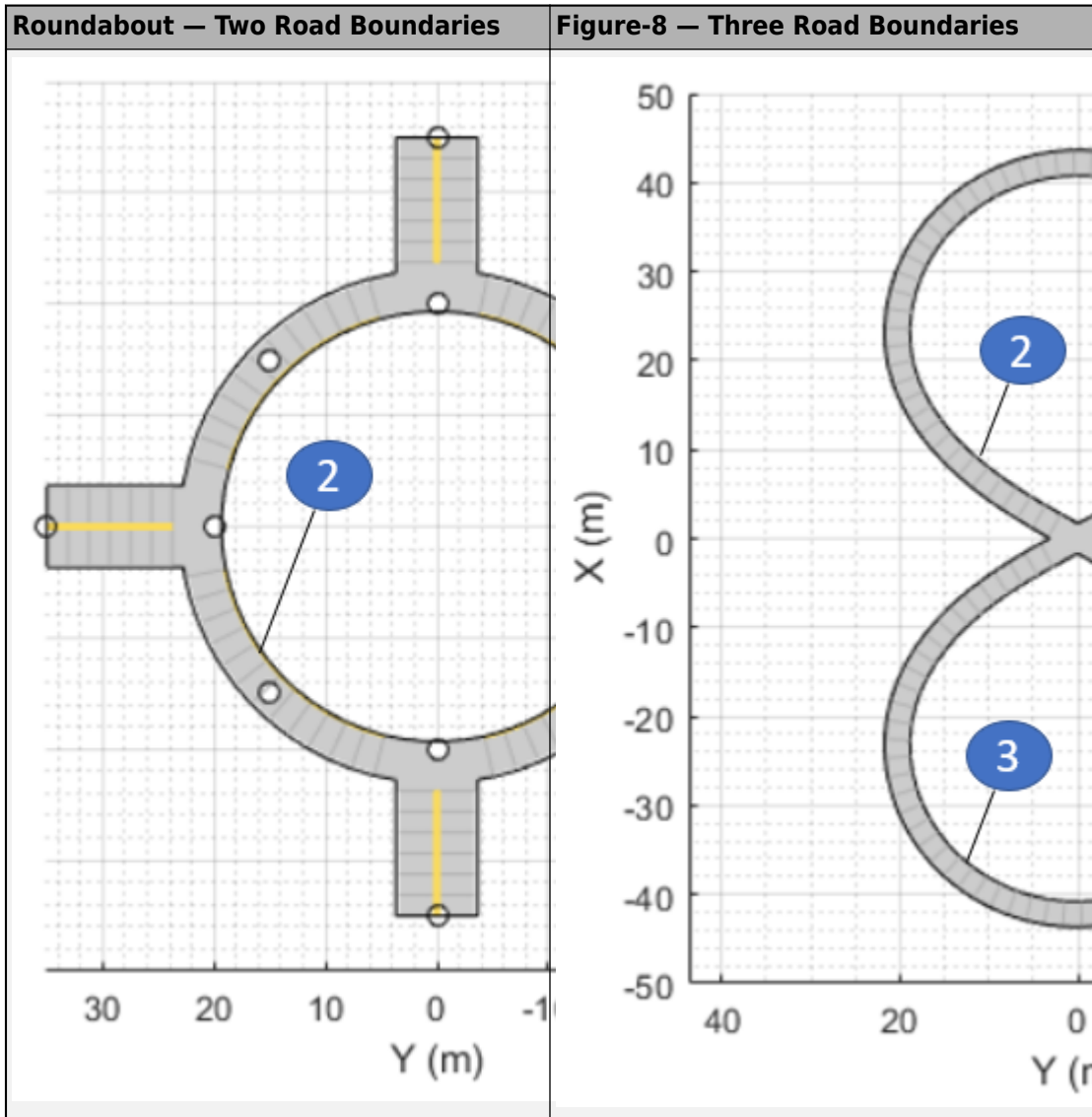
cell array

Road boundaries, returned as a cell array. Each cell in the cell array contains a real-valued N -by-3 matrix representing a road boundary in the scenario, where N is the number of road boundaries. Each row of the matrix corresponds to the (x, y, z) coordinates of a road boundary vertex.

When the input argument is a driving scenario, the road coordinates are with respect to the world coordinates of the driving scenario. When the input argument is an actor, the road coordinates are with respect to the actor coordinate system.

The figures show the number of road boundaries that `rbdry` contains for various road types.





See Also

Objects

drivingScenario

Functions

actor | road | vehicle

Topics

“Driving Scenario Tutorial”

Introduced in R2017a

driving.scenario.roadBoundariesToEgo

Convert road boundaries to ego vehicle coordinates

Syntax

```
egoRoadBoundaries = driving.scenario.roadBoundariesToEgo(  
scenarioRoadBoundaries,ego)  
egoRoadBoundaries = driving.scenario.roadBoundariesToEgo(  
scenarioRoadBoundaries,egoPose)
```

Description

`egoRoadBoundaries = driving.scenario.roadBoundariesToEgo(scenarioRoadBoundaries,ego)` converts road boundaries from the world coordinates of a driving scenario to the coordinate system of the ego vehicle, `ego`.

`egoRoadBoundaries = driving.scenario.roadBoundariesToEgo(scenarioRoadBoundaries,egoPose)` converts road boundaries from world coordinates to vehicle coordinates using the pose of the ego vehicle, `egoPose`.

Examples

Create and Display Road Boundaries

Create a driving scenario containing a figure-8 road specified in the world coordinates of the scenario. Convert the world coordinates of the scenario to the coordinate system of the ego vehicle.

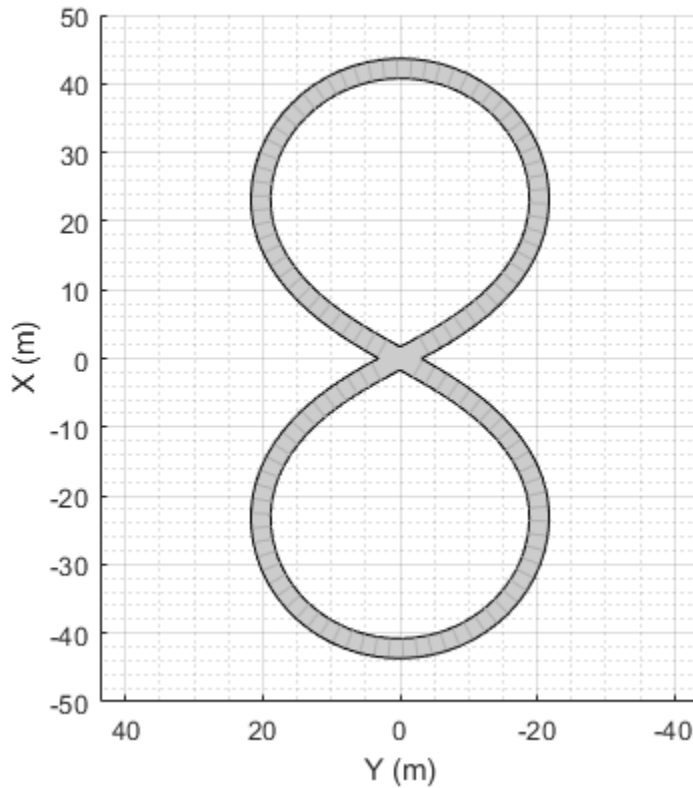
Create an empty driving scenario.

```
scenario = drivingScenario;
```

Add a figure-8 road to the scenario. Display the scenario.

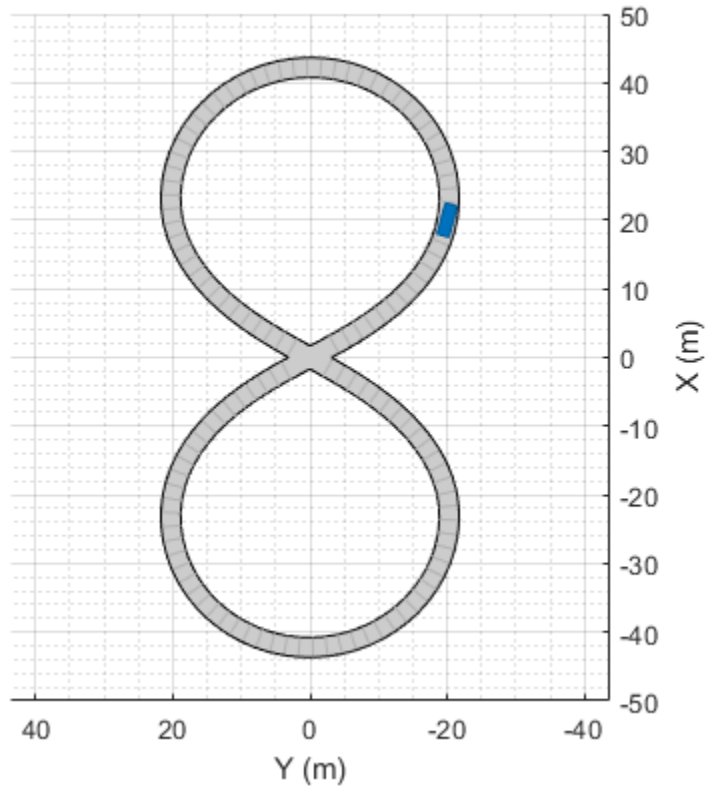
```
roadCenters = [0  0  1
               20 -20 1
               20  20 1
               -20 -20 1
               -20  20 1
               0  0  1];

roadWidth = 3;
bankAngle = [0 15 15 -15 -15 0];
road(scenario,roadCenters,roadWidth,bankAngle);
plot(scenario)
```



Add an ego vehicle to the scenario. Position the vehicle at world coordinates (20, -20) and orient it at a -15 degree yaw angle.

```
ego = actor(scenario, 'Position', [20 -20 0], 'Yaw', -15);
```

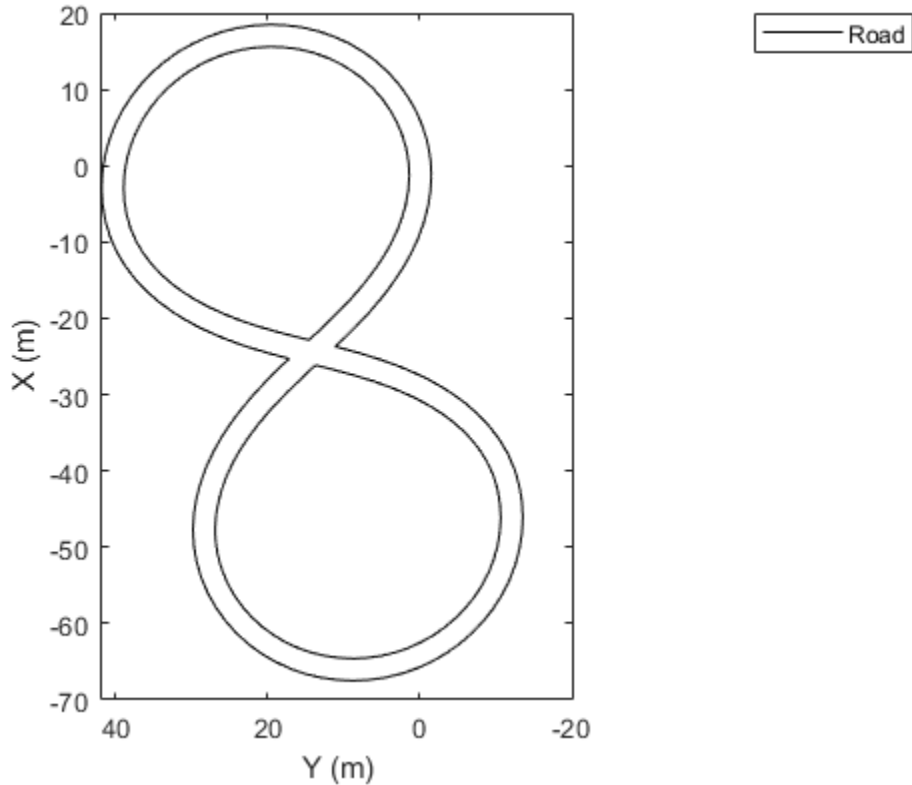


Obtain the road boundaries in ego vehicle coordinates by using the `roadBoundaries` function. Specify the ego vehicle as the input argument.

```
rbEgo1 = roadBoundaries(ego);
```

Display the result on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road');  
plotLaneBoundary(lbp, rbEgo1)
```



Obtain the road boundaries in world coordinates by using the `roadBoundaries` function. Specify the scenario as the input argument.

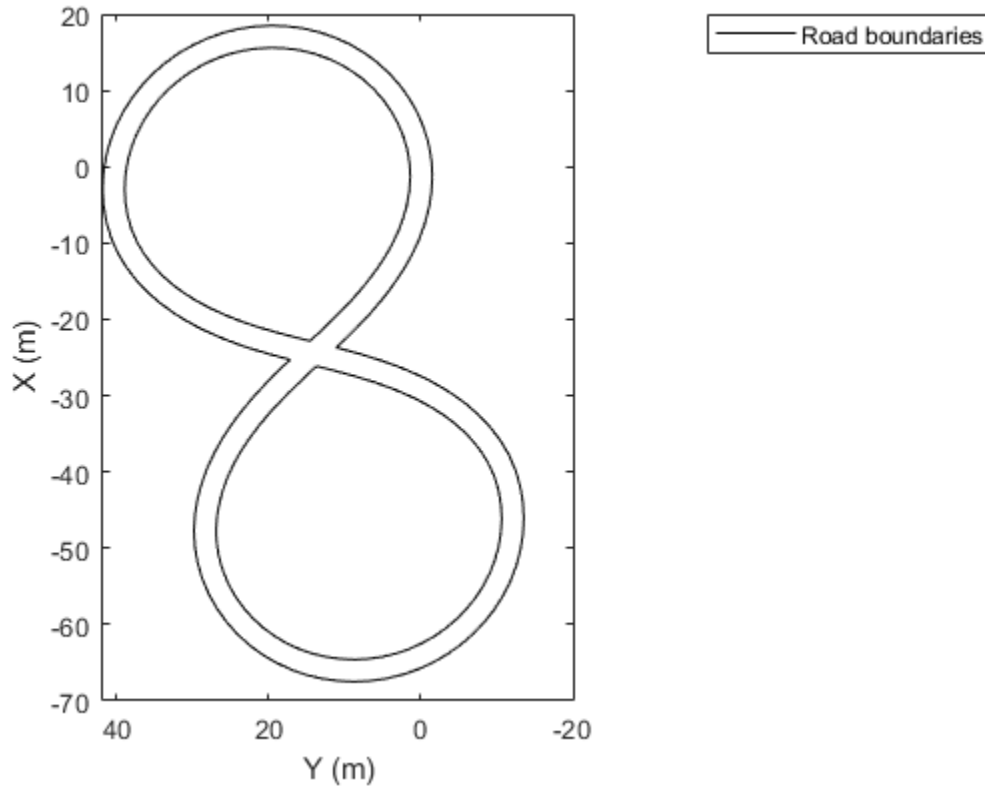
```
rbScenario = roadBoundaries(scenario);
```

Obtain the road boundaries in ego vehicle coordinates by using the `driving.scenario.roadBoundariesToEgo` function.

```
rbEgo2 = driving.scenario.roadBoundariesToEgo(rbScenario,ego);
```

Display the road boundaries on a bird's-eye plot.

```
bep = birdsEyePlot;  
lbp = laneBoundaryPlotter(bep, 'DisplayName', 'Road boundaries');  
plotLaneBoundary(lbp, {rbEgo2})
```



Input Arguments

scenarioRoadBoundaries — Road boundaries of scenario in world coordinates

1-by- N cell array

Road boundaries of the scenario in world coordinates, specified as a 1-by- N cell array. N is the number of road boundaries within the scenario. Each cell corresponds to a road and contains the (x, y, z) coordinates of the road boundaries in a real-valued P -by-3 matrix. P is the number of boundaries and varies from cell to cell. Units are in meters.

ego — Ego vehicle

Actor object | Vehicle object

Ego vehicle, specified as an Actor or Vehicle object. To create these objects, use the actor and vehicle functions, respectively.

egoPose — Ego vehicle pose in world coordinates

structure

Ego vehicle pose in world coordinates, specified as a structure. A pose is the position, velocity, and orientation of an actor.

The ego vehicle pose structure has these fields.

Field	Description
ActorID	Scenario-defined actor identifier, specified as a positive integer.
Position	Position of actor, specified as an [x y z] real-valued vector. Units are in meters.
Velocity	Velocity (v) of actor in the x-, y-, and z-directions, specified as a [v_x v_y v_z] real-valued vector. Units are in meters per second.
Roll	Roll angle of actor, specified as a real scalar. Units are in degrees.
Pitch	Pitch angle of actor, specified as a real scalar. Units are in degrees.
Yaw	Yaw angle of actor, specified as a real scalar. Units are in degrees.
AngularVelocity	Angular velocity (ω) of actor in the x-, y-, and z-directions, specified as an [ω_x ω_y ω_z] real-valued vector. Units are in degrees per second.

For full definitions of these structure fields, see the actor and vehicle functions.

Output Arguments

egoRoadBoundaries — Road boundaries in ego vehicle coordinates

real-valued Q -by-3 matrix

Road boundaries in ego vehicle coordinates, returned as a real-valued Q -by-3 matrix. Q is the number of road boundary point coordinates of the form (x, y, z) .

All road boundaries are contained in the same matrix, with a row of NaN values separating points in different road boundaries. For example, if the input has three road boundaries of length P_1 , P_2 , and P_3 , then $Q = P_1 + P_2 + P_3 + 2$. Units are in meters.

See Also

Objects

drivingScenario

Functions

actor | actorPoses | driving.scenario.targetsToEgo | road | roadBoundaries
| targetPoses | vehicle

Introduced in R2017a

currentLane

Package:

Get current lane of actor

Syntax

```
cl = currentLane(ac)  
[cl,numlanes] = currentLane(ac)
```

Description

`cl = currentLane(ac)` returns the current lane, `cl`, of an actor, `ac`.

`[cl,numlanes] = currentLane(ac)` also returns the number of road lanes, `numlanes`.

Examples

Find Current Lanes of Two Cars

Obtain the current lane boundaries of cars during a driving scenario simulation.

Create a driving scenario containing a straight, three-lane road.

```
scenario = drivingScenario;  
roadCenters = [0 0; 80 0];  
road(scenario,roadCenters,'Lanes',lanespec([1 2],'Width',3));
```

Add an ego vehicle moving at 20 meters per second and a target vehicle moving at 10 meters per second.

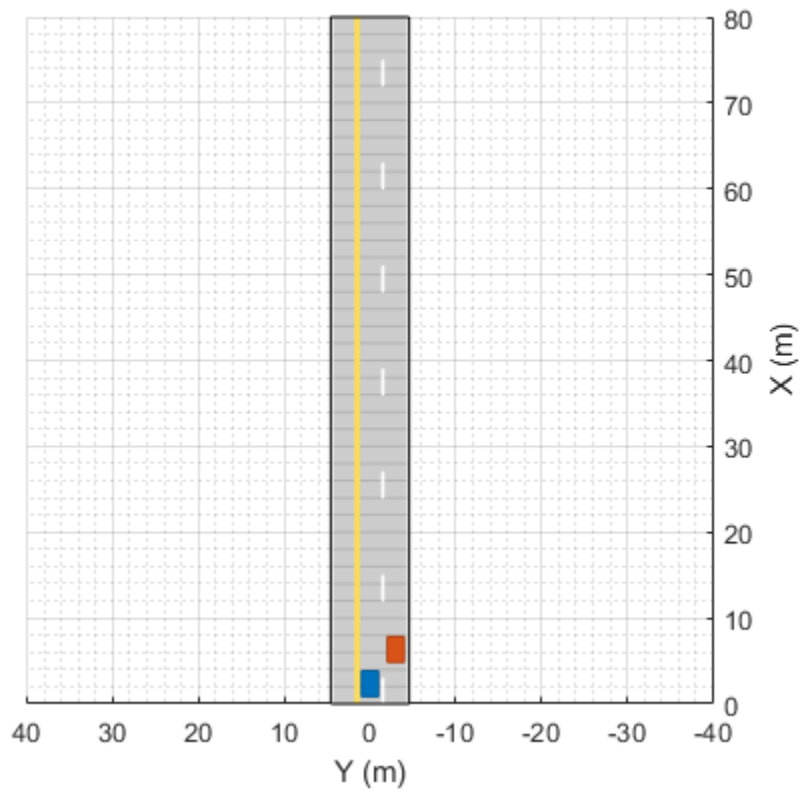
```
ego = vehicle(scenario,'Position',[5 0 0],'Length',3,'Width',2,'Height',1.6);  
trajectory(ego,[1 0 0; 20 0 0; 30 0 0;50 0 0],20);
```



```
target = vehicle(scenario, 'Position', [5 0 0], 'Length', 3, 'Width', 2, 'Height', 1.6);  
trajectory(target, [5 -3 0; 20 -3 0; 30 -3 0; 50 -3 0], 10);
```

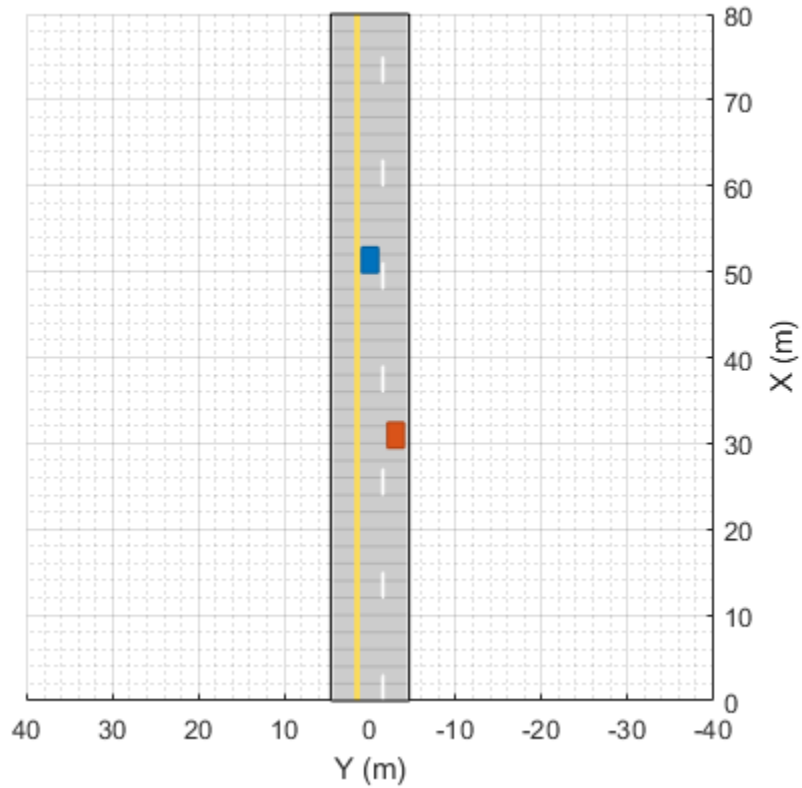
Plot the scenario.

```
plot(scenario)
```



Run the simulation loop.

```
while advance(scenario)  
    [cl1,numlanes] = currentLane(ego);  
    [cl2,numlanes] = currentLane(target);  
end
```



Display the current lane of each vehicle.

```
disp(cl1)  
disp(cl2)
```

2

Input Arguments

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

Output Arguments

cL — Current lane of actor

positive integer | []

Current lane of the actor, returned as a positive integer. Lanes are numbered from left to right, relative to the actor, starting from 1. When the actor is not on a road or is on a road without any lanes specified, `cL` is returned as empty, [].

numLanes — Number of lanes on road

positive integer | []

Number of lanes on the road that the actor is traveling on, returned as a positive integer. When the actor is not on a road or is on a road without any lanes specified, `numLanes` is returned as empty, [].

See Also

Objects

`drivingScenario` | `lanespec`

Functions

`actor` | `laneBoundaries` | `vehicle`

Introduced in R2018a

lanespec

Create road lane specifications

Description

The `lanespec` object defines the lane specifications of a road that was added to a `drivingScenario` object using the `road` function. For more details, see “Lane Specifications” on page 4-489.

Creation

Syntax

```
lnspec = lanespec(numlanes)  
lnspec = lanespec(numlanes,Name,Value)
```

Description

`lnspec = lanespec(numlanes)` creates lane specifications for a road having `numlanes` lanes. `numlanes` sets the `NumLanes` property of the `lanespec` object.

`lnspec = lanespec(numlanes,Name,Value)` sets properties on page 4-478 using one or more name-value pairs. For example, `lanespec(3,'Width',[2.25 3.5 2.25])` specifies a three-lane road with widths from left to right of 2.25 meters, 3.5 meters, and 2.25 meters.

Properties

NumLanes — Number of lanes in road

positive integer | two-element vector of positive integers

This property is read-only.

Number of lanes in the road, specified as a positive integer or two-element vector of positive integers, $[N_L, N_R]$. When NumLanes is a positive integer, all lanes flow in the same direction. When NumLanes is a vector:

- N_L is the number of left lanes, all flowing in one direction.
- N_R is the number of right lanes, all flowing in the opposite direction.

The total number of lanes in the road is the sum of these vector values: $N = N_L + N_R$.

You can set this property when you create the object. After you create the object, this property is read-only.

Example: `[2 2]` specifies two left lanes and two right lanes.

Width — Lane widths

3.6 (default) | positive real scalar | 1-by- N vector of positive real scalars

Lane widths, specified as a positive real scalar or 1-by- N vector of positive real scalars, where N is the number of lanes in the road. N must be equal to numlanes and the corresponding value set in the NumLanes property.

When Width is a scalar, the same value is applied to all lanes. When Width is a vector, the vector elements apply to lanes from left to right. Units are in meters.

Example: `[3.5 3.7 3.7 3.5]`




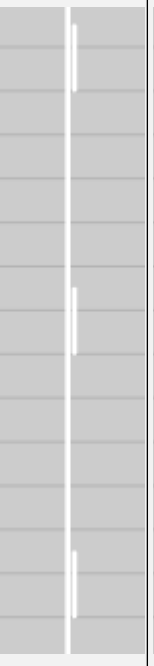
Data Types: double

Marking — Lane markings

lane marking object (default) | 1-by- M array of lane marking objects

Lane markings of road, specified as a lane marking object or a 1-by- M array of lane marking objects. M is the number of lane markings. For a road with N lanes, $M = N + 1$.

To create lane marking objects, use the laneMarking function and specify the type of lane marking.

'Unmarked'	'Solid'	'Dashed'	'DoubleSolid'	'DoubleDashed'	'SolidDashed'	'DashedSolid'
No lane marking	Solid line	Dashed line	Two solid lines	Two dashed lines	Solid line on left, dashed line on right	Dashed line on left, solid line on right
						

By default, for a one-way road, the rightmost and center lane markings are white and the leftmost lane marking is yellow. For two-way roads, the color of the dividing lane marking is yellow.

Example: `[laneMarking('Solid') laneMarking('DoubleDashed') laneMarking('Solid')]` specifies lane markings for a two-lane road. The leftmost and rightmost lane markings are solid lines, and the dividing lane marking is a double-dashed line.

Type — Lane types

DrivingLaneType object (default) | RestrictedLaneType object |
ShoulderLaneType object | ParkingLaneType object | 1-by- M array of lane type
objects

Lane types of road, specified as a homogeneous lane type object or a 1-by- M array of lane type objects. M is the number of lane types.

To create lane type objects, use the `laneType` function and specify the type of lane.

'Driving'	'Border'	'Restricted'	'Shoulder'	'Parking'

Example: `[laneType('Shoulder') laneType('Driving')]` specifies the lane types for a two-lane road. The leftmost lane is the shoulder lane and the rightmost lane is the driving lane.

Examples

Create Straight Four-Lane Road

Create a driving scenario and the road centers for a straight, 80-meter road.

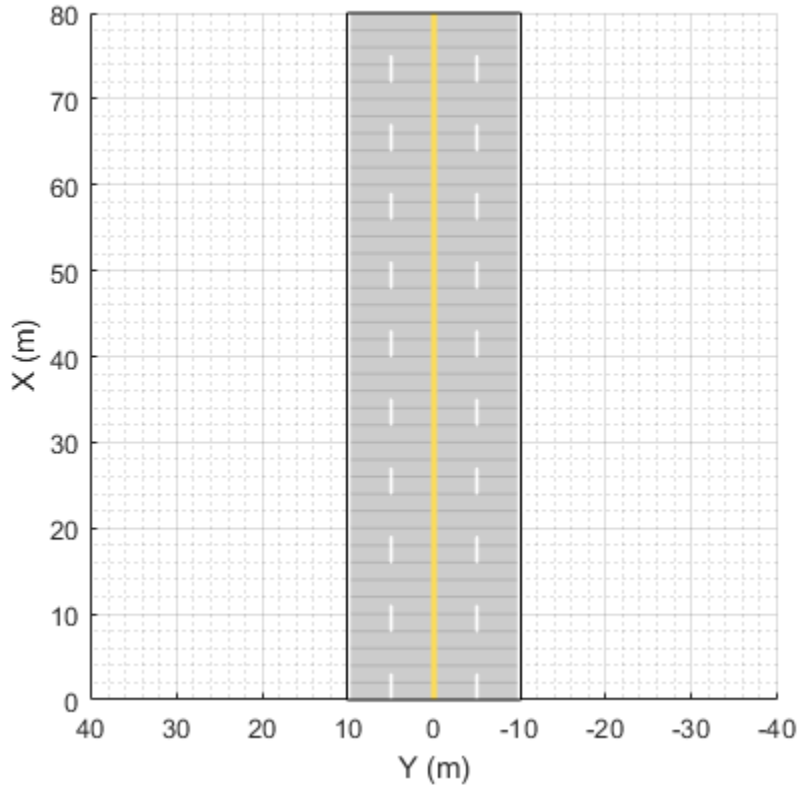
```
scenario = drivingScenario;
roadCenters = [0 0; 80 0];
```

Create a `lanespec` object for a four-lane road. Use the `laneMarking` function to specify its five lane markings. The center line is double-solid and double yellow. The outermost lines are solid and white. The inner lines are dashed and white.

```
solidW = laneMarking('Solid','Width',0.3);
dashW = laneMarking('Dashed','Space',5);
doubleY = laneMarking('DoubleSolid','Color','yellow');
lspec = lanespec([2 2],'Width',[5 5 5 5], ...
    'Marking',[solidW dashW doubleY dashW solidW]);
```

Add the road to the driving scenario. Display the road.

```
road(scenario,roadCenters,'Lanes',lspec);  
plot(scenario)
```



Simulate Car Traveling on S-Curve

Simulate a driving scenario with one car traveling on an S-curve. Create and plot the lane boundaries.

Create the driving scenario with one road having an S-curve.

```
scenario = drivingScenario('StopTime',3);  
roadcenters = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];
```


Create the lanes and add them to the road.

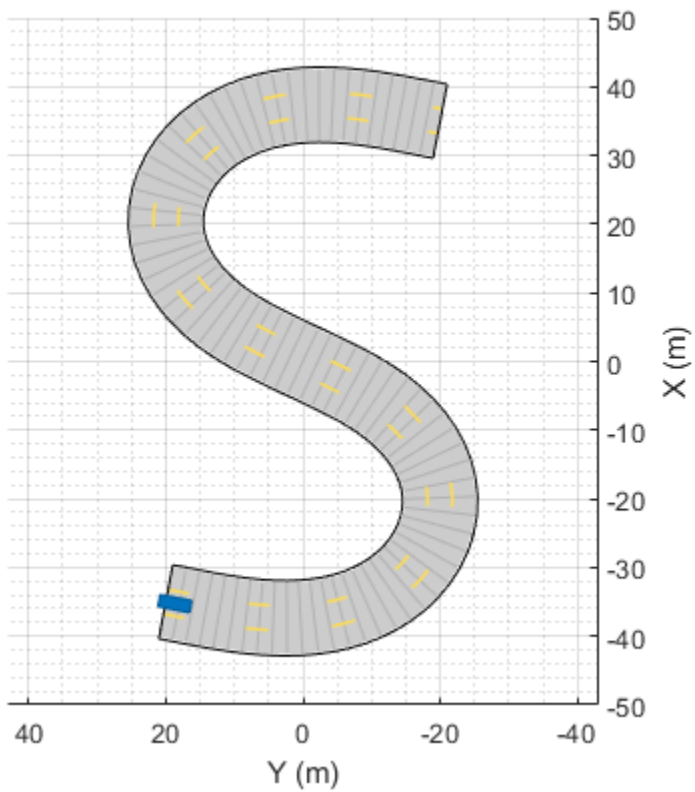
```
lm = [laneMarking('Solid','Color','w'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Solid','Color','w')];  
ls = lanespec(3,'Marking',lm);  
road(scenario,roadcenters,'Lanes',ls);
```

Add an ego vehicle and specify its trajectory from its speed and waypoints. The car travels at 30 meters per second.

```
car = vehicle(scenario, ...  
             'ClassID',1, ...  
             'Position',[-35 20 0]);  
waypoints = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];  
speed = 30;  
trajectory(car,waypoints,speed);
```

Plot the scenario and corresponding chase plot.

```
plot(scenario)
```



`chasePlot(car)`



Run the simulation loop.

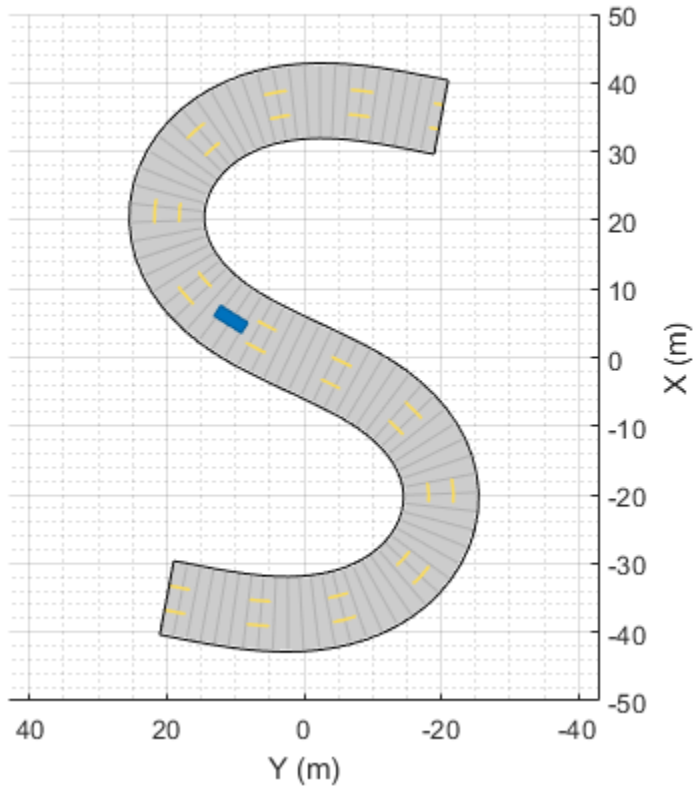
- 1 Initialize a bird's-eye plot and create an outline plotter, left-lane and right-lane boundary plotters, and a road boundary plotter.
- 2 Obtain the road boundaries and rectangular outlines.
- 3 Obtain the lane boundaries to the left and right of the vehicle.
- 4 Advance the simulation and update the plotters.

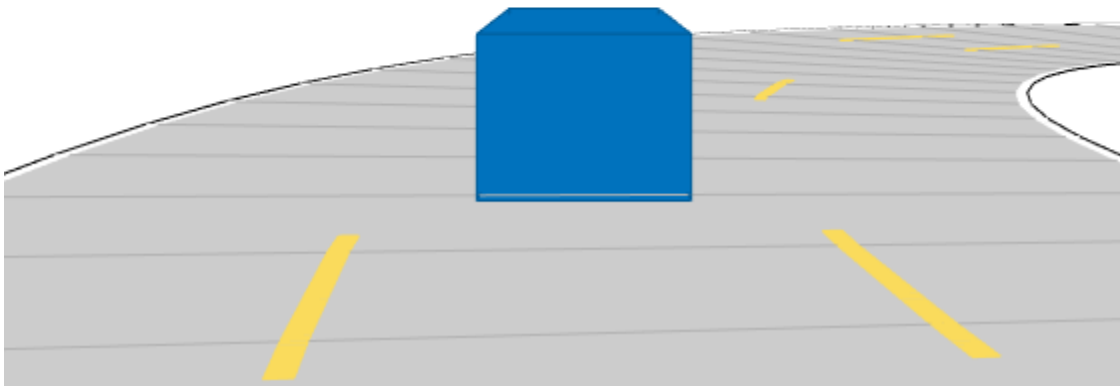
```
bep = birdsEyePlot('XLim',[-40 40], 'YLim',[-30 30]);  
olPlotter = outlinePlotter(bep);  
lblPlotter = laneBoundaryPlotter(bep, 'Color', 'r', 'LineStyle', '-');  
lbrPlotter = laneBoundaryPlotter(bep, 'Color', 'g', 'LineStyle', '-');  
rbsEdgePlotter = laneBoundaryPlotter(bep);
```

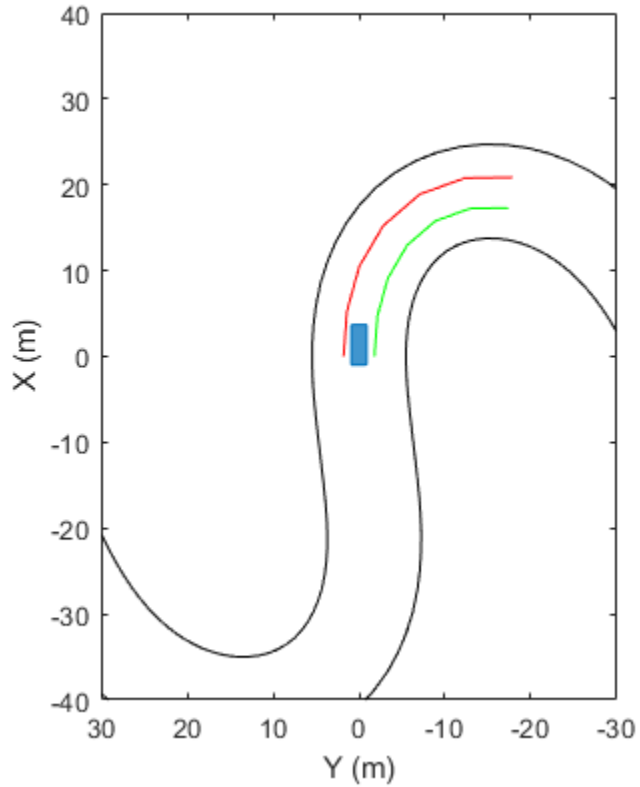
```

legend('off');
while advance(scenario)
    rbs = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    lb = laneBoundaries(car,'XDistance',0:5:30,'LocationType','Center', ...
        'AllBoundaries',false);
    plotLaneBoundary(rbsEdgePlotter,rbs)
    plotLaneBoundary(lblPlotter,{lb(1).Coordinates})
    plotLaneBoundary(lbrPlotter,{lb(2).Coordinates})
    plotOutline(olPlotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
end

```







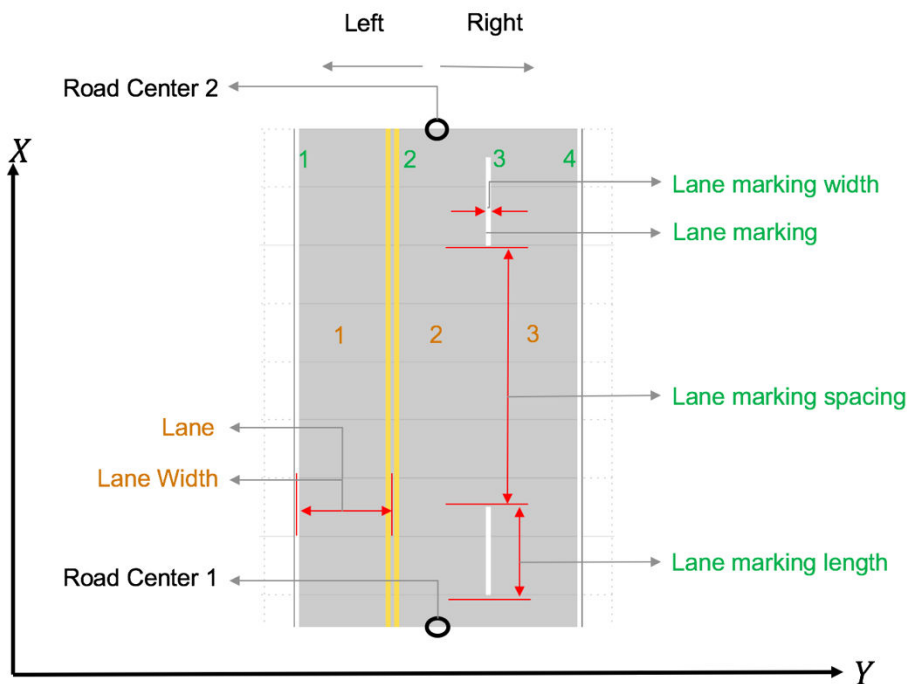
Limitations

- Lane markings in intersections are not supported.
- The number of lanes for a road is fixed. You cannot change lane specifications for a road during a simulation.
- A road can have only one lane specification.

More About

Lane Specifications

The diagram shows the components and geometric properties of roads, lanes, and lane markings.



Left and *right* are defined with respect to the road centers. Specify the road centers as a matrix input to the `road` function. The road centers create a directed line, starting from the first row to the last row of the matrix. *Left* and *right* mean left and right of the directed line. The width of the road is the sum of all lane widths plus half the widths of the left-edge and right-edge boundary markings.

The lane specification object, `lanespec`, defines the road lanes.

- The `NumLanes` property specifies the number of lanes. You must specify the number of lanes when you create this object.

- The `Width` property specifies the width of each lane.
- The `Marking` property contains the specifications of each lane marking in the road. `Marking` is an array of lane marking objects, with one object per lane. To create these objects, use the `laneMarking` function. Lane marking specifications include:
 - `Type` — Type of lane marking (solid, dashed, and so on)
 - `Width` — Lane marking width
 - `Color` — Lane marking color
 - `Length` — For dashed lanes, the length of each dashed line
 - `Spacing` — For dashed lanes, the spacing between dashes
- The `Type` property contains the lane type specifications of each lane in the road. `Type` can be a homogeneous lane type object or heterogeneous lane type array.
 - Homogeneous lane type object contain lane type specifications of all the lanes in the road.
 - Heterogeneous lane type array contain an array of lane type objects, with one object per lane.

To create these objects, use the `laneType` function. Lane type specifications include:

- `Type` — Type of lane (driving, border, and so on)
- `Color` — Lane color
- `Strength` — Strength of the lane color

See Also

`drivingScenario` | `laneBoundaryPlotter` | `laneMarking` | `laneMarkingPlotter` | `laneMarkingVertices` | `laneType` | `plotLaneBoundary` | `plotLaneMarking` | `road`

Introduced in R2018a

laneMarking

Create road lane marking object

Syntax

```
lm = laneMarking(type)
lm = laneMarking(type,Name,Value)
```

Description

`lm = laneMarking(type)` creates a default lane marking object of the specified type (solid lane, dashed lane, and so on). This object defines the characteristics of a lane boundary marking on a road. When creating roads in a driving scenario, you can use lane marking objects as inputs to the `lanespec` object. For more details, see “Lane Specifications” on page 4-502.

`lm = laneMarking(type,Name,Value)` set the properties of the lane marking object using one or more name-value pairs. For example, `laneMarking('Solid','Color','yellow')` creates a solid yellow lane marking.

Examples

Create Straight Four-Lane Road

Create a driving scenario and the road centers for a straight, 80-meter road.

```
scenario = drivingScenario;
roadCenters = [0 0; 80 0];
```

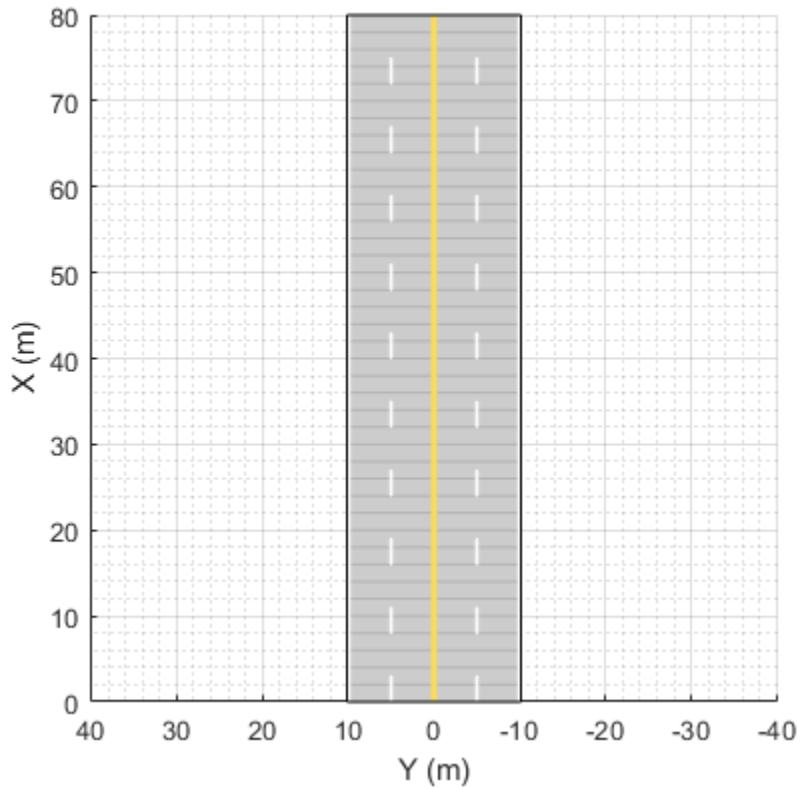
Create a `lanespec` object for a four-lane road. Use the `laneMarking` function to specify its five lane markings. The center line is double-solid and double yellow. The outermost lines are solid and white. The inner lines are dashed and white.

```
solidW = laneMarking('Solid','Width',0.3);
dashW = laneMarking('Dashed','Space',5);
```

```
doubleY = laneMarking('DoubleSolid','Color','yellow');  
lspec = lanespec([2 2],'Width',[5 5 5 5], ...  
    'Marking',[solidW dashW doubleY dashW solidW]);
```

Add the road to the driving scenario. Display the road.

```
road(scenario,roadCenters,'Lanes',lspec);  
plot(scenario)
```



Simulate Car Traveling on S-Curve

Simulate a driving scenario with one car traveling on an S-curve. Create and plot the lane boundaries.

Create the driving scenario with one road having an S-curve.

```
scenario = drivingScenario('StopTime',3);
roadcenters = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];
```

Create the lanes and add them to the road.

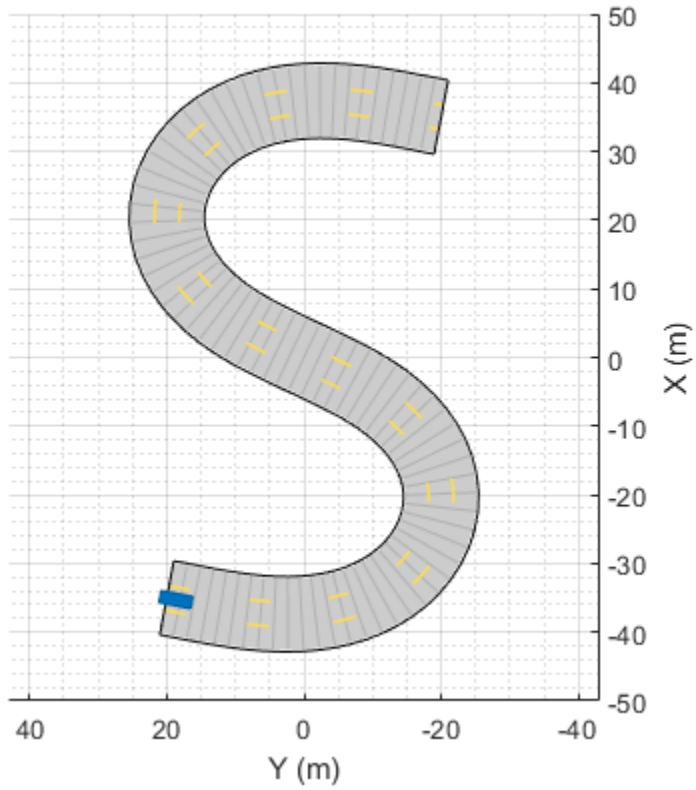
```
lm = [laneMarking('Solid','Color','w'); ...
      laneMarking('Dashed','Color','y'); ...
      laneMarking('Dashed','Color','y'); ...
      laneMarking('Solid','Color','w')];
ls = lanespec(3,'Marking',lm);
road(scenario,roadcenters,'Lanes',ls);
```

Add an ego vehicle and specify its trajectory from its speed and waypoints. The car travels at 30 meters per second.

```
car = vehicle(scenario, ...
              'ClassID',1, ...
              'Position',[-35 20 0]);
waypoints = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];
speed = 30;
trajectory(car,waypoints,speed);
```

Plot the scenario and corresponding chase plot.

```
plot(scenario)
```



`chasePlot(car)`



Run the simulation loop.

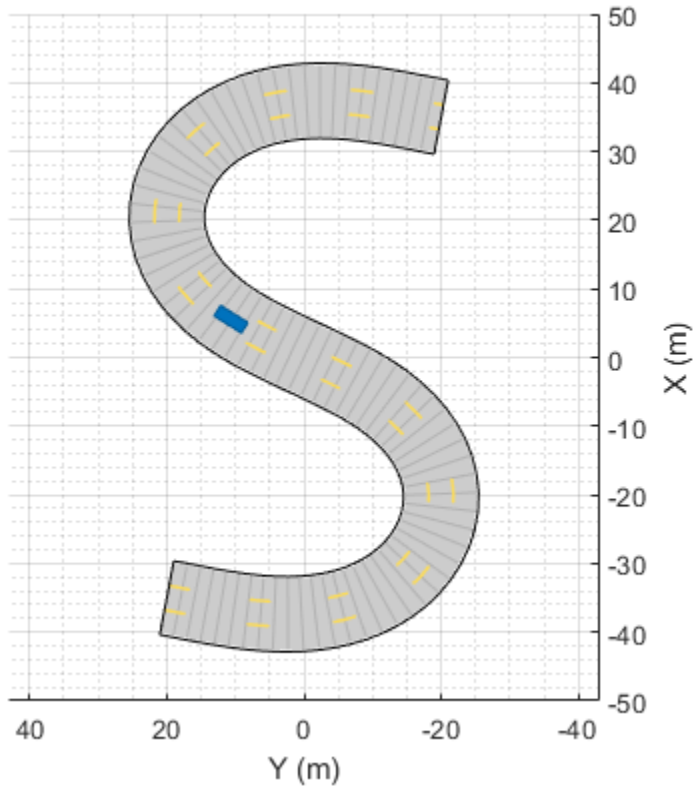
- 1 Initialize a bird's-eye plot and create an outline plotter, left-lane and right-lane boundary plotters, and a road boundary plotter.
- 2 Obtain the road boundaries and rectangular outlines.
- 3 Obtain the lane boundaries to the left and right of the vehicle.
- 4 Advance the simulation and update the plotters.

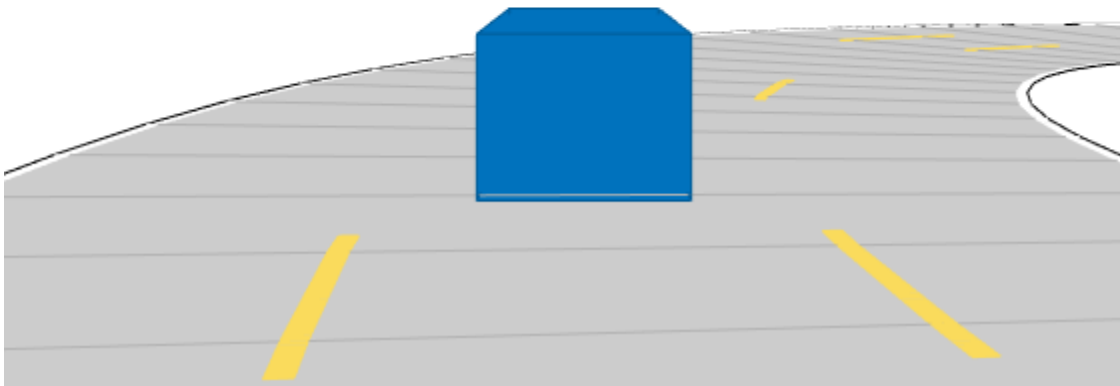
```
bep = birdsEyePlot('XLim',[-40 40], 'YLim',[-30 30]);  
olPlotter = outlinePlotter(bep);  
lblPlotter = laneBoundaryPlotter(bep, 'Color', 'r', 'LineStyle', '-');  
lbrPlotter = laneBoundaryPlotter(bep, 'Color', 'g', 'LineStyle', '-');  
rbsEdgePlotter = laneBoundaryPlotter(bep);
```

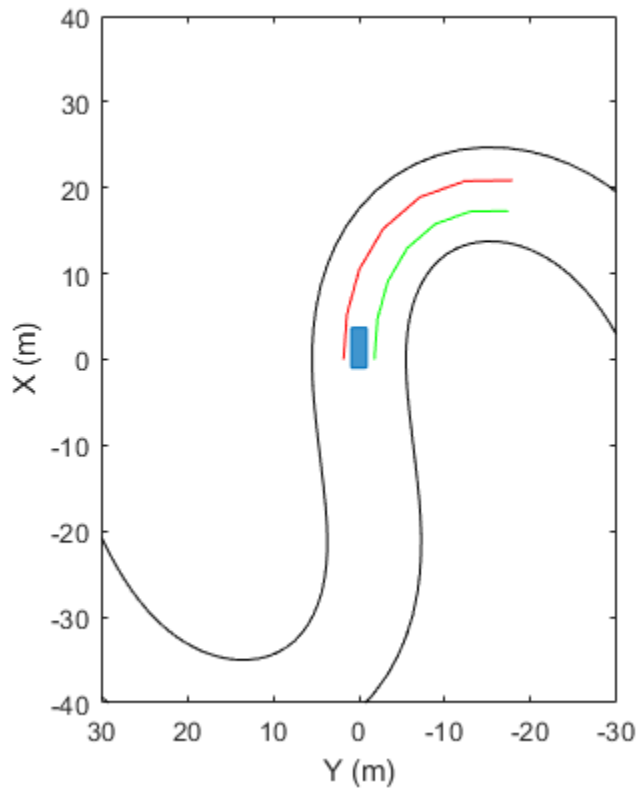
```

legend('off');
while advance(scenario)
    rbs = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    lb = laneBoundaries(car,'XDistance',0:5:30,'LocationType','Center', ...
        'AllBoundaries',false);
    plotLaneBoundary(rbsEdgePlotter,rbs)
    plotLaneBoundary(lblPlotter,{lb(1).Coordinates})
    plotLaneBoundary(lbrPlotter,{lb(2).Coordinates})
    plotOutline(olPlotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
end

```










Input Arguments

type — Type of lane marking

'Unmarked' | 'Solid' | 'Dashed' | 'DoubleSolid' | 'DoubleDashed' |
'SolidDashed' | 'DashedSolid'

Type of lane marking, specified as one of these values.

'Unmarked'	'Solid'	'Dashed'	'DoubleSolid'	'DoubleDashed'	'SolidDashed'	'DashedSolid'
No lane marking	Solid line	Dashed line	Two solid lines	Two dashed lines	Solid line on left, dashed line on right	Dashed line on left, solid line on right
						

The type of lane marking is stored in `Type`, a read-only property of the returned lane marking object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, . . . , NameN, ValueN`.

Example: `laneMarking('Dashed', 'Width', 0.25, 'Length', 5.0)` creates a lane with dashes that are 0.25 meters wide and spaced 5 meters apart.

Width — Lane marking widths

0.15 (default) | positive real scalar

Lane marking widths, specified as the comma-separated pair consisting of 'Width' and a positive real scalar. For a double lane marker, the same width is used for both lines. Units are in meters.






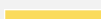

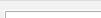
Example: 0.20

Color — Color of lane marking

[1 1 1] (white) (default) | color name | RGB triplet

Color of lane marking, specified as the comma-separated pair consisting of 'Color' and a color name or RGB triplet. For a double lane marker, the same color is used for both lines.

For a custom color, specify an RGB triplet. An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7]. Alternatively, you can specify some common colors by name. This table lists the named color options and the equivalent RGB triplet values.

Color Name	RGB Triplet	Appearance
'red'	[1 0 0]	
'green'	[0 1 0]	
'blue'	[0 0 1]	
'cyan'	[0 1 1]	
'magenta'	[1 0 1]	
'yellow'	[0.98 0.86 0.36]	
'black'	[0 0 0]	
'white'	[1 1 1]	

Example: [0.8 0.8 0.8]

Strength — Saturation strength of lane marking color

1 (default) | real scalar in the range [0, 1]

Saturation strength of lane marking color, specified as the comma-separated pair consisting of 'Strength' and a real scalar in the range [0, 1]. A value of 0 corresponds

to a marking whose color is fully unsaturated. The marking is gray. A value of 1 corresponds to a marking whose color is fully saturated. For a double lane marking, the same strength is used for both lines.

Example: 0.20

Length — Length of dash in dashed lines

3.0 (default) | positive real scalar

Length of dash in dashed lines, specified as the comma-separated pair consisting of 'Length' and a positive real scalar. For a double lane marking, the same length is used for both lines. The dash is the visible part of a dashed line. Units are in meters.

Example: 2.0

Space — Length of space between dashes in dashed lines

9.0 (default) | positive real scalar

Length of space between the end of one dash and the beginning of the next dash, specified as the comma-separated pair consisting of 'Space' and a positive real scalar. For a double lane marking, the same length is used for both lines. Units are in meters.

Example: 2.0

Output Arguments

lm — Lane marking

LaneMarking object | SolidMarking object | DashedMarking object

Lane marking, returned as a LaneMarking object, SolidMarking object, or DashedMarking object. The type of returned object depends on the type of input lane marking specified for the type input.

Input Type	Output Lane Marking	Lane Marking Properties
'Unmarked'	LaneMarking object	<ul style="list-style-type: none"> Type
'Solid'	SolidMarking object	<ul style="list-style-type: none"> Color
'DoubleSolid'		<ul style="list-style-type: none"> Width Strength Type

Input Type	Output Lane Marking	Lane Marking Properties
'Dashed'	DashedMarking object	<ul style="list-style-type: none">• Length• Space• Color• Width• Strength• Type
'DashedSolid'		
'SolidDashed'		
'DoubleDashed'		

You can set these properties when you create the lane marking object by using the corresponding name-value pairs of the `laneMarking` function. To update these properties after creation, use dot notation. For example:

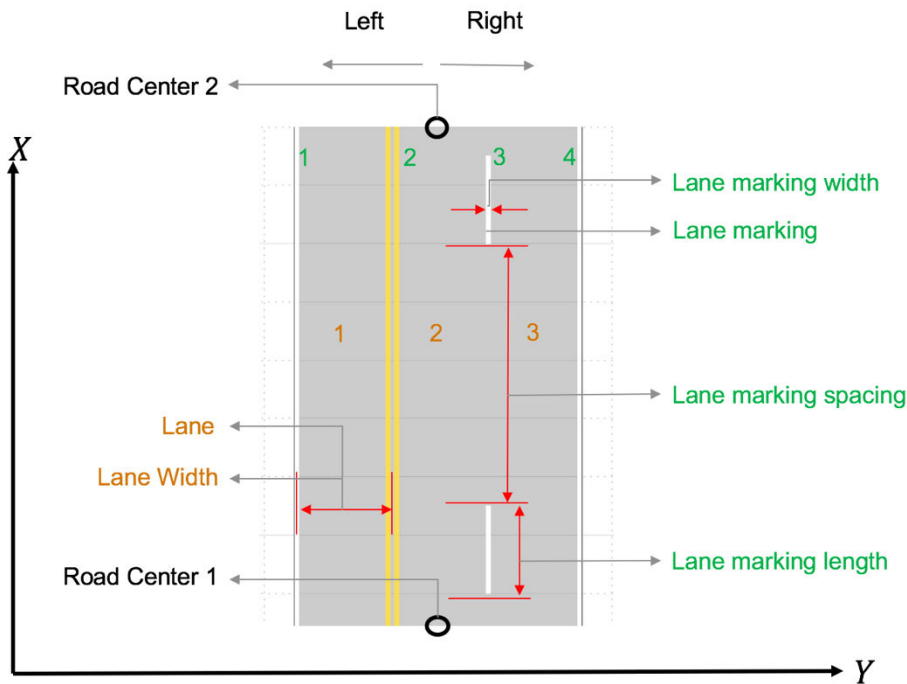
```
lm = laneMarking('Solid');  
lm.Width = 0.2;
```

You can set all properties after creation except `Type`, which is read-only.

More About

Lane Specifications

The diagram shows the components and geometric properties of roads, lanes, and lane markings.



Left and *right* are defined with respect to the road centers. Specify the road centers as a matrix input to the road function. The road centers create a directed line, starting from the first row to the last row of the matrix. Left and right mean left and right of the directed line. The width of the road is the sum of all lane widths plus half the widths of the left-edge and right-edge boundary markings.

The lane specification object, `lanespec`, defines the road lanes.

- The `NumLanes` property specifies the number of lanes. You must specify the number of lanes when you create this object.
- The `Width` property specifies the width of each lane.
- The `Marking` property contains the specifications of each lane marking in the road. `Marking` is an array of lane marking objects, with one object per lane. To create these objects, use the `laneMarking` function. Lane marking specifications include:
 - `Type` — Type of lane marking (solid, dashed, and so on)

- **Width** — Lane marking width
- **Color** — Lane marking color
- **Length** — For dashed lanes, the length of each dashed line
- **Spacing** — For dashed lanes, the spacing between dashes
- The **Type** property contains the lane type specifications of each lane in the road. **Type** can be a homogeneous lane type object or heterogeneous lane type array.
 - Homogeneous lane type object contain lane type specifications of all the lanes in the road.
 - Heterogeneous lane type array contain an array of lane type objects, with one object per lane.

To create these objects, use the `laneType` function. Lane type specifications include:

- **Type** — Type of lane (driving, border, and so on)
- **Color** — Lane color
- **Strength** — Strength of the lane color

See Also

Objects

`drivingScenario` | `lanespec`

Functions

`laneBoundaryPlotter` | `laneMarkingPlotter` | `laneMarkingVertices` | `plotLaneBoundary` | `plotLaneMarking` | `road`

Introduced in R2018a

laneType

Create road lane type object

Syntax

```
lt = laneType(type)
lt = laneType(type, Name, Value)
```

Description

`lt = laneType(type)` returns a road lane type object with properties `Type`, `Color`, and `Strength` to define different lane types for a road.

You can use this object to create driving scenarios with roads that have driving lanes, border lanes, restricted lanes, shoulder lanes, and parking lanes. You can also load this scenario into the **Driving Scenario Designer** app.

For details on the steps involved in using `laneType` function with the `drivingScenario` object and the **Driving Scenario Designer** app, see “More About” on page 4-514.

`lt = laneType(type, Name, Value)` sets the properties of the output lane type object by using one or more name-value pairs.

Examples

Add Roads That Have Different Lane Types to Driving Scenario

This example shows how to define lane types and simulate a driving scenario for a four-lane road that has different lane types.

Create a driving lane object with default property values.

```
drivingLane = laneType('Driving')
```

```
drivingLane =  
    DrivingLaneType with properties:  
  
        Type: Driving  
        Color: [0 0 0]  
        Strength: 1
```

Create a parking lane type object. Specify the color and the strength property values.

```
parkingLane = laneType('Parking','Color',[1 0 0],'Strength',0.1)
```

```
parkingLane =  
    ParkingLaneType with properties:  
  
        Type: Parking  
        Color: [1 0 0]  
        Strength: 0.1000
```

Create a three-element, heterogeneous lane type array by concatenating the driving and the parking lane type objects. The lane type array contains lane types for a four-lane road.

```
lt = [parkingLane drivingLane drivingLane parkingLane];
```

Create lane specification for a four-lane road. Add the lane type array to the lane specification.

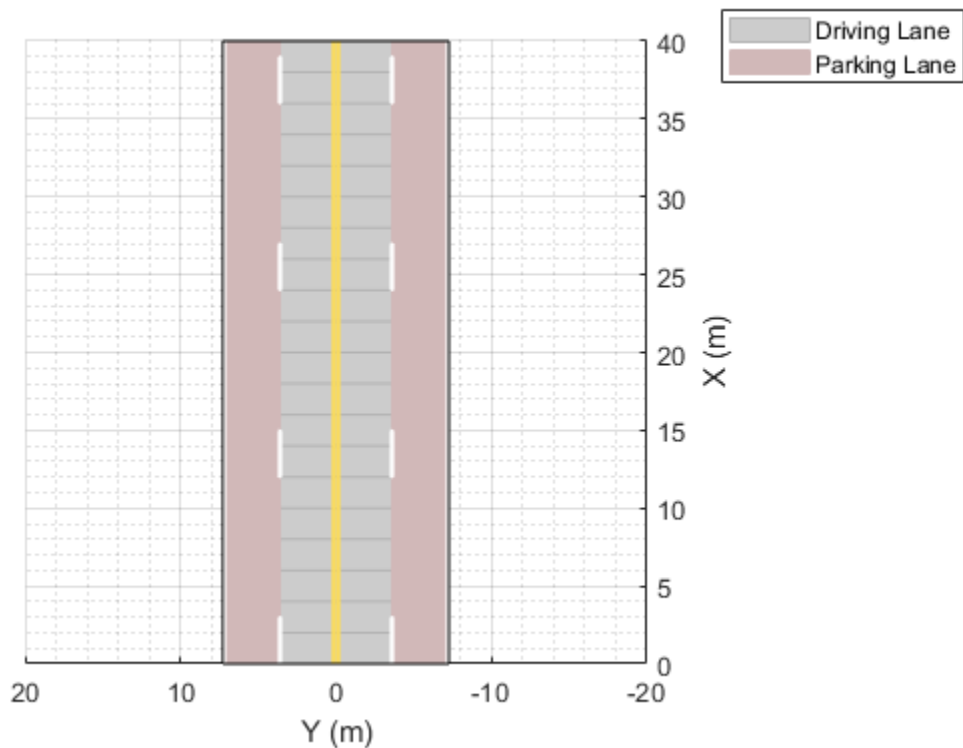
```
ls = lanespec([2 2],'Type',lt);
```

Create a driving scenario object. Add the four-lane road with lane specifications `ls` to the driving scenario.

```
scenario = drivingScenario;  
roadCenters = [0 0 0;40 0 0];  
road(scenario,roadCenters,'Lanes',ls)
```

Plot the scenario. The scenario contains the four-lane road that has two parking lanes and two driving lanes.

```
plot(scenario)  
legend('Driving Lane','Parking Lane')
```

Simulate Vehicles Travelling on Road That Has Multiple Lane Types

Create a heterogeneous lane type object array to define driving, shoulder, and border lane types for a four-lane road.

```
lt = [laneType('Shoulder') laneType('Driving') laneType('Driving') laneType('Border', 'C
```

Display the lane type object array.

```
lt
```

```
lt=1x4 object
  1x4 heterogeneous LaneType (ShoulderLaneType, DrivingLaneType, BorderLaneType) array

  Type
  Color
  Strength
```

Inspect the property values.

```
c = [{lt.Type}' {lt.Color}' {lt.Strength}'];
cell2table(c, 'VariableNames', {'Type', 'Color', 'Strength'})
```

```
ans=4x3 table
  Type          Color          Strength
  _____  _____  _____
  Shoulder    0.59    0.59    0.59         1
  Driving      0         0         0         1
  Driving      0         0         0         1
  Border      0.5         0         1         0.1
```

Pass the lane type object array as input to the `lanespec` function, and then create a lane specification object for the four-lane road.

```
lspec = lanespec([2 2], 'Type', lt);
```

Define the road centers.

```
roadCenters = [0 0 0; 40 0 0];
```

To add roads, create a driving scenario object.

```
scenario = drivingScenario('StopTime', 8);
```

Add roads with the specified road centers and lane types to the driving scenario.

```
road(scenario, roadCenters, 'Lanes', lspec);
```

Add two vehicles to the scenario. Position the vehicles on the driving lane.

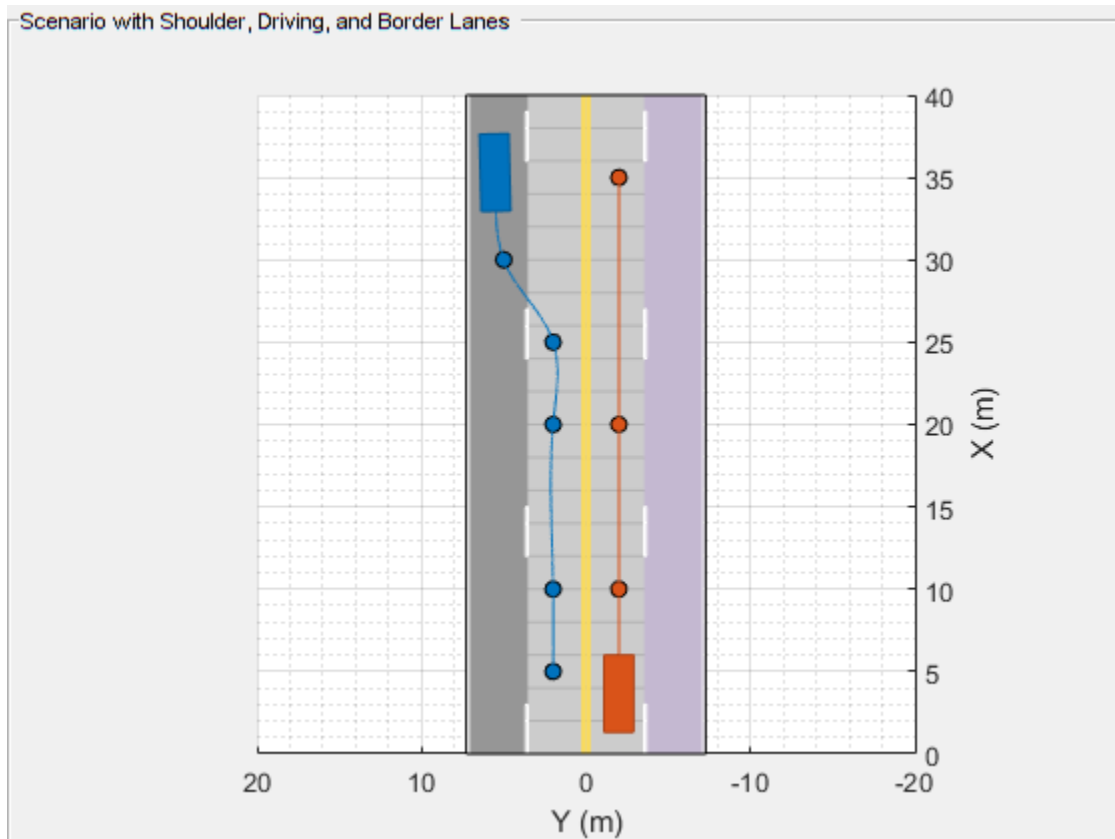
```
vehicle1 = vehicle(scenario, 'Position', [5 2 0]);
vehicle2 = vehicle(scenario, 'Position', [35 -2 0]);
```

Define the vehicle trajectories by using waypoints. Set the vehicle trajectory speeds.

```
waypoints1 = [5 2;10 2;20 2;25 2;30 5;34 5.5];  
trajectory(vehicle1,waypoints1,10)  
waypoints2 = [35 -2;20 -2;10 -2;5 -2];  
trajectory(vehicle2,waypoints2,5)
```

Plot the scenario. To advance the simulation one time step at a time, call the advance function in a loop. Pause every 0.01 second to observe the motion of the vehicles on the plot. The first vehicle travels along the trajectory in the driving lane. It drifts to the shoulder lane for emergency stopping.

```
% Create a custom figure window and define an axes object  
fig = figure;  
movegui(fig,'center');  
hView = uipanel(fig,'Position',[0 0 1 1],'Title','Scenario with Shoulder, Driving, and  
hPlt = axes(hView);  
  
% Plot the generated driving scenario along with the waypoints.  
plot(scenario,'Waypoints','on','Parent',hPlt);  
while advance(scenario)  
    pause(0.01)  
end
```



Input Arguments

type — Lane type

'Driving' | 'Border' | 'Restricted' | 'Shoulder' | 'Parking'

Lane type, specified as 'Driving', 'Border', 'Restricted', 'Shoulder', or 'Parking'.

Lane Type	Description
'Driving'	Lanes for driving

'Border'	Lanes at the road borders
'Restricted'	Lanes reserved for high occupancy vehicles
'Shoulder'	Lanes reserved for emergency stopping
'Parking'	Lanes alongside driving lanes, intended for parking vehicles

Note The lane type input sets the `Type` property of the output lane type object.

Data Types: `char` | `string`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

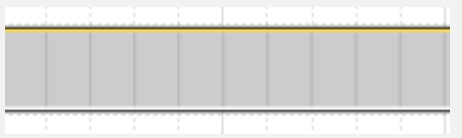
Example: `laneType('Driving', 'Color', 'r')`





Color — Lane color

RGB triplet | color name

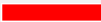




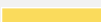


Lane color, specified as the comma-separated pair consisting of `'Color'` and an RGB triplet or color name.

Specify the RGB triplet as a three-element row vector containing the intensities of the red, green, and blue components of the color. The intensities must be in the range $[0, 1]$, for example, `[0.4 0.6 0.7]`. This table lists the RGB triplet values that specify the default colors for different lane types.

Lane Type	RGB Triplet (Default values)	Appearance
'Driving'	<code>[0.8 0.8 0.8]</code>	

'Border'	[0.72 0.72 0.72]	
'Restricted'	[0.59 0.56 0.62]	
'Shoulder'	[0.59 0.59 0.59]	
'Parking'	[0.28 0.28 0.28]	

Alternatively, you can specify some common colors by name. This table lists the named color options and the equivalent RGB triplet values.

Color Name	RGB Triplet	Appearance
'red'	[1 0 0]	
'green'	[0 1 0]	
'blue'	[0 0 1]	
'cyan'	[0 1 1]	
'magenta'	[1 0 1]	
'yellow'	[0.98 0.86 0.36]	
'black'	[0 0 0]	
'white'	[1 1 1]	

Note Use the lane color name-value pair to set the Color property of the output lane type object.

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

Strength — Strength of lane color

1 (default) | real scalar in the range [0, 1]

Strength of lane color, specified as a comma-separated pair consisting of 'Strength' and a real scalar in the range [0, 1]. A value of 0 desaturates the color and the lane color appears gray. A value of 1 fully saturates the color and the lane color is the pure color. You can vary the strength value to modify the level of saturation.

Note Use the strength of lane color name-value pair to set the Strength property of the lane type object.

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

Output Arguments

lt — Lane type

DrivingLaneType object | BorderLaneType object | RestrictedLaneType object | ShoulderLaneType object | ParkingLaneType object

Lane type, returned as a

- DrivingLaneType object
- BorderLaneType object
- RestrictedLaneType object
- ShoulderLaneType object
- ParkingLaneType object

The returned object `lt` depends on the value of the input type.

type	lt
'Driving'	DrivingLaneType object
'Border'	BorderLaneType object

'Restricted'	RestrictedLaneType object
'Shoulder'	ShoulderLaneType object
'Parking'	ParkingLaneType object

You can create a heterogeneous LaneType array by concatenating these different lane type objects.

More About

Create Driving Scenario With Roads That Have Multiple Lane Types

You can add roads that have multiple lane types to the driving scenario by following these steps

- 1 Create an empty `drivingScenario` object.
- 2 Create a lane type object that defines different lane types on the road by using `laneType`.
- 3 Use lane type object as input to the `lanespec` object and define lane specifications for the road.
- 4 Use `lanespec` object as input to the `road` function and add roads that have the specified lane types to the driving scenario.

You can use the `plot` function to visualize the driving scenario.

You can also import a driving scenario containing roads that have different lane types into the **Driving Scenario Designer** app. To import a `drivingScenario` object named `scenario` into the app, use the syntax `drivingScenarioDesigner(scenario)`. In the scenarios, you can:

- Add or edit the road centers.
- Add actors and define actor trajectories.
- Mount sensors on the ego vehicle and simulate detection of actors and lane boundaries.

Note Editing the lane parameters resets all the lanes in the imported road to lane type 'Driving' with the default property values.

See Also

Functions

road | roadNetwork

Objects

drivingScenario | lanespec

Introduced in R2019b

laneMarkingVertices

Package:

Lane marking vertices and faces in driving scenario

Syntax

```
[lmv,lmf] = laneMarkingVertices(scenario)  
[lmv,lmf] = laneMarkingVertices(ac)
```

Description

`[lmv,lmf] = laneMarkingVertices(scenario)` returns the lane marking vertices, `lmv`, and lane marking faces, `lmf`, contained in driving scenario `scenario`. The `lmf` and `lmv` outputs are in the world coordinates of `scenario`. Use lane marking vertices and faces to display lane markings using the `laneMarkingPlotter` function with a bird's-eye plot.

`[lmv,lmf] = laneMarkingVertices(ac)` returns lane marking vertices and faces in the coordinates of driving scenario actor `ac`.

Examples

Display Lane Markings in Car and Pedestrian Scenario

Create a driving scenario containing a car and pedestrian on a straight road. Then, create and display the lane markings of the road on a bird's-eye plot.

Create an empty driving scenario.

```
scenario = drivingScenario;
```

Create a straight, 25-meter road segment with two travel lanes in one direction.

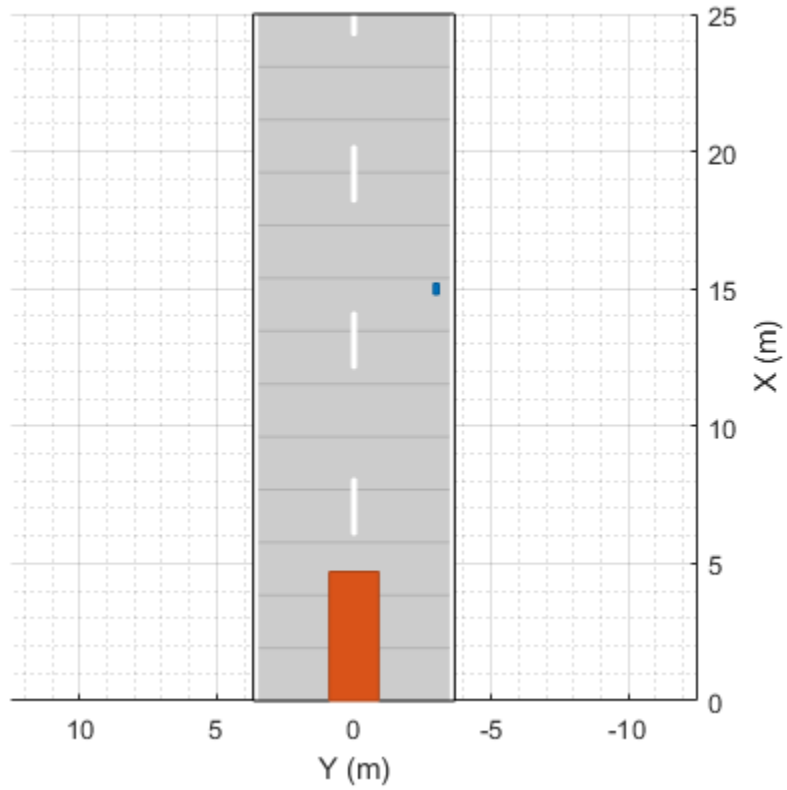
```
lm = [laneMarking('Solid')
      laneMarking('Dashed','Length',2,'Space',4)
      laneMarking('Solid')];
l = lanespec(2,'Marking',lm);
road(scenario,[0 0 0; 25 0 0],'Lanes',l);
```

Add to the driving scenario a pedestrian crossing the road at 1 meter per second and a car following the road at 10 meters per second.

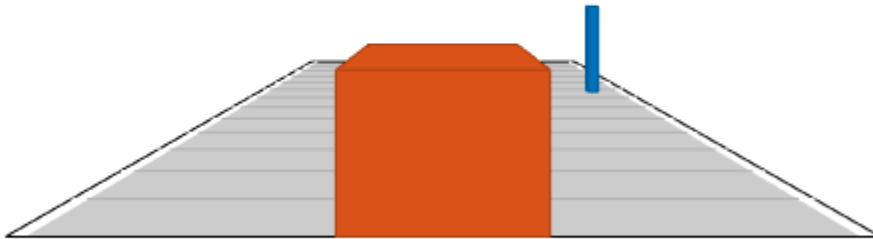
```
ped = actor(scenario,'Length',0.2,'Width',0.4,'Height',1.7);
car = vehicle(scenario);
trajectory(ped,[15 -3 0; 15 3 0],1);
trajectory(car,[car.RearOverhang 0 0; 25-car.Length+car.RearOverhang 0 0],10);
```

Display the scenario and corresponding chase plot.

```
plot(scenario)
```



`chasePlot(car)`

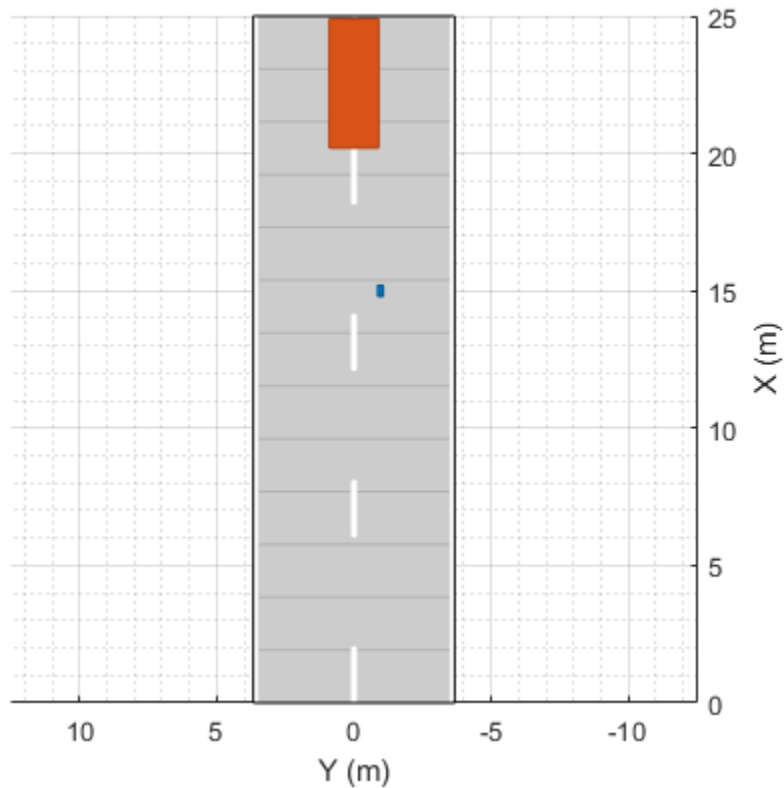


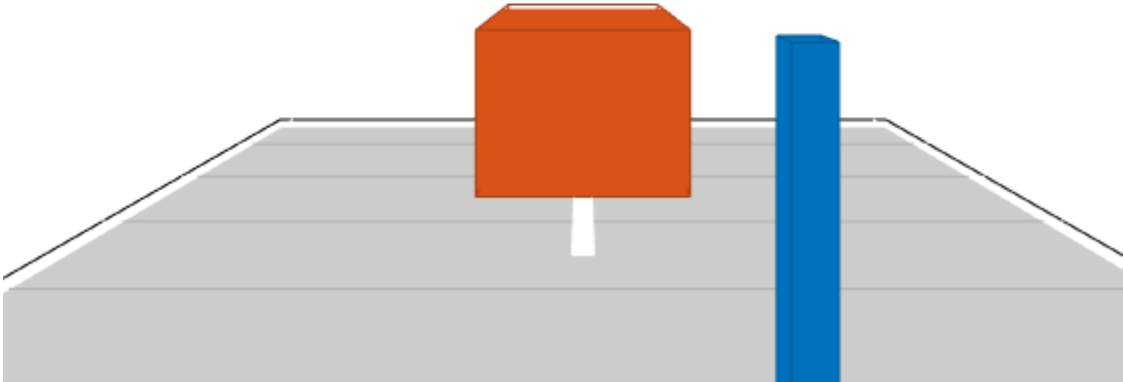
Run the simulation.

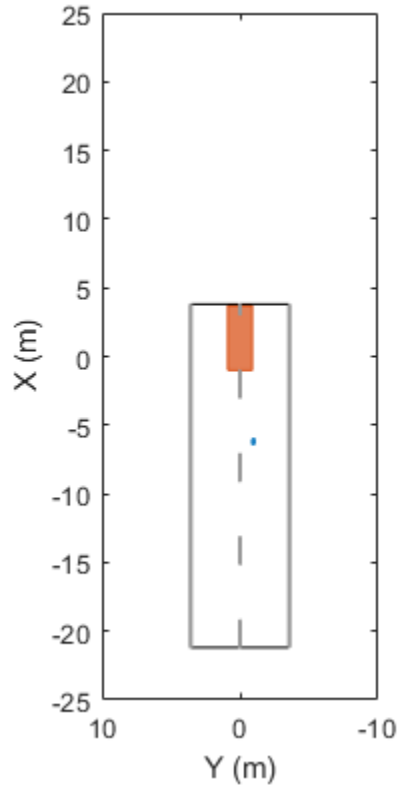
- 1 Create a bird's-eye plot.
- 2 Create an outline plotter, lane boundary plotter, and lane marking plotter for the bird's-eye plot.
- 3 Obtain the road boundaries and target outlines.
- 4 Obtain the lane marking vertices and faces.
- 5 Display the lane boundaries and lane markers.
- 6 Run the simulation loop.

```
bep = birdsEyePlot('XLim',[-25 25], 'YLim',[-10 10]);  
olPlotter = outlinePlotter(bep);
```

```
lbPlotter = laneBoundaryPlotter(bep);  
lmPlotter = laneMarkingPlotter(bep, 'DisplayName', 'Lanes');  
legend('off');  
while advance(scenario)  
    rb = roadBoundaries(car);  
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);  
    [lmv,lmf] = laneMarkingVertices(car);  
    plotLaneBoundary(lbPlotter,rb);  
    plotLaneMarking(lmPlotter,lmv,lmf);  
    plotOutline(olPlotter,position,yaw,length,width, ...  
        'OriginOffset',originOffset,'Color',color);  
end
```







Input Arguments

scenario — Driving scenario

`drivingScenario` object

Driving scenario, specified as a `drivingScenario` object.

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

Output Arguments

lmv — Lane marking vertices

real-valued matrix

Lane marking vertices, returned as a real-valued matrix. Each row of the matrix represents the (x, y, z) coordinates of a vertex.

lmf — Lane marking faces

real-valued matrix

Lane marking faces, returned as a real-valued matrix. Each row of the matrix contains the vertex connections that define a face for one lane marking. For more details, see “Faces” (MATLAB).

Algorithms

This function uses the `patch` function to define lane marking vertices and faces.

See Also

Objects

`drivingScenario`

Functions

`actor` | `laneMarking` | `laneMarkingPlotter` | `patch` | `plotLaneMarking` | `road` | `vehicle`

Introduced in R2018a

laneBoundaries

Package:

Get lane boundaries of actor lane

Syntax

```
lbdry = laneBoundaries(ac)  
lbdry = laneBoundaries(ac,Name,Value)
```

Description

`lbdry = laneBoundaries(ac)` returns the lane boundaries, `lbdry`, of the lane in which the ego vehicle actor, `ac`, is traveling. The lane boundaries are in the coordinate system of the ego vehicle.

`lbdry = laneBoundaries(ac,Name,Value)` specifies options using one or more name-value pairs. For example, `laneBoundaries(ac,'AllLaneBoundaries',true)` returns all lane boundaries of the road on which the ego vehicle actor is traveling.

Examples

Simulate Car Traveling on S-Curve

Simulate a driving scenario with one car traveling on an S-curve. Create and plot the lane boundaries.

Create the driving scenario with one road having an S-curve.

```
scenario = drivingScenario('StopTime',3);  
roadcenters = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];
```

Create the lanes and add them to the road.

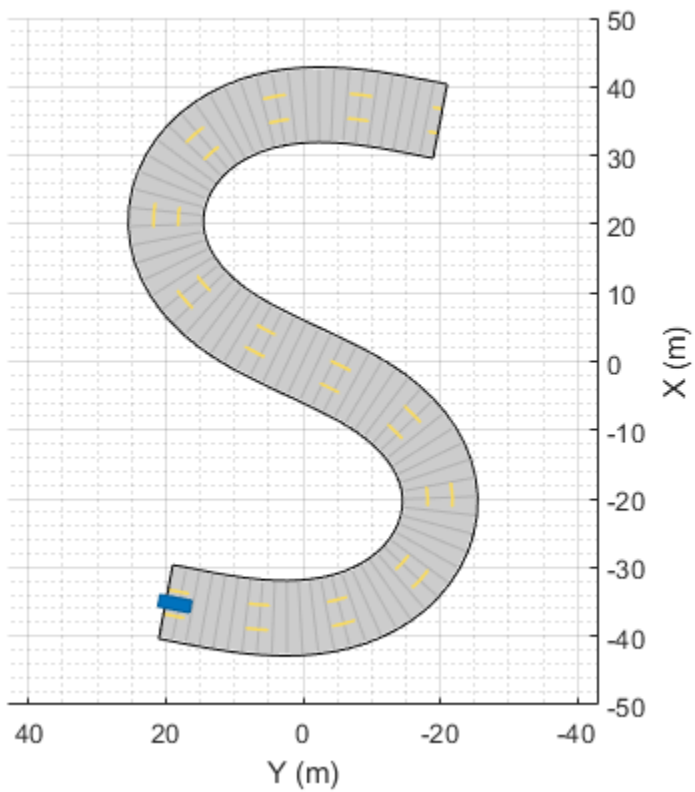
```
lm = [laneMarking('Solid','Color','w'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Dashed','Color','y'); ...  
      laneMarking('Solid','Color','w')];  
ls = lanespec(3,'Marking',lm);  
road(scenario,roadcenters,'Lanes',ls);
```

Add an ego vehicle and specify its trajectory from its speed and waypoints. The car travels at 30 meters per second.

```
car = vehicle(scenario, ...  
             'ClassID',1, ...  
             'Position',[-35 20 0]);  
waypoints = [-35 20 0; -20 -20 0; 0 0 0; 20 20 0; 35 -20 0];  
speed = 30;  
trajectory(car,waypoints,speed);
```

Plot the scenario and corresponding chase plot.

```
plot(scenario)
```



`chasePlot(car)`



Run the simulation loop.

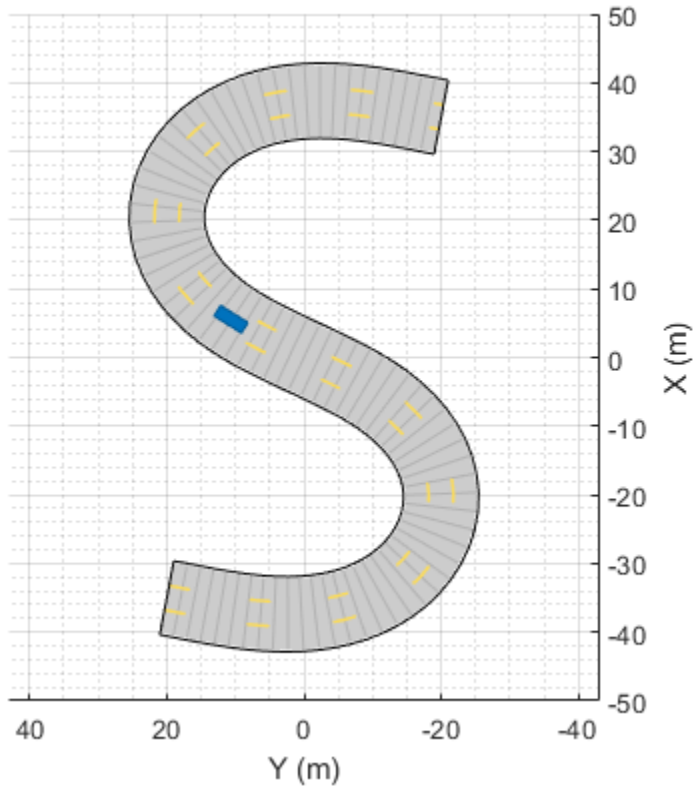
- 1 Initialize a bird's-eye plot and create an outline plotter, left-lane boundary plotters, and a road boundary plotter.
- 2 Obtain the road boundaries and rectangular outlines.
- 3 Obtain the lane boundaries to the left and right of the vehicle.
- 4 Advance the simulation and update the plotters.

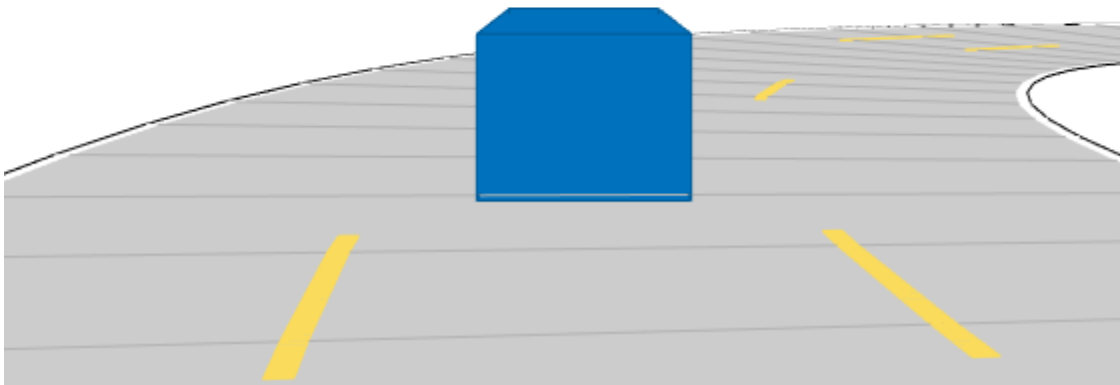
```
bep = birdsEyePlot('XLim',[-40 40], 'YLim',[-30 30]);  
olPlotter = outlinePlotter(bep);  
lblPlotter = laneBoundaryPlotter(bep, 'Color', 'r', 'LineStyle', '-');  
lbrPlotter = laneBoundaryPlotter(bep, 'Color', 'g', 'LineStyle', '-');  
rbsEdgePlotter = laneBoundaryPlotter(bep);
```

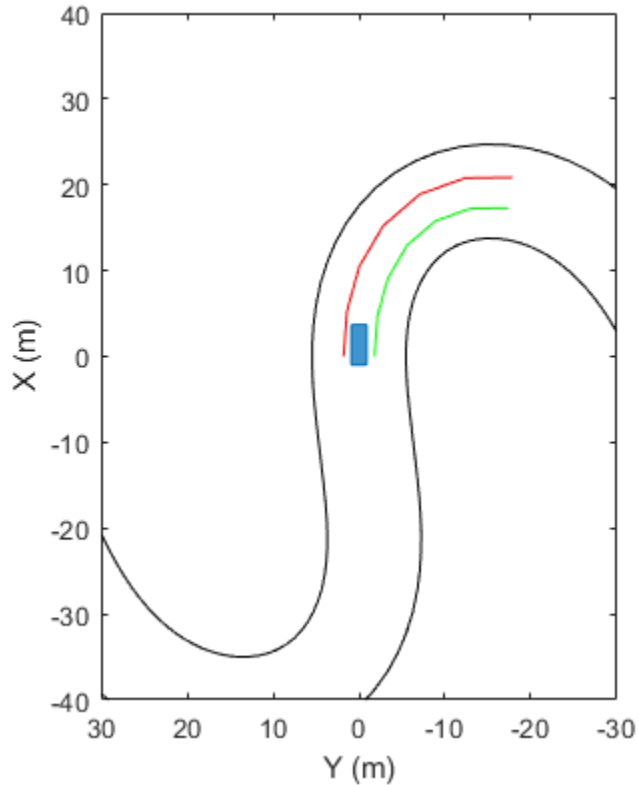
```

legend('off');
while advance(scenario)
    rbs = roadBoundaries(car);
    [position,yaw,length,width,originOffset,color] = targetOutlines(car);
    lb = laneBoundaries(car,'XDistance',0:5:30,'LocationType','Center', ...
        'AllBoundaries',false);
    plotLaneBoundary(rbsEdgePlotter,rbs)
    plotLaneBoundary(lblPlotter,{lb(1).Coordinates})
    plotLaneBoundary(lbrPlotter,{lb(2).Coordinates})
    plotOutline(olPlotter,position,yaw,length,width, ...
        'OriginOffset',originOffset,'Color',color)
end

```







Input Arguments

ac — Actor

Actor object | Vehicle object

Actor belonging to a `drivingScenario` object, specified as an `Actor` or `Vehicle` object. To create these objects, use the `actor` and `vehicle` functions, respectively.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `'LocationType','center'` specifies that lane boundaries are centered on the lane markings.

XDistance — Distances ahead of ego vehicle at which to compute lane boundaries

0 (default) | *N*-element real-valued vector

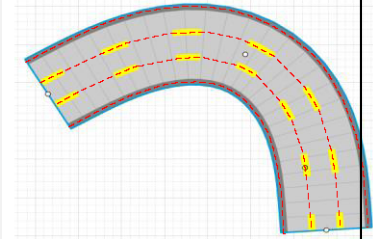
Distances ahead of the ego vehicle at which to compute the lane boundaries, specified as the comma-separated pair consisting of `'XDistance'` and an *N*-element real-valued vector. *N* is the number of distance values.

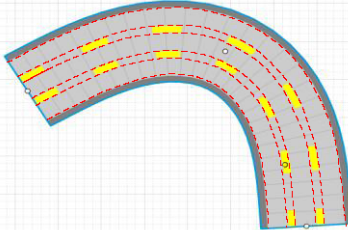
Example: `1:0.1:10` computes the lane boundaries every 0.1 meters at a range from 1 to 10 meters ahead of the ego vehicle.

LocationType — Lane boundary location

'Center' (default) | 'Inner'

Lane boundary location on the lane markings, specified as the comma-separated pair consisting of `'LocationType'` and one of the options in this table.

Lane Boundary Location	Description	Example
'Center'	Lane boundaries are centered on the lane markings.	A three-lane road has four lane boundaries: one per lane marking. 

Lane Boundary Location	Description	Example
'Inner'	Lane boundaries are placed at the inner edges of the lane markings.	<p>A three-lane road has six lane boundaries: two per lane.</p> 

AllBoundaries — Return all lane boundaries on road

false (default) | true

Return all lane boundaries on which the ego vehicle is traveling, specified as the comma-separated pair consisting of 'Value' and false or true.

Lane boundaries are returned from left to right relative to the ego vehicle. When 'AllBoundaries' is false, only the lane boundaries to the left and right of the ego vehicle are returned.

Output Arguments

lbdry — Lane boundaries

array of lane boundary structures

Lane boundaries, returned as an array of lane boundary structures. This table shows the fields for each structure.

Field	Description
-------	-------------

Coordinates	Lane boundary coordinates, specified as a real-valued N -by-3 matrix, where N is the number of lane boundaries. Lane boundary coordinates define the position of points on the boundary at distances specified by the 'XDistance' name-value pair argument of the laneBoundaries function. In addition, a set of boundary coordinates are inserted into the matrix at zero distance. Units are in meters.
Curvature	Lane boundary curvature at each row of the Coordinates matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per meter.
CurvatureDerivative	Derivative of lane boundary curvature at each row of the Coordinates matrix, specified as a real-valued N -by-1 vector. N is the number of lane boundaries. Units are in radians per square meter.
HeadingAngle	Initial lane boundary heading angle, specified as a real scalar. The heading angle of the lane boundary is relative to the ego vehicle heading. Units are in degrees.
LateralOffset	Distance of the lane boundary from the ego vehicle position, specified as a real scalar. An offset to a lane boundary to the left of the ego vehicle is positive. An offset to the right of the ego vehicle is negative. Units are in meters.

BoundaryType	<p>Type of lane boundary marking, specified as one of these values:</p> <ul style="list-style-type: none"> • 'Unmarked' — No physical lane marker exists • 'Solid' — Single unbroken line • 'Dashed' — Single line of dashed lane markers • 'DoubleSolid' — Two unbroken lines • 'DoubleDashed' — Two dashed lines • 'SolidDashed' — Solid line on the left and a dashed line on the right • 'DashedSolid' — Dashed line on the left and a solid line on the right
Strength	<p>Saturation strength of the lane boundary marking, specified as a real scalar from 0 to 1. A value of 0 corresponds to a marking whose color is fully unsaturated. The marking appears gray. A value of 1 corresponds to a marking whose color is fully saturated.</p>
Width	<p>Lane boundary width, specified as a positive real scalar. In a double-line lane marker, the same width is used for both lines and for the space between lines. Units are in meters.</p>
Length	<p>Length of dash in dashed lines, specified as a positive real scalar. In a double-line lane marker, the same length is used for both lines.</p>
Space	<p>Length of space between dashes in dashed lines, specified as a positive real scalar. In a dashed double-line lane marker, the same space is used for both lines.</p>

See Also

Objects

drivingScenario | lanespec

Functions

laneBoundaryPlotter | laneMarking | laneMarkingPlotter | plotLaneBoundary
| plotLaneMarking | road

Introduced in R2018a

clothoidLaneBoundary

Clothoid-shaped lane boundary model

Description

A `clothoidLaneBoundary` object contains information about a clothoid-shaped lane boundary model. A clothoid is a type of curve whose rate of change of curvature varies linearly with distance.

Creation

Syntax

```
bdry = clothoidLaneBoundary  
bdry = clothoidLaneBoundary(Name,Value)
```

Description

`bdry = clothoidLaneBoundary` creates a clothoid lane boundary model, `bdry` with default property values.

`bdry = clothoidLaneBoundary(Name,Value)` sets properties using one or more name-value pairs. For example, `clothoidLaneBoundary('BoundaryType','Solid')` creates a clothoid lane boundary model with solid lane boundaries. Enclose each property name in quotes.

Properties

Curvature — Lane boundary curvature

0 (default) | real scalar

Lane boundary curvature, specified as a real scalar. This property represents the rate of change of lane boundary direction with respect to distance. Units are in degrees per meter.

Example: -1.0

Data Types: single | double

CurvatureDerivative — Derivative of lane boundary curvature

0 (default) | real scalar

Derivative of lane boundary curvature, specified as a real scalar. This property represents the rate of change of lane curvature with respect to distance. Units are in degrees per meter squared.

Example: -0.01

Data Types: single | double

CurveLength — Length of lane boundary along road

0 (default) | nonnegative real scalar

Length of the lane boundary along the road, specified as a nonnegative real scalar. Units are in meters.

Example: 25

Data Types: single | double

HeadingAngle — Initial lane boundary heading

0 (default) | real scalar

Initial lane boundary heading, specified as a real scalar. The heading angle of the lane boundary is relative to the heading of the ego vehicle. Units are in degrees.

Example: 10

Data Types: single | double

LateralOffset — Distance of lane boundary

0 (default) | real scalar

Distance of the lane boundary from the ego vehicle position, specified as a real scalar. A lane boundary offset to the left of the ego vehicle is positive. An offset to the right of the ego vehicle is negative. Units are in meters.

Example: -1.2

Data Types: single | double

BoundaryType — Type of lane boundary marking

'Unmarked' (default) | 'Solid' | 'Dashed' | 'DoubleSolid' | 'DoubleDashed' | 'SolidDashed' | 'DashedSolid'

Type of lane boundary marking, specified as one of these values.

'Unmarked'	'Solid'	'Dashed'	'DoubleSolid'	'DoubleDashed'	'SolidDashed'	'DashedSolid'
No lane marking	Solid line	Dashed line	Two solid lines	Two dashed lines	Solid line on left, dashed line on right	Dashed line on left, solid line on right
						

Strength — Visibility of lane boundary marking

1 (default) | real scalar in the range [0, 1]

Visibility of lane marking, specified as a real scalar in the range [0, 1]. A value of 0 corresponds to a marking that is not visible. A value of 1 corresponds to a marking that is completely visible. For a double lane marking, the same strength is used for both lines.

Example: 0.9

Data Types: single | double

XExtent — Extent of lane boundary marking along X-axis

[0 Inf] (default) | real-valued vector of the form [X_{\min} X_{\max}]

Extent of the lane boundary marking along the X-axis, specified as a real-valued vector of the form [X_{\min} X_{\max}]. Units are in meters. The X-axis runs vertically and is positive in the forward direction of the ego vehicle.

Example: [0 100]

Data Types: single | double

Width — Width of lane boundary marking

0 (default) | nonnegative real scalar

Width of lane boundary marking, specified as a nonnegative real scalar. For a double lane marking, this value applies to the width of each lane marking and to the distance between those markings. Units are in meters.

Example: 0.15

Data Types: single | double

Object Functions

`computeBoundaryModel` Compute lane boundary points from clothoid lane boundary model

Examples

Create Clothoid Lane Boundaries

Create clothoid curves to represent left and right lane boundaries. Then, plot the curves.

Create the left boundary.

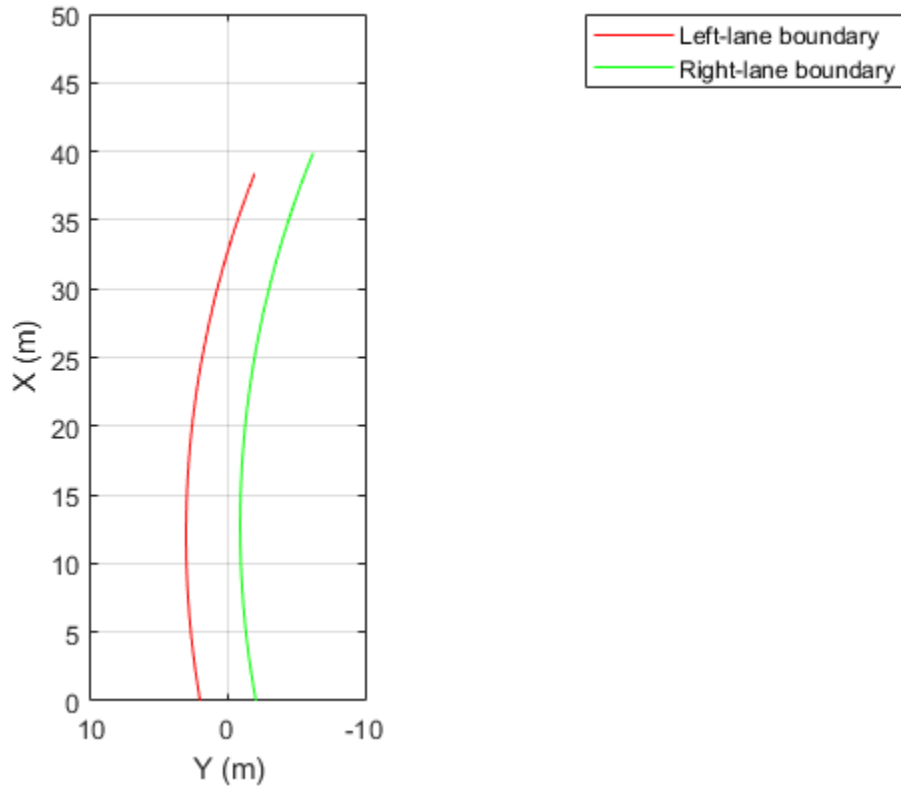
```
lb = clothoidLaneBoundary('BoundaryType','Solid', ...  
    'Strength',1,'Width',0.2,'CurveLength',40, ...  
    'Curvature',-0.8,'LateralOffset',2,'HeadingAngle',10);
```

Create the right boundary with almost identical properties.

