Robotics System Toolbox™

Reference

MATLAB®&SIMULINK®

R2021b

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Robotics System Toolbox™ Reference

Revision History

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September 2015	Online only	Revised for Version 1.1 (R2015b)
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March 2021	Online only	Revised for Version 3.3 (R2021a)
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Contents

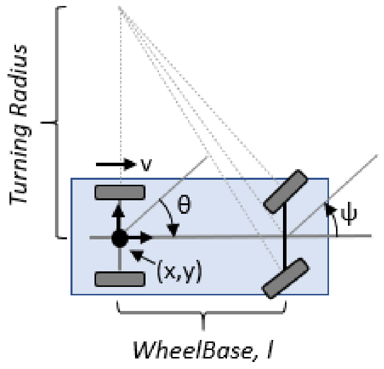
Classes

ackermannKinematics

Car-like steering vehicle model

Description

`ackermannKinematics` creates a car-like vehicle model that uses Ackermann steering. This model represents a vehicle with two axles separated by the distance, Wheelbase. The state of the vehicle is defined as a four-element vector, [*x y theta psi*], with a global *xy*-position, specified in meters. The *xy*-position is located at the middle of the rear axle. The vehicle heading, *theta*, and steering angle, *psi* are specified in radians. The vehicle heading is defined at the center of the rear axle. Angles are given in radians. To compute the time derivative states for the model, use the `derivative` function with input steering commands and the current robot state.



Creation

Syntax

`kinematicModel = ackermannKinematics`

`kinematicModel = ackermannKinematics(Name,Value)`

Description

`kinematicModel = ackermannKinematics` creates an Ackermann kinematic model object with default property values.

`kinematicModel = ackermannKinematics(Name,Value)` sets additional properties to the specified values. You can specify multiple properties in any order.

Properties

`WheelBase` — Distance between front and rear axles
1 (default) | positive numeric scalar

The wheel base refers to the distance between the front and rear axles, specified in meters.

`VehicleSpeedRange` — Range of vehicle wheel speeds
`[-Inf Inf]` (default) | two-element vector

The vehicle speed range is a two-element vector that provides the minimum and maximum vehicle speeds, [*MinSpeed MaxSpeed*], specified in meters per second.

Object Functions

derivative	Time derivative of vehicle state

Examples

Simulate Different Kinematic Models for Mobile Robots

This example shows how to model different robot kinematics models in an environment and compare them.

Define Mobile Robots with Kinematic Constraints

There are a number of ways to model the kinematics of mobile robots. All dictate how the wheel velocities are related to the robot state: `[x y theta]`, as *xy*-coordinates and a robot heading, `theta`, in radians.

Unicycle Kinematic Model

The simplest way to represent mobile robot vehicle kinematics is with a unicycle model, which has a wheel speed set by a rotation about a central axle, and can pivot about its z-axis. Both the differential-drive and bicycle kinematic models reduce down to unicycle kinematics when inputs are provided as vehicle speed and vehicle heading rate and other constraints are not considered.

```
unicycle = unicycleKinematics("VehicleInputs","VehicleSpeedHeadingRate");
```

Differential-Drive Kinematic Model

The differential drive model uses a rear driving axle to control both vehicle speed and head rate. The wheels on the driving axle can spin in both directions. Since most mobile robots have some interface to the low-level wheel commands, this model will again use vehicle speed and heading rate as input to simplify the vehicle control.

```
diffDrive = differentialDriveKinematics("VehicleInputs","VehicleSpeedHeadingRate");
```

To differentiate the behavior from the unicycle model, add a wheel speed velocity constraint to the differential-drive kinematic model

```
diffDrive.WheelSpeedRange = [-10 10]*2*pi;
```

Bicycle Kinematic Model

The bicycle model treats the robot as a car-like model with two axles: a rear driving axle, and a front axle that turns about the z-axis. The bicycle model works under the assumption that wheels on each axle can be modeled as a single, centered wheel, and that the front wheel heading can be directly set, like a bicycle.

```
bicycle = bicycleKinematics("VehicleInputs","VehicleSpeedHeadingRate","MaxSteeringAngle",pi/8);
```

Other Models

The Ackermann kinematic model is a modified car-like model that assumes Ackermann steering. In most car-like vehicles, the front wheels do not turn about the same axis, but instead turn on slightly different axes to ensure that they ride on concentric circles about the center of the vehicle's turn. This difference in turning angle is called Ackermann steering, and is typically enforced by a mechanism in actual vehicles. From a vehicle and wheel kinematics standpoint, it can be enforced by treating the steering angle as a rate input.

```
carLike = ackermannKinematics;
```