```
rb = lb;  
rb.LateralOffset = -2;
```

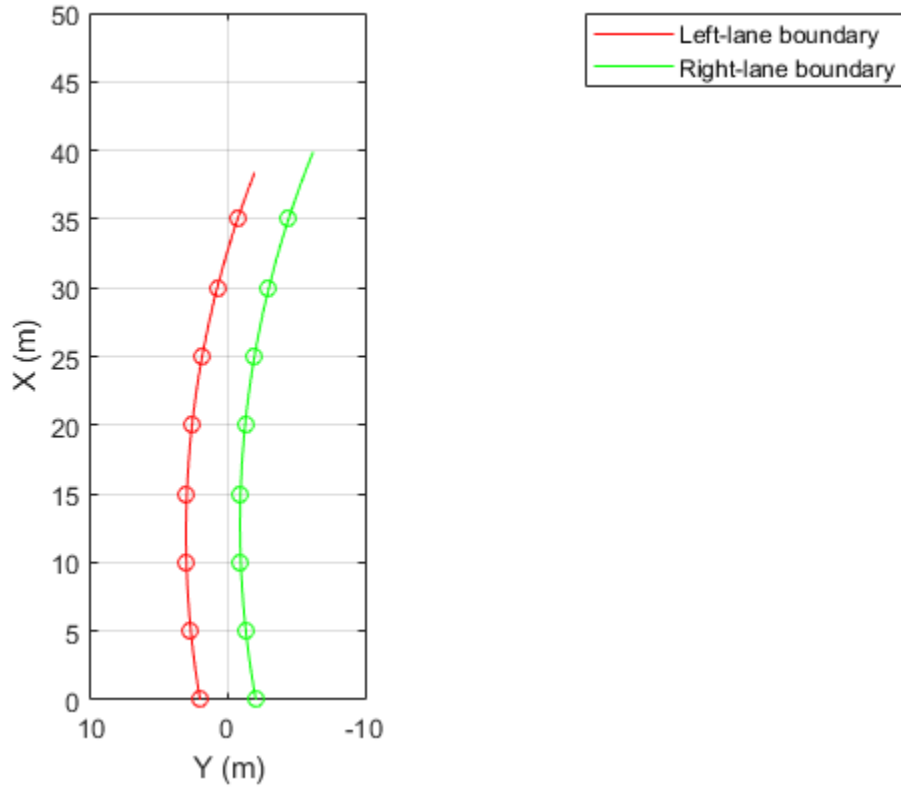
Create a bird's-eye plot. Then, create the lane boundary plotters and plot the boundaries.

```
bep = birdsEyePlot('XLimits',[0 50],'YLimits',[-10 10]);  
lbPlotter = laneBoundaryPlotter(bep,'DisplayName','Left-lane boundary','Color','r');  
rbPlotter = laneBoundaryPlotter(bep,'DisplayName','Right-lane boundary','Color','g');  
plotLaneBoundary(lbPlotter,lb)  
plotLaneBoundary(rbPlotter,rb);  
grid  
hold on
```



Plot the coordinates of selected points along the boundaries.

```
x = 0:5:50;  
yl = computeBoundaryModel(lb,x);  
yr = computeBoundaryModel(rb,x);  
plot(x,yl,'ro')  
plot(x,yr,'go')  
hold off
```



See Also

Objects

lanespec

Functions

laneBoundaries | laneBoundaryPlotter | laneMarking | plotLaneBoundary

Introduced in R2018a

computeBoundaryModel

Compute lane boundary points from clothoid lane boundary model

Syntax

```
yworld = computeBoundaryModel(boundary, xworld)
```

Description

`yworld = computeBoundaryModel(boundary, xworld)` returns the y-coordinates of lane boundary points, `yworld`, derived from a lane boundary, `boundary`, at points specified by the x-coordinates, `xworld`. All points are in world coordinates.

Examples

Create Clothoid Lane Boundaries

Create clothoid curves to represent left and right lane boundaries. Then, plot the curves.

Create the left boundary.

```
lb = clothoidLaneBoundary('BoundaryType', 'Solid', ...
    'Strength', 1, 'Width', 0.2, 'CurveLength', 40, ...
    'Curvature', -0.8, 'LateralOffset', 2, 'HeadingAngle', 10);
```

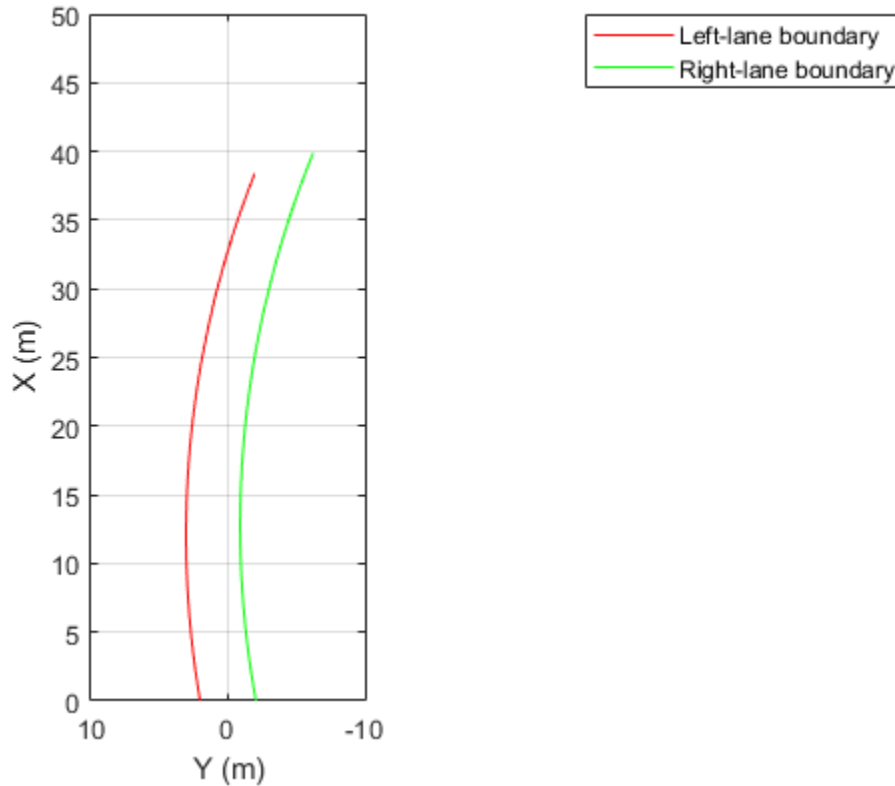
Create the right boundary with almost identical properties.

```
rb = lb;
rb.LateralOffset = -2;
```

Create a bird's-eye plot. Then, create the lane boundary plotters and plot the boundaries.

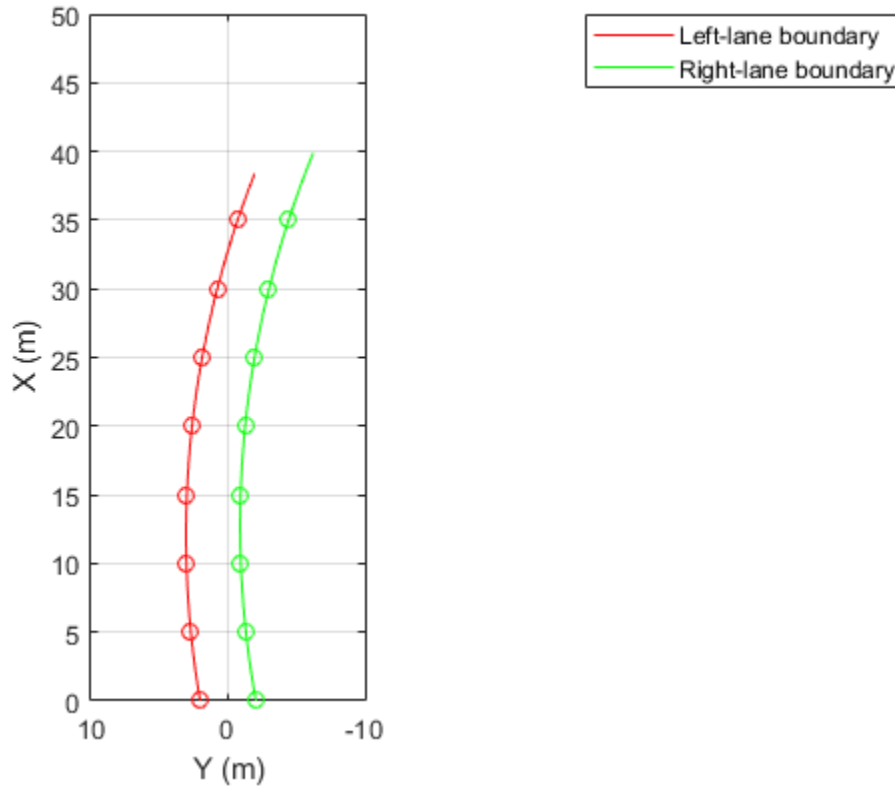
```
bep = birdsEyePlot('XLimits', [0 50], 'YLimits', [-10 10]);
lbPlotter = laneBoundaryPlotter(bep, 'DisplayName', 'Left-lane boundary', 'Color', 'r');
rbPlotter = laneBoundaryPlotter(bep, 'DisplayName', 'Right-lane boundary', 'Color', 'g');
```

```
plotLaneBoundary(lbPlotter,lb)  
plotLaneBoundary(rbPlotter,rb);  
grid  
hold on
```



Plot the coordinates of selected points along the boundaries.

```
x = 0:5:50;  
yl = computeBoundaryModel(lb,x);  
yr = computeBoundaryModel(rb,x);  
plot(x,yl,'ro')  
plot(x,yr,'go')  
hold off
```



Input Arguments

boundary — Lane boundary model

clothoidLaneBoundary object

Lane boundary model, specified as a clothoidLaneBoundary object.

xworld — x-world coordinates

real-valued vector of length N

x-world coordinates, specified as a real-valued vector of length N , where N is the number of coordinates.

Example: 2:2.5:100

Data Types: single | double

Output Arguments

yworld — y-world coordinates

real-valued vector of length N

y-world coordinates, returned as a real-valued vector of length N , where N is the number of coordinates. The length and data type of `yWorld` are the same as for `xWorld`.

Data Types: single | double

See Also

`clothoidLaneBoundary` | `laneBoundaries`

Introduced in R2018a

geoplayer

Visualize streaming geographic map data

Description

A `geoplayer` object is a geographic player that displays the streaming coordinates of a driving route on a map.

- To display the driving route of a vehicle, use the `plotRoute` function.
- To display the position of a vehicle as it drives along a route, use the `plotPosition` function.
- To change the underlying map, or basemap, of the `geoplayer` object, update the `Basemap` property of the object. For more information, see “Custom Basemaps” on page 4-568.

Creation

Syntax

```
player = geoplayer(latCenter, lonCenter)
player = geoplayer(latCenter, lonCenter, zoomLevel)
player = geoplayer( ____, Name, Value)
```

Description

`player = geoplayer(latCenter, lonCenter)` creates a geographic player, centered at latitude coordinate `latCenter` and longitude coordinate `lonCenter`.

`player = geoplayer(latCenter, lonCenter, zoomLevel)` creates a geographic player with a map magnification specified by `zoomLevel`.

`player = geoplayer(____, Name, Value)` sets properties on page 4-548 using one or more name-value pairs, in addition to specifying input arguments from previous syntaxes.

For example, `geoplayer(45,0,'HistoryDepth',5)` creates a geographic player centered at the latitude-longitude coordinate (45, 0), and sets the `HistoryDepth` property such that the player displays the five previous geographic coordinates.

Input Arguments

latCenter — Latitude coordinate

real scalar in the range (-90, 90)

Latitude coordinate at which the geographic player is centered, specified as a real scalar in the range (-90, 90).

Data Types: `single` | `double`

lonCenter — Longitude coordinate

real scalar in the range [-180, 180]

Longitude coordinate at which the geographic player is centered, specified as a real scalar in the range [-180, 180].

Data Types: `single` | `double`

zoomLevel — Magnification

15 | integer in the range [0, 25]

Magnification of the geographic player, specified as an integer in the range [0, 25]. This magnification occurs on a logarithmic scale with base 2. Increasing `zoomLevel` by one doubles the map scale.

Properties

HistoryDepth — Number of previous geographic coordinates to display

0 (default) | nonnegative integer | `Inf`

Number of previous geographic coordinates to display, specified as a nonnegative integer or `Inf`. A value of 0 displays only the current geographic coordinates. A value of `Inf` displays all geographic coordinates previously plotted using the `plotPosition` function.

You can set this property only when you create the object. After you create the object, this property is read-only.

HistoryStyle — Style of displayed geographic coordinates

'point' (default) | 'line'

Style of displayed geographic coordinates, specified as one of these values:

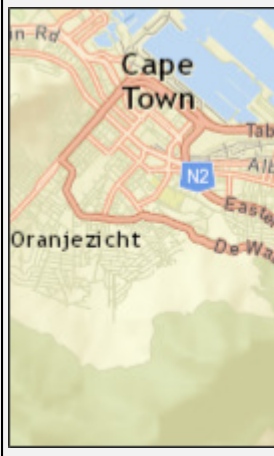
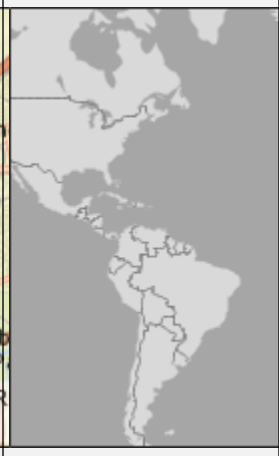

- 'point' — Display the coordinates as discrete, unconnected points.
- 'line' — Display the coordinates as a single connected line.

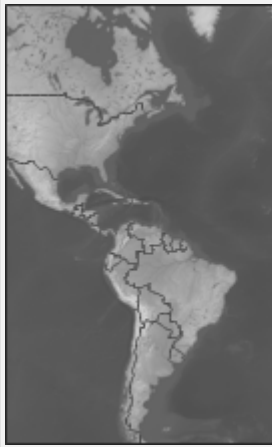





You can set this property when you create the object. After you create the object, this property is read-only.


Basemap — Map on which to plot data

'streets' (default) | 'darkwater' | 'grayterrain' | 'grayland' | 'colorterrain' | ...

Map on which to plot data, specified as one of the basemap names in this table, 'none', or a custom basemap defined using the `addCustomBasemap` function. For more information on adding custom basemaps, see “Custom Basemaps” on page 4-568. For examples on how to add custom basemaps, see “Display Data on OpenStreetMap Basemap” on page 4-555 and “Display Map Data on HERE Basemap” on page 4-560.

	<p>'streets' (default)</p> <p>Street map data composed of geographic map tiles using the World Street Map provided by Esri. For more information about the map, see World Street Map on the Esri ArcGIS website.</p> <p>Hosted by Esri.</p>		<p>'darkwater'</p> <p>Land areas: light-to-moderate gray</p> <p>Ocean and water areas: darker gray</p> <p>Hosted by MathWorks® and derived from public domain data.</p>	
--	---	---	---	--

	<p>'grayterrain'</p> <p>Worldwide terrain depicted monochromatically in shades of gray, combining shaded relief that emphasizes both high mountains and the micro terrain found in lowlands.</p> <p>Hosted by MathWorks.</p>		<p>'grayland'</p> <p>Land areas: light-to-moderate gray land</p> <p>Ocean and water areas: white</p> <p>Hosted by MathWorks.</p>	
	<p>'colorterrain'</p> <p>Shaded relief map blended with a land cover palette. Humid lowlands are green and arid lowlands brown.</p> <p>Hosted by MathWorks.</p>		<p>'bluegreen'</p> <p>Land areas: light green</p> <p>Ocean and water areas: light blue</p> <p>Hosted by MathWorks.</p>	

	<p>'landcover'</p> <p>Satellite-derived land cover data and shaded relief presented with a light, natural palette suitable for making thematic and reference maps (includes ocean-bottom relief).</p> <p>Hosted by MathWorks.</p>	<p>N/A</p>	<p>'none'</p> <p>Geographic axes plots your data with latitude-longitude grid, ticks, and labels but does not include a map.</p>
---	---	------------	--

By default, access to basemaps requires an Internet connection. The exception is the 'darkwater' basemap, which is installed with MATLAB.

If you do not have consistent access to the Internet, you can download the basemaps hosted by MathWorks onto your local system. For more information about downloading basemaps, see “Access Basemaps in MATLAB” (MATLAB). You cannot download basemaps hosted by Esri.

Example: `player = geoplayer(latCenter,lonCenter,'Basemap','darkwater')`

Example: `player.Basemap = 'darkwater'`

Data Types: `char` | `string`

Parent — Parent axes of geographic player

Figure graphics object | Panel graphics object

Parent axes of the geographic player, specified as a Figure graphics object or Panel graphics object. If you do not specify Parent, then `geoplayer` creates the geographic player in a new figure.

You can set this property when you create the object. After you create the object, this property is read-only.

Axes — Axes used by geographic player

GeographicAxes object

Axes used by geographic player, specified as a `GeographicAxes` object. Use this axes to customize the map that the geographic player displays. For an example, see “Customize Geographic Axes” on page 4-562. For details on the properties that you can customize, see `GeographicAxes` Properties.

Object Functions

<code>plotPosition</code>	Display current position in geoplayer figure
<code>plotRoute</code>	Display continuous route in geoplayer figure
<code>reset</code>	Remove all existing plots from geoplayer figure
<code>show</code>	Make geoplayer figure visible
<code>hide</code>	Make geoplayer figure invisible
<code>isOpen</code>	Return true if geoplayer figure is visible

Examples

Animate Sequence of Latitude and Longitude Coordinates

Load a sequence of latitude and longitude coordinates.

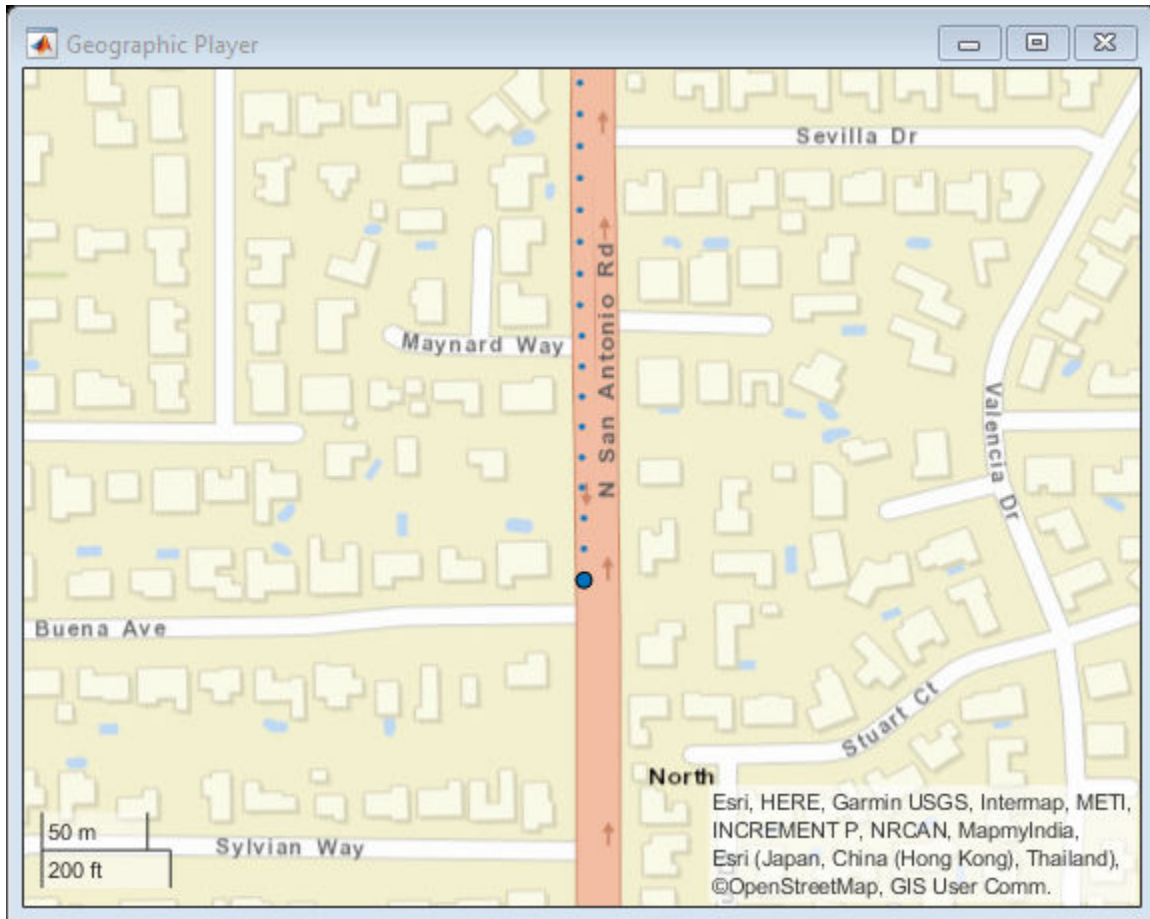
```
data = load('geoSequence.mat');
```

Create a geographic player and configure it to display all points in its history.

```
zoomLevel = 17;  
player = geoplayer(data.latitude(1),data.longitude(1),zoomLevel,'HistoryDepth',Inf);
```

Display the sequence of coordinates.

```
for i = 1:length(data.latitude)  
    plotPosition(player,data.latitude(i),data.longitude(i));  
    pause(0.01)  
end
```



View Position of Vehicle Along Route

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

Create a geographic player and set the zoom level to 12. Compared to the default zoom level, this zoom level zooms the map out by a factor of 8.

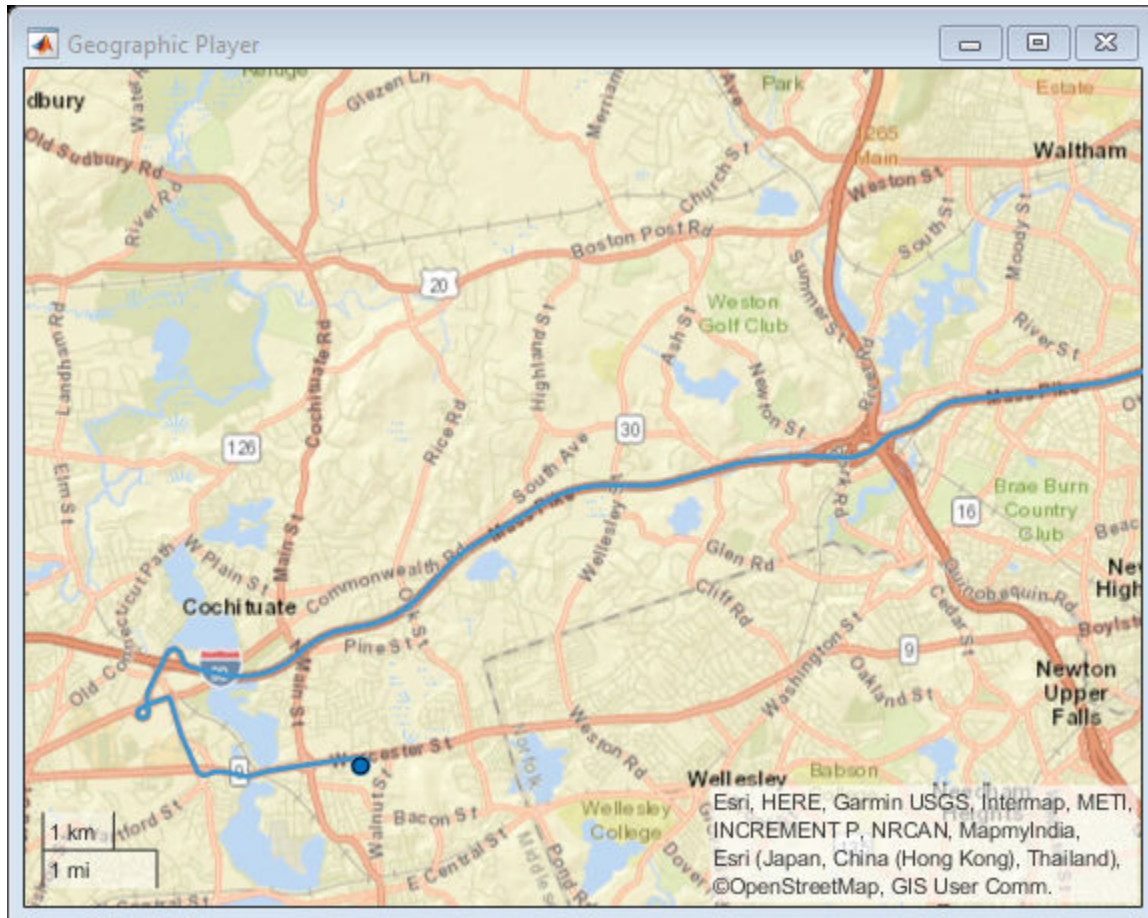
```
player = geoplayer(data.latitude(1),data.longitude(1),12);
```

Display the full route.

```
plotRoute(player,data.latitude,data.longitude);
```

Display the coordinates in a sequence. The circle marker indicates the current position.

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
    pause(0.05)
end
```



Display Data on OpenStreetMap Basemap

This example shows how to display a driving route and vehicle positions on an OpenStreetMap® basemap.

Add the OpenStreetMap basemap to the list of basemaps available for use with the `geoplayer` object. After you add the basemap, you do not need to add it again in future sessions.

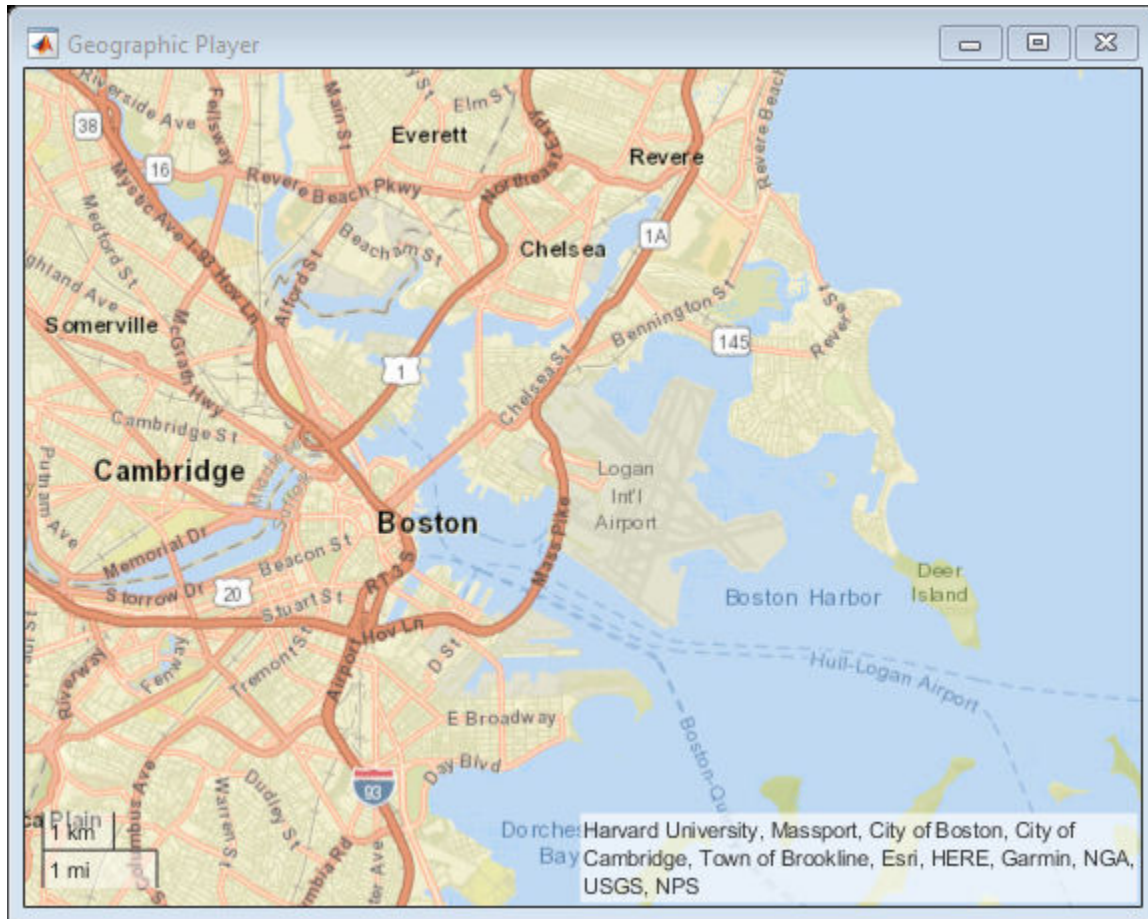
```
name = 'openstreetmap';  
url = 'https://a.tile.openstreetmap.org/{z}/{x}/{y}.png';  
copyright = char(uint8(169));  
attribution = copyright + "OpenStreetMap contributors";  
addCustomBasemap(name,url,'Attribution',attribution)
```

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

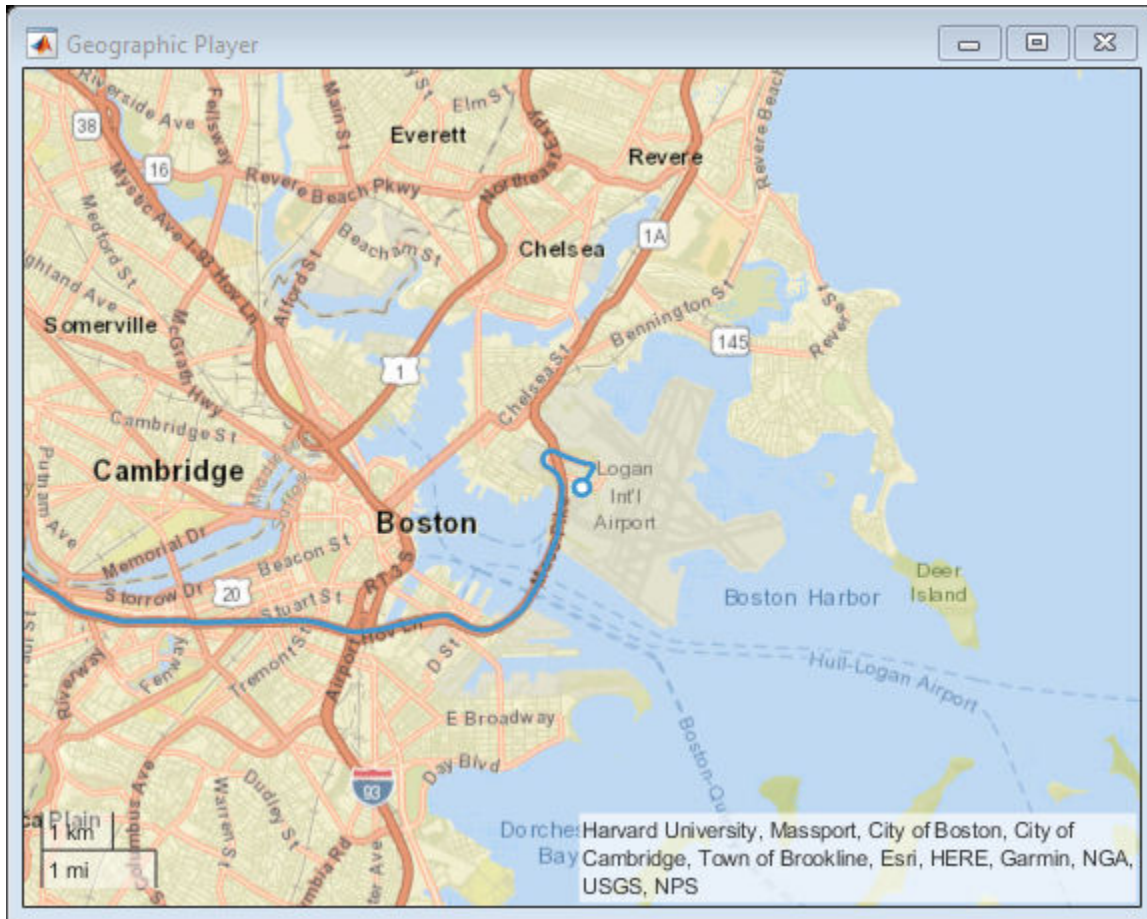
Create a geographic player. Center the geographic player on the first position of the driving route and set the zoom level to 12.

```
zoomLevel = 12;  
player = geoplayer(data.latitude(1),data.longitude(1),zoomLevel);
```



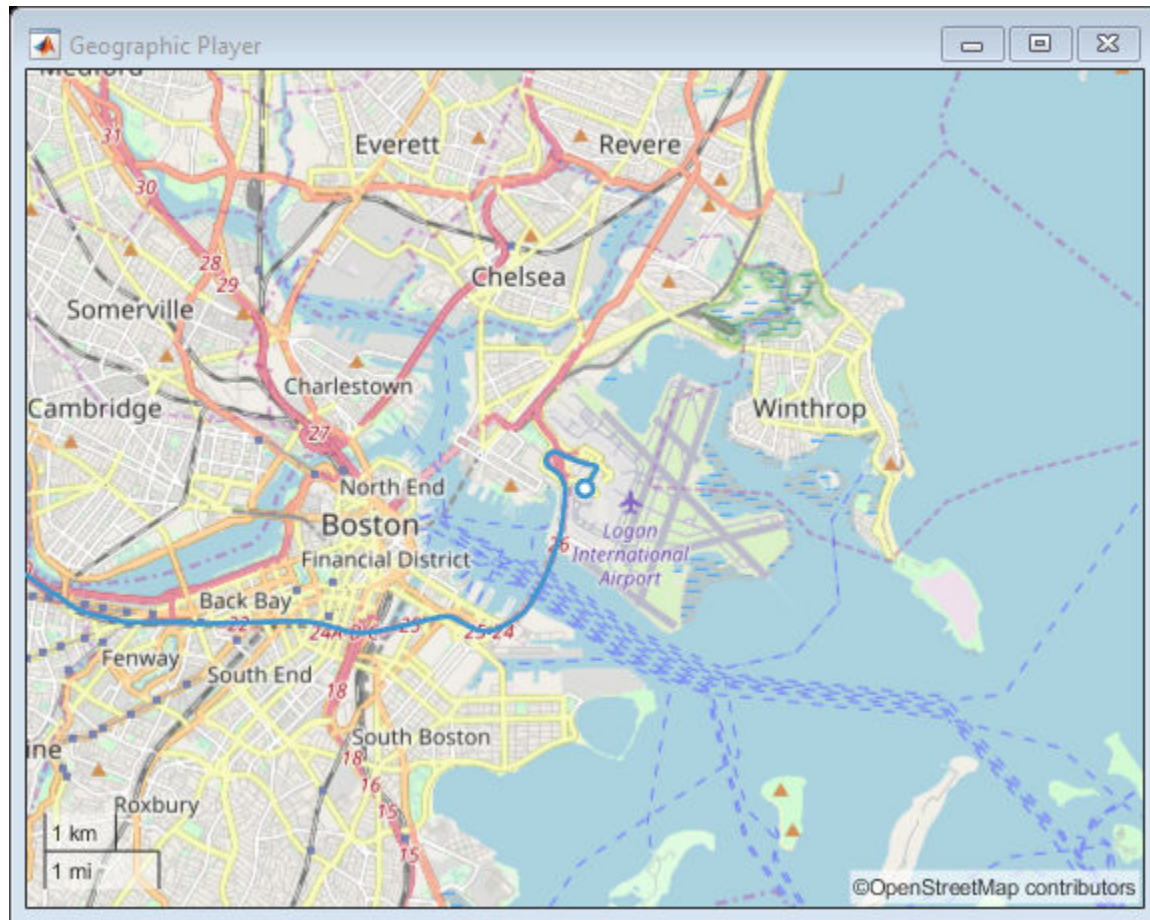
Display the full route.

```
plotRoute(player,data.latitude,data.longitude);
```



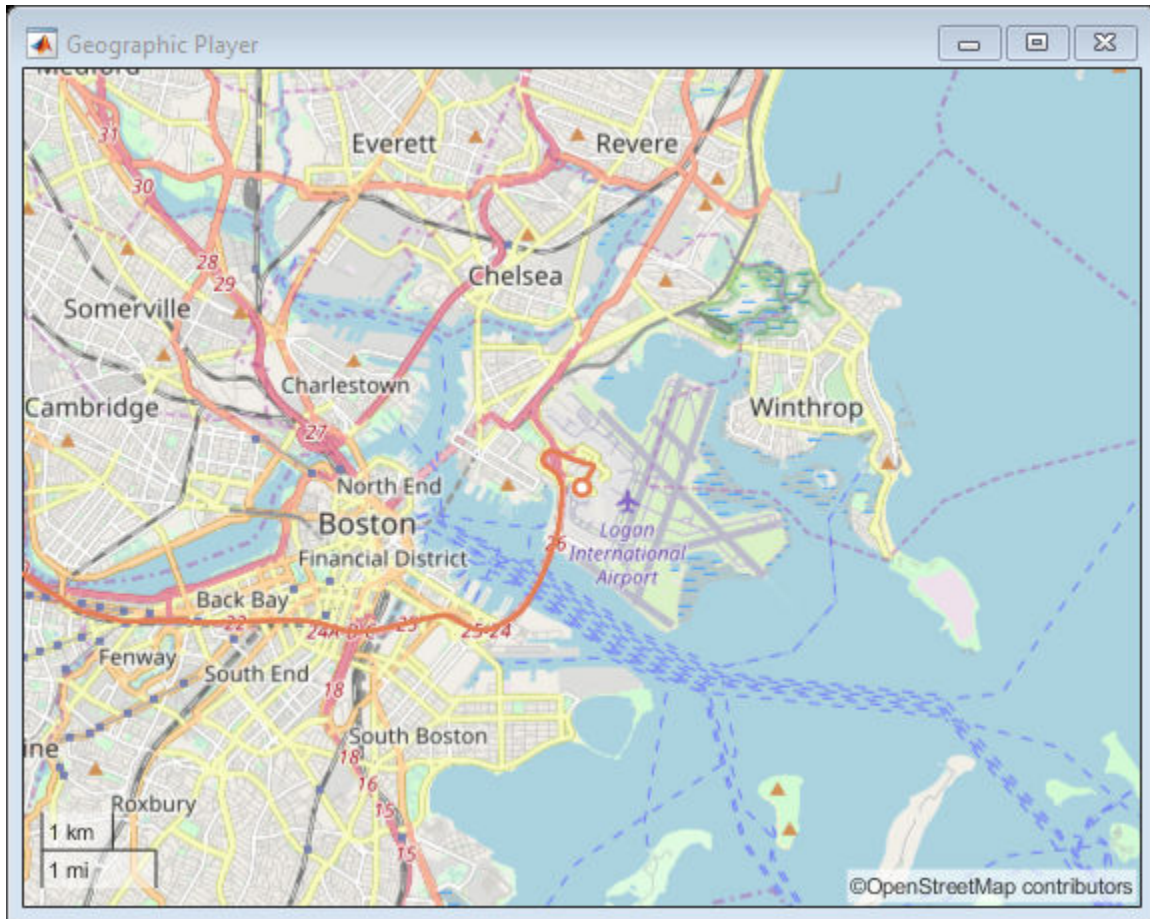
By default, the geographic player uses the World Street Map basemap ('streets') provided by Esri®. Update the geographic player to use the added OpenStreetMap basemap instead.

```
player.Basemap = 'openstreetmap';
```



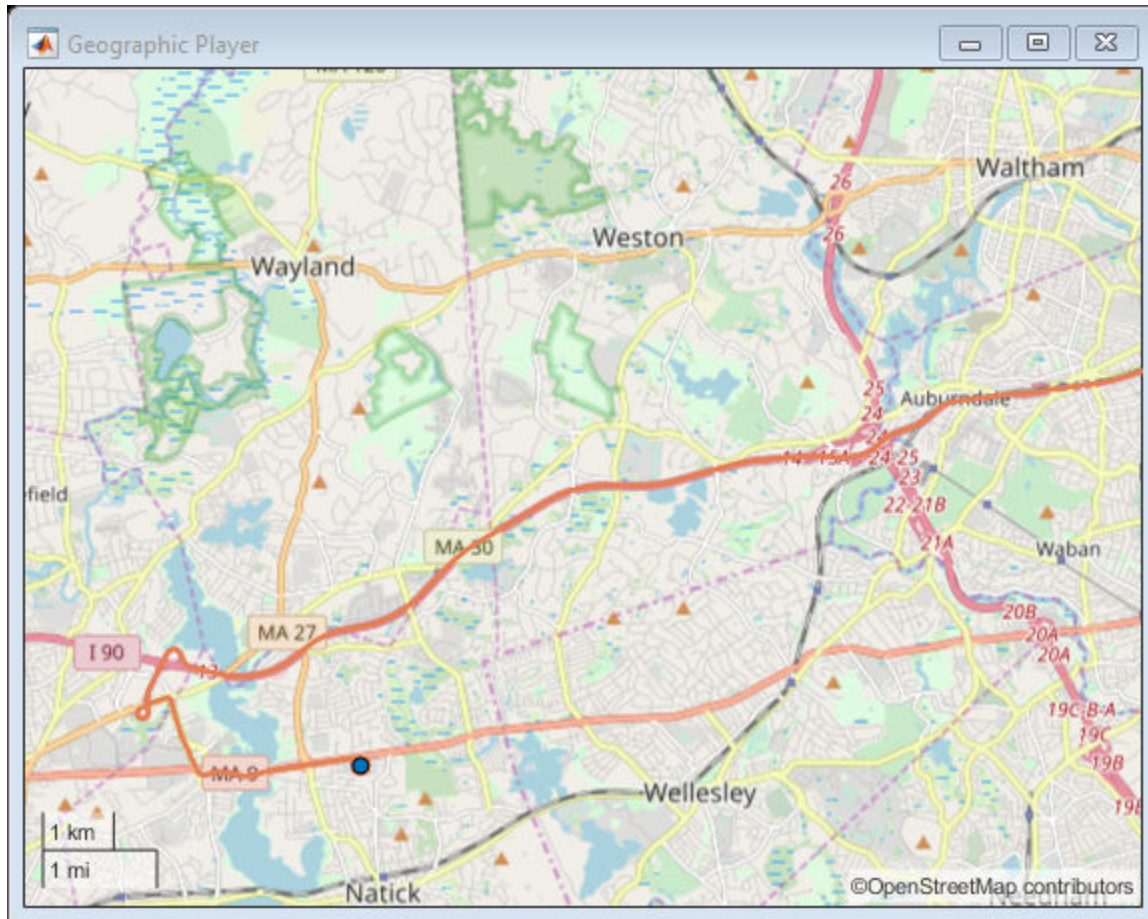
Display the route again.

```
plotRoute(player,data.latitude,data.longitude);
```



Display the positions of the vehicle in a sequence.

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i))
end
```



Display Map Data on HERE Basemap

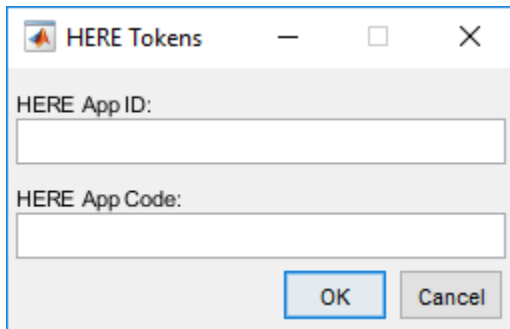
Display a driving route on a basemap provided by HERE Technologies. To use this example, you must have a valid license from HERE Technologies.

Specify the basemap name and map URL.

```
name = 'herestreets';
url = ['https://2.base.maps.cit.api.here.com/maptile/2.1/maptile/', ...
      'newest/normal.day/{z}/{x}/{y}/256/png?app_id=%s&app_code=%s'];
```

Maps from HERE Technologies require a valid license. Create a dialog box. In the dialog box, enter the App ID and App Code corresponding to your HERE license.

```
prompt = {'HERE App ID:', 'HERE App Code:'};
title = 'HERE Tokens';
dims = [1 40]; % Text edit field height and width
hereTokens = inputdlg(prompt,title,dims);
```



If the license is valid, specify the HERE credentials and a custom attribution, load coordinate data, and display the coordinates on the HERE basemap using a `geoplayer` object. If the license is not valid, display an error message.

```
if ~isempty(hereTokens)

    % Add HERE basemap with custom attribution.
    url = sprintf(url,hereTokens{1},hereTokens{2});
    copyrightSymbol = char(169); % Alt code
    attribution = [copyrightSymbol, ' ', datestr(now, 'yyyy'), ' HERE'];
    addCustomBasemap(name,url,'Attribution',attribution);

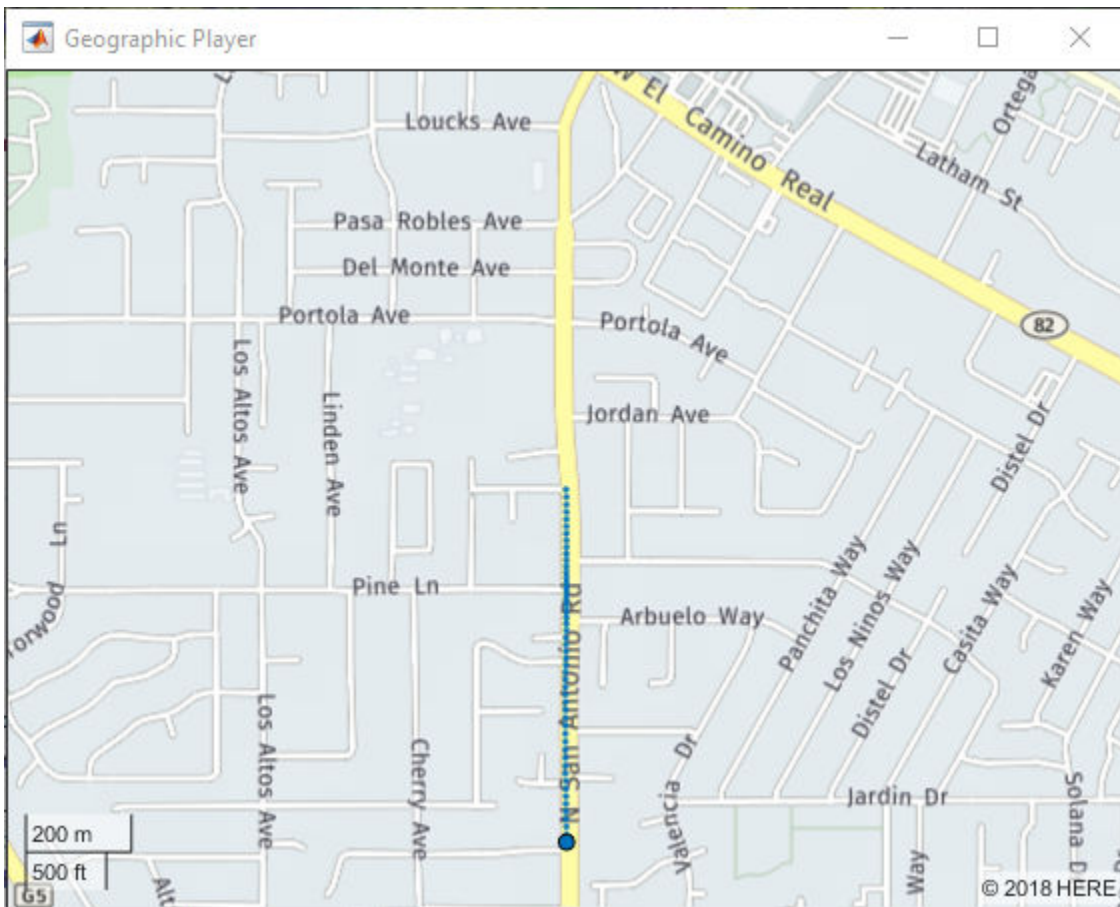
    % Load sample lat,lon coordinates.
    data = load('geoSequence.mat');

    % Create geoplayer with HERE basemap.
    player = geoplayer(data.latitude(1),data.longitude(1), ...
        'Basemap','herestreets','HistoryDepth',Inf);

    % Display the coordinates in a sequence.
```

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
end

else
    error('You must enter valid credentials to access maps from HERE Technologies');
end
```



Customize Geographic Axes

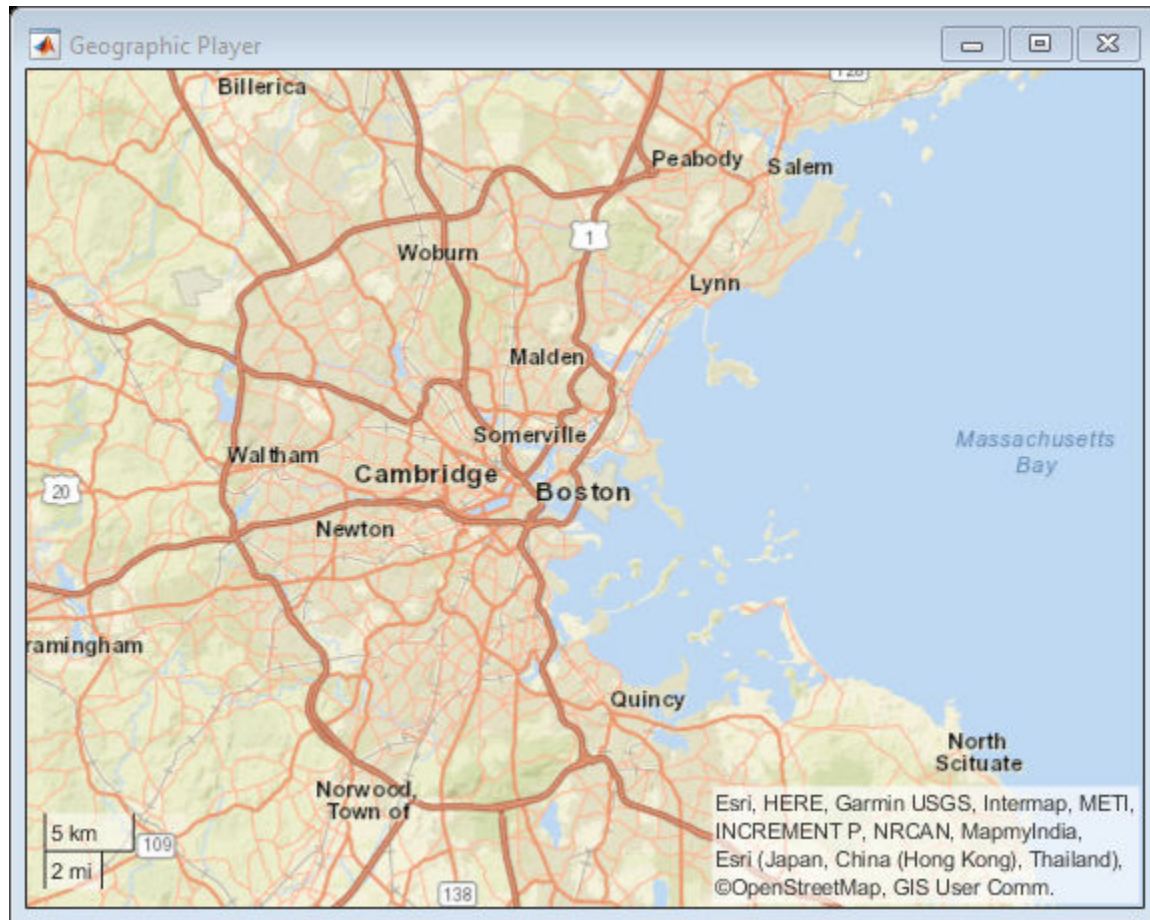
Customize the geographic axes of a `geoplayer` object by adding a custom line between route endpoints.

Load a driving route and vehicle positions along that route.

```
data = load('geoRoute.mat');
```

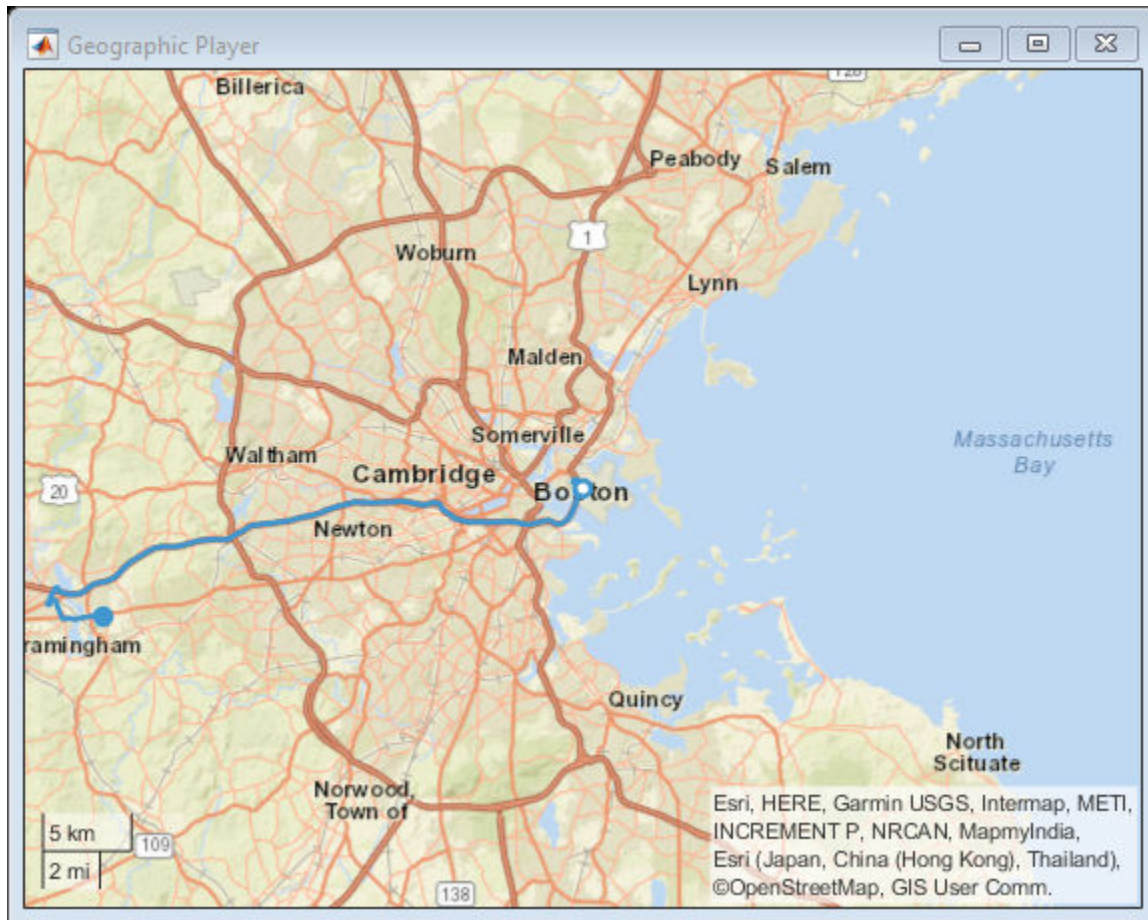
Create a geographic player that is centered on the first position of the vehicle.

```
zoomLevel = 10;  
player = geoplayer(data.latitude(1), data.longitude(1), zoomLevel);
```



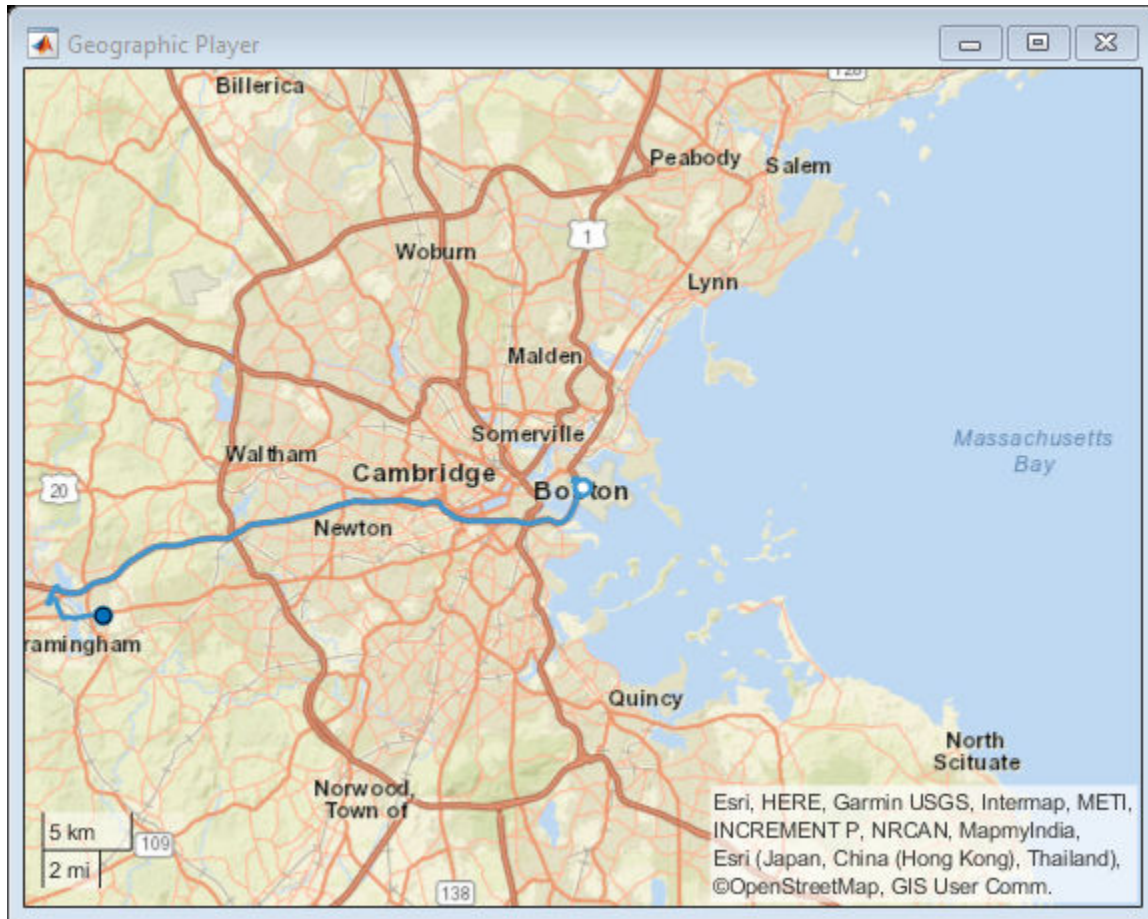
Display the full route.

```
plotRoute(player,data.latitude,data.longitude);
```



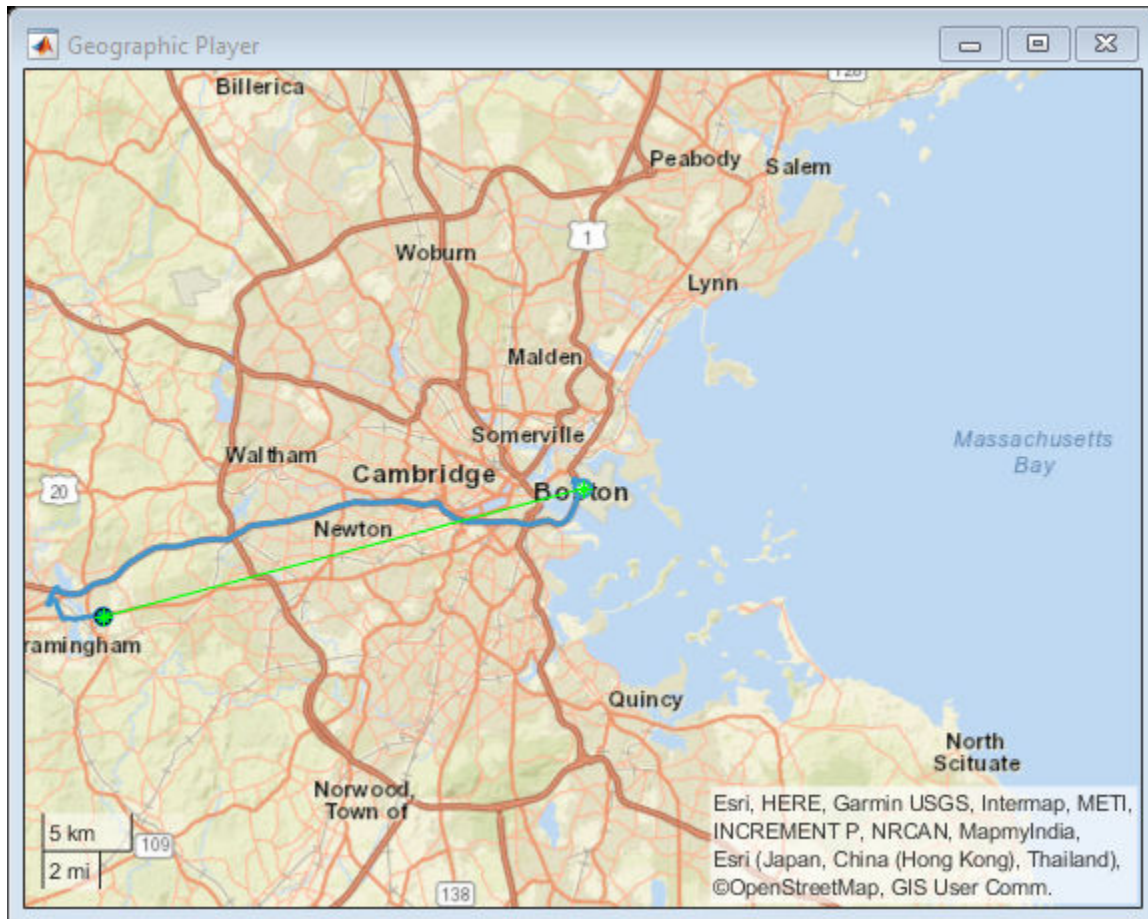
Display positions of the vehicle along the route.

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i))
end
```



Customize the geographic axes by adding a line between the two endpoints of the route.

```
geoplot(player.Axes,[data.latitude(1) data.latitude(end)], ...  
        [data.longitude(1) data.longitude(end)], 'g-*')
```



Limitations

- Geographic map tiles are not available for all locations.

More About

Custom Basemaps

The `geoplayer` object can use custom basemaps from providers such as HERE Technologies and OpenStreetMap.

To make a custom basemap available for use with the `geoplayer` object, use the `addCustomBasemap` function. After you add a custom basemap, it remains available for use in future MATLAB sessions, until you remove the basemap by using the `removeCustomBasemap` function.

To display streaming coordinates on a custom basemap, specify the name of the basemap in the `Basemap` property of the `geoplayer` object.

Note For some custom basemaps, access to the map servers requires a valid license from the map provider.

Tips

- When the `geoplayer` object plots a position that is outside the current view of the map, the object automatically scrolls the map.

See Also

Functions

`addCustomBasemap` | `geoaxes` | `geobasemap` | `geobubble` | `geolimits` | `geoplot` | `geoscatter` | `removeCustomBasemap`

Properties

`GeographicAxes` Properties

Introduced in R2018a

plotPosition

Display current position in geoplayer figure

Syntax

```
plotPosition(player, lat, lon)
plotPosition(player, lat, lon, Name, Value)
```

Description

`plotPosition(player, lat, lon)` plots a point with latitude and longitude coordinates in a geoplayer figure.

`plotPosition(player, lat, lon, Name, Value)` uses `Name, Value` pair arguments to modify the visual style of the plotted points.

For example, `plotPosition(player, 45, 0, 'Color', 'w', 'Marker', '*')` plots a point in the geoplayer figure as a white star.

Examples

View Position of Vehicle Along Route

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

Create a geographic player and set the zoom level to 12. Compared to the default zoom level, this zoom level zooms the map out by a factor of 8.

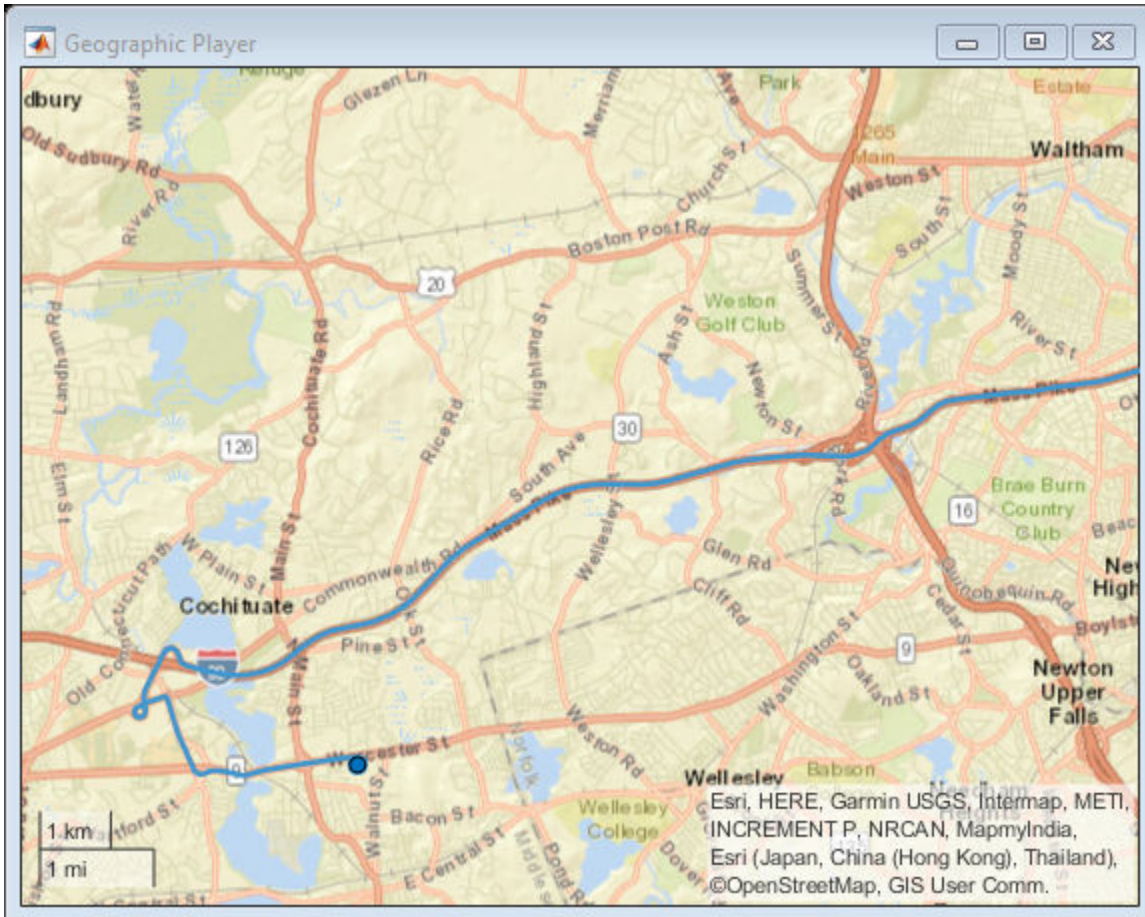
```
player = geoplayer(data.latitude(1), data.longitude(1), 12);
```

Display the full route.

```
plotRoute(player, data.latitude, data.longitude);
```

Display the coordinates in a sequence. The circle marker indicates the current position.

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
    pause(0.05)
end
```



Input Arguments

player — Streaming geographic player

geoplayer object

Streaming geographic player, specified as a geoplayer object.

lat — Latitude coordinate

real scalar in the range [-90, 90]

Latitude coordinate of the point to display in the geographic player, specified as a real scalar in the range [-90, 90].

Data Types: single | double

lon — Longitude coordinate

real scalar in the range [-180, 180]

Longitude coordinate of the point to display in the geographic player, specified as a real scalar in the range [-180, 180].

Data Types: single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'Color', 'k'`

Label — Text description

`' '` (default) | character vector | string scalar

Text description of the point, specified as the comma-separated pair consisting of `'Label'` and a character vector or string scalar.





Example: `'Label', '07:45:00AM'`

Color — Marker color

color name | short color name | RGB triplet

Marker color, specified as the comma-separated pair consisting of 'Color' and a color name, short color name, or RGB triplet. By default, the marker color is selected automatically.

For a custom color, specify an RGB triplet. An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7]. Alternatively, you can specify some common colors by name. This table lists the named color options and the equivalent RGB triplet values.

Color Name	Color Short Name	RGB Triplet	Appearance
'red'	'r'	[1 0 0]	
'green'	'g'	[0 1 0]	
'blue'	'b'	[0 0 1]	
'cyan'	'c'	[0 1 1]	
'magenta'	'm'	[1 0 1]	
'yellow'	'y'	[1 1 0]	
'black'	'k'	[0 0 0]	
'white'	'w'	[1 1 1]	

Example: 'Color',[1 0 1]

Example: 'Color','m'

Example: 'Color','magenta'

Marker — Marker symbol

'o' (default) | '+' | '*' | '.' | 'x' | ...

Marker symbol, specified as the comma-separated pair consisting of 'Marker' and one of the markers in this table.

Value	Description
'o'	Circle
'+'	Plus sign
'*'	Asterisk
'.'	Point

Value	Description
'x'	Cross
'square' or 's'	Square
'diamond' or 'd'	Diamond
'^'	Upward-pointing triangle
'v'	Downward-pointing triangle
'>'	Right-pointing triangle
'<'	Left-pointing triangle
'pentagram' or 'p'	Five-pointed star (pentagram)
'hexagram' or 'h'	Six-pointed star (hexagram)

MarkerSize – Diameter of marker

6 (default) | positive real scalar

Approximate diameter of marker in points, specified as the comma-separated pair consisting of 'MarkerSize' and a positive real scalar. 1 point = 1/72 inch. A marker size larger than 6 can reduce the rendering performance.

See Also

geoplayer | plotRoute | reset

Introduced in R2018a

plotRoute

Display continuous route in `geoplayer` figure

Syntax

```
plotRoute(player, lat, lon)  
plotRoute(player, lat, lon, Name, Value)
```

Description

`plotRoute(player, lat, lon)` displays a route, as defined by a series of latitude-longitude coordinates, in a `geoplayer` figure. The route appears as a continuous line on a map.

`plotRoute(player, lat, lon, Name, Value)` uses `Name, Value` pair arguments to modify the visual style of the route.

For example, `plotRoute(player, [45 46], [0 0], 'Color', 'k')` plots a route in a `geoplayer` figure as a black line.

Examples

View Position of Vehicle Along Route

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

Create a geographic player and set the zoom level to 12. Compared to the default zoom level, this zoom level zooms the map out by a factor of 8.

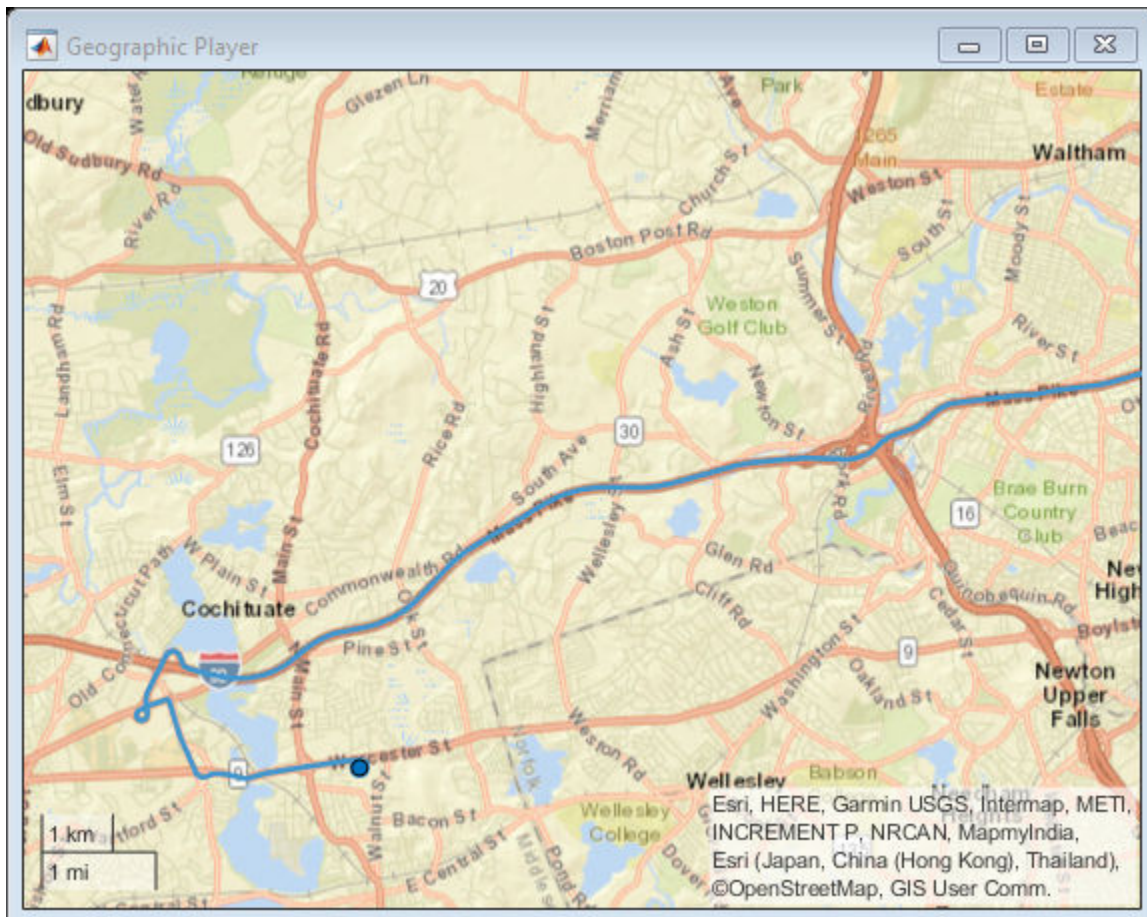
```
player = geoplayer(data.latitude(1), data.longitude(1), 12);
```

Display the full route.

```
plotRoute(player,data.latitude,data.longitude);
```

Display the coordinates in a sequence. The circle marker indicates the current position.

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
    pause(0.05)
end
```



Input Arguments

player — Streaming geographic player

geoplayer object

Streaming geographic player, specified as a geoplayer object.

lat — Latitude coordinates

real-valued vector

Latitude coordinates of points along the route, specified as a real-valued vector with elements in the range [-90, 90].

Data Types: single | double

lon — Longitude coordinates

real-valued vector

Longitude coordinates of points along the route, specified as a real-valued vector with elements in the range [-180, 180].

Data Types: single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of **Name**, **Value** arguments. **Name** is the argument name and **Value** is the corresponding value. **Name** must appear inside quotes. You can specify several name and value pair arguments in any order as **Name1**, **Value1**, ..., **NameN**, **ValueN**.

Example: 'Color', 'g'







Color — Line color

color name | short color name | RGB triplet

Line color, specified as the comma-separated pair consisting of 'Color' and a color name, short color name, or RGB triplet. By default, the line color is selected automatically.

For a custom color, specify an RGB triplet. An RGB triplet is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color. The intensities must be in the range [0, 1]; for example, [0.4 0.6 0.7].

Alternatively, you can specify some common colors by name. This table lists the named color options and the equivalent RGB triplet values.

Color Name	Color Short Name	RGB Triplet	Appearance
'red'	'r'	[1 0 0]	
'green'	'g'	[0 1 0]	
'blue'	'b'	[0 0 1]	
'cyan'	'c'	[0 1 1]	
'magenta'	'm'	[1 0 1]	
'yellow'	'y'	[1 1 0]	
'black'	'k'	[0 0 0]	
'white'	'w'	[1 1 1]	

Example: 'Color',[1 0 1]

Example: 'Color','m'

Example: 'Color','magenta'

LineWidth — Line width

2 (default) | positive number

Line width in points, specified as the comma-separated pair consisting of 'LineWidth' and a positive number. 1 point = 1/72 inch.

ShowEndpoints — Display origin and destination

'on' (default) | 'off'

Display the origin and destination points, specified as the comma-separated pair consisting of 'ShowEndpoints' and 'on' or 'off'. Specify 'on' to display the origin and destination points. The origin marker is white and the destination marker is filled with color.

See Also

geoplayer | plotPosition | reset

Introduced in R2018a

reset

Remove all existing plots from `geoplayer` figure

Syntax

```
reset(player)
```

Description

`reset(player)` removes all previously plotted points and routes from the `geoplayer` figure.

Examples

Reset Geographic Player

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

Create a geographic player with a zoom level of 12. Configure the geographic player to display all points in its history.

```
player = geoplayer(data.latitude(1),data.longitude(1),12,'HistoryDepth',Inf);
```

Display the full route.

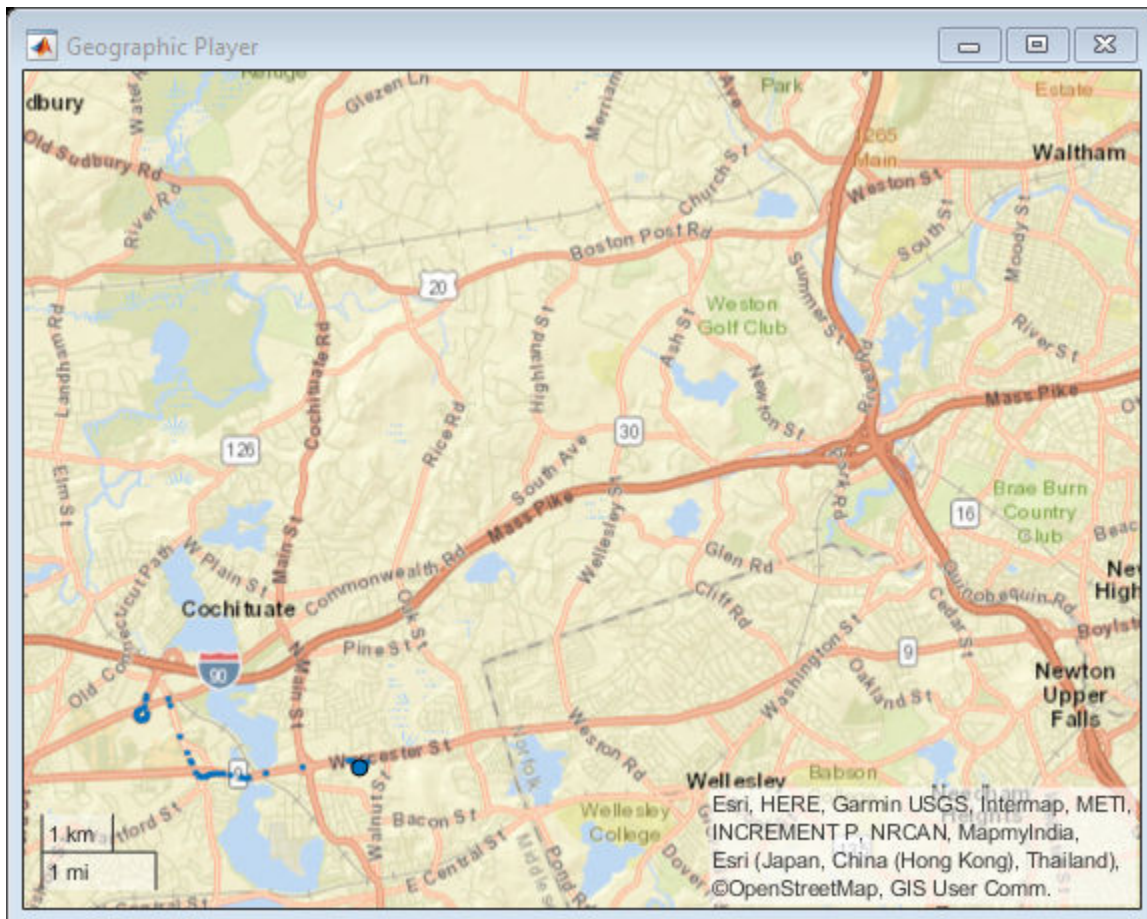
```
plotRoute(player,data.latitude,data.longitude);
```

Display the coordinates in a sequence. The circle marker indicates the current position. At the 200th point, reset the geographic player. Observe that the route and all previously plotted points are removed.

```
for i = 1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
```



```
if i == 200
    reset(player)
end
pause(.05)
end
```



Input Arguments

player — Streaming geographic player

geoplayer object

Streaming geographic player, specified as a geoplayer object.

See Also

geoplayer | plotPosition | plotRoute

Introduced in R2018a

show

Make geoplayer figure visible

Syntax

```
show(player)
```

Description

`show(player)` makes the `geoplayer` figure visible again after closing or hiding it.

Examples

Hide and Show Geographic Player

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

Create a geographic player with a zoom level of 10. Configure the player to show its complete history of plotted points.

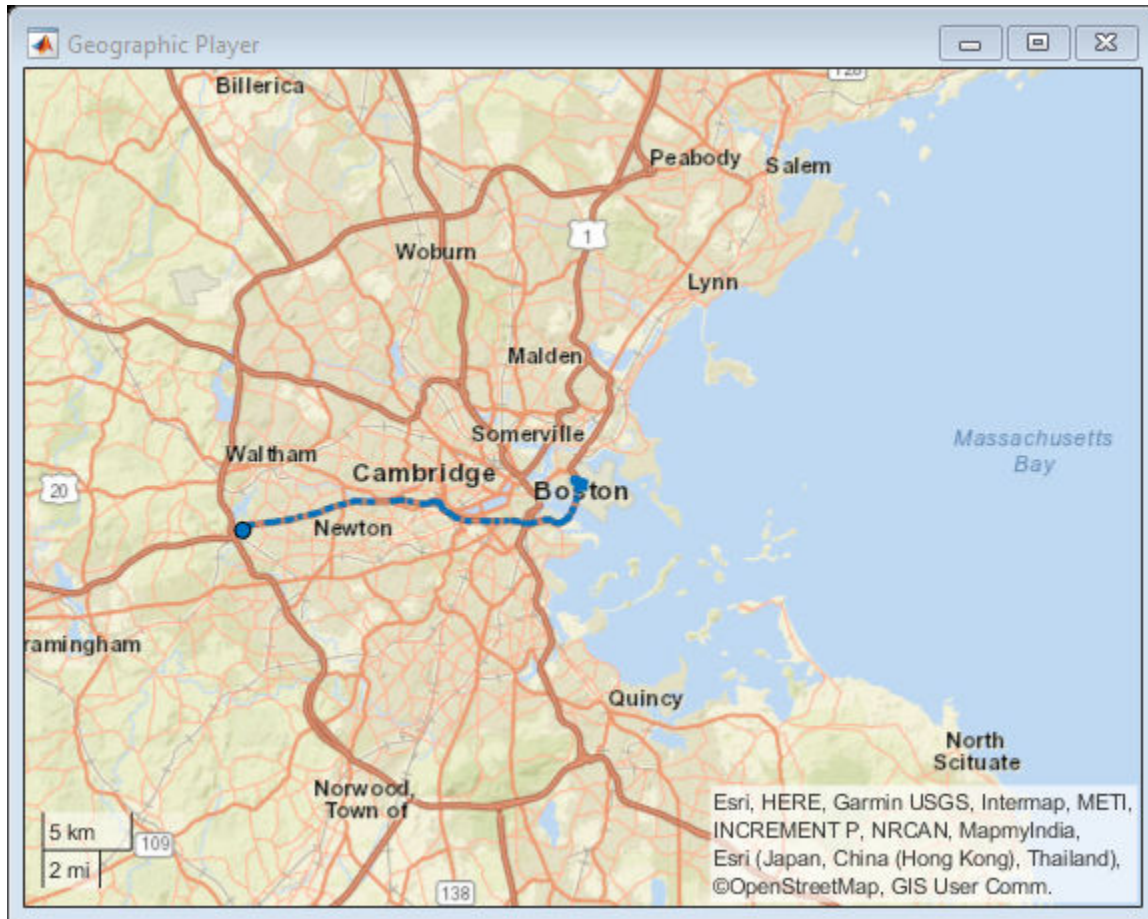
```
player = geoplayer(data.latitude(1),data.longitude(1),10,'HistoryDepth',Inf);
```

Display the first half of the geographic coordinates in a sequence. The circle marker indicates the current position.

```
halfLength = round(length(data.latitude)/2);
```

```
for i = 1:halfLength
    plotPosition(player,data.latitude(i),data.longitude(i));
end
```

4 Objects in Automated Driving Toolbox



Hide the player and confirm that it is no longer visible.

```
hide(player)  
isOpen(player)
```

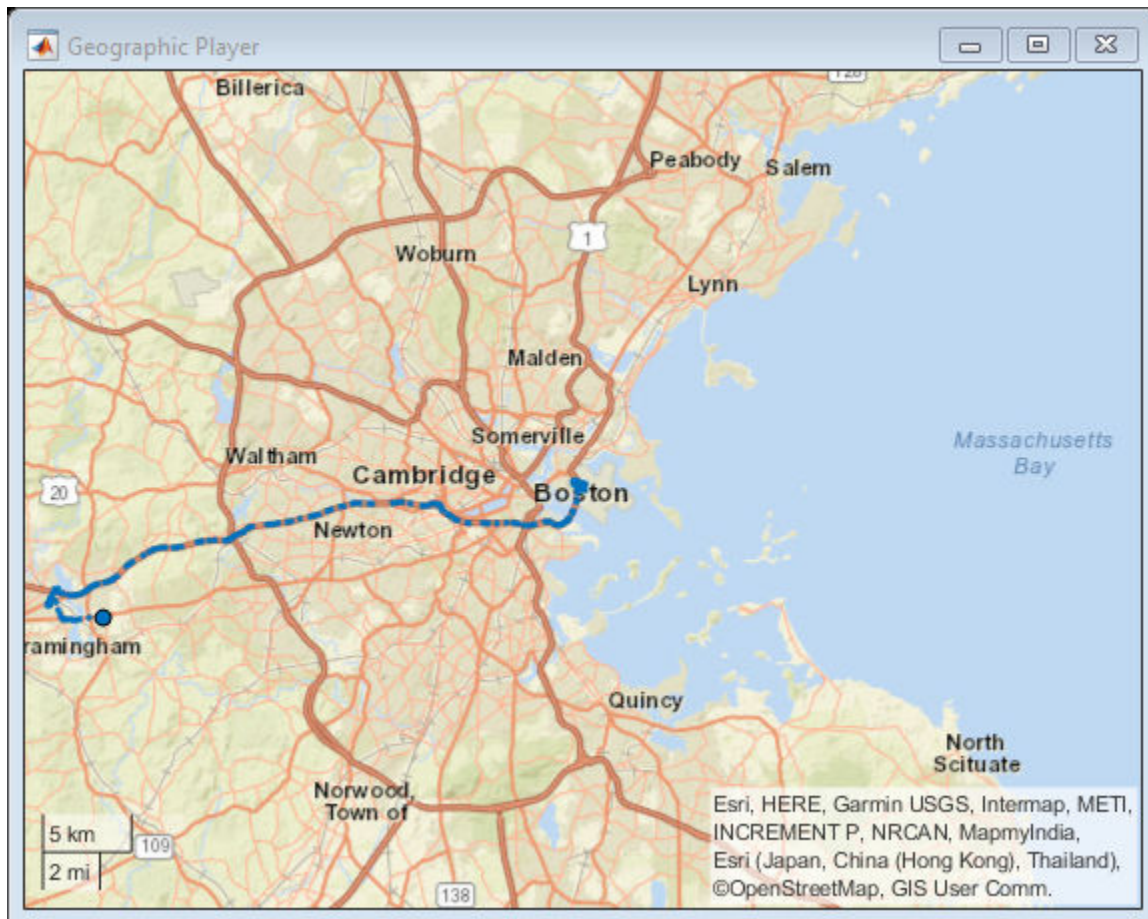
```
ans = logical  
     0
```

Add the remaining half of the geographic coordinates to the map.

```
for i = halfLength+1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
end
```

Show the player. The player now displays both halves of the route.

```
show(player)
```



Input Arguments

player — Streaming geographic player

geoplayer object

Streaming geographic player, specified as a geoplayer object.

See Also

geoplayer | hide | isOpen

Introduced in R2018a

hide

Make `geoplayer` figure invisible

Syntax

```
hide(player)
```

Description

`hide(player)` hides the `geoplayer` figure. To redisplay this figure, use `show(player)`.

Examples

Hide and Show Geographic Player

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

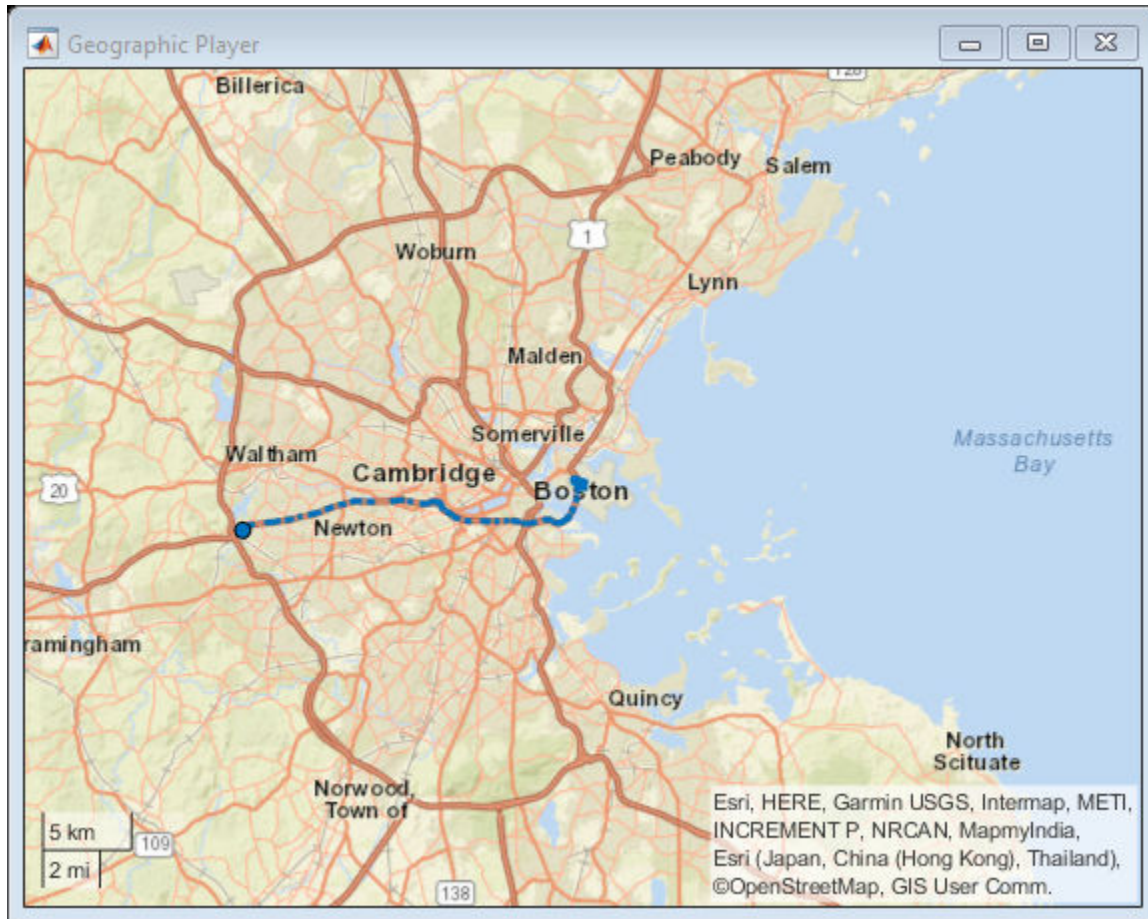
Create a geographic player with a zoom level of 10. Configure the player to show its complete history of plotted points.

```
player = geoplayer(data.latitude(1),data.longitude(1),10,'HistoryDepth',Inf);
```

Display the first half of the geographic coordinates in a sequence. The circle marker indicates the current position.

```
halfLength = round(length(data.latitude)/2);
```

```
for i = 1:halfLength
    plotPosition(player,data.latitude(i),data.longitude(i));
end
```



Hide the player and confirm that it is no longer visible.

```
hide(player)  
isOpen(player)
```

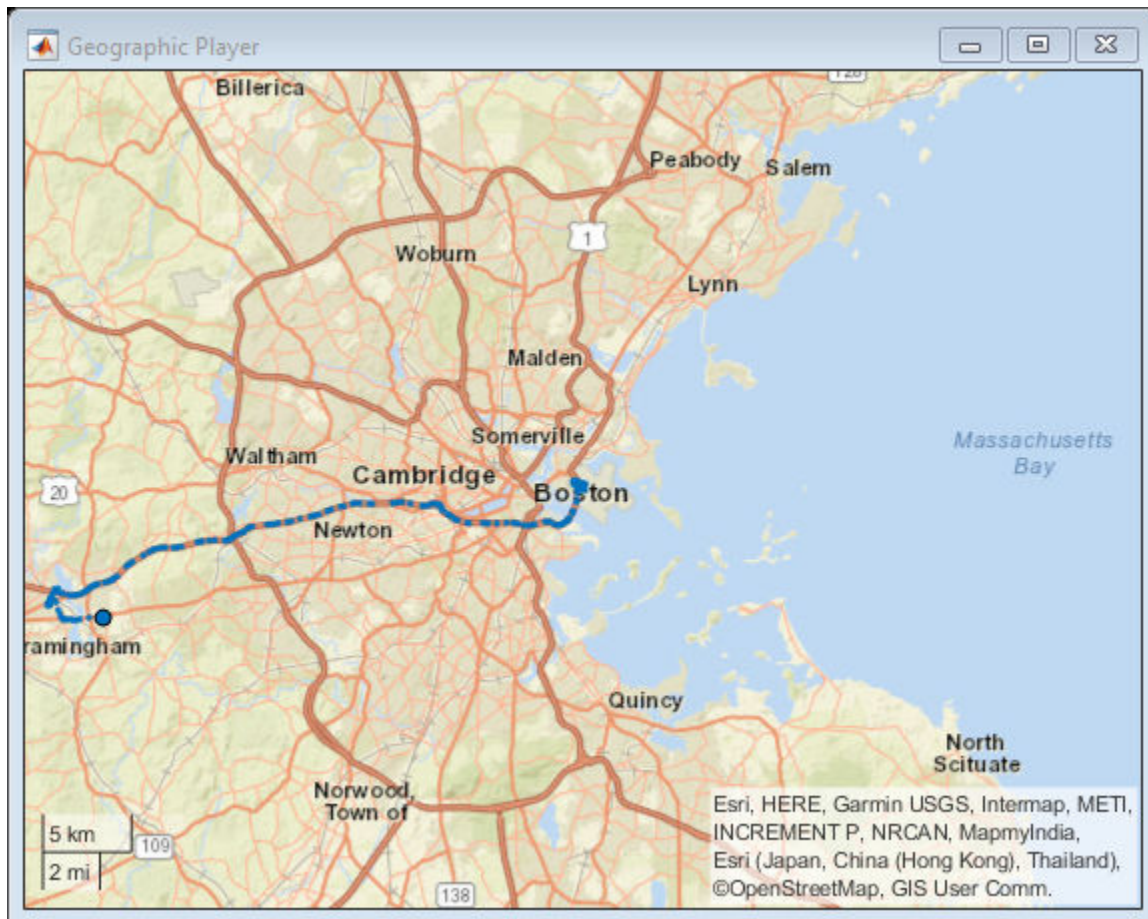
```
ans = logical  
    0
```

Add the remaining half of the geographic coordinates to the map.


```
for i = halfLength+1:length(data.latitude)
    plotPosition(player,data.latitude(i),data.longitude(i));
end
```

Show the player. The player now displays both halves of the route.

```
show(player)
```



Input Arguments

player — Streaming geographic player

geoplayer object

Streaming geographic player, specified as a geoplayer object.

See Also

geoplayer | isOpen | show

Introduced in R2018a

isOpen

Return true if `geoplayer` figure is visible

Syntax

```
tf = isOpen(player)
```

Description

`tf = isOpen(player)` returns logical 1 (true) if the `geoplayer` figure is visible. Otherwise, `isOpen` returns logical 0 (false).

Examples

Plot Points While Geographic Player Is Open

Load a sequence of latitude and longitude coordinates.

```
data = load('geoRoute.mat');
```

Create a geographic player with a zoom level of 12. Configure the player to display all points in its history.

```
player = geoplayer(data.latitude(1),data.longitude(1),12,'HistoryDepth',Inf);
```

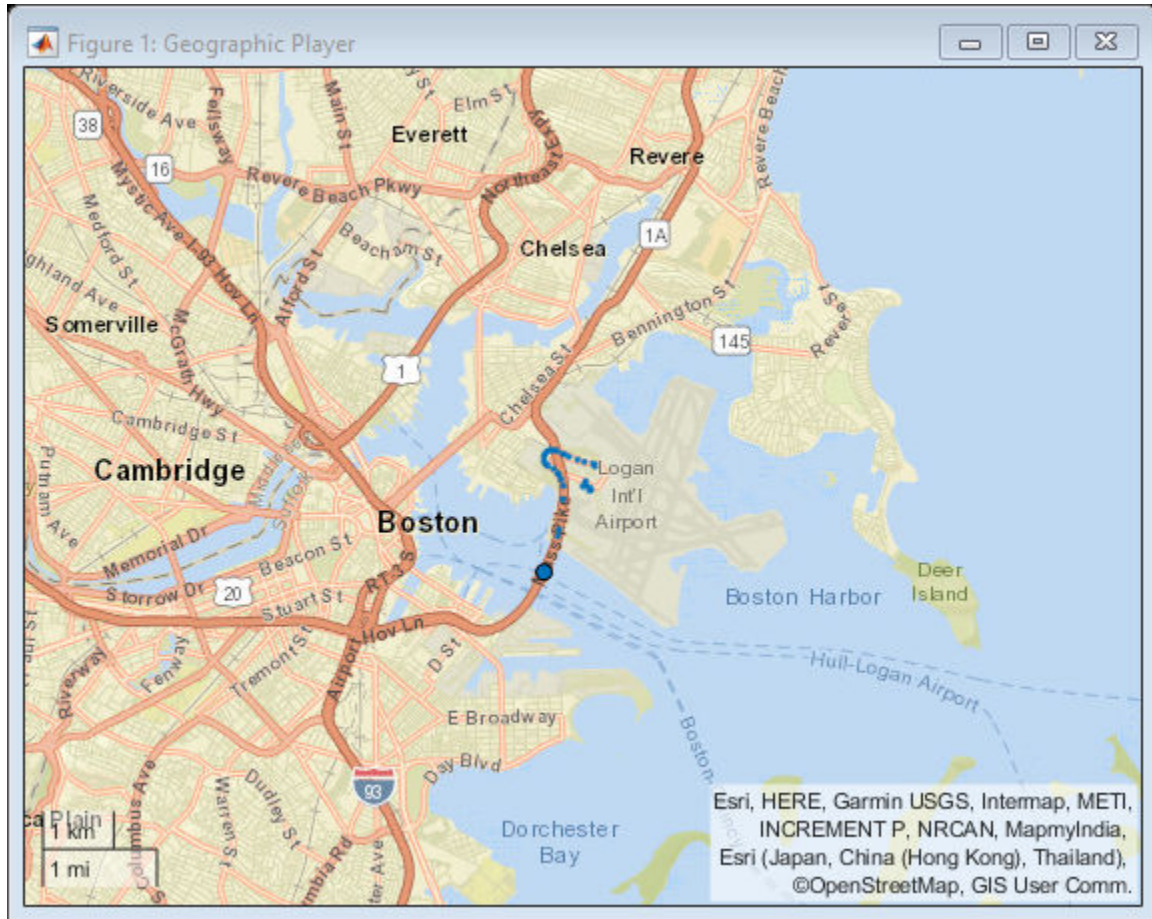
Display the geographic coordinates in a sequence by using the `plotPosition` function. Put the call to `plotPosition` inside a `while` loop, so that the player plots points only while the figure is open. You can exit the loop by closing the figure. If you do not close the figure, then the loop automatically exits when all points are plotted.

```
i = 1;
numPoints = length(data.latitude);
while isOpen(player) && i<=numPoints
    plotPosition(player,data.latitude(i),data.longitude(i))
    pause(0.1)
```

```
i=i+1;  
end
```

To make the figure visible again, use the show function.

```
show(player)
```



Input Arguments

player — Streaming geographic player

geoplayer object

Streaming geographic player, specified as a geoplayer object.

Output Arguments

tf — Visibility of geographic player

1 (true) | 0 (false)

Visibility of geographic player, returned as logical 1 (true) when the geoplayer figure is open, and logical 0 (false) otherwise.

See Also

geoplayer | hide | show

Introduced in R2018a

hereHDLMReader

HERE HD Live Map reader

Description

Use a `hereHDLMReader` object to read high-definition map data for selected map tiles from the HERE HD Live Map² (HERE HDLM) web service, provided by HERE Technologies. HERE HDLM data provides highly detailed and accurate information about the vehicle environment, such as road and lane topology, and is suitable for developing automated driving applications.

You can select specific map tiles from which to read data or select map tiles based on the coordinates of a driving route. To read map data for tiles, use the `read` function and specify the reader as an input argument. For more details, see “Access HERE HD Live Map Data”.

Note Use of the `hereHDLMReader` object requires valid HERE HDLM credentials. If you have not previously set up credentials, a dialog box prompts you to enter them. Enter the **App ID** and **App Code** that you obtained from HERE Technologies, and click **OK**.

Creation

Syntax

```
reader = hereHDLMReader(lat,lon)
reader = hereHDLMReader(tileID)
reader = hereHDLMReader( ____,Name,Value)
```

-
2. You need to enter into a separate agreement with HERE in order to gain access to the HDLM services and to get the required credentials (`app_id` and `app_code`) for using the HERE Service.

Description

`reader = hereHDLMReader(lat, lon)` creates a HERE HDLM reader that can read map data for the HERE map tiles that correspond to a set of latitude and longitude coordinates. The map tiles are at a zoom level of 14.

`reader = hereHDLMReader(tileID)` creates a HERE HDLM reader that can read map data for the map tiles with the specified HERE tile IDs. These tile IDs are stored in the `TileIDs` property of the HERE HDLM reader.

`reader = hereHDLMReader(____, Name, Value)` sets the `Configuration`, `WriteLocation`, and `CoordinateFormat` properties using one or more name-value pairs. For example, `hereHDLMReader(tileID, 'Configuration', config)` creates a reader that is configured to read map tile data from a specific HERE HDLM production catalog or catalog version, where `config` is a `hereHDLMConfiguration` object.

Input Arguments

lat — Latitude coordinates

vector of real values in the range [-90, 90]

Latitude coordinates, specified as a vector of real values in the range [-90, 90].

Use this vector, along with `lon`, to specify the coordinates of a driving route that you want to read map data from.

`lat` and `lon` must be the same size.

Data Types: `double`

lon — Longitude coordinates

vector of real values in the range [-180, 180]

Longitude coordinates, specified as a vector of real values in the range [-180, 180].

Use this vector, along with `lat`, to specify the coordinates of a driving route that you want to read map data from.

`lat` and `lon` must be the same size.

Data Types: `double`

tileID — HERE tile IDs

vector of unsigned 32-bit integers

HERE tile IDs from which to read data, specified as a vector of unsigned 32-bit integers. These tile IDs are stored in the `TileIDs` property of the `hereHDLMReader` object.

The specified map tiles must all come from the same geographic region. For a list of available regions and their corresponding values in the HERE HDLM production catalog, see the `Configuration` property.

If you configure the `hereHDLMReader` object to read data from a specific catalog using the `hereHDLMConfiguration` object, then all tile IDs must be found within that catalog. Otherwise, the reader object returns an error.

Example: `uint32([386497368 386497369])`

Data Types: `uint32`

Properties

TileIDs — HERE tile IDs

vector of unsigned 32-bit integers

This property is read-only.

HERE tile IDs from which to read data, specified as a vector of unsigned 32-bit integers. These tiles correspond to either the specified `lat` and `lon` coordinates or the specified `tileID` tiles.

Example: `uint32([386497368 386497369])`

Data Types: `uint32`

Layers — Map data layers

string array

This property is read-only.

Map data layers available for the selected HERE tile IDs, specified as a string array of layer names. The available map layers vary depending on the geographic region.

To read data from these layers, specify these layer names as inputs to the `read` function.

Configuration — Catalog configuration`hereHDLMConfiguration` object

This property is read-only.

Catalog configuration, specified as a `hereHDLMConfiguration` object. This configuration contains the specific HERE HDLM catalog and catalog version that the `hereHDLMReader` object reads data from.

If you do not specify a configuration at creation, the reader object computes the default configuration by searching the latest version of each production catalog. If all selected map tile IDs are found within a catalog, then the `hereHDLMReader` object is configured to read data from the latest version of that catalog.

You can specify a configuration using either the catalog name or the corresponding region name. This table shows the valid region names and their corresponding HERE HDLM production catalog names.

Region	Catalog
'Asia Pacific'	'here-hdmap-ext-apac-1'
'Eastern Europe'	'here-hdmap-ext-eeu-1'
'India'	'here-hdmap-ext-rn-1'
'Middle East And Africa'	'here-hdmap-ext-mea-1'
'North America'	'here-hdmap-ext-na-1'
'Oceania'	'here-hdmap-ext-au-1'
'South America'	'here-hdmap-ext-sam-1'
'Western Europe'	'here-hdmap-ext-weu-1'

You can set this property when you create the reader object. After you create the object, this property is read-only.

WriteLocation — Folder name of downloaded map data`tempdir` (temporary directory) (default) | string scalar | character vector

This property is read-only.

Name of folder to which HERE HDLM data is downloaded, specified as a string scalar or character vector. The specified folder must exist and have write permissions.

By default, data from the HERE HDLM web service is downloaded to a temporary file location. This temporary file location is deleted at the end of your MATLAB session.

You can set this property when you create the reader object. After you create the object, this property is read-only.

Example: "C:\Users\myName\HERE"

CoordinateFormat – Type of coordinate encoding format

'geographic' (default) | 'raw'

Type of coordinate encoding format to apply to geographic coordinate values, specified as either 'geographic' or 'raw'.

Format	Description	Example
'geographic'	Coordinate values are returned as (latitude, longitude) pairs with decimal degrees.	[42.3743 -71.0266]
'raw'	Coordinate values are returned in the default coordinate encoding format of the HERE HDLM service.	int64(5978842261285240832)

Object Functions

read Read HERE HD Live Map layer data
plot Plot HERE HD Live Map layer data

Examples

Plot and Stream Lane Topology Data from Driving Route

Use the HERE HD Live Map (HERE HDLM) service to read the lane topology data of a driving route and its surrounding area. Plot this data, and then stream the route on a geographic player.

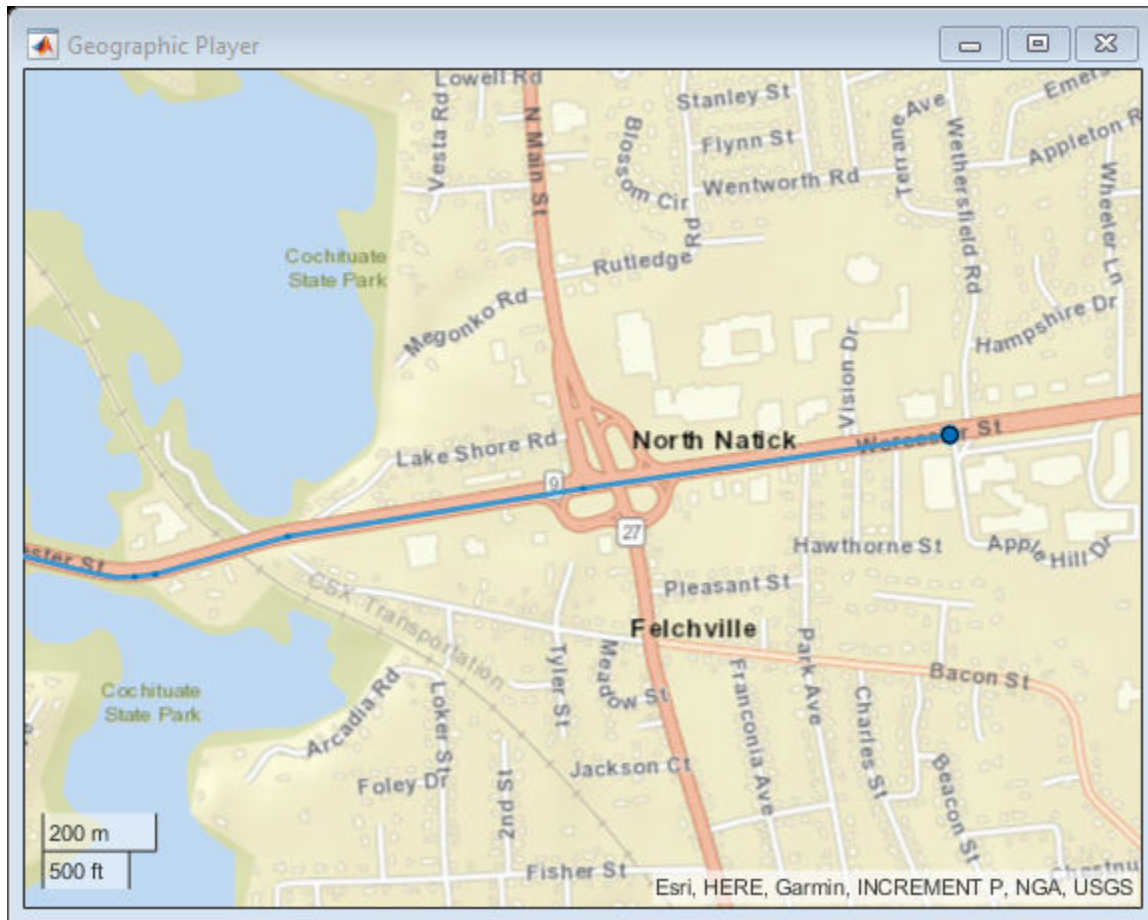
Load the latitude and longitude coordinates of a driving route in Natick, Massachusetts, USA.

```
route = load(fullfile(matlabroot, 'examples', 'driving', 'geoSequenceNatickMA.mat'));  
lat = route.latitude;  
lon = route.longitude;
```

Stream the coordinates on a geographic player.

```
player = geoplayer(lat(1), lon(1), 'HistoryDepth', 5);  
plotRoute(player, lat, lon)
```

```
for idx = 1:length(lat)  
    plotPosition(player, lat(idx), lon(idx))  
end
```

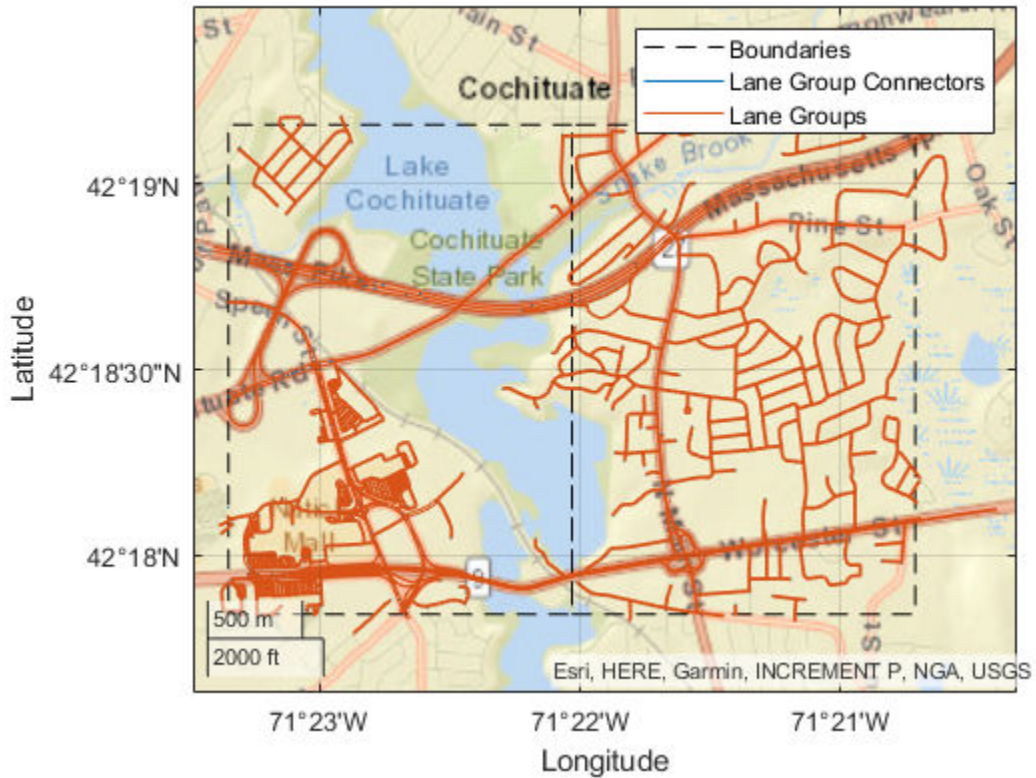


Create a HERE HDLM reader from the route coordinates. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. The reader contains map data for the two map tiles that the route crosses.

```
reader = hereHDLReader(lat,lon);
```

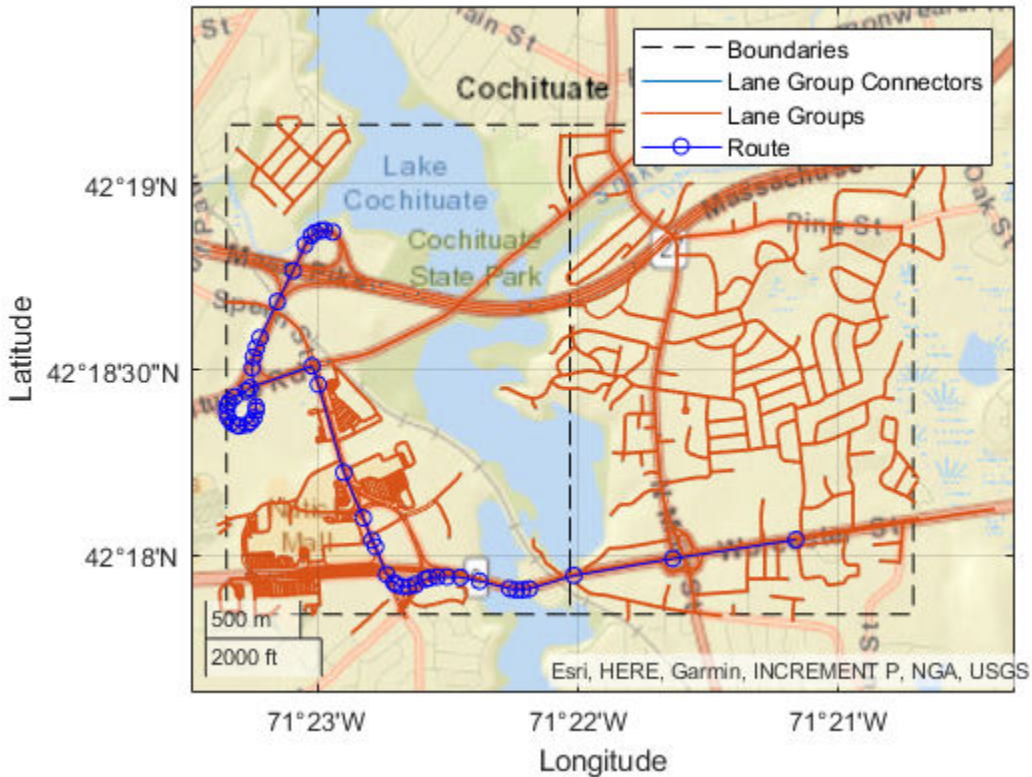
Read lane topology data from the LaneTopology layer of the map tiles. Plot the lane topology.

```
laneTopology = read(reader, 'LaneTopology');
plot(laneTopology)
```



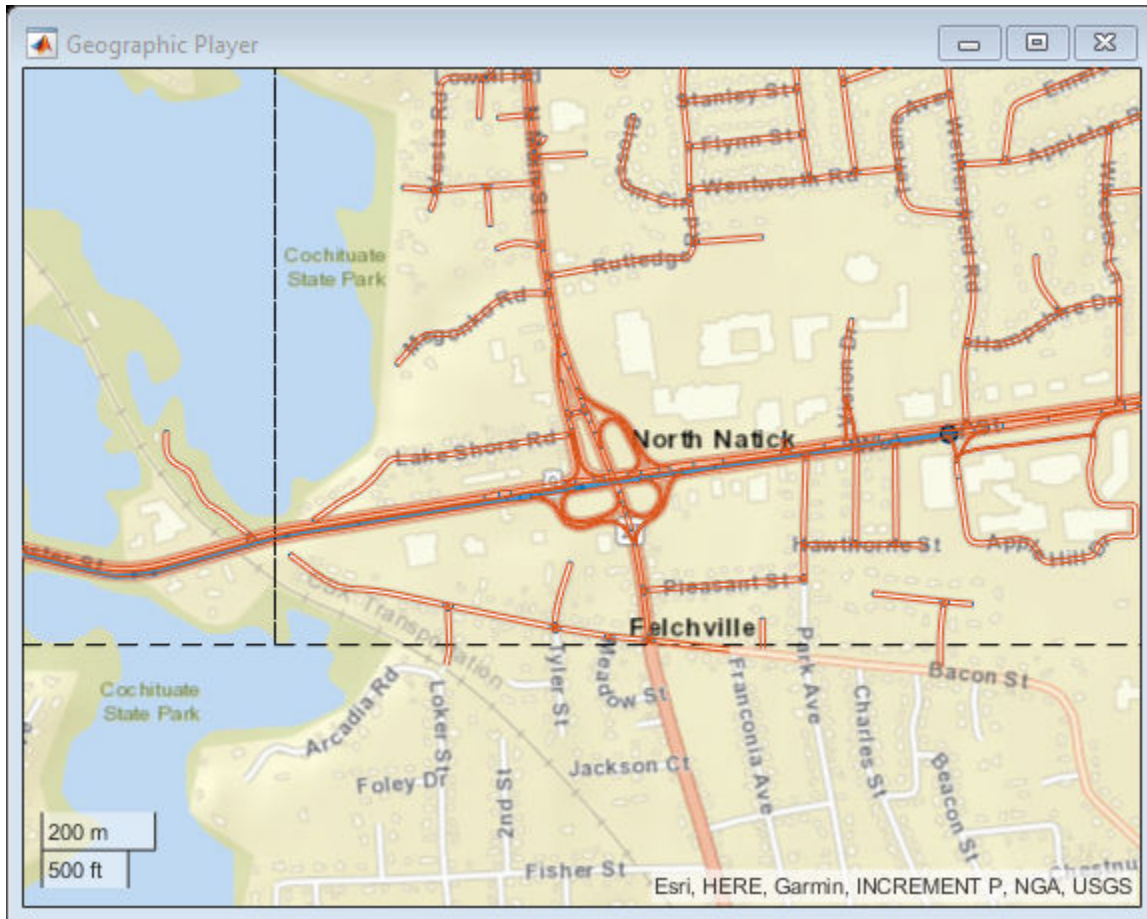
Overlay the route data on the plot.

```
hold on  
geoplot(lat,lon,'bo-','DisplayName','Route');  
hold off
```



Overlay the lane topology data on the geographic player. Stream the route again.

```
plot(laneTopology, 'Axes', player.Axes)
for idx = 1:length(lat)
    plotPosition(player, lat(idx), lon(idx))
end
```



Plot 3-D Lane Geometry on Custom Basemap

Use the HERE HD Live Map (HERE HDLM) web service to read 3-D lane geometry data from a map tile. Then, plot the data on an OpenStreetMap® basemap.

Create a HERE HDLM reader for a map tile ID representing an area of Berlin, Germany. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them.

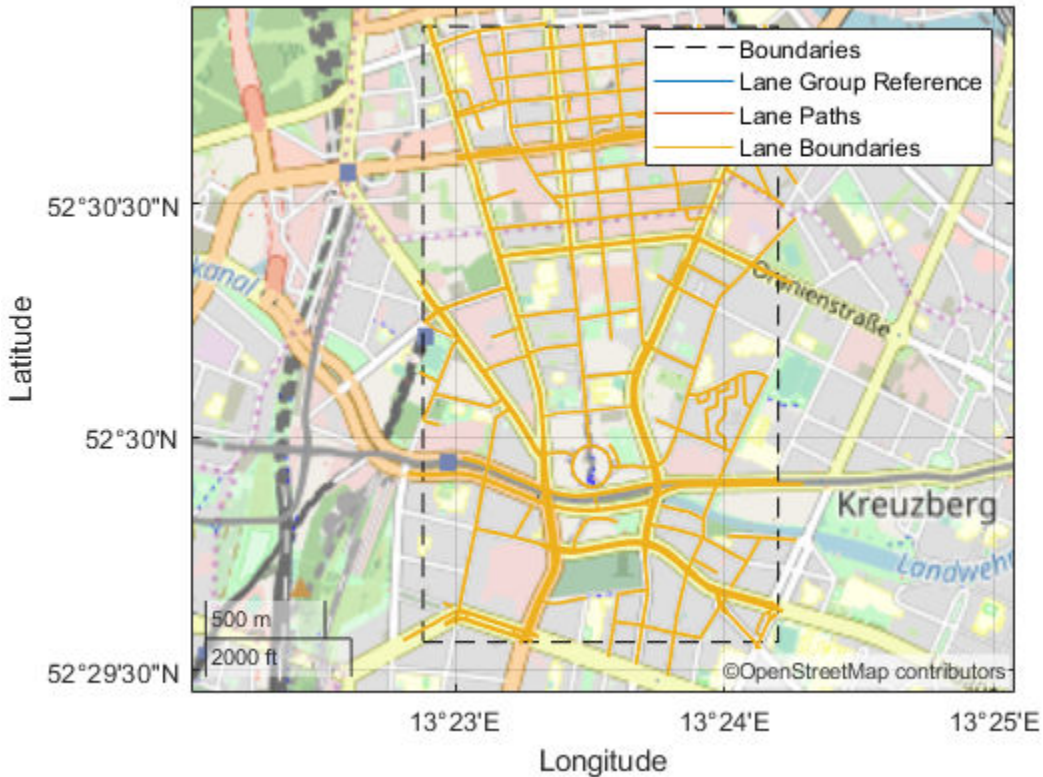
```
tileID = uint32(377894435);  
reader = hereHDLReader(tileID);
```

Add the OpenStreetMap basemap to the list of basemaps available for use with the HERE HDLM service. After you add the basemap, you do not need to add it again in future sessions.

```
name = 'openstreetmap';  
url = 'https://a.tile.openstreetmap.org/{z}/{x}/{y}.png';  
copyright = char(uint8(169));  
attribution = copyright + "OpenStreetMap contributors";  
addCustomBasemap(name,url,'Attribution',attribution)
```

Read 3-D lane geometry data from the LaneGeometryPolyline layer of the map tile. Plot the lane geometry on the openstreetmap basemap.

```
laneGeometryPolyline = read(reader,'LaneGeometryPolyline');  
gx = plot(laneGeometryPolyline);  
geobasemap(gx,'openstreetmap')
```

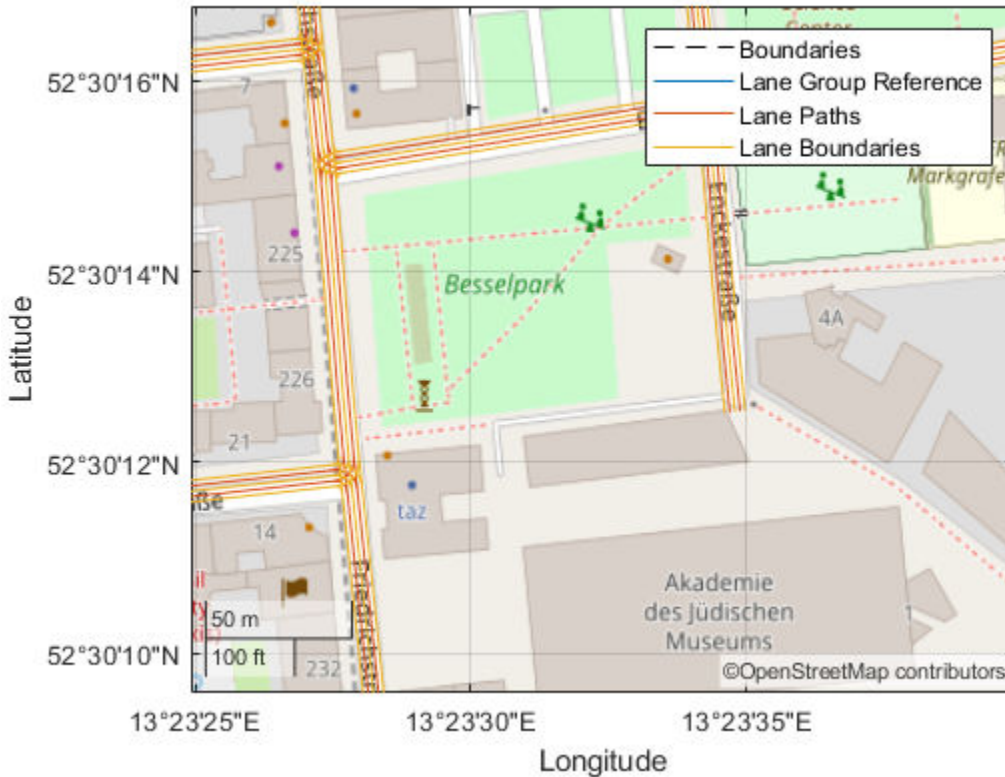



Zoom in on the central coordinate of the map tile.

```
latcenter = laneGeometryPolyline.TileCenterHere3dCoordinate.Here2dCoordinate(1);
loncenter = laneGeometryPolyline.TileCenterHere3dCoordinate.Here2dCoordinate(2);
```

```
offset = 0.001;
latlim = [latcenter-offset, latcenter+offset];
lonlim = [loncenter-offset, loncenter+offset];
```

```
geolimits(latlim, lonlim)
```



Find Shortest Path Between Two Nodes

Use the HERE HD Live Map (HERE HDLM) web service to read the topology geometry data from a map tile. Use this data to find the shortest path between two nodes within the map tile.

Define a HERE tile ID for an area of Stockholm, Sweden.

```
tileID = uint32(378373553);
```

Create a HERE HDLM reader for the tile ID. Configure the reader to search for the tile in only the Western Europe catalog. If you have not previously set up HERE HDLM

credentials, a dialog box prompts you to enter them. The reader contains map data for the specified map tile.

```
config = hereHDLMConfiguration('Western Europe');
reader = hereHDLMReader(tileID, 'Configuration', config);
```

Read the link definitions from the `TopologyGeometry` layer of the map tile. The returned layer object contains the specified `LinksStartingInTile` field and the required map tile fields, such as the tile ID. The other fields are empty. Your map data and catalog version might differ from the ones shown here.

```
topology = read(reader, 'TopologyGeometry', 'LinksStartingInTile')
```

```
topology =
  TopologyGeometry with properties:

  Data:
           HereTileId: 378373553
  IntersectingLinkRefs: []
  LinksStartingInTile: [1240x1 struct]
           NodesInTile: []
  TileCenterHere2dCoordinate: [59.3372 18.0505]

  Metadata:
           Catalog: 'here-hdmap-ext-weu-1'
  CatalogVersion: 3117
```

Use `plot` to visualize `TopologyGeometry` data.

Find the start and end nodes for each link in the `LinksStartingInTile` field.

```
startNodes = [topology.LinksStartingInTile.StartNodeId];
endNodesRef = [topology.LinksStartingInTile.EndNodeRef];
endNodes = [endNodesRef.NodeId];
```

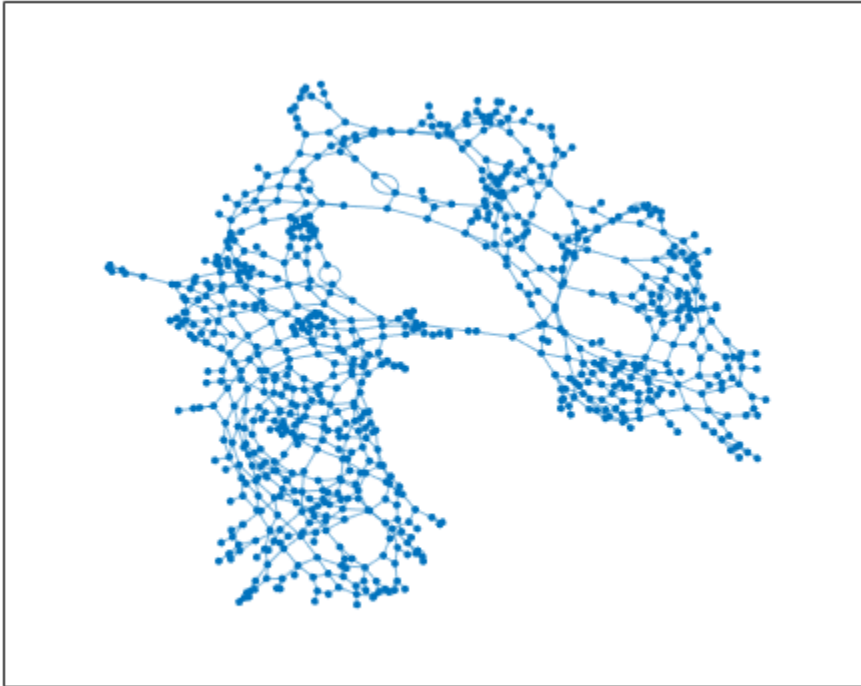
Find the length of each link in meters.

```
linkLengths = [topology.LinksStartingInTile.LinkLengthMeters];
```

Create an undirected graph for the links in the map tile.

```
G = graph(string(startNodes), string(endNodes), double(linkLengths));
H = plot(G, 'Layout', 'force');
title('Undirected Graph')
```

Undirected Graph

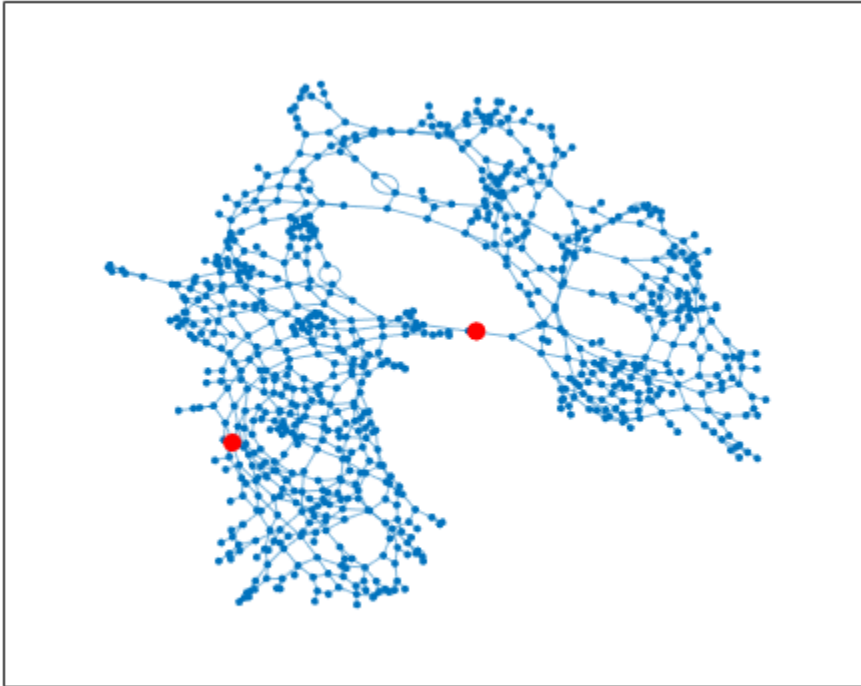


Specify a start and end node to find the shortest path between them. Use the first and last node in the graph as the start and end nodes, respectively. Overlay the nodes on the graph.

```
startNode = G.Nodes.Name(1);  
endNode = G.Nodes.Name(end);
```

```
highlight(H,[startNode endNode], 'NodeColor', 'red', 'MarkerSize', 6)  
title('Undirected Graph - Start and End Nodes')
```

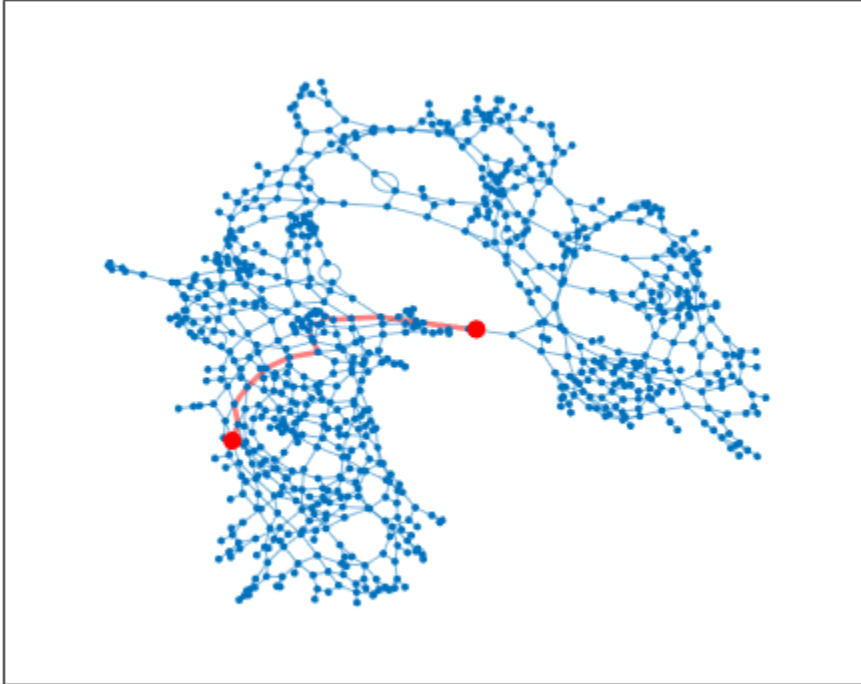
Undirected Graph - Start and End Nodes



Find the shortest path between the two nodes. Plot the path.

```
path = shortestpath(G,startNode,endNode);  
highlight(H,path,'EdgeColor','red','LineWidth',2);  
title('Undirected Graph - Shortest Path')
```

Undirected Graph - Shortest Path



Limitations

- hereHDLMReader objects do not work on Linux machines.
- The HERE HDLM web service determines the geographic coverage of the map data. Map data is not available for all locations.

Tips

- To speed up the performance of the reader, when creating the reader, specify a `hereHDLMConfiguration` object for the `Configuration` property. This object configures the reader to search for the selected map tiles from only a specific geographic region. If you do not specify a configuration object when you create the reader, the reader searches for the map tiles across all geographic regions.
- To save HERE HDLM credentials between MATLAB sessions, select the corresponding option in the HERE HD Live Map Credentials dialog box. To manage HERE HDLM credentials, use the `hereHDLMCredentials` function.

See Also

`geoplayer` | `geoplot` | `hereHDLMConfiguration` | `hereHDLMCredentials`

Topics

“Create Configuration for HERE HD Live Map Reader”

“Access HERE HD Live Map Data”

“HERE HD Live Map Layers”

“Use HERE HD Live Map Data to Verify Lane Configurations”

External Websites

HD Live Map Data Specification

Introduced in R2019a

read

Read HERE HD Live Map layer data

Syntax

```
layerData = read(reader, layerType)
layerData = read(reader, layerType, fields)
```

Description

`layerData = read(reader, layerType)` reads HERE HD Live Map³ (HERE HDLM) data of a specified layer type from a `hereHDLMReader` object and returns an array of layer objects. These layer objects contain map layer data for the HERE map tiles whose IDs correspond to the IDs stored in the `TileIds` property of `reader`.

`layerData = read(reader, layerType, fields)` returns an array of layer objects containing data for only the required fields, such as the `HereTileId` field, and for the specified fields. All other fields in the returned layer objects are returned as empty: `[]`. If you do not require data from all fields within the layer objects, use this syntax to speed up performance of this function.

Examples

Plot and Stream Lane Topology Data from Driving Route

Use the HERE HD Live Map (HERE HDLM) service to read the lane topology data of a driving route and its surrounding area. Plot this data, and then stream the route on a geographic player.

Load the latitude and longitude coordinates of a driving route in Natick, Massachusetts, USA.

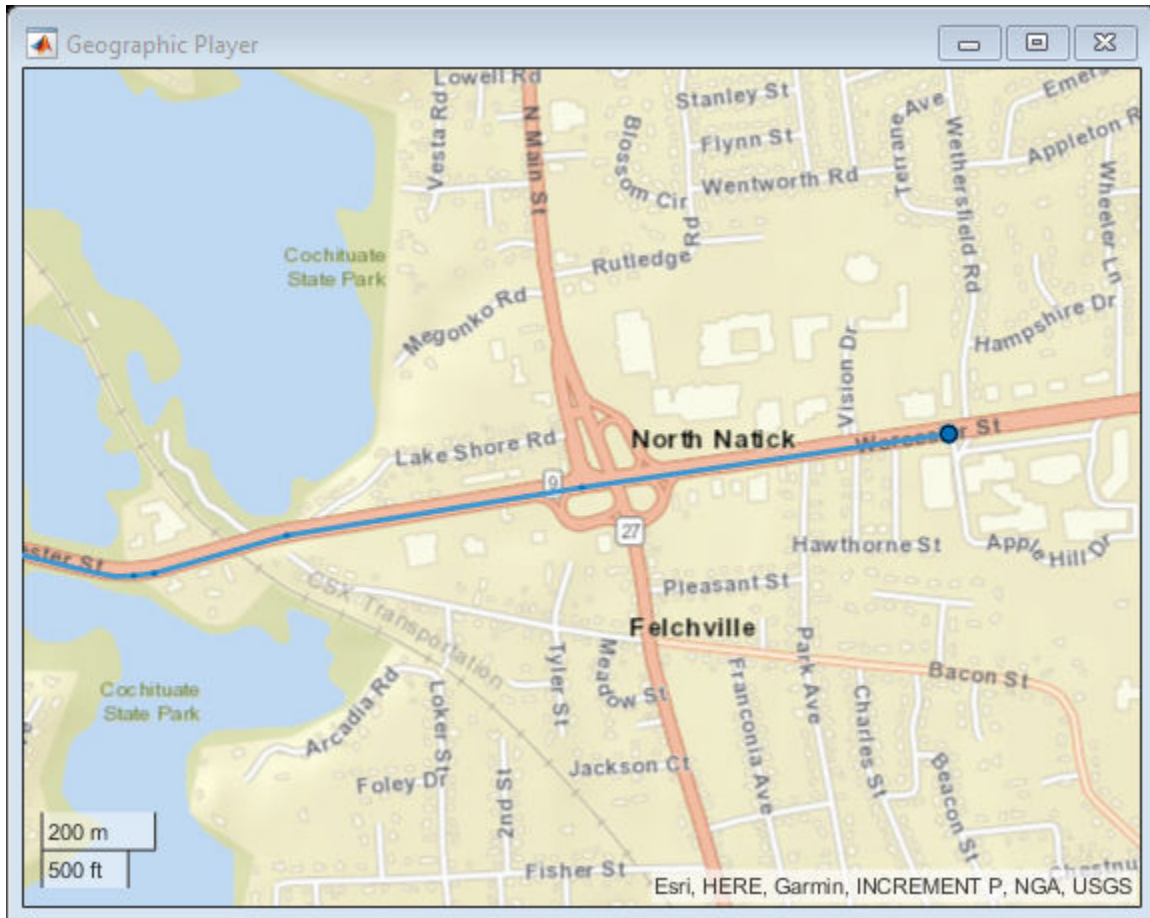
3. You need to enter into a separate agreement with HERE in order to gain access to the HDLM services and to get the required credentials (`app_id` and `app_code`) for using the HERE Service.


```
route = load(fullfile(matlabroot, 'examples', 'driving', 'geoSequenceNatickMA.mat'));
lat = route.latitude;
lon = route.longitude;
```

Stream the coordinates on a geographic player.

```
player = geoplayer(lat(1),lon(1), 'HistoryDepth',5);
plotRoute(player, lat, lon)
```

```
for idx = 1:length(lat)
    plotPosition(player, lat(idx), lon(idx))
end
```

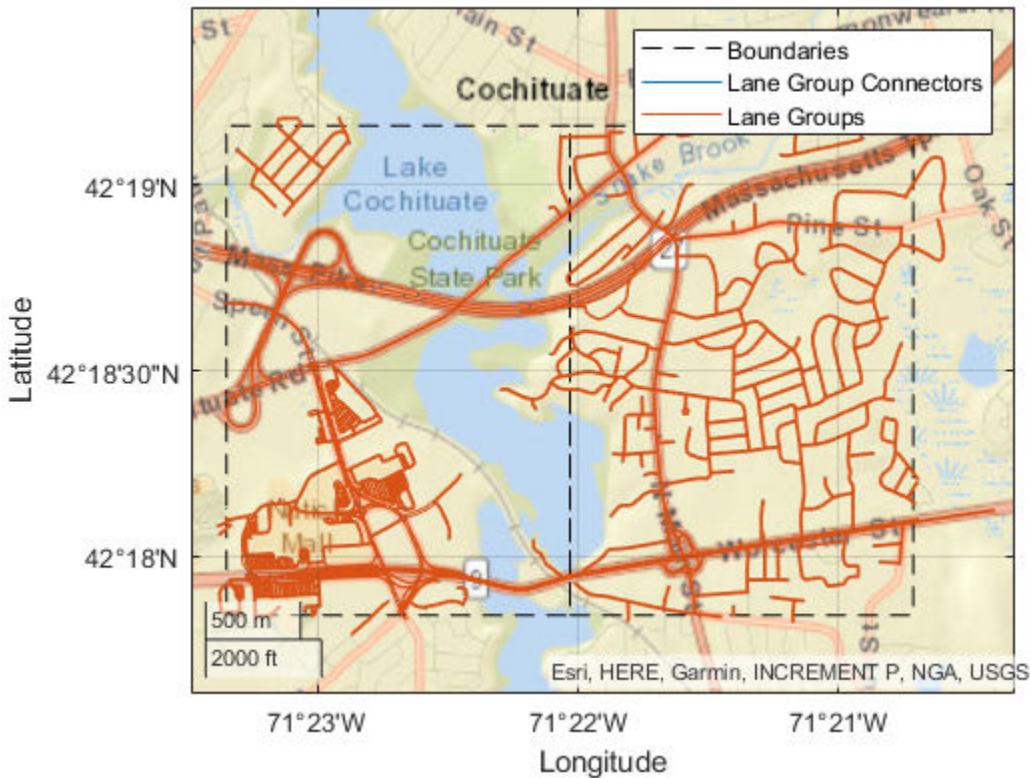


Create a HERE HDLM reader from the route coordinates. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. The reader contains map data for the two map tiles that the route crosses.

```
reader = hereHDLMReader(lat,lon);
```

Read lane topology data from the LaneTopology layer of the map tiles. Plot the lane topology.

```
laneTopology = read(reader,'LaneTopology');  
plot(laneTopology)
```

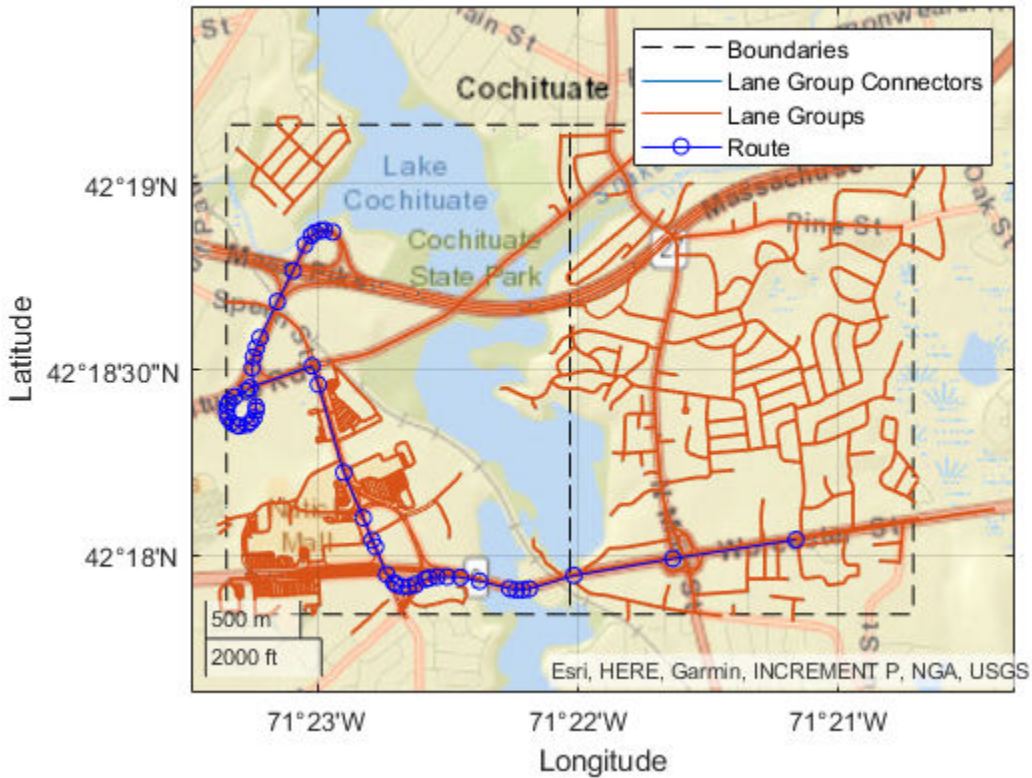


Overlay the route data on the plot.

```

hold on
geoplot(lat,lon,'bo-','DisplayName','Route');
hold off

```

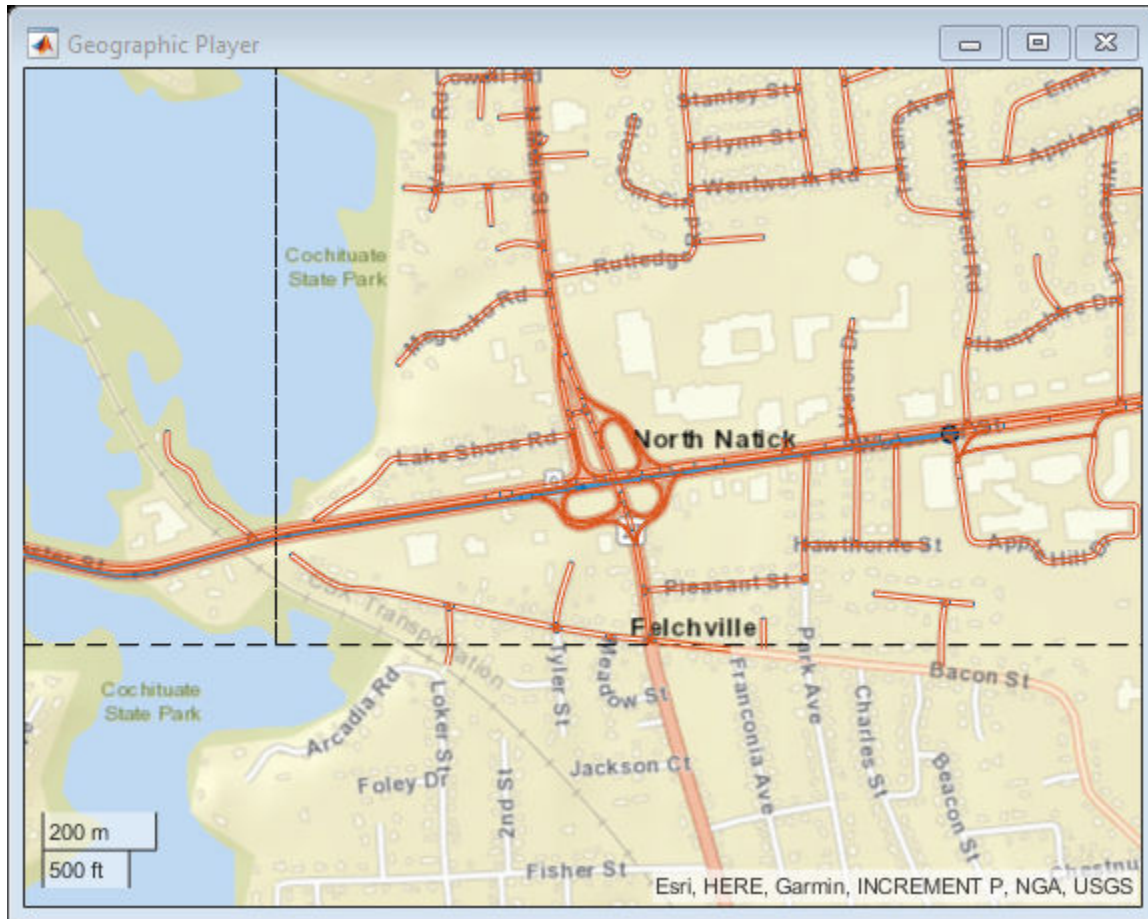


Overlay the lane topology data on the geographic player. Stream the route again.

```

plot(laneTopology,'Axes',player.Axes)
for idx = 1:length(lat)
    plotPosition(player,lat(idx),lon(idx))
end

```



Find Shortest Path Between Two Nodes

Use the HERE HD Live Map (HERE HDLM) web service to read the topology geometry data from a map tile. Use this data to find the shortest path between two nodes within the map tile.

Define a HERE tile ID for an area of Stockholm, Sweden.

```
tileID = uint32(378373553);
```

Create a HERE HDLM reader for the tile ID. Configure the reader to search for the tile in only the Western Europe catalog. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. The reader contains map data for the specified map tile.

```
config = hereHDLConfiguration('Western Europe');
reader = hereHDLReader(tileID, 'Configuration', config);
```

Read the link definitions from the TopologyGeometry layer of the map tile. The returned layer object contains the specified LinksStartingInTile field and the required map tile fields, such as the tile ID. The other fields are empty. Your map data and catalog version might differ from the ones shown here.

```
topology = read(reader, 'TopologyGeometry', 'LinksStartingInTile')
```

```
topology =
  TopologyGeometry with properties:

    Data:
           HereTileId: 378373553
    IntersectingLinkRefs: []
    LinksStartingInTile: [1240x1 struct]
           NodesInTile: []
    TileCenterHere2dCoordinate: [59.3372 18.0505]

    Metadata:
           Catalog: 'here-hdmap-ext-weu-1'
    CatalogVersion: 3117
```

Use plot to visualize TopologyGeometry data.

Find the start and end nodes for each link in the LinksStartingInTile field.

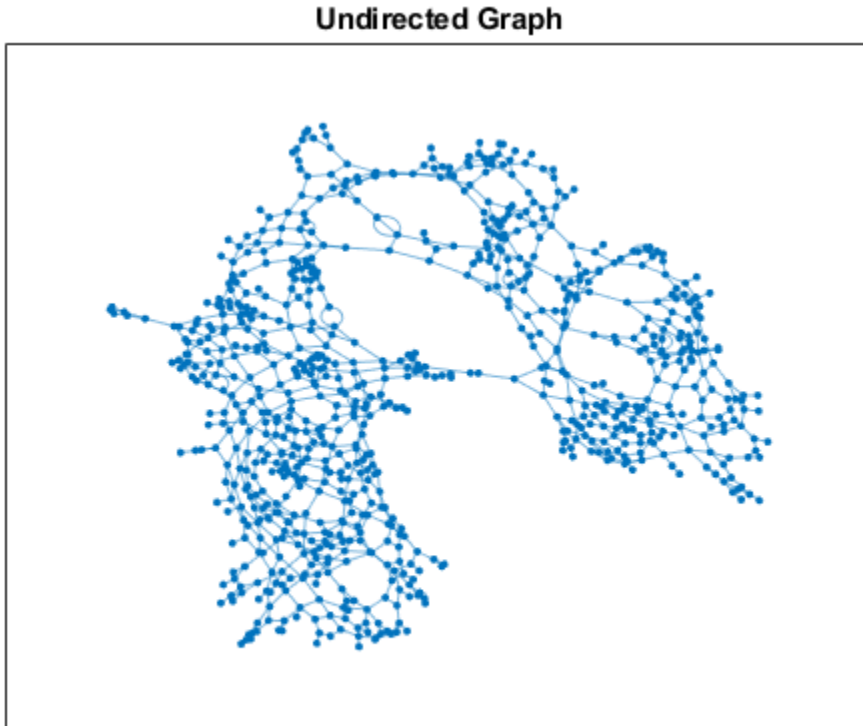
```
startNodes = [topology.LinksStartingInTile.StartNodeId];
endNodesRef = [topology.LinksStartingInTile.EndNodeRef];
endNodes = [endNodesRef.NodeId];
```

Find the length of each link in meters.

```
linkLengths = [topology.LinksStartingInTile.LinkLengthMeters];
```

Create an undirected graph for the links in the map tile.

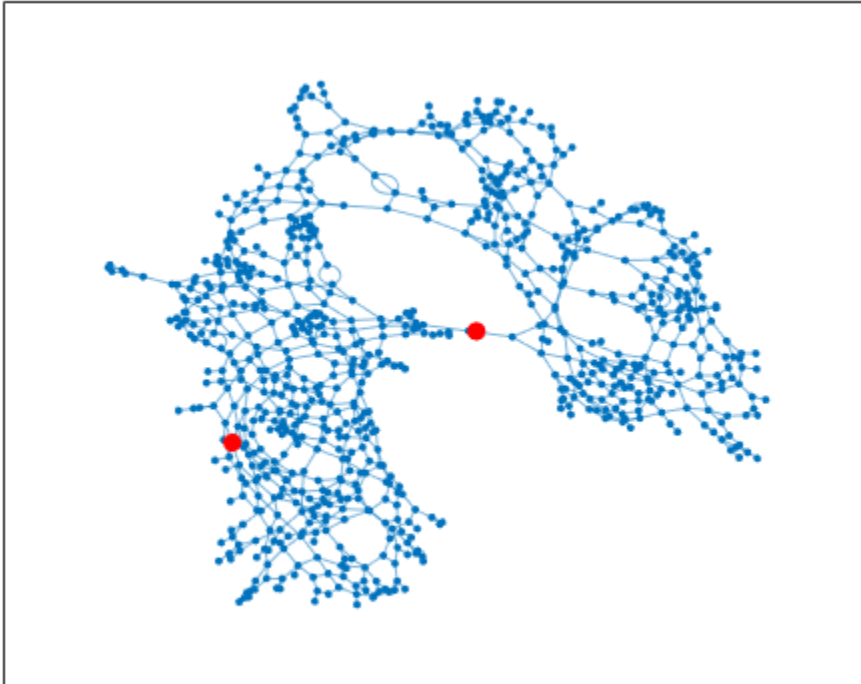
```
G = graph(string(startNodes),string(endNodes),double(linkLengths));  
H = plot(G,'Layout','force');  
title('Undirected Graph')
```



Specify a start and end node to find the shortest path between them. Use the first and last node in the graph as the start and end nodes, respectively. Overlay the nodes on the graph.

```
startNode = G.Nodes.Name(1);  
endNode = G.Nodes.Name(end);  
  
highlight(H,[startNode endNode],'NodeColor','red','MarkerSize',6)  
title('Undirected Graph - Start and End Nodes')
```

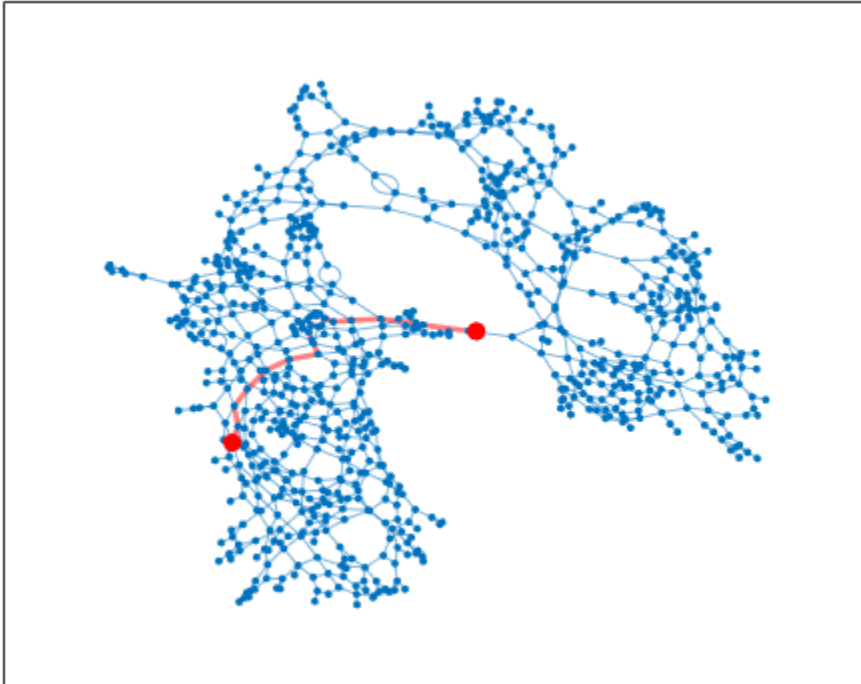
Undirected Graph - Start and End Nodes



Find the shortest path between the two nodes. Plot the path.

```
path = shortestpath(G,startNode,endNode);  
highlight(H,path,'EdgeColor','red','LineWidth',2);  
title('Undirected Graph - Shortest Path')
```

Undirected Graph - Shortest Path



Input Arguments

reader — Input HERE HDLM reader

hereHDLMReader object

Input HERE HDLM reader, specified as a hereHDLMReader object.

layerType — Layer type

string scalar | character vector

Layer type from which to read data, specified as a string scalar or character vector. `layerType` must be a valid layer type for the map tiles stored in `reader`. To see the list of valid layers, use the `Layers` property of `reader`.

Example: "AdasAttributes"

Example: 'LaneTopology'

fields — Layer object fields

string scalar | character vector | string array | cell array of character vectors

Layer object fields from which to read data, specified as a string scalar, character vector, string array, or cell array of character vectors. All fields must be valid fields of the layer specified by `layerType`. You can specify only the top-level fields of this layer. You cannot specify its metadata fields.

In the returned array of layer objects, only required fields, such as the `HereTileId` field, and the specified fields contain data. All other fields are returned as empty: `[]`.

For a list of the valid top-level data fields for each layer type, see the `data output` argument.

Example: 'LinkAttribution'

Example: "NodeAttribution"

Example: ["LinkAttribution" "NodeAttribution"]

Example: {'LinkAttribution', 'NodeAttribution'}

Output Arguments

layerData — HERE HDLM layer data

T-by-1 array of layer objects

HERE HDLM layer data, returned as a *T*-by-1 array of layer objects. *T* is the number of map tile IDs stored in the `TileIds` property of the specified `reader`. Each layer object contains map data that is of type `layerType`, for a HERE map tile that was read from `reader`. Such data can include the geometry of links (streets) and nodes (intersections and dead-ends) within the map tiles, as well as various road-level and lane-level attributes. The layer objects also contain metadata specifying the catalog and catalog version from which the `read` function obtained the data.

The properties of the layer objects correspond to valid HERE HDLM layer fields. In these layer objects, the names of the layer fields are modified to fit the MATLAB naming convention for object properties. For each layer field name, the first letter and first letter after each underscore are capitalized and the underscores are removed. This table shows sample name changes.

HERE HDLM Layer Fields	MATLAB Layer Object Property
here_tile_id	HereTileId
tile_center_here_2d_coordinate	TileCenterHere2dCoordinate
nodes_in_tile	NodesInTile

The layer objects are MATLAB structures whose properties correspond to structure fields. To access data from these fields, use dot notation.

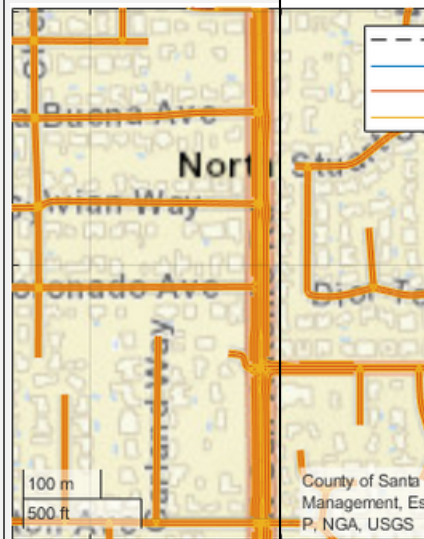
For example, this code selects the `NodeId` subfield from the `NodeAttribution` field of a layer:

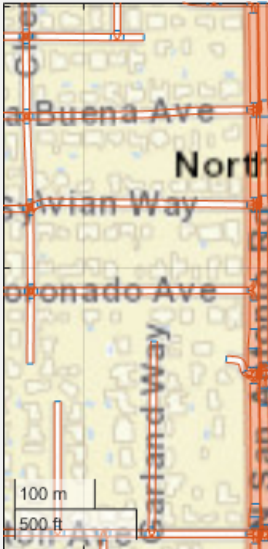
```
layerData.NodeAttribution.NodeId
```

This table summarizes the valid types of layer objects and their top-level data fields. The available layers are for the Road Centerline Model and HD Lane Model. For an overview of HERE HDLM layers and the models they belong to, see “HERE HD Live Map Layers”. For a full description of the fields, see HD Live Map Data Specification on the HERE Technologies website.

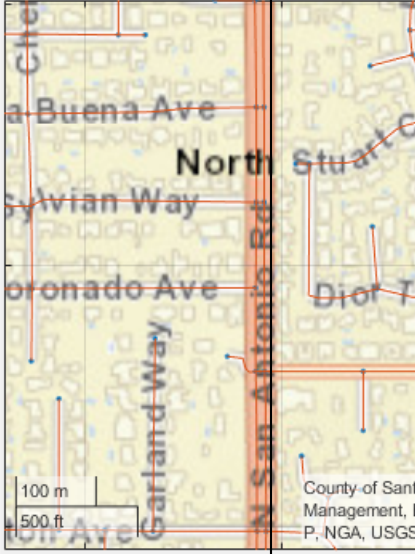
Layer Object	Description	Top-Level Data Fields (Layer Object Properties)	Plot Support
<code>AdasAttributes</code>	Precision geometry measurements, such as slope, elevation, and curvature of roads. Use this data to develop advanced driver assistance systems (ADAS).	<ul style="list-style-type: none"> • <code>HereTileId</code> • <code>LinkAttribution</code> • <code>NodeAttribution</code> 	Not available

Layer Object	Description	Top-Level Data Fields (Layer Object Properties)	Plot Support
ExternalReferenceAttributes	References to external map links, nodes, and topologies for other HERE maps.	<ul style="list-style-type: none"> • HereTileId • LinkAttribution • NodeAttribution 	Not available
LaneAttributes	Lane-level attributes, such as direction of travel and lane type.	<ul style="list-style-type: none"> • HereTileId • LaneGroupAttribution 	Not available
LaneGeometryPolyline	3-D lane geometry composed of a set of 3-D points joined into polylines.	<ul style="list-style-type: none"> • HereTileId • TileCenterHere3dCoordinate • LaneGroupGeometries 	Available — Use the plot function.



Layer Object	Description	Top-Level Data Fields (Layer Object Properties)	Plot Support
LaneRoadReferences	Road and lane group references and range information. Use this data to translate positions between the Road Centerline Model and the HD Lane Model.	<ul style="list-style-type: none"> • HereTileId • LaneGroupLinkReferences • LinkLaneGroupReferences 	Not available
LaneTopology	Topologies of the HD Lane model, including lane group, lane group connector, lane, and lane connector topologies. This layer also contains the simplified 2-D boundary geometry of the lane model for determining map tile affinity and overflow.	<ul style="list-style-type: none"> • HereTileId • TileCenterHere2dCoordinate • LaneGroupsStartingInTile • LaneGroupConnectorsInTile • IntersectingLaneGroupRefs 	Available — Use the plot function. 

Layer Object	Description	Top-Level Data Fields (Layer Object Properties)	Plot Support
RoutingAttributes	Road attributes related to navigation and conditions. These attributes are mapped parametrically to the 2-D polyline geometry in the topology layer.	<ul style="list-style-type: none"> • HereTileId • LinkAttribution • NodeAttribution • StrandAttribution • AttributionGroupList 	Not available
RoutingLaneAttributes	Core navigation lane attributes and conditions, such as the number of lanes in a road. These values are mapped parametrically to 2-D polylines along the road links.	<ul style="list-style-type: none"> • HereTileId • LinkAttribution 	Not available
SpeedAttributes	Speed-related road attributes, such as speed limits. These attributes are mapped to the 2-D polyline geometry of the topology layer.	<ul style="list-style-type: none"> • HereTileId • LinkAttribution 	Not available

Layer Object	Description	Top-Level Data Fields (Layer Object Properties)	Plot Support
TopologyGeometry	Topology and 2-D line geometry of the road. This layer also contains definitions of the nodes and links in the map tile.	<ul style="list-style-type: none"> • HereTileId • TileCenterHere2dCoordinate • NodesInTile • LinksStartingInTile • IntersectingLinkRefs 	Available — Use the plot function. 

See Also

[hereHDLConfiguration](#) | [hereHDLCredentials](#) | [hereHDLReader](#) | [plot](#)

Topics

- “Read and Visualize Data Using HERE HD Live Map Reader”
- “Access HERE HD Live Map Data”
- “HERE HD Live Map Layers”
- “Use HERE HD Live Map Data to Verify Lane Configurations”

External Websites

HD Live Map Data Specification

Introduced in R2019a

plot

Package: `driving.heremaps`

Plot HERE HD Live Map layer data

Syntax

```
plot(layerData)
plot(layerData, 'Axes', gxIn)
gxOut = plot( ___ )
```

Description

`plot(layerData)` plots HERE HD Live Map⁴ (HERE HDLM) layer data on a geographic axes. `layerData` is a map layer object that was read from the selected tiles of a `hereHDLMReader` object by using the `read` function.

`plot(layerData, 'Axes', gxIn)` plots the layer data in the specified geographic axes, `gxIn`.

`gxOut = plot(___)` plots the layer data and returns the geographic axes on which the data was plotted, using the inputs from any of the preceding syntaxes. Use `gxOut` to modify properties of the geographic axes.

Examples

Plot Road Topology Data from Driving Route

Load a sequence of latitude and longitude coordinates from a driving route.

```
data = load('geoSequence.mat')
```

4. You need to enter into a separate agreement with HERE in order to gain access to the HDLM services and to get the required credentials (`app_id` and `app_code`) for using the HERE Service.

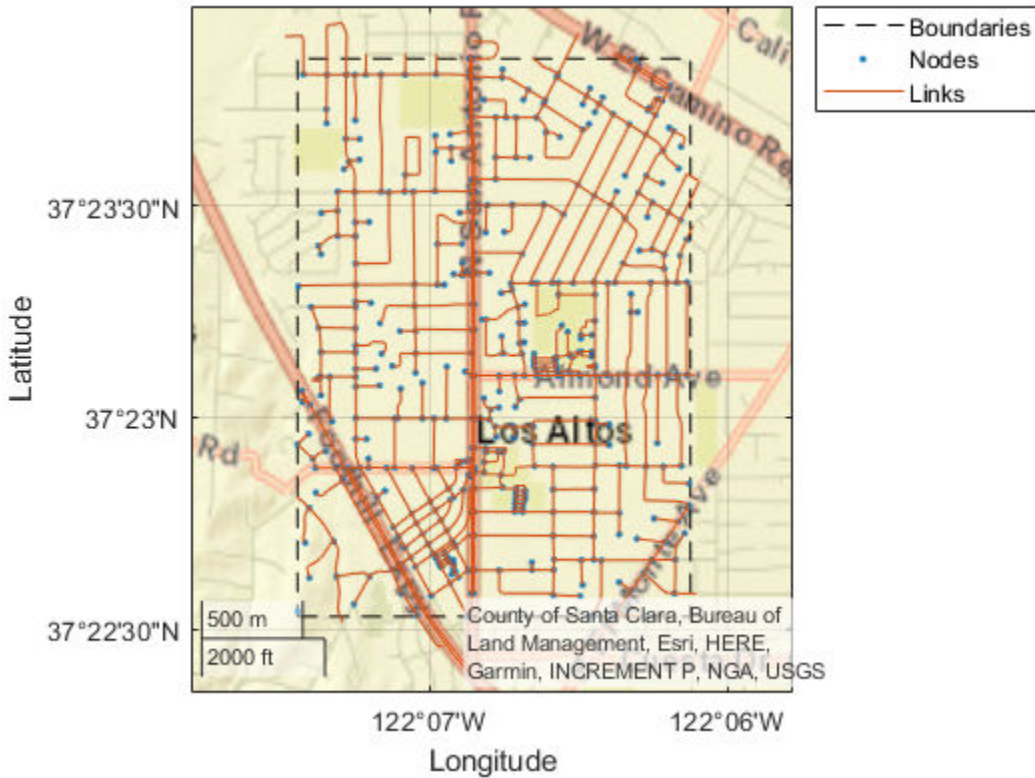

```
data = struct with fields:
    latitude: [1000x1 double]
    longitude: [1000x1 double]
```

Create a HERE HD Live Map (HERE HDLM) reader from the specified coordinates. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. The reader contains layered map data for the tile that the driving route is on.

```
reader = hereHDLMReader(data.latitude,data.longitude);
```

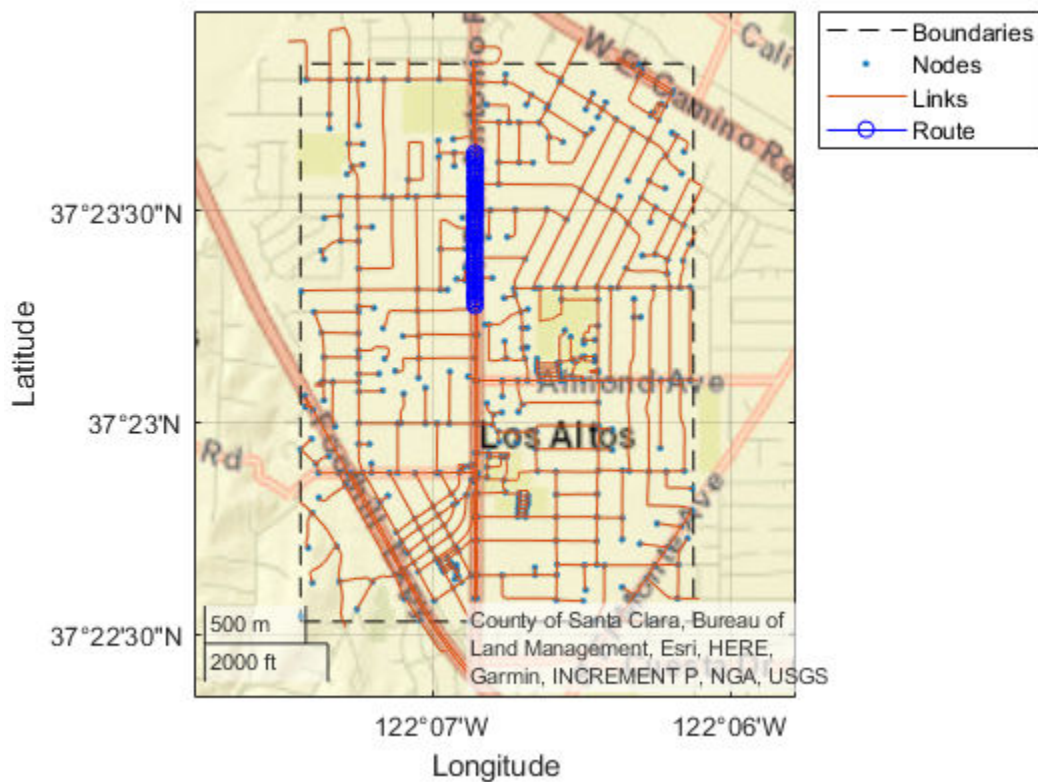
Read road topology data from the TopologyGeometry layer. Plot the data.

```
roadTopology = read(reader,'TopologyGeometry');
plot(roadTopology)
legend('Location','northeastoutside')
```



Overlay the driving route coordinates on the plot.

```
hold on  
geoplot(data.latitude,data.longitude,'bo-','DisplayName','Route')  
hold off
```



Zoom in on the route.

```
latcenter = median(data.latitude);
loncenter = median(data.longitude);
```

```
offset = 0.005;
latlim = [latcenter-offset, latcenter+offset];
lonlim = [loncenter-offset, loncenter+offset];
```

```
geolimits(latlim, lonlim)
```



Plot and Stream Lane Topology Data from Driving Route

Use the HERE HD Live Map (HERE HDLM) service to read the lane topology data of a driving route and its surrounding area. Plot this data, and then stream the route on a geographic player.

Load the latitude and longitude coordinates of a driving route in Natick, Massachusetts, USA.

```
route = load(fullfile(matlabroot, 'examples', 'driving', 'geoSequenceNatickMA.mat'));
lat = route.latitude;
lon = route.longitude;
```

Stream the coordinates on a geographic player.

```
player = geoplayer(lat(1),lon(1), 'HistoryDepth',5);
plotRoute(player, lat, lon)
```

```
for idx = 1:length(lat)
    plotPosition(player, lat(idx), lon(idx))
end
```

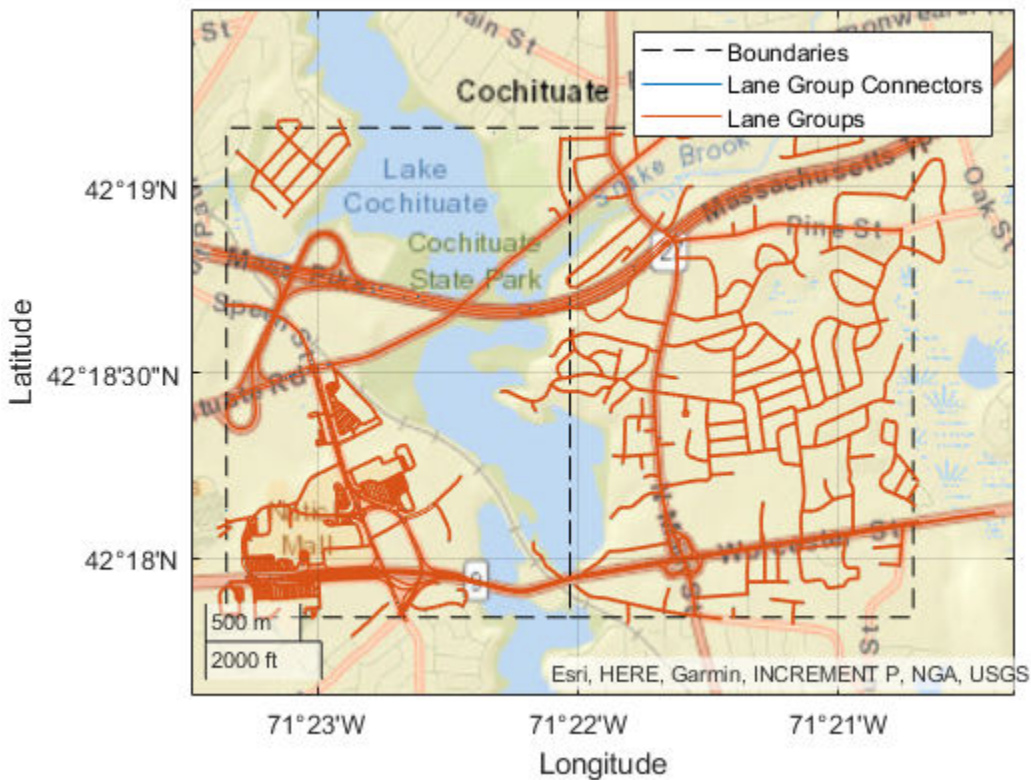


Create a HERE HDLM reader from the route coordinates. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. The reader contains map data for the two map tiles that the route crosses.

```
reader = hereHDLReader(lat,lon);
```

Read lane topology data from the LaneTopology layer of the map tiles. Plot the lane topology.

```
laneTopology = read(reader,'LaneTopology');  
plot(laneTopology)
```

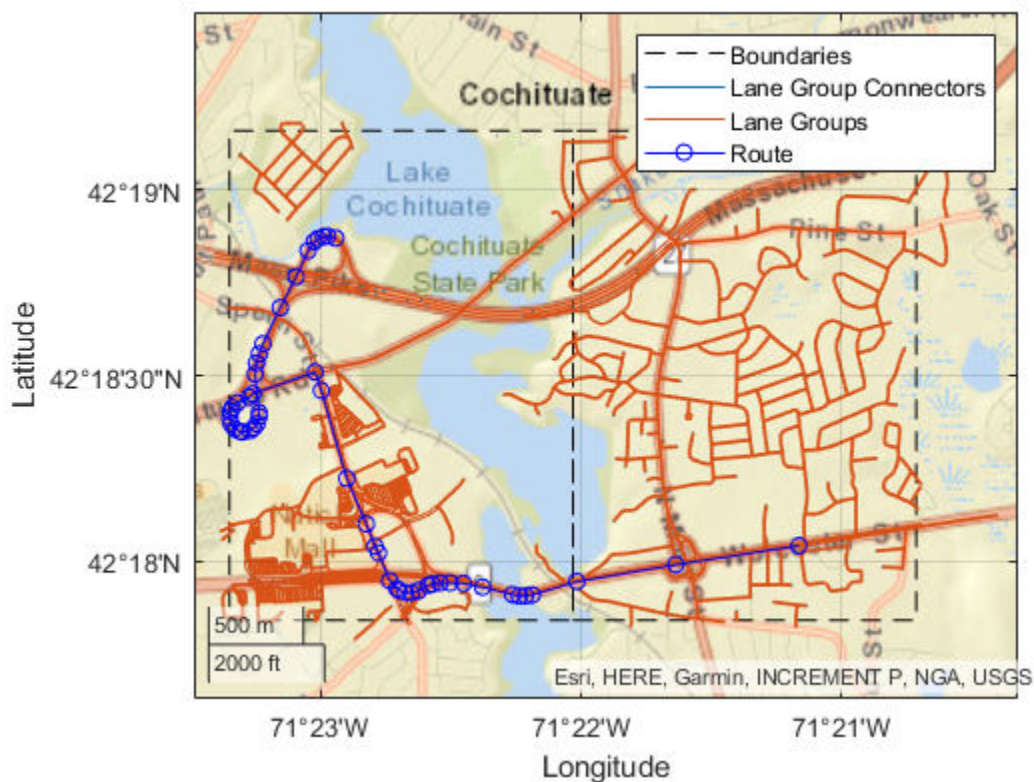


Overlay the route data on the plot.

```

hold on
geoplot(lat,lon,'bo-','DisplayName','Route');
hold off

```

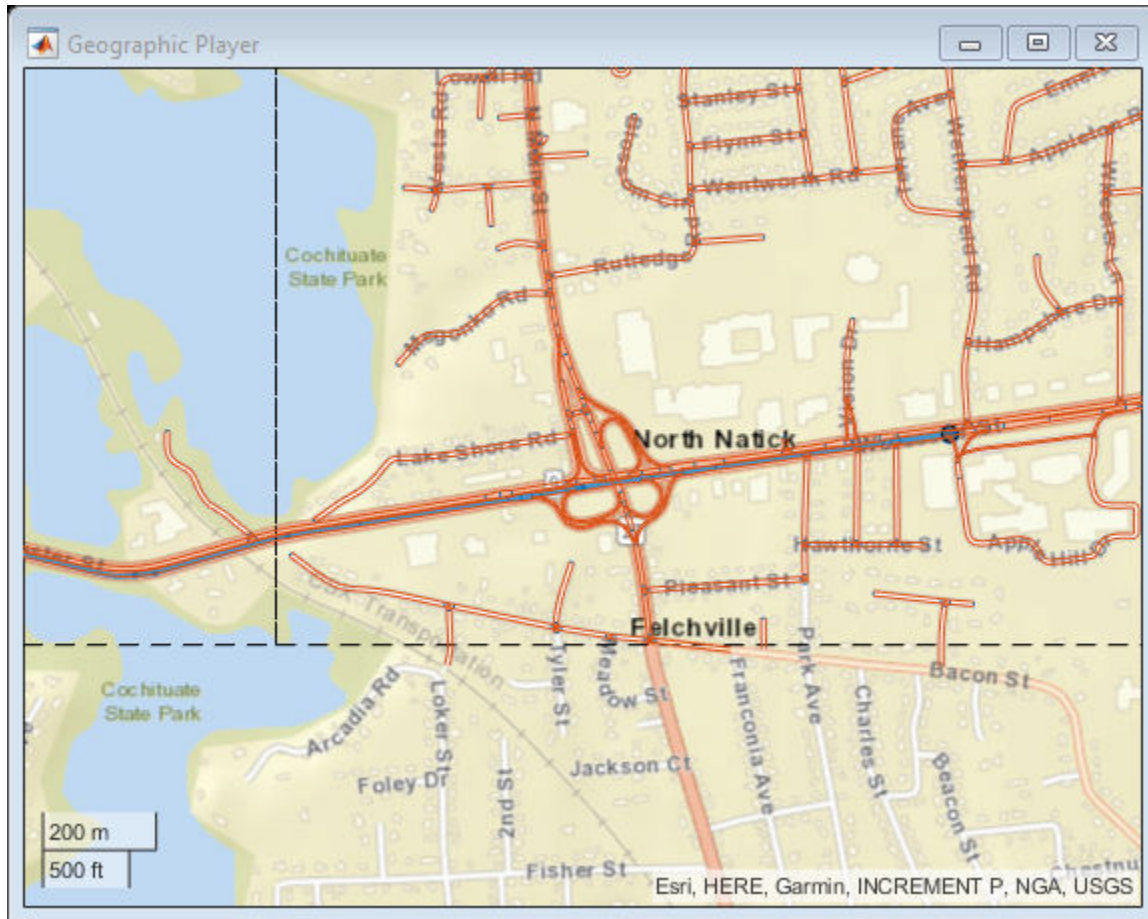


Overlay the lane topology data on the geographic player. Stream the route again.

```

plot(laneTopology, 'Axes', player.Axes)
for idx = 1:length(lat)
    plotPosition(player, lat(idx), lon(idx))
end

```



Plot 3-D Lane Geometry on Custom Basemap

Use the HERE HD Live Map (HERE HDLM) web service to read 3-D lane geometry data from a map tile. Then, plot the data on an OpenStreetMap® basemap.

Create a HERE HDLM reader for a map tile ID representing an area of Berlin, Germany. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them.

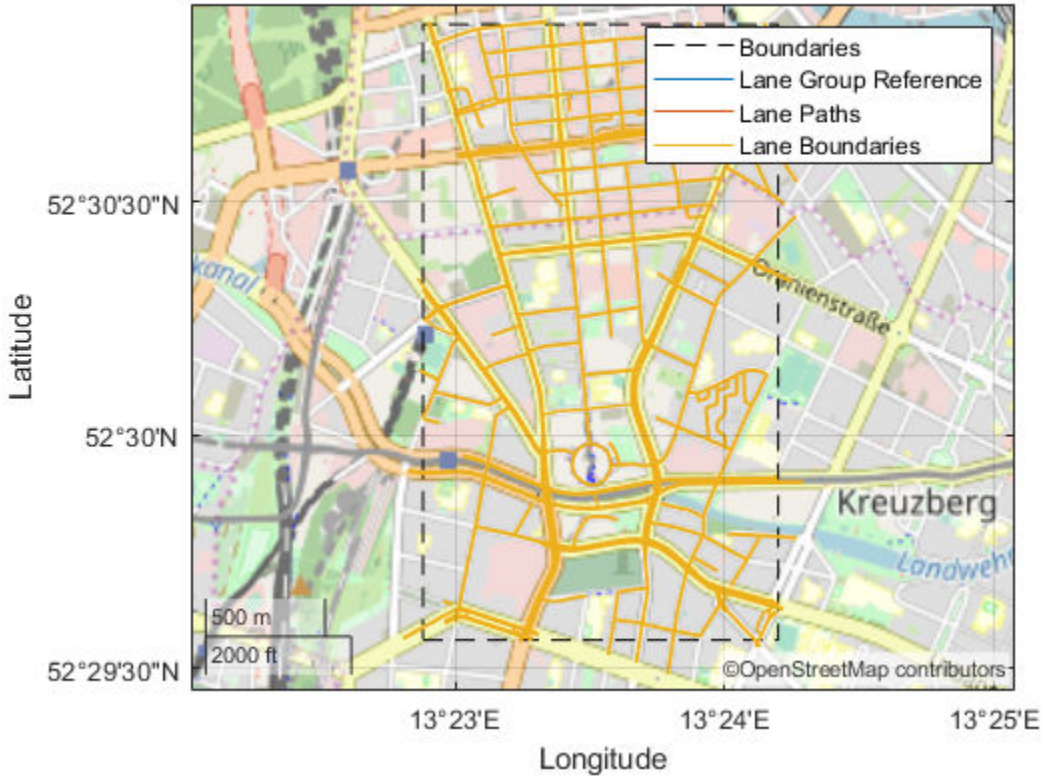

```
tileID = uint32(377894435);  
reader = hereHDLMReader(tileID);
```

Add the OpenStreetMap basemap to the list of basemaps available for use with the HERE HDLM service. After you add the basemap, you do not need to add it again in future sessions.

```
name = 'openstreetmap';  
url = 'https://a.tile.openstreetmap.org/{z}/{x}/{y}.png';  
copyright = char(uint8(169));  
attribution = copyright + "OpenStreetMap contributors";  
addCustomBasemap(name,url,'Attribution',attribution)
```

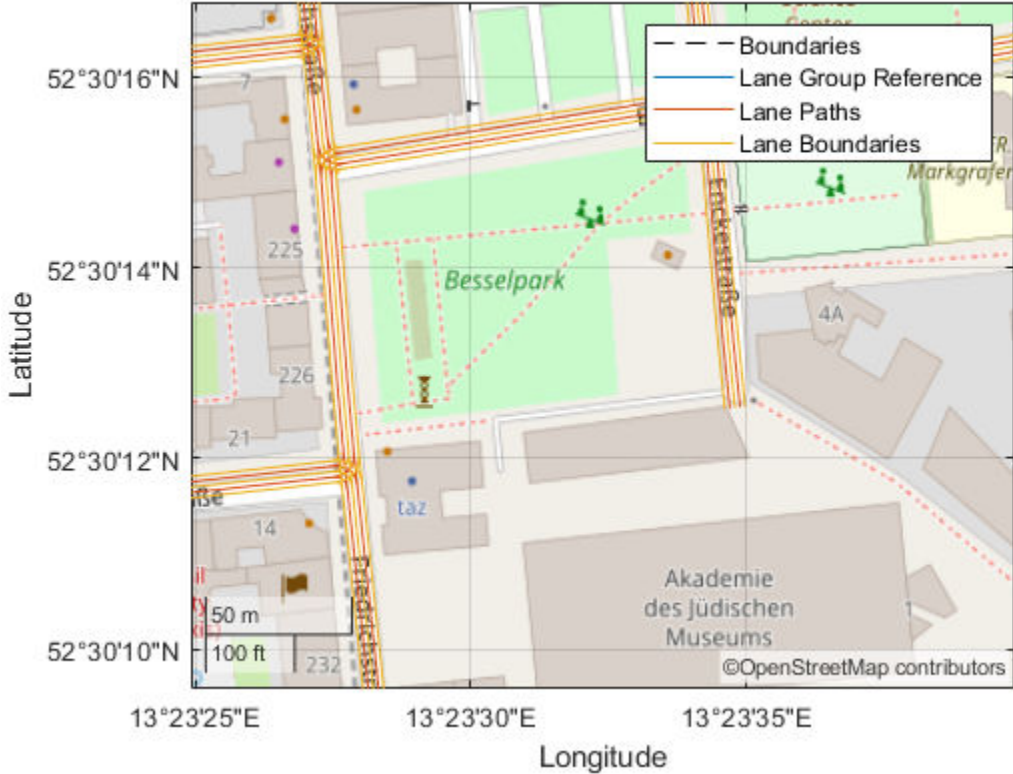
Read 3-D lane geometry data from the LaneGeometryPolyline layer of the map tile. Plot the lane geometry on the openstreetmap basemap.

```
laneGeometryPolyline = read(reader,'LaneGeometryPolyline');  
gx = plot(laneGeometryPolyline);  
geobasemap(gx,'openstreetmap')
```



Zoom in on the central coordinate of the map tile.

```
latcenter = laneGeometryPolyline.TileCenterHere3dCoordinate.Here2dCoordinate(1);  
loncenter = laneGeometryPolyline.TileCenterHere3dCoordinate.Here2dCoordinate(2);  
  
offset = 0.001;  
latlim = [latcenter-offset, latcenter+offset];  
lonlim = [loncenter-offset, loncenter+offset];  
  
geolimits(latlim, lonlim)
```



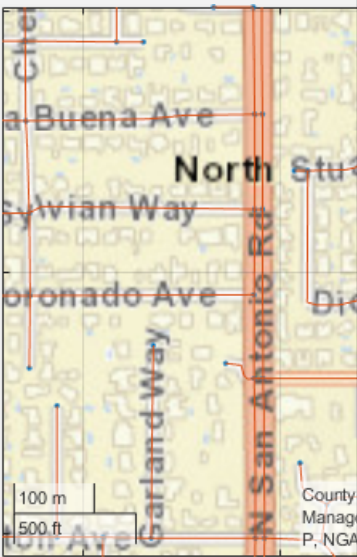
Input Arguments

layerData — HERE HDLM layer data

LaneGeometryPolyline object | LaneTopology object | TopologyGeometry object

HERE HDLM layer data to plot, specified as one of the layer objects shown in the table.

Layer Object	Description	Sample Plot
LaneGeometryPolyline	3-D lane geometry composed of a set of 3-D points joined into polylines.	
LaneTopology	Topologies of the HD Lane model, including lane group, lane group connector, lane, and lane connector topologies. This layer also contains the simplified 2-D boundary geometry of the lane model for determining map tile affinity and overflow.	

Layer Object	Description	Sample Plot
TopologyGeometry	Topology and 2-D line geometry of the road. This layer also contains definitions of the links (streets) and nodes (intersections and dead-ends) in the map tile.	

To obtain these layers from map tiles selected by a `hereHDLReader` object, use the `read` function.

gxIn — Geographic axes on which to plot data

`GeographicAxes` object

Geographic axes on which to plot data, specified as a `GeographicAxes` object.

Output Arguments

gxOut — Geographic axes on which data is plotted

`GeographicAxes` object

Geographic axes on which data is plotted, returned as a `GeographicAxes` object. Use this object to customize the map display. For more details, see `GeographicAxes` Properties.

See Also

[geoaxes](#) | [geobasemap](#) | [geoplayer](#) | [geoplot](#) | [hereHDLMReader](#) | [read](#)

Topics

[GeographicAxes Properties](#)

[“Read and Visualize Data Using HERE HD Live Map Reader”](#)

[“Access HERE HD Live Map Data”](#)

[“Use HERE HD Live Map Data to Verify Lane Configurations”](#)

External Websites

[HD Live Map Data Specification](#)

Introduced in R2019a

hereHDLMConfiguration

Configure HERE HD Live Map reader

Description

A `hereHDLMConfiguration` object configures a `hereHDLMReader` object to search for map data in only a specific HERE HD Live Map⁵ (HDLM) production catalog or catalog version. These catalogs correspond to various geographic regions, such as India, Western Europe, and North America. Use this configuration object to speed up the performance of the reader, so that it does not search unnecessary catalogs. The configuration object is stored in the `Configuration` property of a `hereHDLMReader` object. For more details on creating configuration objects, see “Create Configuration for HERE HD Live Map Reader”.

Note Use of the `hereHDLMConfiguration` object requires valid HERE HDLM credentials. If you have not previously set up credentials, a dialog box prompts you to enter them. Enter the **App ID** and **App Code** that you obtained from HERE Technologies, and click **OK**.

Creation

Syntax

```
config = hereHDLMConfiguration(catalog)
config = hereHDLMConfiguration(region)
config = hereHDLMConfiguration( ____, catalogVersion)
```

Description

`config = hereHDLMConfiguration(catalog)` creates a `hereHDLMConfiguration` object for the latest version of the specified HERE HDLM catalog. A `hereHDLMReader`

-
5. You need to enter into a separate agreement with HERE in order to gain access to the HDLM services and to get the required credentials (`app_id` and `app_code`) for using the HERE Service.

object with this configuration searches for the selected map tiles within only the catalog and version specified by that configuration.

`config = hereHDLConfiguration(region)` creates a `hereHDLConfiguration` object for the latest version of the catalog that corresponds to the specified region.

`config = hereHDLConfiguration(___, catalogVersion)` creates a `hereHDLConfiguration` object for the specified version of the catalog. Along with the catalog version, specify either the catalog name or the region name that corresponds to a catalog.

Input Arguments

catalog — Name of HERE HDLM production catalog

string scalar | character vector

Name of HERE HDLM production catalog, specified as a string scalar or character vector. This table shows the valid region names and their corresponding HERE HDLM production catalog names.

Region	Catalog
'Asia Pacific'	'here-hdmap-ext-apac-1'
'Eastern Europe'	'here-hdmap-ext-eeu-1'
'India'	'here-hdmap-ext-rn-1'
'Middle East And Africa'	'here-hdmap-ext-mea-1'
'North America'	'here-hdmap-ext-na-1'
'Oceania'	'here-hdmap-ext-au-1'
'South America'	'here-hdmap-ext-sam-1'
'Western Europe'	'here-hdmap-ext-weu-1'

Example: 'here-hdmap-ext-sam-1'

region — Name of geographic region

string scalar | character vector

Name of geographic region that corresponds to a HERE HDLM production catalog, specified as a string scalar or character vector. This table shows the valid region names and their corresponding HERE HDLM production catalog names.

Region	Catalog
'Asia Pacific'	'here-hdmap-ext-apac-1'
'Eastern Europe'	'here-hdmap-ext-eeu-1'
'India'	'here-hdmap-ext-rn-1'
'Middle East And Africa'	'here-hdmap-ext-mea-1'
'North America'	'here-hdmap-ext-na-1'
'Oceania'	'here-hdmap-ext-au-1'
'South America'	'here-hdmap-ext-sam-1'
'Western Europe'	'here-hdmap-ext-weu-1'

Example: 'South America'

catalogVersion — Version number of HERE HDLM production catalog

positive integer

Version number of a HERE HDLM production catalog, specified as a positive integer. The HERE HDLM web service determines the availability of previous versions of the catalog. If you specify a version of a catalog that is not available, then hereHDLMConfiguration returns an error.

Properties

Catalog — Name of HERE HDLM production catalog

string scalar | character vector

This property is read-only.

Name of HERE HDLM production catalog, specified as a string scalar or character vector.

- If you specified the `catalog` input argument, then this property is set to the name of that catalog.
- If you specified the `region` input argument, then this property is set to the catalog name that corresponds to that region.

CatalogVersion — Version number of HERE HDLM production catalog

positive integer

This property is read-only.

Version number of a HERE HDLM production catalog, specified as a positive integer. The version number corresponds to the value specified in the `catalogVersion` input argument. If you do not specify `catalogVersion`, then this property is set to the latest version of the catalog specified in the `Catalog` property.

Examples

Create Configuration for Specific Catalog

Define a HERE tile ID for an area of Hyderabad, India.

```
tileID = uint32(375084810);
```

Create a HERE HD Live Map (HERE HDLM) configuration object for the India catalog. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. Your catalog version might differ from the one shown here.

```
config = hereHDLMConfiguration('here-hdmap-ext-rn-1')
```

```
config =  
  hereHDLMConfiguration with properties:  
      Catalog: 'here-hdmap-ext-rn-1'  
  CatalogVersion: 12
```

Create a HERE HDLM reader using the specified HERE tile ID and configuration object. During creation, `hereHDLMReader` searches for the tile ID within only the India catalog. This reader is configured to read map data from only the India catalog.

```
reader = hereHDLMReader(tileID, 'Configuration', config);
```

Create Configuration for Specific Region

Load a sequence of latitude and longitude coordinates for a driving route in Boston, MA, USA.

```
data = load('geoRoute.mat')  
  
data = struct with fields:  
    latitude: [256×1 double]  
    longitude: [256×1 double]
```

Create a HERE HD Live Map (HERE HDLM) configuration object for the region that the driving route is in (North America). If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. Your catalog version might differ from the one shown here.

```
config = hereHDLMConfiguration('North America')  
  
config =  
    hereHDLMConfiguration with properties:  
  
        Catalog: 'here-hdmap-ext-na-1'  
        CatalogVersion: 2291
```

Create a HERE HDLM reader using the specified coordinates and configuration object. During creation, `hereHDLMReader` searches for map tiles containing these coordinates. It searches within only the catalog that is associated with the North America region. The created reader is configured to read map data from only the North America catalog.

```
reader = hereHDLMReader(data.latitude,data.longitude,'Configuration',config);
```

Create Configuration for Specific Catalog Version

Create a HERE HD Live Map (HERE HDLM) configuration object for the previous version of a catalog.

Load a sequence of latitude and longitude coordinates for a driving route in Los Altos, California, USA.

```
data = load('geoSequence.mat')  
  
data = struct with fields:  
    latitude: [1000×1 double]  
    longitude: [1000×1 double]
```

Create a HERE HDLM configuration object for the latest version of the North America catalog. If you have not previously set up HERE HDLM credentials, a dialog box prompts you to enter them. Your catalog version might differ from the one shown here.

```
catalog = 'here-hdmap-ext-na-1';
configLatest = hereHDLMConfiguration(catalog)

configLatest =
  hereHDLMConfiguration with properties:

        Catalog: 'here-hdmap-ext-na-1'
    CatalogVersion: 2291
```

Create a configuration object for the previous version of the catalog.

```
previousVersion = configLatest.CatalogVersion - 1;
config = hereHDLMConfiguration(catalog,previousVersion)

config =
  hereHDLMConfiguration with properties:

        Catalog: 'here-hdmap-ext-na-1'
    CatalogVersion: 2290
```

Create a HERE HDLM reader using the specified configuration object. The reader is configured to read data from only the previous version of the North America catalog.