Set up Simulation Parameters

These mobile robots will follow a set of waypoints that is designed to show some differences caused by differing kinematics.

```
waypoints = [0 0; 0 10; 10 10; 5 10; 11 9; 4 -5];
% Define the total time and the sample rate
sampleTime = 0.05;               % Sample time [s]
tVec = 0:sampleTime:20;          % Time array

initPose = [waypoints(1,:)'; 0]; % Initial pose (x y theta)
```

Create a Vehicle Controller

The vehicles follow a set of waypoints using a Pure Pursuit controller. Given a set of waypoints, the robot current state, and some other parameters, the controller outputs vehicle speed and heading rate.

```
% Define a controller. Each robot requires its own controller
controller1 = controllerPurePursuit("Waypoints",waypoints,"DesiredLinearVelocity",3,"MaxAngularVe
controller2 = controllerPurePursuit("Waypoints",waypoints,"DesiredLinearVelocity",3,"MaxAngularVe
controller3 = controllerPurePursuit("Waypoints",waypoints,"DesiredLinearVelocity",3,"MaxAngularVe
```

Simulate the Models Using an ODE Solver

The models are simulated using the `derivative` function to update the state. This example uses an ordinary differential equation (ODE) solver to generate a solution. Another way would be to update the state using a loop, as shown in “Path Following for a Differential Drive Robot”.

Since the ODE solver requires all outputs to be provided as a single output, the pure pursuit controller must be wrapped in a function that outputs the linear velocity and heading angular velocity as a single output. An example helper, `exampleHelperMobileRobotController`, is used for that purpose. The example helper also ensures that the robot stops when it is within a specified radius of the goal.

```
goalPoints = waypoints(end,:)';
goalRadius = 1;
```

`ode45` is called once for each type of model. The derivative function computes the state outputs with initial state set by `initPose`. Each derivative accepts the corresponding kinematic model object, the current robot pose, and the output of the controller at that pose.

```
% Compute trajectories for each kinematic model under motion control
[tUnicycle,unicyclePose] = ode45(@(t,y)derivative(unicycle,y,exampleHelperMobileRobotController(
[tBicycle,bicyclePose] = ode45(@(t,y)derivative(bicycle,y,exampleHelperMobileRobotController(con
[tDiffDrive,diffDrivePose] = ode45(@(t,y)derivative(diffDrive,y,exampleHelperMobileRobotControlle
```

Plot Results

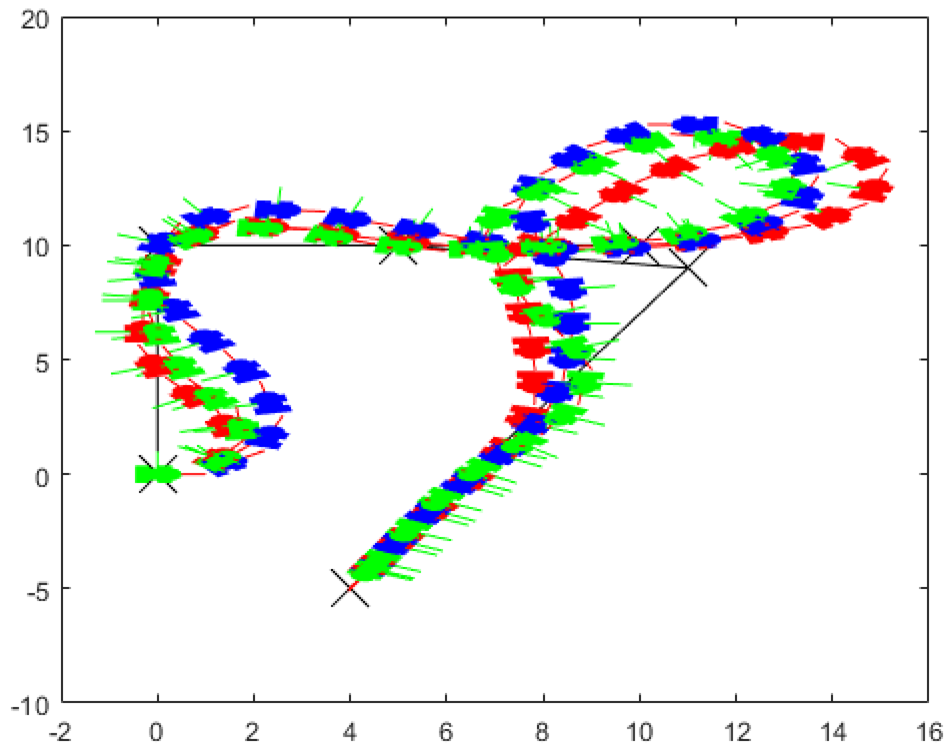
The results of the ODE solver can be easily viewed on a single plot using `plotTransforms` to visualize the results of all trajectories at once.