```
reader = hereHDLMReader(data.latitude,data.longitude,'Configuration',config);
```

Tips

- To save HERE HDLM credentials between MATLAB sessions, select the corresponding option in the HERE HD Live Map Credentials dialog box. To manage HERE HDLM credentials, use the `hereHDLMCredentials` function.

See Also

`hereHDLMCredentials` | `hereHDLMReader`

Topics

“Create Configuration for HERE HD Live Map Reader”

“Access HERE HD Live Map Data”

Introduced in R2019a

inflationCollisionChecker

Collision-checking configuration for costmap based on inflation

Description

The `inflationCollisionChecker` function creates an `InflationCollisionChecker` object, which holds the collision-checking configuration of a vehicle costmap. A vehicle costmap with this configuration inflates the size of obstacles in the vehicle environment. This inflation is based on the specified `InflationCollisionChecker` properties, such as the dimensions of the vehicle and the radius of circles required to enclose the vehicle. For more details, see “Algorithms” on page 4-658. Path planning algorithms, such as `pathPlannerRRT`, use this costmap collision-checking configuration to avoid inflated obstacles and plan collision-free paths through an environment.

Use the `InflationCollisionChecker` object to set the `CollisionChecker` property of your `vehicleCostmap` object. This collision-checking configuration affects the return values of the `checkFree` and `checkOccupied` functions used by `vehicleCostmap`. These values indicate whether a vehicle pose is *free* or *occupied*.

Creation

Syntax

```
ccConfig = inflationCollisionChecker
ccConfig = inflationCollisionChecker(vehicleDims)
ccConfig = inflationCollisionChecker(vehicleDims,numCircles)
ccConfig = inflationCollisionChecker( ____,Name,Value)
```

Description

`ccConfig = inflationCollisionChecker` creates an `InflationCollisionChecker` object, `ccConfig`, that holds the collision-checking

configuration of a vehicle costmap. This object uses one circle to enclose the vehicle. The dimensions of the vehicle correspond to the values of a default `vehicleDimensions` object.

`ccConfig = inflationCollisionChecker(vehicleDims)` specifies the dimensions of the vehicle, where `vehicleDims` is a `vehicleDimensions` object. The `vehicleDims` input sets the `VehicleDimensions` property of `ccConfig`.

`ccConfig = inflationCollisionChecker(vehicleDims,numCircles)` also specifies the number of circles used to enclose the vehicle. The `numCircles` input sets the `NumCircles` property of `ccConfig`.

`ccConfig = inflationCollisionChecker(____,Name,Value)` sets the `CenterPlacements` and `InflationRadius` properties using name-value pairs and the inputs from any of the preceding syntaxes. Enclose each property name in quotes.

Example: `inflationCollisionChecker('CenterPlacements',[0.2 0.5 0.8],'InflationRadius',1.2)`

Properties

NumCircles — Number of circles enclosing the vehicle

1 (default) | positive integer

Number of circles used to enclose the vehicle and calculate the inflation radius, specified as a positive integer. Typical values are from 1 to 5.

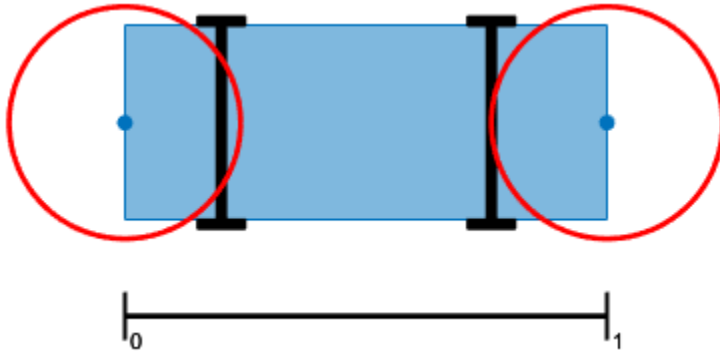
- For faster but more conservative collision checking, decrease the number of circles. This approach improves performance because the path planning algorithm makes fewer collision checks.
- For slower but more precise collision checking, increase the number of circles. This approach is useful when planning a path around tight corners or through narrow corridors, such as in a parking lot.

CenterPlacements — Normalized placement of circle centers

1-by-`NumCircles` vector of real values in the range [0, 1]

Normalized placement of circle centers along the longitudinal axis of the vehicle, specified as a 1-by-`NumCircles` vector of real values in the range [0, 1].

- A value of 0 places a circle center at the rear of the vehicle.
- A value of 1 places a circle center at the front of the vehicle.



Specify `CenterPlacements` when you want to align the circles with exact positions on the vehicle. If you leave `CenterPlacements` unspecified, the object computes the center placements so that the circles completely enclose the vehicle. If you change the number of center placements, `NumCircles` is updated to the number of elements in `CenterPlacements`.

VehicleDimensions – Vehicle dimensions

`vehicleDimensions` object

Vehicle dimensions used to compute the inflation radius, specified as a `vehicleDimensions` object. By default, the `InflationCollisionChecker` object uses the dimensions of a default `vehicleDimensions` object. Vehicle dimensions are in world units.

InflationRadius – Inflation radius

nonnegative real number

Inflation radius, specified as a nonnegative real number. By default, the object computes the inflation radius based on the values of `NumCircles`, `CenterPlacements`, and `VehicleDimensions`. For more details, see “Algorithms” on page 4-658.

Object Functions

`plot` Plot collision configuration

Examples

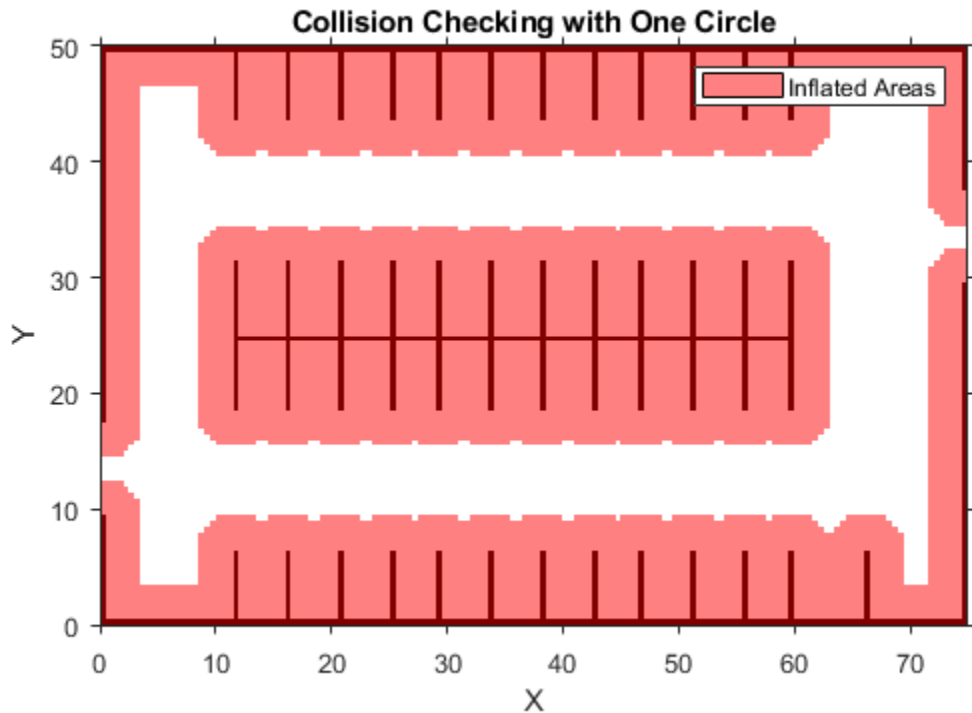
Plan Path Using Different Collision-Checking Configurations

Plan a vehicle path to a narrow parking spot by using the optimized rapidly exploring random tree (RRT*) algorithm. Try different collision-checking configurations in the costmap used by the RRT* path planner.

Load and display a costmap of a parking lot. The costmap is a `vehicleCostmap` object. By default, `vehicleCostmap` uses a collision-checking configuration that inflates obstacles based on a radius of only one circle enclosing the vehicle. The costmap overinflates the obstacles (the parking spot boundaries).

```
data = load('parkingLotCostmap.mat');
costmap = data.parkingLotCostmap;

figure
plot(costmap)
title('Collision Checking with One Circle')
```



Use `inflationCollisionChecker` to create a new collision-checking configuration for the costmap.

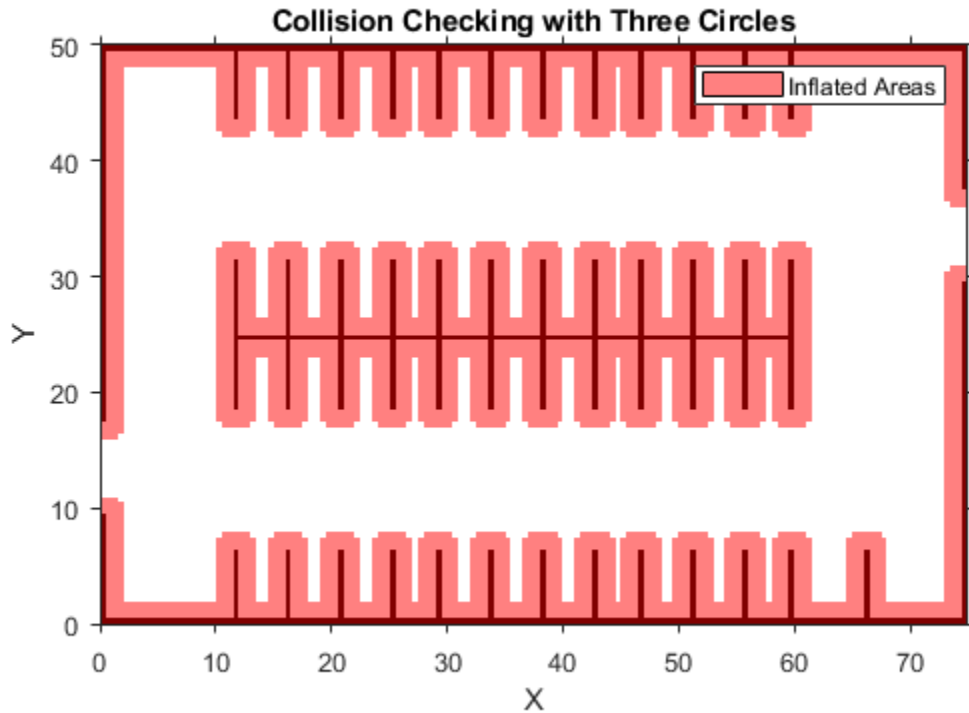
- To decrease inflation of the obstacles, increase the number of circles enclosing the vehicle.
- To specify the dimensions of the vehicle, use a `vehicleDimensions` object.

Specify the collision-checking configuration in the `CollisionChecker` property of the costmap.

```
vehicleDims = vehicleDimensions(4.5,1.7); % 4.5 m long, 1.7 m wide
numCircles = 3;
ccConfig = inflationCollisionChecker(vehicleDims,numCircles);
costmap.CollisionChecker = ccConfig;
```

Display the costmap with the new collision-checking configuration. The inflated areas are reduced.

```
figure
plot(costmap)
title('Collision Checking with Three Circles')
```

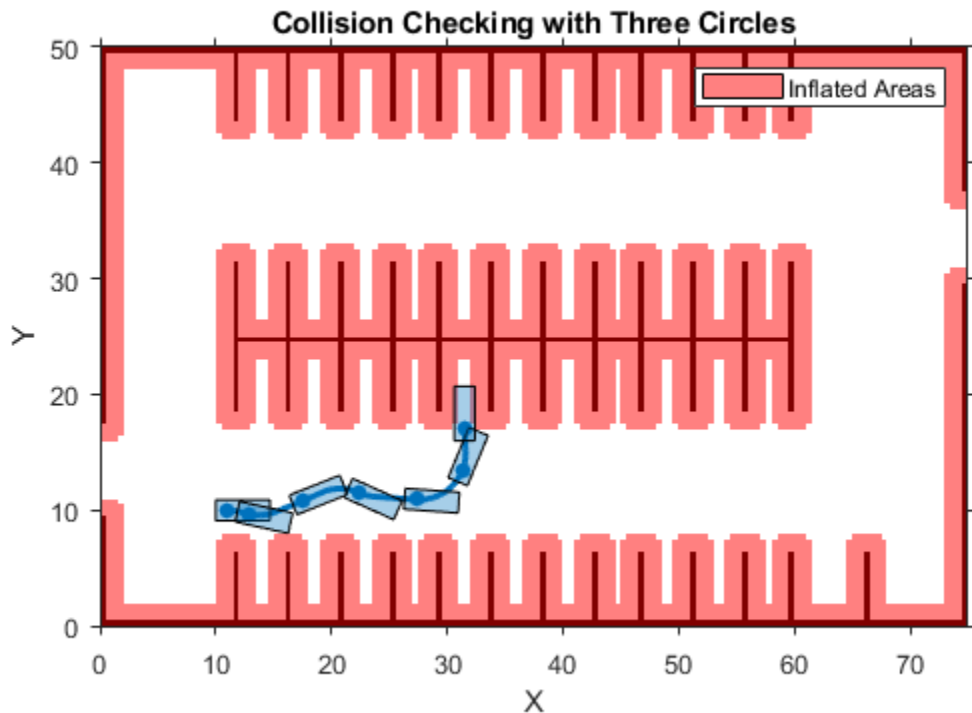


Define a planning problem: a vehicle starts near the left entrance of the parking lot and ends in a parking spot.

```
startPose = [11 10 0]; % [meters, meters, degrees]
goalPose = [31.5 17 90];
```

Use a `pathPlannerRRT` object to plan a path to the parking spot. Plot the planned path.

```
planner = pathPlannerRRT(costmap);  
refPath = plan(planner, startPose, goalPose);  
  
hold on  
plot(refPath)  
hold off
```



Create Collision-Checking Configuration with Center Placements

Create a collision-checking configuration for a costmap. Manually specify the circle centers so that they fully enclose the vehicle.

Define the dimensions of a vehicle by using a `vehicleDimensions` object.

```
length = 5; % meters
width = 2; % meters
vehicleDims = vehicleDimensions(length,width);
```

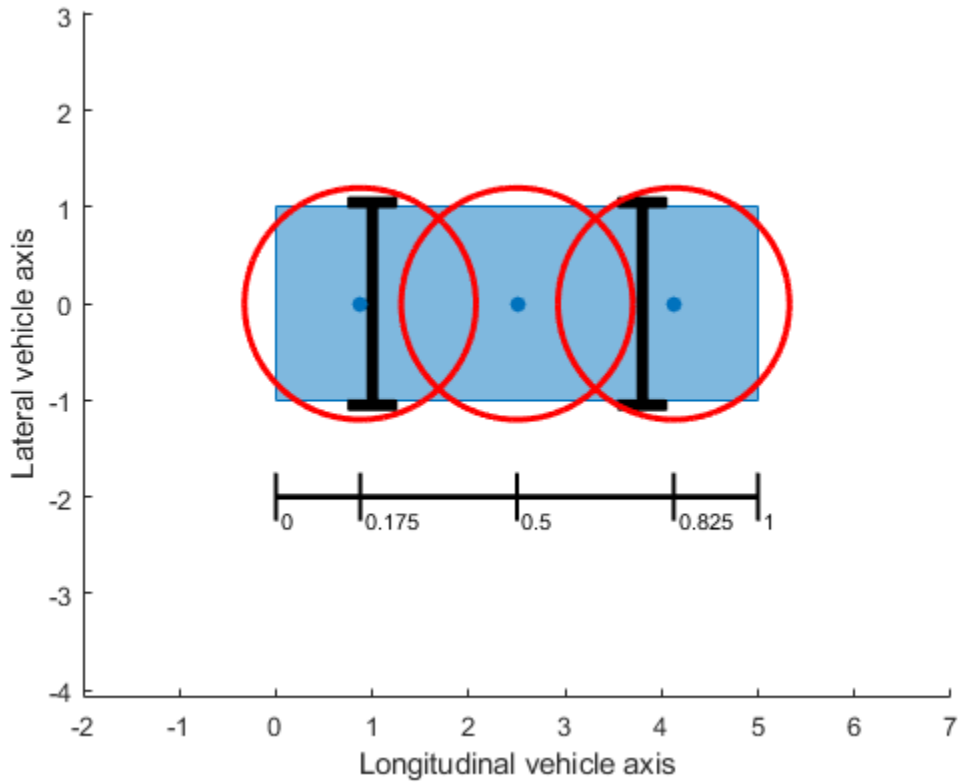
Define three circle centers and the inflation radius to use for collision checking. Place one center at the vehicle's midpoint. Offset the other two centers by an equal amount on either end of the vehicle.

```
distFromSide = 0.175;
centerPlacements = [distFromSide 0.5 1-distFromSide];
inflationRadius = 1.2;
```

Create and display the collision-checking configuration.

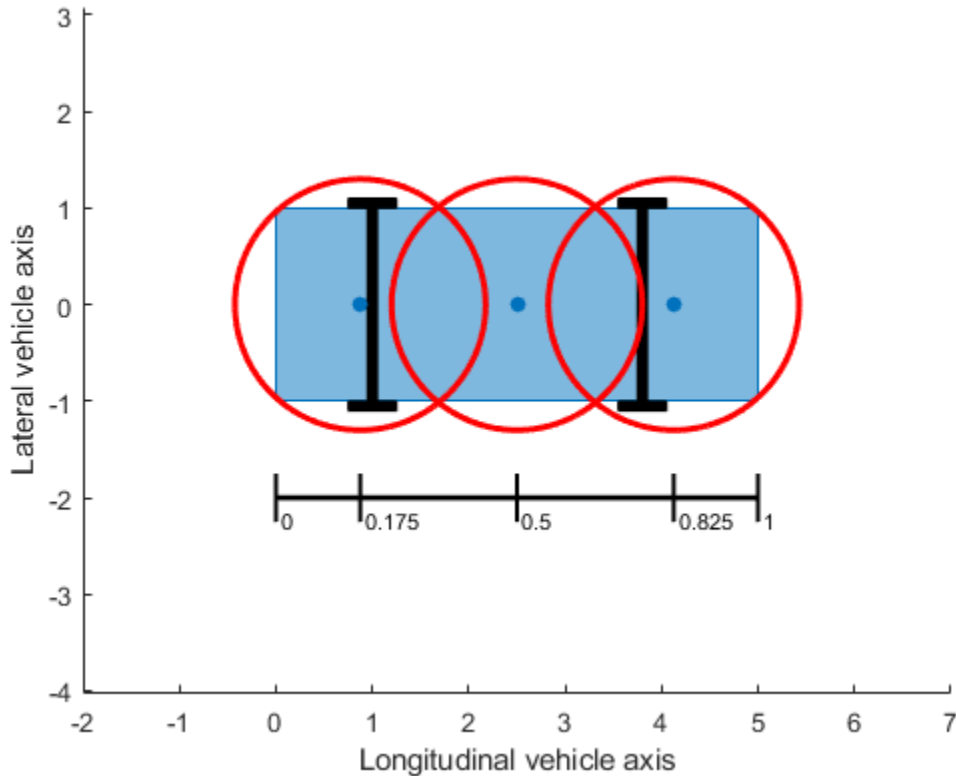
```
ccConfig = inflationCollisionChecker(vehicleDims, ...
    'CenterPlacements',centerPlacements,'InflationRadius',inflationRadius);

figure
plot(ccConfig)
```



In this configuration, the corners of the vehicle are not enclosed within the circles. To fully enclose the vehicle, increase the inflation radius. Display the updated configuration.

```
ccConfig.InflationRadius = 1.3;  
plot(ccConfig)
```



Use this collision-checking configuration to create a 10-by-20 meter costmap.

```
costmap = vehicleCostmap(10,20,0.1,'CollisionChecker',ccConfig);
```

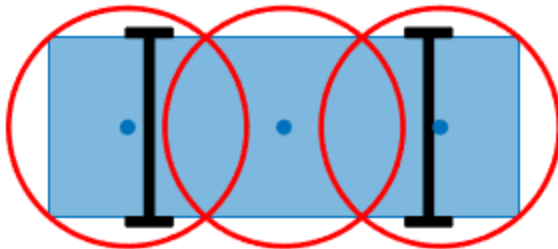
Tips

- To visually verify that the circles completely enclose the vehicle, use the `plot` function. If the circles do not completely enclose the vehicle, some of the free poses returned by `checkFree` (or unoccupied poses returned by `checkOccupied`) might actually be in collision.

Algorithms

The `InflationRadius` property of `InflationCollisionChecker` determines the amount, in world units, by which to inflate obstacles. By default, `InflationRadius` is equal to the radius of the smallest set of overlapping circles required to completely enclose the vehicle, as determined by the following properties:

- `NumCircles` — Number of circles used to enclose the vehicle
- `CenterPlacements` — Placements of the circle centers along the longitudinal axis of the vehicle
- `VehicleDimensions` — Dimensions of the vehicle



For more details about how this collision-checking configuration defines inflated areas in a costmap, see the “Algorithms” on page 4-841 section of `vehicleCostmap`.

References

- [1] Ziegler, J., and C. Stiller. "Fast Collision Checking for Intelligent Vehicle Motion Planning." *IEEE Intelligent Vehicle Symposium*. June 21-24, 2010.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- All inputs to `inflationCollisionChecker` must be compile-time constants.

See Also

Objects

`pathPlannerRRT` | `vehicleCostmap` | `vehicleDimensions`

Topics

“Automated Parking Valet”

Introduced in R2018b

plot

Plot collision configuration

Syntax

```
plot(ccConfig)  
plot(ccConfig,Name,Value)
```

Description

`plot(ccConfig)` plots the collision-checking configuration of an `InflationCollisionChecker` object. Use `plot` to visually verify that the circles in the configuration fully enclose the vehicle.

`plot(ccConfig,Name,Value)` specifies options using one or more `Name,Value` pair arguments. For example, `plot(ccConfig,'Ruler','Off')` turns off the ruler that indicates the locations of the circle centers.

Examples

Create Collision-Checking Configuration with Center Placements

Create a collision-checking configuration for a costmap. Manually specify the circle centers so that they fully enclose the vehicle.

Define the dimensions of a vehicle by using a `vehicleDimensions` object.

```
length = 5; % meters  
width = 2; % meters  
vehicleDims = vehicleDimensions(length,width);
```

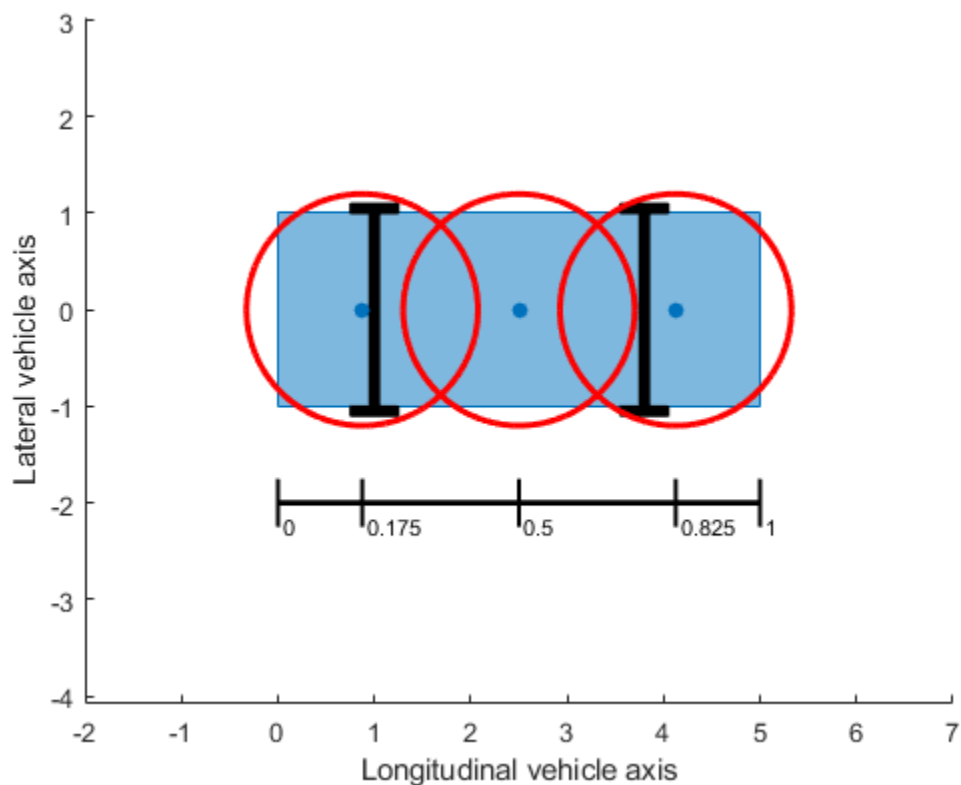
Define three circle centers and the inflation radius to use for collision checking. Place one center at the vehicle's midpoint. Offset the other two centers by an equal amount on either end of the vehicle.

```
distFromSide = 0.175;  
centerPlacements = [distFromSide 0.5 1-distFromSide];  
inflationRadius = 1.2;
```

Create and display the collision-checking configuration.

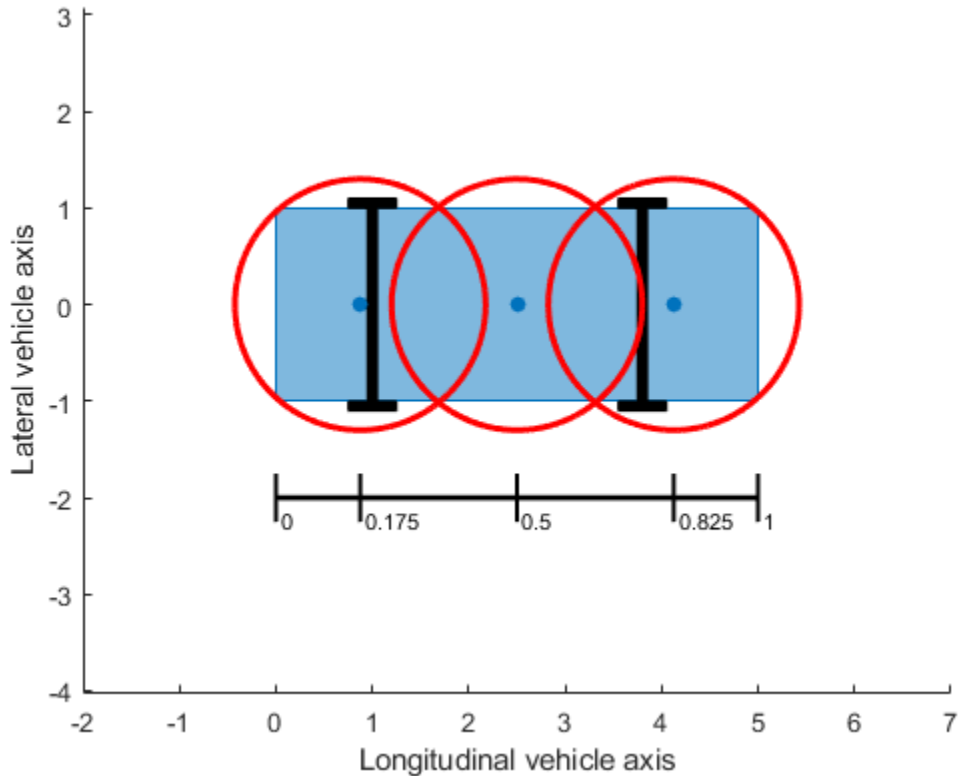
```
ccConfig = inflationCollisionChecker(vehicleDims, ...  
    'CenterPlacements',centerPlacements,'InflationRadius',inflationRadius);
```

```
figure  
plot(ccConfig)
```



In this configuration, the corners of the vehicle are not enclosed within the circles. To fully enclose the vehicle, increase the inflation radius. Display the updated configuration.

```
ccConfig.InflationRadius = 1.3;  
plot(ccConfig)
```



Use this collision-checking configuration to create a 10-by-20 meter costmap.

```
costmap = vehicleCostmap(10,20,0.1,'CollisionChecker',ccConfig);
```

Input Arguments

ccConfig — Collision-checking configuration

InflationCollisionChecker object

Collision-checking configuration, specified as an `InflationCollisionChecker` object. To create a collision-checking configuration, use the `inflationCollisionChecker` function.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `plot(ccConfig, 'Parent', ax)` plots the collision configuration in axes `ax`.

Parent — Axes on which to plot collision configuration

Axes object

Axes on which to plot the collision configuration, specified as the comma-separated pair consisting of `'Parent'` and an Axes object. To create an Axes object, use the `axes` function.

To plot the collision configuration in a new figure, leave `'Parent'` unspecified.

Ruler — Display ruler

`'on'` (default) | `'off'`

Display the ruler that shows the locations of the circle centers, specified as the comma-separated pair consisting of `'Ruler'` and `'on'` or `'off'`.

See Also

`inflationCollisionChecker`

Introduced in R2018b

parabolicLaneBoundary

Parabolic lane boundary model

Description

The `parabolicLaneBoundary` object contains information about a parabolic lane boundary model.

Creation

To generate parabolic lane boundary models that fit a set of boundary points and an approximate width, use the `findParabolicLaneBoundaries` function. If you already know your parabolic parameters, create lane boundary models by using the `parabolicLaneBoundary` function (described here).

Syntax

```
boundaries = parabolicLaneBoundary(parabolicParameters)
```

Description

`boundaries = parabolicLaneBoundary(parabolicParameters)` creates an array of parabolic lane boundary models from an array of `[A B C]` parameters for the parabolic equation $y = Ax^2 + Bx + C$. Points within the lane boundary models are in world coordinates.

Input Arguments

parabolicParameters — Coefficients for parabolic models

`[A B C]` real-valued vector | matrix of `[A B C]` values

Coefficients for parabolic models of the form $y = Ax^2 + Bx + C$, specified as an [A B C] real-valued vector or as a matrix of [A B C] values. Each row of `parabolicParameters` describes a separate parabolic lane boundary model.

Properties

Parameters — Coefficients for parabolic model

[A B C] real-valued vector

Coefficients for a parabolic model of the form $y = Ax^2 + Bx + C$, specified as an [A B C] real-valued vector.

BoundaryType — Type of boundary

`LaneBoundaryType`

Type of boundary, specified as a `LaneBoundaryType` of supported lane boundaries. The supported lane boundary types are:

- Unmarked
- Solid
- Dashed
- BottsDots
- DoubleSolid

Specify a lane boundary type as `LaneBoundaryType.BoundaryType`. For example:

`LaneBoundaryType.BottsDots`

Strength — Strength of boundary model

real scalar

Strength of the boundary model, specified as a real scalar. `Strength` is the ratio of the number of unique x-axis locations on the boundary to the length of the boundary specified by the `XExtent` property. A solid line without any breaks has a higher strength than a dotted line that has breaks along the full length of the boundary.

XExtent — Length of boundary along x-axis

[minX maxX] real-valued vector

Length of the boundary along the x-axis, specified as a [minX maxX] real-valued vector that describes the minimum and maximum x-axis locations.

Object Functions

`computeBoundaryModel` Obtain y-coordinates of lane boundaries given x-coordinates

Examples

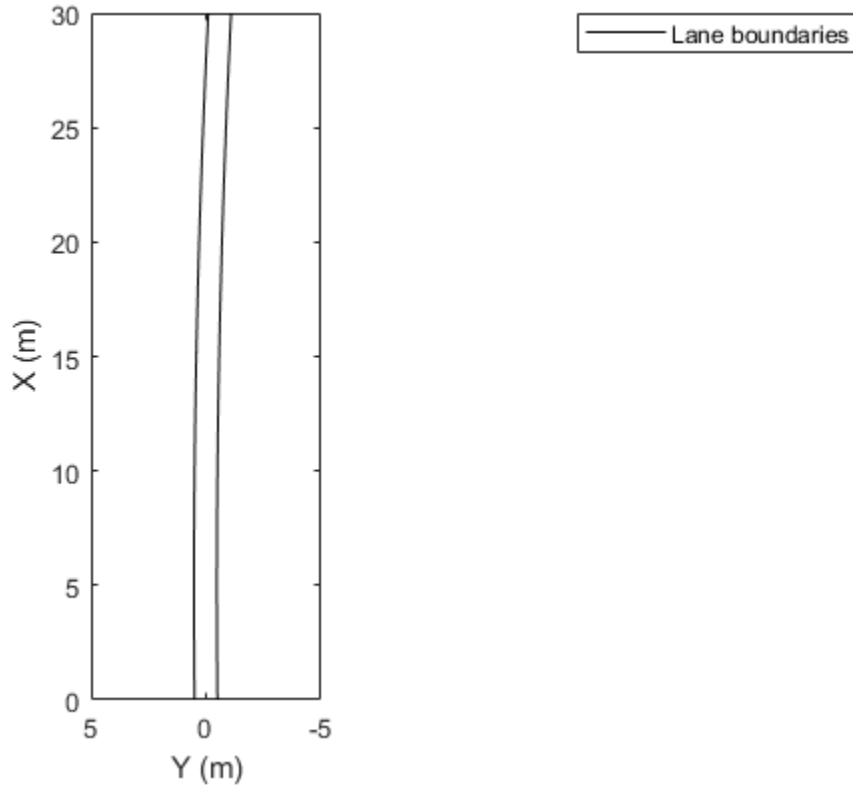
Create Parabolic Lane Boundaries

Create left-lane and right-lane parabolic boundary models.

```
llane = parabolicLaneBoundary([-0.001 0.01 0.5]);  
rlane = parabolicLaneBoundary([-0.001 0.01 -0.5]);
```

Create a bird's-eye plot and lane boundary plotter. Plot the lane boundaries.

```
bep = birdsEyePlot('XLimits',[0 30],'YLimits',[-5 5]);  
lbPlotter = laneBoundaryPlotter(bep,'DisplayName','Lane boundaries');  
plotLaneBoundary(lbPlotter, [llane rlane]);
```

Find Parabolic Lane Boundaries in Bird's-Eye-View Image

Find lanes in an image by using parabolic lane boundary models. Overlay the identified lanes on the original image and on a bird's-eye-view transformation of the image.

Load an image of a road with lanes. The image was obtained from a camera sensor mounted on the front of a vehicle.

```
I = imread('road.png');
```

Transform the image into a bird's-eye-view image by using a preconfigured sensor object. This object models the sensor that captured the original image.

```
bevSensor = load('birdsEyeConfig');  
birdsEyeImage = transformImage(bevSensor.birdsEyeConfig,I);  
imshow(birdsEyeImage)
```

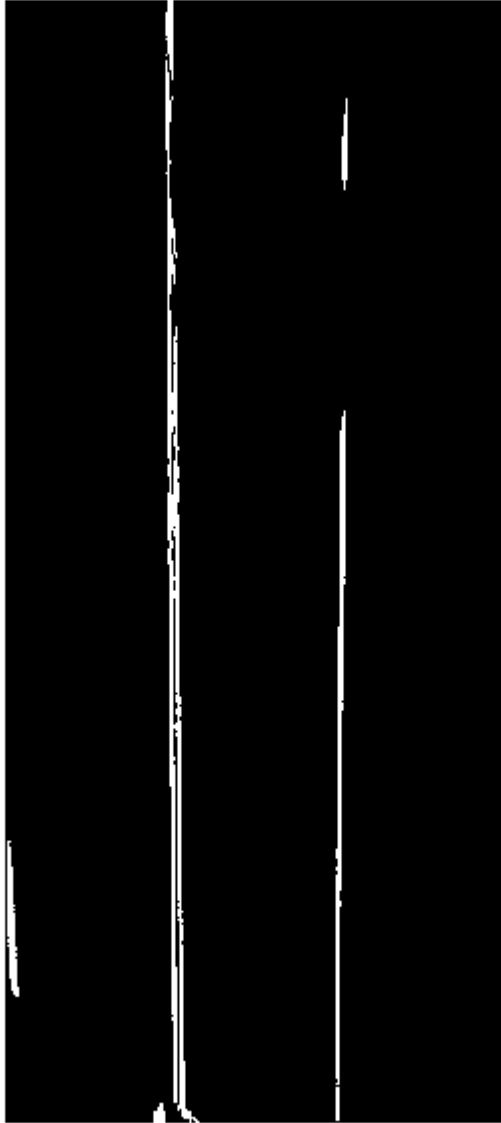


Set the approximate lane marker width in world units (meters).

```
approxBoundaryWidth = 0.25;
```

Detect lane features and display them as a black-and-white image.

```
birdsEyeBW = segmentLaneMarkerRidge(rgb2gray(birdsEyeImage), ...  
    bevSensor.birdsEyeConfig,approxBoundaryWidth);  
imshow(birdsEyeBW)
```



Obtain lane candidate points in world coordinates.

```
[imageX,imageY] = find(birdsEyeBW);  
xyBoundaryPoints = imageToVehicle(bevSensor.birdsEyeConfig,[imageY,imageX]);
```

Find lane boundaries in the image by using the `findParabolicLaneBoundaries` function. By default, the function returns a maximum of two lane boundaries. The boundaries are stored in an array of `parabolicLaneBoundary` objects.

```
boundaries = findParabolicLaneBoundaries(xyBoundaryPoints,approxBoundaryWidth);
```

Use `insertLaneBoundary` to overlay the lanes on the original image. The `XPoints` vector represents the lane points, in meters, that are within range of the ego vehicle's sensor. Specify the lanes in different colors. By default, lanes are yellow.

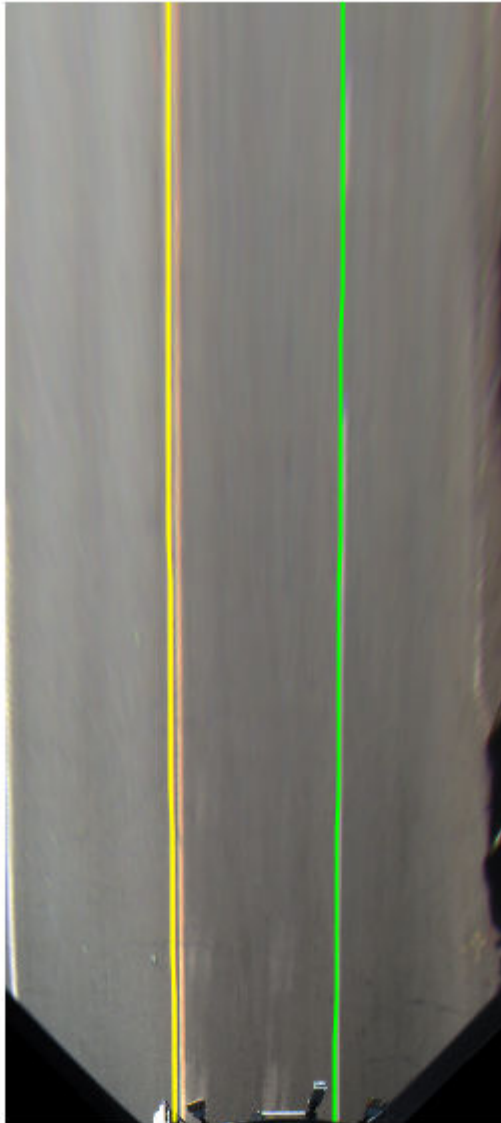
```
XPoints = 3:30;
```

```
figure  
sensor = bevSensor.birdsEyeConfig.Sensor;  
lanesI = insertLaneBoundary(I,boundaries(1),sensor,XPoints);  
lanesI = insertLaneBoundary(lanesI,boundaries(2),sensor,XPoints,'Color','green');  
imshow(lanesI)
```



View the lanes in the bird's-eye-view image.

```
figure
BEconfig = bevSensor.birdsEyeConfig;
lanesBEI = insertLaneBoundary(birdsEyeImage,boundaries(1),BEconfig,XPoints);
lanesBEI = insertLaneBoundary(lanesBEI,boundaries(2),BEconfig,XPoints,'Color','green');
imshow(lanesBEI)
```



See Also

Apps

Ground Truth Labeler

Objects

cubicLaneBoundary

Functions

evaluateLaneBoundaries | findParabolicLaneBoundaries |
insertLaneBoundary

Introduced in R2017a

cubicLaneBoundary

Cubic lane boundary model

Description

The `cubicLaneBoundary` object contains information about a cubic lane boundary model.

Creation

To generate cubic lane boundary models that fit a set of boundary points and an approximate width, use the `findCubicLaneBoundaries` function. If you already know your cubic parameters, create lane boundary models by using the `cubicLaneBoundary` function (described here).

Syntax

```
boundaries = cubicLaneBoundary(cubicParameters)
```

Description

`boundaries = cubicLaneBoundary(cubicParameters)` creates an array of cubic lane boundary models from an array of `[A B C D]` parameters for the cubic equation $y = Ax^3 + Bx^2 + Cx + D$. Points within the lane boundary models are in world coordinates.

Input Arguments

cubicParameters — Parameters for cubic models

`[A B C D]` real-valued vector | matrix of `[A B C D]` values

Parameters for cubic models of the form $y = Ax^3 + Bx^2 + Cx + D$, specified as an `[A B C D]` real-valued vector or as a matrix of `[A B C D]` values. Each row of `cubicParameters` describes a separate cubic lane boundary model.

Properties

Parameters — Coefficients for cubic model

[A B C D] real-valued vector

Coefficients for a cubic model of the form $y = Ax^3 + Bx^2 + Cx + D$, specified as an [A B C D] real-valued vector.

BoundaryType — Type of boundary

LaneBoundaryType

Type of boundary, specified as a LaneBoundaryType of supported lane boundaries. The supported lane boundary types are:

- Unmarked
- Solid
- Dashed
- BottsDots
- DoubleSolid

Specify a lane boundary type as LaneBoundaryType.*BoundaryType*. For example:

LaneBoundaryType.BottsDots

Strength — Strength of boundary model

real scalar

Strength of the boundary model, specified as a real scalar. Strength is the ratio of the number of unique x-axis locations on the boundary to the length of the boundary specified by the XExtent property. A solid line without any breaks has a higher strength than a dotted line that has breaks along the full length of the boundary.

XExtent — Length of boundary along x-axis

[minX maxX] real-valued vector

Length of the boundary along the x-axis, specified as a [minX maxX] real-valued vector that describes the minimum and maximum x-axis locations.

Object Functions

`computeBoundaryModel` Obtain y-coordinates of lane boundaries given x-coordinates

Examples

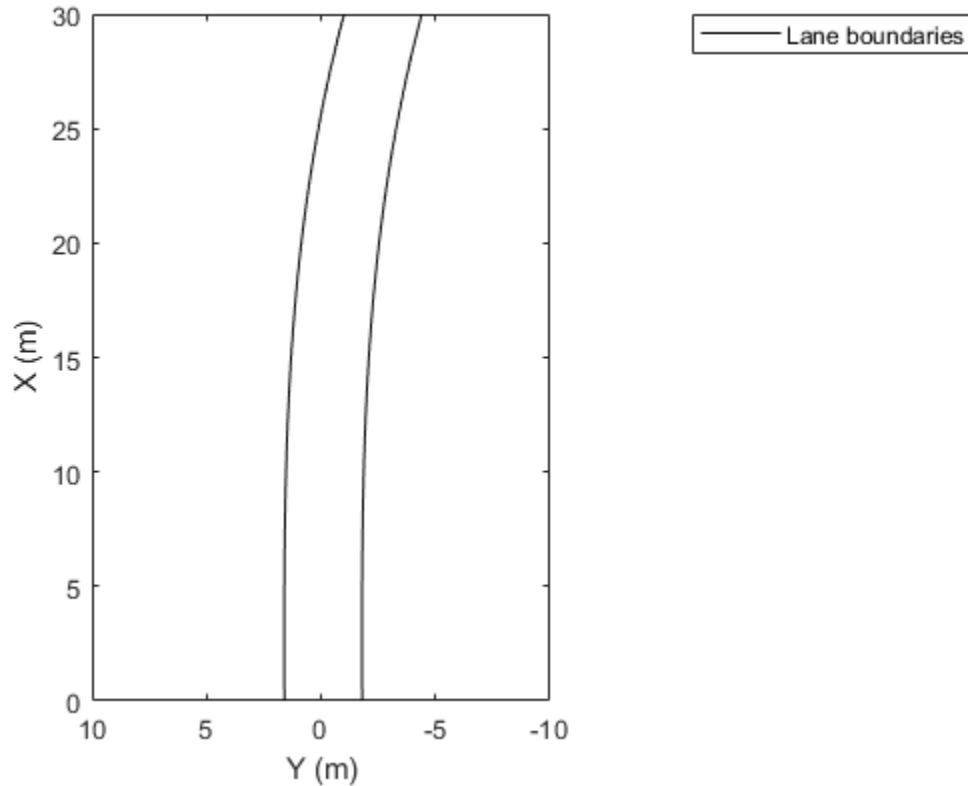
Create Cubic Lane Boundaries

Create left-lane and right-lane cubic boundary models.

```
llane = cubicLaneBoundary([-0.0001 0.0 0.003 1.6]);  
rlane = cubicLaneBoundary([-0.0001 0.0 0.003 -1.8]);
```

Create a bird's-eye plot and lane boundary plotter. Plot the lane boundaries.

```
bep = birdsEyePlot('XLimits',[0 30],'YLimits',[-10 10]);  
lbPlotter = laneBoundaryPlotter(bep,'DisplayName','Lane boundaries');  
  
plotLaneBoundary(lbPlotter, [llane rlane]);
```



Find Cubic Lane Boundaries in Bird's-Eye-View Image

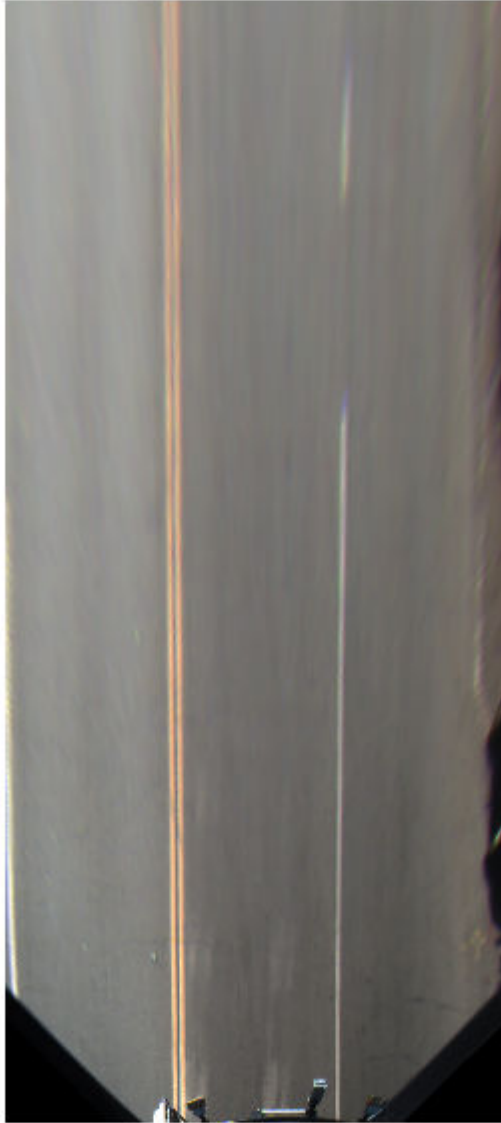
Find lanes in an image by using cubic lane boundary models. Overlay the identified lanes on the original image and on a bird's-eye-view transformation of the image.

Load an image of a road with lanes. The image was obtained from a camera sensor mounted on the front of a vehicle.

```
I = imread('road.png');
```

Transform the image into a bird's-eye-view image by using a preconfigured sensor object. This object models the sensor that captured the original image.

```
bevSensor = load('birdsEyeConfig');  
birdsEyeImage = transformImage(bevSensor.birdsEyeConfig,I);  
imshow(birdsEyeImage)
```

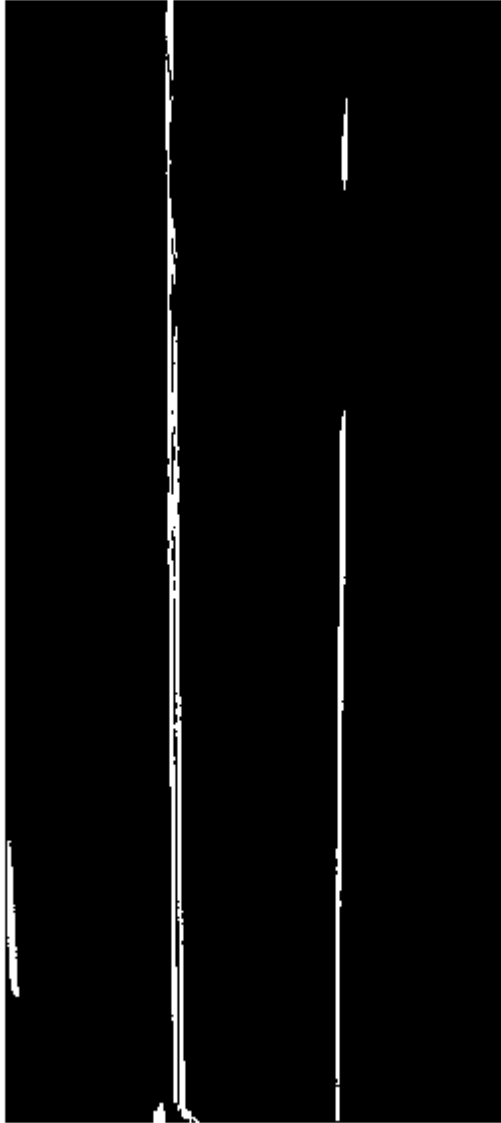


Set the approximate lane marker width in world units (meters).

```
approxBoundaryWidth = 0.25;
```

Detect lane features and display them as a black-and-white image.

```
birdsEyeBW = segmentLaneMarkerRidge(rgb2gray(birdsEyeImage), ...  
    bevSensor.birdsEyeConfig,approxBoundaryWidth);  
imshow(birdsEyeBW)
```

Obtain lane candidate points in world coordinates.

```
[imageX,imageY] = find(birdsEyeBW);  
xyBoundaryPoints = imageToVehicle(bevSensor.birdsEyeConfig,[imageY,imageX]);
```

Find lane boundaries in the image by using the `findCubicLaneBoundaries` function. By default, the function returns a maximum of two lane boundaries. The boundaries are stored in an array of `cubicLaneBoundary` objects.

```
boundaries = findCubicLaneBoundaries(xyBoundaryPoints,approxBoundaryWidth);
```

Use `insertLaneBoundary` to overlay the lanes on the original image. The `XPoints` vector represents the lane points, in meters, that are within range of the ego vehicle's sensor. Specify the lanes in different colors. By default, lanes are yellow.

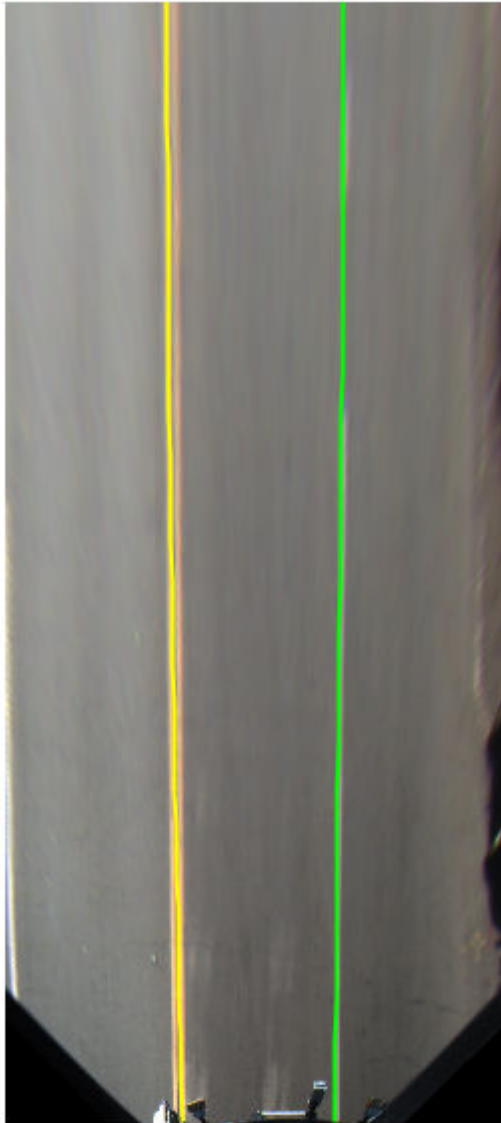
```
XPoints = 3:30;
```

```
figure  
sensor = bevSensor.birdsEyeConfig.Sensor;  
lanesI = insertLaneBoundary(I,boundaries(1),sensor,XPoints);  
lanesI = insertLaneBoundary(lanesI,boundaries(2),sensor,XPoints,'Color','green');  
imshow(lanesI)
```



View the lanes in the bird's-eye-view image.

```
figure
BEconfig = bevSensor.birdsEyeConfig;
lanesBEI = insertLaneBoundary(birdsEyeImage,boundaries(1),BEconfig,XPoints);
lanesBEI = insertLaneBoundary(lanesBEI,boundaries(2),BEconfig,XPoints,'Color','green')
imshow(lanesBEI)
```



See Also

Apps

Ground Truth Labeler

Objects

parabolicLaneBoundary

Functions

evaluateLaneBoundaries | findCubicLaneBoundaries | insertLaneBoundary

Introduced in R2018a

computeBoundaryModel

Obtain y-coordinates of lane boundaries given x-coordinates

Syntax

```
yWorld = computeBoundaryModel(boundaries,xWorld)
```

Description

`yWorld = computeBoundaryModel(boundaries,xWorld)` computes the y-axis world coordinates of lane boundary models at the specified x-axis world coordinates.

- If `boundaries` is a single lane boundary model, then `yWorld` is a vector of coordinates corresponding to the coordinates in `xWorld`.
- If `boundaries` is an array of lane boundary models, then `yWorld` is a matrix. Each row or column of `yWorld` corresponds to a lane boundary model computed at the x-coordinates in row or column vector `xWorld`.

Examples

Compute Lane Boundary

Create a `parabolicLaneBoundary` object to model a lane boundary. Compute the positions of the lane along a set of x-axis locations.

Specify the parabolic parameters and create a lane boundary model.

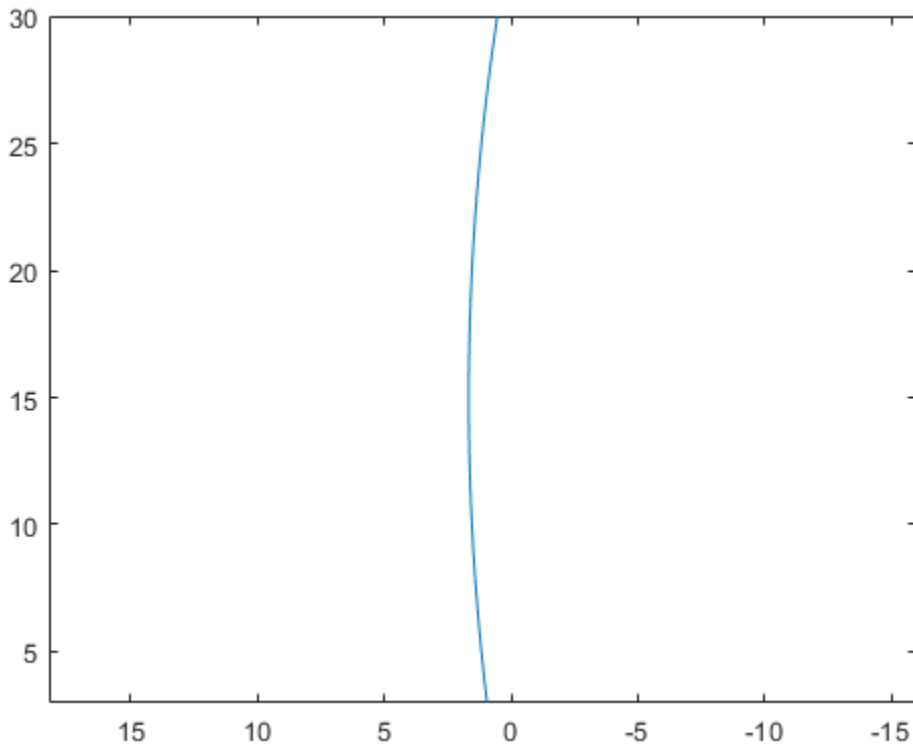
```
parabolicParams = [-0.005 0.15 0.55];  
lb = parabolicLaneBoundary(parabolicParams);
```

Compute the y-axis locations for given x-axis locations within the range of a camera sensor mounted to the front of a vehicle.

```
xWorld = 3:30; % in meters  
yWorld = computeBoundaryModel(lb,xWorld);
```

Plot the lane boundary points. To fit the coordinate system, flip the axis order and change the x-direction.

```
plot(yWorld,xWorld)  
axis equal  
set(gca,'XDir','reverse')
```



Plot Path of Ego Vehicle

Create a 3-meter-wide lane.

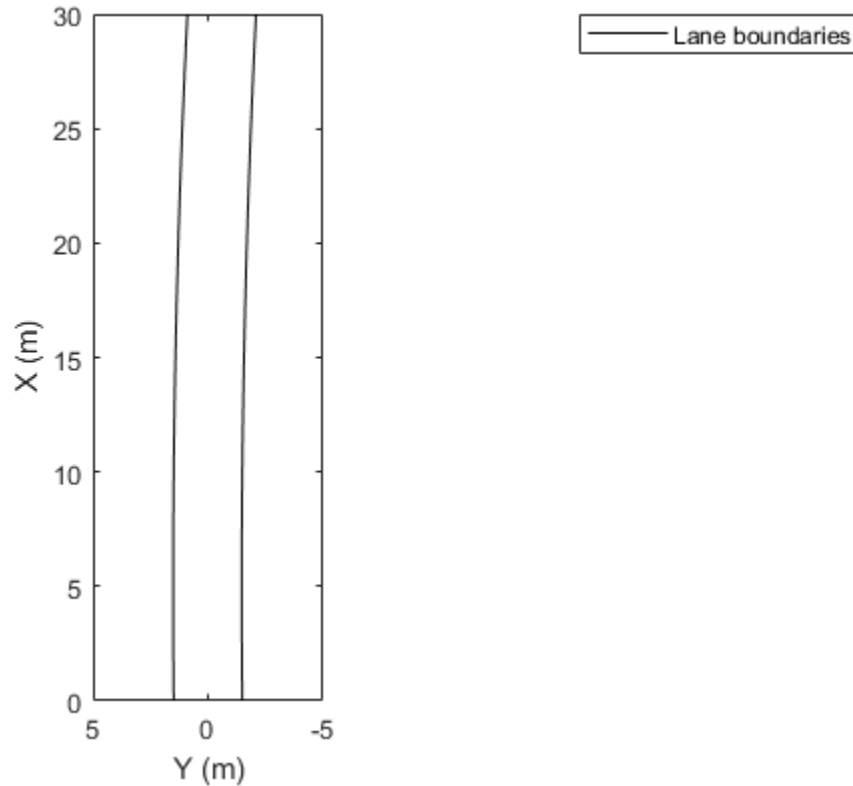
```
lb = parabolicLaneBoundary([-0.001,0.01,1.5]);  
rb = parabolicLaneBoundary([-0.001,0.01,-1.5]);
```

Compute the lane boundary model manually from 0 to 30 meters along the x-axis.

```
xWorld = (0:30)';  
yLeft = computeBoundaryModel(lb,xWorld);  
yRight = computeBoundaryModel(rb,xWorld);
```

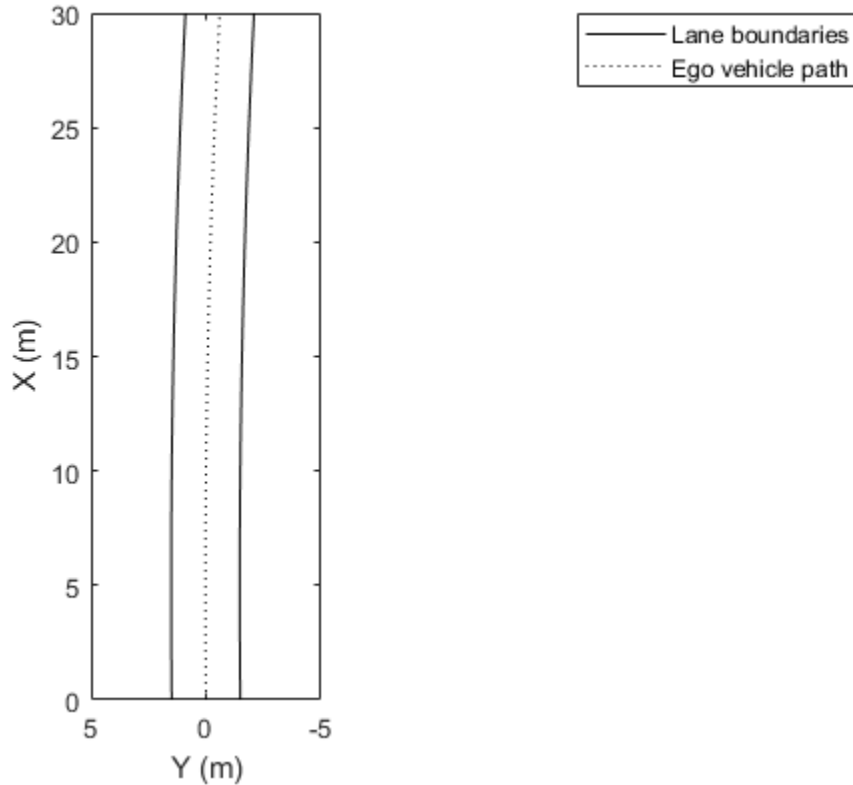
Create a bird's-eye plot and lane boundary plotter. Display the lane information on the bird's-eye plot.

```
bep = birdsEyePlot('XLimits',[0 30],'YLimits',[-5 5]);  
lanePlotter = laneBoundaryPlotter(bep,'DisplayName','Lane boundaries');  
plotLaneBoundary(lanePlotter,{xWorld,yLeft},{xWorld,yRight});
```

Create a path plotter. Create and display the path of an ego vehicle that travels through the center of the lane.

```
yCenter = (yLeft + yRight)/2;  
egoPathPlotter = pathPlotter(bep, 'DisplayName', 'Ego vehicle path');  
plotPath(egoPathPlotter, {[xWorld, yCenter]});
```



Find Candidate Ego Lane Boundaries

Find candidate ego lane boundaries from an array of lane boundaries.

Create an array of cubic lane boundaries.

```
lbs = [cubicLaneBoundary([-0.0001, 0.0, 0.003, 1.6]), ...
       cubicLaneBoundary([-0.0001, 0.0, 0.003, 4.6]), ...
       cubicLaneBoundary([-0.0001, 0.0, 0.003, -1.6]), ...
       cubicLaneBoundary([-0.0001, 0.0, 0.003, -4.6])];
```

For each lane boundary, compute the y-axis location at which the x-coordinate is 0.

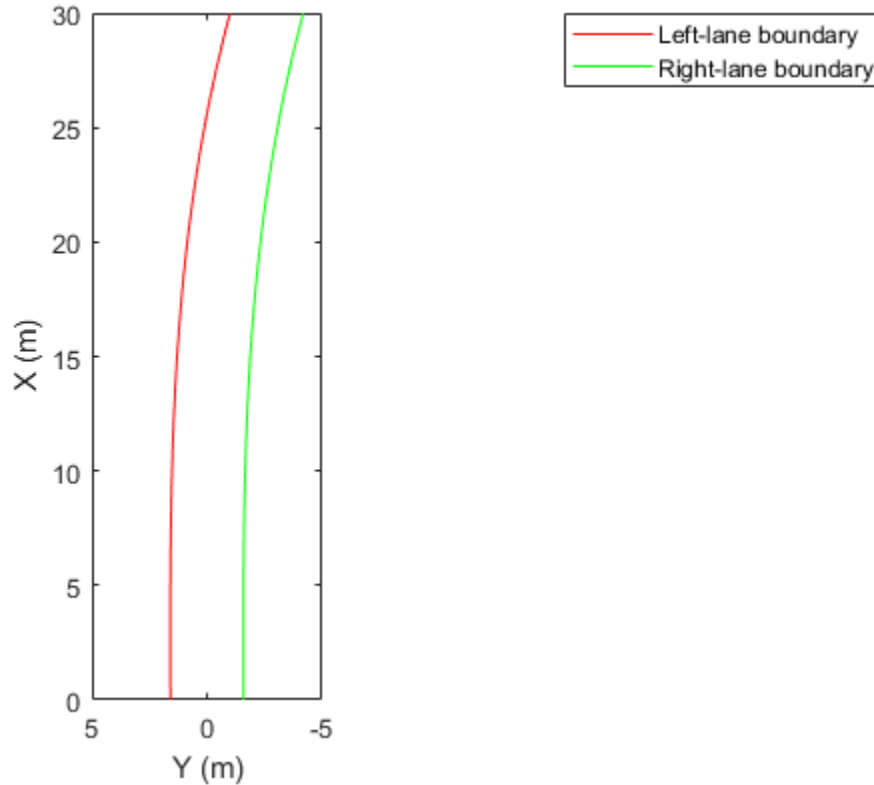
```
xWorld = 0; % meters  
yWorld = computeBoundaryModel(lbs,0);
```

Use the computed locations to find the ego lane boundaries that best meet the criteria.

```
leftEgoBoundaryIndex = find(yWorld == min(yWorld(yWorld>0)));  
rightEgoBoundaryIndex = find(yWorld == max(yWorld(yWorld<=0)));  
leftEgoBoundary = lbs(leftEgoBoundaryIndex);  
rightEgoBoundary = lbs(rightEgoBoundaryIndex);
```

Plot the boundaries using a bird's-eye plot and lane boundary plotter.

```
bep = birdsEyePlot('XLimits',[0 30], 'YLimits',[-5 5]);  
lbPlotter = laneBoundaryPlotter(bep, 'DisplayName', 'Left-lane boundary', 'Color', 'r');  
rbPlotter = laneBoundaryPlotter(bep, 'DisplayName', 'Right-lane boundary', 'Color', 'g');  
plotLaneBoundary(lbPlotter, leftEgoBoundary)  
plotLaneBoundary(rbPlotter, rightEgoBoundary)
```



Input Arguments

boundaries — Lane boundary models

lane boundary object | array of lane boundary objects

Lane boundary models containing the parameters used to compute the y -axis coordinates, specified as a lane boundary object or an array of lane boundary objects. Valid objects are `parabolicLaneBoundary` and `cubicLaneBoundary`.

xWorld — x -axis locations of boundaries

real scalar | real-valued vector

x-axis locations of the boundaries in world coordinates, specified as a real scalar or real-valued vector.

See Also

Objects

cubicLaneBoundary | parabolicLaneBoundary

Functions

insertLaneBoundary

Introduced in R2017a

monoCamera

Configure monocular camera sensor

Description

The `monoCamera` object holds information about the configuration of a monocular camera sensor. Configuration information includes the camera intrinsics, camera extrinsics such as its orientation (as described by pitch, yaw, and roll), and the camera location within the vehicle. To estimate the intrinsic and extrinsic camera parameters, see “Calibrate a Monocular Camera”.

For images captured by the camera, you can use the `imageToVehicle` and `vehicleToImage` functions to transform point locations between image coordinates and vehicle coordinates. These functions apply projective transformations (homography), which enable you to estimate distances from a camera mounted on the vehicle to locations on a flat road surface.

Creation

Syntax

```
sensor = monoCamera(intrinsics,height)
sensor = monoCamera(intrinsics,height,Name,Value)
```

Description

`sensor = monoCamera(intrinsics,height)` creates a `monoCamera` object that contains the configuration of a monocular camera sensor, given the intrinsic parameters of the camera and the height of the camera above the ground. `intrinsics` and `height` set the `Intrinsics` and `Height` properties of the camera.

`sensor = monoCamera(intrinsics,height,Name,Value)` sets properties on page 4-697 using one or more name-value pairs. For example,

`monoCamera(intrinsics,1.5,'Pitch',1)` creates a monocular camera sensor that is 1.5 meters above the ground and has a 1-degree pitch toward the ground. Enclose each property name in quotes.

Properties

Intrinsics — Intrinsic camera parameters

`cameraIntrinsics` object | `cameraParameters` object

Intrinsic camera parameters, specified as either a `cameraIntrinsics` or `cameraParameters` object. The intrinsic camera parameters include the focal length and optical center of the camera, and the size of the image produced by the camera.

You can set this property when you create the object. After you create the object, this property is read-only.

Height — Height from road surface to camera sensor

real scalar

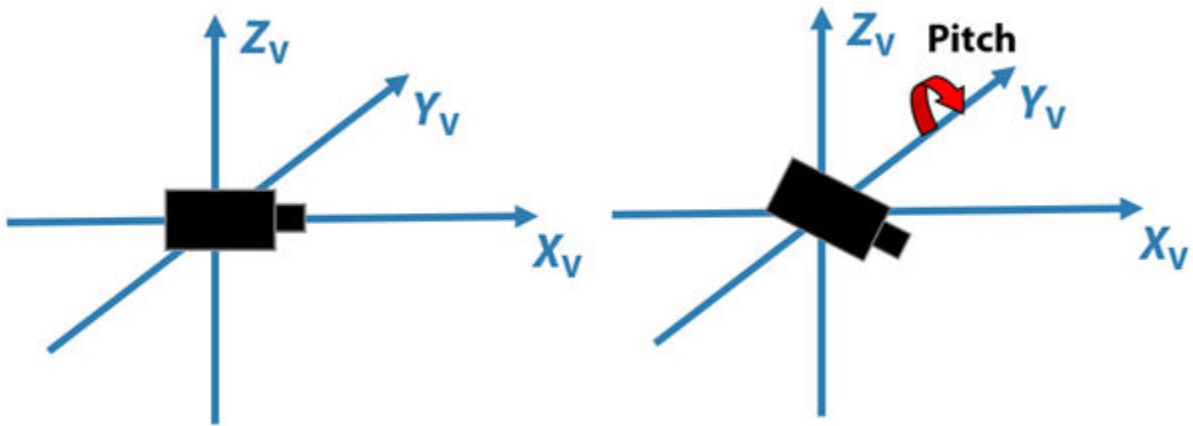
Height from the road surface to the camera sensor, specified as a real scalar. The height is the perpendicular distance from the ground to the focal point of the camera. Specify the height in world units, such as meters. To estimate this value, use the `estimateMonoCameraParameters` function.

Pitch — Pitch angle

real scalar

Pitch angle between the horizontal plane of the vehicle and the optical axis of the camera, specified as a real scalar in degrees. To estimate this value, use the `estimateMonoCameraParameters` function.

`Pitch` uses the ISO convention for rotation, with a clockwise positive angle direction when looking in the positive direction of the vehicle's Y_V axis.



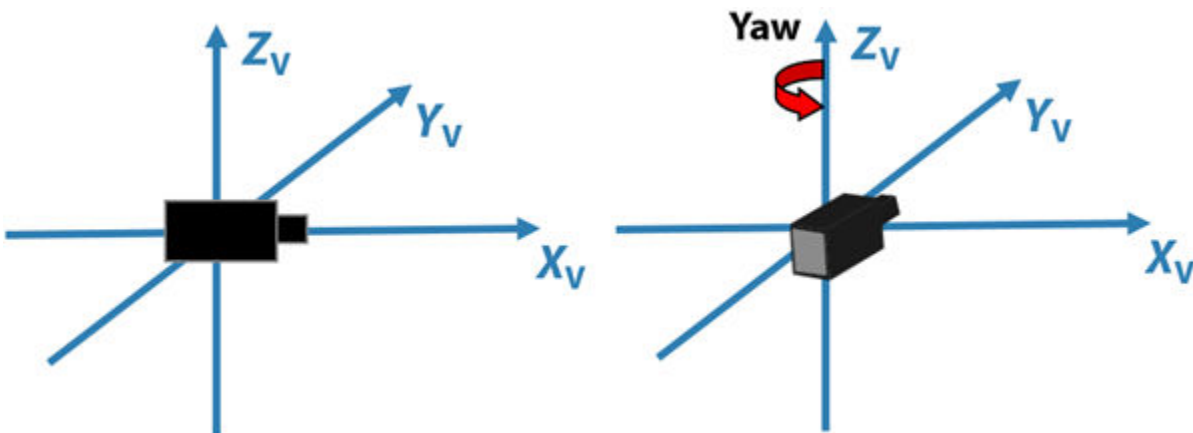
For more details, see “Angle Directions” on page 4-709.

Yaw — Yaw angle

real scalar

Yaw angle between the X_v axis of the vehicle and the optical axis of the camera, specified as a real scalar in degrees. To estimate this value, use the `estimateMonoCameraParameters` function.

Yaw uses the ISO convention for rotation, with a clockwise positive angle direction when looking in the positive direction of the vehicle's Z_v axis.



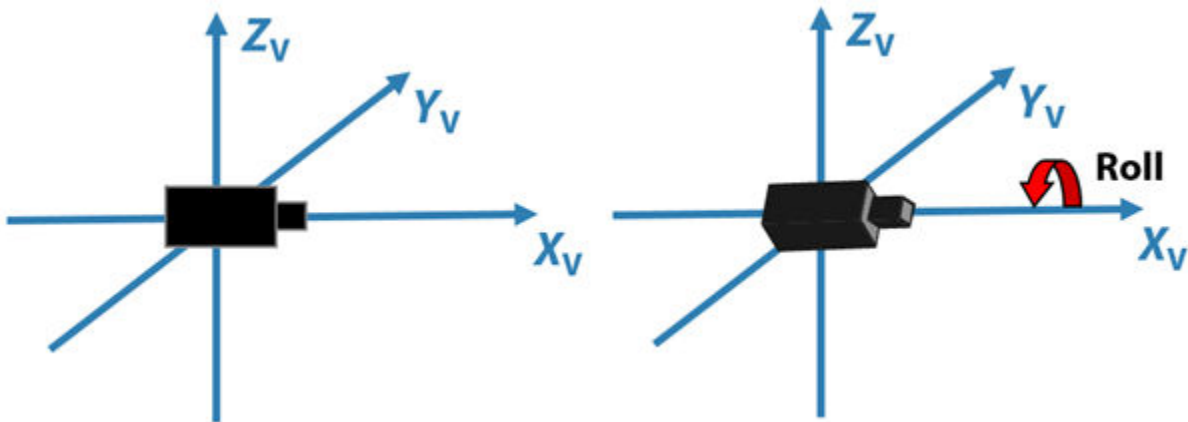
For more details, see “Angle Directions” on page 4-709.

Roll — Roll angle

real scalar

Roll angle of the camera around its optical axis, returned as a real scalar in degrees. To estimate this value, use the `estimateMonoCameraParameters` function.

Roll uses the ISO convention for rotation, with a clockwise positive angle direction when looking in the positive direction of the vehicle's X_V axis.



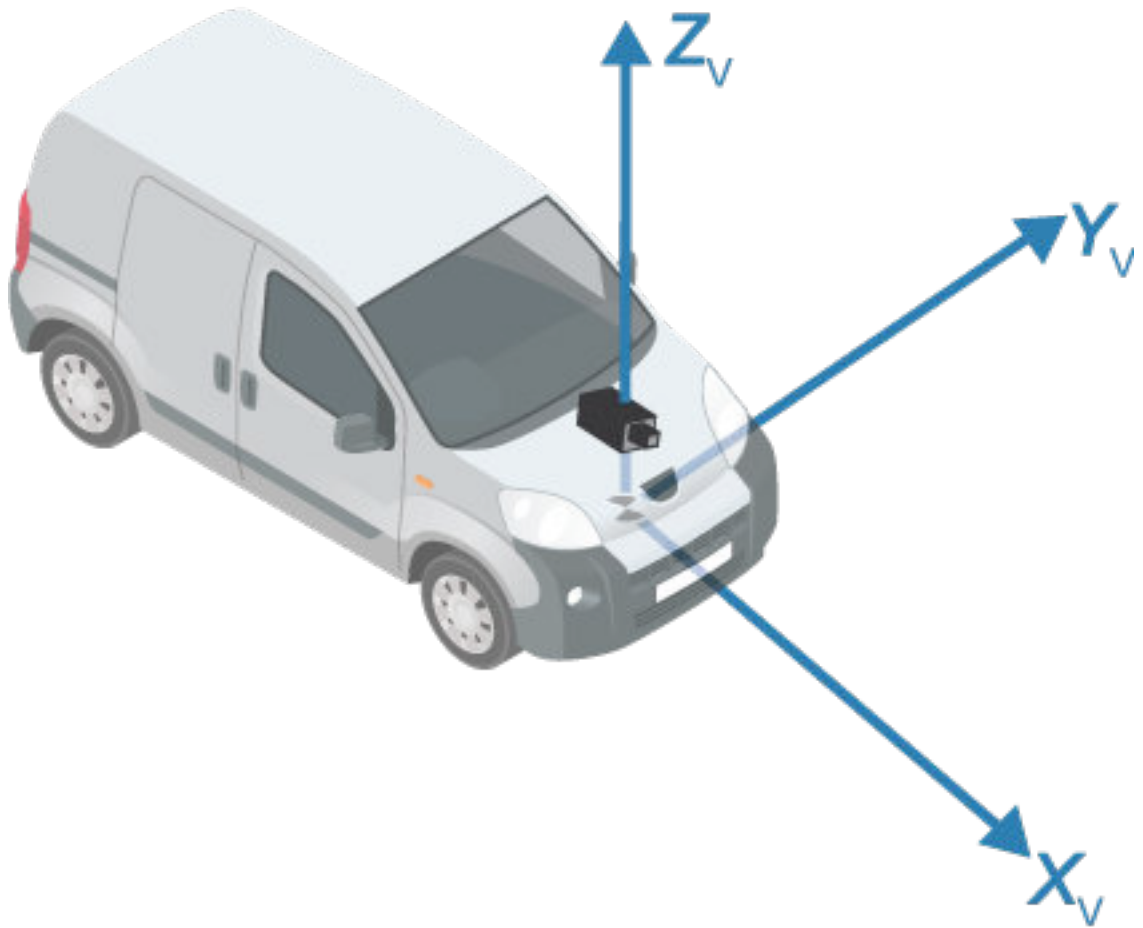
For more details, see “Angle Directions” on page 4-709.

SensorLocation — Location of center of camera sensor

[0 0] (default) | two-element vector

Location of the center of the camera sensor, specified as a two-element vector of the form $[x \ y]$. Use this property to change the placement of the camera. Units are in the vehicle coordinate system (X_V , Y_V , Z_V).

By default, the camera sensor is located at the (X_V , Y_V) origin, at the height specified by `Height`.



WorldUnits — World coordinate system units

'meters' | character vector | string scalar

World coordinate system units, specified as a character vector or string scalar. This property only stores the unit type and does not affect any calculations. Any text is valid.

You can set this property when you create the object. After you create the object, this property is read-only.

Object Functions

imageToVehicle Convert image coordinates to vehicle coordinates
vehicleToImage Convert vehicle coordinates to image coordinates

Examples

Create Monocular Camera Object

Create a forward-facing monocular camera sensor mounted on an ego vehicle. Examine an image captured from the camera and determine locations within the image in both vehicle and image coordinates.

Set the intrinsic parameters of the camera. Specify the focal length, the principal point of the image plane, and the output image size. Units are in pixels. Save the intrinsics as a cameraIntrinsics object.

```
focalLength = [800 800];  
principalPoint = [320 240];  
imageSize = [480 640];
```

```
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

Specify the position of the camera. Position the camera 2.18 meters above the ground with a 14-degree pitch toward the ground.

```
height = 2.18;  
pitch = 14;
```

Define a monocular camera sensor using the intrinsic camera parameters and the position of the camera. Load an image from the camera.

```
sensor = monoCamera(intrinsics,height,'Pitch',pitch);
```

```
Ioriginal = imread('road.png');  
figure  
imshow(Ioriginal)  
title('Original Image')
```

Original Image



Determine the image coordinates of a point 10 meters directly in front of the camera. The X -axis points forward from the camera and the Y -axis points to the left.

```
xyVehicleLoc1 = [10 0];  
xyImageLoc1 = vehicleToImage(sensor,xyVehicleLoc1)
```

```
xyImageLoc1 = 1×2
```

```
320.0000 216.2296
```

Display the point on the image.

```
IvehicleToImage = insertMarker(Ioriginal,xyImageLoc1);  
IvehicleToImage = insertText(IvehicleToImage,xyImageLoc1 + 5,'10 meters');  
figure  
imshow(IvehicleToImage)  
title('Vehicle-to-Image Point')
```



Determine the vehicle coordinates of a point that lies on the road surface in the image.

```
xyImageLoc2 = [300 300];  
xyVehicleLoc2 = imageToVehicle(sensor,xyImageLoc2)
```

```
xyVehicleLoc2 = 1x2
```

```
6.5959    0.1732
```

The point is about 6.6 meters in front of the vehicle and about 0.17 meters to the left of the vehicle center.

Display the vehicle coordinates of the point on the image.

```
IimageToVehicle = insertMarker(Ioriginal,xyImageLoc2);  
displayText = sprintf('%.2f m, %.2f m',xyVehicleLoc2);  
IimageToVehicle = insertText(IimageToVehicle,xyImageLoc2 + 5,displayText);  
  
figure  
imshow(IimageToVehicle)  
title('Image-to-Vehicle Point')
```

Image-to-Vehicle Point



Generate Visual Detections from Monocular Camera

Create a vision sensor by using a monocular camera configuration, and generate detections from that sensor.

Specify the intrinsic parameters of the camera and create a `monoCamera` object from these parameters. The camera is mounted on top of an ego vehicle at a height of 1.5 meters above the ground and a pitch of 1 degree toward the ground.

```
focalLength = [800 800];  
principalPoint = [320 240];
```

```
imageSize = [480 640];  
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

```
height = 1.5;  
pitch = 1;  
monoCamConfig = monoCamera(intrinsics,height,'Pitch',pitch);
```

Create a vision detection generator using the monocular camera configuration.

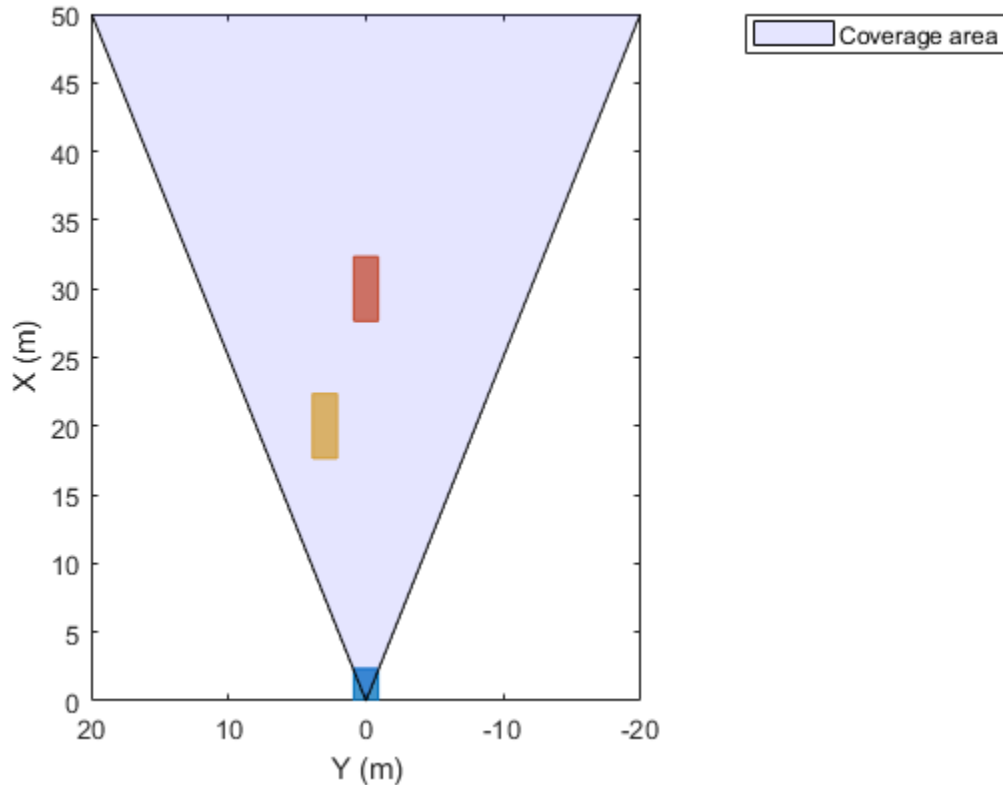
```
visionSensor = visionDetectionGenerator(monoCamConfig);
```

Generate a driving scenario with an ego vehicle and two target cars. Position the first target car 30 meters directly in front of the ego vehicle. Position the second target car 20 meters in front of the ego vehicle but offset to the left by 3 meters.

```
scenario = drivingScenario;  
egoVehicle = vehicle(scenario);  
targetCar1 = vehicle(scenario,'Position',[30 0 0]);  
targetCar2 = vehicle(scenario,'Position',[20 3 0]);
```

Use a bird's-eye plot to display the vehicle outlines and sensor coverage area.

```
figure  
bep = birdsEyePlot('XLim',[0 50],'YLim',[-20 20]);  
  
olPlotter = outlinePlotter(bep);  
[position,yaw,length,width,originOffset,color] = targetOutlines(egoVehicle);  
plotOutline(olPlotter,position,yaw,length,width);  
  
caPlotter = coverageAreaPlotter(bep,'DisplayName','Coverage area','FaceColor','blue');  
plotCoverageArea(caPlotter,visionSensor.SensorLocation,visionSensor.MaxRange, ...  
    visionSensor.Yaw,visionSensor.FieldOfView(1))
```

Obtain the poses of the target cars from the perspective of the ego vehicle. Use these poses to generate detections from the sensor.

```
poses = targetPoses(egoVehicle);
[dets,numValidDets] = visionSensor(poses,scenario.SimulationTime);
```

Display the (X,Y) positions of the valid detections. For each detection, the (X,Y) positions are the first two values of the Measurement field.

```
for i = 1:numValidDets
    XY = dets{i}.Measurement(1:2);
    detXY = sprintf('Detection %d: X = %.2f meters, Y = %.2f meters',i,XY);
    disp(detXY)
end
```

Detection 1: X = 19.09 meters, Y = 2.79 meters
Detection 2: X = 27.81 meters, Y = 0.08 meters

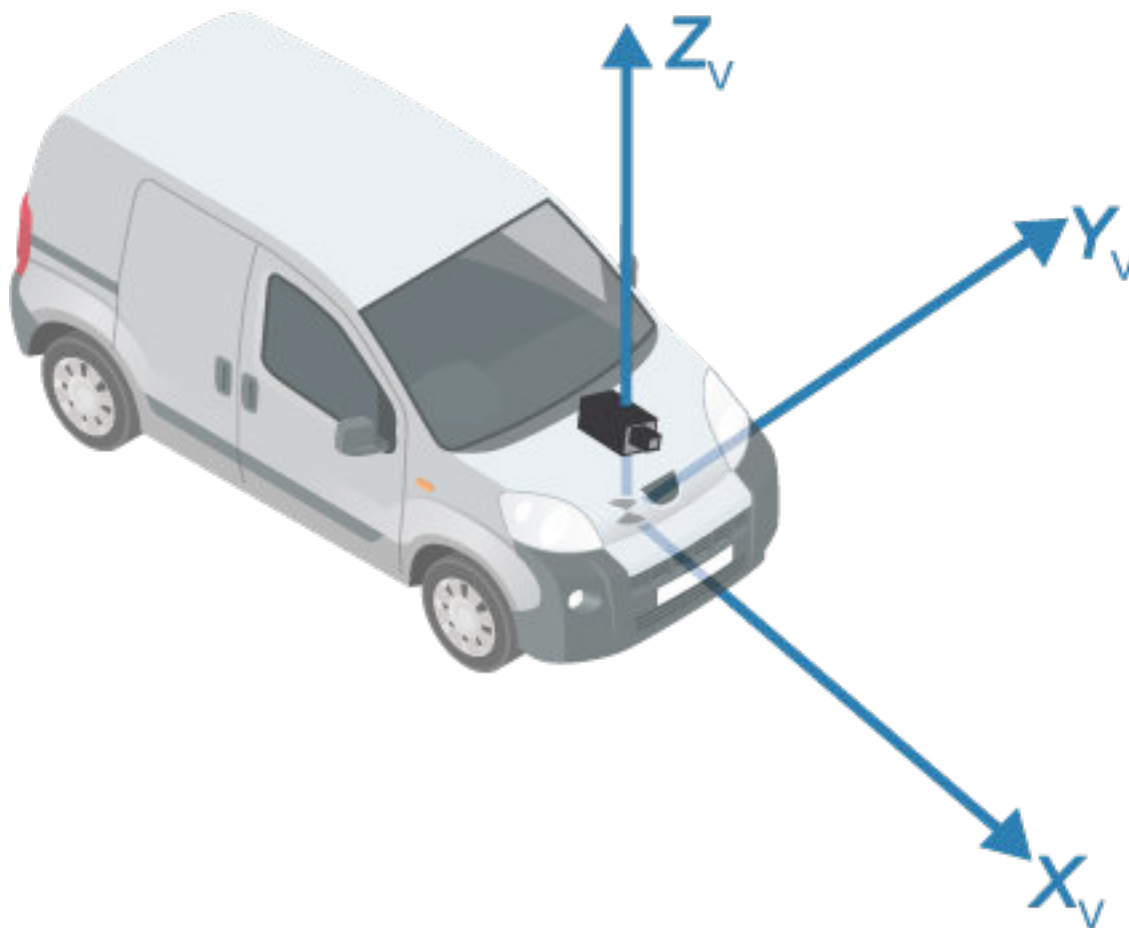
More About

Vehicle Coordinate System

In the vehicle coordinate system (X_v , Y_v , Z_v) defined by `monoCamera`:

- The X_v -axis points forward from the vehicle.
- The Y_v -axis points to the left, as viewed when facing forward.
- The Z_v -axis points up from the ground to maintain the right-handed coordinate system.

The default origin of this coordinate system is on the road surface, directly below the camera center. The focal point of the camera defines this center point.

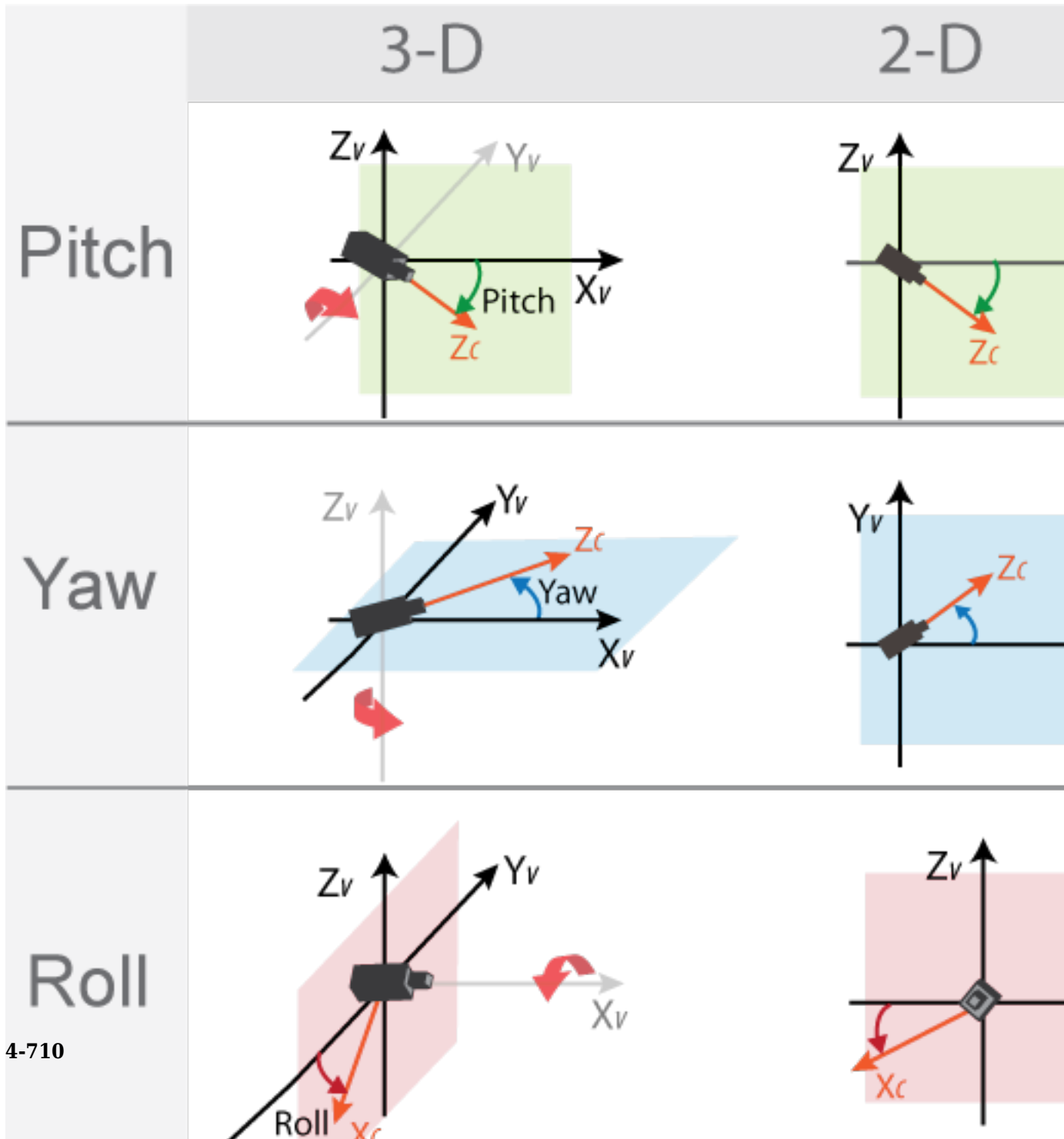


To change the placement of the origin within the vehicle coordinate system, update the `SensorLocation` property.

For more details about the vehicle coordinate system, see “Coordinate Systems in Automated Driving Toolbox”.

Angle Directions

The monocular camera sensor uses clockwise positive angle directions when looking in the positive direction of the Z-, Y-, and X-axes, respectively.



Compatibility Considerations

Direction of yaw angle rotation adjusted

Behavior changed in R2018a

Starting in R2018a, the `monoCamera` object uses the correct direction of rotation for the yaw angle. When you look in the positive direction of the vehicle's Z-axis, the yaw angle is now positive in the clockwise direction. Previously, this angle was positive in the counterclockwise direction.

If you are using R2017b or earlier, to use the correct direction of rotation, update the yaw angle to its negative value. For example, to update the yaw angle for a `monoCamera` object named `sensor`, use this code:

```
sensor.Yaw = -sensor.Yaw;
```

Extended Capabilities

C/C++ Code Generation

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

See Also

Apps

[Camera Calibrator](#)

Functions

[estimateCameraParameters](#) | [estimateMonoCameraParameters](#) | [extrinsics](#)

Objects

[birdsEyeView](#) | [cameraIntrinsics](#) | [cameraParameters](#)

Topics

[“Calibrate a Monocular Camera”](#)

“Configure Monocular Fisheye Camera”
“Visual Perception Using Monocular Camera”
“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

vehicleToImage

Convert vehicle coordinates to image coordinates

Syntax

```
imagePoints = vehicleToImage(monoCam,vehiclePoints)
```

Description

`imagePoints = vehicleToImage(monoCam,vehiclePoints)` converts $[x\ y]$ or $[x\ y\ z]$ vehicle coordinates to $[x\ y]$ image coordinates by applying a projective transformation. The monocular camera object, `monoCam`, contains the camera parameters.

Examples

Create Monocular Camera Object

Create a forward-facing monocular camera sensor mounted on an ego vehicle. Examine an image captured from the camera and determine locations within the image in both vehicle and image coordinates.

Set the intrinsic parameters of the camera. Specify the focal length, the principal point of the image plane, and the output image size. Units are in pixels. Save the intrinsics as a `cameraIntrinsics` object.

```
focalLength = [800 800];  
principalPoint = [320 240];  
imageSize = [480 640];
```

```
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

Specify the position of the camera. Position the camera 2.18 meters above the ground with a 14-degree pitch toward the ground.

```
height = 2.18;  
pitch = 14;
```

Define a monocular camera sensor using the intrinsic camera parameters and the position of the camera. Load an image from the camera.

```
sensor = monoCamera(intrinsics,height,'Pitch',pitch);
```

```
Ioriginal = imread('road.png');  
figure  
imshow(Ioriginal)  
title('Original Image')
```

Original Image



Determine the image coordinates of a point 10 meters directly in front of the camera. The X-axis points forward from the camera and the Y-axis points to the left.

```
xyVehicleLoc1 = [10 0];  
xyImageLoc1 = vehicleToImage(sensor,xyVehicleLoc1)
```

```
xyImageLoc1 = 1×2
```

```
    320.0000    216.2296
```

Display the point on the image.

```
IvehicleToImage = insertMarker(Ioriginal,xyImageLoc1);  
IvehicleToImage = insertText(IvehicleToImage,xyImageLoc1 + 5,'10 meters');  
figure  
imshow(IvehicleToImage)  
title('Vehicle-to-Image Point')
```

Vehicle-to-Image Point



Determine the vehicle coordinates of a point that lies on the road surface in the image.

```
xyImageLoc2 = [300 300];  
xyVehicleLoc2 = imageToVehicle(sensor, xyImageLoc2)
```

```
xyVehicleLoc2 = 1x2
```

```
6.5959    0.1732
```

The point is about 6.6 meters in front of the vehicle and about 0.17 meters to the left of the vehicle center.

Display the vehicle coordinates of the point on the image.

```
IimageToVehicle = insertMarker(Ioriginal,xyImageLoc2);  
displayText = sprintf('%.2f m, %.2f m',xyVehicleLoc2);  
IimageToVehicle = insertText(IimageToVehicle,xyImageLoc2 + 5,displayText);
```

```
figure  
imshow(IimageToVehicle)  
title('Image-to-Vehicle Point')
```

Image-to-Vehicle Point



Input Arguments

monoCam — Monocular camera parameters

monoCamera object

Monocular camera parameters, specified as a monoCamera object.

vehiclePoints — Vehicle points

M -by-2 matrix | M -by-3 matrix

Vehicle points, specified as an M -by-2 or M -by-3 matrix containing M number of $[x \ y]$ or $[x \ y \ z]$ vehicle coordinates.

Output Arguments

imagePoints — Image points

M -by-2 matrix

Image points, returned as an M -by-2 matrix containing M number of $[x \ y]$ image coordinates.

See Also

Objects

monoCamera

Functions

imageToVehicle

Topics

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

imageToVehicle

Convert image coordinates to vehicle coordinates

Syntax

```
vehiclePoints = imageToVehicle(monoCam,imagePoints)
```

Description

`vehiclePoints = imageToVehicle(monoCam,imagePoints)` converts image coordinates to $[x\ y]$ vehicle coordinates by applying a projective transformation. The monocular camera object, `monoCam`, contains the camera parameters.

Examples

Create Monocular Camera Object

Create a forward-facing monocular camera sensor mounted on an ego vehicle. Examine an image captured from the camera and determine locations within the image in both vehicle and image coordinates.

Set the intrinsic parameters of the camera. Specify the focal length, the principal point of the image plane, and the output image size. Units are in pixels. Save the intrinsics as a `cameraIntrinsics` object.

```
focalLength = [800 800];  
principalPoint = [320 240];  
imageSize = [480 640];
```

```
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

Specify the position of the camera. Position the camera 2.18 meters above the ground with a 14-degree pitch toward the ground.

```
height = 2.18;  
pitch = 14;
```

Define a monocular camera sensor using the intrinsic camera parameters and the position of the camera. Load an image from the camera.

```
sensor = monoCamera(intrinsics,height,'Pitch',pitch);
```

```
Ioriginal = imread('road.png');  
figure  
imshow(Ioriginal)  
title('Original Image')
```

Original Image



Determine the image coordinates of a point 10 meters directly in front of the camera. The X-axis points forward from the camera and the Y-axis points to the left.

```
xyVehicleLoc1 = [10 0];  
xyImageLoc1 = vehicleToImage(sensor,xyVehicleLoc1)
```

```
xyImageLoc1 = 1×2
```

```
    320.0000    216.2296
```

Display the point on the image.

```
IvehicleToImage = insertMarker(Ioriginal,xyImageLoc1);  
IvehicleToImage = insertText(IvehicleToImage,xyImageLoc1 + 5,'10 meters');  
figure  
imshow(IvehicleToImage)  
title('Vehicle-to-Image Point')
```

Vehicle-to-Image Point



Determine the vehicle coordinates of a point that lies on the road surface in the image.

```
xyImageLoc2 = [300 300];  
xyVehicleLoc2 = imageToVehicle(sensor, xyImageLoc2)
```

```
xyVehicleLoc2 = 1x2
```

```
6.5959    0.1732
```

The point is about 6.6 meters in front of the vehicle and about 0.17 meters to the left of the vehicle center.

Display the vehicle coordinates of the point on the image.


```
IimageToVehicle = insertMarker(Ioriginal,xyImageLoc2);  
displayText = sprintf('%.2f m, %.2f m',xyVehicleLoc2);  
IimageToVehicle = insertText(IimageToVehicle,xyImageLoc2 + 5,displayText);
```

```
figure  
imshow(IimageToVehicle)  
title('Image-to-Vehicle Point')
```

Image-to-Vehicle Point



Input Arguments

monoCam — Monocular camera parameters

monoCamera object

Monocular camera parameters, specified as a monoCamera object.

imagePoints — Image points

M -by-2 matrix

Image points, specified as an M -by-2 matrix containing M number of $[x\ y]$ image coordinates.

Output Arguments

vehiclePoints — Vehicle points

M -by-2 matrix

Vehicle points, returned as an M -by-2 matrix containing M number of $[x\ y]$ vehicle coordinates.

See Also

Objects

monoCamera

Functions

vehicleToImage

Topics

“Coordinate Systems in Automated Driving Toolbox”

Introduced in R2017a

multiObjectTracker

Track objects using GNN assignment

Description

The `multiObjectTracker` System object initializes, confirms, predicts, corrects, and deletes the tracks of moving objects. Inputs to the multi-object tracker are detection reports generated by an `objectDetection` object, `radarDetectionGenerator` object, or `visionDetectionGenerator` object. The multi-object tracker accepts detections from multiple sensors and assigns them to tracks using a global nearest neighbor (GNN) criterion. Each detection is assigned to a separate track. If the detection cannot be assigned to any track, based on the `AssignmentThreshold` property, the tracker creates a new track. The tracks are returned in a structure array.

A new track starts in a *tentative* state. If enough detections are assigned to a tentative track, its status changes to *confirmed*. If the detection is a known classification (the `ObjectClassID` field of the returned track is nonzero), that track can be confirmed immediately. For details on the multi-object tracker properties used to confirm tracks, see “Algorithms” on page 4-741.

When a track is confirmed, the multi-object tracker considers that track to represent a physical object. If detections are not added to the track within a specifiable number of updates, the track is deleted.

The tracker also estimates the state vector and state vector covariance matrix for each track using a Kalman filter. These state vectors are used to predict a track's location in each frame and determine the likelihood of each detection being assigned to each track.

To track objects using a multi-object tracker:

- 1 Create the `multiObjectTracker` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects? \(MATLAB\)](#).

Creation

Syntax

```
tracker = multiObjectTracker  
tracker = multiObjectTracker(Name,Value)
```

Description

`tracker = multiObjectTracker` creates a `multiObjectTracker` System object with default property values.

`tracker = multiObjectTracker(Name,Value)` sets properties on page 4-726 for the multi-object tracker using one or more name-value pairs. For example, `multiObjectTracker('FilterInitializationFcn',@initcvkf,'MaxNumTracks',100)` creates a multi-object tracker that uses a constant-velocity, unscented Kalman filter and maintains a maximum of 100 tracks. Enclose each property name in quotes.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see [System Design in MATLAB Using System Objects \(MATLAB\)](#).

FilterInitializationFcn — Kalman filter initialization function

@initcvkf (default) | function handle | character vector | string scalar

Kalman filter initialization function, specified as a function handle or as a character vector or string scalar of the name of a valid Kalman filter initialization function.

Automated Driving Toolbox supplies several initialization functions that you can use to specify `FilterInitializationFcn`.

Initialization Function	Function Definition
<code>initcvekf</code>	Initialize constant-velocity extended Kalman filter.
<code>initcvkf</code>	Initialize constant-velocity linear Kalman filter.
<code>initcvukf</code>	Initialize constant-velocity unscented Kalman filter.
<code>initcaekf</code>	Initialize constant-acceleration extended Kalman filter.
<code>initcakf</code>	Initialize constant-acceleration linear Kalman filter.
<code>initcaukf</code>	Initialize constant-acceleration unscented Kalman filter.
<code>initctekf</code>	Initialize constant-turnrate extended Kalman filter.
<code>initctukf</code>	Initialize constant-turnrate unscented Kalman filter.

You can also write your own initialization function. The input to this function must be a detection report created by `objectDetection`. The output of this function must be a Kalman filter object: `trackingKF`, `trackingEKF`, or `trackingUKF`. To guide you in writing this function, you can examine the details of the supplied functions from within MATLAB. For example:

```
type initcvkf
```

Data Types: `function_handle` | `char` | `string`

AssignmentThreshold – Detection assignment threshold

30 (default) | positive real scalar

Detection assignment threshold, specified as a positive real scalar. To assign a detection to a track, the detection's normalized distance from the track must be less than the assignment threshold. If some detections remain unassigned to tracks that you want them assigned to, increase the threshold. If some detections are assigned to incorrect tracks, decrease the threshold.

Data Types: `double`

ConfirmationParameters — Confirmation parameters for track creation

[2 3] (default) | two-element vector of positive increasing integers

Confirmation parameters for track creation, specified as a two-element vector of positive increasing integers, [M N], where M is less than N. A track is confirmed when at least M detections are assigned to the track during the first N updates after track initialization.

- When setting M, take into account the probability of object detection for the sensors. The probability of detection depends on factors such as occlusion or clutter. You can reduce M when tracks fail to be confirmed or increase M when too many false detections are assigned to tracks.
- When setting N, consider the number of times you want the tracker to update before it makes a confirmation decision. For example, if a tracker updates every 0.05 seconds, and you allow 0.5 seconds to make a confirmation decision, set N = 10.

Example: [3 5]

Data Types: double

NumCoastingUpdates — Coasting threshold for track deletion

5 (default) | positive integer

Coasting threshold for track deletion, specified as a positive integer. A track coasts when no detections are assigned to that confirmed track after one or more prediction steps. If the number of coasting steps exceeds this coasting threshold, the object deletes the track.

Data Types: double

MaxNumTracks — Maximum number of tracks

200 (default) | positive integer

Maximum number of tracks that the tracker can maintain, specified as a positive integer.

Data Types: double

MaxNumSensors — Maximum number of sensors

20 (default) | positive integer

Maximum number of sensors that can be connected to the tracker, specified as a positive integer.

When you specify detections as input to the multi-object tracker,

MaxNumSensors must be greater than or equal to the highest SensorIndex value in the detections cell array of objectDetection objects used to update the multi-object tracker. This property determines how many sets of ObjectAttributes fields each output track can have.

Data Types: double

HasCostMatrixInput — Enable cost matrix input

false (default) | true

Enable a cost matrix as input to the multiObjectTracker System object or to the updateTracks function, specified as false or true.

Data Types: logical

NumTracks — Number of tracks maintained by multi-object tracker

nonnegative integer

This property is read-only.

Number of tracks maintained by the multi-object tracker, specified as a nonnegative integer.

Data Types: double

NumConfirmedTracks — Number of confirmed tracks

nonnegative integer

This property is read-only.

Number of confirmed tracks, specified as a nonnegative integer. The IsConfirmed fields of the output track structures indicate which tracks are confirmed.

Data Types: double

Usage

To update tracks, call the created multi-object tracker with arguments, as if it were a function (described here). Alternatively, update tracks by using the updateTracks function, specifying the multi-object tracker as an input argument.

Syntax

```
confirmedTracks = tracker(detections,time)
[confirmedTracks,tentativeTracks] = tracker(detections,time)
[confirmedTracks,tentativeTracks,allTracks] = tracker(detections,
time)
[___] = tracker(detections,time,costMatrix)
```

Description

`confirmedTracks = tracker(detections,time)` creates, updates, and deletes tracks in the multi-object tracker and returns details about the confirmed tracks. Updates are based on the specified list of `detections`, and all tracks are updated to the specified `time`. Each element in the returned `confirmedTracks` structure array corresponds to a single track.

`[confirmedTracks,tentativeTracks] = tracker(detections,time)` also returns a structure array containing details about the tentative tracks.

`[confirmedTracks,tentativeTracks,allTracks] = tracker(detections,time)` also returns a structure array containing details about all the confirmed and tentative tracks, `allTracks`. The tracks are returned in the order by which the tracker internally maintains them. You can use this output to help you calculate the cost matrix, an optional input argument.

`[___] = tracker(detections,time,costMatrix)` specifies a cost matrix, returning any of the outputs from preceding syntaxes.

To specify a cost matrix, set the `HasCostMatrixInput` property of the `multiObjectTracker` System object to `true`.

Input Arguments

detections — Detection list

cell array of `objectDetection` objects

Detection list, specified as a cell array of `objectDetection` objects. The `Time` property value of each `objectDetection` object must be less than or equal to the current time of update, `time`, and greater than the previous time value used to update the multi-object tracker.

time — Time of update

real scalar

Time of update, specified as a real scalar. The multi-object tracker updates all tracks to this time. Units are in seconds.

`time` must be greater than or equal to the largest `Time` property value of the `objectDetection` objects in the input `detections` list. `time` must increase in value with each update to the multi-object tracker.

Data Types: `double`**costMatrix — Cost matrix** N_T -by- N_D matrix

Cost matrix, specified as a real-valued N_T -by- N_D matrix, where N_T is the number of existing tracks, and N_D is the number of current detections. The rows of the cost matrix correspond to the existing tracks. The columns correspond to the detections. Tracks are ordered as they appear in the list of tracks in the `allTracks` output argument of the previous update to the multi-object tracker.

In the first update to the multi-object tracker, or when the multi-object tracker has no previous tracks, assign the cost matrix a size of $[0, N_D]$. The cost must be calculated so that lower costs indicate a higher likelihood that the multi-object tracker assigns a detection to a track. To prevent certain detections from being assigned to certain tracks, use `Inf`.

Dependencies

To enable specification of the cost matrix when updating tracks, set the `HasCostMatrixInput` property of the multi-object tracker to `true`

Data Types: `double`**Output Arguments****confirmedTracks — Confirmed tracks**

structure array

Confirmed tracks, returned as a structure array with these fields.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

A track is confirmed if:

- At least `M` detections are assigned to the track during the first `N` updates after track initialization. To specify the values `[M N]`, use the `ConfirmationParameters` property of the multi-object tracker.
- The `ObjectDetection` object initiating the track has an `ObjectClassID` greater than zero.

tentativeTracks — Tentative tracks

structure array

Tentative tracks, returned as a structure array with these fields.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

A track is tentative before it is confirmed.

allTracks – All confirmed and tentative tracks

structure array

All confirmed and tentative tracks, returned as a structure array with these fields.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.

Field	Definition
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to `multiObjectTracker`

<code>isLocked</code>	Determine if System object is in use
<code>getTrackFilterProperties</code>	Obtain filter properties of track from multi-object tracker
<code>setTrackFilterProperties</code>	Set filter properties of track from multi-object tracker
<code>updateTracks</code>	Update multi-object tracker with new detections

Common to All System Objects

<code>step</code>	Run System object algorithm
-------------------	-----------------------------

release Release resources and allow changes to System object property values and input characteristics

reset Reset internal states of System object

Examples

Track Single Object Using Multi-Object Tracker

Create a multiObjectTracker System object™ using the default filter initialization function for a 2-D constant-velocity model. For this motion model, the state vector is $[x;vx;y;vy]$.

```
tracker = multiObjectTracker('ConfirmationParameters',[4 5], ...
    'NumCoastingUpdates',10);
```

Create a detection by specifying an objectDetection object. To use this detection with the multi-object tracker, enclose the detection in a cell array.

```
detime = 1.0;
det = { ...
    objectDetection(detime,[10; -1], ...
        'SensorIndex',1, ...
        'ObjectAttributes',{'ExampleObject',1}) ...
    };
```

Update the multi-object tracker with this detection. The time at which you update the multi-object tacker must be greater than or equal to the time at which the object was detected.

```
updatetime = 1.25;
[confirmedTracks,tentativeTracks,allTracks] = tracker(det,updatetime);
```

Create another detection of the same object and update the multi-object tracker. The tracker maintains only one track.

```
detime = 1.5;
det = { ...
    objectDetection(detime,[10.1; -1.1], ...
        'SensorIndex',1, ...
        'ObjectAttributes',{'ExampleObject',1}) ...
    };
```

```
updatetime = 1.75;  
[confirmedTracks,tentativeTracks,allTracks] = tracker(det,updatetime);
```

Determine whether the track has been verified by checking the number of confirmed tracks.

```
numConfirmed = tracker.NumConfirmedTracks  
  
numConfirmed = 0
```

Examine the position and velocity of the tracked object. Because the track has not been confirmed, get the position and velocity from the `tentativeTracks` structure.

```
positionSelector = [1 0 0 0; 0 0 1 0];  
velocitySelector = [0 1 0 0; 0 0 0 1];  
position = getTrackPositions(tentativeTracks,positionSelector)
```

```
position = 1x2  
  
    10.1426    -1.1426
```

```
velocity = getTrackVelocities(tentativeTracks,velocitySelector)
```

```
velocity = 1x2  
  
    0.1852    -0.1852
```

Confirm and Delete Track in Multi-Object Tracker

Create a sequence of detections of a moving object. Track the detections using a `multiObjectTracker` System object™. Observe how the tracks switch from tentative to confirmed and then to deleted.

Create a multi-object tracker using the `initcakf` filter initialization function. The tracker models 2-D constant-acceleration motion. For this motion model, the state vector is $[x;vx;ax;y;vy;ay]$.

```
tracker = multiObjectTracker('FilterInitializationFcn',@initcakf, ...  
    'ConfirmationParameters',[3 4], 'NumCoastingUpdates',6);
```

Create a sequence of detections of a moving target using `objectDetection`. To use these detections with the `multiObjectTracker`, enclose the detections in a cell array.

```
dt = 0.1;
pos = [10; -1];
vel = [10; 5];
for detno = 1:2
    time = (detno-1)*dt;
    det = { ...
        objectDetection(time,pos, ...
            'SensorIndex',1, ...
            'ObjectAttributes',{'ExampleObject',1}) ...
    };
    [confirmedTracks,tentativeTracks,allTracks] = tracker(det,time);
    pos = pos + vel*dt;
    meas = pos;
end
```

Verify that the track has not been confirmed yet by checking the number of confirmed tracks.

```
numConfirmed = tracker.NumConfirmedTracks
numConfirmed = 0
```

Because the track is not confirmed, get the position and velocity from the `tentativeTracks` structure.

```
positionSelector = [1 0 0 0 0 0; 0 0 0 1 0 0];
velocitySelector = [0 1 0 0 0 0; 0 0 0 0 1 0];
position = getTrackPositions(tentativeTracks,positionSelector)

position = 1x2

    10.6669    -0.6665

velocity = getTrackVelocities(tentativeTracks,velocitySelector)

velocity = 1x2

    3.3473    1.6737
```

Add more detections to confirm the track.

```
for detno = 3:5
    time = (detno-1)*dt;
    det = { ...
        objectDetection(time,pos, ...
            'SensorIndex',1, ...
            'ObjectAttributes',{'ExampleObject',1}) ...
    };
    [confirmedTracks,tentativeTracks,allTracks] = tracker(det,time);
    pos = pos + vel*dt;
    meas = pos;
end
```

Verify that the track has been confirmed, and display the position and velocity vectors for that track.

```
numConfirmed = tracker.NumConfirmedTracks

numConfirmed = 1

position = getTrackPositions(confirmedTracks,positionSelector)

position = 1x2

    13.8417    0.9208

velocity = getTrackVelocities(confirmedTracks,velocitySelector)

velocity = 1x2

    9.4670    4.7335
```

Let the tracker run but do not add new detections. The existing track is deleted.

```
for detno = 6:20
    time = (detno-1)*dt;
    det = {};
    [confirmedTracks,tentativeTracks,allTracks] = tracker(det,time);
    pos = pos + vel*dt;
    meas = pos;
end
```

Verify that the tracker has no tentative or confirmed tracks.

```
isempty(allTracks)
```



```
ans = logical
     1
```

Generate Radar Detections of Multiple Vehicles

Generate detections using a forward-facing automotive radar mounted on an ego vehicle. Assume that there are three targets:

- Vehicle 1 is in the center lane, directly in front of the ego vehicle, and driving at the same speed.
- Vehicle 2 is in the left lane and driving faster than the ego vehicle by 12 kilometers per hour.
- Vehicle 3 is in the right lane and driving slower than the ego vehicle by 5 kilometers per hour.

All positions, velocities, and measurements are relative to the ego vehicle. Run the simulation for ten steps.

```
dt = 0.1;
pos1 = [150 0 0];
pos2 = [160 10 0];
pos3 = [130 -10 0];
vel1 = [0 0 0];
vel2 = [12*1000/3600 0 0];
vel3 = [-5*1000/3600 0 0];
car1 = struct('ActorID',1,'Position',pos1,'Velocity',vel1);
car2 = struct('ActorID',2,'Position',pos2,'Velocity',vel2);
car3 = struct('ActorID',3,'Position',pos3,'Velocity',vel3);
```

Create an automotive radar sensor that is offset from the ego vehicle. By default, the sensor location is at (3.4,0) meters from the vehicle center and 0.2 meters above the ground plane. Turn off the range rate computation so that the radar sensor measures position only.

```
radar = radarDetectionGenerator('DetectionCoordinates','Sensor Cartesian', ...
    'MaxRange',200,'RangeResolution',10,'AzimuthResolution',10, ...
    'FieldOfView',[40 15],'UpdateInterval',dt,'HasRangeRate',false);
tracker = multiObjectTracker('FilterInitializationFcn',@initcvkf, ...
    'ConfirmationParameters',[3 4],'NumCoastingUpdates',6);
```

Generate detections with the radar from the non-ego vehicles. The output detections form a cell array and can be passed directly in to the `multiObjectTracker`.

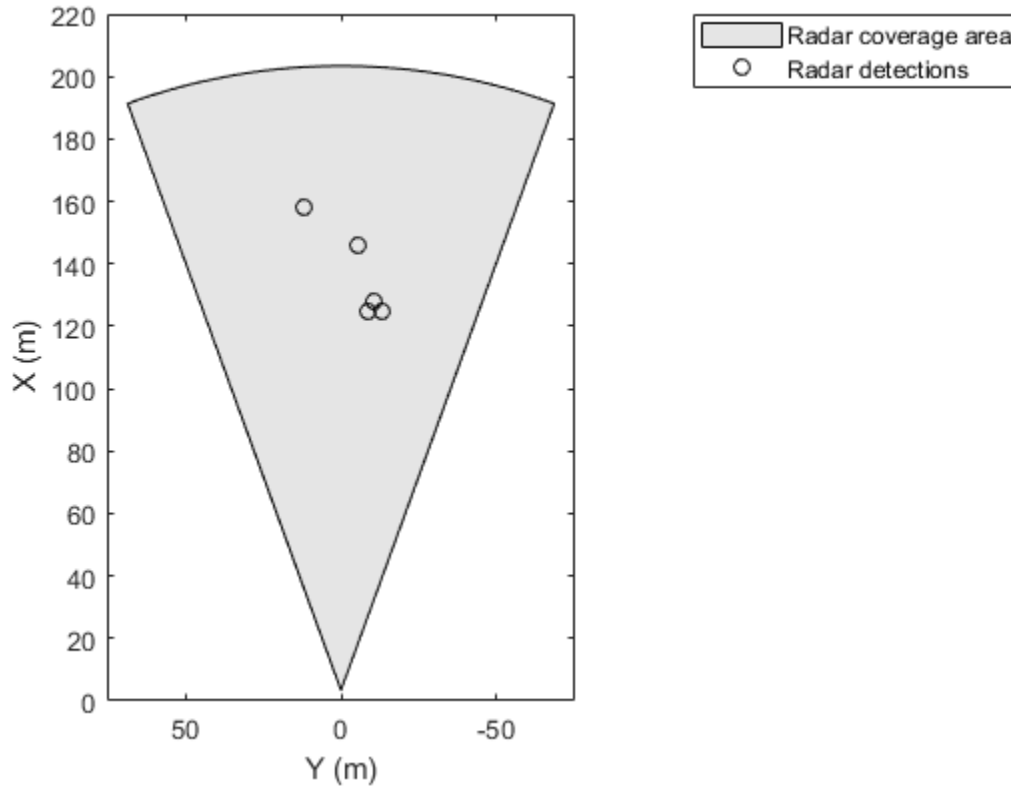
```
simTime = 0;
nsteps = 10;
for k = 1:nsteps
    dets = radar([car1 car2 car3],simTime);
    [confirmedTracks,tentativeTracks,allTracks] = tracker(dets,simTime);
```

Move the cars one time step and update the multi-object tracker.

```
simTime = simTime + dt;
car1.Position = car1.Position + dt*car1.Velocity;
car2.Position = car2.Position + dt*car2.Velocity;
car3.Position = car3.Position + dt*car3.Velocity;
end
```

Use `birdsEyePlot` to create an overhead view of the detections. Plot the sensor coverage area. Extract the X and Y positions of the targets by converting the Measurement fields of the cell array into a MATLAB array. Display the detections on the bird's-eye plot.

```
BEplot = birdsEyePlot('XLim',[0 220],'YLim',[-75 75]);
caPlotter = coverageAreaPlotter(BEplot,'DisplayName','Radar coverage area');
plotCoverageArea(caPlotter,radar.SensorLocation,radar.MaxRange, ...
    radar.Yaw,radar.FieldOfView(1))
detPlotter = detectionPlotter(BEplot,'DisplayName','Radar detections');
detPos = cellfun(@(d)d.Measurement(1:2),dets,'UniformOutput',false);
detPos = cell2mat(detPos)';
if ~isempty(detPos)
    plotDetection(detPlotter,detPos)
end
```



Algorithms

When you pass detections into a multi-object tracker, the System object:

- Attempts to assign the input detections to existing tracks, using the `assignDetectionsToTracks` function.
- Creates new tracks from unassigned detections.
- Updates already assigned tracks and possibly confirms them, based on the `ConfirmationParameters` property of the multi-object tracker.

- Deletes tracks that have no assigned detections within the last `NumCoastingUpdates` updates.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- See “System Objects in MATLAB Code Generation” (MATLAB Coder).
- All the detections used with a multi-object tracker must have properties with the same sizes and types.
- If you use the `ObjectAttributes` field within an `objectDetection` object, you must specify this field as a cell containing a structure. The structure for all detections must have the same fields and the values in these fields must always have the same size and type. The form of the structure cannot change during simulation.
- If `ObjectAttributes` are contained in the detection, the `SensorIndex` value of the detection cannot be greater than 10.
- The first update to the multi-object tracker must contain at least one detection.

See Also

Functions

`assignDetectionsToTracks` | `getTrackPositions` | `getTrackVelocities`

Objects

`drivingScenario` | `objectDetection` | `radarDetectionGenerator` | `trackingEKF` | `trackingKF` | `trackingUKF` | `visionDetectionGenerator`

Topics

“Multiple Object Tracking Tutorial”

“Track Multiple Vehicles Using a Camera”

“Track Pedestrians from a Moving Car”

Introduced in R2017a

getTrackFilterProperties

Obtain filter properties of track from multi-object tracker

Syntax

```
values = getTrackFilterProperties(tracker,trackID,property)
values = getTrackFilterProperties(tracker,
trackID,property1,...,propertyN)
```

Description

`values = getTrackFilterProperties(tracker,trackID,property)` returns the tracking filter property values for a specific track within a multi-object tracker. `trackID` is the ID of that specific track.

`values = getTrackFilterProperties(tracker, trackID,property1,...,propertyN)` returns multiple property values. You can specify the properties in any order.

Examples

Display and Set Tracking Filter Properties in Multi-Object Tracker

Create a `multiObjectTracker` System object™ using a constant-acceleration, linear Kalman filter for all tracks.

```
tracker = multiObjectTracker('FilterInitializationFcn',@initcakf, ...
    'ConfirmationParameters',[4 5], 'NumCoastingUpdates',9);
```

Create two detections and generate tracks for these detections.

```
detection1 = objectDetection(1.0,[10; 10]);
detection2 = objectDetection(1.0,[1000; 1000]);
[~,tracks] = tracker([detection1 detection2],1.1)
```

```
tracks=2x9 struct
  TrackID
  Time
  Age
  State
  StateCovariance
  IsConfirmed
  IsCoasted
  ObjectClassID
  ObjectAttributes
```

Get filter property values for the first track. Display the process noise values.

```
values = getTrackFilterProperties(tracker,1,'MeasurementNoise','ProcessNoise','MotionM
values{2}
```

```
ans = 6x6
```

0.0000	0.0005	0.0050	0	0	0
0.0005	0.0100	0.1000	0	0	0
0.0050	0.1000	1.0000	0	0	0
0	0	0	0.0000	0.0005	0.0050
0	0	0	0.0005	0.0100	0.1000
0	0	0	0.0050	0.1000	1.0000

Set new values for this property by doubling the process noise for the first track. Display the updated process noise values.

```
setTrackFilterProperties(tracker,1,'ProcessNoise',2*values{2});
values = getTrackFilterProperties(tracker,1,'ProcessNoise');
values{1}
```

```
ans = 6x6
```

0.0001	0.0010	0.0100	0	0	0
0.0010	0.0200	0.2000	0	0	0
0.0100	0.2000	2.0000	0	0	0
0	0	0	0.0001	0.0010	0.0100
0	0	0	0.0010	0.0200	0.2000
0	0	0	0.0100	0.2000	2.0000

Input Arguments

tracker — Multi-object tracker

`multiObjectTracker` System object

Multi-object tracker, specified as a `multiObjectTracker` System object.

trackID — Track ID

positive integer

Track ID, specified as a positive integer. `trackID` must be a valid track in `tracker`.

property — Tracking filter property

character vector | string scalar

Tracking filter property to return values for, specified as a character vector or string scalar. `property` must be a valid property of the tracking filter used by `tracker`. Valid tracking filters are `trackingKF`, `trackingEKF`, and `trackingUKF`.

You can specify additional properties in any order.

Example: `'MeasurementNoise', 'ProcessNoise'`

Data Types: `char` | `string`

Output Arguments

values — Tracking filter property values

cell array

Tracking filter property values, returned as a cell array. Each element in the cell array corresponds to the values of a specified property. `getTrackFilterProperties` returns the values in the same order in which you specified the corresponding properties.

See Also

Objects

`multiObjectTracker` | `trackingEKF` | `trackingKF` | `trackingUKF`

Functions

setTrackFilterProperties | updateTracks

Introduced in R2017a

setTrackFilterProperties

Set filter properties of track from multi-object tracker

Syntax

```
setTrackFilterProperties(tracker, trackID, property, value)  
setTrackFilterProperties(tracker,  
trackID, property1, value1, ..., propertyN, valueN)
```

Description

`setTrackFilterProperties(tracker, trackID, property, value)` sets the specified tracking filter property to the indicated value for a specific track within the multi-object tracker. `trackID` is the ID of that specific track.

`setTrackFilterProperties(tracker, trackID, property1, value1, ..., propertyN, valueN)` sets multiple property values. You can specify the property-value pairs in any order.

Examples

Display and Set Tracking Filter Properties in Multi-Object Tracker

Create a `multiObjectTracker` System object™ using a constant-acceleration, linear Kalman filter for all tracks.

```
tracker = multiObjectTracker('FilterInitializationFcn', @initcakf, ...  
    'ConfirmationParameters', [4 5], 'NumCoastingUpdates', 9);
```

Create two detections and generate tracks for these detections.

```
detection1 = objectDetection(1.0, [10; 10]);  
detection2 = objectDetection(1.0, [1000; 1000]);  
[~, tracks] = tracker([detection1 detection2], 1.1)
```

```
tracks=2x9 struct
  TrackID
  Time
  Age
  State
  StateCovariance
  IsConfirmed
  IsCoasted
  ObjectClassID
  ObjectAttributes
```

Get filter property values for the first track. Display the process noise values.

```
values = getTrackFilterProperties(tracker,1,'MeasurementNoise','ProcessNoise','MotionM
values{2}
```

```
ans = 6x6
```

0.0000	0.0005	0.0050	0	0	0
0.0005	0.0100	0.1000	0	0	0
0.0050	0.1000	1.0000	0	0	0
0	0	0	0.0000	0.0005	0.0050
0	0	0	0.0005	0.0100	0.1000
0	0	0	0.0050	0.1000	1.0000

Set new values for this property by doubling the process noise for the first track. Display the updated process noise values.

```
setTrackFilterProperties(tracker,1,'ProcessNoise',2*values{2});
values = getTrackFilterProperties(tracker,1,'ProcessNoise');
values{1}
```

```
ans = 6x6
```

0.0001	0.0010	0.0100	0	0	0
0.0010	0.0200	0.2000	0	0	0
0.0100	0.2000	2.0000	0	0	0
0	0	0	0.0001	0.0010	0.0100
0	0	0	0.0010	0.0200	0.2000
0	0	0	0.0100	0.2000	2.0000

Input Arguments

tracker — Multi-object tracker

multiObjectTracker System object

Multi-object tracker, specified as a multiObjectTracker System object.

trackID — Track ID

positive integer

Track ID, specified as a positive integer. trackID must be a valid track in tracker.

property — Tracking filter property

character vector | string scalar

Tracking filter property to set values for, specified as a character vector or string scalar. property must be a valid property of the tracking filter used by tracker. Valid tracking filters are trackingKF, trackingEKF, and trackingUKF.

You can specify additional property-value pairs in any order.

Example: 'MeasurementNoise',eye(2,2),'MotionModel','2D Constant Acceleration'

Data Types: char | string

value — Value to set tracking filter property to

valid MATLAB expression

Value to set the corresponding tracking filter property to, specified as a MATLAB expression. value must be a valid value of the corresponding property.

You can specify additional property-value pairs in any order.

Example: 'MeasurementNoise',eye(2,2),'MotionModel','2D Constant Acceleration'

See Also

Objects

multiObjectTracker | trackingEKF | trackingKF | trackingUKF

Functions

getTrackFilterProperties | updateTracks

Introduced in R2017a

updateTracks

Update multi-object tracker with new detections

Syntax

```
confirmedTracks = updateTracks(tracker,detections,time)
[confirmedTracks,tentativeTracks] = updateTracks(tracker,detections,
time)
[confirmedTracks,tentativeTracks,allTracks] = updateTracks(tracker,
detections,time)
[ ___ ] = updateTracks(tracker,detections,time,costMatrix)
```

Description

`confirmedTracks = updateTracks(tracker,detections,time)` creates, updates, and deletes tracks in the `multiObjectTracker` System object, `tracker`. Updates are based on the specified list of `detections`, and all tracks are updated to the specified `time`. Each element in the returned `confirmedTracks` structure array corresponds to a single track.

`[confirmedTracks,tentativeTracks] = updateTracks(tracker,detections,time)` also returns a structure array containing details about the tentative tracks.

`[confirmedTracks,tentativeTracks,allTracks] = updateTracks(tracker,detections,time)` also returns a structure array containing details about all confirmed and tentative tracks, `allTracks`. The tracks are returned in the order by which the tracker internally maintains them. You can use this output to help you calculate the cost matrix, an optional input argument.

`[___] = updateTracks(tracker,detections,time,costMatrix)` specifies a cost matrix, returning any of the outputs from preceding syntaxes.

To specify a cost matrix, set the `HasCostMatrixInput` property of `tracker` to `true`.

Examples

Generate Radar Detections of Multiple Vehicles

Generate detections using a forward-facing automotive radar mounted on an ego vehicle. Assume that there are three targets:

- Vehicle 1 is in the center lane, directly in front of the ego vehicle, and driving at the same speed.
- Vehicle 2 is in the left lane and driving faster than the ego vehicle by 12 kilometers per hour.
- Vehicle 3 is in the right lane and driving slower than the ego vehicle by 5 kilometers per hour.

All positions, velocities, and measurements are relative to the ego vehicle. Run the simulation for ten steps.

```
dt = 0.1;
pos1 = [150 0 0];
pos2 = [160 10 0];
pos3 = [130 -10 0];
vel1 = [0 0 0];
vel2 = [12*1000/3600 0 0];
vel3 = [-5*1000/3600 0 0];
car1 = struct('ActorID',1,'Position',pos1,'Velocity',vel1);
car2 = struct('ActorID',2,'Position',pos2,'Velocity',vel2);
car3 = struct('ActorID',3,'Position',pos3,'Velocity',vel3);
```

Create an automotive radar sensor that is offset from the ego vehicle. By default, the sensor location is at (3.4,0) meters from the vehicle center and 0.2 meters above the ground plane. Turn off the range rate computation so that the radar sensor measures position only.

```
radar = radarDetectionGenerator('DetectionCoordinates','Sensor Cartesian', ...
    'MaxRange',200,'RangeResolution',10,'AzimuthResolution',10, ...
    'FieldOfView',[40 15],'UpdateInterval',dt,'HasRangeRate',false);
tracker = multiObjectTracker('FilterInitializationFcn',@initcvkf, ...
    'ConfirmationParameters',[3 4],'NumCoastingUpdates',6);
```

Generate detections with the radar from the non-ego vehicles. The output detections form a cell array and can be passed directly in to the `multiObjectTracker`.

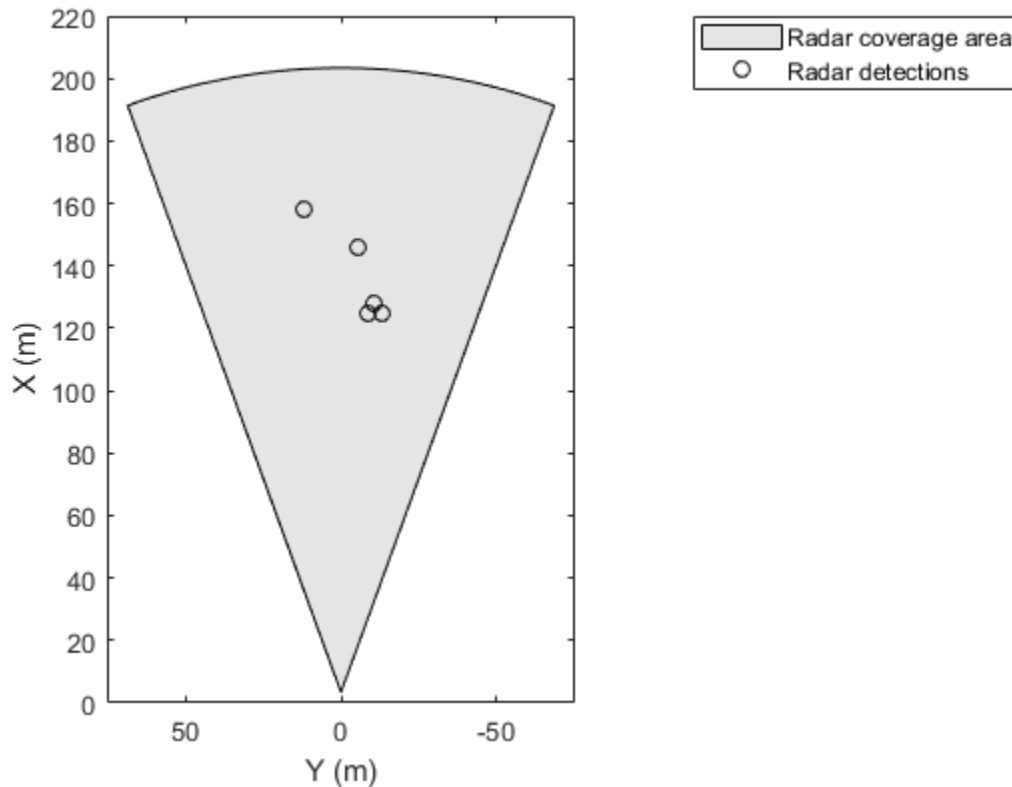
```
simTime = 0;
nsteps = 10;
for k = 1:nsteps
    dets = radar([car1 car2 car3],simTime);
    [confirmedTracks,tentativeTracks,allTracks] = updateTracks(tracker,dets,simTime);
```

Move the cars one time step and update the multi-object tracker.

```
simTime = simTime + dt;
car1.Position = car1.Position + dt*car1.Velocity;
car2.Position = car2.Position + dt*car2.Velocity;
car3.Position = car3.Position + dt*car3.Velocity;
end
```

Use `birdsEyePlot` to create an overhead view of the detections. Plot the sensor coverage area. Extract the X and Y positions of the targets by converting the Measurement fields of the cell array into a MATLAB array. Display the detections on the bird's-eye plot.

```
BEplot = birdsEyePlot('XLim',[0 220],'YLim',[-75 75]);
caPlotter = coverageAreaPlotter(BEplot,'DisplayName','Radar coverage area');
plotCoverageArea(caPlotter,radar.SensorLocation,radar.MaxRange, ...
    radar.Yaw,radar.FieldOfView(1))
detPlotter = detectionPlotter(BEplot,'DisplayName','Radar detections');
detPos = cellfun(@(d)d.Measurement(1:2),dets,'UniformOutput',false);
detPos = cell2mat(detPos)';
if ~isempty(detPos)
    plotDetection(detPlotter,detPos)
end
```

Input Arguments

tracker — Multi-object tracker

`multiObjectTracker` System object

Multi-object tracker, specified as a `multiObjectTracker` System object.

detections — Detection list

cell array of `objectDetection` objects

Detection list, specified as a cell array of `objectDetection` objects. The `Time` property value of each `objectDetection` object must be less than or equal to the current time of

update, time, and greater than the previous time value used to update the multi-object tracker.

time — Time of update

real scalar

Time of update, specified as a real scalar. The multi-object tracker updates all tracks to this time. Units are in seconds.

time must be greater than or equal to the largest Time property value of the objectDetection objects in the input detections list. time must increase in value with each update to the multi-object tracker.

Data Types: double

costMatrix — Cost matrix

N_T -by- N_D matrix

Cost matrix, specified as a real-valued N_T -by- N_D matrix, where N_T is the number of existing tracks, and N_D is the number of current detections. The rows of the cost matrix correspond to the existing tracks. The columns correspond to the detections. Tracks are ordered as they appear in the list of tracks in the allTracks output argument of the previous update to the multi-object tracker.

In the first update to the multi-object tracker, or when the multi-object tracker has no previous tracks, assign the cost matrix a size of $[0, N_D]$. The cost must be calculated so that lower costs indicate a higher likelihood that the multi-object tracker assigns a detection to a track. To prevent certain detections from being assigned to certain tracks, use Inf.

Dependencies

To enable specification of the cost matrix when updating tracks, set the HasCostMatrixInput property of the multi-object tracker to true

Data Types: double

Output Arguments

confirmedTracks — Confirmed tracks

structure array

Confirmed tracks, returned as a structure array with these fields.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

A track is confirmed if:

- At least `M` detections are assigned to the track during the first `N` updates after track initialization. To specify the values `[M N]`, use the `ConfirmationParameters` property of the multi-object tracker.
- The `objectDetection` object initiating the track has an `ObjectClassID` greater than zero.

tentativeTracks — Tentative tracks

structure array

Tentative tracks, returned as a structure array with these fields.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

A track is tentative before it is confirmed.

allTracks – All confirmed and tentative tracks

structure array

All confirmed and tentative tracks, returned as a structure array with these fields.

Field	Definition
TrackID	Unique track identifier.
Time	Time at which the track is updated. Units are in seconds.

Field	Definition
Age	Number of updates since track initialization.
State	Updated state vector. The state vector is specific to each type of Kalman filter.
StateCovariance	Updated state covariance matrix. The covariance matrix is specific to each type of Kalman filter.
IsConfirmed	Confirmation status. This field is <code>true</code> if the track is confirmed to be a real target.
IsCoasted	Coasting status. This field is <code>true</code> if the track is updated without a new detection.
ObjectClassID	Integer value representing the object classification. The value <code>0</code> represents an unknown classification. Nonzero classifications apply only to confirmed tracks.
ObjectAttributes	Cell array of object attributes reported by the sensor making the detection.

Algorithms

When you pass detections into `updateTracks`, the function:

- Attempts to assign the input detections to existing tracks, using the `assignDetectionsToTracks` function.
- Creates new tracks from unassigned detections.
- Updates already assigned tracks and possibly confirms them, based on the `ConfirmationParameters` property of the multi-object tracker.
- Deletes tracks that have no assigned detections within the last `NumCoastingUpdates` updates.

See Also

Objects

`multiObjectTracker` | `objectDetection`

Functions

`getTrackFilterProperties` | `setTrackFilterProperties`

Introduced in R2017a

acfObjectDetectorMonoCamera

Detect objects in monocular camera using aggregate channel features

Description

The `acfObjectDetectorMonoCamera` contains information about an aggregate channel features (ACF) object detector that is configured for use with a monocular camera sensor. To detect objects in an image that was captured by the camera, pass the detector to the `detect` function.

Creation

- 1 Create an `acfObjectDetector` object by calling the `trainACFObjectDetector` function with training data.

```
detector = trainACFObjectDetector(trainingData,...);
```

Alternatively, create a pretrained detector using functions such as `vehicleDetectorACF` or `peopleDetectorACF`.

- 2 Create a `monoCamera` object to model the monocular camera sensor.

```
sensor = monoCamera(...);
```

- 3 Create an `acfObjectDetectorMonoCamera` object by passing the detector and sensor as inputs to the `configureDetectorMonoCamera` function. The configured detector inherits property values from the original detector.

```
configuredDetector = configureDetectorMonoCamera(detector,sensor,...);
```

Properties

modelName — Name of classification model

character vector | string scalar

Name of the classification model, specified as a character vector or string scalar. By default, the name is set to the heading of the second column of the `trainingData` table

specified in the `trainACFObjectDetector` function. You can modify this name after creating your `acfObjectDetectorMonoCamera` object.

Example: `'stopSign'`

ObjectTrainingSize — Size of training images

[height width] vector

This property is read-only.

Size of training images, specified as a *[height width]* vector.

Example: `[100 100]`

NumWeakLearners — Number of weak learners

integer

This property is read-only.

Number of weak learners used in the detector, specified as an integer.

`NumWeakLearners` is less than or equal to the maximum number of weak learners for the last training stage. To restrict this maximum, you can use the `'MaxWeakLearners'` name-value pair in the `trainACFObjectDetector` function.

Camera — Camera configuration

`monoCamera` object

This property is read-only.

Camera configuration, specified as a `monoCamera` object. The object contains the camera intrinsics, the location, the pitch, yaw, and roll placement, and the world units for the parameters. Use the intrinsics to transform the object points in the image to world coordinates, which you can then compare to the values in the `WorldObjectSize` property.

WorldObjectSize — Range of object widths and lengths

[minWidth maxWidth] vector | *[minWidth maxWidth; minLength maxLength]* vector

Range of object widths and lengths in world units, specified as a *[minWidth maxWidth]* vector or *[minWidth maxWidth; minLength maxLength]* vector. Specifying the range of object lengths is optional.

Object Functions

`detect` Detect objects using ACF object detector configured for monocular camera

Examples

Detect Vehicles Using Monocular Camera and ACF

Configure an ACF object detector for use with a monocular camera mounted on an ego vehicle. Use this detector to detect vehicles within video frames captured by the camera.

Load an `acfObjectDetector` object pretrained to detect vehicles.

```
detector = vehicleDetectorACF;
```

Model a monocular camera sensor by creating a `monoCamera` object. This object contains the camera intrinsics and the location of the camera on the ego vehicle.

```
focalLength = [309.4362 344.2161]; % [fx fy]
principalPoint = [318.9034 257.5352]; % [cx cy]
imageSize = [480 640]; % [mrows ncols]
height = 2.1798; % height of camera above ground, in meters
pitch = 14; % pitch of camera, in degrees
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);
```

```
monCam = monoCamera(intrinsics,height,'Pitch',pitch);
```

Configure the detector for use with the camera. Limit the width of detected objects to a typical range for vehicle widths: 1.5-2.5 meters. The configured detector is an `acfObjectDetectorMonoCamera` object.

```
vehicleWidth = [1.5 2.5];
detectorMonoCam = configureDetectorMonoCamera(detector,monCam,vehicleWidth);
```

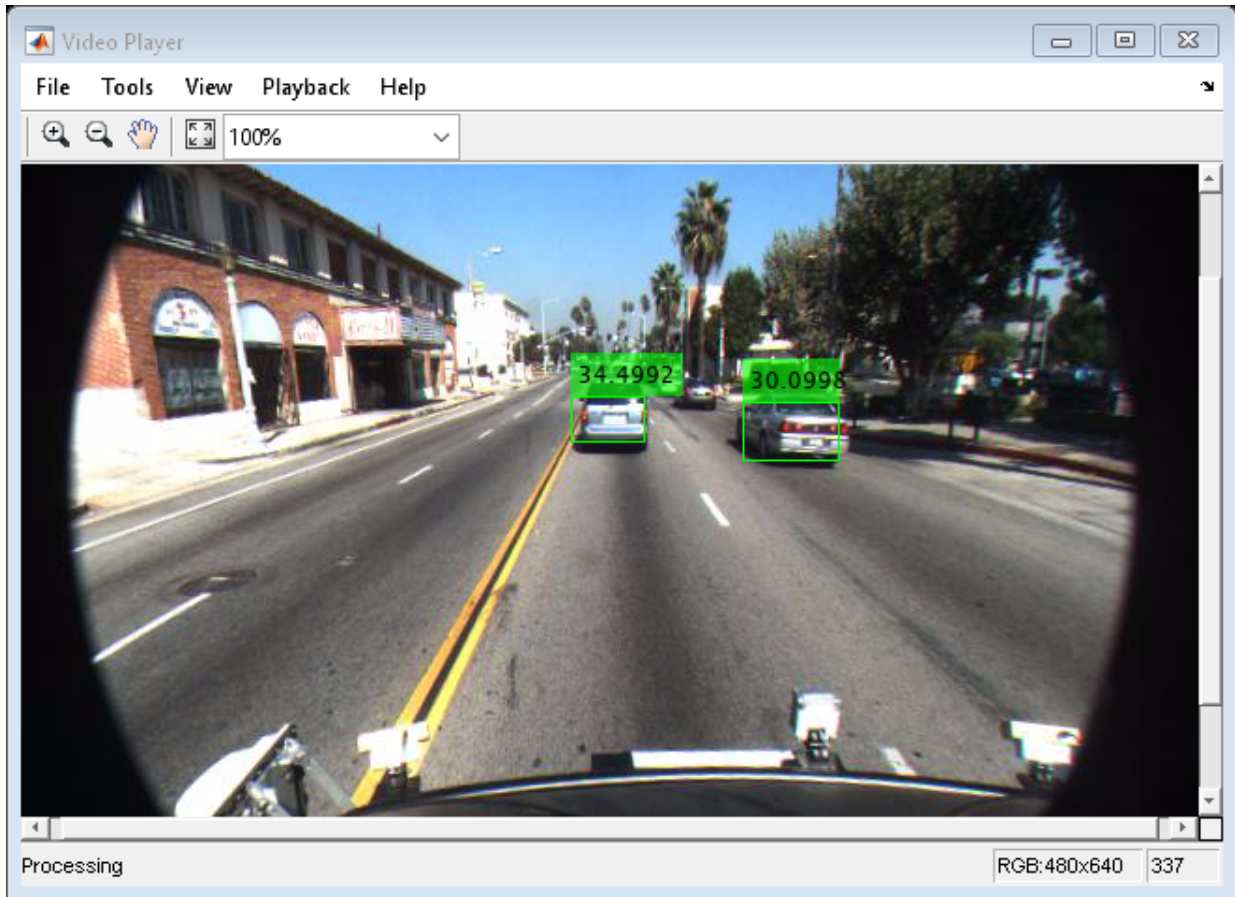
Load a video captured from the camera, and create a video reader and player.

```
videoFile = fullfile(toolboxdir('driving'),'drivingdata','caltech_washington1.avi');
reader = vision.VideoFileReader(videoFile,'VideoOutputDataType','uint8');
videoPlayer = vision.VideoPlayer('Position',[29 597 643 386]);
```

Run the detector in a loop over the video. Annotate the video with the bounding boxes for the detections and the detection confidence scores.

```
cont = ~isDone(reader);
while cont
    I = reader();

    % Run the detector.
    [bboxes,scores] = detect(detectorMonoCam,I);
    if ~isempty(bboxes)
        I = insertObjectAnnotation(I, ...
                                   'rectangle',bboxes, ...
                                   scores, ...
                                   'Color','g');
    end
    videoPlayer(I)
    % Exit the loop if the video player figure is closed.
    cont = ~isDone(reader) && isOpen(videoPlayer);
end
```



Extended Capabilities

C/C++ Code Generation

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

This function supports C/C++ code generation with the limitations:

- Supports code generation (requires MATLAB Coder™) only in generic MATLAB Host Computer target platform.

See Also

Apps

Ground Truth Labeler

Functions

configureDetectorMonoCamera | peopleDetectorACF |
trainACFObjectDetector | vehicleDetectorACF

Objects

monoCamera

Introduced in R2017a

detect

Detect objects using ACF object detector configured for monocular camera

Syntax

```
bboxes = detect(detector,I)
[bboxes,scores] = detect(detector,I)
[ ___ ]= detect(detector,I,roi)
[ ___ ] = detect( ___ ,Name,Value)
```

Description

`bboxes = detect(detector,I)` detects objects within image `I` using an aggregate channel features (ACF) object detector configured for a monocular camera. The locations of objects detected are returned as a set of bounding boxes.

`[bboxes,scores] = detect(detector,I)` also returns the detection confidence scores for each bounding box.

`[___]= detect(detector,I,roi)` detects objects within the rectangular search region specified by `roi`, using any of the preceding syntaxes.

`[___] = detect(___ ,Name,Value)` specifies options using one or more `Name,Value` pair arguments. For example, `detect(detector,I,'WindowStride',2)` sets the stride of the sliding window used to detect objects to 2.

Examples

Detect Vehicles Using Monocular Camera and ACF

Configure an ACF object detector for use with a monocular camera mounted on an ego vehicle. Use this detector to detect vehicles within video frames captured by the camera.

Load an `acfObjectDetector` object pretrained to detect vehicles.

```
detector = vehicleDetectorACF;
```

Model a monocular camera sensor by creating a `monoCamera` object. This object contains the camera intrinsics and the location of the camera on the ego vehicle.

```
focalLength = [309.4362 344.2161]; % [fx fy]
principalPoint = [318.9034 257.5352]; % [cx cy]
imageSize = [480 640]; % [mrows ncols]
height = 2.1798; % height of camera above ground, in meters
pitch = 14; % pitch of camera, in degrees
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);

monCam = monoCamera(intrinsics,height,'Pitch',pitch);
```

Configure the detector for use with the camera. Limit the width of detected objects to a typical range for vehicle widths: 1.5–2.5 meters. The configured detector is an `acfObjectDetectorMonoCamera` object.

```
vehicleWidth = [1.5 2.5];
detectorMonoCam = configureDetectorMonoCamera(detector,monCam,vehicleWidth);
```

Load a video captured from the camera, and create a video reader and player.

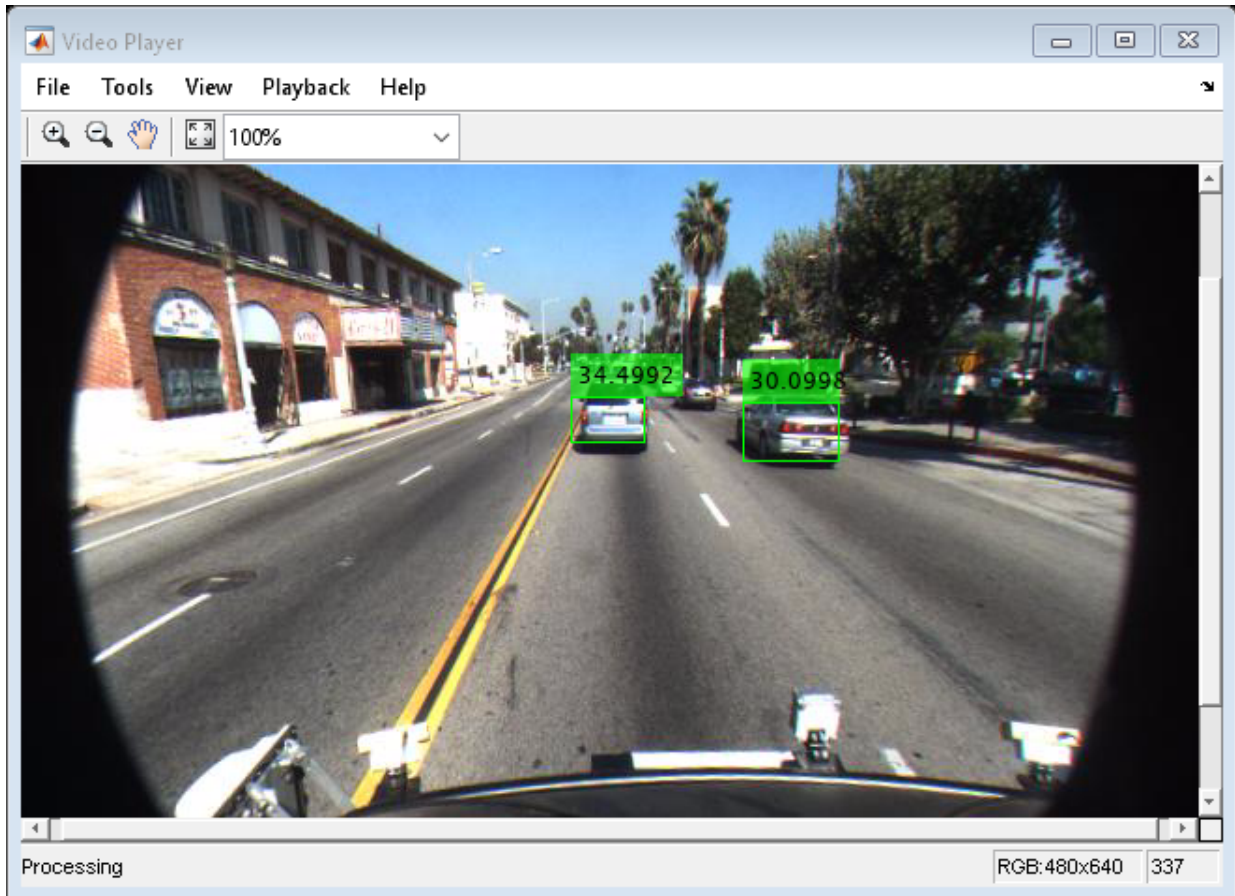
```
videoFile = fullfile(toolboxdir('driving'),'drivingdata','caltech_washington1.avi');
reader = vision.VideoFileReader(videoFile,'VideoOutputDataType','uint8');
videoPlayer = vision.VideoPlayer('Position',[29 597 643 386]);
```

Run the detector in a loop over the video. Annotate the video with the bounding boxes for the detections and the detection confidence scores.

```
cont = ~isDone(reader);
while cont
    I = reader();

    % Run the detector.
    [bboxes,scores] = detect(detectorMonoCam,I);
    if ~isempty(bboxes)
        I = insertObjectAnnotation(I, ...
            'rectangle',bboxes, ...
            scores, ...
            'Color','g');
    end
    videoPlayer(I)
    % Exit the loop if the video player figure is closed.
```

```
cont = ~isDone(reader) && isOpen(videoPlayer);  
end
```



Input Arguments

detector — ACF object detector configured for monocular camera
acfObjectDetectorMonoCamera object

ACF object detector configured for a monocular camera, specified as an `acfObjectDetectorMonoCamera` object. To create this object, use the

`configureDetectorMonoCamera` function with a `monoCamera` object and trained `acfObjectDetector` object as inputs.

I — Input image

grayscale image | RGB image

Input image, specified as a real, nonsparse, grayscale or RGB image.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`

roi — Search region of interest

`[x y width height]` vector

Search region of interest, specified as an `[x y width height]` vector. The vector specifies the upper left corner and size of a region in pixels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, . . . , NameN, ValueN`.

Example: `'NumScaleLevels', 4`

NumScaleLevels — Number of scale levels per octave

8 (default) | positive integer

Number of scale levels per octave, specified as the comma-separated pair consisting of `'NumScaleLevels'` and a positive integer. Each octave is a power-of-two downscaling of the image. To detect people at finer scale increments, increase this number. Recommended values are in the range [4, 8].

WindowStride — Stride for sliding window

4 (default) | positive integer

Stride for the sliding window, specified as the comma-separated pair consisting of `'WindowStride'` and a positive integer. This value indicates the distance for the function to move the window in both the `x` and `y` directions. The sliding window scans the images for object detection.

SelectStrongest — Select strongest bounding box for each object

`true` (default) | `false`

Select the strongest bounding box for each detected object, specified as the comma-separated pair consisting of 'SelectStrongest' and either `true` or `false`.

- `true` — Return the strongest bounding box per object. To select these boxes, `detect` calls the `selectStrongestBbox` function, which uses nonmaximal suppression to eliminate overlapping bounding boxes based on their confidence scores.
- `false` — Return all detected bounding boxes. You can then create your own custom operation to eliminate overlapping bounding boxes.

MinSize — Minimum region size

[height width] vector

Minimum region size that contains a detected object, specified as the comma-separated pair consisting of 'MinSize' and a *[height width]* vector. Units are in pixels.

By default, `MinSize` is the smallest object that the trained detector can detect.

MaxSize — Maximum region size

`size(I)` (default) | *[height width]* vector

Maximum region size that contains a detected object, specified as the comma-separated pair consisting of 'MaxSize' and a *[height width]* vector. Units are in pixels.

To reduce computation time, set this value to the known maximum region size for the objects being detected in the image. By default, 'MaxSize' is set to the height and width of the input image, `I`.

Threshold — Classification accuracy threshold

`-1` (default) | numeric scalar

Classification accuracy threshold, specified as the comma-separated pair consisting of 'Threshold' and a numeric scalar. Recommended values are in the range `[-1, 1]`. During multiscale object detection, the threshold value controls the accuracy and speed for classifying image subregions as either objects or nonobjects. To speed up the performance at the risk of missing true detections, increase this threshold.

Output Arguments

bboxes — Location of objects detected within image

M-by-4 matrix

Location of objects detected within the input image, returned as an M -by-4 matrix, where M is the number of bounding boxes. Each row of `bboxes` contains a four-element vector of the form `[x y width height]`. This vector specifies the upper left corner and size of that corresponding bounding box in pixels.

scores — Detection confidence scores

M -by-1 vector

Detection confidence scores, returned as an M -by-1 vector, where M is the number of bounding boxes. A higher score indicates higher confidence in the detection.

See Also

Apps

Ground Truth Labeler

Functions

`configureDetectorMonoCamera` | `selectStrongestBbox` |
`trainACFObjectDetector`

Objects

`acfObjectDetector` | `monoCamera`

Introduced in R2017a

fastRCNNObjectDetectorMonoCamera

Detect objects in monocular camera using Fast R-CNN deep learning detector

Description

The `fastRCNNObjectDetectorMonoCamera` object contains information about a Fast R-CNN (regions with convolutional neural networks) object detector that is configured for use with a monocular camera sensor. To detect objects in an image that was captured by the camera, pass the detector to the `detect` function. To classify image regions, pass the detector to the `classifyRegions` function.

When using `detect` or `classifyRegions` with `fastRCNNObjectDetectorMonoCamera`, use of a CUDA®-enabled NVIDIA® GPU with a compute capability of 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox™.

Creation

- 1 Create a `fastRCNNObjectDetector` object by calling the `trainFastRCNNObjectDetector` function with training data (requires Deep Learning Toolbox).

```
detector = trainFastRCNNObjectDetector(trainingData,...);
```

- 2 Create a `monoCamera` object to model the monocular camera sensor.

```
sensor = monoCamera(...);
```

- 3 Create a `fastRCNNObjectDetectorMonoCamera` object by passing the detector and sensor as inputs to the `configureDetectorMonoCamera` function. The configured detector inherits property values from the original detector.

```
configuredDetector = configureDetectorMonoCamera(detector,sensor,...);
```

Properties

modelName — Name of classification model

character vector | string scalar

Name of the classification model, specified as a character vector or string scalar. By default, the name is set to the heading of the second column of the `trainingData` table specified in the `trainFastRCNNObjectDetector` function. You can modify this name after creating your `fastRCNNObjectDetectorMonoCamera` object.

Example: 'stopSign'

network — Trained Fast R-CNN object detection network

object

This property is read-only.

Trained Fast R-CNN detection network, specified as an object. This object stores the layers that define the convolutional neural network used within the Fast R-CNN detector. This network classifies region proposals produced by the `RegionProposalFcn` property.

RegionProposalFcn — Region proposal method

function handle

Region proposal method, specified as a function handle.

classNames — Object class names

cell array

This property is read-only.

Names of the object classes that the Fast R-CNN detector was trained to find, specified as a cell array. This property is set by the `trainingData` input argument for the `trainFastRCNNObjectDetector` function. Specify the class names as part of the `trainingData` table.

MinObjectSize — Minimum object size supported

[height width] vector

This property is read-only.

Minimum object size supported by the Fast R-CNN network, specified as a *[height width]* vector. The minimum size depends on the network architecture.

Camera — Camera configuration

monoCamera object

This property is read-only.

Camera configuration, specified as a monoCamera object. The object contains the camera intrinsics, the location, the pitch, yaw, and roll placement, and the world units for the parameters. Use the intrinsics to transform the object points in the image to world coordinates, which you can then compare to the values in the WorldObjectSize property.

WorldObjectSize — Range of object widths and lengths

[minWidth maxWidth] vector | [minWidth maxWidth; minLength maxLength] vector

Range of object widths and lengths in world units, specified as a [minWidth maxWidth] vector or [minWidth maxWidth; minLength maxLength] vector. Specifying the range of object lengths is optional.

Object Functions

detect	Detect objects using Fast R-CNN object detector configured for monocular camera
classifyRegions	Classify objects in image regions using Fast R-CNN object detector configured for monocular camera

See Also

Apps

Ground Truth Labeler

Functions

configureDetectorMonoCamera | trainFastRCNNObjectDetector

Objects

fastRCNNObjectDetector | monoCamera

Topics

“Getting Started with R-CNN, Fast R-CNN, and Faster R-CNN” (Computer Vision Toolbox)

Introduced in R2017a

detect

Detect objects using Fast R-CNN object detector configured for monocular camera

Syntax

```
bboxes = detect(detector,I)
[bboxes,scores] = detect(detector,I)
[ ____,labels] = detect(detector,I)
[ ____ ] = detect( ____, roi)
detectionResults = detect(detector,ds)
[ ____ ] = detect( ____,Name,Value)
```

Description

`bboxes = detect(detector,I)` detects objects within image `I` using a Fast R-CNN (regions with convolutional neural networks) object detector configured for a monocular camera. The locations of objects detected are returned as a set of bounding boxes.

When using this function, use of a CUDA-enabled NVIDIA GPU with a compute capability of 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

`[bboxes,scores] = detect(detector,I)` also returns the detection confidence scores for each bounding box.

`[____,labels] = detect(detector,I)` also returns a categorical array of labels assigned to the bounding boxes, using any of the preceding syntaxes. The labels used for object classes are defined during training using the `trainFastRCNNObjectDetector` function.

`[____] = detect(____, roi)` detects objects within the rectangular search region specified by `roi`.

`detectionResults = detect(detector,ds)` detects objects within the series of images returned by the `read` function of the input datastore.

[___] = detect(___, Name, Value) specifies options using one or more Name, Value pair arguments. For example, detect(detector, I, 'NumStrongestRegions', 1000) limits the number of strongest region proposals to 1000.

Input Arguments

detector — Fast R-CNN object detector configured for monocular camera

fastRCNNObjectDetectorMonoCamera object

Fast R-CNN object detector configured for a monocular camera, specified as a fastRCNNObjectDetectorMonoCamera object. To create this object, use the configureDetectorMonoCamera function with a monoCamera object and trained fastRCNNObjectDetector object as inputs.

ds — Datastore

datastore object

Datastore, specified as a datastore object containing a collection of images. Each image must be a grayscale, RGB, or multichannel image. The function processes only the first column of the datastore, which must contain images and must be cell arrays or tables with multiple columns.

I — Input image

grayscale image | RGB image

Input image, specified as a real, nonsparse, grayscale or RGB image.

The detector is sensitive to the range of the input image. Therefore, ensure that the input image range is similar to the range of the images used to train the detector. For example, if the detector was trained on uint8 images, rescale this input image to the range [0, 255] by using the im2uint8 or rescale function. The size of this input image should be comparable to the sizes of the images used in training. If these sizes are very different, the detector has difficulty detecting objects because the scale of the objects in the input image differs from the scale of the objects the detector was trained to identify. Consider whether you used the SmallestImageDimension property during training to modify the size of training images.

Data Types: uint8 | uint16 | int16 | double | single | logical

roi — Search region of interest*[x y width height]* vector

Search region of interest, specified as an *[x y width height]* vector. The vector specifies the upper left corner and size of a region in pixels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'NumStrongestRegions', 1000`

NumStrongestRegions — Maximum number of strongest region proposals

2000 (default) | positive integer | Inf

Maximum number of strongest region proposals, specified as the comma-separated pair consisting of `'NumStrongestRegions'` and a positive integer. Reduce this value to speed up processing time at the cost of detection accuracy. To use all region proposals, specify this value as `Inf`.

SelectStrongest — Select strongest bounding box

true (default) | false

Select the strongest bounding box for each detected object, specified as the comma-separated pair consisting of `'SelectStrongest'` and either `true` or `false`.

- `true` — Return the strongest bounding box per object. To select these boxes, `detect` calls the `selectStrongestBboxMulticlass` function, which uses nonmaximal suppression to eliminate overlapping bounding boxes based on their confidence scores.

For example:

```
selectStrongestBboxMulticlass(bbox, scores, ...
    'RatioType', 'Min', ...
    'OverlapThreshold', 0.5);
```

- `false` — Return all detected bounding boxes. You can then create your own custom operation to eliminate overlapping bounding boxes.

MinSize — Minimum region size

[height width] vector

Minimum region size that contains a detected object, specified as the comma-separated pair consisting of 'MinSize' and a *[height width]* vector. Units are in pixels.

By default, MinSize is the smallest object that the trained `detector` can detect.

MaxSize — Maximum region size

`size(I)` (default) | *[height width]* vector

Maximum region size that contains a detected object, specified as the comma-separated pair consisting of 'MaxSize' and a *[height width]* vector. Units are in pixels.

To reduce computation time, set this value to the known maximum region size for the objects being detected in the image. By default, 'MaxSize' is set to the height and width of the input image, `I`.

MiniBatchSize — Minimum batch size

128 (default) | scalar

Minimum batch size, specified as the comma-separated pair consisting of 'MiniBatchSize' and a scalar value. Use the `MiniBatchSize` to process a large collection of images. Images are grouped into minibatches and processed as a batch to improve computation efficiency. Increase the minibatch size to decrease processing time. Decrease the size to use less memory.

ExecutionEnvironment — Hardware resource

'auto' (default) | 'gpu' | 'cpu'

Hardware resource on which to run the detector, specified as the comma-separated pair consisting of 'ExecutionEnvironment' and 'auto', 'gpu', or 'cpu'.

- 'auto' — Use a GPU if it is available. Otherwise, use the CPU.
- 'gpu' — Use the GPU. To use a GPU, you must have Parallel Computing Toolbox and a CUDA enabled NVIDIA GPU with a compute capability of 3.0 or higher. If a suitable GPU is not available, the function returns an error.
- 'cpu' — Use the CPU.

Output Arguments

bboxes — Location of objects detected within image

M-by-4 matrix

Location of objects detected within the input image, returned as an *M*-by-4 matrix, where *M* is the number of bounding boxes. Each row of **bboxes** contains a four-element vector of the form [*x y width height*]. This vector specifies the upper left corner and size of that corresponding bounding box in pixels.

scores — Detection scores

M-by-1 vector

Detection confidence scores, returned as an *M*-by-1 vector, where *M* is the number of bounding boxes. A higher score indicates higher confidence in the detection.

labels — Labels for bounding boxes

M-by-1 categorical array

Labels for bounding boxes, returned as an *M*-by-1 categorical array of *M* labels. You define the class names used to label the objects when you train the input detector.

detectionResults — Detection results

3-column table

Detection results, returned as a 3-column table with variable names, *Boxes*, *Scores*, and *Labels*. The *Boxes* column contains *M*-by-4 matrices, of *M* bounding boxes for the objects found in the image. Each row contains a bounding box as a 4-element vector in the format [*x,y,width,height*]. The format specifies the upper-left corner location and size in pixels of the bounding box in the corresponding image.

See Also

Apps

Ground Truth Labeler

Functions

`configureDetectorMonoCamera` | `selectStrongestBboxMulticlass` | `trainFastRCNNObjectDetector`

Objects

fastRCNNObjectDetectorMonoCamera | monoCamera

Introduced in R2017a

classifyRegions

Classify objects in image regions using Fast R-CNN object detector configured for monocular camera

Syntax

```
[labels,scores] = classifyRegions(detector,I,rois)
[labels,scores,allScores] = classifyRegions(detector,I,rois)
[___] = classifyRegions( ___, 'ExecutionEnvironment', resource)
```

Description

`[labels,scores] = classifyRegions(detector,I,rois)` classifies objects within the regions of interest of image `I`, using a Fast R-CNN (regions with convolutional neural networks) object detector configured for a monocular camera. For each region, `classifyRegions` returns the class label with the corresponding highest classification score.

When using this function, use of a CUDA enabled NVIDIA GPU with a compute capability of 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

`[labels,scores,allScores] = classifyRegions(detector,I,rois)` also returns all the classification scores of each region. The scores are returned in an M -by- N matrix of M regions and N class labels.

`[___] = classifyRegions(___, 'ExecutionEnvironment', resource)` specifies the hardware resource used to classify objects within image regions. You can use this name-value pair with any of the preceding syntaxes.

Input Arguments

detector — Fast R-CNN object detector configured for monocular camera
fastRCNNObjectDetectorMonoCamera object

Fast R-CNN object detector configured for a monocular camera, specified as a `fastRCNNObjectDetectorMonoCamera` object. To create this object, use the `configureDetectorMonoCamera` function with a `monoCamera` object and trained `fastRCNNObjectDetector` object as inputs.

I — Input image

grayscale image | RGB image

Input image, specified as a real, nonsparse, grayscale or RGB image.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`

rois — Regions of interest

M-by-4 matrix

Regions of interest within the image, specified as an *M*-by-4 matrix defining *M* rectangular regions. Each row contains a four-element vector of the form `[x y width height]`. This vector specifies the upper left corner and size of a region in pixels.

resource — Hardware resource

'auto' (default) | 'gpu' | 'cpu'

Hardware resource used to classify image regions, specified as 'ExecutionEnvironment' and 'auto', 'gpu', or 'cpu'.

- 'auto' — Use a GPU if it is available. Otherwise, use the CPU.
- 'gpu' — Use the GPU. To use a GPU, you must have Parallel Computing Toolbox and a CUDA enabled NVIDIA GPU with a compute capability of 3.0 or higher. If a suitable GPU is not available, the function returns an error.
- 'cpu' — Use the CPU.

Example: 'ExecutionEnvironment', 'cpu'

Output Arguments

labels — Classification labels of regions

M-by-1 categorical array

Classification labels of regions, returned as an *M*-by-1 categorical array. *M* is the number of regions of interest in `rois`. Each class name in `labels` corresponds to a classification

score in `scores` and a region of interest in `rois`. `classifyRegions` obtains the class names from the input `detector`.

scores — Highest classification score per region

M-by-1 vector of values in the range [0, 1]

Highest classification score per region, returned as an *M*-by-1 vector of values in the range [0, 1]. *M* is the number of regions of interest in `rois`. Each classification score in `scores` corresponds to a class name in `labels` and a region of interest in `rois`. A higher score indicates higher confidence in the classification.

allScores — All classification scores per region

M-by-*N* matrix of values in the range [0, 1]

All classification scores per region, returned as an *M*-by-*N* matrix of values in the range [0, 1]. *M* is the number of regions in `rois`. *N* is the number of class names stored in the input `detector`. Each row of classification scores in `allScores` corresponds to a region of interest in `rois`. A higher score indicates higher confidence in the classification.

See Also

Apps

Ground Truth Labeler

Functions

`configureDetectorMonoCamera` | `trainFastRCNNObjectDetector`

Objects

`fastRCNNObjectDetectorMonoCamera` | `monoCamera`

Introduced in R2017a

fasterRCNNObjectDetectorMonoCamera

Detect objects in monocular camera using Faster R-CNN deep learning detector

Description

The `fasterRCNNObjectDetectorMonoCamera` object contains information about a Faster R-CNN (regions with convolutional neural networks) object detector that is configured for use with a monocular camera sensor. To detect objects in an image that was captured by the camera, pass the detector to the `detect` function.

When using the `detect` function with `fasterRCNNObjectDetectorMonoCamera`, use of a CUDA enabled NVIDIA GPU with a compute capability of 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

Creation

- 1 Create a `fasterRCNNObjectDetector` object by calling the `trainFasterRCNNObjectDetector` function with training data (requires Deep Learning Toolbox).

```
detector = trainFasterRCNNObjectDetector(trainingData,...);
```

Alternatively, create a pretrained detector by using the `vehicleDetectorFasterRCNN` function.

- 2 Create a `monoCamera` object to model the monocular camera sensor.

```
sensor = monoCamera(...);
```

- 3 Create a `fasterRCNNObjectDetectorMonoCamera` object by passing the detector and sensor as inputs to the `configureDetectorMonoCamera` function. The configured detector inherits property values from the original detector.

```
configuredDetector = configureDetectorMonoCamera(detector,sensor,...);
```


Properties

ModelName — Name of classification model

character vector | string scalar

This property is read-only.

Name of the classification model, specified as a character vector or string scalar. By default, the name is set to the heading of the second column of the `trainingData` table specified in the `trainFasterRCNNObjectDetector` function. You can modify this name after creating your `fasterRCNNObjectDetectorMonoCamera` object.

Network — Trained Fast R-CNN object detection network

DAGNetwork object

This property is read-only.

Trained Fast R-CNN object detection network, specified as a DAGNetwork object. This object stores the layers that define the convolutional neural network used within the Faster R-CNN detector.

AnchorBoxes — Size of anchor boxes

M -by-2 matrix

This property is read-only.

Size of anchor boxes, specified as an M -by-2 matrix, where each row is in the format [*height width*]. This value is set during training.

ClassNames — Object class names

cell array

This property is read-only.

Names of the object classes that the Faster R-CNN detector was trained to find, specified as a cell array. This property is set by the `trainingData` input argument for the `trainFasterRCNNObjectDetector` function. Specify the class names as part of the `trainingData` table.

MinObjectSize — Minimum object size supported

[*height width*] vector

This property is read-only.

Minimum object size supported by the Faster R-CNN network, specified as a [*height width*] vector. The minimum size depends on the network architecture.

Camera — Camera configuration

`monoCamera` object

This property is read-only.

Camera configuration, specified as a `monoCamera` object. The object contains the camera intrinsics, the location, the pitch, yaw, and roll placement, and the world units for the parameters. Use the intrinsics to transform the object points in the image to world coordinates, which you can then compare to the values in the `WorldObjectSize` property.

WorldObjectSize — Range of object widths and lengths

[*minWidth maxWidth*] vector | [*minWidth maxWidth; minLength maxLength*] vector

Range of object widths and lengths in world units, specified as a [*minWidth maxWidth*] vector or [*minWidth maxWidth; minLength maxLength*] vector. Specifying the range of object lengths is optional.

Object Functions

`detect` Detect objects using Faster R-CNN object detector configured for monocular camera

Examples

Detect Vehicles Using Monocular Camera and Faster R-CNN

Configure a Faster R-CNN object detector for use with a monocular camera mounted on an ego vehicle. Use this detector to detect vehicles within an image captured by the camera.

Load a `fasterRCNNObjectDetector` object pretrained to detect vehicles.

```
detector = vehicleDetectorFasterRCNN;
```

Model a monocular camera sensor by creating a `monoCamera` object. This object contains the camera intrinsics and the location of the camera on the ego vehicle.

```
focalLength = [309.4362 344.2161];    % [fx fy]
principalPoint = [318.9034 257.5352]; % [cx cy]
imageSize = [480 640];              % [mrows ncols]
height = 2.1798;                    % height of camera above ground, in meters
pitch = 14;                          % pitch of camera, in degrees
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);

monCam = monoCamera(intrinsics,height,'Pitch',pitch);
```

Configure the detector for use with the camera. Limit the width of detected objects to a typical range for vehicle widths: 1.5-2.5 meters. The configured detector is a `fasterRCNNObjectDetectorMonoCamera` object.

```
vehicleWidth = [1.5 2.5];
detectorMonoCam = configureDetectorMonoCamera(detector,monCam,vehicleWidth);
```

Read in an image captured by the camera.

```
I = imread('carsinfront.png');
imshow(I)
```



Detect the vehicles in the image by using the detector. Annotate the image with the bounding boxes for the detections and the detection confidence scores.

```
[bboxes,scores] = detect(detectorMonoCam,I);  
I = insertObjectAnnotation(I,'rectangle',bboxes,scores,'Color','g');  
imshow(I)
```



See Also

Apps

Ground Truth Labeler

Functions

`configureDetectorMonoCamera` | `trainFasterRCNNObjectDetector` |
`vehicleDetectorFasterRCNN`

Objects

fasterRCNNObjectDetector | monoCamera

Topics

“Getting Started with R-CNN, Fast R-CNN, and Faster R-CNN” (Computer Vision Toolbox)

Introduced in R2017a

detect

Detect objects using Faster R-CNN object detector configured for monocular camera

Syntax

```
bboxes = detect(detector,I)
[bboxes,scores] = detect(detector,I)
[___,labels] = detect(detector,I)
[___] = detect(___,roi)
detectionResults = detect(detector,ds)
[___] = detect(___,Name,Value)
```

Description

`bboxes = detect(detector,I)` detects objects within image `I` using a Faster R-CNN (regions with convolutional neural networks) object detector configured for a monocular camera. The locations of objects detected are returned as a set of bounding boxes.

When using this function, use of a CUDA-enabled NVIDIA GPU with a compute capability of 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

`[bboxes,scores] = detect(detector,I)` also returns the detection confidence scores for each bounding box.

`[___,labels] = detect(detector,I)` also returns a categorical array of labels assigned to the bounding boxes, using any of the preceding syntaxes. The labels used for object classes are defined during training using the `trainFasterRCNNObjectDetector` function.

`[___] = detect(___,roi)` detects objects within the rectangular search region specified by `roi`.

`detectionResults = detect(detector,ds)` detects objects within the series of images returned by the `read` function of the input datastore.

[___] = detect(___, Name, Value) specifies options using one or more Name, Value pair arguments. For example, detect(detector, I, 'NumStrongestRegions', 1000) limits the number of strongest region proposals to 1000.

Examples

Detect Vehicles Using Monocular Camera and Faster R-CNN

Configure a Faster R-CNN object detector for use with a monocular camera mounted on an ego vehicle. Use this detector to detect vehicles within an image captured by the camera.

Load a fasterRCNNObjectDetector object pretrained to detect vehicles.

```
detector = vehicleDetectorFasterRCNN;
```

Model a monocular camera sensor by creating a monoCamera object. This object contains the camera intrinsics and the location of the camera on the ego vehicle.

```
focalLength = [309.4362 344.2161]; % [fx fy]
principalPoint = [318.9034 257.5352]; % [cx cy]
imageSize = [480 640]; % [mrows ncols]
height = 2.1798; % height of camera above ground, in meters
pitch = 14; % pitch of camera, in degrees
intrinsics = cameraIntrinsics(focalLength, principalPoint, imageSize);

monCam = monoCamera(intrinsics, height, 'Pitch', pitch);
```

Configure the detector for use with the camera. Limit the width of detected objects to a typical range for vehicle widths: 1.5-2.5 meters. The configured detector is a fasterRCNNObjectDetectorMonoCamera object.

```
vehicleWidth = [1.5 2.5];
detectorMonoCam = configureDetectorMonoCamera(detector, monCam, vehicleWidth);
```

Read in an image captured by the camera.

```
I = imread('carsinfront.png');
imshow(I)
```




Detect the vehicles in the image by using the detector. Annotate the image with the bounding boxes for the detections and the detection confidence scores.

```
[bboxes,scores] = detect(detectorMonoCam,I);  
I = insertObjectAnnotation(I,'rectangle',bboxes,scores,'Color','g');  
imshow(I)
```



Input Arguments

detector — **Faster R-CNN object detector configured for monocular camera**
fasterRCNNObjectDetectorMonoCamera object

Faster R-CNN object detector configured for a monocular camera, specified as a fasterRCNNObjectDetectorMonoCamera object. To create this object, use the configureDetectorMonoCamera function with a monoCamera object and trained fasterRCNNObjectDetector object as inputs.

ds — Datastore

datastore object

Datastore, specified as a datastore object containing a collection of images. Each image must be a grayscale, RGB, or multichannel image. The function processes only the first column of the datastore, which must contain images and must be cell arrays or tables with multiple columns.

I — Input image

grayscale image | RGB image

Input image, specified as a real, nonsparse, grayscale or RGB image.

The detector is sensitive to the range of the input image. Therefore, ensure that the input image range is similar to the range of the images used to train the detector. For example, if the detector was trained on `uint8` images, rescale this input image to the range `[0, 255]` by using the `im2uint8` or `rescale` function. The size of this input image should be comparable to the sizes of the images used in training. If these sizes are very different, the detector has difficulty detecting objects because the scale of the objects in the input image differs from the scale of the objects the detector was trained to identify. Consider whether you used the `SmallestImageDimension` property during training to modify the size of training images.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`**roi — Search region of interest**`[x y width height]` vector

Search region of interest, specified as an `[x y width height]` vector. The vector specifies the upper left corner and size of a region in pixels.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'NumStrongestRegions', 1000`**NumStrongestRegions — Maximum number of strongest region proposals**2000 (default) | positive integer | `Inf`

Maximum number of strongest region proposals, specified as the comma-separated pair consisting of 'NumStrongestRegions' and a positive integer. Reduce this value to speed up processing time at the cost of detection accuracy. To use all region proposals, specify this value as `Inf`.

SelectStrongest — Select strongest bounding box

`true` (default) | `false`

Select the strongest bounding box for each detected object, specified as the comma-separated pair consisting of 'SelectStrongest' and either `true` or `false`.

- `true` — Return the strongest bounding box per object. To select these boxes, `detect` calls the `selectStrongestBboxMulticlass` function, which uses nonmaximal suppression to eliminate overlapping bounding boxes based on their confidence scores.

For example:

```
selectStrongestBboxMulticlass(bbox,scores, ...  
    'RatioType','Min', ...  
    'OverlapThreshold',0.5);
```

- `false` — Return all detected bounding boxes. You can then create your own custom operation to eliminate overlapping bounding boxes.

MinSize — Minimum region size

[height width] vector

Minimum region size that contains a detected object, specified as the comma-separated pair consisting of 'MinSize' and a *[height width]* vector. Units are in pixels.

By default, `MinSize` is the smallest object that the trained detector can detect.

MaxSize — Maximum region size

`size(I)` (default) | *[height width]* vector

Maximum region size that contains a detected object, specified as the comma-separated pair consisting of 'MaxSize' and a *[height width]* vector. Units are in pixels.

To reduce computation time, set this value to the known maximum region size for the objects being detected in the image. By default, 'MaxSize' is set to the height and width of the input image, `I`.

MiniBatchSize — Minimum batch size

128 (default) | scalar

Minimum batch size, specified as the comma-separated pair consisting of 'MiniBatchSize' and a scalar value. Use the MiniBatchSize to process a large collection of images. Images are grouped into minibatches and processed as a batch to improve computation efficiency. Increase the minibatch size to decrease processing time. Decrease the size to use less memory.

ExecutionEnvironment — Hardware resource

'auto' (default) | 'gpu' | 'cpu'

Hardware resource on which to run the detector, specified as the comma-separated pair consisting of 'ExecutionEnvironment' and 'auto', 'gpu', or 'cpu'.

- 'auto' — Use a GPU if it is available. Otherwise, use the CPU.
- 'gpu' — Use the GPU. To use a GPU, you must have Parallel Computing Toolbox and a CUDA enabled NVIDIA GPU with a compute capability of 3.0 or higher. If a suitable GPU is not available, the function returns an error.
- 'cpu' — Use the CPU.

Output Arguments

bboxes — Location of objects detected within image

M-by-4 matrix

Location of objects detected within the input image, returned as an *M*-by-4 matrix, where *M* is the number of bounding boxes. Each row of *bboxes* contains a four-element vector of the form [*x* *y* *width* *height*]. This vector specifies the upper left corner and size of that corresponding bounding box in pixels.

scores — Detection scores

M-by-1 vector

Detection confidence scores, returned as an *M*-by-1 vector, where *M* is the number of bounding boxes. A higher score indicates higher confidence in the detection.

labels — Labels for bounding boxes

M-by-1 categorical array

Labels for bounding boxes, returned as an M -by-1 categorical array of M labels. You define the class names used to label the objects when you train the input detector.

detectionResults — Detection results

3-column table

Detection results, returned as a 3-column table with variable names, *Boxes*, *Scores*, and *Labels*. The *Boxes* column contains M -by-4 matrices, of M bounding boxes for the objects found in the image. Each row contains a bounding box as a 4-element vector in the format $[x,y,width,height]$. The format specifies the upper-left corner location and size in pixels of the bounding box in the corresponding image.

See Also

Apps

Ground Truth Labeler

Functions

`configureDetectorMonoCamera` | `selectStrongestBboxMulticlass` |
`trainFasterRCNNObjectDetector`

Objects

`fasterRCNNObjectDetectorMonoCamera` | `monoCamera`

Introduced in R2017a

yolov2ObjectDetectorMonoCamera

Detect objects in monocular camera using YOLO v2 deep learning detector

Description

The `yolov2ObjectDetectorMonoCamera` object contains information about you only look once version 2 (YOLO v2) object detector that is configured for use with a monocular camera sensor. To detect objects in an image captured by the camera, pass the detector to the `detect` object function.

When using the `detect` object function with a `yolov2ObjectDetectorMonoCamera` object, use of a CUDA-enabled NVIDIA GPU with a compute capability of 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

Creation

- 1 Create a `yolov2ObjectDetector` object by calling the `trainYOLOv2ObjectDetector` function with training data (requires Deep Learning Toolbox).

```
detector = trainYOLOv2ObjectDetector(trainingData, ____);
```
- 2 Create a `monoCamera` object to model the monocular camera sensor.

```
sensor = monoCamera(____);
```
- 3 Create a `yolov2ObjectDetectorMonoCamera` object by passing the detector and sensor as inputs to the `configureDetectorMonoCamera` function. The configured detector inherits property values from the original detector.

```
configuredDetector = configureDetectorMonoCamera(detector, sensor, ____);
```

Properties

Camera — Camera configuration

`monoCamera` object

This property is read-only.

Camera configuration, specified as a `monoCamera` object. The object contains the camera intrinsics, the location, the pitch, yaw, and roll placement, and the world units for the parameters. Use the intrinsics to transform the object points in the image to world coordinates, which you can then compare to the values in the `WorldObjectSize` property.

WorldObjectSize — Range of object widths and lengths

`[minWidth maxWidth]` vector | `[minWidth maxWidth; minLength maxLength]` vector

Range of object widths and lengths in world units, specified as a `[minWidth maxWidth]` vector or `[minWidth maxWidth; minLength maxLength]` vector. Specifying the range of object lengths is optional.

ModelName — Name of classification model

character vector | string scalar

Name of the classification model, specified as a character vector or string scalar. By default, the name is set to the heading of the second column of the `trainingData` table specified in the `trainYOLOv2ObjectDetector` function. You can modify this name after creating the `yoloV2ObjectDetectorMonoCamera` object.

Network — Trained YOLO v2 object detection network

`DAGNetwork` object

This property is read-only.

Trained YOLO v2 object detection network, specified as a `DAGNetwork` object. This object stores the layers that are used within the YOLO v2 object detector.

ClassNames — Names of object classes

cell array of character vectors

This property is read-only.

Names of the object classes that the YOLO v2 object detector was trained to find, specified as a cell array of character vectors. This property is set by the `trainingData` input argument for the `trainYOLOv2ObjectDetector` function. Specify the class names as part of the `trainingData` table.

AnchorBoxes — Size of anchor boxes

M -by-2 matrix

This property is read-only.

Size of anchor boxes, specified as an M -by-2 matrix, where each row is of form $[height\ width]$. This value specifies the height and width of M anchor boxes. This property is set by the `AnchorBoxes` property of the output layer in the YOLO v2 network.

The anchor boxes are defined when creating the YOLO v2 network by using the `yolov2Layers` function. Alternatively, if you create the YOLO v2 network layer-by-layer, the anchor boxes are defined by using the `yolov2OutputLayer` function.

Object Functions

`detect` Detect objects using YOLO v2 object detector configured for monocular camera

Examples

Detect Vehicles Using Monocular Camera and YOLO v2

Configure a YOLO v2 object detector for use with a monocular camera mounted on an ego vehicle. Use this detector to detect vehicles within an image captured by the camera.

Load a `yolov2ObjectDetector` object pretrained to detect vehicles.

```
vehicleDetector = load('yolov2VehicleDetector.mat', 'detector');
detector = vehicleDetector.detector;
```

Model a monocular camera sensor by creating a `monoCamera` object. This object contains the camera intrinsics and the location of the camera on the ego vehicle.

```
focalLength = [309.4362 344.2161]; % [fx fy]
principalPoint = [318.9034 257.5352]; % [cx cy]
imageSize = [480 640]; % [mrows ncols]
height = 2.1798; % height of camera above ground, in meters
pitch = 14; % pitch of camera, in degrees
intrinsics = cameraIntrinsics(focalLength,principalPoint,imageSize);

sensor = monoCamera(intrinsics,height,'Pitch',pitch);
```

Configure the detector for use with the camera. Limit the width of detected objects to 2-3 meters. The configured detector is a `yolov2ObjectDetectorMonoCamera` object.

```
vehicleWidth = [2 3];  
detectorMonoCam = configureDetectorMonoCamera(detector,sensor,vehicleWidth);
```

Read in an image captured by the camera.

```
I = imread('carsinfront.png');
```

Detect the vehicles in the image by using the detector. Annotate the image with the bounding boxes for the detections and the detection confidence scores.

```
[bboxes,scores,labels] = detect(detectorMonoCam,I);  
I = insertObjectAnnotation(I,'rectangle',bboxes,scores,'Color','g');  
imshow(I)
```



Display the labels for detected bounding boxes. The labels specify the class names of the detected objects.

```
disp(labels)
    vehicle
    vehicle
```

See Also

Apps

Ground Truth Labeler

Functions

`configureDetectorMonoCamera` | `trainYOLOv2ObjectDetector`

Objects

`monoCamera` | `yolov2ObjectDetector`

Topics

“Getting Started with YOLO v2” (Computer Vision Toolbox)

“Object Detection Using YOLO v2 Deep Learning” (Computer Vision Toolbox)

Introduced in R2019a

detect

Detect objects using YOLO v2 object detector configured for monocular camera

Syntax

```
bboxes = detect(detector,I)
[bboxes,scores] = detect(detector,I)
[___,labels] = detect(detector,I)
[___] = detect(___,roi)
detectionResults = detect(detector,ds)
[___] = detect(___,Name,Value)
```

Description

`bboxes = detect(detector,I)` detects objects within image `I` using you look only once version 2 (YOLO v2) object detector configured for a monocular camera. The locations of objects detected are returned as a set of bounding boxes.

When using this function, use of a CUDA-enabled NVIDIA GPU with a compute capability of 3.0 or higher is highly recommended. The GPU reduces computation time significantly. Usage of the GPU requires Parallel Computing Toolbox.

`[bboxes,scores] = detect(detector,I)` also returns the detection confidence scores for each bounding box.

`[___,labels] = detect(detector,I)` returns a categorical array of labels assigned to the bounding boxes in addition to the output arguments from the previous syntax. The labels used for object classes are defined during training using the `trainYOLOv2ObjectDetector` function.

`[___] = detect(___,roi)` detects objects within the rectangular search region specified by `roi`. Use output arguments from any of the previous syntaxes. Specify input arguments from any of the previous syntaxes.

`detectionResults = detect(detector,ds)` detects objects within the series of images returned by the `read` function of the input datastore.

[___] = detect(____, Name, Value) also specifies options using one or more Name, Value pair arguments in addition to the input arguments in any of the preceding syntaxes.

Examples

Detect Vehicles in Traffic Scenes from Monocular Video Using YOLO v2

Configure a YOLO v2 object detector for detecting vehicles within a video captured by a monocular camera.

Load a yolov2objectDetector object pretrained to detect vehicles.

```
vehicleDetector = load('yolov2VehicleDetector.mat', 'detector');
detector = vehicleDetector.detector;
```

Model a monocular camera sensor by creating a monoCamera object. This object contains the camera intrinsics and the location of the camera on the ego vehicle.

```
focalLength = [309.4362 344.2161]; % [fx fy]
principalPoint = [318.9034 257.5352]; % [cx cy]
imageSize = [480 640]; % [mrows ncols]
height = 2.1798; % Height of camera above ground, in meters
pitch = 14; % Pitch of camera, in degrees
intrinsics = cameraIntrinsics(focalLength, principalPoint, imageSize);

sensor = monoCamera(intrinsics, height, 'Pitch', pitch);
```

Configure the detector for use with the camera. Limit the width of detected objects to 1.5-2.5 meters. The configured detector is a yolov2objectDetectorMonoCamera object.

```
vehicleWidth = [1.5 2.5];
detectorMonoCam = configureDetectorMonoCamera(detector, sensor, vehicleWidth);
```

Set up the video file reader and read the input monocular video.

```
videoFile = '05_highway_lanechange_25s.mp4';
obj.reader = vision.VideoFileReader(videoFile, 'VideoOutputDataType', 'uint8');
```

Create a video player to display the video and the output detections.

```
obj.videoPlayer = vision.DeployableVideoPlayer();
```

Detect vehicles in the video by using the detector. Specify the detection threshold as 0.6. Annotate the video with the bounding boxes for the detections, labels, and detection confidence scores.

```
cont = ~isDone(obj.reader);  
while cont  
    I = step(obj.reader);  
    [bboxes,scores,labels] = detect(detectorMonoCam,I,'Threshold',0.6); % Run the YOLO  
  
    if ~isempty(bboxes)  
        displayLabel = strcat(cellstr(labels),':',num2str(scores));  
        I = insertObjectAnnotation(I,'rectangle',bboxes,displayLabel);  
    end  
    step(obj.videoPlayer, I);  
    cont = ~isDone(obj.reader) && isOpen(obj.videoPlayer); % Exit the loop if the video  
end
```

Input Arguments

detector — YOLO v2 object detector configured for monocular camera

`yolov2objectDetectorMonoCamera` object

YOLO v2 object detector configured for monocular camera, specified as a `yolov2objectDetectorMonoCamera` object. To create this object, use the `configureDetectorMonoCamera` function with a `monoCamera` object and trained `yolov2objectDetector` object as inputs.

I — Test image

2-D grayscale image | 2-D RGB image

Test image, specified as a real, nonsparse, grayscale, or RGB image.

The range of the test image must be same as the range of the images used to train the YOLO v2 object detector. For example, if the detector was trained on `uint8` images, the test image must also have pixel values in the range [0, 255]. Otherwise, use the `im2uint8` or `rescale` function to rescale the pixel values in the test image.

Data Types: `uint8` | `uint16` | `int16` | `double` | `single` | `logical`

roi — Search region of interest

four-element vector of form `[x y width height]`

Search region of interest, specified as a four-element vector of form `[x y width height]`. The vector specifies the upper left corner and size of a region of interest in pixels.

ds — Datastore

datastore object

Datastore, specified as a datastore object containing a collection of images. Each image must be a grayscale, RGB, or multichannel image. The function processes only the first column of the datastore, which must contain images and must be cell arrays or tables with multiple columns.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1, Value1, . . . , NameN, ValueN`.

Example: `detect(detector, I, 'Threshold', 0.25)`

Threshold — Detection threshold

0.5 (default) | scalar in the range [0, 1]

Detection threshold, specified as a comma-separated pair consisting of `'Threshold'` and a scalar in the range [0, 1]. Detections that have scores less than this threshold value are removed. To reduce false positives, increase this value.

SelectStrongest — Select strongest bounding box

true (default) | false

Select the strongest bounding box for each detected object, specified as the comma-separated pair consisting of `'SelectStrongest'` and true or false.

- `true` — Returns the strongest bounding box per object. The method calls the `selectStrongestBboxMulticlass` function, which uses nonmaximal suppression to eliminate overlapping bounding boxes based on their confidence scores.

By default, the `selectStrongestBboxMulticlass` function is called as follows

```
selectStrongestBboxMulticlass(bbox,scores,...  
                               'RatioType','Min',...  
                               'OverlapThreshold',0.5);
```

- `false` — Return all the detected bounding boxes. You can then write your own custom method to eliminate overlapping bounding boxes.

MinSize — Minimum region size

`[1 1]` (default) | vector of the form `[height width]`

Minimum region size, specified as the comma-separated pair consisting of `'MinSize'` and a vector of the form `[height width]`. Units are in pixels. The minimum region size defines the size of the smallest region containing the object.

By default, `'MinSize'` is 1-by-1.

MaxSize — Maximum region size

`size(I)` (default) | vector of the form `[height width]`

Maximum region size, specified as the comma-separated pair consisting of `'MaxSize'` and a vector of the form `[height width]`. Units are in pixels. The maximum region size defines the size of the largest region containing the object.

By default, `'MaxSize'` is set to the height and width of the input image, `I`. To reduce computation time, set this value to the known maximum region size for the objects that can be detected in the input test image.

ExecutionEnvironment — Hardware resource

`'auto'` (default) | `'gpu'` | `'cpu'`

Hardware resource on which to run the detector, specified as the comma-separated pair consisting of `'ExecutionEnvironment'` and `'auto'`, `'gpu'`, or `'cpu'`.

- `'auto'` — Use a GPU if it is available. Otherwise, use the CPU.
- `'gpu'` — Use the GPU. To use a GPU, you must have Parallel Computing Toolbox and a CUDA-enabled NVIDIA GPU with a compute capability of 3.0 or higher. If a suitable GPU is not available, the function returns an error.
- `'cpu'` — Use the CPU.

Acceleration — Performance optimization

`'auto'` (default) | `'mex'` | `'none'`

Performance optimization, specified as the comma-separated pair consisting of 'Acceleration' and one of the following:

- 'auto' — Automatically apply a number of optimizations suitable for the input network and hardware resource.
- 'mex' — Compile and execute a MEX function. This option is available when using a GPU only. Using a GPU requires Parallel Computing Toolbox and a CUDA enabled NVIDIA GPU with compute capability 3.0 or higher. If Parallel Computing Toolbox or a suitable GPU is not available, then the function returns an error.
- 'none' — Disable all acceleration.

The default option is 'auto'. If 'auto' is specified, MATLAB will apply a number of compatible optimizations. If you use the 'auto' option, MATLAB does not ever generate a MEX function.

Using the 'Acceleration' options 'auto' and 'mex' can offer performance benefits, but at the expense of an increased initial run time. Subsequent calls with compatible parameters are faster. Use performance optimization when you plan to call the function multiple times using new input data.

The 'mex' option generates and executes a MEX function based on the network and parameters used in the function call. You can have several MEX functions associated with a single network at one time. Clearing the network variable also clears any MEX functions associated with that network.

The 'mex' option is only available for input data specified as a numeric array, cell array of numeric arrays, table, or image datastore. No other types of datastore support the 'mex' option.

The 'mex' option is only available when you are using a GPU. You must also have a C/C++ compiler installed. For setup instructions, see “MEX Setup” (GPU Coder).

'mex' acceleration does not support all layers. For a list of supported layers, see “Supported Layers” (GPU Coder).

Output Arguments

bboxes — Location of objects detected within image

M-by-4 matrix

Location of objects detected within the input image, returned as an M -by-4 matrix, where M is the number of bounding boxes. Each row of `bboxes` contains a four-element vector of the form `[x y width height]`. This vector specifies the upper left corner and size of that corresponding bounding box in pixels.

scores — Detection scores

M -by-1 vector

Detection confidence scores, returned as an M -by-1 vector, where M is the number of bounding boxes. A higher score indicates higher confidence in the detection.

labels — Labels for bounding boxes

M -by-1 categorical array

Labels for bounding boxes, returned as an M -by-1 categorical array of M labels. You define the class names used to label the objects when you train the input detector.

detectionResults — Detection results

3-column table

Detection results, returned as a 3-column table with variable names, *Boxes*, *Scores*, and *Labels*. The *Boxes* column contains M -by-4 matrices, of M bounding boxes for the objects found in the image. Each row contains a bounding box as a 4-element vector in the format `[x,y,width,height]`. The format specifies the upper-left corner location and size in pixels of the bounding box in the corresponding image.

See Also

Apps

Ground Truth Labeler

Functions

`configureDetectorMonoCamera` | `evaluateDetectionMissRate` |
`evaluateDetectionPrecision` | `selectStrongestBboxMulticlass` |
`trainYOLOv2ObjectDetector`

Objects

`monoCamera` | `yoloV2ObjectDetectorMonoCamera`

Introduced in R2019a

pathPlannerRRT

Configure RRT* path planner

Description

The `pathPlannerRRT` object configures a vehicle path planner based on the optimal rapidly exploring random tree (RRT*) algorithm. An RRT* path planner explores the environment around the vehicle by constructing a tree of random collision-free poses.

Once the `pathPlannerRRT` object is configured, use the `plan` function to plan a path from the start pose to the goal.

Creation

Syntax

```
planner = pathPlannerRRT(costmap)
planner = pathPlannerRRT(costmap,Name,Value)
```

Description

`planner = pathPlannerRRT(costmap)` returns a `pathPlannerRRT` object for planning a vehicle path. `costmap` is a `vehicleCostmap` object specifying the environment around the vehicle. `costmap` sets the `Costmap` property value.

`planner = pathPlannerRRT(costmap,Name,Value)` sets properties on page 4-815 of the path planner by using one or more name-value pair arguments. For example, `pathPlanner(costmap, 'GoalBias', 0.5)` sets the `GoalBias` property to a probability of 0.5. Enclose each property name in quotes.

Properties

Costmap — Costmap of vehicle environment

`vehicleCostmap` object

Costmap of the vehicle environment, specified as a `vehicleCostmap` object. The costmap is used for collision checking of the randomly generated poses. Specify this costmap when creating your `pathPlannerRRT` object using the `costmap` input.

GoalTolerance — Tolerance around goal pose

`[0.5 0.5 5]` (default) | `[xTol, yTol, θ Tol]` vector

Tolerance around the goal pose, specified as an `[xTol, yTol, θ Tol]` vector. The path planner finishes planning when the vehicle reaches the goal pose within these tolerances for the (x, y) position and the orientation angle, θ . The `xTol` and `yTol` values are in the same world units as the `vehicleCostmap`. `θ Tol` is in degrees.

GoalBias — Probability of selecting goal pose

`0.1` (default) | real scalar in the range `[0, 1]`

Probability of selecting the goal pose instead of a random pose, specified as a real scalar in the range `[0, 1]`. Large values accelerate reaching the goal at the risk of failing to circumnavigate obstacles.

ConnectionMethod — Method used to connect poses

`'Dubins'` (default) | `'Reeds-Shepp'`

Method used to calculate the connection between consecutive poses, specified as `'Dubins'` or `'Reeds-Shepp'`. Use `'Dubins'` if only forward motions are allowed.

The `'Dubins'` method contains a sequence of three primitive motions, each of which is one of these types:

- Straight (forward)
- Left turn at the maximum steering angle of the vehicle (forward)
- Right turn at the maximum steering angle of the vehicle (forward)

If you use this connection method, then the segments of the planned vehicle path are stored as an array of `driving.DubinsPathSegment` objects.

The `'Reeds-Shepp'` method contains a sequence of three to five primitive motions, each of which is one of these types:

- Straight (forward or reverse)
- Left turn at the maximum steering angle of the vehicle (forward or reverse)
- Right turn at the maximum steering angle of the vehicle (forward or reverse)

If you use this connection method, then the segments of the planned vehicle path are stored as an array of `driving.ReedsSheppPathSegment` objects.

The `MinTurningRadius` property determines the maximum steering angle.

ConnectionDistance — Maximum distance between poses

5 (default) | positive real scalar

Maximum distance between two connected poses, specified as a positive real scalar. `pathPlannerRRT` computes the connection distance along the path between the two poses, with turns included. Larger values result in longer path segments between poses.

MinTurningRadius — Minimum turning radius of vehicle

4 (default) | positive real scalar

Minimum turning radius of the vehicle, specified as a positive real scalar. This value corresponds to the radius of the turning circle at the maximum steering angle. Larger values limit the maximum steering angle for the path planner, and smaller values result in sharper turns. The default value is calculated using a wheelbase of 2.8 meters with a maximum steering angle of 35 degrees.

MinIterations — Minimum number of planner iterations

100 (default) | positive integer

Minimum number of planner iterations for exploring the costmap, specified as a positive integer. Increasing this value increases the sampling of alternative paths in the costmap.

MaxIterations — Maximum number of planner iterations

10000 (default) | positive integer

Maximum number of planner iterations for exploring the costmap, specified as a positive integer. Increasing this value increases the number of samples for finding a valid path. If a valid path is not found, the path planner exits after exceeding this maximum.

ApproximateSearch — Enable approximate nearest neighbor search

true (default) | false

Enable approximate nearest neighbor search, specified as `true` or `false`. Set this value to `true` to use a faster, but approximate, search algorithm. Set this value to `false` to use an exact search algorithm at the cost of increased computation time.

Object Functions

`plan` Plan vehicle path using RRT* path planner
`plot` Plot path planned by RRT* path planner

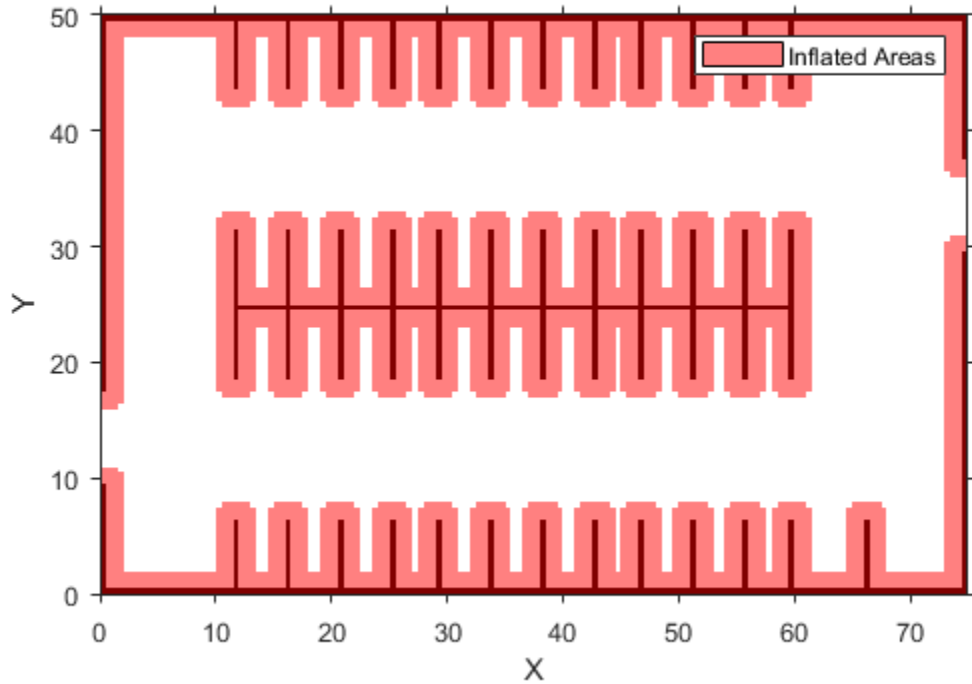
Examples

Plan Path to Parking Spot

Plan a vehicle path to a parking spot by using the RRT* algorithm.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmapReducedInflation.mat');  
costmap = data.parkingLotCostmapReducedInflation;  
plot(costmap)
```



Define start and goal poses for the path planner as $[x, y, \theta]$ vectors. World units for the (x, y) locations are in meters. World units for the θ orientation values are in degrees.

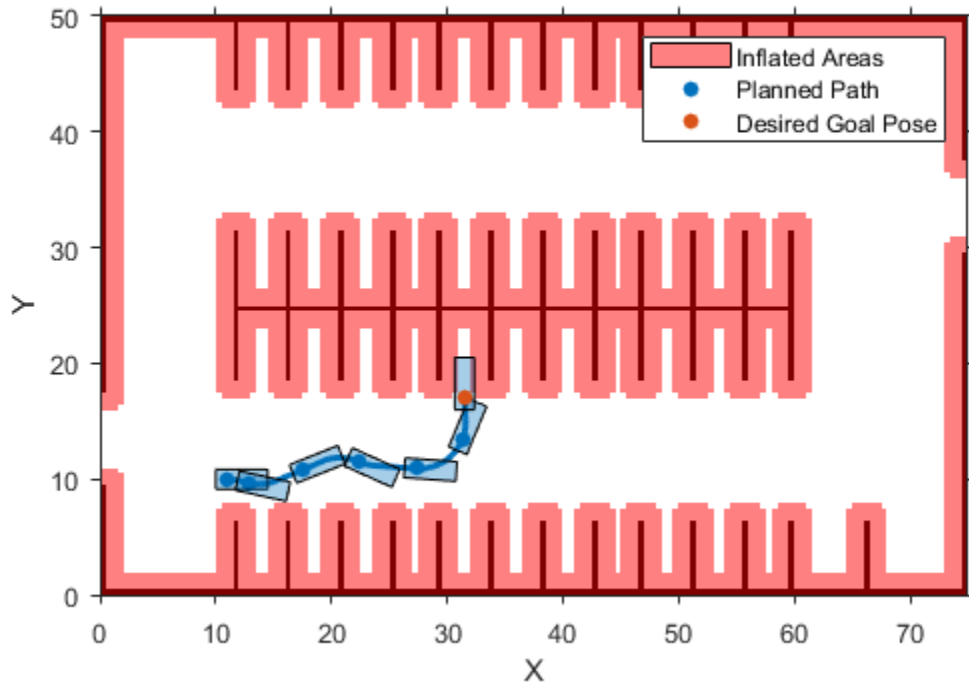
```
startPose = [11, 10, 0]; % [meters, meters, degrees]
goalPose = [31.5, 17, 90];
```

Create an RRT* path planner to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Plot the planned path.

```
plot(planner)
```

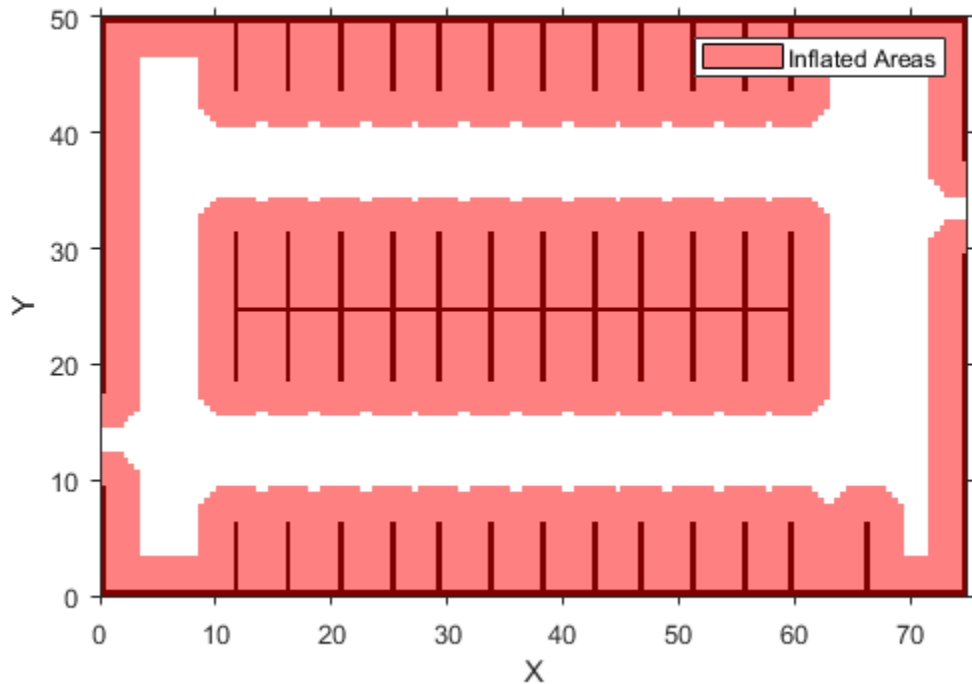



Plan Path and Check Its Validity

Plan a vehicle path through a parking lot by using the optimal rapidly exploring random tree (RRT*) algorithm. Check that the path is valid, and then plot the transition poses along the path.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmap.mat');  
costmap = data.parkingLotCostmap;  
plot(costmap)
```



Define start and goal poses for the vehicle as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation angles are in degrees.

```
startPose = [4, 4, 90]; % [meters, meters, degrees]  
goalPose = [30, 13, 0];
```

Use a `pathPlannerRRT` object to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);  
refPath = plan(planner, startPose, goalPose);
```

Check that the path is valid.

```
isPathValid = checkPathValidity(refPath,costmap)
```

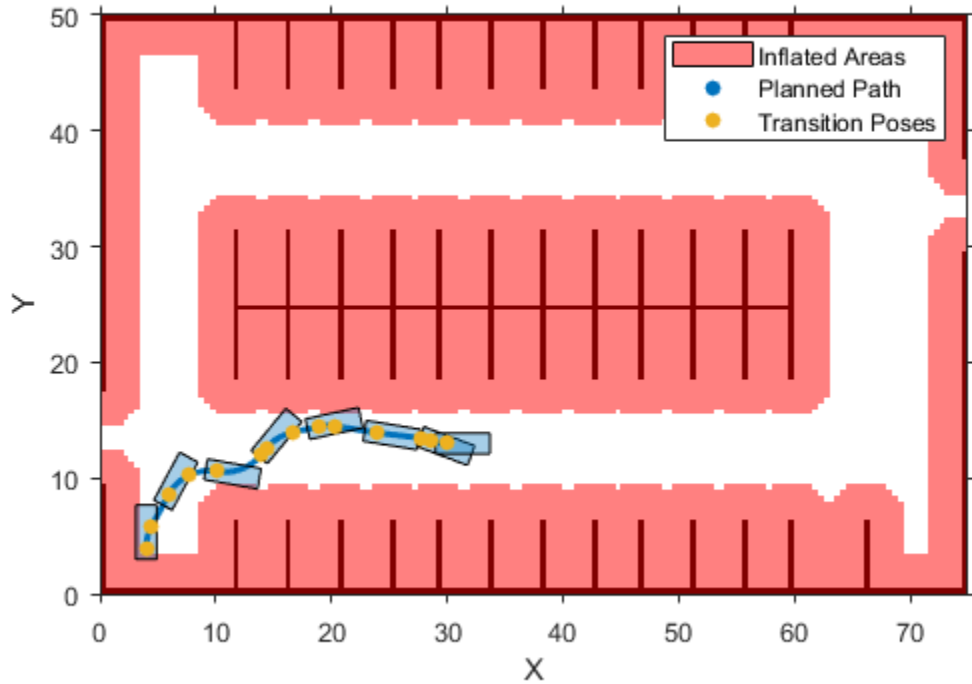
```
isPathValid = logical  
1
```

Interpolate the transition poses along the path.

```
transitionPoses = interpolate(refPath);
```

Plot the planned path and the transition poses on the costmap.

```
hold on  
plot(refPath,'DisplayName','Planned Path')  
scatter(transitionPoses(:,1),transitionPoses(:,2),[],'filled', ...  
        'DisplayName','Transition Poses')  
hold off
```



Tips

- Updating any of the properties of the planner clears the planned path from `pathPlannerRRT`. Calling `plot` displays only the costmap until a path is planned using `plan`.
- To improve performance, the `pathPlannerRRT` object uses an approximate nearest neighbor search. This search technique checks only \sqrt{N} nodes, where N is the number of nodes to search. To use exact nearest neighbor search, set the `ApproximateSearch` property to `false`.

- The Dubins and Reeds-Shepp connection methods are assumed to be kinematically feasible and ignore inertial effects. These methods make the path planner suitable for low velocity environments, where inertial effects of wheel forces are small.

References

- [1] Karaman, Sertac, and Emilio Frazzoli. "Optimal Kinodynamic Motion Planning Using Incremental Sampling-Based Methods." *49th IEEE Conference on Decision and Control (CDC)*. 2010.
- [2] Shkel, Andrei M., and Vladimir Lumelsky. "Classification of the Dubins Set." *Robotics and Autonomous Systems*. Vol. 34, Number 4, 2001, pp. 179-202.
- [3] Reeds, J. A., and L. A. Shepp. "Optimal paths for a car that goes both forwards and backwards." *Pacific Journal of Mathematics*. Vol. 145, Number 2, 1990, pp. 367-393.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- The `ConnectionMethod`, `MinIterations`, `MaxIterations`, and `ApproximateSearch` properties must be compile-time constants.

See Also

Functions

`checkPathValidity` | `lateralControllerStanley` | `plan` | `plot` | `smoothPathSpline`

Blocks

Lateral Controller Stanley

Objects

driving.Path | vehicleCostmap

Topics

“Automated Parking Valet”

Introduced in R2018a

plan

Plan vehicle path using RRT* path planner

Syntax

```
refPath = plan(planner,startPose,goalPose)
[refPath,tree] = plan(planner,startPose,goalPose)
```

Description

`refPath = plan(planner,startPose,goalPose)` plans a vehicle path from `startPose` to `goalPose` using the input `pathPlannerRRT` object. This object configures an optimal rapidly exploring random tree (RRT*) path planner.

`[refPath,tree] = plan(planner,startPose,goalPose)` also returns the exploration tree, `tree`.

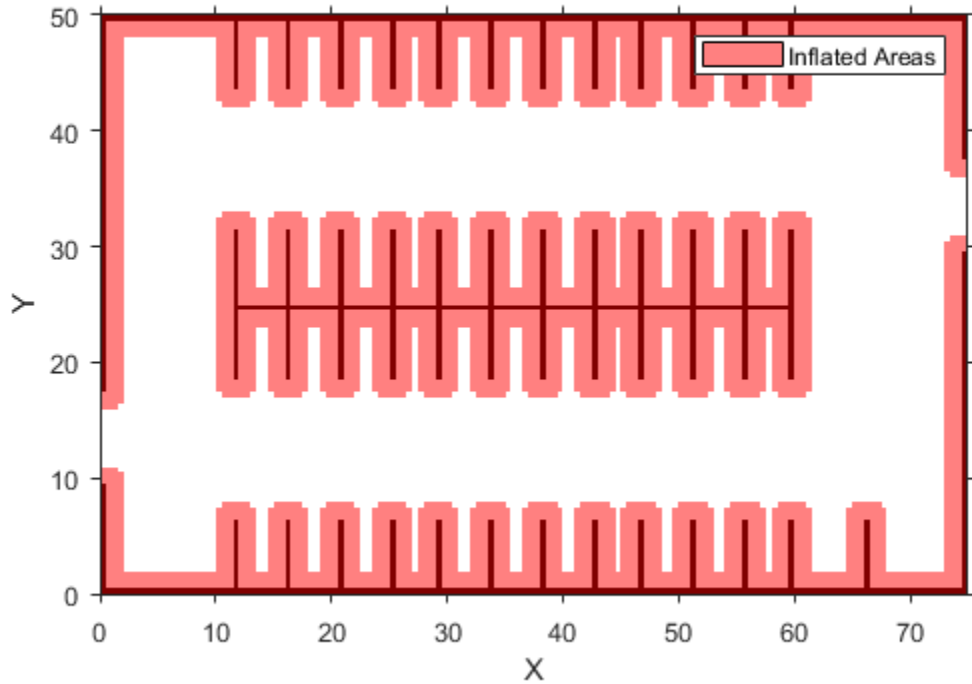
Examples

Plan Path to Parking Spot

Plan a vehicle path to a parking spot by using the RRT* algorithm.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmapReducedInflation.mat');
costmap = data.parkingLotCostmapReducedInflation;
plot(costmap)
```



Define start and goal poses for the path planner as $[x, y, \theta]$ vectors. World units for the (x, y) locations are in meters. World units for the θ orientation values are in degrees.

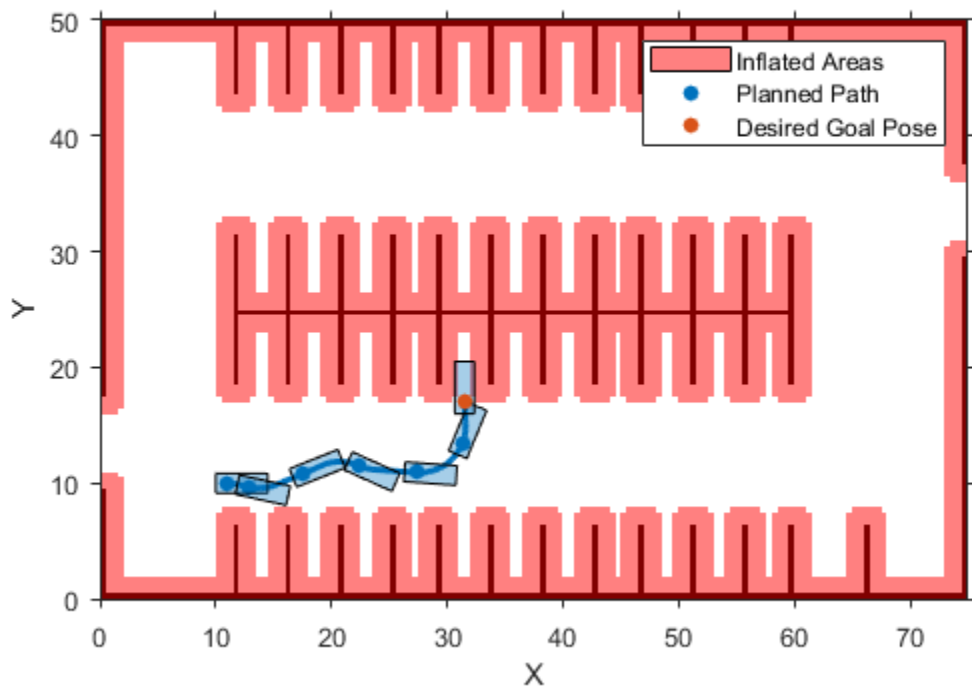
```
startPose = [11, 10, 0]; % [meters, meters, degrees]
goalPose = [31.5, 17, 90];
```

Create an RRT* path planner to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Plot the planned path.

```
plot(planner)
```

Input Arguments

planner — RRT* path planner

pathPlannerRRT object

RRT* path planner, specified as a pathPlannerRRT object.

startPose — Initial pose of vehicle

$[x, y, \theta]$ vector

Initial pose of the vehicle, specified as an $[x, y, \theta]$ vector. x and y are in world units, such as meters. θ is in degrees.

goalPose — Goal pose of vehicle

[*x*, *y*, θ] vector

Goal pose of the vehicle, specified as an [*x*, *y*, θ] vector. *x* and *y* are in world units, such as meters. θ is in degrees.

The vehicle achieves its goal pose when the last pose in the path is within the `GoalTolerance` property of planner.

Output Arguments

refPath — Planned vehicle path

`driving.Path` object

Planned vehicle path, returned as a `driving.Path` object containing reference poses along the planned path. If planning was unsuccessful, the path has no poses. To check if the path is still valid due to costmap updates, use the `checkPathValidity` function.

tree — Exploration tree

digraph object

Exploration tree, returned as a digraph object. Nodes within `tree` represent explored vehicle poses. Edges within `tree` represent the distance between connected nodes.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- The optional `tree` output argument, a digraph object, is not supported.

See Also

Functions

`checkPathValidity` | `plot`

Objects

`digraph` | `driving.Path` | `pathPlannerRRT` | `vehicleCostmap`

Topics

“Automated Parking Valet”

Introduced in R2018a

plot

Plot path planned by RRT* path planner

Syntax

```
plot(planner)  
plot(planner,Name,Value)
```

Description

`plot(planner)` plots the path planned by the input `pathPlannerRRT` object. When specified as an input to the `plan` function, this object plans a path using the rapidly exploring random tree (RRT*) algorithm. If a path has not been planned using `plan`, or if properties of the `pathPlannerRRT` planner have changed since using `plan`, then `plot` displays only the costmap of `planner`.

`plot(planner,Name,Value)` specifies options using one or more name-value pair arguments. For example, `plot(planner,'Tree','on')` plots the poses explored by the RRT* path planner.

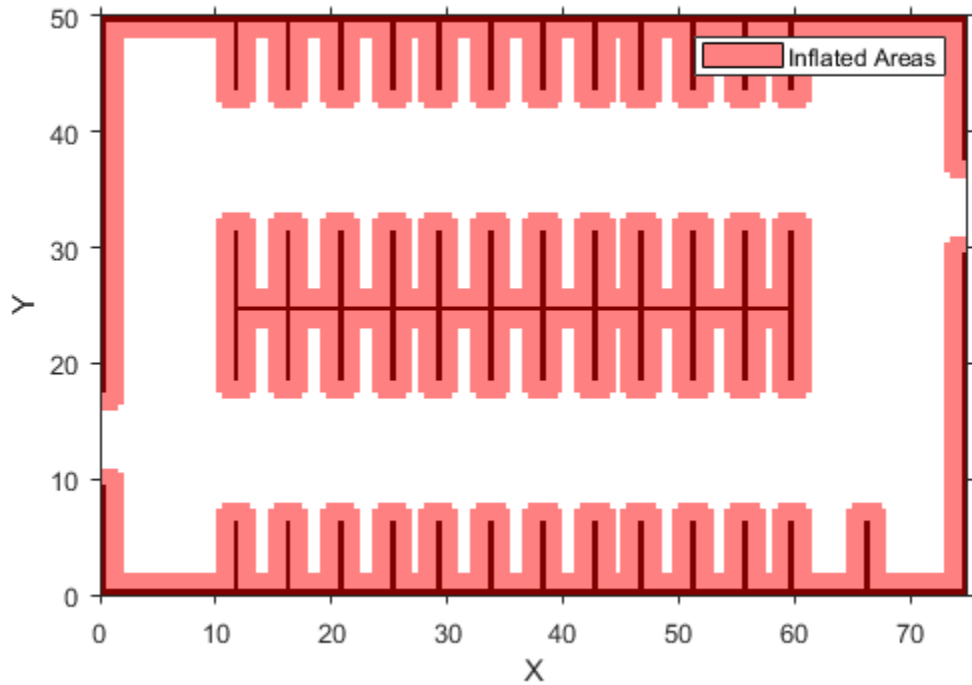
Examples

Plan Path to Parking Spot

Plan a vehicle path to a parking spot by using the RRT* algorithm.

Load a costmap of a parking lot. Plot the costmap to see the parking lot and inflated areas for the vehicle to avoid.

```
data = load('parkingLotCostmapReducedInflation.mat');  
costmap = data.parkingLotCostmapReducedInflation;  
plot(costmap)
```



Define start and goal poses for the path planner as $[x, y, \theta]$ vectors. World units for the (x,y) locations are in meters. World units for the θ orientation values are in degrees.

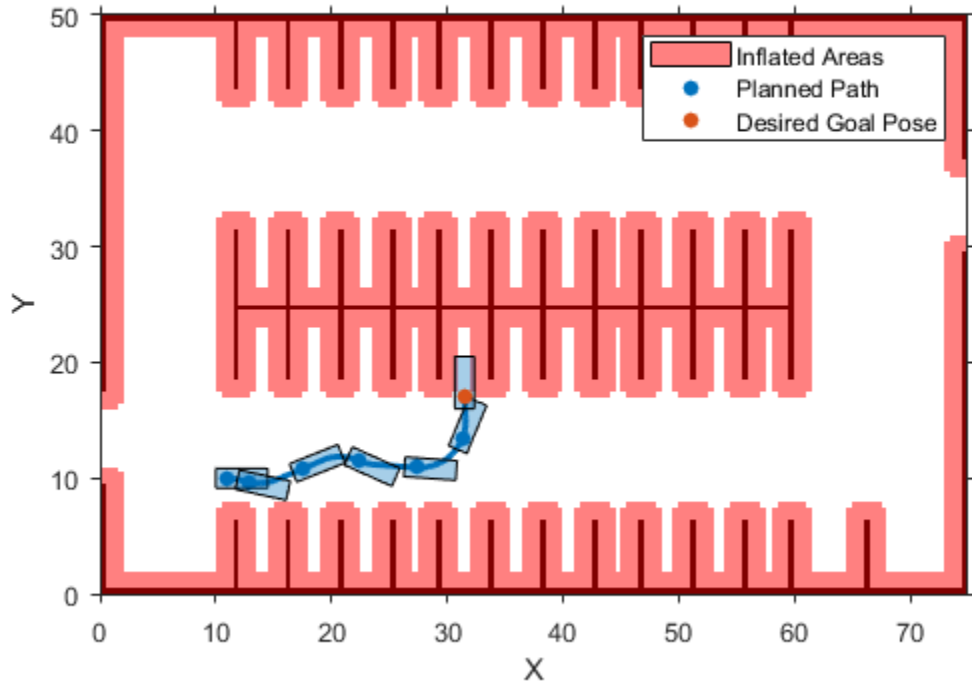
```
startPose = [11, 10, 0]; % [meters, meters, degrees]
goalPose = [31.5, 17, 90];
```

Create an RRT* path planner to plan a path from the start pose to the goal pose.

```
planner = pathPlannerRRT(costmap);
refPath = plan(planner, startPose, goalPose);
```

Plot the planned path.

```
plot(planner)
```



Input Arguments

planner — RRT* path planner

pathPlannerRRT object

RRT* path planner, specified as a pathPlannerRRT object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `'Vehicle', 'off'`

Parent — Axes object

axes object

Axes object in which to draw the plot, specified as the comma-separated pair consisting of `'Parent'` and an axes object. If you do not specify `Parent`, a new figure is created.

Tree — Display exploration tree

`'off'` (default) | `'on'`

Display exploration tree, specified as the comma-separated pair consisting of `'Tree'` and `'off'` or `'on'`. Setting this value to `'on'` displays the poses explored by the RRT* path planner, `planner`.

Vehicle — Display vehicle

`'on'` (default) | `'off'`

Display vehicle, specified as the comma-separated pair consisting of `'Vehicle'` and `'on'` or `'off'`. Setting this value to `'off'` disables the vehicle displayed along the path planned by the RRT* path planner, `planner`.

See Also

Functions

`checkPathValidity` | `plan`

Objects

`driving.Path` | `pathPlannerRRT` | `vehicleCostmap`

Topics

“Automated Parking Valet”

Introduced in R2018a

vehicleCostmap

Costmap representing planning space around vehicle

Description

The `vehicleCostmap` object creates a costmap that represents the planning search space around a vehicle. The costmap holds information about the environment, such as obstacles or areas that the vehicle cannot traverse. To check for collisions, the costmap inflates obstacles using the inflation radius specified in the `CollisionChecker` property. The costmap is used by path planning algorithms, such as `pathPlannerRRT`, to find collision-free paths for the vehicle to follow.

The costmap is stored as a 2-D grid of cells, often called an occupancy grid or occupancy map. Each grid cell in the costmap has a value in the range $[0, 1]$ representing the cost of navigating through that grid cell. The state of each grid cell is free, occupied, or unknown, as determined by the `FreeThreshold` and `OccupiedThreshold` properties.

The following figure shows a costmap with sample costs and grid cell states.



Creation

Syntax

```
costmap = vehicleCostmap(C)
costmap = vehicleCostmap(mapWidth,mapLength)
costmap = vehicleCostmap(mapWidth,mapLength,costVal)
costmap = vehicleCostmap(occMap)
costmap = vehicleCostmap( ____, 'MapLocation',mapLocation)
costmap = vehicleCostmap( ____,Name,Value)
```

Description

`costmap = vehicleCostmap(C)` creates a vehicle costmap using the cost values in matrix `C`.

`costmap = vehicleCostmap(mapWidth,mapLength)` creates a vehicle costmap representing an area of width `mapWidth` and length `mapLength` in world units. By default, each grid cell is in the unknown state.

`costmap = vehicleCostmap(mapWidth,mapLength,costVal)` also assigns a default cost, `costVal`, to each cell in the grid.

`costmap = vehicleCostmap(occMap)` creates a vehicle costmap from the occupancy map `occMap`. Use of this syntax requires Navigation Toolbox™.

`costmap = vehicleCostmap(____, 'MapLocation',mapLocation)` specifies in `mapLocation` the bottom-left corner coordinates of the costmap. Specify `'MapLocation',mapLocation` after any of the preceding inputs and in any order among the `Name,Value` pair arguments.

`costmap = vehicleCostmap(____,Name,Value)` uses `Name,Value` pair arguments to specify the `FreeThreshold`, `OccupiedThreshold`, `CollisionChecker`, and `CellSize` properties. For example, `vehicleCostmap(C, 'CollisionChecker',ccConfig)` uses an `inflationCollisionChecker` object, `ccConfig`, to represent the vehicle shape and check for collisions. After you create the object, you can update all of these properties except `CellSize`.

Input Arguments

C — Cost values

matrix of real values in the range [0, 1]

Cost values, specified as a matrix of real values that are in the range [0, 1].

When creating a `vehicleCostmap` object, if you do not specify `C` or a uniform cost value, `costVal`, then the default cost value of each grid cell is $(FreeThreshold + OccupiedThreshold)/2$.

Data Types: `single` | `double`

mapWidth — Width of costmap

positive real scalar

Width of costmap, in world units, specified as a positive real scalar.

mapLength — Length of costmap

positive real scalar

Length of costmap, in world units, specified as a positive real scalar.

costVal — Uniform cost value

real scalar in the range [0, 1]

Uniform cost value applied to all cells in the costmap, specified as a real scalar in the range [0, 1].

When creating a `vehicleCostmap` object, if you do not specify `costVal` or a cost value matrix, `C`, then the default cost value of each grid cell is $(FreeThreshold + OccupiedThreshold)/2$.

occMap — Occupancy map

`occupancyMap` object | `binaryOccupancyMap` object

Occupancy map, specified as an `occupancyMap` or `binaryOccupancyMap` object. Use of this argument requires Navigation Toolbox.

mapLocation — Costmap location

`[0 0]` (default) | two-element real-valued vector of form `[mapX mapY]`

Costmap location, specified as a two-element real-valued vector of the form $[mapX \ mapY]$. This vector specifies the coordinate location of the bottom-left corner of the costmap.

Example: 'MapLocation', [8 8]

Properties

FreeThreshold — Threshold below which grid cell is free

0.2 (default) | real scalar in the range [0, 1]

Threshold below which a grid cell is free, specified as a real scalar in the range [0, 1].

A grid cell with cost c can have one of these states:

- If $c < \text{FreeThreshold}$, the grid cell state is *free*.
- If $c \geq \text{FreeThreshold}$ and $c \leq \text{OccupiedThreshold}$, the grid cell state is *unknown*.
- If $c > \text{OccupiedThreshold}$, the grid cell state is *occupied*.

OccupiedThreshold — Threshold above which grid cell is occupied

0.65 (default) | real scalar in the range [0, 1]

Threshold above which a grid cell is occupied, specified as a real scalar in the range [0, 1].

A grid cell with cost c can have one of these states:

- If $c < \text{FreeThreshold}$, the grid cell state is *free*.
- If $c \geq \text{FreeThreshold}$ and $c \leq \text{OccupiedThreshold}$, the grid cell state is *unknown*.
- If $c > \text{OccupiedThreshold}$, the grid cell state is *occupied*.

CollisionChecker — Collision-checking configuration

`inflationCollisionChecker()` (default) | `InflationCollisionChecker` object

Collision-checking configuration, specified as an `InflationCollisionChecker` object. To create this object, use the `inflationCollisionChecker` function. Using the properties of the `InflationCollisionChecker` object, you can configure:

- The inflation radius used to inflate obstacles in the costmap
- The number of circles used to enclose the vehicle when calculating the inflation radius

- The placement of each circle along the longitudinal axis of the vehicle
- The dimensions of the vehicle

By default, `CollisionChecker` uses the default `InflationCollisionChecker` object, which is created using the syntax `inflationCollisionChecker()`. This collision-checking configuration encloses the vehicle in one circle.

MapExtent — Extent of costmap

four-element, nonnegative integer vector of form `[xmin xmax ymin ymax]`

This property is read-only.

Extent of costmap around the vehicle, specified as a four-element, nonnegative integer vector of the form `[xmin xmax ymin ymax]`.

- `xmin` and `xmax` describe the length of the map in world coordinates.
- `ymin` and `ymax` describe the width of the map in world coordinates.

CellSize — Side length of each square cell

1 (default) | positive real scalar

Side length of each square cell, in world units, specified as a positive real scalar. For example, a side length of 1 implies a grid where each cell is a square of size 1-by-1 meters. Smaller values improve the resolution of the search space at the cost of increased memory consumption.

You can specify `CellSize` when you create the `vehicleCostmap` object. However, after you create the object, `CellSize` becomes read-only.

MapSize — Size of costmap grid

two-element, positive integer vector of form `[nrows ncols]`

This property is read-only.

Size of costmap grid, specified as a two-element, positive integer vector of the form `[nrows ncols]`.

- `nrows` is the number of grid cell rows in the costmap.
- `ncols` is the number of grid cell columns in the costmap.

Object Functions

checkFree	Check vehicle costmap for collision-free poses or points
checkOccupied	Check vehicle costmap for occupied poses or points
getCosts	Get cost value of cells in vehicle costmap
setCosts	Set cost value of cells in vehicle costmap
plot	Plot vehicle costmap

Examples

Create and Populate a Vehicle Costmap

Create a 10-by-20 meter costmap that is divided into square cells of size 0.5-by-0.5 meters. Specify a default cost value of 0.5 for all cells.

```
mapWidth = 10;
mapLength = 20;
costVal = 0.5;
cellSize = 0.5;

costmap = vehicleCostmap(mapWidth,mapLength,costVal,'CellSize',cellSize)

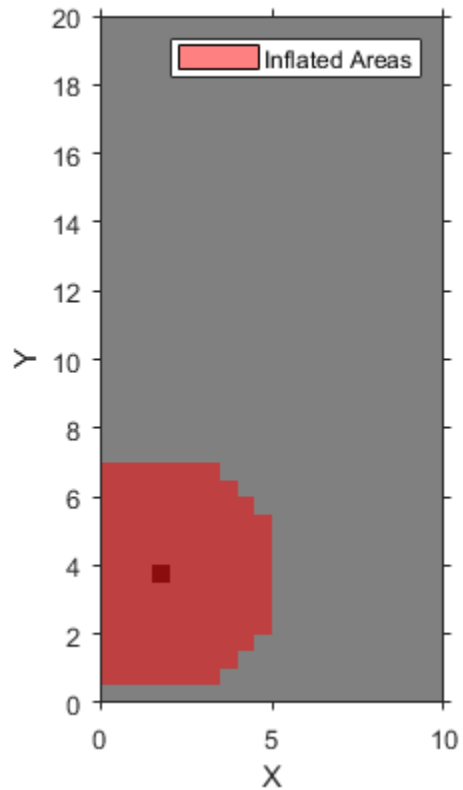
costmap =
  vehicleCostmap with properties:

    FreeThreshold: 0.2000
    OccupiedThreshold: 0.6500
    CollisionChecker: [1x1 driving.costmap.InflationCollisionChecker]
    CellSize: 0.5000
    MapSize: [40 20]
    MapExtent: [0 10 0 20]
```

Mark an obstacle on the costmap. Display the costmap.

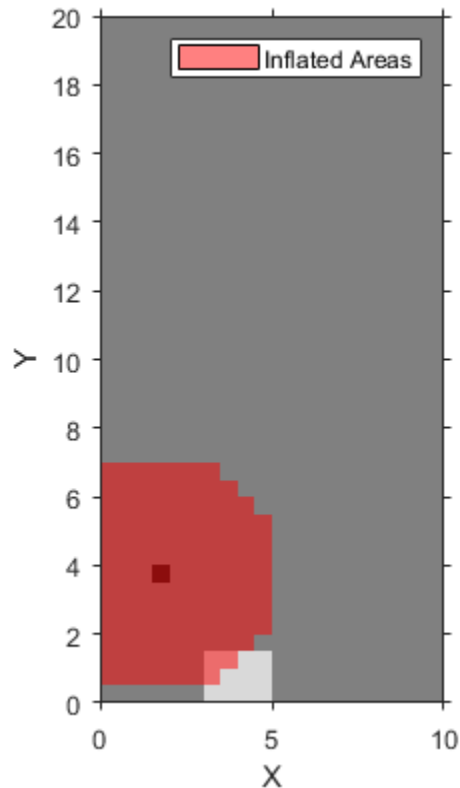
```
occupiedVal = 0.9;
xyPoint = [2,4];
setCosts(costmap,xyPoint,occupiedVal)

plot(costmap)
```



Mark an obstacle-free area on the costmap. Display the costmap again.

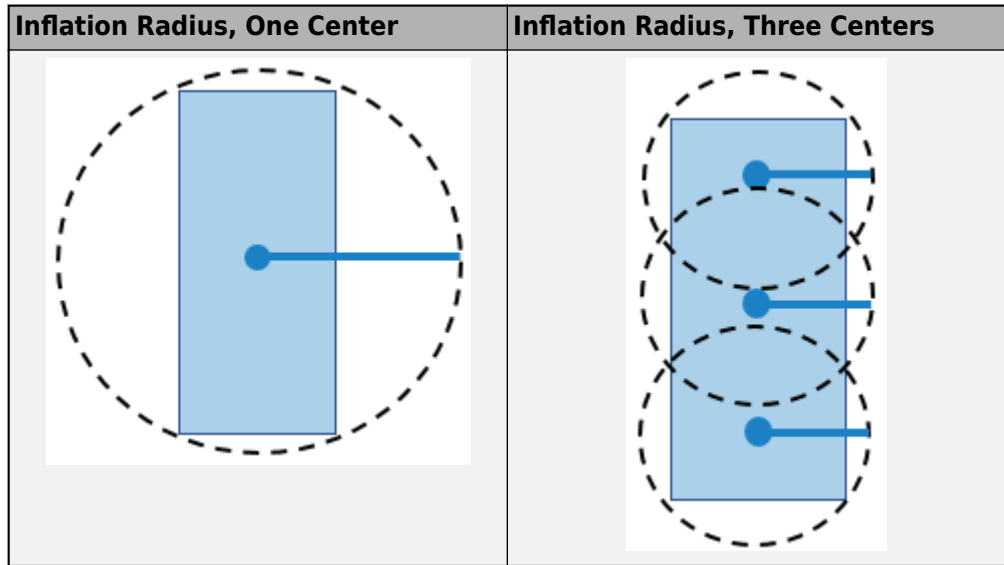
```
freeVal = 0.15;  
[X,Y] = meshgrid(3.5:cellSize:5,0.5:cellSize:1.5);  
setCosts(costmap,[X(:),Y(:)],freeVal)  
plot(costmap)
```



Algorithms

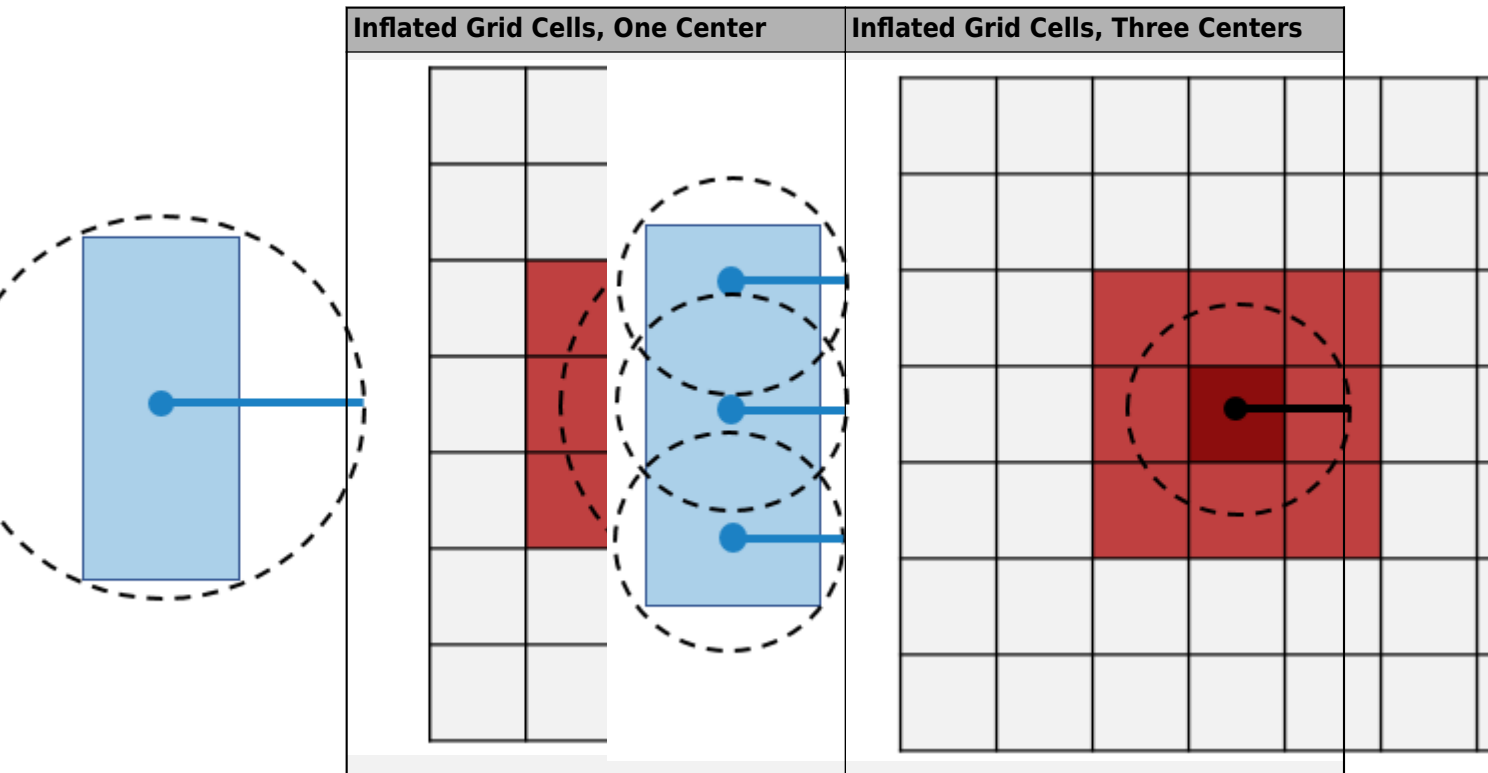
To simplify checking for whether a vehicle pose is in collision, `vehicleCostmap` inflates the size of obstacles. The collision-checking algorithm follows these steps:

- 1 Calculate the inflation radius, in world units, from the vehicle dimensions. The default inflation radius is equal to the radius of the smallest set of overlapping circles required to completely enclose the vehicle. The center points of the circles lie along the longitudinal axis of the vehicle. Increasing the number of circles decreases the inflation radius, which enables more precise collision checking.



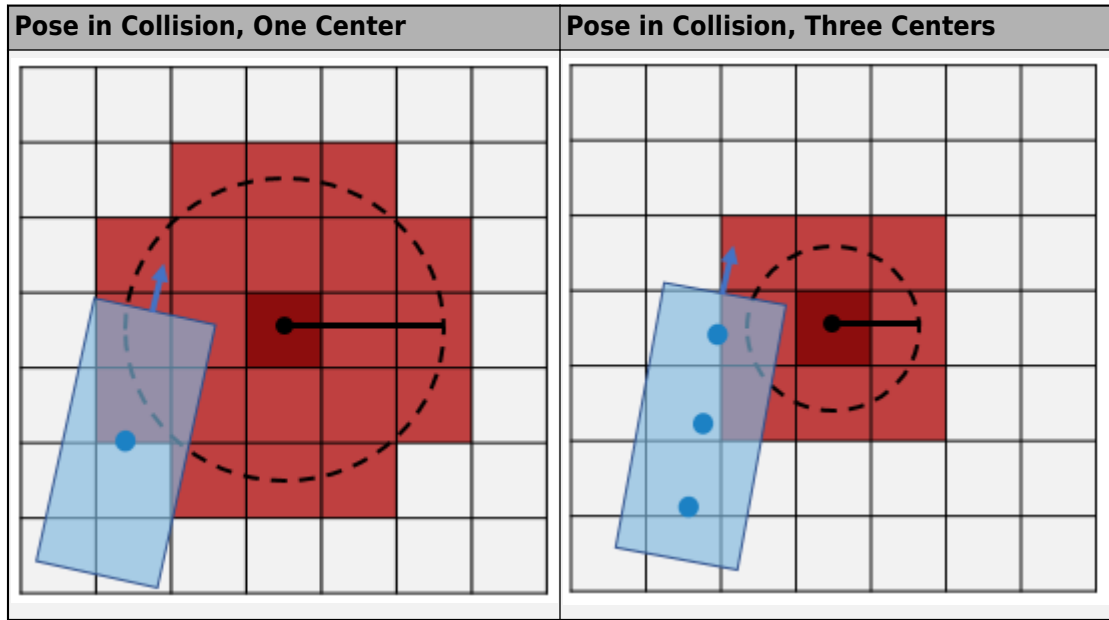
- 2** Convert the inflation radius to a number of grid cells, R . Round up noninteger values of R to the next largest integer.
- 3** Inflate the size of obstacles using R . Label all cells in the inflated area as occupied.

The diagrams show occupied cells in dark red. Cells in the inflated area are colored in light red. The solid black line shows the original inflation radius. In the diagram on the left, R is 3. In the diagram on the right, R is 2.



- 4 Check whether the center points of the vehicle lie on inflated grid cells.
 - If any center point lies on an inflated grid cell, then the vehicle pose is *occupied*. The `checkOccupied` function returns `true`. An occupied pose does not necessarily mean a collision. For example, the vehicle might lie on an inflated grid cell but not on the grid cell that is actually occupied.
 - If no center points lie on inflated grid cells, and the cost value of each cell containing a center point is less than `FreeThreshold`, then the vehicle pose is *free*. The `checkFree` function returns `true`.
 - If no center points lie on inflated grid cells, and the cost value of any cell containing a center point is greater than `FreeThreshold`, then the vehicle pose is *unknown*. Both `checkFree` and `checkOccupied` return `false`.

The following poses are considered in collision because at least one center point is on an inflated area.



Compatibility Considerations

InflationRadius and VehicleDimensions properties will be removed

Warns starting in R2019b

The `InflationRadius` and `VehicleDimensions` properties of `vehicleCostmap` will be removed in a future release. Instead:

- 1 Use the `inflationCollisionChecker` function to create an `InflationCollisionChecker` object, which has the properties `InflationRadius` and `VehicleDimensions`.
- 2 Specify this object as the value of the `CollisionChecker` property of `vehicleCostmap`.

If you do specify these properties, the values in the corresponding properties of `CollisionChecker` are updated to match.

When the `vehicleCostmap` object was introduced in R2018a, this object inflated obstacles based on the specified inflation radius and vehicle dimensions only. The `InflationCollisionChecker` object, which is specified in the `CollisionChecker` property of `vehicleCostmap`, provides additional configuration options for inflating obstacles. For example, you can specify the number of circles used to compute the inflation radius, enabling more precise collision checking.

Update Code

The table shows a typical usage of the `InflationRadius` and `VehicleDimensions` properties of `vehicleCostmap`. It also shows how to update your code using the corresponding properties of an `InflationCollisionChecker` object.

Discouraged Usage	Recommended Replacement
<pre>vehicleDims = vehicleDimensions(5,2); inflationRadius = 1.2; costmap = vehicleCostmap(C, ... 'VehicleDimensions',vehicleDims, ... 'InflationRadius',inflationRadius);</pre>	<pre>vehicleDims = vehicleDimensions(5,2); inflationRadius = 1.2; ccConfig = inflationCollisionChecker(vehicleDims, ... 'InflationRadius',inflationRadius); costmap = vehicleCostmap(C, ... 'CollisionChecker',ccConfig);</pre>

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- The collision-checking configuration stored in the `CollisionChecker` property must be a compile-time constant.
- The `mapLocation` input argument must be a compile-time constant.

See Also

`inflationCollisionChecker` | `pathPlannerRRT`

Topics

“Automated Parking Valet”

“Create Occupancy Grid Using Monocular Camera and Semantic Segmentation”

Introduced in R2018a

checkFree

Check vehicle costmap for collision-free poses or points

Syntax

```
free = checkFree(costmap, vehiclePoses)
free = checkFree(costmap, xyPoints)
freeMat = checkFree(costmap)
```

Description

The `checkFree` function checks whether vehicle poses or points are free from obstacles on the vehicle costmap. Path planning algorithms use `checkFree` to check whether candidate vehicle poses along a path are navigable.

To simplify the collision check for a vehicle pose, `vehicleCostmap` inflates obstacles according to the vehicle's `InflationRadius`, as specified by the `CollisionChecker` property of the costmap. The collision checker calculates the inflation radius by enclosing the vehicle in a set of overlapping circles of radius R , where the centers of these circles lie along the longitudinal axis of the vehicle. The inflation radius is the minimum R needed to fully enclose the vehicle in these circles.

A vehicle pose is collision-free when the following conditions apply:

- None of the vehicle's circle centers lie on an inflated grid cell.
- The cost value of each containing a circle center is less than the `FreeThreshold` of the costmap.

For more details, see the algorithm on page 4-841 on the `vehicleCostmap` reference page.

`free = checkFree(costmap, vehiclePoses)` checks whether the vehicle poses are free from collision with obstacles on the costmap.

`free = checkFree(costmap, xyPoints)` checks whether (x, y) points in `xyPoints` are free from collision with obstacles on the costmap.

`freeMat = checkFree(costmap)` returns a logical matrix that indicates whether each cell of the costmap is free.

Examples

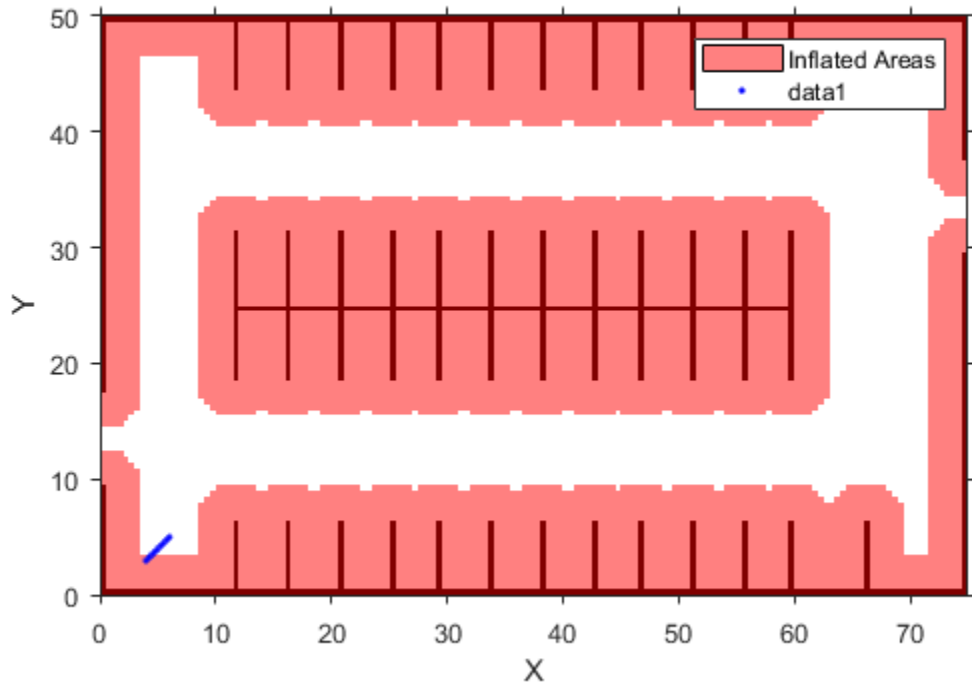
Check If Sequence of Poses Is Collision-Free

Load a costmap from a parking lot.

```
data = load('parkingLotCostmap.mat');  
parkMap = data.parkingLotCostmap;  
plot(parkMap)
```

Create vehicle poses following a straight-line path. `x` and `y` are the (x,y) coordinates of the rear axle of the vehicle. `theta` is the angle of the rear axle with respect to the x -axis. Note that the dimensions of the vehicle are stored in the `CollisionChecker.VehicleDimensions` property of the costmap, and that there is an offset between the rear axle of the vehicle and its center.

```
x = 4:0.25:6;  
y = 3:0.25:5;  
theta = repmat(45,size(x));  
vehiclePoses = [x',y',theta'];  
hold on  
plot(x,y,'b.')  
hold off
```



The first few (x,y) coordinates of the rear axle are within the inflated area. However, this does not imply a collision because the center of the vehicle may be outside the inflated area. Check if the poses are collision-free.

```
free = checkFree(parkMap, vehiclePoses)
```

```
free = 9x1 logical array
```

```
1
1
1
1
1
1
1
```

```
1  
1  
1
```

All values of `free` are 1 (true), so all poses are collision-free. The center of the vehicle does not enter the inflated area at any pose.

Input Arguments

costmap — Costmap

vehicleCostmap object

Costmap, specified as a `vehicleCostmap` object.

vehiclePoses — Vehicle poses

m -by-3 matrix of $[x, y, \theta]$ vectors

Vehicle poses, specified as an m -by-3 matrix of $[x, y, \theta]$ vectors. m is the number of poses.

x and y specify the location of the vehicle in world units, such as meters. This location is the center of the rear axle of the vehicle.

θ specifies the orientation angle of the vehicle in degrees with respect to the x -axis. θ is positive in the clockwise direction.

Example: `[3.4 2.6 0]` specifies a vehicle with the center of the rear axle at (3.4, 2.6) and an orientation angle of 0 degrees.

xyPoints — Points

M -by-2 real-valued matrix

Points, specified as an M -by-2 real-valued matrix that represents the (x, y) coordinates of M points.

Example: `[3.4 2.6]` specifies a single point at (3.4, 2.6)

Example: `[3 2; 3 3; 4 7]` specifies three points: (3, 2), (3, 3), and (4, 7)

Output Arguments

free — Vehicle pose or point is free

M-by-1 logical vector

Vehicle pose or point is free, returned as an *M*-by-1 logical vector. An element of `free` is 1 (`true`) when the corresponding vehicle pose in `vehiclePoses` or point in `xyPoints` is collision-free.

freeMat — Costmap cell is free

logical matrix

Costmap cell is free, returned as a logical matrix of the same size as the costmap grid. This size is specified by the `MapSize` property of the `costmap`. An element of `freeMat` is 1 (`true`) when the corresponding cell in `costmap` is unoccupied and the cost value of the cell is below the `FreeThreshold` of the costmap.

Tips

- If you specify a small value of `InflationRadius` that does not completely enclose the vehicle, then `checkFree` might report occupied poses as collision-free. To avoid this situation, the default value of `InflationRadius` completely encloses the vehicle.

Extended Capabilities

C/C++ Code Generation

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

See Also

Objects

`inflationCollisionChecker` | `pathPlannerRRT` | `vehicleCostmap`

Functions

`checkOccupied` | `checkPathValidity`

Introduced in R2018a

checkOccupied

Check vehicle costmap for occupied poses or points

Syntax

```
occ = checkOccupied(costmap, vehiclePoses)
occ = checkOccupied(costmap, xyPoints)
occMat = checkOccupied(costmap)
```

Description

The `checkOccupied` function checks whether vehicle poses or points are occupied by obstacles on the vehicle costmap. Path planning algorithms use `checkOccupied` to check whether candidate vehicle poses along a path are navigable.

To simplify the collision check for a vehicle pose, `vehicleCostmap` inflates obstacles according to the vehicle's `InflationRadius`, as specified by the `CollisionChecker` property of the costmap. The collision checker calculates the inflation radius by enclosing the vehicle in a set of overlapping circles of radius R , where the centers of these circles lie along the longitudinal axis of the vehicle. The inflation radius is the minimum R needed to fully enclose the vehicle in these circles. A vehicle pose is collision-free when none of the centers of these circles lie on an inflated grid cell. For more details, see the algorithm on page 4-841 on the `vehicleCostmap` reference page.

`occ = checkOccupied(costmap, vehiclePoses)` checks whether the vehicle poses are occupied.

`occ = checkOccupied(costmap, xyPoints)` checks whether (x, y) points in `xyPoints` are occupied.

`occMat = checkOccupied(costmap)` returns a logical matrix that indicates whether each cell of the costmap is occupied.

Examples

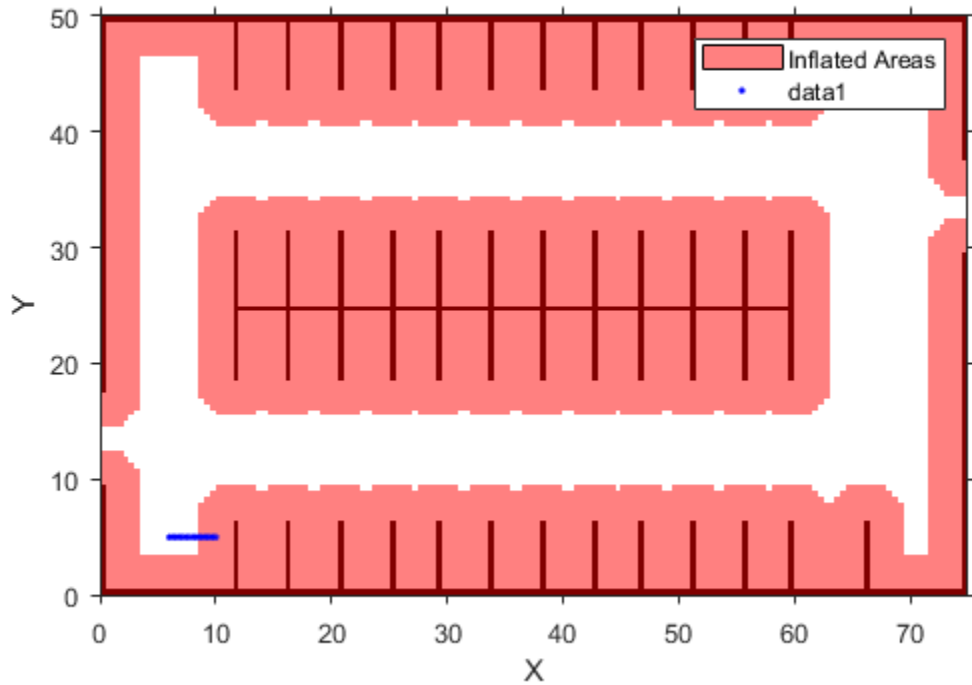
Check If Sequence of Poses Enters Occupied Cell

Load a costmap from a parking lot.

```
data = load('parkingLotCostmap.mat');  
parkMap = data.parkingLotCostmap;  
plot(parkMap)
```

Create vehicle poses following a straight-line path. `x` and `y` are the (x,y) coordinates of the rear axle of the vehicle. `theta` is the angle of the rear axle with respect to the x -axis. Note that the dimensions of the vehicle are stored in the `vehicleDimensions` property of the costmap, and that there is an offset between the rear axle of the vehicle and its center.

```
x = 6:0.25:10;  
y = repmat(5,size(x));  
theta = zeros(size(x));  
vehiclePoses = [x',y',theta'];  
hold on  
plot(x,y,'b.')
```



Check if the poses are occupied.

```
occ = checkOccupied(parkMap,vehiclePoses)
```

occ = 17x1 logical array

```
0
0
0
0
0
1
1
1
```

```
1  
1  
⋮
```

The vehicle poses are occupied beginning with the sixth pose. In other words, the center of the vehicle in the sixth pose lies within the inflation radius of an occupied grid cell.

Input Arguments

costmap — Costmap

vehicleCostmap object

Costmap, specified as a vehicleCostmap object.

vehiclePoses — Vehicle poses

m -by-3 matrix of $[x, y, \theta]$ vectors

Vehicle poses, specified as an m -by-3 matrix of $[x, y, \theta]$ vectors. m is the number of poses.

x and y specify the location of the vehicle in world units, such as meters. This location is the center of the rear axle of the vehicle.

θ specifies the orientation angle of the vehicle in degrees with respect to the x -axis. θ is positive in the clockwise direction.

Example: `[3.4 2.6 0]` specifies a vehicle with the center of the rear axle at (3.4, 2.6) and an orientation angle of 0 degrees.

xyPoints — Points

M -by-2 real-valued matrix

Points, specified as an M -by-2 real-valued matrix that represents the (x, y) coordinates of M points.

Example: `[3.4 2.6]` specifies a single point at (3.4, 2.6)

Example: `[3 2; 3 3; 4 7]` specifies three points: (3, 2), (3, 3), and (4, 7)

Output Arguments

occ — Vehicle pose or point is occupied

M-by-1 logical vector

Vehicle pose or point is occupied, returned as an *M*-by-1 logical vector. An element of `occ` is 1 (`true`) when the corresponding vehicle pose in `vehiclePoses` or planar point in `xyPoints` is occupied.

occMat — Costmap cell is occupied

logical matrix

Costmap cell is occupied, returned as a logical matrix of the same size as the costmap grid. This size is specified by the `MapSize` property of the `costmap`. An element of `occMat` is 1 (`true`) when the corresponding cell in `costmap` is occupied.

Extended Capabilities

C/C++ Code Generation

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

See Also

Objects

`inflationCollisionChecker` | `pathPlannerRRT` | `vehicleCostmap`

Functions

`checkFree` | `checkPathValidity`

Introduced in R2018a

getCosts

Get cost value of cells in vehicle costmap

Syntax

```
costVals = getCosts(costmap,xyPoints)
costMat = getCosts(costmap)
```

Description

`costVals = getCosts(costmap,xyPoints)` returns a vector, `costVals`, that contains the costs for the (x, y) points in `xyPoints` in the vehicle costmap.

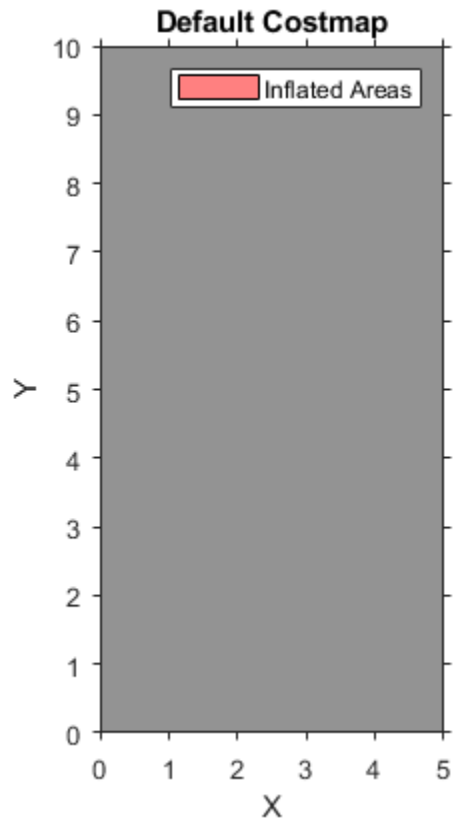
`costMat = getCosts(costmap)` returns a matrix, `costMat`, that contains the cost of each cell in the costmap.

Examples

Get Cost Matrix and Set Cost Values

Create a 5-by-10 meter vehicle costmap. Cells have side length 1, in the world units of meters. Set the inflation radius to 1. Plot the costmap, and get the default cost matrix.

```
costmap = vehicleCostmap(5,10);
costmap.CollisionChecker.InflationRadius = 1;
plot(costmap)
title('Default Costmap')
```

```
getCosts(costmap)
```

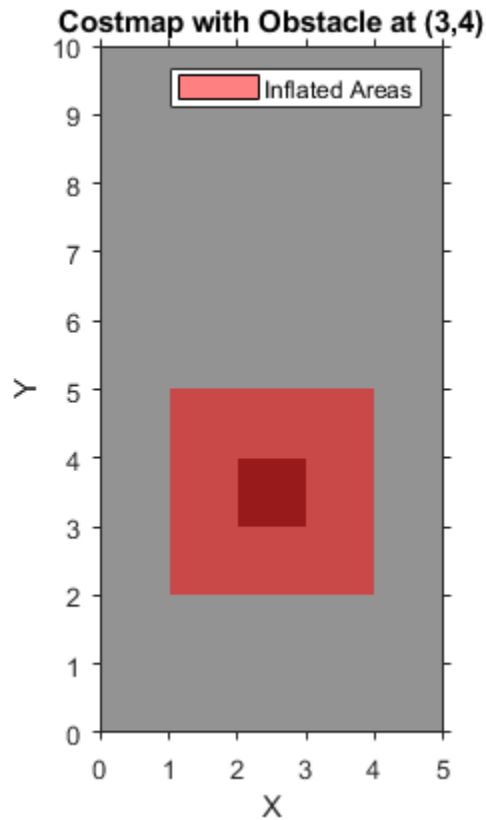
```
ans = 10x5
```

```
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250  
0.4250    0.4250    0.4250    0.4250    0.4250
```

```
0.4250    0.4250    0.4250    0.4250    0.4250
```

Mark an obstacle at the (x,y) coordinate (3,4) by increasing the cost of that cell.

```
setCosts(costmap,[3,4],0.8);  
plot(costmap)  
title('Costmap with Obstacle at (3,4)')
```



Get the cost of three cells: the cell with the obstacle, a cell adjacent to the obstacle, and a cell outside the inflation radius of the obstacle.

```
costVal = getCosts(costmap,[3 4;2 4;4 7])
```

```
costVal = 3x1
    0.8000
    0.4250
    0.4250
```

Although the plot of the costmap displays the cell with the obstacle and its adjacent cells in shades of red, only the cell with the obstacle has a higher cost value of 0.8. The other cells still have the default cost value of 0.425.

Input Arguments

costmap — Costmap

vehicleCostmap object

Costmap, specified as a `vehicleCostmap` object.

xyPoints — Points

M -by-2 real-valued matrix

Points, specified as an M -by-2 real-valued matrix that represents the (x, y) coordinates of M points.

Example: `[3.4 2.6]` specifies a single point at (3.4, 2.6)

Example: `[3 2;3 3;4 7]` specifies three points: (3, 2), (3, 3), and (4, 7)

Output Arguments

costVals — Cost of points

M -element real-valued vector

Cost of points in `xyPoints`, returned as an M -element real-valued vector.

costMat — Cost of all cells

real-valued matrix

Cost of all cells in `costmap`, returned as a real-valued matrix of the same size as the costmap grid. This size is specified by the `MapSize` property of the costmap.

Extended Capabilities

C/C++ Code Generation

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

See Also

`setCosts` | `vehicleCostmap`

Introduced in R2018a

plot

Plot vehicle costmap

Syntax

```
plot(costmap)
plot(costmap,Name,Value)
```

Description

The `plot` function displays a vehicle costmap. The darkness of each cell is proportional to the cost value of the cell. Cells with low cost are bright, and cells containing obstacles with high cost are dark. Inflated areas are displayed with a red hue, and cells outside the inflated area are displayed in grayscale.

`plot(costmap)` plots the vehicle costmap in the current axes.

`plot(costmap,Name,Value)` plots the vehicle costmap using name-value pair arguments to specify the parent axes or to adjust the display of inflated areas.

Examples

Display a Vehicle on a Costmap

Load a costmap from a parking lot. Display the costmap.

```
data = load('parkingLotCostmap.mat');
parkMap = data.parkingLotCostmap;
plot(parkMap)
```

Create a template polyshape object with the dimensions of the car.

```
carDims = parkMap.CollisionChecker.VehicleDimensions
```

```
carDims =  
  vehicleDimensions with properties:  
  
    Length: 4.7000  
    Width: 1.8000  
    Height: 1.4000  
    Wheelbase: 2.8000  
    RearOverhang: 1  
    FrontOverhang: 0.9000  
    WorldUnits: 'meters'
```

```
ro = carDims.RearOverhang;  
fo = carDims.FrontOverhang;  
wb = carDims.Wheelbase;  
hw = carDims.Width/2;  
X = [-ro,wb+fo,wb+fo,-ro];  
Y = [-hw,-hw,hw,hw];  
templateShape = polyshape(X',Y');
```

Create a function handle to move the template to a specified vehicle pose. This move function translates the polyshape `s` to the coordinate `(x,y)` and then rotates the polyshape by an angle `theta` about the point `(x,y)`.

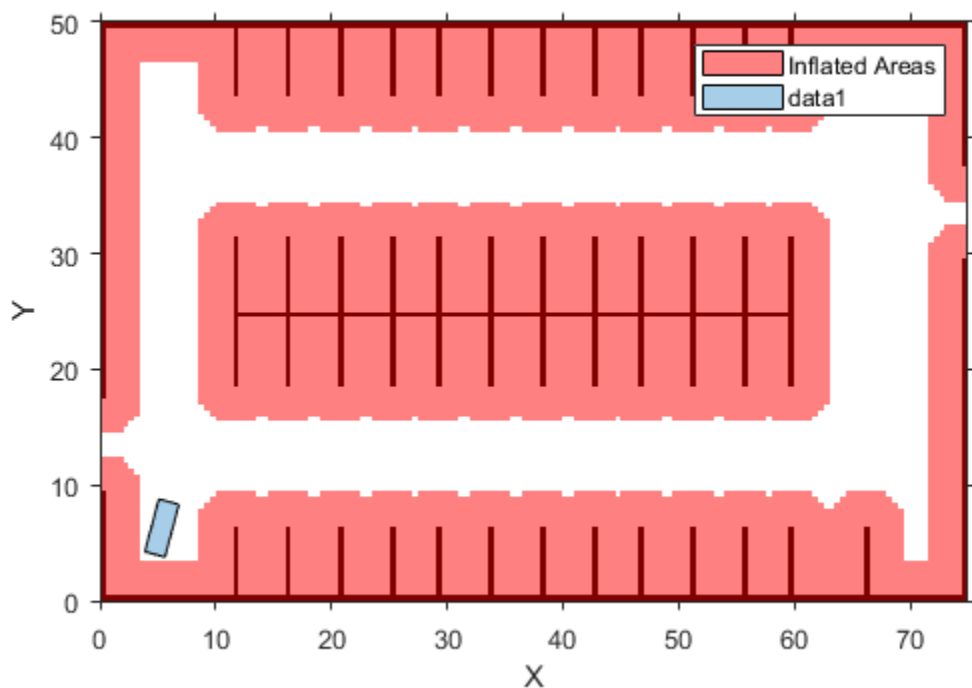
```
move = @(s,x,y,theta) rotate(translate(s,[x,y]), ...  
    theta,[x,y]);
```

Move the car template to a pose.

```
carPose = [5,5,75];  
carShape = move(templateShape,carPose(1),carPose(2),carPose(3));
```

Plot the car on the costmap.

```
hold on  
plot(carShape)
```



Input Arguments

costmap — Costmap

vehicleCostmap object

Costmap, specified as a vehicleCostmap object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes.

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

Example: `'Inflation', 'off'`

Inflation — Display inflated areas

`'on'` (default) | `'off'`

Display inflated areas, specified as the comma-separated pair consisting of `'Inflation'` and one of the following.

- `'on'`—Cells in the inflated area have a red hue.
- `'off'`—Cells containing obstacles have a red hue, but other cells in the inflated area are displayed in grayscale.

Parent — Axes on which to plot costmap

axes handle

Axes on which to plot the costmap, specified as the comma-separated pair consisting of `'Parent'` and an axes handle. By default, `plot` uses the current axes handle, which is returned by the `gca` function.

See Also

`polyshape` | `vehicleCostmap` | `vehicleDimensions`

Introduced in R2018a

setCosts

Set cost value of cells in vehicle costmap

Syntax

```
setCosts(costmap,xyPoints,costVals)
```

Description

`setCosts(costmap,xyPoints,costVals)` sets the costs, `costVals`, for the (x, y) points in `xyPoints` in the vehicle costmap.

Examples

Mark Rectangular Obstacle on Vehicle Costmap

Create a 10-by-15 meter vehicle costmap. Cells have a side length of 1 meter.

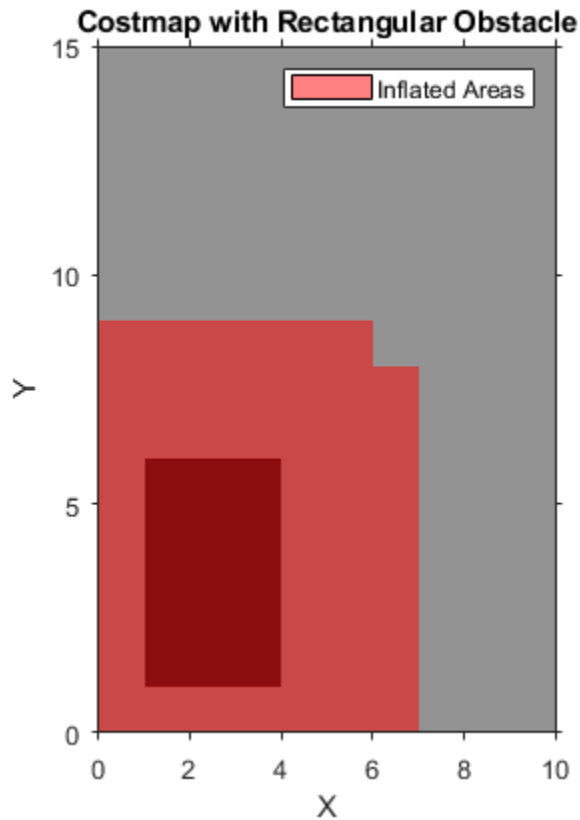
```
costmap = vehicleCostmap(10,15);
```

Define a set of (x,y) coordinates that correspond to a 3-by-5 meter rectangle.

```
[x,y] = meshgrid(2:4,2:6);  
xyPoints = [x(:),y(:)];
```

Mark the rectangle as an obstacle by increasing the cost of its cells to 0.9.

```
costVal = 0.9;  
setCosts(costmap,xyPoints,costVal);  
plot(costmap)  
title('Costmap with Rectangular Obstacle')
```



Input Arguments

costmap — Costmap

vehicleCostmap object

Costmap, specified as a `vehicleCostmap` object.

xyPoints — Points

M -by-2 real-valued matrix

Points, specified as an M -by-2 real-valued matrix that represents the (x, y) coordinates of M points.

Example: `[3.4 2.6]` specifies a single point at (3.4, 2.6)

Example: `[3 2;3 3;4 7]` specifies three points: (3, 2), (3, 3), and (4, 7)

costVals — Cost of points

M-element real-valued vector

Cost of points in `xyPoints`, specified as an *M*-element real-valued vector.

Example: `0.8` specifies the cost of a single point

Example: `[0.2 0.5 0.8]` specifies the cost of three points

Extended Capabilities

C/C++ Code Generation

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

See Also

`getCosts` | `vehicleCostmap`

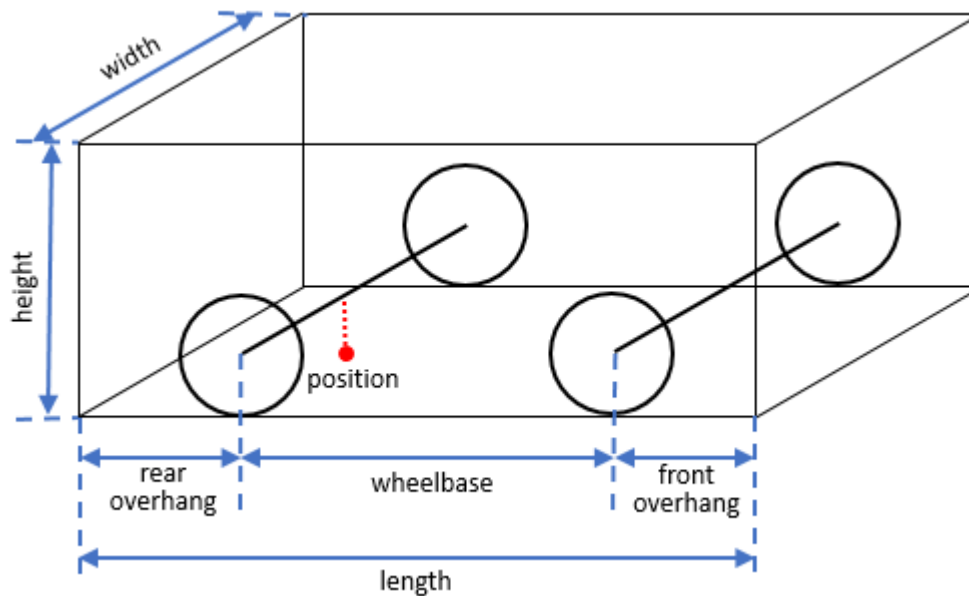
Introduced in R2018a

vehicleDimensions

Store vehicle dimensions

Description

The `vehicleDimensions` object stores vehicle dimensions. The figure shows the dimensions that are included in the `vehicleDimensions`.



The position of the vehicle is often represented as a single point located on the ground at the center of the rear axle, as indicated by the red dot in the figure. This position corresponds to the natural center of rotation of the vehicle.

The table lists typical vehicle types and their corresponding dimensions.

Vehicle Classification	Length	Width	Height	Wheelbase	Front Overhang	Rear Overhang
Automobile (sedan)	4.7 m	1.8 m	1.4 m	2.8 m	0.9 m	1.0 m
Motorcycle	2.2 m	0.6 m	1.5 m	1.51 m	0.37 m	0.32 m

Creation

Syntax

```

vdims = vehicleDimensions
vdims = vehicleDimensions(l,w,h)
vdims = vehicleDimensions( ____,Name,Value)

```

Description

`vdims = vehicleDimensions` creates a `vehicleDimensions` object with a default length of 4.7 m, width of 1.8 m, and height of 1.4 m.

`vdims = vehicleDimensions(l,w,h)` creates a `vehicleDimensions` object and sets the `Length`, `Width`, and `Height` properties.

`vdims = vehicleDimensions(____,Name,Value)` uses one or more name-value pair arguments to set the `Wheelbase`, `FrontOverhang`, `RearOverhang`, and `WorldUnits` properties. `Name` is the property name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ..., NameN,ValueN`.

Properties

Length — Length of vehicle

4.7 (default) | positive real scalar

Length of vehicle, specified as a positive real scalar.

Data Types: double

Width — Width of vehicle

1.8 (default) | positive real scalar

Width of vehicle, specified as a positive real scalar.

Data Types: double

Height — Height of vehicle

1.4 (default) | positive real scalar

Height of vehicle, specified as a positive real scalar.

Data Types: double

FrontOverhang — Front overhang of vehicle

0.9 (default) | real scalar

Front overhang of vehicle, specified as a real scalar. The front overhang is the distance between the front of the vehicle and the front axle. `FrontOverhang` can be negative.

Data Types: double

RearOverhang — Rear overhang of vehicle

1.0 (default) | real scalar

Rear overhang of vehicle, specified as a real scalar. The rear overhang is the distance between the rear of the vehicle and the rear axle. `RearOverhang` can be negative.

Data Types: double

Wheelbase — Distance between axles

2.8 (default) | positive real scalar

The distance between the front and rear axles of the vehicle, specified as a positive real scalar.

Data Types: double

WorldUnits — Units of measurement

'meters' (default) | character array

Units of measurement, specified as a character array. The units do not affect the values of measurements.

Examples

Specify Dimensions of a Motorcycle

Store the dimensions of a motorcycle with length 2.2, width 0.6, and height 1.5 meters. Also specify the distance that the motorcycle extends ahead of the front axle and behind the rear axle.

```
vdims = vehicleDimensions(2.2,0.6,1.5, ...  
    'FrontOverhang',0.37, 'RearOverhang',0.32)
```

```
vdims =  
    vehicleDimensions with properties:
```

```
        Length: 2.2000  
        Width: 0.6000  
        Height: 1.5000  
        Wheelbase: 1.5100  
        RearOverhang: 0.3200  
        FrontOverhang: 0.3700  
        WorldUnits: 'meters'
```

Tips

- The Length of the vehicle is the sum of the Wheelbase, FrontOverhang, and RearOverhang. If you change FrontOverhang, then the value of Wheelbase automatically adjusts to keep Length constant. Any change resulting in a negative wheelbase causes an error.
- You can use the vehicle dimensions to define a vehicleCostmap that represents the planning search space around a vehicle. Path planning algorithms, such as pathPlannerRRT, use vehicle dimensions to find a path for the vehicle to follow.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- All inputs to `vehicleDimensions` must be compile-time constants.

See Also

`vehicle` | `vehicleCostmap`

Introduced in R2018a

objectDetection

Report for single object detection

Description

An `objectDetection` object contains an object detection report that was obtained by a sensor for a single object. You can use the `objectDetection` output as the input to trackers such as `multiObjectTracker`.

Creation

Syntax

```
detection = objectDetection(time, measurement)
detection = objectDetection( ____, Name, Value)
```

Description

`detection = objectDetection(time, measurement)` creates an object detection at the specified time from the specified measurement.

`detection = objectDetection(____, Name, Value)` creates a detection object with properties specified as one or more `Name, Value` pair arguments. Any unspecified properties have default values. You cannot specify the `Time` or `Measurement` properties using `Name, Value` pairs.

Input Arguments

time — Detection time

nonnegative real scalar

Detection time, specified as a nonnegative real scalar. This argument sets the `Time` property.

measurement — Object measurement

real-valued N -element vector

Object measurement, specified as a real-valued N -element vector. N is determined by the coordinate system used to report detections and other parameters that you specify in the `MeasurementParameters` property for the `objectDetection` object.

This argument sets the `Measurement` property.

Output Arguments

detection — Detection report

`objectDetection` object

Detection report for a single object, returned as an `objectDetection` object. An `objectDetection` object contains these properties:

Property	Definition
Time	Measurement time
Measurement	Object measurements
MeasurementNoise	Measurement noise covariance matrix
SensorIndex	Unique ID of the sensor
ObjectClassID	Object classification
MeasurementParameters	Parameters used by initialization functions of nonlinear Kalman tracking filters
ObjectAttributes	Additional information passed to tracker

Properties

Time — Detection time

nonnegative real scalar

Detection time, specified as a nonnegative real scalar. You cannot set this property as a name-value pair. Use the `time` input argument instead.

Example: `5.0`

Data Types: `double`

Measurement — Object measurementreal-valued N -element vector

Object measurement, specified as a real-valued N -element vector. You cannot set this property as a name-value pair. Use the `measurement` input argument instead.

Example: `[1.0; -3.4]`Data Types: `double` | `single`**MeasurementNoise — Measurement noise covariance**scalar | real positive semi-definite symmetric N -by- N matrix

Measurement noise covariance, specified as a scalar or a real positive semi-definite symmetric N -by- N matrix. N is the number of elements in the measurement vector. For the scalar case, the matrix is a square diagonal N -by- N matrix having the same data interpretation as the measurement.

Example: `[5.0, 1.0; 1.0, 10.0]`Data Types: `double` | `single`**SensorIndex — Sensor identifier**

1 | positive integer

Sensor identifier, specified as a positive integer. The sensor identifier lets you distinguish between different sensors and must be unique to the sensor.

Example: 5

Data Types: `double`**ObjectClassID — Object class identifier**

0 (default) | positive integer

Object class identifier, specified as a positive integer. Object class identifiers distinguish between different kinds of objects. The value 0 denotes an unknown object type. If the class identifier is nonzero, `multiObjectTracker` immediately creates a confirmed track from the detection.

Example: 1

Data Types: `double`**MeasurementParameters — Measurement function parameters**

{ } (default) | structure array | cell containing structure array | cell array

Measurement function parameters, specified as a structure array, a cell containing a structure array, or a cell array. The property contains all the arguments used by the measurement function specified by the `MeasurementFcn` property of a nonlinear tracking filter such as `trackingEKF` or `trackingUKF`.

The table shows sample fields for the `MeasurementParameters` structures.

Field	Description	Example
Frame	Frame used to report measurements, specified as one of these values: <ul style="list-style-type: none"> • 'rectangular' — Detections are reported in rectangular coordinates. • 'spherical' — Detections are reported in spherical coordinates. 	'spherical'
OriginPosition	Position offset of the origin of the frame relative to the parent frame, specified as an [x y z] real-valued vector.	[0 0 0]
OriginVelocity	Velocity offset of the origin of the frame relative to the parent frame, specified as a [vx vy vz] real-valued vector.	[0 0 0]
Orientation	Frame rotation matrix, specified as a 3-by-3 real-valued orthonormal matrix.	[1 0 0; 0 1 0; 0 0 1]
HasAzimuth	Logical scalar indicating if azimuth is included in the measurement.	1

Field	Description	Example
HasElevation	Logical scalar indicating if elevation is included in the measurement. For measurements reported in a rectangular frame, and if HasElevation is false, the reported measurements assume 0 degrees of elevation.	1
HasRange	Logical scalar indicating if range is included in the measurement.	1
HasVelocity	Logical scalar indicating if the reported detections include velocity measurements. For measurements reported in the rectangular frame, if HasVelocity is false, the measurements are reported as [x y z]. If HasVelocity is true, measurements are reported as [x y z vx vy vz].	1
IsParentToChild	Logical scalar indicating if Orientation performs a frame rotation from the parent coordinate frame to the child coordinate frame. When IsParentToChild is false, then Orientation performs a frame rotation from the child coordinate frame to the parent coordinate frame.	0

ObjectAttributes — Object attributes

{ } (default) | cell array

Object attributes passed through the tracker, specified as a cell array. These attributes are added to the output of the `multiObjectTracker` but not used by the tracker.

Example: `{[10,20,50,100], 'radar1'}`

Examples

Create Detection from Position Measurement

Create a detection from a position measurement. The detection is made at a timestamp of one second from a position measurement of `[100;250;10]` in Cartesian coordinates.

```
detection = objectDetection(1,[100;250;10])
```

```
detection =  
  objectDetection with properties:  
  
          Time: 1  
    Measurement: [3x1 double]  
  MeasurementNoise: [3x3 double]  
      SensorIndex: 1  
    ObjectClassID: 0  
  MeasurementParameters: {}  
    ObjectAttributes: {}
```

Create Detection With Measurement Noise

Create an `objectDetection` from a time and position measurement. The detection is made at a time of one second for an object position measurement of `[100;250;10]`. Add measurement noise and set other properties using Name-Value pairs.

```
detection = objectDetection(1,[100;250;10], 'MeasurementNoise',10, ...  
    'SensorIndex',1, 'ObjectAttributes', {'Example object',5})
```

```
detection =  
  objectDetection with properties:
```

```
Time: 1
Measurement: [3x1 double]
MeasurementNoise: [3x3 double]
SensorIndex: 1
ObjectClassID: 0
MeasurementParameters: {}
ObjectAttributes: {'Example object' [5]}
```

Extended Capabilities

C/C++ Code Generation

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

See Also

Objects

[multiObjectTracker](#) | [radarDetectionGenerator](#) | [trackingEKF](#) | [trackingKF](#) | [trackingUKF](#) | [visionDetectionGenerator](#)

Introduced in R2017a

trackingKF

Linear Kalman filter for object tracking

Description

A `trackingKF` object is a discrete-time linear Kalman filter used to track the positions and velocities of objects that can be encountered in an automated driving scenario. Such objects include automobiles, pedestrians, bicycles, and stationary structures or obstacles. A Kalman filter is a recursive algorithm for estimating the evolving state of a process when measurements are made on the process. The filter is linear when the evolution of the state follows a linear motion model and the measurements are linear functions of the state. The filter assumes that both the process and measurements have additive noise. When the process noise and measurement noise are Gaussian, the Kalman filter is the optimal minimum mean squared error (MMSE) state estimator for linear processes.

You can use this object in these ways:

- Explicitly set the motion model. Set the motion model property, `MotionModel`, to `Custom`, and then use the `StateTransitionModel` property to set the state transition matrix.
- Set the `MotionModel` property to a predefined state transition model:

Motion Model
'1D Constant Velocity'
'1D Constant Acceleration'
'2D Constant Velocity'
'2D Constant Acceleration'
'3D Constant Velocity'
'3D Constant Acceleration'

Creation

Syntax

```
filter = trackingKF
filter = trackingKF(F,H)
filter = trackingKF(F,H,G)
filter = trackingKF('MotionModel',model)
filter = trackingKF( ____,Name,Value)
```

Description

`filter = trackingKF` creates a linear Kalman filter object for a discrete-time, 2-D, constant-velocity moving object. The Kalman filter uses default values for the `StateTransitionModel`, `MeasurementModel`, and `ControlModel` properties. The function also sets the `MotionModel` property to '2D Constant Velocity'.

`filter = trackingKF(F,H)` specifies the state transition model, `F`, and the measurement model, `H`. With this syntax, the function also sets the `MotionModel` property to 'Custom'.

`filter = trackingKF(F,H,G)` also specifies the control model, `G`. With this syntax, the function also sets the `MotionModel` property to 'Custom'.

`filter = trackingKF('MotionModel',model)` sets the motion model property, `MotionModel`, to `model`.

`filter = trackingKF(____,Name,Value)` configures the properties of the Kalman filter by using one or more `Name,Value` pair arguments and any of the previous syntaxes. Any unspecified properties take default values.

Properties

State — Kalman filter state

0 (default) | real-valued scalar | real-valued M -element vector

Kalman filter state, specified as a real-valued M -element vector. M is the size of the state vector. Typical state vector sizes are described in the `MotionModel` property. When the initial state is specified as a scalar, the state is expanded into an M -element vector.

You can set the state to a scalar in these cases:

- When the `MotionModel` property is set to 'Custom', M is determined by the size of the state transition model.
- When the `MotionModel` property is set to '2D Constant Velocity', '3D Constant Velocity', '2D Constant Acceleration', or '3D Constant Acceleration', you must first specify the state as an M -element vector. You can use a scalar for all subsequent specifications of the state vector.

Example: `[200;0.2;-40;-0.01]`

Data Types: double

StateCovariance — State estimation error covariance

1 (default) | positive scalar | positive-definite real-valued M -by- M matrix

State error covariance, specified as a positive scalar or a positive-definite real-valued M -by- M matrix, where M is the size of the state. Specifying the value as a scalar creates a multiple of the M -by- M identity matrix. This matrix represents the uncertainty in the state.

Example: `[20 0.1; 0.1 1]`

Data Types: double

MotionModel — Kalman filter motion model

'Custom' (default) | '1D Constant Velocity' | '2D Constant Velocity' | '3D Constant Velocity' | '1D Constant Acceleration' | '2D Constant Acceleration' | '3D Constant Acceleration'

Kalman filter motion model, specified as 'Custom' or one of these predefined models. In this case, the state vector and state transition matrix take the form specified in the table.

Motion Model	Form of State Vector	Form of State Transition Model
'1D Constant Velocity'	$[x; v_x]$	$[1 \ dt; \ 0 \ 1]$

Motion Model	Form of State Vector	Form of State Transition Model
'2D Constant Velocity'	$[x; vx; y; vy]$	Block diagonal matrix with the $[1 \ dt; 0 \ 1]$ block repeated for the x and y spatial dimensions
'3D Constant Velocity'	$[x; vx; y; vy; z; vz]$	Block diagonal matrix with the $[1 \ dt; 0 \ 1]$ block repeated for the x , y , and z spatial dimensions.
'1D Constant Acceleration'	$[x; vx; ax]$	$[1 \ dt \ 0.5*dt^2; 0 \ 1 \ dt; 0 \ 0 \ 1]$
'2D Constant Acceleration'	$[x; vx; ax; y; vy; ay]$	Block diagonal matrix with $[1 \ dt \ 0.5*dt^2; 0 \ 1 \ dt; 0 \ 0 \ 1]$ blocks repeated for the x and y spatial dimensions
'3D Constant Acceleration'	$[x; vx, ax; y; vy; ay; z; vz; az]$	Block diagonal matrix with the $[1 \ dt \ 0.5*dt^2; 0 \ 1 \ dt; 0 \ 0 \ 1]$ block repeated for the x , y , and z spatial dimensions

When the `ControlModel` property is defined, every nonzero element of the state transition model is replaced by `dt`.

When `MotionModel` is 'Custom', you must specify a state transition model matrix, a measurement model matrix, and optionally, a control model matrix as input arguments to the Kalman filter.

Data Types: `char`

StateTransitionModel – State transition model between time steps

$[1 \ 1 \ 0 \ 0; 0 \ 1 \ 0 \ 0; 0 \ 0 \ 1 \ 1; 0 \ 0 \ 0 \ 1]$ (default) | real-valued M -by- M matrix

State transition model between time steps, specified as a real-valued M -by- M matrix. M is the size of the state vector. In the absence of controls and noise, the state transition model relates the state at any time step to the state at the previous step. The state transition model is a function of the filter time step size.

Example: `[1 0; 1 2]`

Dependencies

To enable this property, set `MotionModel` to 'Custom'.

Data Types: `double`

ControlModel — Control model

`[]` (default) | M -by- L real-valued matrix

Control model, specified as an M -by- L matrix. M is the dimension of the state vector and L is the number of controls or forces. The control model adds the effect of controls on the evolution of the state.

Example: `[.01 0.2]`

Data Types: `double`

ProcessNoise — Covariance of process noise

1 (default) | positive scalar | real-valued positive-definite M -by- M matrix

Covariance of process noise, specified as a positive scalar or an M -by- M matrix where M is the dimension of the state. If you specify this property as a scalar, the filter uses the value as a multiplier of the M -by- M identity matrix. Process noise expresses the uncertainty in the dynamic model and is assumed to be zero-mean Gaussian white noise.

Example: `[1.0 0.05; 0.05 2]`

Data Types: `double`

MeasurementModel — Measurement model from state vector

`[1 0 0 0; 0 0 1 0]` (default) | real-valued N -by- M matrix

Measurement model from the state vector, specified as a real-valued N -by- M matrix, where N is the size of the measurement vector and M is the size of the state vector. The measurement model is a linear matrix that determines predicted measurements from the predicted state.

Example: `[1 0.5 0.01; 1.0 1 0]`

Data Types: `double`

MeasurementNoise — Measurement noise covariance

1 (default) | positive scalar | positive-definite real-valued N -by- N matrix

Covariance of the measurement noise, specified as a positive scalar or a positive-definite, real-valued N -by- N matrix, where N is the size of the measurement vector. If you specify this property as a scalar, the filter uses the value as a multiplier of the N -by- N identity matrix. Measurement noise represents the uncertainty of the measurement and is assumed to be zero-mean Gaussian white noise.

Example: 0.2

Data Types: double

Object Functions

predict	Predict state and state estimation error covariance of linear Kalman filter
correct	Correct state and state estimation error covariance using tracking filter
correctjpd	Correct state and state estimation error covariance using tracking filter and JPDA
distance	Distances between current and predicted measurements of tracking filter
likelihood	Likelihood of measurement from tracking filter
clone	Create duplicate tracking filter
residual	Measurement residual and residual noise from tracking filter
initialize	Initialize state and covariance of tracking filter

Examples

Constant-Velocity Linear Kalman Filter

Create a linear Kalman filter that uses a 2D Constant Velocity motion model. Assume that the measurement consists of the object's x-y location.

Specify the initial state estimate to have zero velocity.

```
x = 5.3;
y = 3.6;
initialState = [x;0;y;0];
KF = trackingKF('MotionModel', '2D Constant Velocity', 'State', initialState);
```

Create the measured positions from a constant-velocity trajectory.

```
vx = 0.2;
vy = 0.1;
```

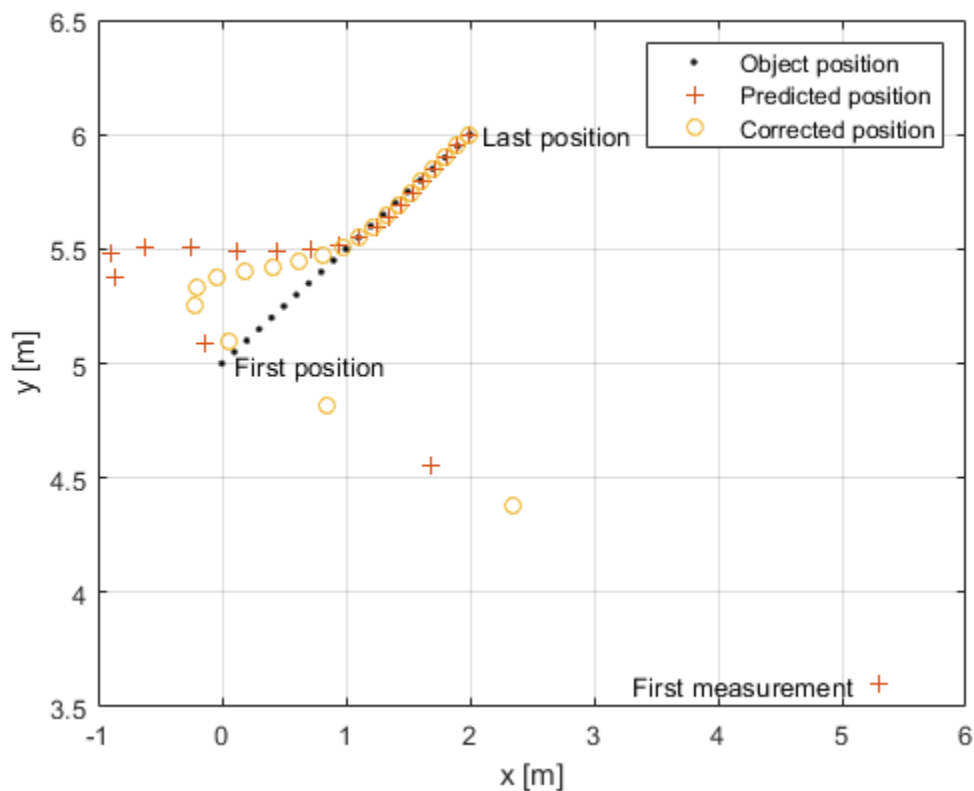
```
T = 0.5;  
pos = [0:vx*T:2;5:vy*T:6]';
```

Predict and correct the state of the object.

```
for k = 1:size(pos,1)  
    pstates(k,:) = predict(KF,T);  
    cstates(k,:) = correct(KF,pos(k,:));  
end
```

Plot the tracks.

```
plot(pos(:,1),pos(:,2),'k.', pstates(:,1),pstates(:,3),'+', ...  
      cstates(:,1),cstates(:,3),'o')  
xlabel('x [m]')  
ylabel('y [m]')  
grid  
xt = [x-2 pos(1,1)+0.1 pos(end,1)+0.1];  
yt = [y pos(1,2) pos(end,2)];  
text(xt,yt,{'First measurement', 'First position', 'Last position'})  
legend('Object position', 'Predicted position', 'Corrected position')
```



More About

Filter Parameters

This table relates the filter model parameters to the object properties. M is the size of the state vector. N is the size of the measurement vector. L is the size of the control model.

Model Parameter	Description	Filter Property	Size
F_k	State transition model that specifies a linear model of the force-free equations of motion of the object. This model, together with the control model, determines the state at time $k+1$ as a function of the state at time k . The state transition model depends on the time step of the filter.	StateTransitionModel	M -by- M
H_k	Measurement model that specifies how the measurements are linear functions of the state.	MeasurementModel	N -by- M
G_k	Control model describing the controls or forces acting on the object.	ControlModel	M -by- L
x_k	Estimate of the state of the object.	State	M -
P_k	Estimated covariance matrix of the state. The covariance represents the uncertainty in the values of the state.	StateCovariance	M -by- M

Model Parameter	Description	Filter Property	Size
Q_k	Estimate of the process noise covariance matrix at step k . Process noise is a measure of the uncertainty in your dynamic model and is assumed to be zero-mean white Gaussian noise.	ProcessNoise	M -by- M
R_k	Estimate of the measurement noise covariance at step k . Measurement noise represents the uncertainty of the measurement and is assumed to be zero-mean white Gaussian noise.	MeasurementNoise	N -by- N

Algorithms

The Kalman filter describes the motion of an object by estimating its state. The state generally consists of object position and velocity and possibly its acceleration. The state can span one, two, or three spatial dimensions. Most frequently, you use the Kalman filter to model constant-velocity or constant-acceleration motion. A linear Kalman filter assumes that the process obeys the following linear stochastic difference equation:

$$x_{k+1} = F_k x_k + G_k u_k + v_k$$

x_k is the state at step k . F_k is the state transition model matrix. G_k is the control model matrix. u_k represents known generalized controls acting on the object. In addition to the specified equations of motion, the motion may be affected by random noise perturbations, v_k . The state, the state transition matrix, and the controls together provide enough information to determine the future motion of the object in the absence of noise.

In the Kalman filter, the measurements are also linear functions of the state,

$$z_k = H_k x_k + w_k$$

where H_k is the measurement model matrix. This model expresses the measurements as functions of the state. A measurement can consist of an object position, position and velocity, or its position, velocity, and acceleration, or some function of these quantities. The measurements can also include noise perturbations, w_k .

These equations, in the absence of noise, model the actual motion of the object and the actual measurements. The noise contributions at each step are unknown and cannot be modeled. Only the noise covariance matrices are known. The state covariance matrix is updated with knowledge of the noise covariance only.

For a brief description of the linear Kalman filter algorithm, see “Linear Kalman Filters” .

References

- [1] Brown, R.G. and P.Y.C. Wang. *Introduction to Random Signal Analysis and Applied Kalman Filtering*. 3rd Edition. New York: John Wiley & Sons, 1997.
- [2] Kalman, R. E. "A New Approach to Linear Filtering and Prediction Problems." *Transaction of the ASME-Journal of Basic Engineering*, Vol. 82, Series D, March 1960, pp. 35-45.
- [3] Blackman, Samuel. *Multiple-Target Tracking with Radar Applications*. Artech House. 1986.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- When you create a `trackingKF` object, and you specify the `MotionModel` property as any value other than 'Custom', then you must specify the state vector explicitly at construction time using the `State` property. The choice of motion model determines the size of the state vector. However, motion models do not specify the data type, for

example, double precision or single precision. Both size and data type are required for code generation.

See Also

Functions

`initcakf` | `initcvkf`

Objects

`multiObjectTracker` | `trackingEKF` | `trackingUKF`

Topics

“Linear Kalman Filters”

Introduced in R2017a

trackingEKF

Extended Kalman filter for object tracking

Description

A `trackingEKF` object is a discrete-time extended Kalman filter used to track the positions and velocities of objects that can be encountered in an automated driving scenario. Such objects include automobiles, pedestrians, bicycles, and stationary structures or obstacles. A Kalman filter is a recursive algorithm for estimating the evolving state of a process when measurements are made on the process. The extended Kalman filter can model the evolution of a state when the state follows a nonlinear motion model, when the measurements are nonlinear functions of the state, or when both conditions apply. The extended Kalman filter is based on the linearization of the nonlinear equations. This approach leads to a filter formulation similar to the linear Kalman filter, `trackingKF`.

The process and measurements can have Gaussian noise, which you can include in these ways:

- Add noise to both the process and the measurements. In this case, the sizes of the process noise and measurement noise must match the sizes of the state vector and measurement vector, respectively.
- Add noise in the state transition function, the measurement model function, or in both functions. In these cases, the corresponding noise sizes are not restricted.

Creation

Syntax

```
filter = trackingEKF  
filter = trackingEKF(transitionfcn,measurementfcn,state)  
filter = trackingEKF( ____,Name,Value)
```

Description

`filter = trackingEKF` creates an extended Kalman filter object for a discrete-time system by using default values for the `StateTransitionFcn`, `MeasurementFcn`, and `State` properties. The process and measurement noises are assumed to be additive.

`filter = trackingEKF(transitionfcn,measurementfcn,state)` specifies the state transition function, `transitionfcn`, the measurement function, `measurementfcn`, and the initial state of the system, `state`.

`filter = trackingEKF(___,Name,Value)` configures the properties of the extended Kalman filter object by using one or more `Name,Value` pair arguments and any of the previous syntaxes. Any unspecified properties have default values.

Properties

State — Kalman filter state

real-valued M -element vector

Kalman filter state, specified as a real-valued M -element vector, where M is the size of the filter state.

Example: `[200; 0.2]`

Data Types: `double`

StateCovariance — State estimation error covariance

positive-definite real-valued M -by- M matrix

State error covariance, specified as a positive-definite real-valued M -by- M matrix where M is the size of the filter state. The covariance matrix represents the uncertainty in the filter state.

Example: `[20 0.1; 0.1 1]`

StateTransitionFcn — State transition function

function handle

State transition function, specified as a function handle. This function calculates the state vector at time step k from the state vector at time step $k - 1$. The function can take additional input parameters, such as control inputs or time step size. The function can also include noise values.

The valid syntaxes for the state transition function depend on whether the filter has additive process noise. The table shows the valid syntaxes based on the value of the `HasAdditiveProcessNoise` property.

Valid Syntaxes (HasAdditiveProcessNoise = true)	Valid Syntaxes (HasAdditiveProcessNoise = false)
<p> <code>x(k) = statetransitionfcn(x(k-1))</code> <code>x(k) = statetransitionfcn(x(k-1),parameters)</code> </p> <ul style="list-style-type: none"> • <code>x(k)</code> is the state at time <code>k</code>. • <code>parameters</code> stands for all additional arguments required by the state transition function. 	<p> <code>x(k) = statetransitionfcn(x(k-1),w(k-1))</code> <code>x(k) = statetransitionfcn(x(k-1),w(k-1),dt)</code> <code>x(k) = statetransitionfcn(__,parameters)</code> </p> <ul style="list-style-type: none"> • <code>x(k)</code> is the state at time <code>k</code>. • <code>w(k)</code> is a value for the process noise at time <code>k</code>. • <code>dt</code> is the time step of the <code>trackingEKF</code> filter, <code>filter</code>, specified in the most recent call to the <code>predict</code> function. The <code>dt</code> argument applies when you use the filter within a tracker and call the <code>predict</code> function with the filter to predict the state of the tracker at the next time step. For the nonadditive process noise case, the tracker assumes that you explicitly specify the time step by using this syntax: <code>predict(filter,dt)</code>. • <code>parameters</code> stands for all additional arguments required by the state transition function.

Example: `@constacc`

Data Types: `function_handle`

StateTransitionJacobianFcn — Jacobian of state transition function

`function handle`

Jacobian of the state transition function, specified as a function handle. This function has the same input arguments as the state transition function.

The valid syntaxes for the Jacobian of the state transition function depend on whether the filter has additive process noise. The table shows the valid syntaxes based on the value of the `HasAdditiveProcessNoise` property.

Valid Syntaxes (HasAdditiveProcessNoise = true)	Valid Syntaxes (HasAdditiveProcessNoise = false)
<p><code>Jx(k) = statejacobianfcn(x(k))</code> <code>Jx(k) = statejacobianfcn(x(k),parameters)</code></p> <ul style="list-style-type: none"> • $x(k)$ is the state at time k. • $Jx(k)$ denotes the Jacobian of the predicted state with respect to the previous state. This Jacobian is an M-by-M matrix at time k. The Jacobian function can take additional input parameters, such as control inputs or time-step size. • <code>parameters</code> stands for all additional arguments required by the Jacobian function, such as control inputs or time-step size. 	<p><code>[Jx(k),Jw(k)] = statejacobianfcn(x(k),w(k))</code> <code>[Jx(k),Jw(k)] = statejacobianfcn(x(k),w(k),dt)</code> <code>[Jx(k),Jw(k)] = statejacobianfcn(__,parameters)</code></p> <ul style="list-style-type: none"> • $x(k)$ is the state at time k • $w(k)$ is a sample Q-element vector of the process noise at time k. Q is the size of the process noise covariance. The process noise vector in the nonadditive case does not need to have the same dimensions as the state vector. • $Jx(k)$ denotes the Jacobian of the predicted state with respect to the previous state. This Jacobian is an M-by-M matrix at time k. The Jacobian function can take additional input parameters, such as control inputs or time-step size. • $Jw(k)$ denotes the M-by-Q Jacobian of the predicted state with respect to the process noise elements. • <code>dt</code> is the time step of the <code>trackingEKF</code> filter, <code>filter</code>, specified in the most recent call to the <code>predict</code> function. The <code>dt</code> argument applies when you use the filter within a tracker and call the <code>predict</code> function with the <code>filter</code> to predict the state of the tracker at the next time step. For the nonadditive process noise case, the tracker assumes that you explicitly specify the time step by using this syntax: <code>predict(filter,dt)</code>. • <code>parameters</code> stands for all additional arguments required by the Jacobian

Valid Syntaxes (HasAdditiveProcessNoise = true)	Valid Syntaxes (HasAdditiveProcessNoise = false)
	function, such as control inputs or time-step size.

If this property is not specified, the Jacobians are computed by numeric differencing at each call of the `predict` function. This computation can increase the processing time and numeric inaccuracy.

Example: `@constaccjac`

Data Types: `function_handle`

ProcessNoise — Process noise covariance

1 (default) | positive real scalar | positive-definite real-valued matrix

Process noise covariance, specified as a scalar or matrix.

- When `HasAdditiveProcessNoise` is `true`, specify the process noise covariance as a positive real scalar or a positive-definite real-valued M -by- M matrix. M is the dimension of the state vector. When specified as a scalar, the matrix is a multiple of the M -by- M identity matrix.
- When `HasAdditiveProcessNoise` is `false`, specify the process noise covariance as a Q -by- Q matrix. Q is the size of the process noise vector.

You must specify `ProcessNoise` before any call to the `predict` function. In later calls to `predict`, you can optionally specify the process noise as a scalar. In this case, the process noise matrix is a multiple of the Q -by- Q identity matrix.

Example: `[1.0 0.05; 0.05 2]`

HasAdditiveProcessNoise — Model additive process noise

`true` (default) | `false`

Option to model process noise as additive, specified as `true` or `false`. When this property is `true`, process noise is added to the state vector. Otherwise, noise is incorporated into the state transition function.

MeasurementFcn — Measurement model function

`function_handle`

Measurement model function, specified as a function handle. This function can be a nonlinear function that models measurements from the predicted state. Input to the

function is the M -element state vector. The output is the N -element measurement vector. The function can take additional input arguments, such as sensor position and orientation.

- If `HasAdditiveMeasurementNoise` is `true`, specify the function using one of these syntaxes:

```
z(k) = measurementfcn(x(k))
```

```
z(k) = measurementfcn(x(k),parameters)
```

$x(k)$ is the state at time k and $z(k)$ is the predicted measurement at time k . The `parameters` argument stands for all additional arguments required by the measurement function.

- If `HasAdditiveMeasurementNoise` is `false`, specify the function using one of these syntaxes:

```
z(k) = measurementfcn(x(k),v(k))
```

```
z(k) = measurementfcn(x(k),v(k),parameters)
```

$x(k)$ is the state at time k and $v(k)$ is the measurement noise at time k . The `parameters` argument stands for all additional arguments required by the measurement function.

Example: @cameas

Data Types: `function_handle`

MeasurementJacobianFcn — Jacobian of measurement function

`function handle`

Jacobian of the measurement function, specified as a function handle. The function has the same input arguments as the measurement function. The function can take additional input parameters, such as sensor position and orientation.

- If `HasAdditiveMeasurementNoise` is `true`, specify the Jacobian function using one of these syntaxes:

```
Jmx(k) = measjacobianfcn(x(k))
```

```
Jmx(k) = measjacobianfcn(x(k),parameters)
```

$x(k)$ is the state at time k . $J_x(k)$ denotes the N -by- M Jacobian of the measurement function with respect to the state. The `parameters` argument stands for all arguments required by the measurement function.

- If `HasAdditiveMeasurementNoise` is `false`, specify the Jacobian function using one of these syntaxes:

```
[Jmx(k),Jmv(k)] = measjacobianfcn(x(k),v(k))
```

```
[Jmx(k),Jmv(k)] = measjacobianfcn(x(k),v(k),parameters)
```

$x(k)$ is the state at time k and $v(k)$ is an R -dimensional sample noise vector. $J_{mx}(k)$ denotes the N -by- M Jacobian of the measurement function with respect to the state. $J_{mv}(k)$ denotes the Jacobian of the N -by- R measurement function with respect to the measurement noise. The `parameters` argument stands for all arguments required by the measurement function.

If not specified, measurement Jacobians are computed using numerical differencing at each call to the `correct` function. This computation can increase processing time and numerical inaccuracy.

Example: `@cameasjac`

Data Types: `function_handle`

MeasurementNoise — Measurement noise covariance

1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix.

- When `HasAdditiveMeasurementNoise` is `true`, specify the measurement noise covariance as a scalar or an N -by- N matrix. N is the size of the measurement vector. When specified as a scalar, the matrix is a multiple of the N -by- N identity matrix.
- When `HasAdditiveMeasurementNoise` is `false`, specify the measurement noise covariance as an R -by- R matrix. R is the size of the measurement noise vector.

You must specify `MeasurementNoise` before any call to the `correct` function. After the first call to `correct`, you can optionally specify the measurement noise as a scalar. In this case, the measurement noise matrix is a multiple of the R -by- R identity matrix.

Example: `0.2`

HasAdditiveMeasurementNoise — Model additive measurement noise

true (default) | false

Option to enable additive measurement noise, specified as true or false. When this property is true, noise is added to the measurement. Otherwise, noise is incorporated into the measurement function.

Object Functions

predict	Predict state and state estimation error covariance of tracking filter
correct	Correct state and state estimation error covariance using tracking filter
correctjpd	Correct state and state estimation error covariance using tracking filter and JPDA
distance	Distances between current and predicted measurements of tracking filter
likelihood	Likelihood of measurement from tracking filter
clone	Create duplicate tracking filter
residual	Measurement residual and residual noise from tracking filter
initialize	Initialize state and covariance of tracking filter

Examples

Constant-Velocity Extended Kalman Filter

Create a two-dimensional trackingEKF object and use name-value pairs to define the StateTransitionJacobianFcn and MeasurementJacobianFcn properties. Use the predefined constant-velocity motion and measurement models and their Jacobians.

```
EKF = trackingEKF(@constvel,@cvmeas,[0;0;0;0], ...  
    'StateTransitionJacobianFcn',@constveljac, ...  
    'MeasurementJacobianFcn',@cvmeasjac);
```

Run the filter. Use the predict and correct functions to propagate the state. You may call predict and correct in any order and as many times you want. Specify the measurement in Cartesian coordinates.

```
measurement = [1;1;0];  
[xpred, Ppred] = predict(EKF);  
[xcorr, Pcorr] = correct(EKF,measurement);  
[xpred, Ppred] = predict(EKF);  
[xpred, Ppred] = predict(EKF);
```

xpred = 4×1

```
1.2500
0.2500
1.2500
0.2500
```

Ppred = 4×4

```
11.7500  4.7500  0  0
 4.7500  3.7500  0  0
 0  0  11.7500  4.7500
 0  0  4.7500  3.7500
```

More About

Filter Parameters

This table relates the filter model parameters to the object properties. M is the size of the state vector. N is the size of the measurement vector.

Filter Parameter	Description	Filter Property	Size
f	State transition function that specifies the equations of motion of the object. This function determines the state at time $k+1$ as a function of the state and the controls at time k . The state transition function depends on the time-increment of the filter.	StateTransitionFcn	Function returns M -element vector

Filter Parameter	Description	Filter Property	Size
h	Measurement function that specifies how the measurements are functions of the state and measurement noise.	MeasurementFcn	Function returns N -element vector
x_k	Estimate of the object state.	State	M -element vector
P_k	State error covariance matrix representing the uncertainty in the values of the state.	StateCovariance	M -by- M matrix
Q_k	Estimate of the process noise covariance matrix at step k . Process noise is a measure of the uncertainty in the dynamic model. It is assumed to be zero-mean white Gaussian noise.	ProcessNoise	M -by- M matrix when HasAdditiveProcessNoise is true. Q -by- Q matrix when HasAdditiveProcessNoise is false
R_k	Estimate of the measurement noise covariance at step k . Measurement noise reflects the uncertainty of the measurement. It is assumed to be zero-mean white Gaussian noise.	MeasurementNoise	N -by- N matrix when HasAdditiveMeasurementNoise is true. R -by- R when HasAdditiveMeasurementNoise is false.

Filter Parameter	Description	Filter Property	Size
F	Function determining Jacobian of propagated state with respect to previous state.	StateTransitionJacobianFcn	M -by- M matrix
H	Function determining Jacobians of measurement with respect to the state and measurement noise.	MeasurementJacobianFcn	N -by- M for state vector Jacobian and N -by- R for measurement vector Jacobian

Algorithms

The extended Kalman filter estimates the state of a process governed by this nonlinear stochastic equation:

$$x_{k+1} = f(x_k, u_k, w_k, t)$$

x_k is the state at step k . $f()$ is the state transition function. Random noise perturbations, w_k , can affect the object motion. The filter also supports a simplified form,

$$x_{k+1} = f(x_k, u_k, t) + w_k$$

To use the simplified form, set `HasAdditiveProcessNoise` to `true`.

In the extended Kalman filter, the measurements are also general functions of the state:

$$z_k = h(x_k, v_k, t)$$

$h(x_k, v_k, t)$ is the measurement function that determines the measurements as functions of the state. Typical measurements are position and velocity or some function of position and velocity. The measurements can also include noise, represented by v_k . Again, the filter offers a simpler formulation.

$$z_k = h(x_k, t) + v_k$$

To use the simplified form, set `HasAdditiveMeasurementNoise` to `true`.

These equations represent the actual motion and the actual measurements of the object. However, the noise contribution at each step is unknown and cannot be modeled deterministically. Only the statistical properties of the noise are known.

References

- [1] Brown, R.G. and P.Y.C. Wang. *Introduction to Random Signal Analysis and Applied Kalman Filtering*. 3rd Edition. New York: John Wiley & Sons, 1997.
- [2] Kalman, R. E. "A New Approach to Linear Filtering and Prediction Problems." *Transactions of the ASME-Journal of Basic Engineering*. Vol. 82, Series D, March 1960, pp. 35-45.
- [3] Blackman, Samuel and R. Popoli. *Design and Analysis of Modern Tracking Systems*. Artech House.1999.
- [4] Blackman, Samuel. *Multiple-Target Tracking with Radar Applications*. Artech House. 1986.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initcaekf | initctekf | initcvekf

Objects

multiObjectTracker | trackingKF | trackingUKF

Topics

“Extended Kalman Filters”

Introduced in R2017a

trackingUKF

Unscented Kalman filter for object tracking

Description

The `trackingUKF` object is a discrete-time unscented Kalman filter used to track the positions and velocities of objects that can be encountered in an automated driving scenario. Such objects include automobiles, pedestrians, bicycles, and stationary structures or obstacles. An unscented Kalman filter is a recursive algorithm for estimating the evolving state of a process when measurements are made on the process. The unscented Kalman filter can model the evolution of a state that obeys a nonlinear motion model. The measurements can also be nonlinear functions of the state, and the process and measurements can have noise. Use an unscented Kalman filter when the current state is a nonlinear function of the previous state, when the measurements are nonlinear functions of the state, or when both conditions apply. The unscented Kalman filter estimates the uncertainty about the state, and its propagation through the nonlinear state and measurement equations, by using a fixed number of sigma points. Sigma points are chosen by using the unscented transformation, as parameterized by the `Alpha`, `Beta`, and `Kappa` properties.

Creation

Syntax

```
filter = trackingUKF
filter = trackingUKF(transitionfcn,measurementfcn,state)
filter = trackingUKF( ___,Name,Value)
```

Description

`filter = trackingUKF` creates an unscented Kalman filter object for a discrete-time system by using default values for the `StateTransitionFcn`, `MeasurementFcn`, and `State` properties. The process and measurement noises are assumed to be additive.

`filter = trackingUKF(transitionfcn,measurementfcn,state)` specifies the state transition function, `transitionfcn`, the measurement function, `measurementfcn`, and the initial state of the system, `state`.

`filter = trackingUKF(____,Name,Value)` configures the properties of the unscented Kalman filter object using one or more `Name, Value` pair arguments and any of the previous syntaxes. Any unspecified properties have default values.

Properties

State — Kalman filter state

real-valued M -element vector

Kalman filter state, specified as a real-valued M -element vector, where M is the size of the filter state.

Example: `[200; 0.2]`

Data Types: `double`

StateCovariance — State estimation error covariance

positive-definite real-valued M -by- M matrix

State error covariance, specified as a positive-definite real-valued M -by- M matrix where M is the size of the filter state. The covariance matrix represents the uncertainty in the filter state.

Example: `[20 0.1; 0.1 1]`

StateTransitionFcn — State transition function

function handle

State transition function, specified as a function handle. This function calculates the state vector at time step k from the state vector at time step $k - 1$. The function can take additional input parameters, such as control inputs or time step size. The function can also include noise values.

The valid syntaxes for the state transition function depend on whether the filter has additive process noise. The table shows the valid syntaxes based on the value of the `HasAdditiveProcessNoise` property.

Valid Syntaxes (HasAdditiveProcessNoise = true)	Valid Syntaxes (HasAdditiveProcessNoise = false)
<p> <code>x(k) = statetransitionfcn(x(k-1))</code> <code>x(k) = statetransitionfcn(x(k-1),parameters)</code> </p> <ul style="list-style-type: none"> • <code>x(k)</code> is the state at time <code>k</code>. • <code>parameters</code> stands for all additional arguments required by the state transition function. 	<p> <code>x(k) = statetransitionfcn(x(k-1),w(k-1))</code> <code>x(k) = statetransitionfcn(x(k-1),w(k-1),dt)</code> <code>x(k) = statetransitionfcn(__,parameters)</code> </p> <ul style="list-style-type: none"> • <code>x(k)</code> is the state at time <code>k</code>. • <code>w(k)</code> is a value for the process noise at time <code>k</code>. • <code>dt</code> is the time step of the <code>trackingUKF</code> filter, <code>filter</code>, specified in the most recent call to the <code>predict</code> function. The <code>dt</code> argument applies when you use the filter within a tracker and call the <code>predict</code> function with the filter to predict the state of the tracker at the next time step. For the nonadditive process noise case, the tracker assumes that you explicitly specify the time step by using this syntax: <code>predict(filter,dt)</code>. • <code>parameters</code> stands for all additional arguments required by the state transition function.

Example: @constacc

Data Types: function_handle

ProcessNoise – Process noise covariance

1 (default) | positive real scalar | positive-definite real-valued matrix

Process noise covariance, specified as a scalar or matrix.

- When `HasAdditiveProcessNoise` is `true`, specify the process noise covariance as a positive real scalar or a positive-definite real-valued M -by- M matrix. M is the dimension of the state vector. When specified as a scalar, the matrix is a multiple of the M -by- M identity matrix.
- When `HasAdditiveProcessNoise` is `false`, specify the process noise covariance as a Q -by- Q matrix. Q is the size of the process noise vector.

You must specify `ProcessNoise` before any call to the `predict` function. In later calls to `predict`, you can optionally specify the process noise as a scalar. In this case, the process noise matrix is a multiple of the Q -by- Q identity matrix.

Example: `[1.0 0.05; 0.05 2]`

HasAdditiveProcessNoise — Model additive process noise

`true` (default) | `false`

Option to model process noise as additive, specified as `true` or `false`. When this property is `true`, process noise is added to the state vector. Otherwise, noise is incorporated into the state transition function.

MeasurementFcn — Measurement model function

function handle

Measurement model function, specified as a function handle. This function can be a nonlinear function that models measurements from the predicted state. Input to the function is the M -element state vector. The output is the N -element measurement vector. The function can take additional input arguments, such as sensor position and orientation.

- If `HasAdditiveMeasurementNoise` is `true`, specify the function using one of these syntaxes:

$$z(k) = \text{measurementfcn}(x(k))$$

$$z(k) = \text{measurementfcn}(x(k), \text{parameters})$$

$x(k)$ is the state at time k and $z(k)$ is the predicted measurement at time k . The `parameters` argument stands for all additional arguments required by the measurement function.

- If `HasAdditiveMeasurementNoise` is `false`, specify the function using one of these syntaxes:

$$z(k) = \text{measurementfcn}(x(k), v(k))$$

$$z(k) = \text{measurementfcn}(x(k), v(k), \text{parameters})$$

$x(k)$ is the state at time k and $v(k)$ is the measurement noise at time k . The `parameters` argument stands for all additional arguments required by the measurement function.

Example: `@cameas`

Data Types: `function_handle`

MeasurementNoise — Measurement noise covariance

1 (default) | positive scalar | positive-definite real-valued matrix

Measurement noise covariance, specified as a positive scalar or positive-definite real-valued matrix.

- When `HasAdditiveMeasurementNoise` is `true`, specify the measurement noise covariance as a scalar or an N -by- N matrix. N is the size of the measurement vector. When specified as a scalar, the matrix is a multiple of the N -by- N identity matrix.
- When `HasAdditiveMeasurementNoise` is `false`, specify the measurement noise covariance as an R -by- R matrix. R is the size of the measurement noise vector.

You must specify `MeasurementNoise` before any call to the `correct` function. After the first call to `correct`, you can optionally specify the measurement noise as a scalar. In this case, the measurement noise matrix is a multiple of the R -by- R identity matrix.

Example: 0.2

HasAdditiveMeasurementNoise — Model additive measurement noise

`true` (default) | `false`

Option to enable additive measurement noise, specified as `true` or `false`. When this property is `true`, noise is added to the measurement. Otherwise, noise is incorporated into the measurement function.

Alpha — Sigma point spread around state

1.0×10^{-3} (default) | positive scalar greater than 0 and less than or equal to 1

Sigma point spread around state, specified as a positive scalar greater than 0 and less than or equal to 1.

Beta — Distribution of sigma points

2 (default) | nonnegative scalar

Distribution of sigma points, specified as a nonnegative scalar. This parameter incorporates knowledge of the noise distribution of states for generating sigma points. For Gaussian distributions, setting `Beta` to 2 is optimal.

Kappa — Secondary scaling factor for generating sigma points

0 (default) | scalar from 0 to 3

Secondary scaling factor for generation of sigma points, specified as a scalar from 0 to 3. This parameter helps specify the generation of sigma points.

Object Functions

<code>predict</code>	Predict state and state estimation error covariance of tracking filter
<code>correct</code>	Correct state and state estimation error covariance using tracking filter
<code>correctjpd</code>	Correct state and state estimation error covariance using tracking filter and JPDA
<code>distance</code>	Distances between current and predicted measurements of tracking filter
<code>likelihood</code>	Likelihood of measurement from tracking filter
<code>clone</code>	Create duplicate tracking filter
<code>residual</code>	Measurement residual and residual noise from tracking filter
<code>initialize</code>	Initialize state and covariance of tracking filter

Examples

Constant-Velocity Unscented Kalman Filter

Create a `trackingUKF` object using the predefined constant-velocity motion model, `constvel`, and the associated measurement model, `cvmeas`. These models assume that the state vector has the form $[x;vx;y;vy]$ and that the position measurement is in Cartesian coordinates, $[x;y;z]$. Set the sigma point spread property to $1e-2$.

```
filter = trackingUKF(@constvel,@cvmeas,[0;0;0;0], 'Alpha', 1e-2);
```

Run the filter. Use the `predict` and `correct` functions to propagate the state. You can call `predict` and `correct` in any order and as many times as you want.

```
meas = [1;1;0];
[xpred, Ppred] = predict(filter);
[xcorr, Pcorr] = correct(filter,meas);
[xpred, Ppred] = predict(filter);
[xpred, Ppred] = predict(filter)
```

```
xpred = 4×1
```

```
1.2500
0.2500
1.2500
```

0.2500

Ppred = 4×4

```

11.7500    4.7500   -0.0000    0.0000
 4.7500    3.7500   -0.0000    0.0000
-0.0000   -0.0000   11.7500    4.7500
 0.0000    0.0000    4.7500    3.7500
    
```

More About

Filter Parameters

This table relates the filter model parameters to the object properties. M is the size of the state vector. N is the size of the measurement vector.

Model Parameter	Description	Filter Property	Size
f	State transition function that specifies the equations of motion of the object. This function determines the state at time $k+1$ as a function of the state and the controls at time k . The state transition function depends on the time-increment of the filter.	StateTransitionFcn	Function returns M -element vector

Model Parameter	Description	Filter Property	Size
h	Measurement function that specifies how the measurements are functions of the state and measurement noise.	MeasurementFcn	Function returns N -element vector
x_k	Estimate of the object state.	State	M
P_k	State error covariance matrix representing the uncertainty in the values of the state	StateCovariance	M -by- M
Q_k	Estimate of the process noise covariance matrix at step k . Process noise is measure of the uncertainty in your dynamic model and is assumed to be zero-mean white Gaussian noise	ProcessNoise	M -by- M when HasAdditiveProcessNoise is true. Q -by- Q when HasAdditiveProcessNoise is false.
R_k	Estimate of the measurement noise covariance at step k . Measurement noise reflects the uncertainty of the measurement and is assumed to be zero-mean white Gaussian noise.	MeasurementNoise	N -by- N when HasAdditiveMeasurementNoise is true. R -by- R when HasAdditiveMeasurementNoise is false.
α	Determines spread of sigma points.	Alpha	scalar

Model Parameter	Description	Filter Property	Size
β	A <i>priori</i> knowledge of sigma point distribution.	Beta	scalar
κ	Secondary scaling parameter.	Kappa	scalar

Algorithms

The unscented Kalman filter estimates the state of a process governed by a nonlinear stochastic equation

$$x_{k+1} = f(x_k, u_k, w_k, t)$$

where x_k is the state at step k . $f()$ is the state transition function, u_k are the controls on the process. The motion may be affected by random noise perturbations, w_k . The filter also supports a simplified form,

$$x_{k+1} = f(x_k, u_k, t) + w_k$$

To use the simplified form, set `HasAdditiveProcessNoise` to `true`.

In the unscented Kalman filter, the measurements are also general functions of the state,

$$z_k = h(x_k, v_k, t)$$

where $h(x_k, v_k, t)$ is the measurement function that determines the measurements as functions of the state. Typical measurements are position and velocity or some function of these. The measurements can include noise as well, represented by v_k . Again the class offers a simpler formulation

$$z_k = h(x_k, t) + v_k$$

To use the simplified form, set `HasAdditiveMeasurementNoise` to `true`.

These equations represent the actual motion of the object and the actual measurements. However, the noise contribution at each step is unknown and cannot be modeled exactly. Only statistical properties of the noise are known.

References

- [1] Brown, R.G. and P.Y.C. Wang. *Introduction to Random Signal Analysis and Applied Kalman Filtering*. 3rd Edition. New York: John Wiley & Sons, 1997.
- [2] Kalman, R. E. "A New Approach to Linear Filtering and Prediction Problems." *Transactions of the ASME-Journal of Basic Engineering*. Vol. 82, Series D, March 1960, pp. 35-45.
- [3] Wan, Eric A. and R. van der Merwe. "The Unscented Kalman Filter for Nonlinear Estimation". *Adaptive Systems for Signal Processing, Communications, and Control*. AS-SPCC, IEEE, 2000, pp.153-158.
- [4] Wan, Merle. "The Unscented Kalman Filter." In *Kalman Filtering and Neural Networks*. Edited by Simon Haykin. John Wiley & Sons, Inc., 2001.
- [5] Sarkka S. "Recursive Bayesian Inference on Stochastic Differential Equations." Doctoral Dissertation. Helsinki University of Technology, Finland. 2006.
- [6] Blackman, Samuel. *Multiple-Target Tracking with Radar Applications*. Artech House, 1986.

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

cameas | cameasjac | constacc | constaccjac | constturn | constturnjac | constvel | constveljac | ctmeas | ctmeasjac | cvmeas | cvmeasjac | initcaukf | initctukf | initcvukf

Objects

multiObjectTracker | trackingEKF | trackingKF

Introduced in R2017a

clone

Create duplicate tracking filter

Syntax

```
filterClone = clone(filter)
```

Description

`filterClone = clone(filter)` creates a copy of a tracking filter that has the same property values as the original filter.

Input Arguments

filter — Filter for object tracking

`trackingKF object` | `trackingEKF object` | `trackingUKF object`

Filter for object tracking, specified as one of these objects:

- `trackingKF` — Linear Kalman filter
- `trackingEKF` — Extended Kalman filter
- `trackingUKF` — Unscented Kalman filter

Output Arguments

filterClone — Cloned filter

`tracking filter object`

Cloned filter, returned as a tracking filter object of the same type as `filter`. The cloned filter has the same properties as the original filter.

Extended Capabilities

C/C++ Code Generation

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

See Also

`correct` | `correctjpda` | `distance` | `initialize` | `likelihood` | `predict` | `residual`

Introduced in R2017a

correct

Correct state and state estimation error covariance using tracking filter

Syntax

```
[xcorr,Pcorr] = correct(filter,zmeas)
[xcorr,Pcorr] = correct(filter,zmeas,measparams)
[xcorr,Pcorr] = correct(filter,zmeas,zcov)
correct(filter, ___)
xcorr = correct(filter, ___)
```

Description

`[xcorr,Pcorr] = correct(filter,zmeas)` returns the corrected state, `xcorr`, and the corrected state estimation error covariance, `Pcorr`, for the next time step of the input tracking filter based on the current measurement, `zmeas`. The corrected values overwrite the internal state and state estimation error covariance of `filter`.

`[xcorr,Pcorr] = correct(filter,zmeas,measparams)` specifies additional parameters used by the measurement function that is defined in the `MeasurementFcn` property of `filter`. You can return any of the outputs from preceding syntaxes.

If `filter` is a `trackingKF` object, then you cannot use this syntax.

`[xcorr,Pcorr] = correct(filter,zmeas,zcov)` specifies additional measurement covariance, `zcov`, used in the `MeasurementNoise` property of `filter`.

You can use this syntax only when `filter` is a `trackingKF` object.

`correct(filter, ___)` updates `filter` with the corrected state and state estimation error covariance without returning the corrected values. Specify the tracking filter and any of the input argument combinations from preceding syntaxes.

`xcorr = correct(filter, ___)` updates `filter` with the corrected state and state estimation error covariance but returns only the corrected state, `xcorr`.

Examples

Constant-Velocity Extended Kalman Filter

Create a two-dimensional trackingEKF object and use name-value pairs to define the `StateTransitionJacobianFcn` and `MeasurementJacobianFcn` properties. Use the predefined constant-velocity motion and measurement models and their Jacobians.

```
EKF = trackingEKF(@constvel,@cvmeas,[0;0;0;0], ...  
    'StateTransitionJacobianFcn',@constveljac, ...  
    'MeasurementJacobianFcn',@cvmeasjac);
```

Run the filter. Use the `predict` and `correct` functions to propagate the state. You may call `predict` and `correct` in any order and as many times you want. Specify the measurement in Cartesian coordinates.

```
measurement = [1;1;0];  
[xpred, Ppred] = predict(EKF);  
[xcorr, Pcorr] = correct(EKF,measurement);  
[xpred, Ppred] = predict(EKF);  
[xpred, Ppred] = predict(EKF)
```

```
xpred = 4×1
```

```
1.2500  
0.2500  
1.2500  
0.2500
```

```
Ppred = 4×4
```

```
11.7500    4.7500         0         0  
4.7500    3.7500         0         0  
         0         0    11.7500    4.7500  
         0         0    4.7500    3.7500
```


Input Arguments

filter — Filter for object tracking

trackingKF object | trackingEKF object | trackingUKF object

Filter for object tracking, specified as one of these objects:

- trackingKF — Linear Kalman filter
- trackingEKF — Extended Kalman filter
- trackingUKF — Unscented Kalman filter

zmeas — Measurement of filter

vector | matrix

Measurement of the tracked object, specified as a vector or matrix.

Data Types: single | double

measparams — Measurement parameters

comma-separated list of arguments

Measurement function arguments, specified as a comma-separated list of arguments. These arguments are the same ones that are passed into the measurement function specified by the MeasurementFcn property of the tracking filter. If filter is a trackingKF object, then you cannot specify measparams.

Suppose you set MeasurementFcn to @cameas, and then call correct:

```
[xcorr,Pcorr] = correct(filter,frame,sensorpos,sensorvel)
```

The correct function internally calls the following:

```
meas = cameas(state,frame,sensorpos,sensorvel)
```

zcov — Measurement covariance

M -by- M matrix

Measurement covariance, specified as an M -by- M matrix, where M is the dimension of the measurement. The same measurement covariance matrix is assumed for all measurements in zmeas.

Data Types: single | double

Output Arguments

xcorr — Corrected state of filter

vector | matrix

Corrected state of the filter, specified as a vector or matrix. The `State` property of the input `filter` is overwritten with this value.

Pcorr — Corrected state covariance of filter

vector | matrix

Corrected state covariance of the filter, specified as a vector or matrix. The `StateCovariance` property of the input `filter` is overwritten with this value.

Extended Capabilities

C/C++ Code Generation

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

See Also

`clone` | `correctjpd` | `distance` | `initialize` | `likelihood` | `predict` | `residual`

Introduced in R2017a

correctjpda

Correct state and state estimation error covariance using tracking filter and JPDA

Syntax

```
[xcorr,Pcorr] = correctjpda(filter,zmeas)
[xcorr,Pcorr] = correctjpda(filter,zmeas,jpdacoeffs,measparams)
[xcorr,Pcorr] = correctjpda(filter,zmeas,jpdacoeffs,zcov)
correctjpda(filter, ___)
xcorr = correctjpda(filter, ___)
```

Description

`[xcorr,Pcorr] = correctjpda(filter,zmeas)` returns the corrected state, `xcorr`, and the corrected state estimation error covariance, `Pcorr`, for the next time step of the input tracking filter. The corrected values are based on a set of measurements, `zmeas`, and their joint probabilistic data association coefficients, `jpdacoeffs`. These values overwrite the internal state and state estimation error covariance of `filter`.

`[xcorr,Pcorr] = correctjpda(filter,zmeas,jpdacoeffs,measparams)` specifies additional parameters used by the measurement function that is defined in the `MeasurementFcn` property of the tracking filter object.

If `filter` is a `trackingKF` object, then you cannot use this syntax.

`[xcorr,Pcorr] = correctjpda(filter,zmeas,jpdacoeffs,zcov)` specifies additional measurement covariance, `zcov`, used in the `MeasurementNoise` property of `filter`.

You can use this syntax only when `filter` is a `trackingKF` object.

`correctjpda(filter, ___)` updates `filter` with the corrected state and state estimation error covariance without returning the corrected values. Specify the tracking filter and any of the input argument combinations from preceding syntaxes.

`xcorr = correctjpdca(filter, ___)` updates `filter` with the corrected state and state estimation error covariance but returns only the corrected state, `xcorr`.

Input Arguments

filter — Filter for object tracking

trackingKF object | trackingEKF object | trackingUKF object

Filter for object tracking, specified as one of these objects:

- `trackingKF` — Linear Kalman filter
- `trackingEKF` — Extended Kalman filter
- `trackingUKF` — Unscented Kalman filter

zmeas — Measurements

M -by- N matrix

Measurements, specified as an M -by- N matrix, where M is the dimension of a single measurement, and N is the number of measurements.

Data Types: `single` | `double`

jpdacoeffs — Joint probabilistic data association coefficients

$(N+1)$ -element vector

Joint probabilistic data association coefficients, specified as an $(N+1)$ -element vector. The i th ($i = 1, \dots, N$) element of `jpdacoeffs` is the joint probability that the i th measurement in `zmeas` is associated with the filter. The last element of `jpdacoeffs` corresponds to the probability that no measurement is associated with the filter. The sum of all elements of `jpdacoeffs` must equal 1.

Data Types: `single` | `double`

zcov — Measurement covariance

M -by- M matrix

Measurement covariance, specified as an M -by- M matrix, where M is the dimension of the measurement. The same measurement covariance matrix is assumed for all measurements in `zmeas`.

Data Types: `single` | `double`

measparams — Measurement parameters

comma-separated list of arguments

Measurement function arguments, specified as a comma-separated list of arguments. These arguments are the same ones that are passed into the measurement function specified by the `MeasurementFcn` property of the tracking filter. If `filter` is a `trackingKF` object, then you cannot specify `measparams`.

Suppose you set `MeasurementFcn` to `@cameas`, and then call `correctjpda`:

```
[xcorr,Pcorr] = correctjpda(filter,frame,sensorpos,sensorvel)
```

The `correctjpda` function internally calls the following:

```
meas = cameas(state,frame,sensorpos,sensorvel)
```

Output Arguments

xcorr — Corrected state

P -element vector

Corrected state, returned as a P -element vector, where P is the dimension of the estimated state. The corrected state represents the *a posteriori* estimate of the state vector, taking into account the current measurements and their associated probabilities.

Pcorr — Corrected state error covariance

positive-definite P -by- P matrix

Corrected state error covariance, returned as a positive-definite P -by- P matrix, where P is the dimension of the state estimate. The corrected state covariance matrix represents the *a posteriori* estimate of the state covariance matrix, taking into account the current measurements and their associated probabilities.

More About

JPDA Correction Algorithm for Discrete Extended Kalman Filter

In the measurement update of a regular Kalman filter, the filter usually only needs to update the state and covariance based on one measurement. For instance, the equations for measurement update of a discrete extended Kalman filter can be given as

$$\begin{aligned}x_k^+ &= x_k^- + K_k(y - h(x_k^-)) \\ P_k^+ &= P_k^- - K_k S_k K_k^T\end{aligned}$$

where x_k^- and x_k^+ are the a priori and a posteriori state estimates, respectively, K_k is the Kalman gain, y is the actual measurement, and $h(x_k^-)$ is the predicted measurement. P_k^- and P_k^+ are the a priori and a posteriori state error covariance matrices, respectively. The innovation matrix S_k is defined as

$$S_k = H_k P_k^- H_k^T$$

where H_k is the Jacobian matrix for the measurement function h .

In the workflow of a JPDA tracker, the filter needs to process multiple probable measurements y_i ($i = 1, \dots, N$) with varied probabilities of association β_i ($i = 0, 1, \dots, N$). Note that β_0 is the probability that no measurements is associated with the filter. The measurement update equations for a discrete extended Kalman filter used for a JPDA tracker are

$$\begin{aligned}x_k^+ &= x_k^- + K_k \sum_{i=1}^N \beta_i (y_i - h(x_k^-)) \\ P_k^+ &= P_k^- - (1 - \beta_0) K_k S_k K_k^T + P_k\end{aligned}$$

where

$$P_k = K_k \sum_{i=1}^N \left[\beta_i (y_i - h(x_k^-))(y_i - h(x_k^-))^T - (\delta y)(\delta y)^T \right] K_k^T$$

and

$$\delta y = \sum_{j=1}^N \beta_j (y_j - h(x_k^-))$$

Note that these equations only apply to trackingEKF and are not the exact equations used in other tracking filters.

References

- [1] Fortmann, T., Y. Bar-Shalom, and M. Scheffe. "Sonar Tracking of Multiple Targets Using Joint Probabilistic Data Association." *IEEE Journal of Ocean Engineering*. Vol. 8, Number 3, 1983, pp. 173-184.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

correctjpd supports only double-precision code generation, not single-precision.

See Also

`clone` | `correct` | `distance` | `initialize` | `likelihood` | `predict` | `residual`

Introduced in R2019a

distance

Distances between current and predicted measurements of tracking filter

Syntax

```
dist = distance(filter,zmeas)  
dist = distance(filter,zmeas,measparams)
```

Description

`dist = distance(filter,zmeas)` computes the normalized distances between one or more current object measurements, `zmeas`, and the corresponding predicted measurements computed by the input `filter`. Use this function to assign measurements to tracks.

This distance computation takes into account the covariance of the predicted state and the measurement noise.

`dist = distance(filter,zmeas,measparams)` specifies additional parameters that are used by the `MeasurementFcn` of the filter.

If `filter` is a `trackingKF` object, then you cannot use this syntax.

Input Arguments

filter — Filter for object tracking

`trackingKF` object | `trackingEKF` object | `trackingUKF` object

Filter for object tracking, specified as one of these objects:

- `trackingKF` — Linear Kalman filter
- `trackingEKF` — Extended Kalman filter
- `trackingUKF` — Unscented Kalman filter

zmeas — Measurements of tracked objects

matrix

Measurements of tracked objects, specified as a matrix. Each row of the matrix contains a measurement vector.

measparams — Parameters for measurement function

cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function that is defined in the `MeasurementFcn` property of the filter. If `filter` is a `trackingKF` object, then you cannot specify `measparams`.

Suppose you set the `MeasurementFcn` property of `filter` to `@cameas`, and then set these values:

```
measurementParams = {frame, sensorpos, sensorpos}
```

The `distance` function internally calls the following:

```
cameas(state, frame, sensorpos, sensorvel)
```

Output Arguments

dist — Distances between measurements

row vector

Distances between measurements, returned as a row vector. Each element corresponds to a distance between the predicted measurement in the input `filter` and a measurement contained in a row of `zmeas`.

Algorithms

The `distance` function computes the normalized distance between the filter object and a set of measurements. This distance computation is a variant of the Mahalanobis distance and takes into account the residual (the difference between the object measurement and the value predicted by the filter), the residual covariance, and the measurement noise.

Consider an extended Kalman filter with state x and measurement z . The equations used to compute the residual, z_{res} , and the residual covariance, S , are

$$\begin{aligned}z_{\text{res}} &= z - h(x), \\ S &= R + HPH^T,\end{aligned}$$

where:

- h is the measurement function defined in the `MeasurementFcn` property of the filter.
- R is the measurement noise covariance defined in the `MeasurementNoise` property of the filter.
- H is the Jacobian of the measurement function defined in the `MeasurementJacobianFcn` property of the filter.

The residual covariance calculation for other filters can vary slightly from the one shown because tracking filters have different ways of propagating the covariance to the measurement space. For example, instead of using the Jacobian of the measurement function to propagate the covariance, unscented Kalman filters sample the covariance, and then propagate the sampled points.

The equation for the Mahalanobis distance, d^2 , is

$$d^2 = z_{\text{res}}^T S^{-1} z_{\text{res}},$$

The distance function computes the normalized distance, d_n , as

$$d_n = d^2 + \log(|S|),$$

where $\log(|S|)$ is the logarithm of the determinant of residual covariance S .

The $\log(|S|)$ term accounts for tracks that are coasted, meaning that they are predicted but have not had an update for a long time. Tracks in this state can make S very large, resulting in a smaller Mahalanobis distance relative to the updated tracks. This difference in distance values can cause the coasted tracks to incorrectly take detections from the updated tracks. The $\log(|S|)$ term compensates for this effect by penalizing such tracks, whose predictions are highly uncertain.

Extended Capabilities

C/C++ Code Generation

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

See Also

`clone` | `correct` | `correctjpd` | `initialize` | `likelihood` | `predict` | `residual`

Introduced in R2017a

initialize

Initialize state and covariance of tracking filter

Syntax

```
initialize(filter, state, statecov)  
initialize(filter, state, statecov, Name, Value)
```

Description

`initialize(filter, state, statecov)` initializes the filter by setting the `State` and `StateCovariance` properties of the filter with the corresponding `state` and `statecov` inputs.

`initialize(filter, state, statecov, Name, Value)` also initializes properties of filter by using one or more name-value pairs. Specify the name of the filter property and the value to which you want to initialize it. You cannot change the size or type of the properties that you initialize.

Input Arguments

filter — Filter for object tracking

`trackingKF` object | `trackingEKF` object | `trackingUKF` object

Filter for object tracking, specified as one of these objects:

- `trackingKF` — Linear Kalman filter
- `trackingEKF` — Extended Kalman filter
- `trackingUKF` — Unscented Kalman filter

state — Filter state

real-valued M -element vector

Filter state, specified as a real-valued M -element vector, where M is the size of the filter state.

Example: `[200; 0.2]`

Data Types: `double`

statecov — State estimation error covariance

positive-definite real-valued M -by- M matrix

State estimation error covariance, specified as a positive-definite real-valued M -by- M matrix. M is the size of the filter state. The covariance matrix represents the uncertainty in the filter state.

Example: `[20 0.1; 0.1 1]`

Extended Capabilities

C/C++ Code Generation

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

See Also

`clone` | `correct` | `correctjpd` | `distance` | `likelihood` | `predict` | `residual`

Introduced in R2018b

likelihood

Likelihood of measurement from tracking filter

Syntax

```
measlikelihood = likelihood(filter,zmeas)
measlikelihood = likelihood(filter,zmeas,measparams)
```

Description

`measlikelihood = likelihood(filter,zmeas)` returns the likelihood of a measurement, `zmeas`, that was produced by the specified filter, `filter`.

`measlikelihood = likelihood(filter,zmeas,measparams)` specifies additional parameters that are used by the `MeasurementFcn` of the filter.

If `filter` is a `trackingKF` object, then you cannot use this syntax.

Input Arguments

filter — Filter for object tracking

`trackingKF` object | `trackingEKF` object | `trackingUKF` object

Filter for object tracking, specified as one of these objects:

- `trackingKF` — Linear Kalman filter
- `trackingEKF` — Extended Kalman filter
- `trackingUKF` — Unscented Kalman filter

zmeas — Current measurement of tracked object

vector | matrix

Current measurement of a tracked object, specified a vector or matrix.

measparams — Parameters for measurement function

cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function that is defined in the `MeasurementFcn` of the input filter. If filter is a `trackingKF` object, then you cannot specify `measparams`.

Output Arguments

measlikelihood — Likelihood of measurement

scalar

Likelihood of measurement, returned as a scalar.

Extended Capabilities

C/C++ Code Generation

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

See Also

`clone` | `correct` | `correctjpd` | `distance` | `initialize` | `predict` | `residual`

Introduced in R2018a

predict

Predict state and state estimation error covariance of tracking filter

Syntax

```
[xpred,Ppred] = predict(filter)
[xpred,Ppred] = predict(filter,dt)
[xpred,Ppred] = predict(filter,predparams)

predict(filter, ___)
xpred = predict(filter, ___)
```

Description

`[xpred,Ppred] = predict(filter)` returns the predicted state, `xpred`, and the predicted state estimation error covariance, `Ppred`, for the next time step of the input tracking filter. The predicted values overwrite the internal state and state estimation error covariance of `filter`.

`[xpred,Ppred] = predict(filter,dt)` specifies the time step as a positive scalar in seconds, and returns one or more of the outputs from the preceding syntaxes.

`[xpred,Ppred] = predict(filter,predparams)` specifies additional prediction parameters used by the state transition function. The state transition function is defined in the `StateTransitionFcn` property of `filter`.

`predict(filter, ___)` updates `filter` with the predicted state and state estimation error covariance without returning the predicted values. Specify the tracking filter and any of the input argument combinations from preceding syntaxes.

`xpred = predict(filter, ___)` updates `filter` with the predicted state and state estimation error covariance but returns only the predicted state, `xpred`.

Examples

Constant-Velocity Extended Kalman Filter

Create a two-dimensional `trackingEKF` object and use name-value pairs to define the `StateTransitionJacobianFcn` and `MeasurementJacobianFcn` properties. Use the predefined constant-velocity motion and measurement models and their Jacobians.

```
EKF = trackingEKF(@constvel,@cvmeas,[0;0;0;0], ...
    'StateTransitionJacobianFcn',@constveljac, ...
    'MeasurementJacobianFcn',@cvmeasjac);
```

Run the filter. Use the `predict` and `correct` functions to propagate the state. You may call `predict` and `correct` in any order and as many times you want. Specify the measurement in Cartesian coordinates.

```
measurement = [1;1;0];
[xpred, Ppred] = predict(EKF);
[xcorr, Pcorr] = correct(EKF,measurement);
[xpred, Ppred] = predict(EKF);
[xpred, Ppred] = predict(EKF)
```

```
xpred = 4×1
```

```
    1.2500
    0.2500
    1.2500
    0.2500
```

```
Ppred = 4×4
```

```
    11.7500    4.7500         0         0
     4.7500    3.7500         0         0
         0         0    11.7500    4.7500
         0         0     4.7500    3.7500
```

Input Arguments

filter — Filter for object tracking

trackingEKF object | trackingUKF object

Filter for object tracking, specified as one of these objects:

- trackingEKF — Extended Kalman filter
- trackingUKF — Unscented Kalman filter

To use the `predict` function with a `trackingKF` linear Kalman filter, see `predict(trackingKF)`.

dt — Time step

positive scalar

Time step for next prediction, specified as a positive scalar in seconds.

predparams — Prediction parameters

comma-separated list of arguments

Prediction parameters used by the state transition function, specified as a comma-separated list of arguments. These arguments are the same arguments that are passed into the state transition function specified by the `StateTransitionFcn` property of the input `filter`.

Suppose you set the `StateTransitionFcn` property to `@constacc` and then call the `predict` function:

```
[xpred,Ppred] = predict(filter,dt)
```

The `predict` function internally calls the following:

```
state = constacc(state,dt)
```

Output Arguments

xpred — Predicted state of filter

vector | matrix

Predicted state of the filter, specified as a vector or matrix. The `State` property of the input `filter` is overwritten with this value.

Ppred — Predicted state covariance of filter

vector | matrix

Predicted state covariance of the filter, specified as a vector or matrix. The `StateCovariance` property of the input `filter` is overwritten with this value.

Extended Capabilities

C/C++ Code Generation

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

See Also

`clone` | `correct` | `correctjpd` | `distance` | `initialize` | `likelihood` | `residual`

Introduced in R2017a

predict

Predict state and state estimation error covariance of linear Kalman filter

Syntax

```
[xpred,Ppred] = predict(filter)
[xpred,Ppred] = predict(filter,u)
[xpred,Ppred] = predict(filter,F)
[xpred,Ppred] = predict(filter,F,Q)
[xpred,Ppred] = predict(filter,u,F,G)
[xpred,Ppred] = predict(filter,u,F,G,Q)

[xpred,Ppred] = predict(filter,dt)
[xpred,Ppred] = predict(filter,u,dt)

predict(filter, ___ )
xpred = predict(filter, ___ )
```

Description

`[xpred,Ppred] = predict(filter)` returns the predicted state, `xpred`, and the predicted state estimation error covariance, `Ppred`, for the next time step of the input linear Kalman filter. The predicted values overwrite the internal state and state estimation error covariance of `filter`.

This syntax applies when you set the `ControlModel` property of `filter` to an empty matrix.

`[xpred,Ppred] = predict(filter,u)` specifies a control input, or force, `u`, and returns one or more of the outputs from the preceding syntaxes.

This syntax applies when you set the `ControlModel` property of `filter` to a nonempty matrix.

`[xpred,Ppred] = predict(filter,F)` specifies the state transition model, `F`. Use this syntax to change the state transition model during a simulation.

This syntax applies when you set the `ControlModel` property of `filter` to an empty matrix.

`[xpred,Ppred] = predict(filter,F,Q)` specifies the state transition model, `F`, and the process noise covariance, `Q`. Use this syntax to change the state transition model and process noise covariance during a simulation.

This syntax applies when you set the `ControlModel` property of `filter` to an empty matrix.

`[xpred,Ppred] = predict(filter,u,F,G)` specifies the force or control input, `u`, the state transition model, `F`, and the control model, `G`. Use this syntax to change the state transition model and control model during a simulation.

This syntax applies when you set the `ControlModel` property of `filter` to a nonempty matrix.

`[xpred,Ppred] = predict(filter,u,F,G,Q)` specifies the force or control input, `u`, the state transition model, `F`, the control model, `G`, and the process noise covariance, `Q`. Use this syntax to change the state transition model, control model, and process noise covariance during a simulation.

This syntax applies when you set the `ControlModel` property of `filter` to a nonempty matrix.

`[xpred,Ppred] = predict(filter,dt)` returns the predicted outputs after time step `dt`.

This syntax applies when the `MotionModel` property of `filter` is not set to 'Custom' and the `ControlModel` property is set to an empty matrix.

`[xpred,Ppred] = predict(filter,u,dt)` also specifies a force or control input, `u`.

This syntax applies when the `MotionModel` property of `filter` is not set to 'Custom' and the `ControlModel` property is set to a nonempty matrix.

`predict(filter, ___)` updates `filter` with the predicted state and state estimation error covariance without returning the predicted values. Specify the tracking filter and any of the input argument combinations from preceding syntaxes.

`xpred = predict(filter, ___)` updates `filter` with the predicted state and state estimation error covariance but returns only the predicted state, `xpred`.

Examples

Constant-Velocity Linear Kalman Filter

Create a linear Kalman filter that uses a 2D Constant Velocity motion model. Assume that the measurement consists of the object's x-y location.

Specify the initial state estimate to have zero velocity.

```
x = 5.3;
y = 3.6;
initialState = [x;0;y;0];
KF = trackingKF('MotionModel','2D Constant Velocity','State',initialState);
```

Create the measured positions from a constant-velocity trajectory.

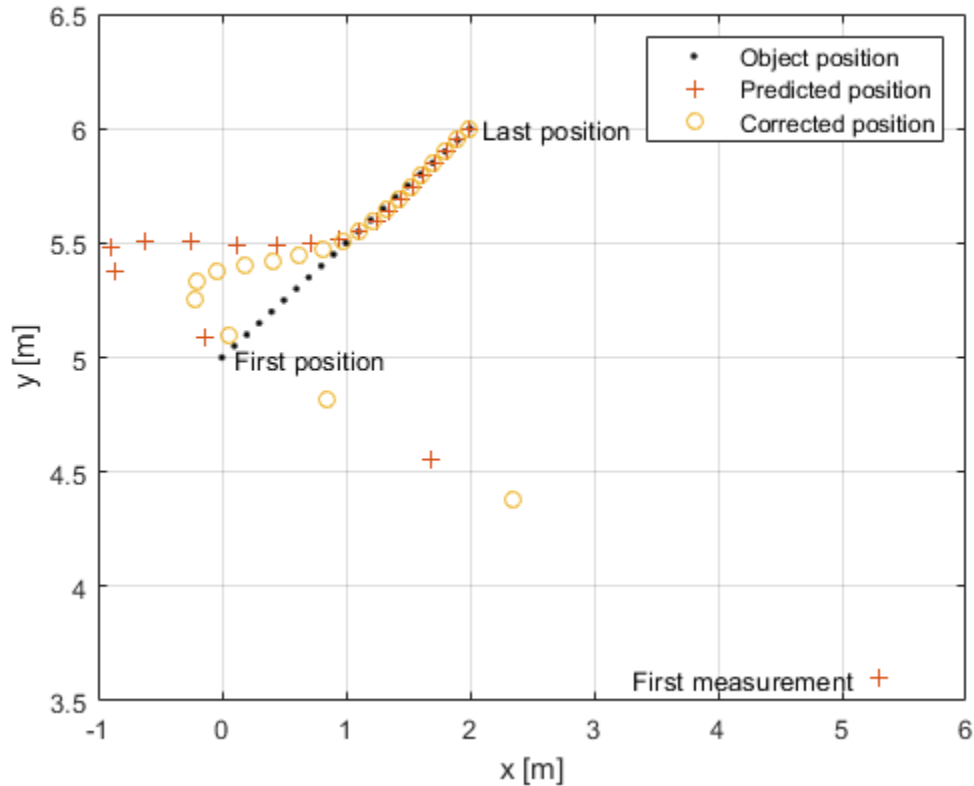
```
vx = 0.2;
vy = 0.1;
T = 0.5;
pos = [0:vx*T:2;5:vy*T:6]';
```

Predict and correct the state of the object.

```
for k = 1:size(pos,1)
    pstates(k,:) = predict(KF,T);
    cstates(k,:) = correct(KF,pos(k,:));
end
```

Plot the tracks.

```
plot(pos(:,1),pos(:,2),'k.', pstates(:,1),pstates(:,3),'+', ...
      cstates(:,1),cstates(:,3),'o')
xlabel('x [m]')
ylabel('y [m]')
grid
xt = [x-2 pos(1,1)+0.1 pos(end,1)+0.1];
yt = [y pos(1,2) pos(end,2)];
text(xt,yt,{'First measurement','First position','Last position'})
legend('Object position', 'Predicted position', 'Corrected position')
```



Input Arguments

filter — Linear Kalman filter for object tracking

trackingKF object

Linear Kalman filter for object tracking, specified as a trackingKF object.

u — Control vector

real-valued L -element vector

Control vector, specified as a real-valued L -element vector.

F — State transition model

real-valued M -by- M matrix

State transition model, specified as a real-valued M -by- M matrix, where M is the size of the state vector.

Q — Process noise covariance matrix

positive-definite, real-valued M -by- M matrix

Process noise covariance matrix, specified as a positive-definite, real-valued M -by- M matrix, where M is the length of the state vector.

G — Control model

real-valued M -by- L matrix

Control model, specified as a real-valued M -by- L matrix. M is the size of the state vector. L is the number of independent controls.

dt — Time step

positive scalar

Time step, specified as a positive scalar. Units are in seconds.

Output Arguments

xpred — Predicted state

real-valued M -element vector

Predicted state, returned as a real-valued M -element vector. The predicted state represents the deducible estimate of the state vector, propagated from the previous state using the state transition and control models.

Ppred — Predicted state error covariance matrix

real-valued M -by- M matrix

Predicted state covariance matrix, specified as a real-valued M -by- M matrix. M is the size of the state vector. The predicted state covariance matrix represents the *deducible* estimate of the covariance matrix vector. The filter propagates the covariance matrix from the previous estimate.

Extended Capabilities

C/C++ Code Generation

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

See Also

[clone](#) | [correct](#) | [correctjpda](#) | [distance](#) | [initialize](#) | [likelihood](#) | [residual](#)

Introduced in R2017a

residual

Measurement residual and residual noise from tracking filter

Syntax

```
[zres, rescov] = residual(filter, zmeas)  
[zres, rescov] = residual(filter, zmeas, measparams)
```

Description

`[zres, rescov] = residual(filter, zmeas)` computes the residual and residual covariance of the current given measurement, `zmeas`, with the predicted measurement in the tracking filter, `filter`. This function applies to filters that assume a Gaussian distribution for noise.

`[zres, rescov] = residual(filter, zmeas, measparams)` specifies additional parameters that are used by the `MeasurementFcn` of the filter.

If `filter` is a `trackingKF` object, then you cannot use this syntax.

Input Arguments

filter — Filter for object tracking

`trackingKF` object | `trackingEKF` object | `trackingUKF` object

Filter for object tracking, specified as one of these objects:

- `trackingKF` — Linear Kalman filter
- `trackingEKF` — Extended Kalman filter
- `trackingUKF` — Unscented Kalman filter

zmeas — Current measurement of tracked object

vector | matrix

Current measurement of a tracked object, specified as a vector or matrix.

measparams — Parameters for measurement function

cell array

Parameters for measurement function, specified as a cell array. The parameters are passed to the measurement function that is defined in the `MeasurementFcn` property of the input `filter`. If `filter` is a `trackingKF` object, then you cannot specify `measparams`.

Output Arguments

zres — Residual between current and predicted measurement

matrix

Residual between current and predicted measurement, returned as a matrix.

rescov — Residual covariance

matrix

Residual covariance, returned as a matrix.

Algorithms

The residual is the difference between a measurement and the value predicted by the filter. For Kalman filters, the residual calculation depends on whether the filter is linear or nonlinear.

Linear Kalman Filters

Given a linear Kalman filter with a current measurement of z , the residual z_{res} is defined as

$$z_{\text{res}} = z - Hx,$$

where:

- H is the measurement model set by the `MeasurementModel` property of the filter.
- x is the current filter state.

The covariance of the residual, S , is defined as

$$S = R + HPH^T,$$

where:

- P is the state covariance matrix.
- R is the measurement noise matrix set by the `MeasurementNoise` property of the filter.

Nonlinear Kalman Filters

Given a nonlinear Kalman filter with a current measurement of z , the residual z_{res} is defined as:

$$z_{\text{res}} = z - h(x),$$

where:

- h is the measurement function set by the `MeasurementFcn` property.
- x is the current filter state.

The covariance of the residual, S , is defined as:

$$S = R + R_p,$$

where:

- R is the measurement noise matrix set by the `MeasurementNoise` property of the filter.
- R_p is the state covariance matrix projected onto the measurement space.

Extended Capabilities

C/C++ Code Generation

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

See Also

`clone` | `correct` | `correctjpd` | `distance` | `initialize` | `likelihood` | `predict`

Introduced in R2018a

Scene Dimensions

Curved Road

Curved road 3D environment

Description

The **Curved Road** scene is a 3D environment of a curved highway loop. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to Curved road.

Explore Curved Road Scene

Explore the 3D Curved Road scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.CurvedRoad
```

```
spatialRef =
    imref2d with properties:
```

```

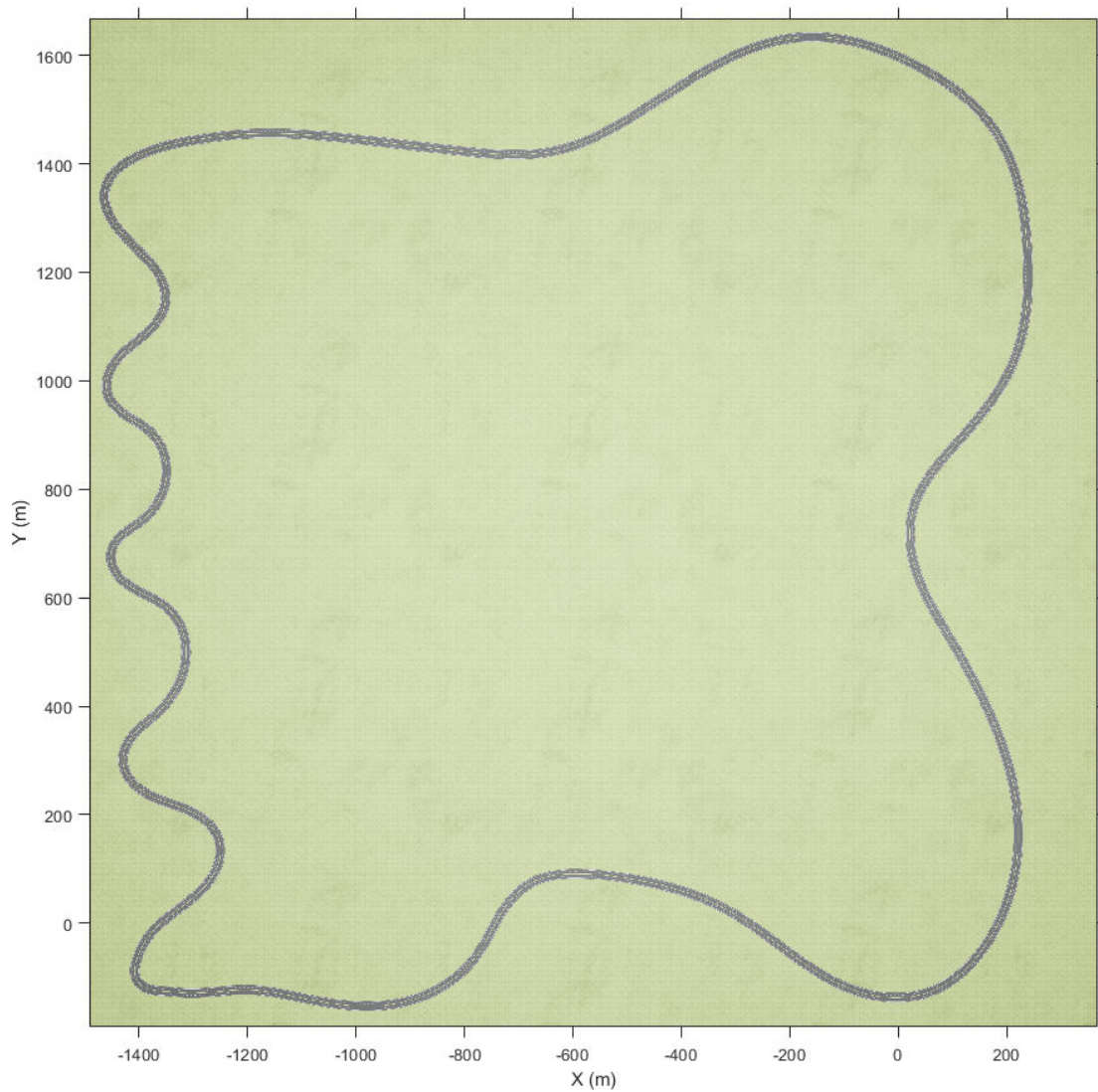
        XWorldLimits: [-1.4918e+03 367.9000]
        YWorldLimits: [-191.4200 1.6683e+03]
        ImageSize: [4845 4845]
PixelExtentInWorldX: 0.3838
PixelExtentInWorldY: 0.3838
ImageExtentInWorldX: 1.8597e+03
ImageExtentInWorldY: 1.8597e+03
    XIntrinsicLimits: [0.5000 4.8455e+03]
    YIntrinsicLimits: [0.5000 4.8455e+03]
```

Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

By default, the `imshow` function displays Y-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the Y-direction to `'normal'` so that Y-axis values increase from bottom to top.

```
figure
fileName = 'sim3d_CurvedRoad.jpg';
I = imshow(fileName,spatialRef);
set(gca,'YDir','normal')
xlabel('X (m)')
ylabel('Y (m)')
```

5 Scene Dimensions



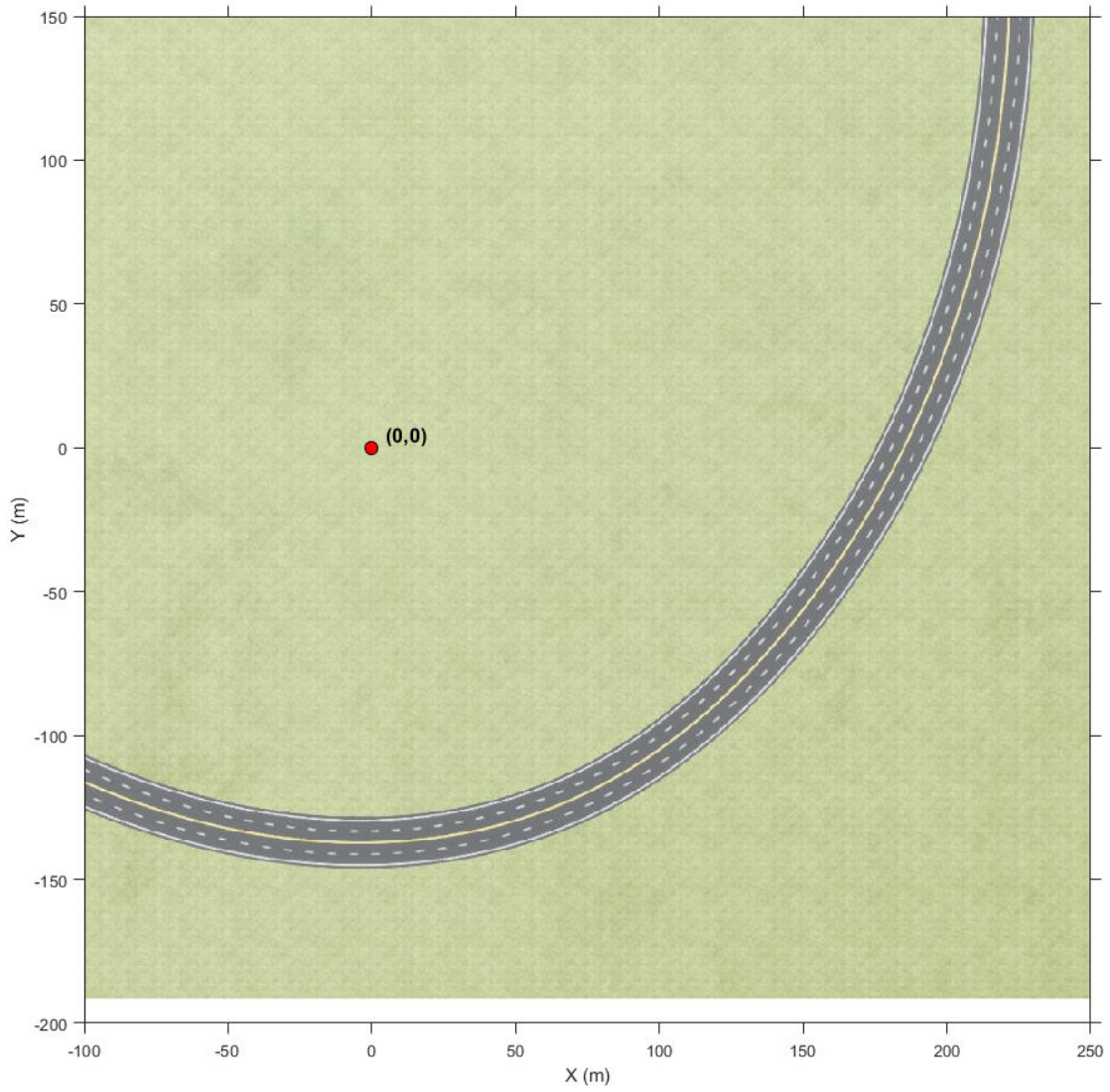
Zoom in on the origin of the scene. Place a marker at the origin.

```
xlim([-100 250])  
ylim([-200 150])
```



```
hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 5; % px
text(offset,offset,'(0,0)','Color','k','FontWeight','bold','FontSize',12)
hold off
```

5 Scene Dimensions



See Also

Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | Straight Road | US City Block | US Highway | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

Double Lane Change

Double lane change 3D environment

Description

The **Double Lane Change** scene is a 3D environment of a straight road containing cones, traffic signs, and barrels. The cones are set up for a vehicle to perform a double lane change maneuver. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to Double lane change.

Explore Double Lane Change Scene

Explore the 3D Double Lane Change scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.DoubleLaneChange

spatialRef =
  imref2d with properties:

        XWorldLimits: [-130.5500 783.3500]
        YWorldLimits: [-456.1500 457.7500]
        ImageSize: [4845 4845]
        PixelExtentInWorldX: 0.1886
        PixelExtentInWorldY: 0.1886
        ImageExtentInWorldX: 913.9000
        ImageExtentInWorldY: 913.9000
        XIntrinsicLimits: [0.5000 4.8455e+03]
        YIntrinsicLimits: [0.5000 4.8455e+03]
```

Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

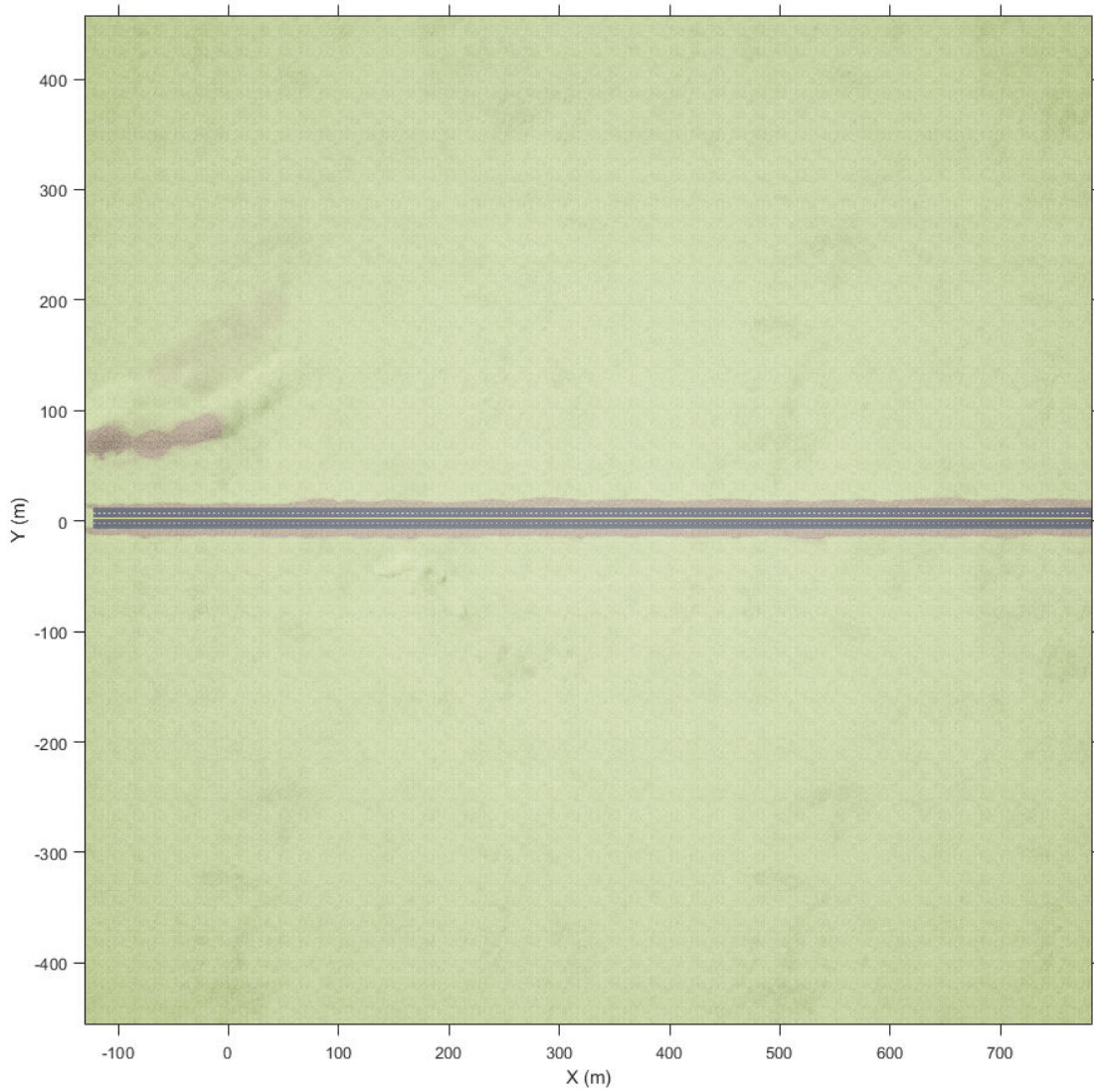
By default, the `imshow` function displays *Y*-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the *Y*-direction to `'normal'` so that *Y*-axis values increase from bottom to top.

The image displays only the area of the scene containing the parking lot. The full scene has a length and width of 2016 meters.

```
figure
fileName = 'sim3d_DoubleLaneChange.jpg';
I = imshow(fileName,spatialRef);
```

5 Scene Dimensions

```
set(gca, 'YDir', 'normal')  
xlabel('X (m)')  
ylabel('Y (m)')
```

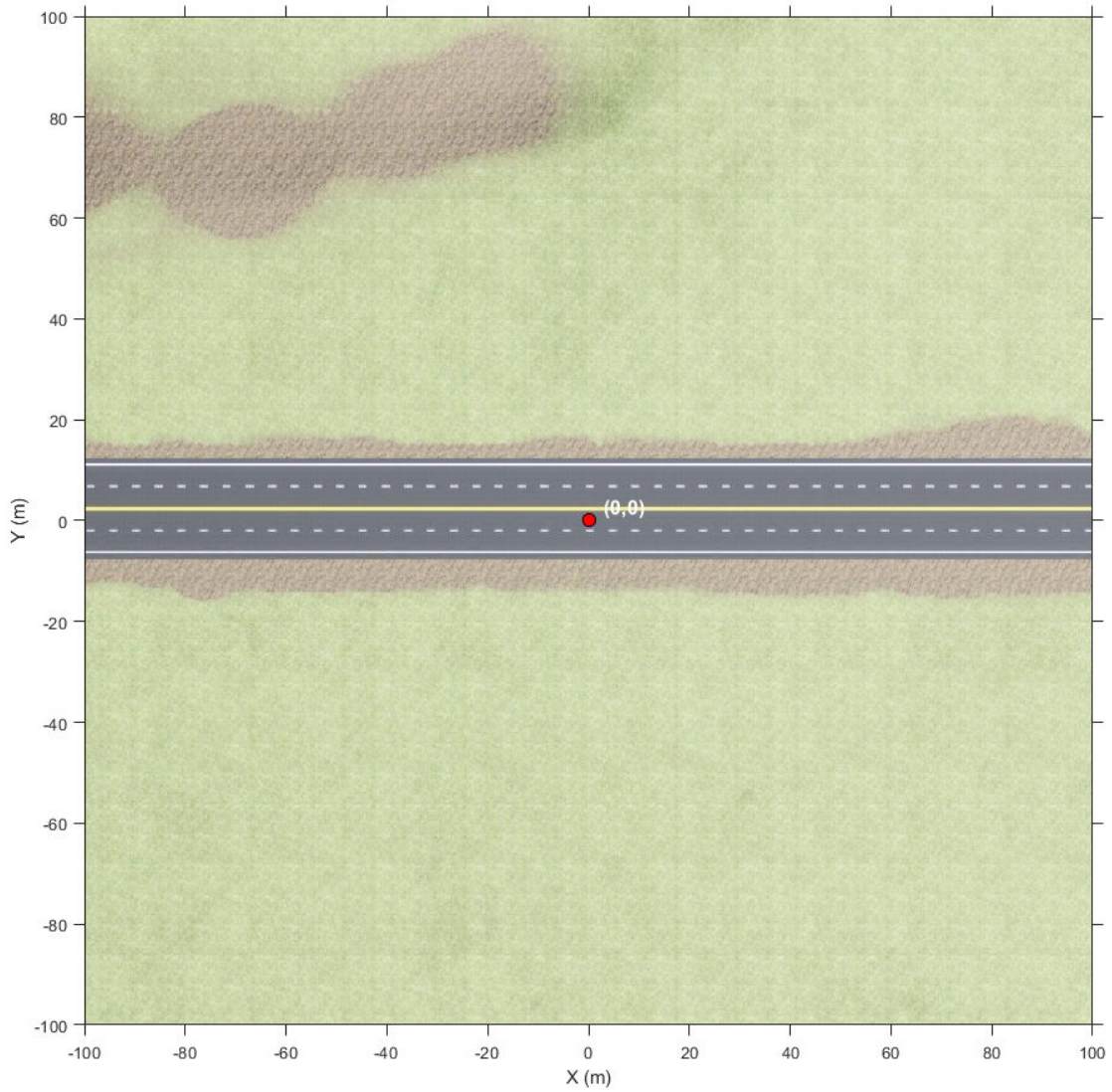


Zoom in on the origin of the scene. Place a marker at the origin. If you place a vehicle at the scene origin and set the vehicle's yaw angle to θ , the traffic cones for performing the double lane change maneuver are directly in front of the vehicle.

```
xlim([-100 100])
ylim([-100 100])

hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 3; % px
text(offset,offset,'(0,0)','Color','w','FontWeight','bold','FontSize',12)
hold off
```

5 Scene Dimensions



See Also

Curved Road | Large Parking Lot | Open Surface | Parking Lot | Straight Road | US City Block | US Highway | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

Large Parking Lot

Large parking lot 3D environment

Description

The **Large Parking Lot** scene is a 3D environment of a large parking lot that contains cones, curbs, traffic signs, and parked vehicles. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to Large parking lot.

Explore Large Parking Lot Scene

Explore the 3D Large Parking Lot scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.LargeParkingLot

spatialRef =
    imref2d with properties:

        XWorldLimits: [-78.5000 61.5000]
        YWorldLimits: [-75 65]
        ImageSize: [4845 4845]
        PixelExtentInWorldX: 0.0289
        PixelExtentInWorldY: 0.0289
        ImageExtentInWorldX: 140
        ImageExtentInWorldY: 140
        XIntrinsicLimits: [0.5000 4.8455e+03]
        YIntrinsicLimits: [0.5000 4.8455e+03]
```

Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

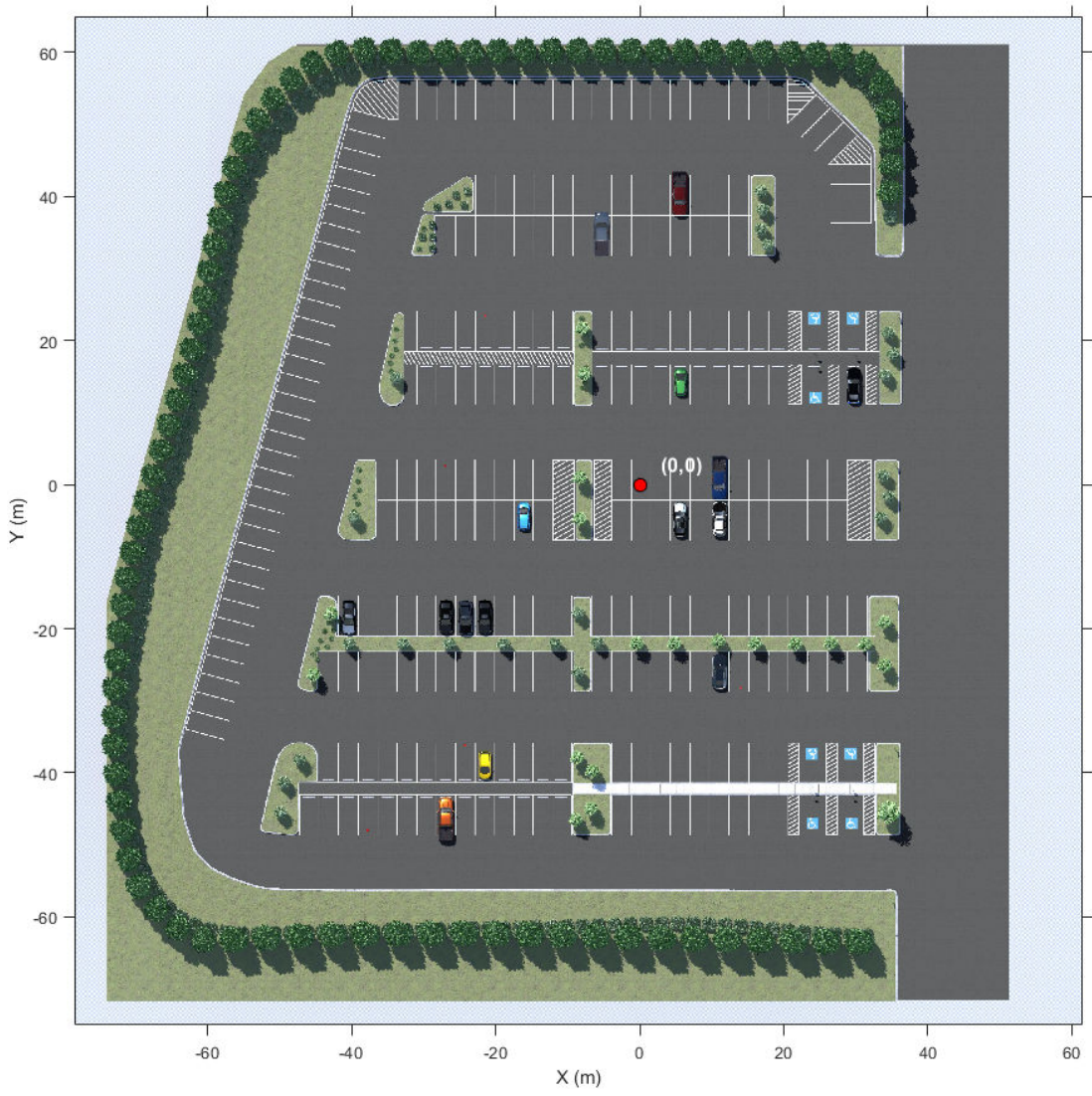
By default, the `imshow` function displays *Y*-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the *Y*-direction to `'normal'` so that *Y*-axis values increase from bottom to top.

Place a marker at the origin of the scene.

```
figure
fileName = 'sim3d_LargeParkingLot.jpg';
I = imshow(fileName,spatialRef);
set(gca,'YDir','normal')
```

```
xlabel('X (m)')
ylabel('Y (m)')

hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 3; % px
text(offset,offset,'(0,0)','Color','w','FontWeight','bold','FontSize',12)
hold off
```



See Also

Curved Road | Double Lane Change | Open Surface | Parking Lot | Straight Road | US City Block | US Highway | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

Open Surface

Open surface 3D environment

Description

The **Open Surface** scene contains a 3D environment of an open, black road surface. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to Open surface.

Explore Open Surface Scene

Explore the 3D Open Surface scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');  
spatialRef = data.spatialReference.OpenSurface
```

```
spatialRef =  
    imref2d with properties:  
  
        XWorldLimits: [-130.5500 894.4500]  
        YWorldLimits: [-567.2500 457.7500]  
        ImageSize: [4845 4845]  
        PixelExtentInWorldX: 0.2116  
        PixelExtentInWorldY: 0.2116  
        ImageExtentInWorldX: 1025  
        ImageExtentInWorldY: 1025  
        XIntrinsicLimits: [0.5000 4.8455e+03]  
        YIntrinsicLimits: [0.5000 4.8455e+03]
```

Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

By default, the `imshow` function displays *Y*-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the *Y*-direction to `'normal'` so that *Y*-axis values increase from bottom to top.

Place a marker at the origin of the scene.

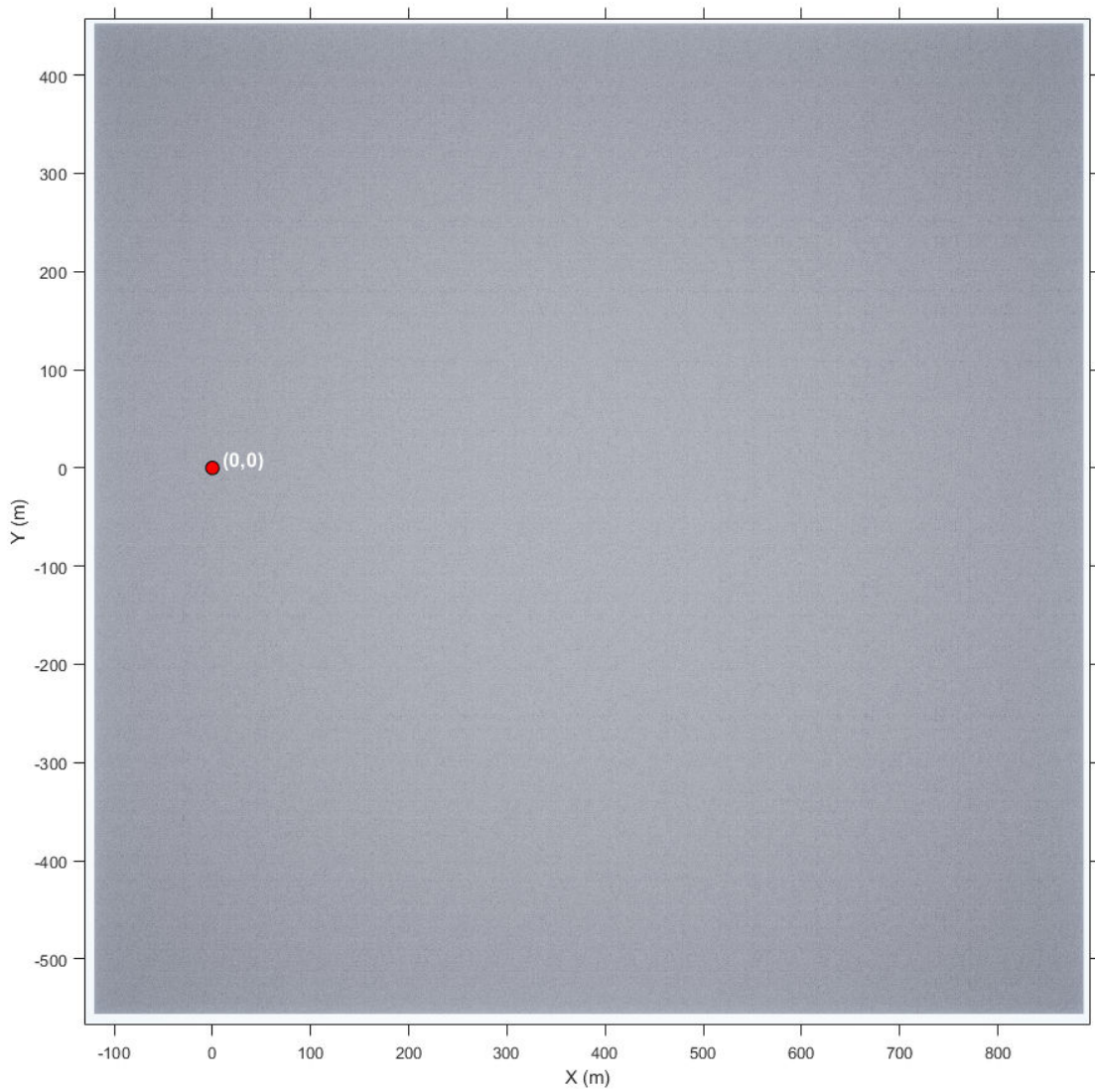
```
figure  
fileName = 'sim3d_OpenSurface.jpg';  
I = imshow(fileName,spatialRef);  
set(gca,'YDir','normal')
```



```
xlabel('X (m)')
ylabel('Y (m)')

hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 10; % px
text(offset,offset,'(0,0)','Color','w','FontWeight','bold','FontSize',12)
hold off
```

5 Scene Dimensions



See Also

Curved Road | Double Lane Change | Large Parking Lot | Parking Lot | Straight Road | US City Block | US Highway | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

Parking Lot

Parking lot 3D environment

Description

The **Parking Lot** scene is a 3D environment of a parking lot. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to Parking lot.

Explore Parking Lot Scene

Explore the 3D Parking Lot scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.ParkingLot
```

```
spatialRef =
  imref2d with properties:
```

```
    XWorldLimits: [-195.5000  8.9000]
    YWorldLimits: [-27.1000 177.3000]
    ImageSize: [4845 4845]
PixelExtentInWorldX: 0.0422
PixelExtentInWorldY: 0.0422
ImageExtentInWorldX: 204.4000
ImageExtentInWorldY: 204.4000
  XIntrinsicLimits: [0.5000 4.8455e+03]
  YIntrinsicLimits: [0.5000 4.8455e+03]
```

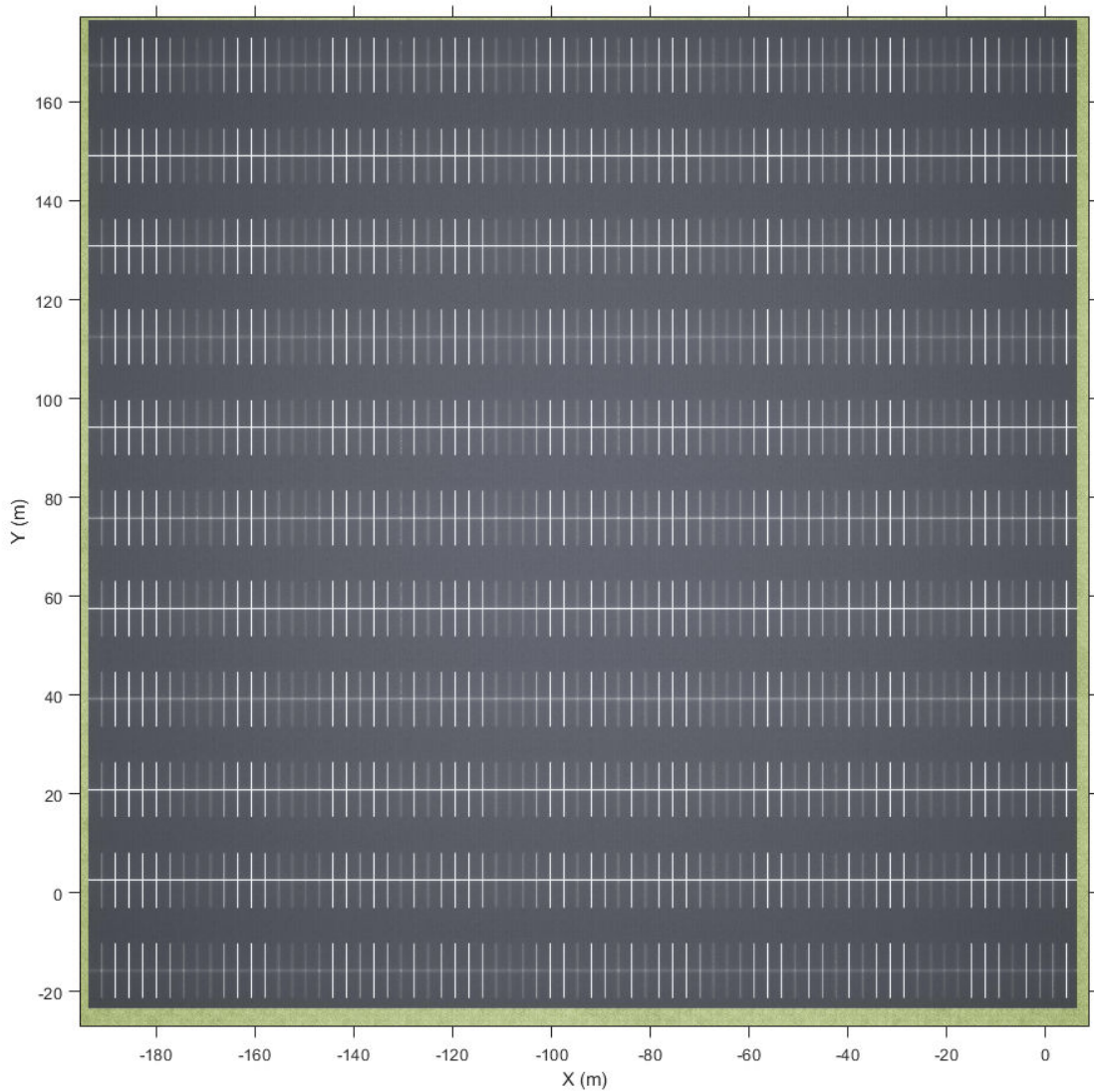
Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

By default, the `imshow` function displays Y-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the Y-direction to `'normal'` so that Y-axis values increase from bottom to top.

The image displays only the area of the scene containing the parking lot. The full scene has a length and width of 705.6 meters.

```
figure
fileName = 'sim3d_ParkingLot.jpg';
I = imshow(fileName,spatialRef);
set(gca,'YDir','normal')
xlabel('X (m)')
ylabel('Y (m)')
```

5 Scene Dimensions

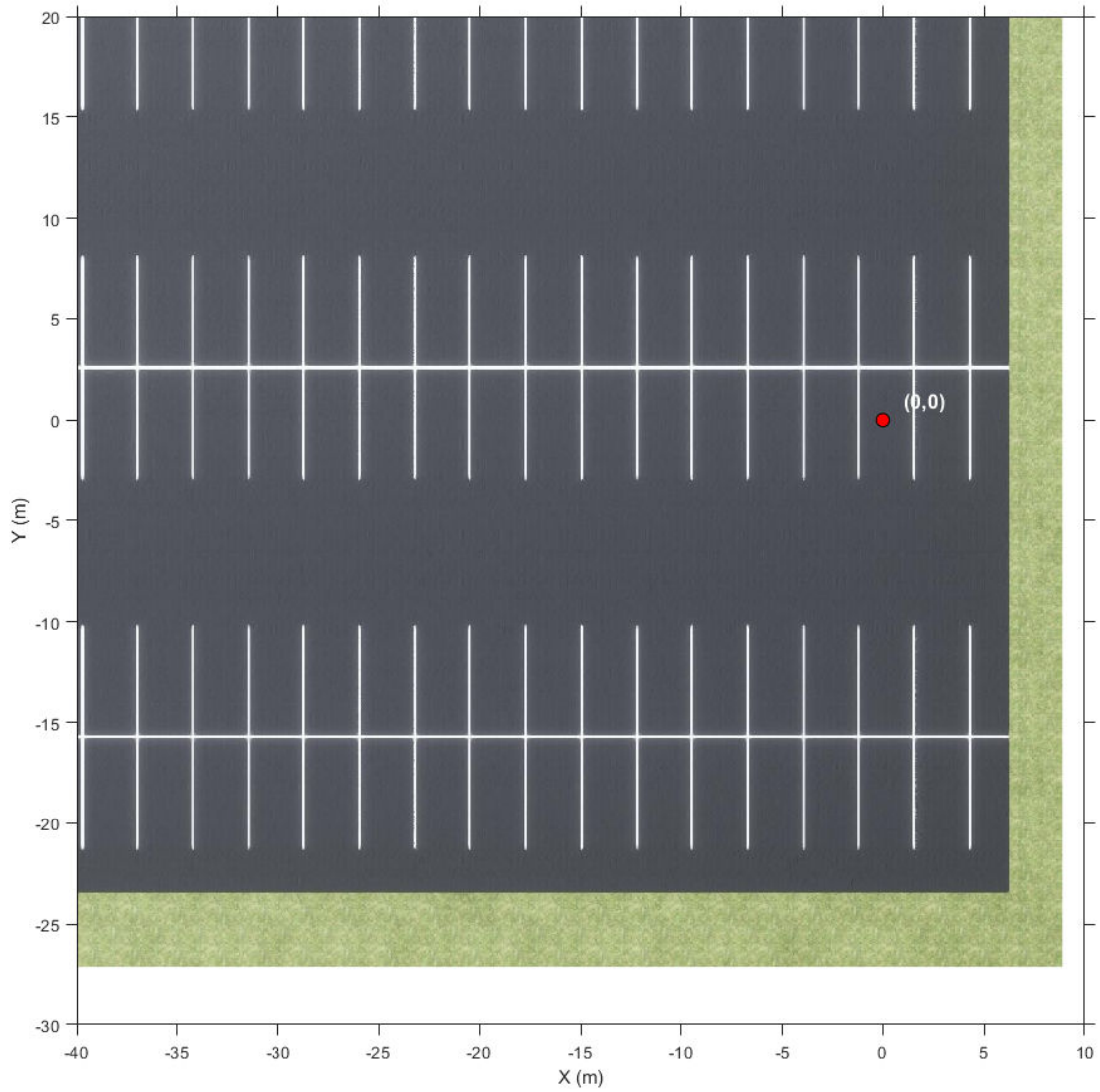


Zoom in on the origin of the scene. Place a marker at the origin.

```
xlim([-40 10])  
ylim([-30 20])
```

```
hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 1; % px
text(offset,offset,'(0,0)','Color','w','FontWeight','bold','FontSize',12)
hold off
```

5 Scene Dimensions



See Also

Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Straight Road | US City Block | US Highway | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems in Automated Driving Toolbox”

Straight Road

Straight road 3D environment

Description

The **Straight Road** scene is a 3D environment of a straight four-lane divided highway. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to `Straight road`.

Explore Straight Road Scene

Explore the 3D Straight Road scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.StraightRoad

spatialRef =
    imref2d with properties:

        XWorldLimits: [-130.5500 783.3500]
        YWorldLimits: [-456.1500 457.7500]
        ImageSize: [4845 4845]
        PixelExtentInWorldX: 0.1886
        PixelExtentInWorldY: 0.1886
        ImageExtentInWorldX: 913.9000
        ImageExtentInWorldY: 913.9000
        XIntrinsicLimits: [0.5000 4.8455e+03]
        YIntrinsicLimits: [0.5000 4.8455e+03]
```

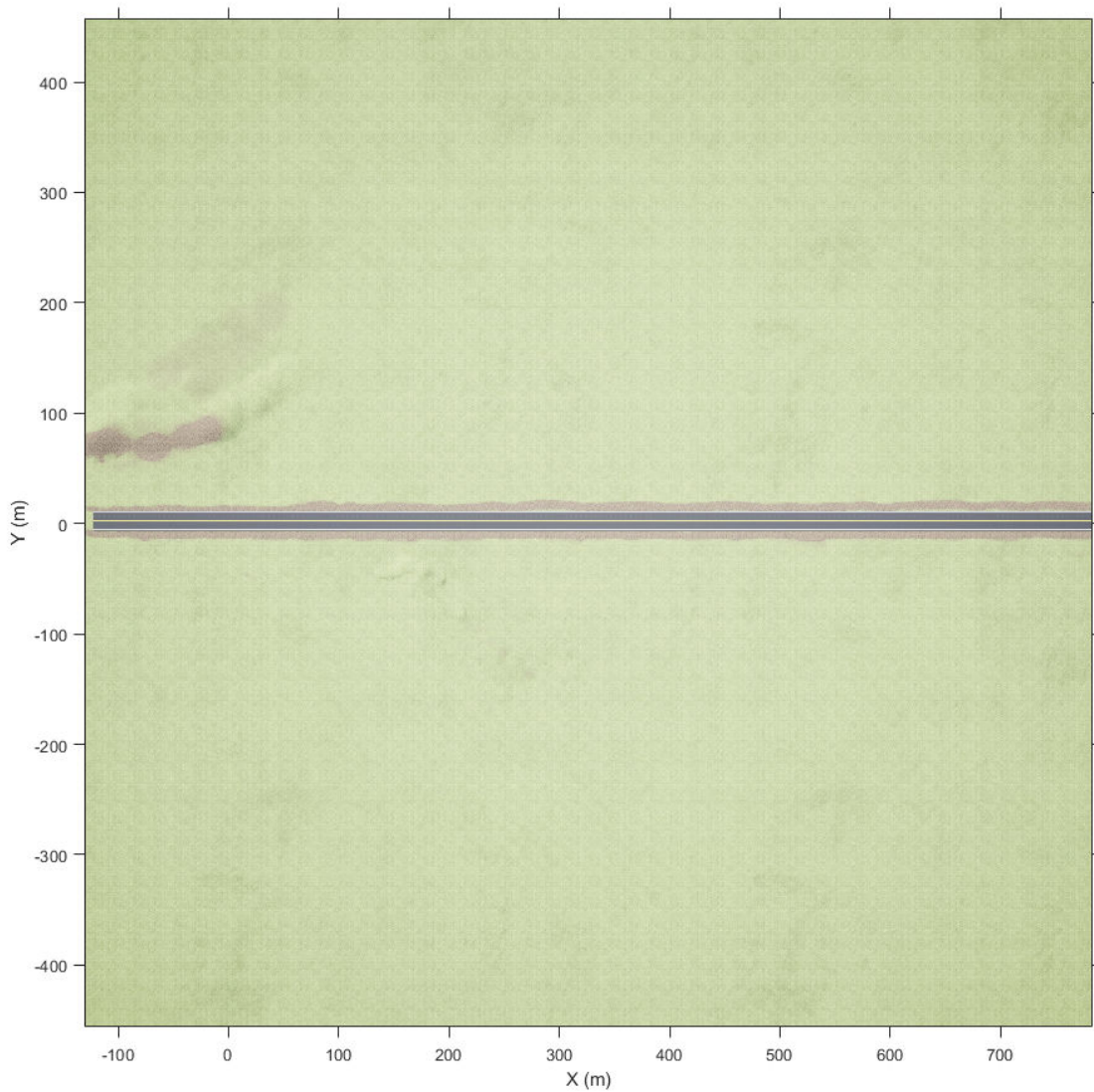
Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

By default, the `imshow` function displays Y-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the Y-direction to `'normal'` so that Y-axis values increase from bottom to top.

The image displays only the area of the scene containing the straight road. The full scene has a length and width of 2016 meters.

```
figure
fileName = 'sim3d_StraightRoad.jpg';
I = imshow(fileName,spatialRef);
set(gca,'YDir','normal')
xlabel('X (m)')
ylabel('Y (m)')
```

5 Scene Dimensions

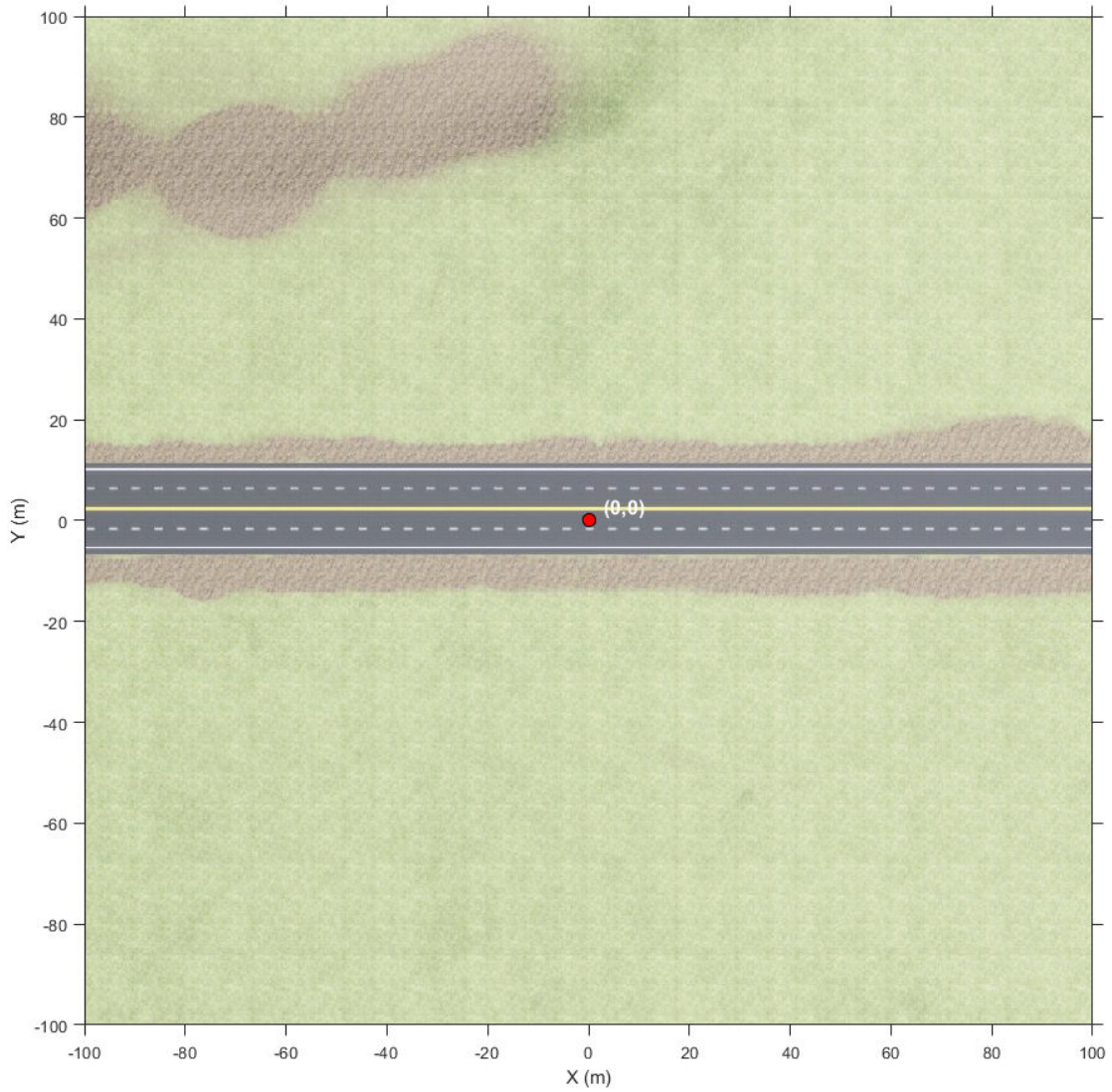


Zoom in on the origin of the scene. Place a marker at the origin.

```
xlim([-100 100])  
ylim([-100 100])
```

```
hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 3; % px
text(offset,offset,'(0,0)','Color','w','FontWeight','bold','FontSize',12)
hold off
```

5 Scene Dimensions



See Also

Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | US City Block | US Highway | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

US City Block

US city block 3D environment

Description

The **US City Block** scene is a 3D environment of a US city block that contains 15 intersections. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to US city block.

Explore US City Block Scene

Explore the 3D US City Block scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.USCityBlock
```

```
spatialRef =
  imref2d with properties:
      XWorldLimits: [-243.0500 200.2500]
      YWorldLimits: [-215.6500 227.6500]
      ImageSize: [4845 4845]
      PixelExtentInWorldX: 0.0915
      PixelExtentInWorldY: 0.0915
      ImageExtentInWorldX: 443.3000
      ImageExtentInWorldY: 443.3000
      XIntrinsicLimits: [0.5000 4.8455e+03]
      YIntrinsicLimits: [0.5000 4.8455e+03]
```

Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

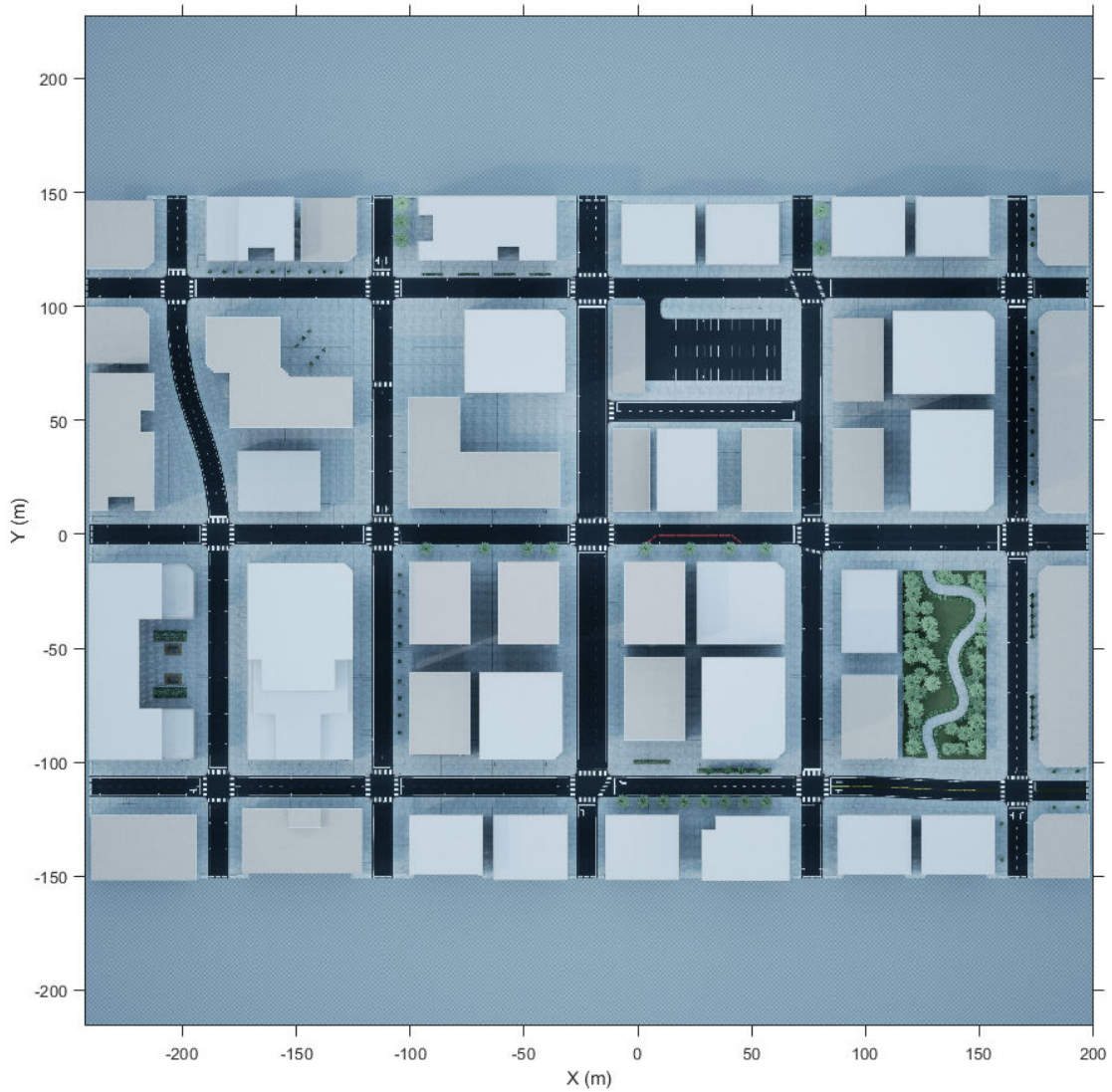
By default, the `imshow` function displays *Y*-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the *Y*-direction to `'normal'` so that *Y*-axis values increase from bottom to top.

The image displays only the area of the scene containing the city block. The full scene has a length and width of 2040 meters.

```
figure
fileName = 'sim3d_USCityBlock.jpg';
I = imshow(fileName,spatialRef);
```

5 Scene Dimensions

```
set(gca,'YDir','normal')  
xlabel('X (m)')  
ylabel('Y (m)')
```

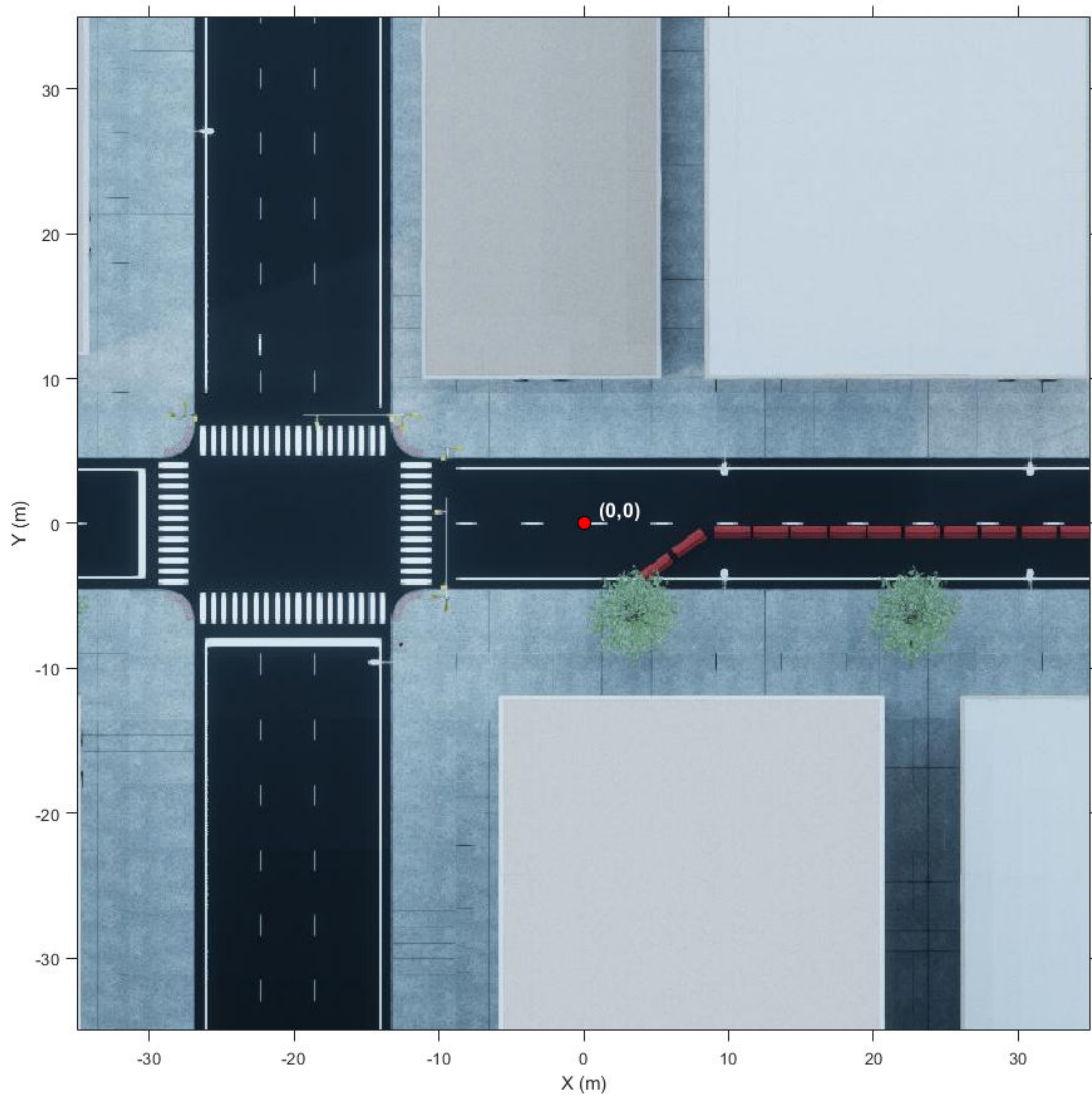


Zoom in on the origin of the scene. Place a marker at the origin.

```
xlim([-35 35])
ylim([-35 35])

hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 1; % px
text(offset,offset,'(0,0)','Color','w','FontWeight','bold','FontSize',12)
hold off
```

5 Scene Dimensions



See Also

Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | Straight Road | US Highway | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

US Highway

US highway 3D environment

Description

The **US Highway** scene is a 3D environment of a US highway that contains barriers, cones, and traffic signs. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to US highway.

Explore US Highway Scene

Explore the 3D US Highway scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.USHighway

spatialRef =
    imref2d with properties:

        XWorldLimits: [2.8218e+03 5.0868e+03]
        YWorldLimits: [-3.7469e+03 -1.4820e+03]
        ImageSize: [5585 5585]
        PixelExtentInWorldX: 0.4055
        PixelExtentInWorldY: 0.4055
        ImageExtentInWorldX: 2.2649e+03
        ImageExtentInWorldY: 2.2649e+03
        XIntrinsicLimits: [0.5000 5.5855e+03]
        YIntrinsicLimits: [0.5000 5.5855e+03]
```

Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

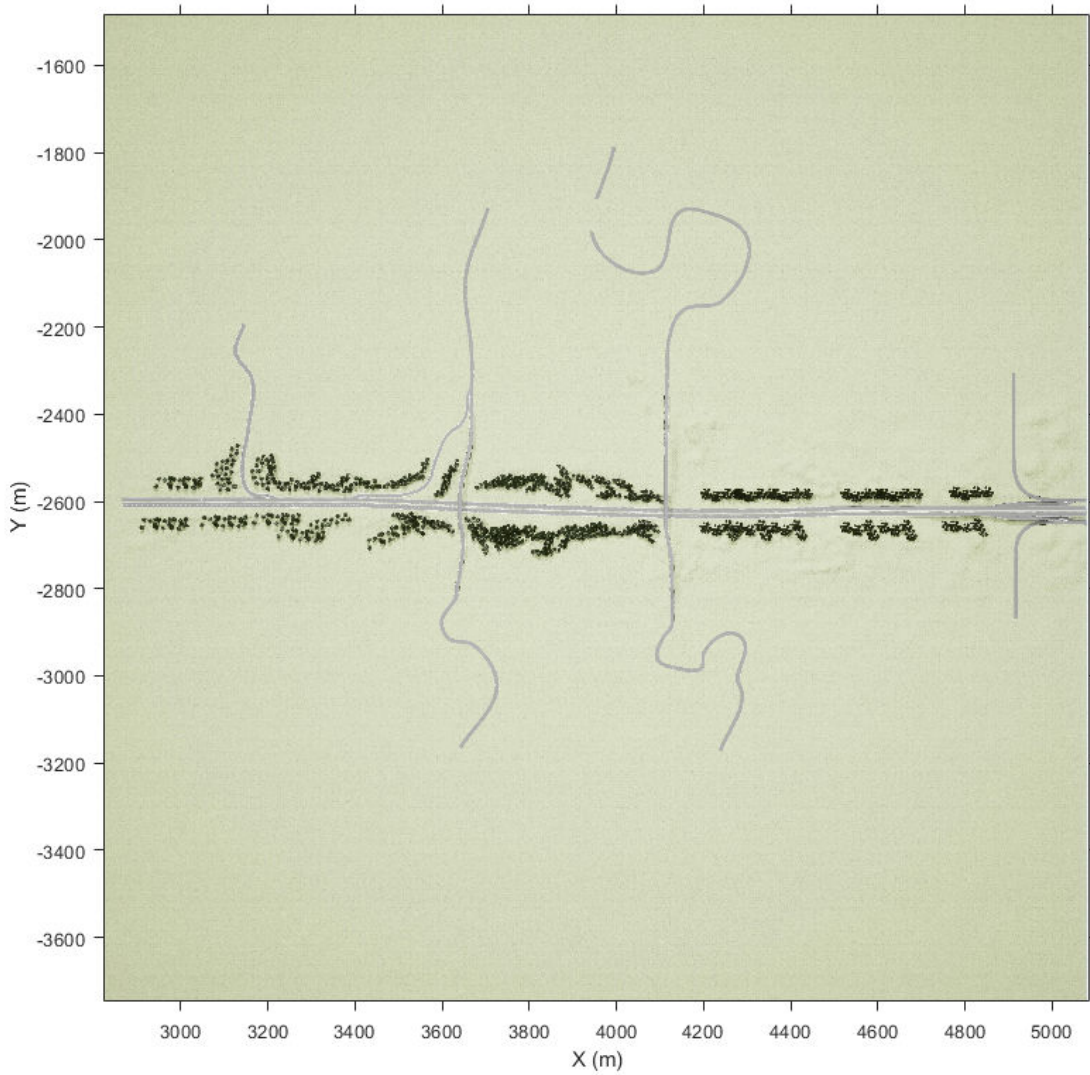
By default, the `imshow` function displays Y-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the Y-direction to `'normal'` so that Y-axis values increase from bottom to top.

The image displays only the area of the scene containing the highway. The full scene has a length and width of 10,160 meters. The origin of the scene is outside the range of the displayed image.

```
figure
fileName = 'sim3d_USHighway.jpg';
```

5 Scene Dimensions

```
I = imshow(fileName,spatialRef);  
set(gca,'YDir','normal')  
xlabel('X (m)')  
ylabel('Y (m)')
```



See Also

Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | Straight Road | US City Block | Virtual Mcity

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

Virtual Mcity

Virtual Mcity 3D environment

Description

The **Virtual Mcity** scene is a 3D environment containing a virtual representation of Mcity®, which is a testing ground belonging to the University of Michigan. For more details, see Mcity Test Facility.

The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving algorithm within this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene description** parameter to `Virtual Mcity`.

Explore Virtual Mcity Scene

Explore the 3D Virtual Mcity scene and inspect its dimensions by using a corresponding 2D top-view image of the scene.

You can use this image to inspect the scene before simulation and choose starting coordinates for vehicles. For details on using these images to select waypoints for path-following applications, see the “Select Waypoints for 3D Simulation” example.

Load the 2D spatial referencing object that corresponds to the scene. This `imref2d` object describes the relationship between the pixels in the image and the world coordinates of the scene.

```
data = load('sim3d_SpatialReferences.mat');
spatialRef = data.spatialReference.VirtualMcity
```

```
spatialRef =
  imref2d with properties:
```

```

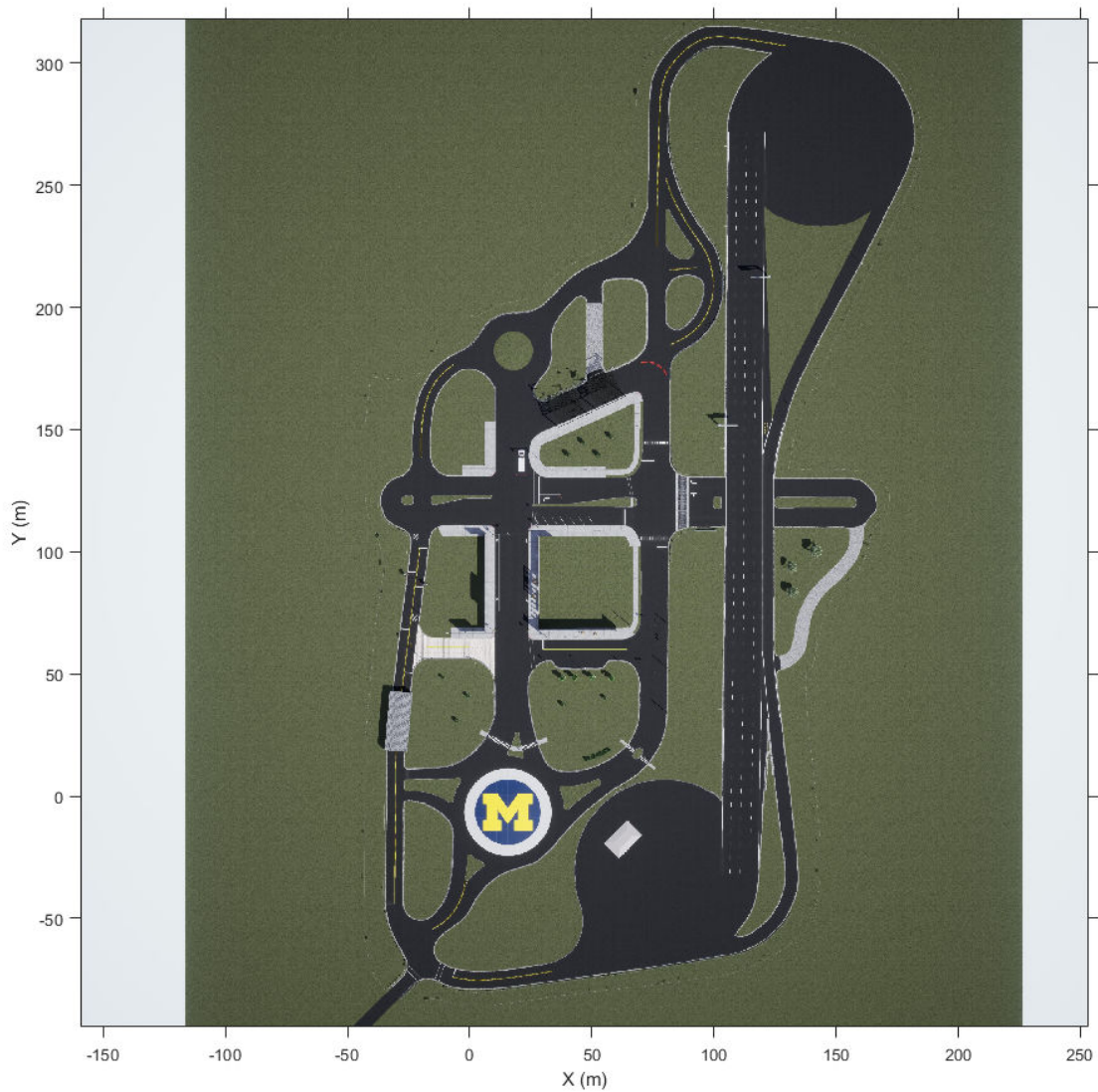
    XWorldLimits: [-159.3500 253.3500]
    YWorldLimits: [-94.4500 318.2500]
      ImageSize: [4845 4845]
PixelExtentInWorldX: 0.0852
PixelExtentInWorldY: 0.0852
ImageExtentInWorldX: 412.7000
ImageExtentInWorldY: 412.7000
  XIntrinsicLimits: [0.5000 4.8455e+03]
  YIntrinsicLimits: [0.5000 4.8455e+03]
```

Display the image corresponding to the scene. Use the spatial referencing object to display the axes in the world coordinates of the scene. Units are in meters.

By default, the `imshow` function displays Y-axis values that increase from top to bottom. To align with the Automated Driving Toolbox™ world coordinate system, set the Y-direction to `'normal'` so that Y-axis values increase from bottom to top.

The image displays only the area of the scene containing the city. The full scene has a length of 541.44 meters and a width of 342.98 meters.

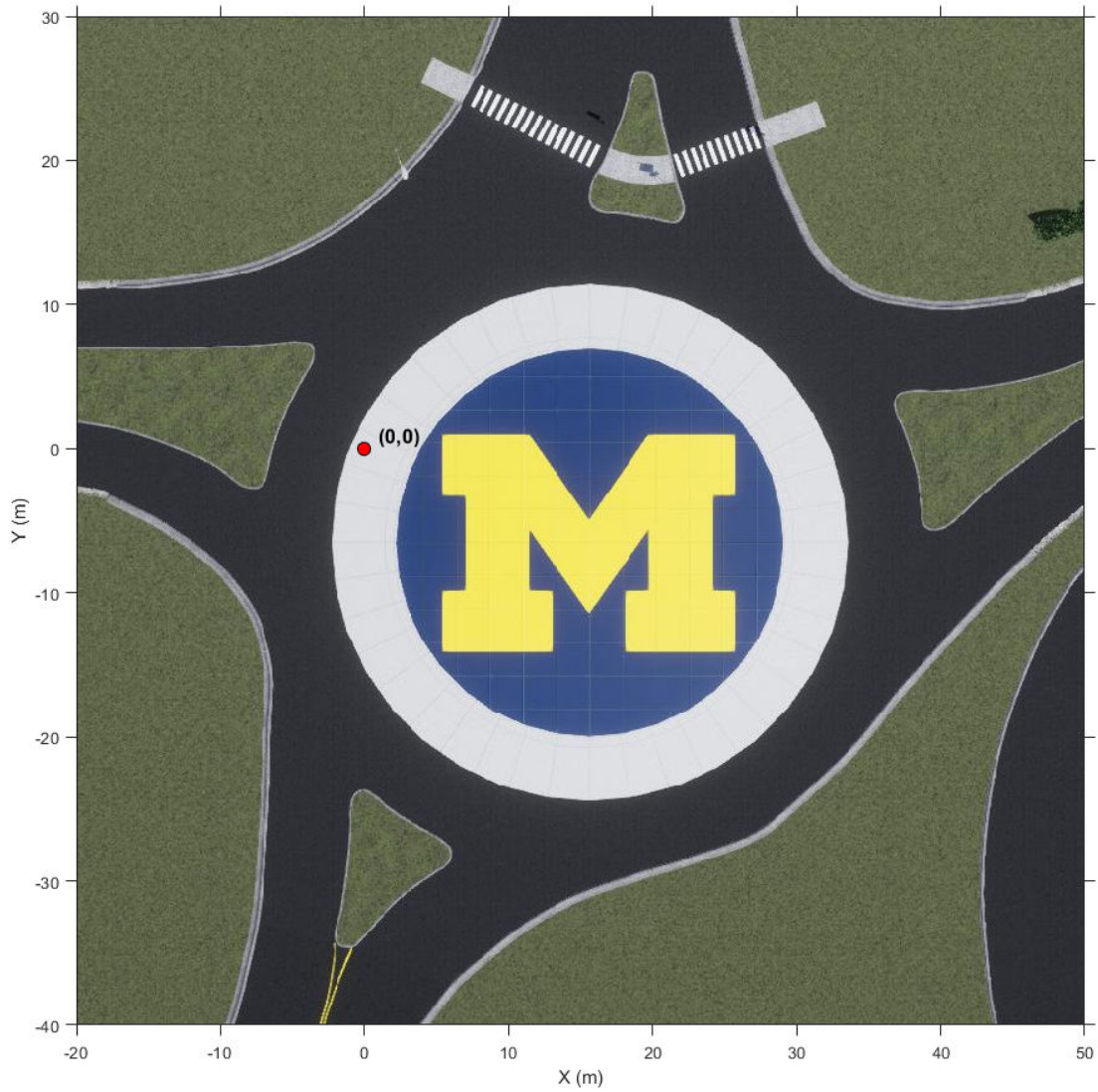
```
figure
fileName = 'sim3d_VirtualMcity.jpg';
I = imshow(fileName,spatialRef);
set(gca,'YDir','normal')
xlabel('X (m)')
ylabel('Y (m)')
```



Zoom in on the origin of the scene. Place a marker at the origin.

```
xlim([-20 50])  
ylim([-40 30])
```

```
hold on
plot(0,0,'o','MarkerFaceColor','r','MarkerEdgeColor','k','MarkerSize',8)
offset = 1; % px
text(offset,offset,'(0,0)','Color','k','FontWeight','bold','FontSize',12)
hold off
```



See Also

Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | Straight Road | US City Block | US Highway

Topics

“3D Simulation for Automated Driving”

“3D Simulation Environment Requirements and Limitations”

“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

External Websites

Mcity Test Facility

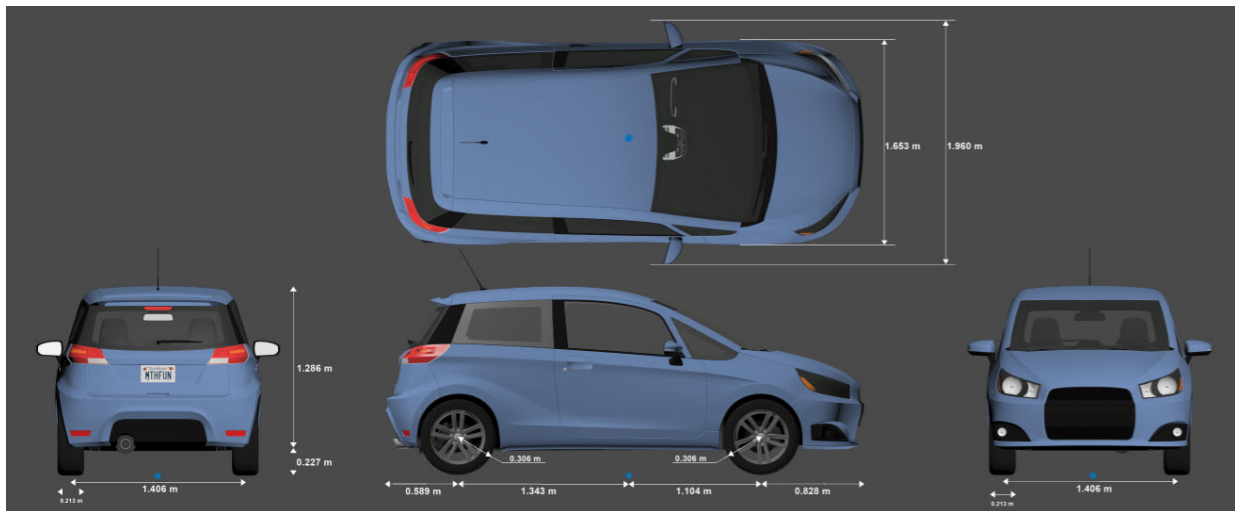
Vehicle Dimensions

Hatchback

Hatchback vehicle dimensions

Description

Hatchback is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

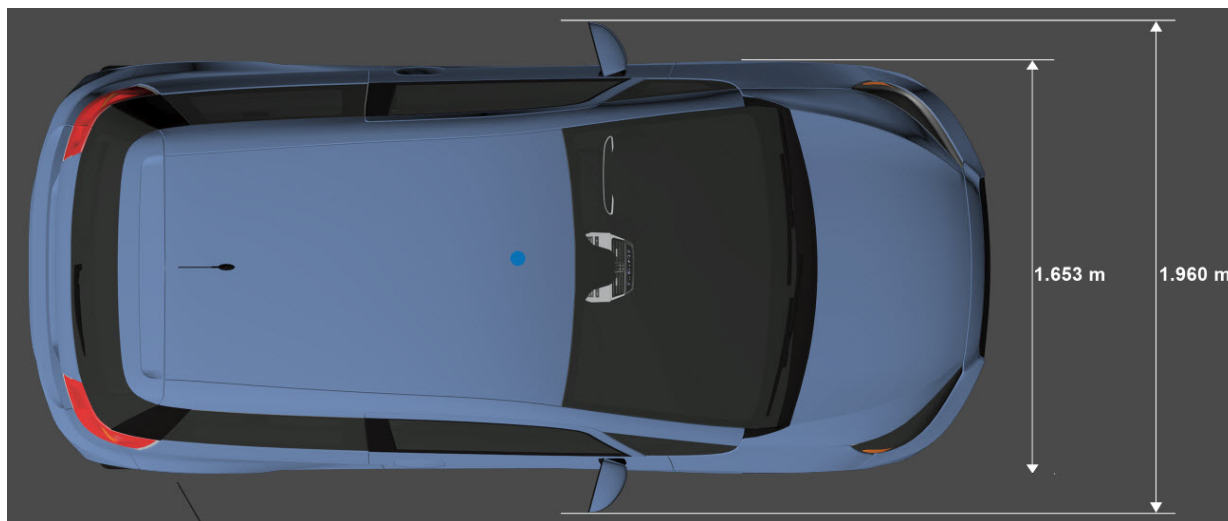


To add this type of vehicle to the 3D simulation environment:

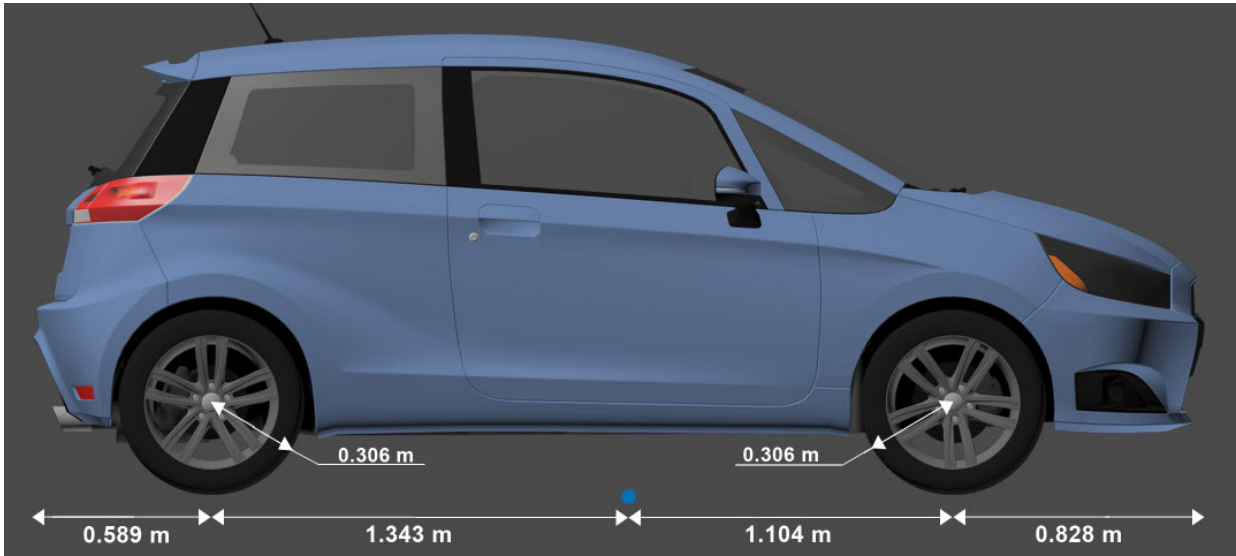
- 1 Add a Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In this block, set the **Type** parameter to Hatchback.

Dimensions

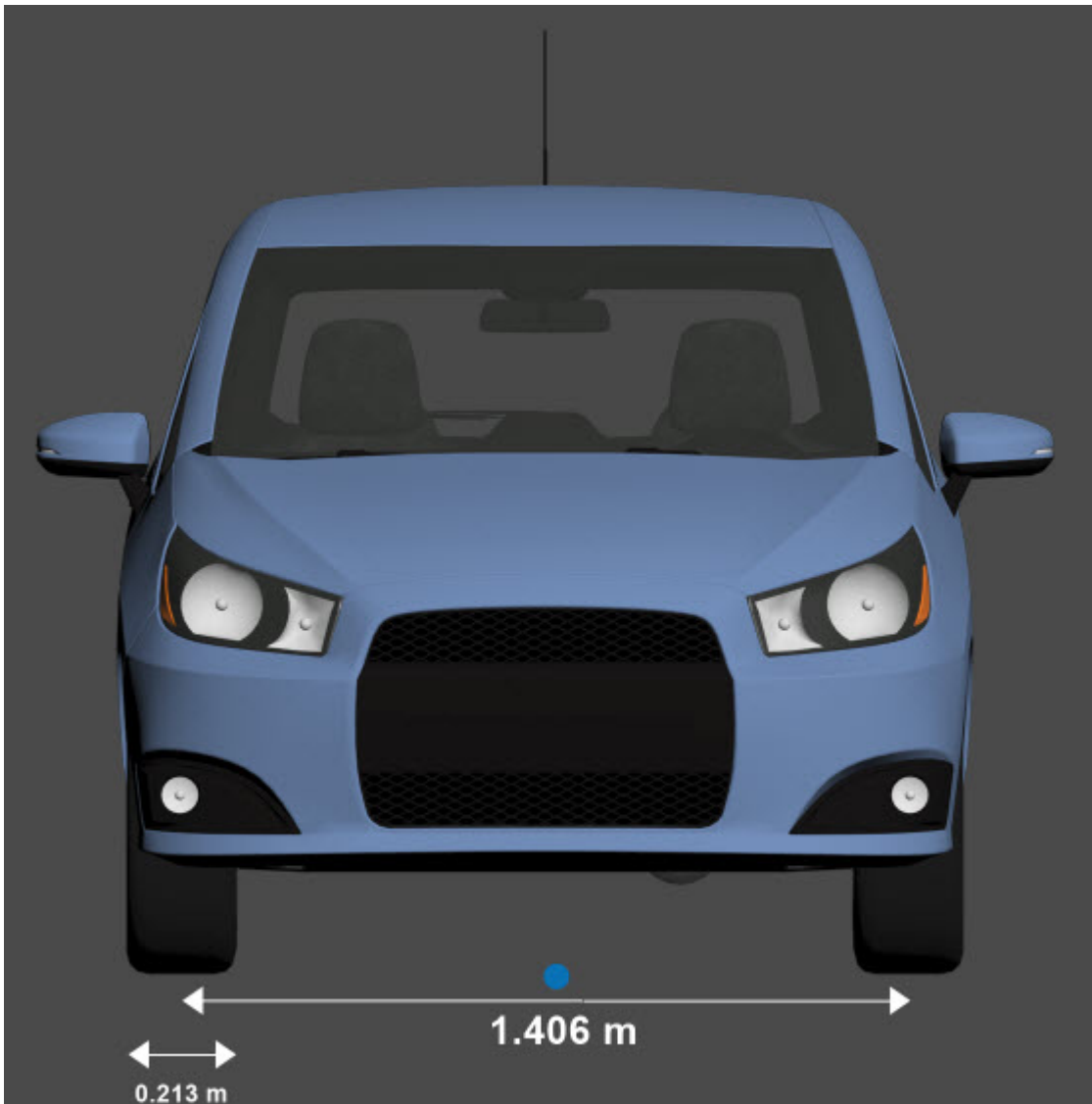
Top-down view – Vehicle width dimensions
diagram



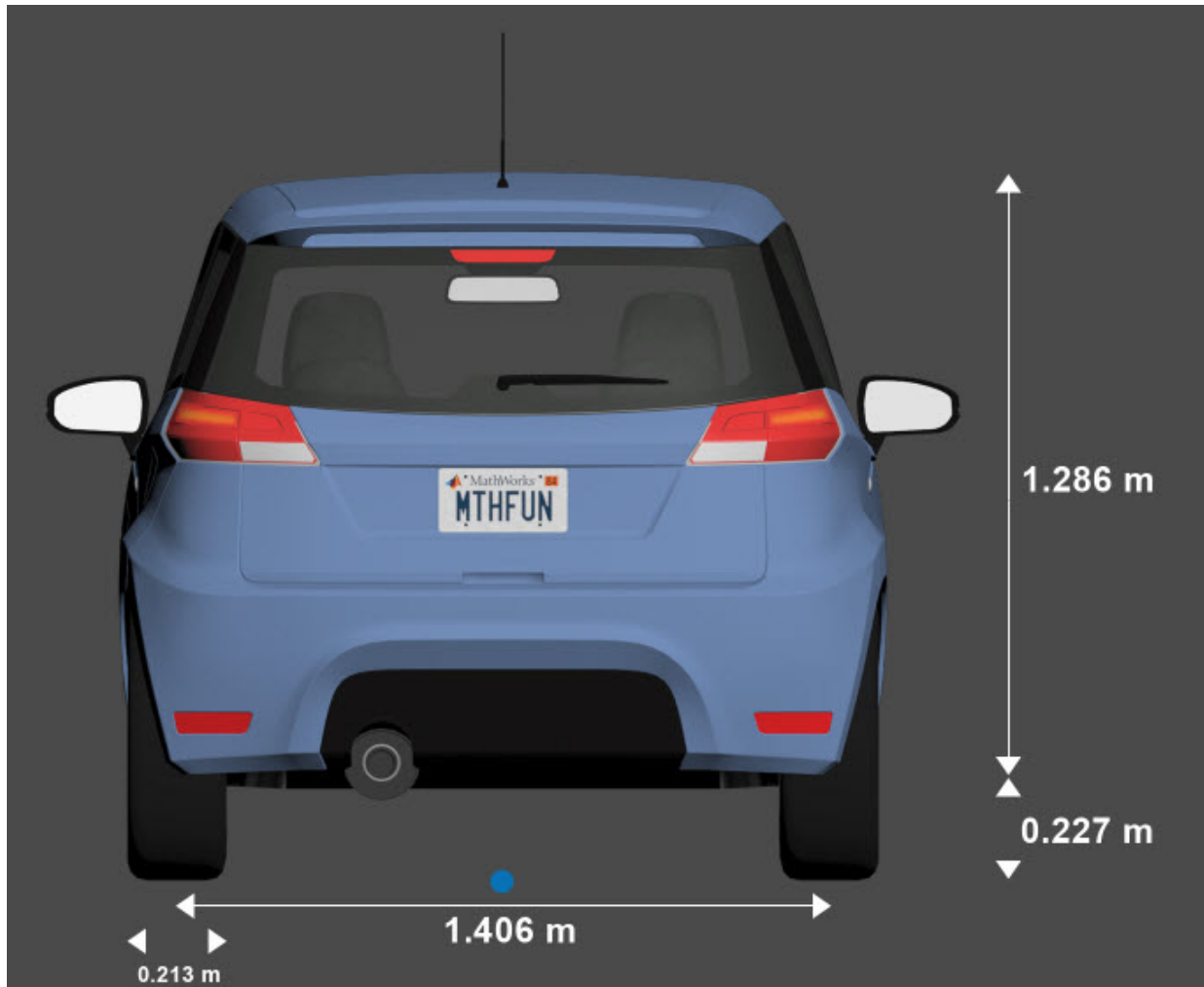
Side view – Vehicle length, front overhang, and rear overhang dimensions
diagram



Front view – Tire width and front axle dimensions
diagram



Rear view – Vehicle height and rear axle dimensions
diagram



Specify Hatchback Vehicle Dimensions

When simulating a path planner in the 3D environment, the path planner must use a vehicle whose dimensions are consistent with one used in the 3D environment. To make these dimensions consistent, you can use a `vehicleDimensions` object.

Specify the dimensions of a Hatchback vehicle in a `vehicleDimensions` object. Units are in meters. For an example that uses this object in a path planner, see “Visualize Automated Parking Valet Using 3D Simulation”.

```
centerToFront = 1.104;
centerToRear  = 1.343;
frontOverhang = 0.828;
rearOverhang  = 0.589;
vehicleWidth  = 1.653;
vehicleHeight = 1.513;
vehicleLength = centerToFront + centerToRear + frontOverhang + rearOverhang;

hatchbackDims = vehicleDimensions(vehicleLength,vehicleWidth,vehicleHeight, ...
    'FrontOverhang',frontOverhang,'RearOverhang',rearOverhang)

hatchbackDims =
    vehicleDimensions with properties:

        Length: 3.8640
         Width: 1.6530
         Height: 1.5130
    Wheelbase: 2.4470
    RearOverhang: 0.5890
    FrontOverhang: 0.8280
    WorldUnits: 'meters'
```

See Also

[Muscle Car](#) | [Sedan](#) | [Small Pickup Truck](#) | [Sport Utility Vehicle](#)

Topics

“3D Simulation for Automated Driving”

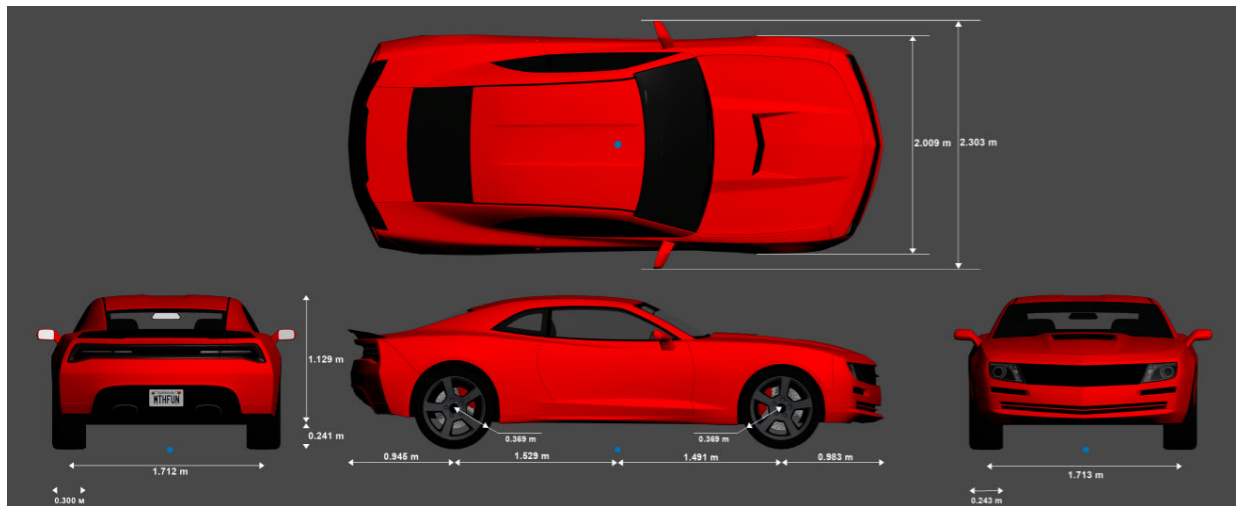
“Coordinate Systems in Automated Driving Toolbox”

Muscle Car

Muscle car vehicle dimensions

Description

Muscle Car is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The following diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

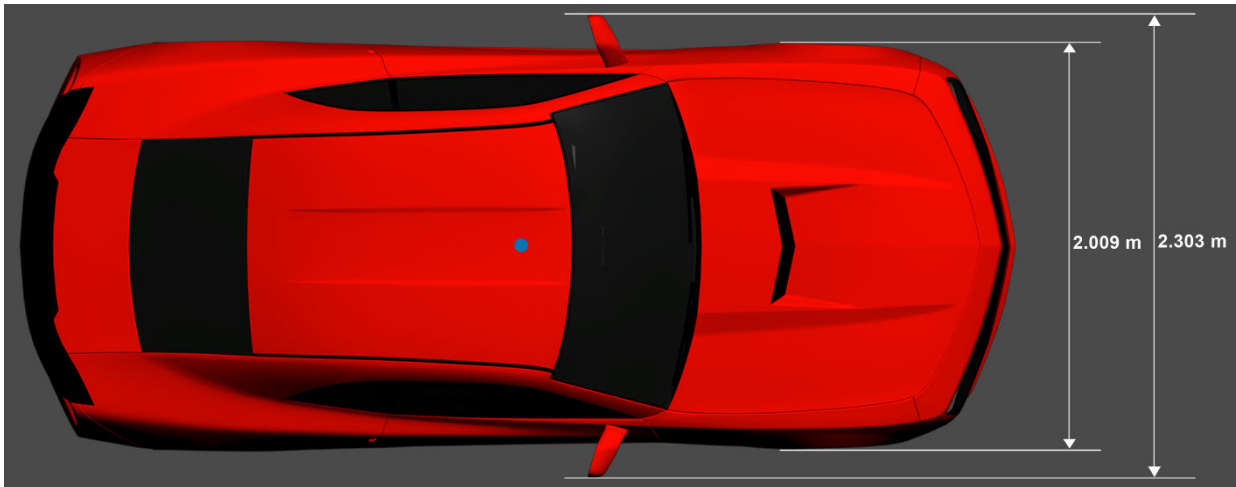


To add this type of vehicle to the 3D simulation environment:

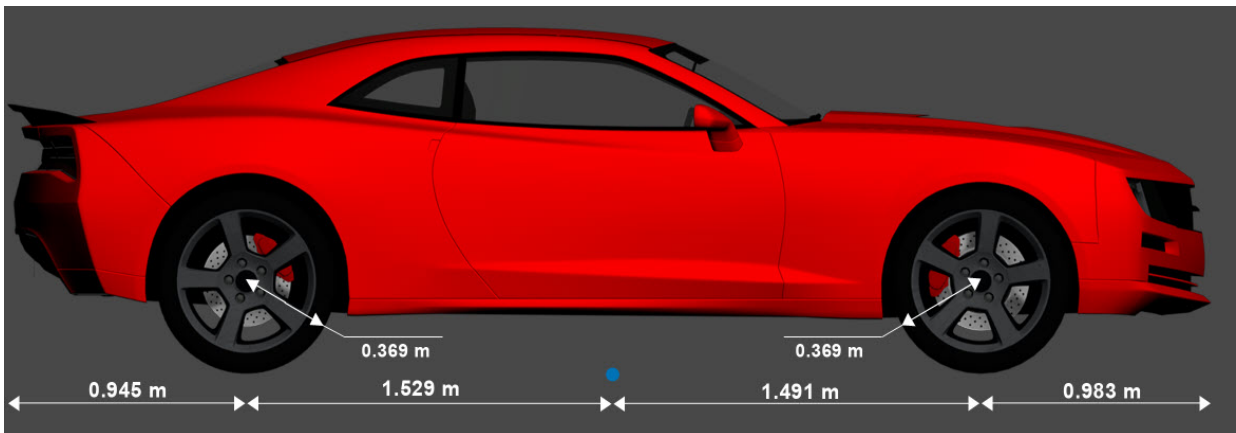
- 1 Add a Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In this block, set the **Type** parameter to **Muscle car**.

Dimensions

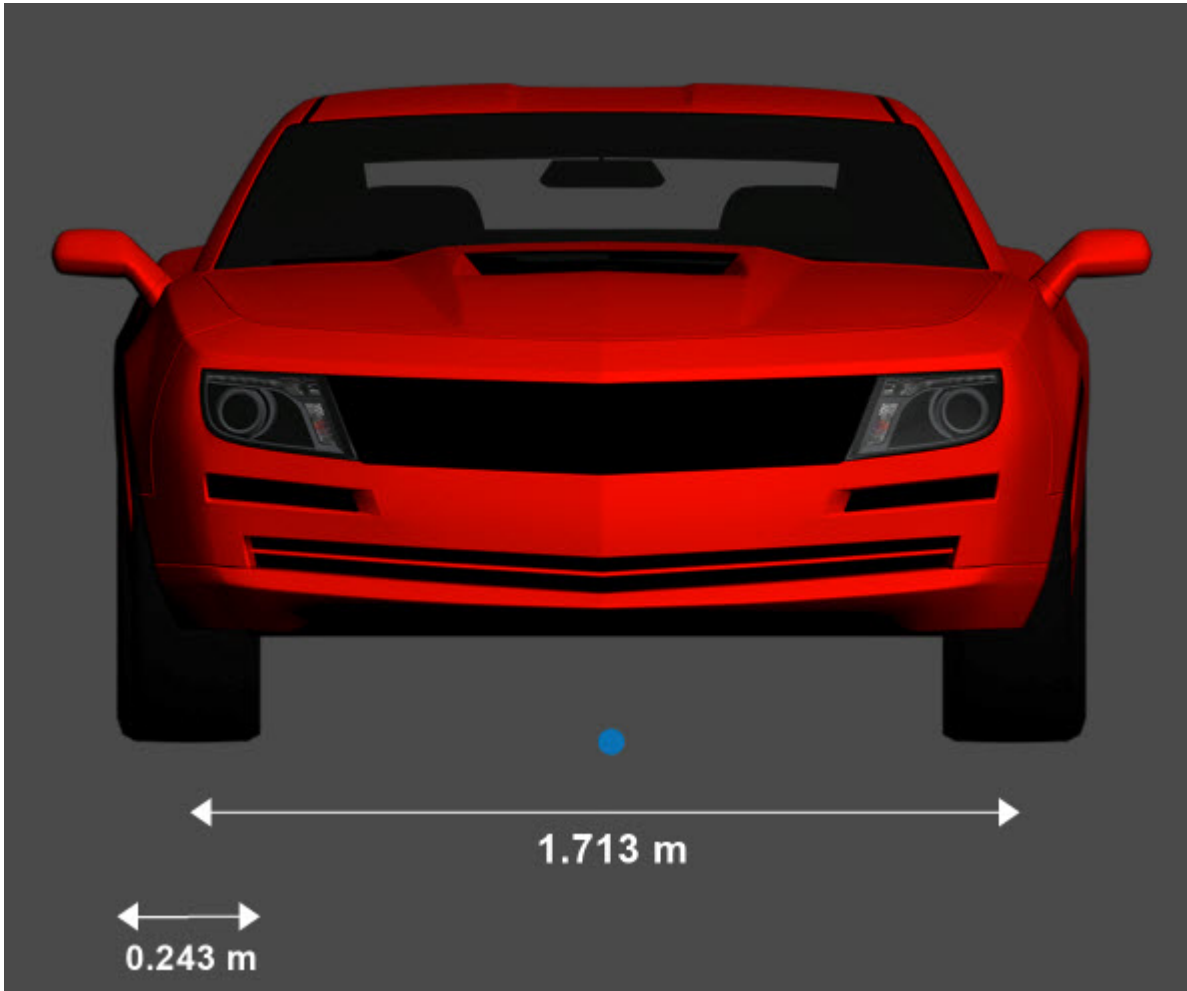
Top-down view – Vehicle width dimensions
diagram



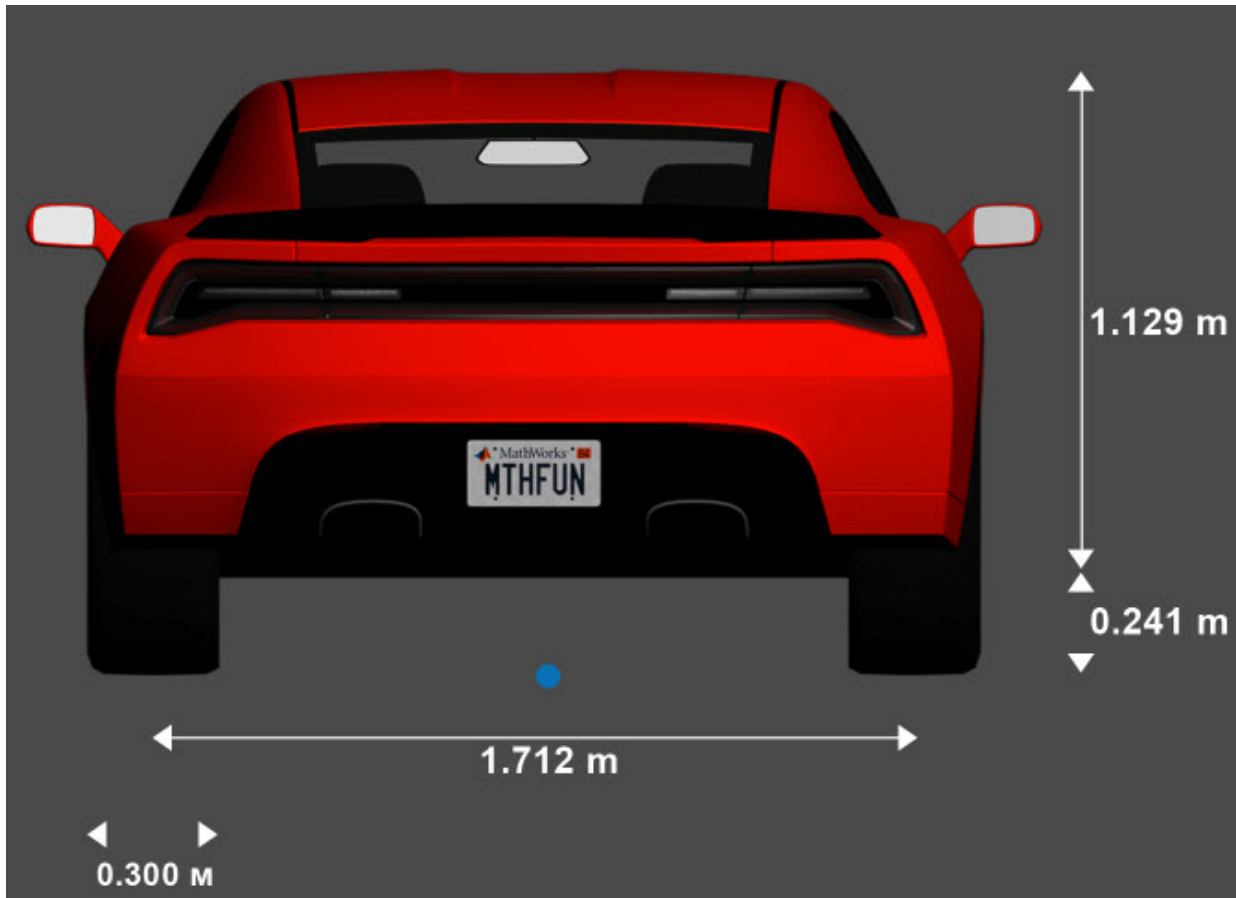
Side view – Vehicle length, front overhang, and rear overhang dimensions
diagram



Front view – Tire width and front axle dimensions
diagram



Rear view – Vehicle height and rear axle dimensions
diagram



Specify Muscle Car Vehicle Dimensions

When simulating a path planner in the 3D environment, the path planner must use a vehicle whose dimensions are consistent with one used in the 3D environment. To make these dimensions consistent, you can use a `vehicleDimensions` object.

Specify the dimensions of a Muscle Car vehicle in a `vehicleDimensions` object. Units are in meters. For an example that uses this object in a path planner, see “Visualize Automated Parking Valet Using 3D Simulation”.

```
centerToFront = 1.491;
centerToRear  = 1.529;
frontOverhang = 0.983;
rearOverhang  = 0.945;
vehicleWidth  = 2.009;
vehicleHeight = 1.370;
vehicleLength = centerToFront + centerToRear + frontOverhang + rearOverhang;

muscleCarDims = vehicleDimensions(vehicleLength,vehicleWidth,vehicleHeight, ...
    'FrontOverhang',frontOverhang,'RearOverhang',rearOverhang)

muscleCarDims =
    vehicleDimensions with properties:

        Length: 4.9480
        Width: 2.0090
        Height: 1.3700
        Wheelbase: 3.0200
        RearOverhang: 0.9450
        FrontOverhang: 0.9830
        WorldUnits: 'meters'
```

See Also

Hatchback | Sedan | Small Pickup Truck | Sport Utility Vehicle

Topics

“3D Simulation for Automated Driving”

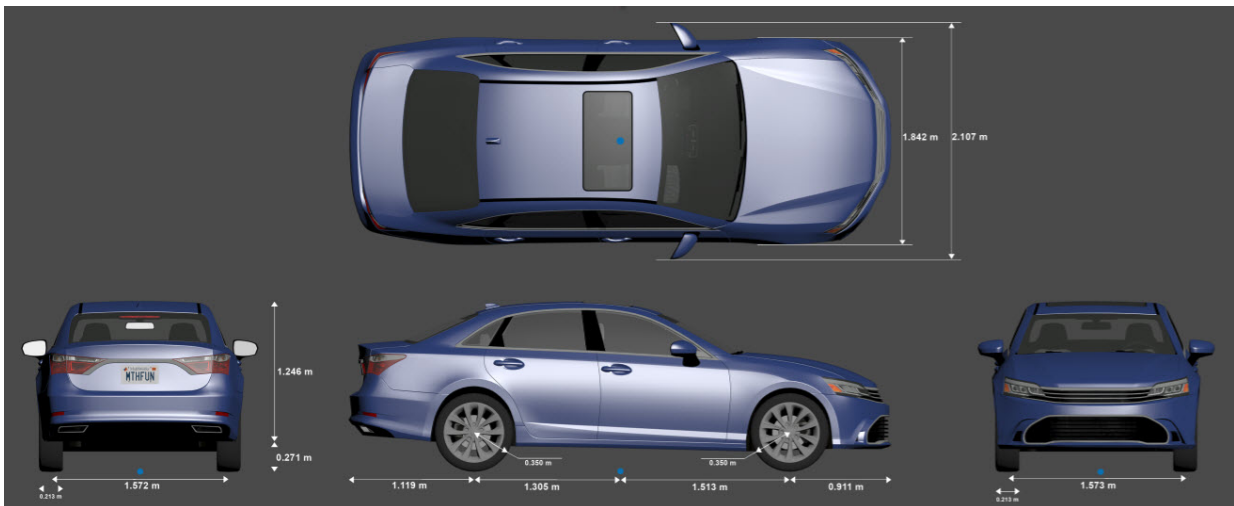
“Coordinate Systems for 3D Simulation in Automated Driving Toolbox”

Sedan

Sedan vehicle dimensions

Description

Sedan is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

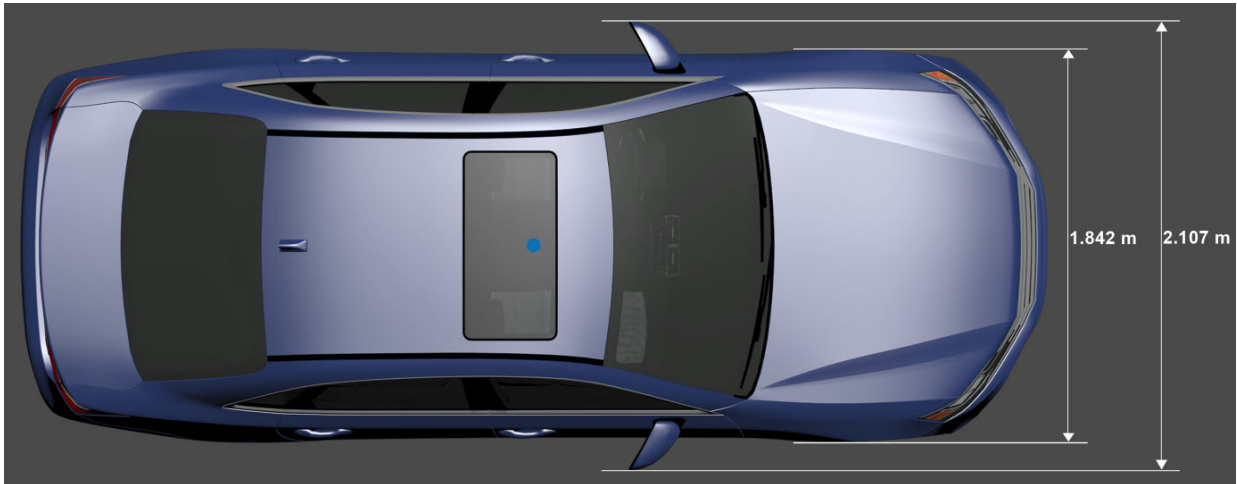


To add this type of vehicle to the 3D simulation environment:

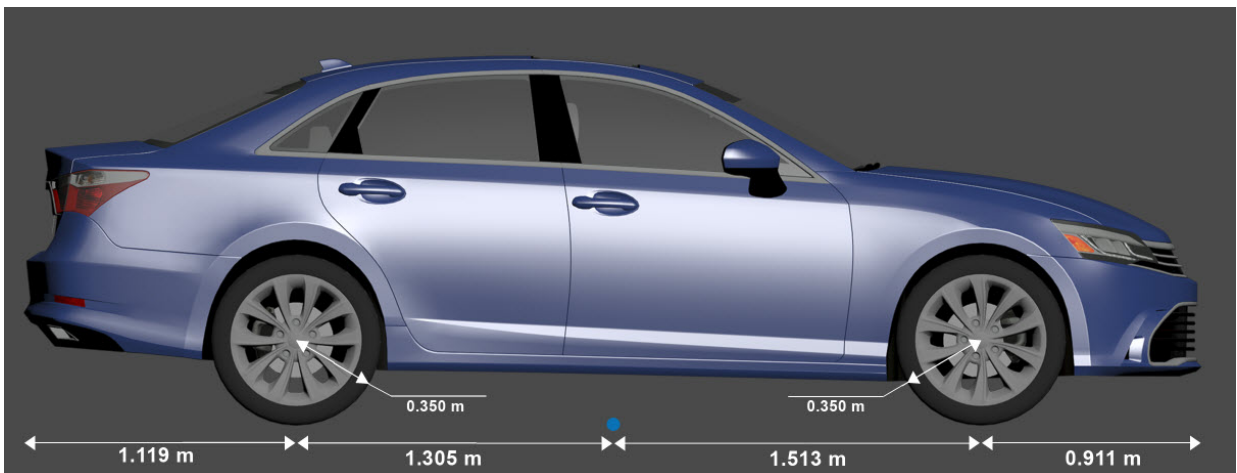
- 1 Add a Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In this block, set the **Type** parameter to Sedan.

Dimensions

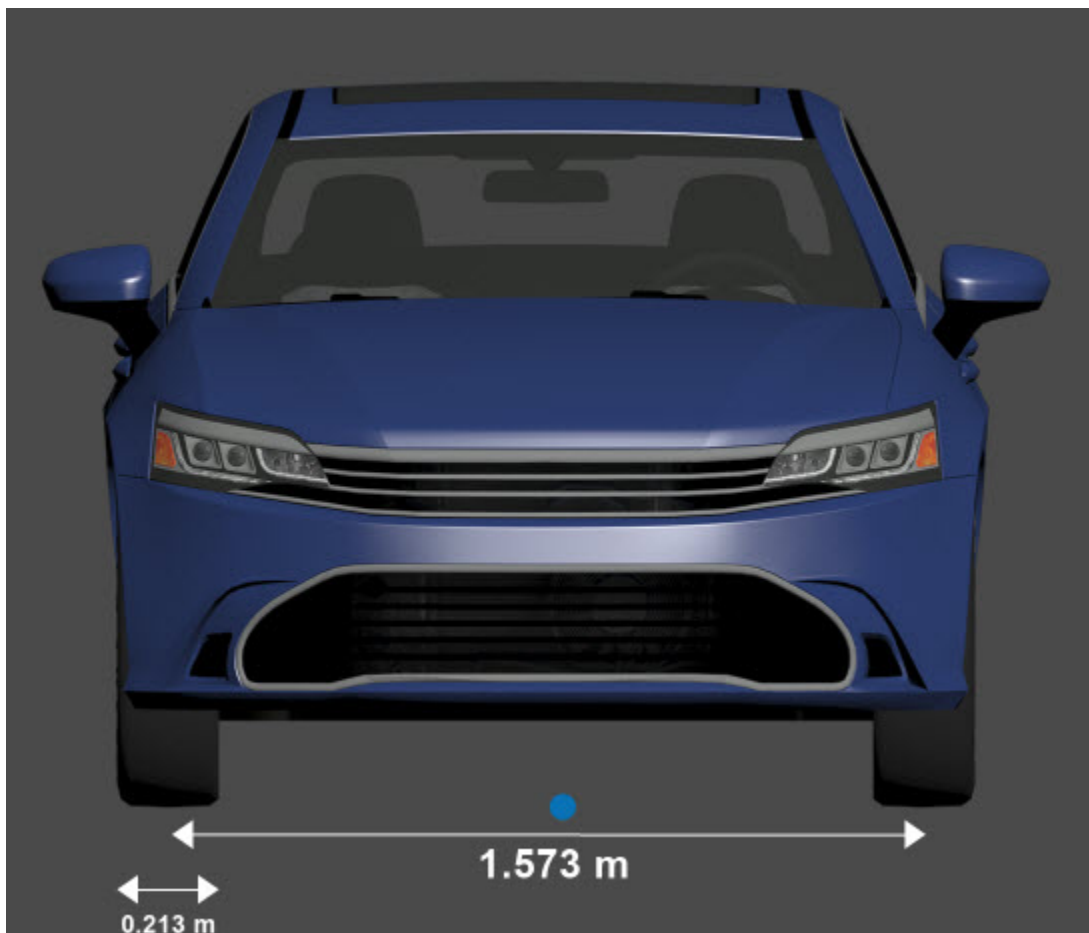
Top-down view – Vehicle width dimensions diagram



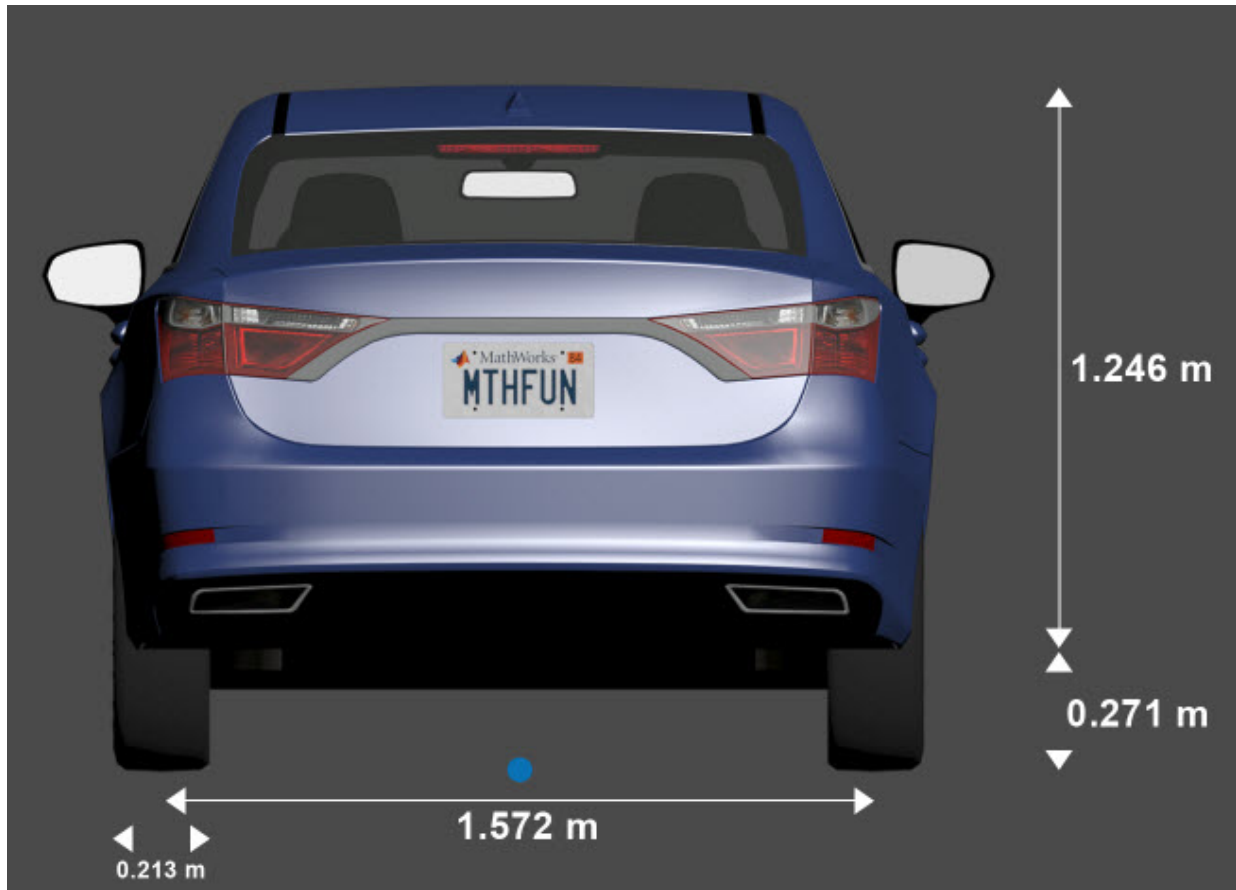
Side view – Vehicle length, front overhang, and rear overhang dimensions diagram



Front view – Tire width and front axle dimensions
diagram



Rear view – Vehicle height and rear axle dimensions
diagram



Specify Sedan Vehicle Dimensions

When simulating a path planner in the 3D environment, the path planner must use a vehicle whose dimensions are consistent with one used in the 3D environment. To make these dimensions consistent, you can use a `vehicleDimensions` object.

Specify the dimensions of a Sedan vehicle in a `vehicleDimensions` object. Units are in meters. For an example that uses this object in a path planner, see “Visualize Automated Parking Valet Using 3D Simulation”.


```
centerToFront = 1.513;
centerToRear = 1.305;
frontOverhang = 0.911;
rearOverhang = 1.119;
vehicleWidth = 1.842;
vehicleHeight = 1.517;
vehicleLength = centerToFront + centerToRear + frontOverhang + rearOverhang;

sedanDims = vehicleDimensions(vehicleLength,vehicleWidth,vehicleHeight, ...
    'FrontOverhang',frontOverhang,'RearOverhang',rearOverhang)

sedanDims =
    vehicleDimensions with properties:

        Length: 4.8480
        Width: 1.8420
        Height: 1.5170
        Wheelbase: 2.8180
        RearOverhang: 1.1190
        FrontOverhang: 0.9110
        WorldUnits: 'meters'
```

See Also

Hatchback | Muscle Car | Small Pickup Truck | Sport Utility Vehicle

Topics

“3D Simulation for Automated Driving”

“Coordinate Systems in Automated Driving Toolbox”

Sport Utility Vehicle

Sport utility vehicle dimensions

Description

Sport Utility Vehicle is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The following diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

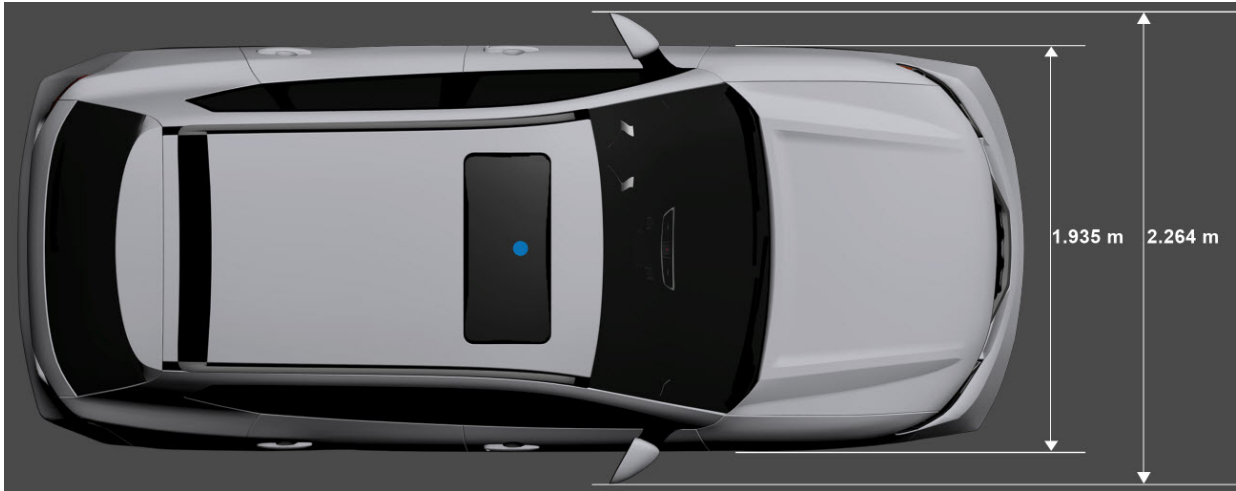


To add this type of vehicle to the 3D simulation environment:

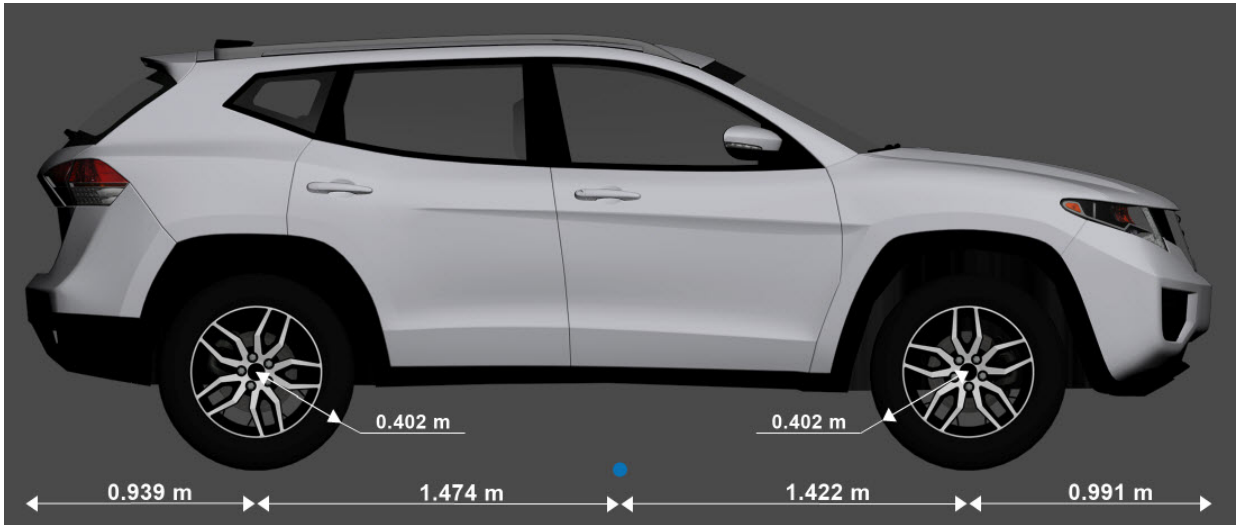
- 1 Add a Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In this block, set the **Type** parameter to Sport utility vehicle.

Dimensions

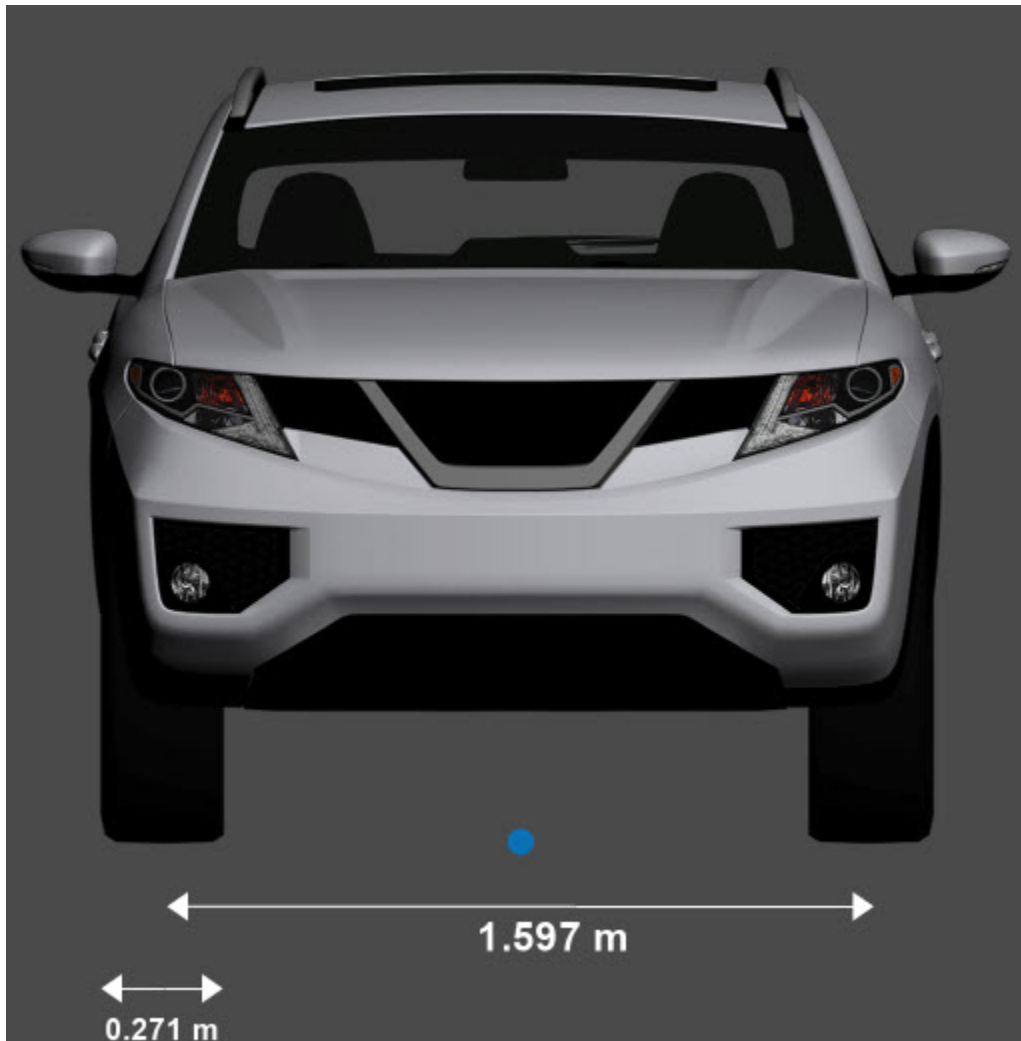
Top-down view – Vehicle width dimensions
diagram



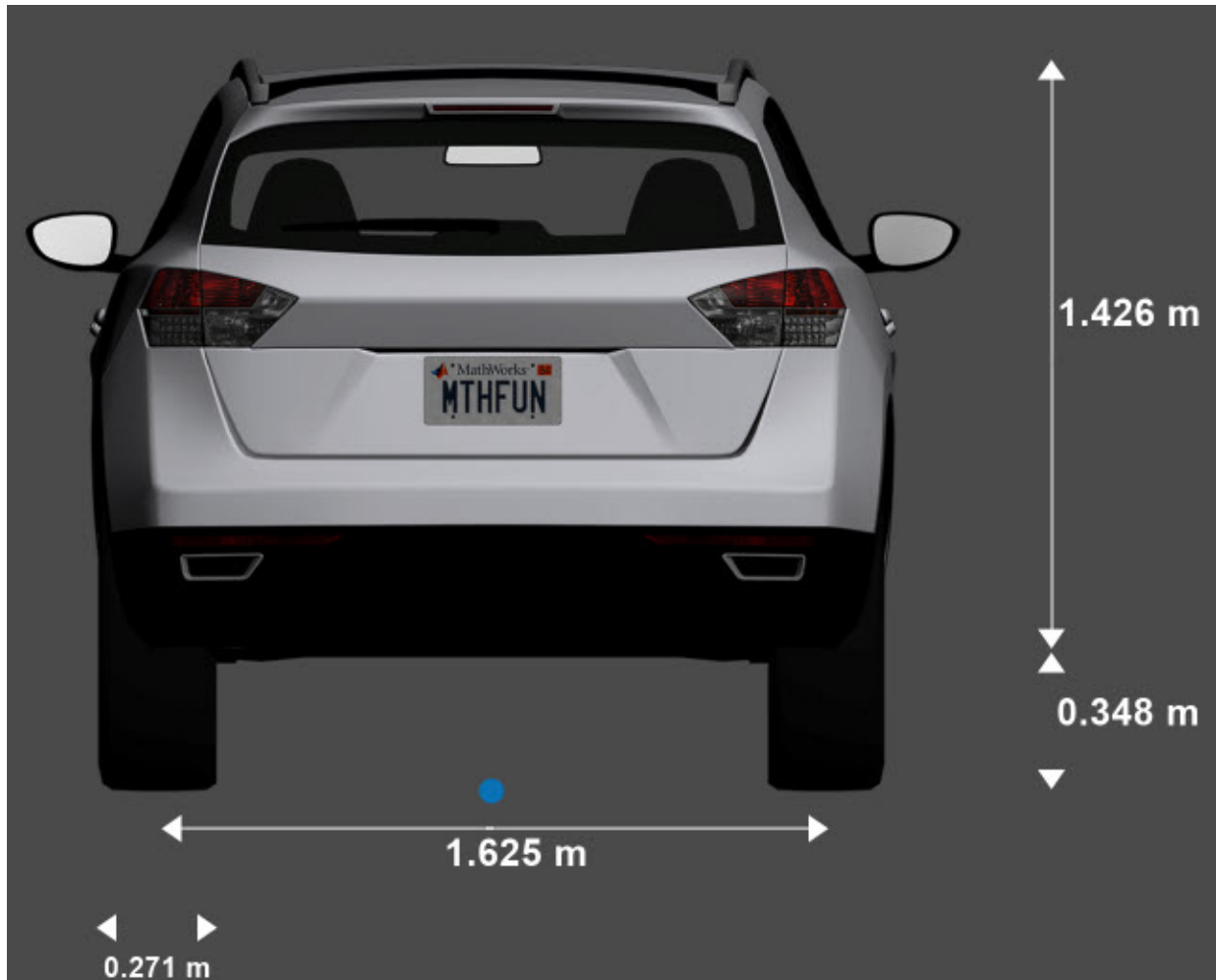
Side view – Vehicle length, front overhang, and rear overhang dimensions
diagram



Front view — Tire width and front axle dimensions
diagram



Rear view – Vehicle height and rear axle dimensions
diagram



Specify Sport Utility Vehicle Dimensions

When simulating a path planner in the 3D environment, the path planner must use a vehicle whose dimensions are consistent with one used in the 3D environment. To make these dimensions consistent, you can use a `vehicleDimensions` object.

Specify the dimensions of a Sport Utility Vehicle in a `vehicleDimensions` object. Units are in meters. For an example that uses this object in a path planner, see “Visualize Automated Parking Valet Using 3D Simulation”.

```
centerToFront = 1.422;
centerToRear  = 1.474;
frontOverhang = 0.991;
rearOverhang  = 0.939;
vehicleWidth  = 1.935;
vehicleHeight = 1.774;
vehicleLength = centerToFront + centerToRear + frontOverhang + rearOverhang;
```

```
suvDims = vehicleDimensions(vehicleLength,vehicleWidth,vehicleHeight, ...
    'FrontOverhang',frontOverhang,'RearOverhang',rearOverhang)
```

```
suvDims =
    vehicleDimensions with properties:
```

```
    Length: 4.8260
    Width: 1.9350
    Height: 1.7740
    Wheelbase: 2.8960
    RearOverhang: 0.9390
    FrontOverhang: 0.9910
    WorldUnits: 'meters'
```

See Also

[Hatchback](#) | [Muscle Car](#) | [Sedan](#) | [Small Pickup Truck](#)

Topics

“3D Simulation for Automated Driving”

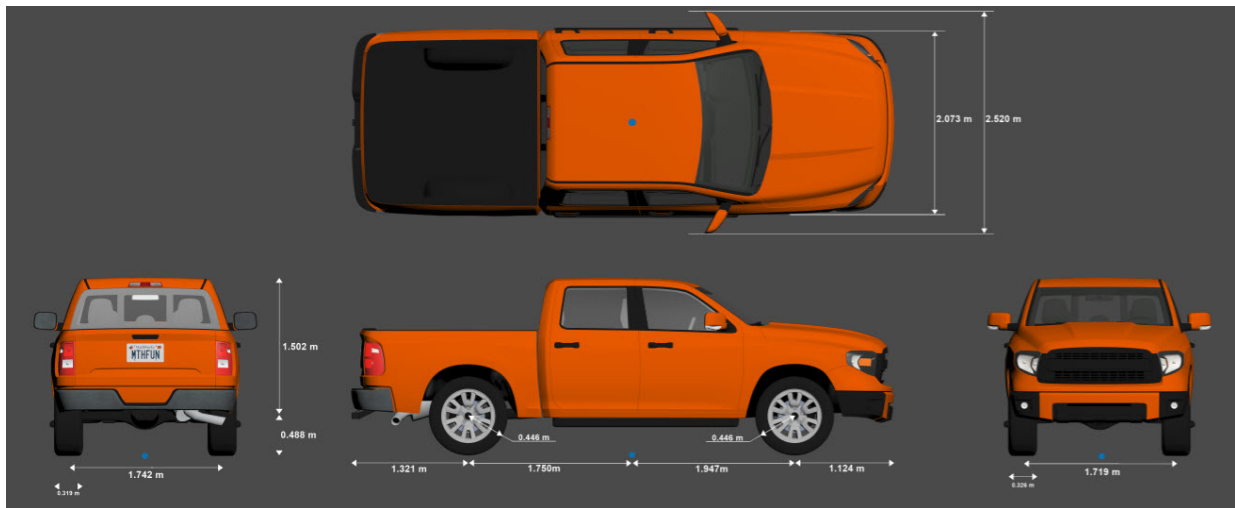
“Coordinate Systems in Automated Driving Toolbox”

Small Pickup Truck

Small pickup truck vehicle dimensions

Description

Small Pickup Truck is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The following diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

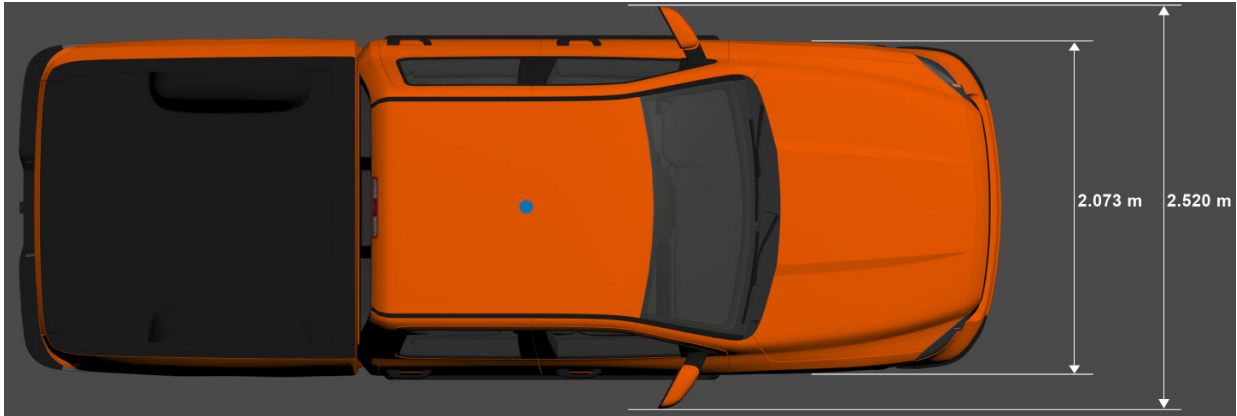


To add this type of vehicle to the 3D simulation environment:

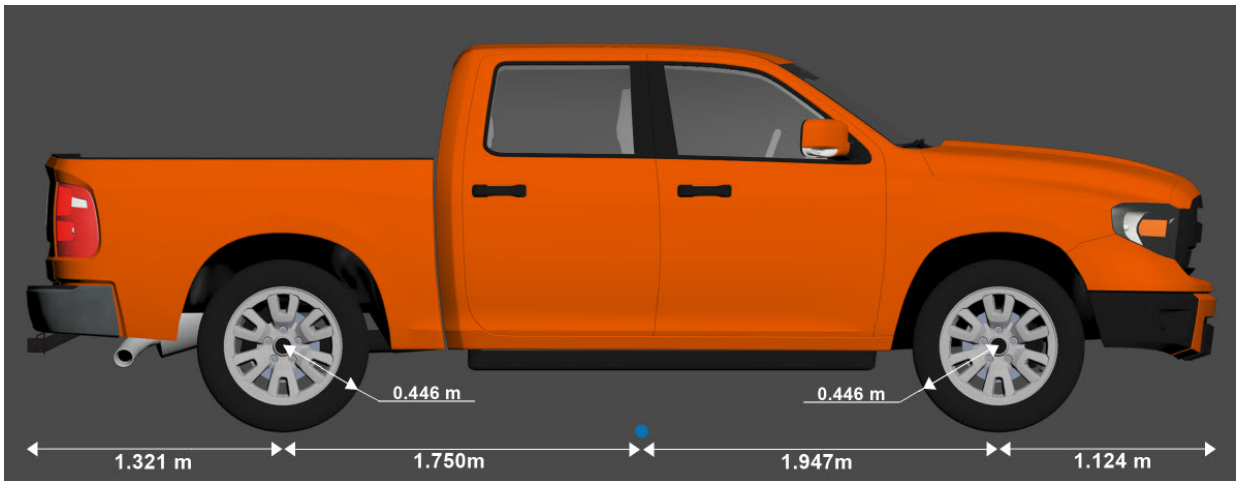
- 1 Add a Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In this block, set the **Type** parameter to **Small pickup truck**.

Dimensions

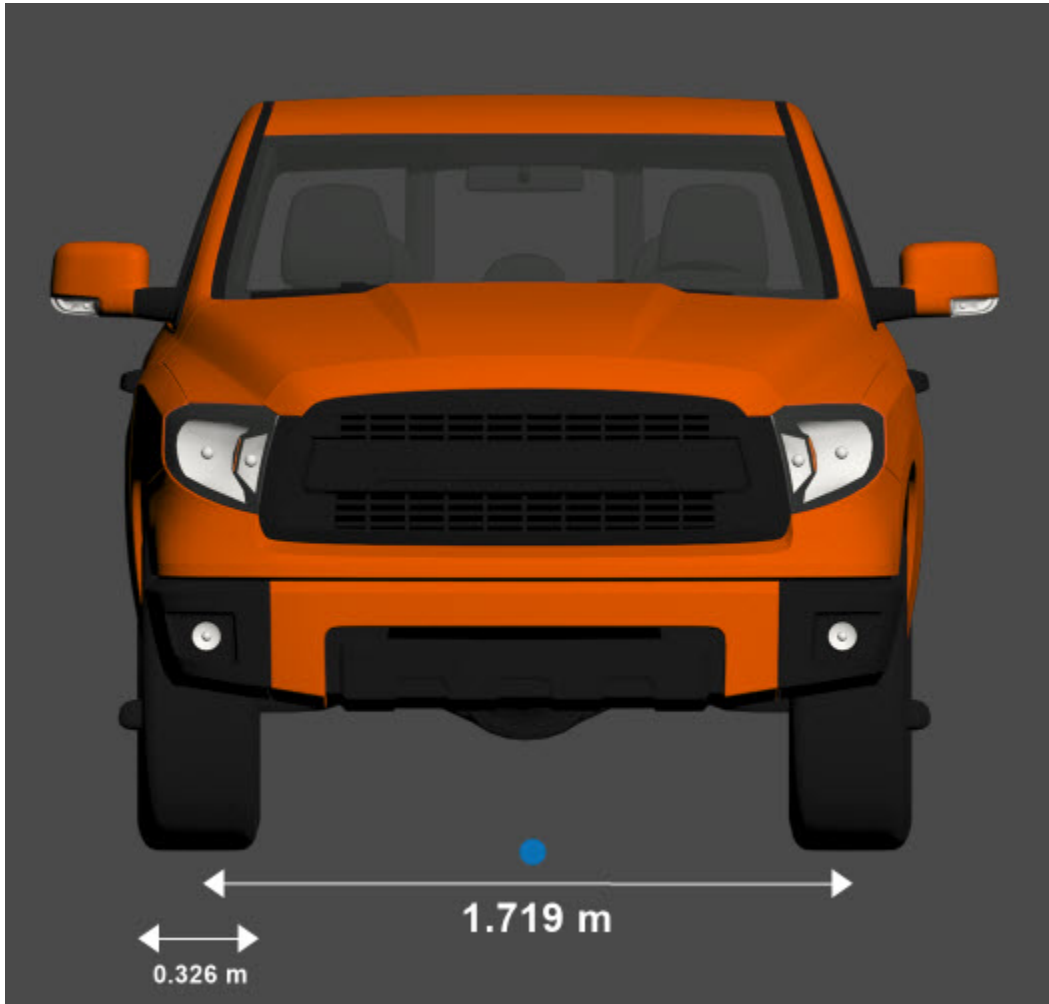
Top-down view – Vehicle width dimensions
diagram



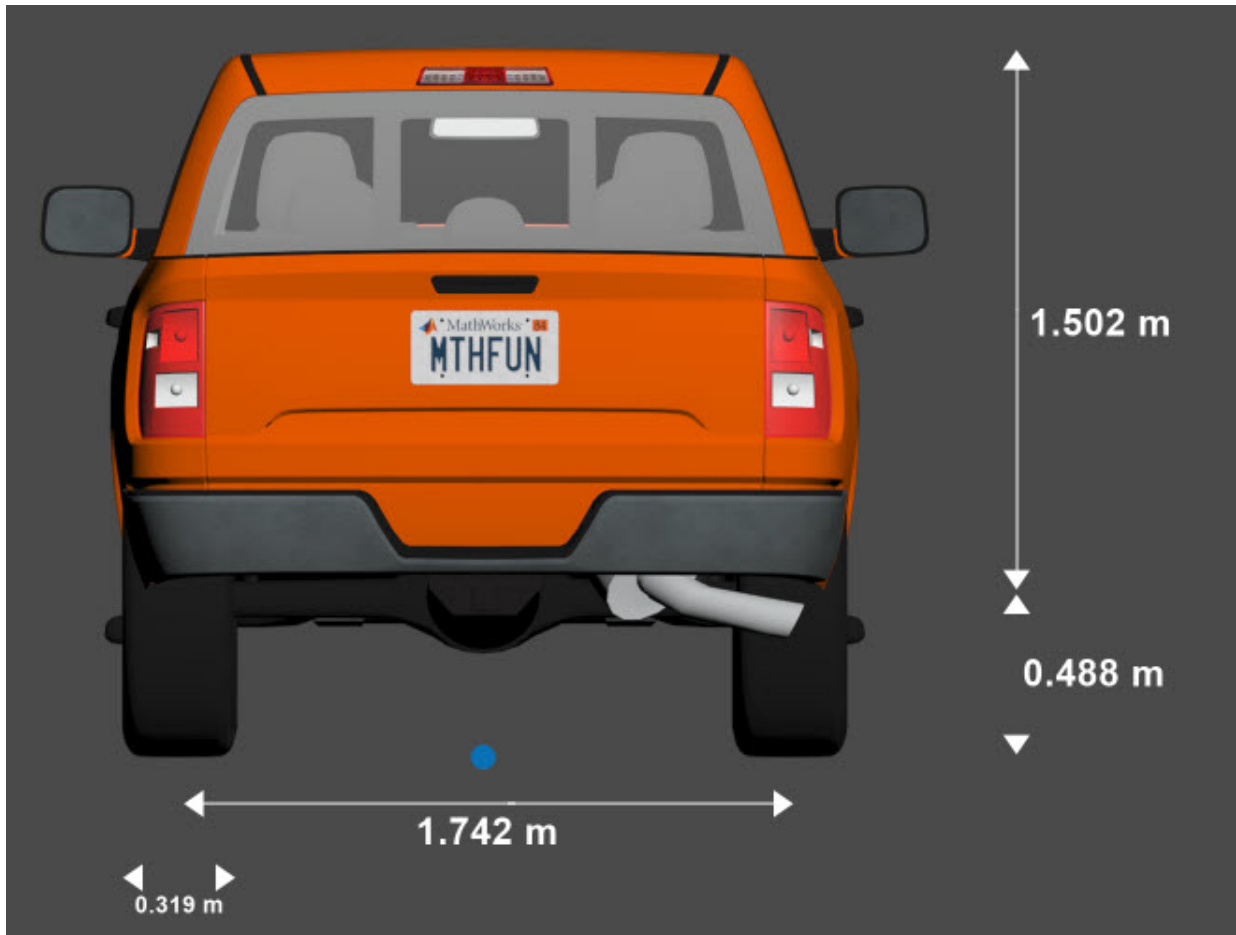
Side view – Vehicle length, front overhang, and rear overhang dimensions
diagram



Front view – Tire width and front axle dimensions
diagram



Rear view — Vehicle height and rear axle dimensions
diagram



Specify Small Pickup Truck Vehicle Dimensions

When simulating a path planner in the 3D environment, the path planner must use a vehicle whose dimensions are consistent with one used in the 3D environment. To make these dimensions consistent, you can use a `vehicleDimensions` object.

Specify the dimensions of a Small Pickup Truck vehicle in a `vehicleDimensions` object. Units are in meters. For an example that uses this object in a path planner, see “Visualize Automated Parking Valet Using 3D Simulation”.

```
centerToFront = 1.947;
centerToRear  = 1.750;
frontOverhang = 1.124;
rearOverhang  = 1.321;
vehicleWidth  = 2.073;
vehicleHeight = 1.990;
vehicleLength = centerToFront + centerToRear + frontOverhang + rearOverhang;

smallPickupTruckDims = vehicleDimensions(vehicleLength,vehicleWidth,vehicleHeight, ...
    'FrontOverhang',frontOverhang,'RearOverhang',rearOverhang)

smallPickupTruckDims =
    vehicleDimensions with properties:

        Length: 6.1420
        Width: 2.0730
        Height: 1.9900
        Wheelbase: 3.6970
        RearOverhang: 1.3210
        FrontOverhang: 1.1240
        WorldUnits: 'meters'
```

See Also

[Hatchback](#) | [Muscle Car](#) | [Sedan](#) | [Sport Utility Vehicle](#)

Topics

“3D Simulation for Automated Driving”

“Coordinate Systems in Automated Driving Toolbox”