The pose outputs must first be converted to indexed matrices of translations and quaternions.

```
unicycleTranslations = [unicyclePose(:,1:2) zeros(length(unicyclePose),1)];
unicycleRot = axang2quat([repmat([0 0 1],length(unicyclePose),1) unicyclePose(:,3)]);

bicycleTranslations = [bicyclePose(:,1:2) zeros(length(bicyclePose),1)];
bicycleRot = axang2quat([repmat([0 0 1],length(bicyclePose),1) bicyclePose(:,3)]);

diffDriveTranslations = [diffDrivePose(:,1:2) zeros(length(diffDrivePose),1)];
diffDriveRot = axang2quat([repmat([0 0 1],length(diffDrivePose),1) diffDrivePose(:,3)]);
```

Next, the set of all transforms can be plotted and viewed from the top. The paths of the unicycle, bicycle, and differential-drive robots are red, blue, and green, respectively. To simplify the plot, only show every tenth output.

```
figure
plot(waypoints(:,1),waypoints(:,2),"kx-","MarkerSize",20);
hold all
plotTransforms(unicycleTranslations(1:10:end,:),unicycleRot(1:10:end,:),'MeshFilePath','groundveh
plotTransforms(bicycleTranslations(1:10:end,:),bicycleRot(1:10:end,:),'MeshFilePath','groundvehic
plotTransforms(diffDriveTranslations(1:10:end,:),diffDriveRot(1:10:end,:),'MeshFilePath','groundv
view(0,90)
```



Simulate Ackermann Kinematic Model with Steering Angle Constraints

Simulate a mobile robot model that uses Ackermann steering with constraints on its steering angle. During simulation, the model maintains maximum steering angle after it reaches the steering limit. To see the effect of steering saturation, you compare the trajectory of two robots, one with the constraints on the steering angle and the other without any steering constraints.

Define the Model

Define the Ackermann kinematic model. In this car-like model, the front wheels are a given distance apart. To ensure that they turn on concentric circles, the wheels have different steering angles. While turning, the front wheels receive the steering input as rate of change of steering angle.

```
carLike = ackermannKinematics;
```

Set Up Simulation Parameters

Set the mobile robot to follow a constant linear velocity and receive a constant steering rate as input. Simulate the constrained robot for a longer period to demonstrate steering saturation.

```
velo = 5;     % Constant linear velocity
psidot = 1;   % Constant left steering rate

% Define the total time and sample rate
sampleTime = 0.05;                  % Sample time [s]
```

```
timeEnd1 = 1.5;                     % Simulation end time for unconstrained robot
timeEnd2 = 10;                      % Simulation end time for constrained robot
tVec1 = 0:sampleTime:timeEnd1;      % Time array for unconstrained robot
tVec2 = 0:sampleTime:timeEnd2;      % Time array for constrained robot

initPose = [0;0;0;0];               % Initial pose (x y theta phi)
```

Create Options Structure for ODE Solver

In this example, you pass an `options` structure as argument to the ODE solver. The `options` structure contains the information about the steering angle limit. To create the `options` structure, use the `Events` option of `odeset` and the created event function, `detectSteeringSaturation`. `detectSteeringSaturation` sets the maximum steering angle to 45 degrees.

For a description of how to define `detectSteeringSaturation`, see **Define Event Function** at the end of this example.

```
options = odeset('Events',@detectSteeringSaturation);
```

Simulate Model Using ODE Solver

Next, you use the `derivative` function and an ODE solver, `ode45`, to solve the model and generate the solution.

```
% Simulate the unconstrained robot
[t1,pose1] = ode45(@(t,y)derivative(carLike,y,[velo psidot]),tVec1,initPose);

% Simulate the constrained robot
[t2,pose2,te,ye,ie] = ode45(@(t,y)derivative(carLike,y,[velo psidot]),tVec2,initPose,options);
```

Detect Steering Saturation

When the model reaches the steering limit, it registers a timestamp of the event. The time it took to reach the limit is stored in `te`.

```
if te < timeEnd2
    str1 = "Steering angle limit was reached at ";
    str2 = " seconds";
    comp = str1 + te + str2;
    disp(comp)
end
```

```
Steering angle limit was reached at 0.785 seconds
```

Simulate Constrained Robot with New Initial Conditions

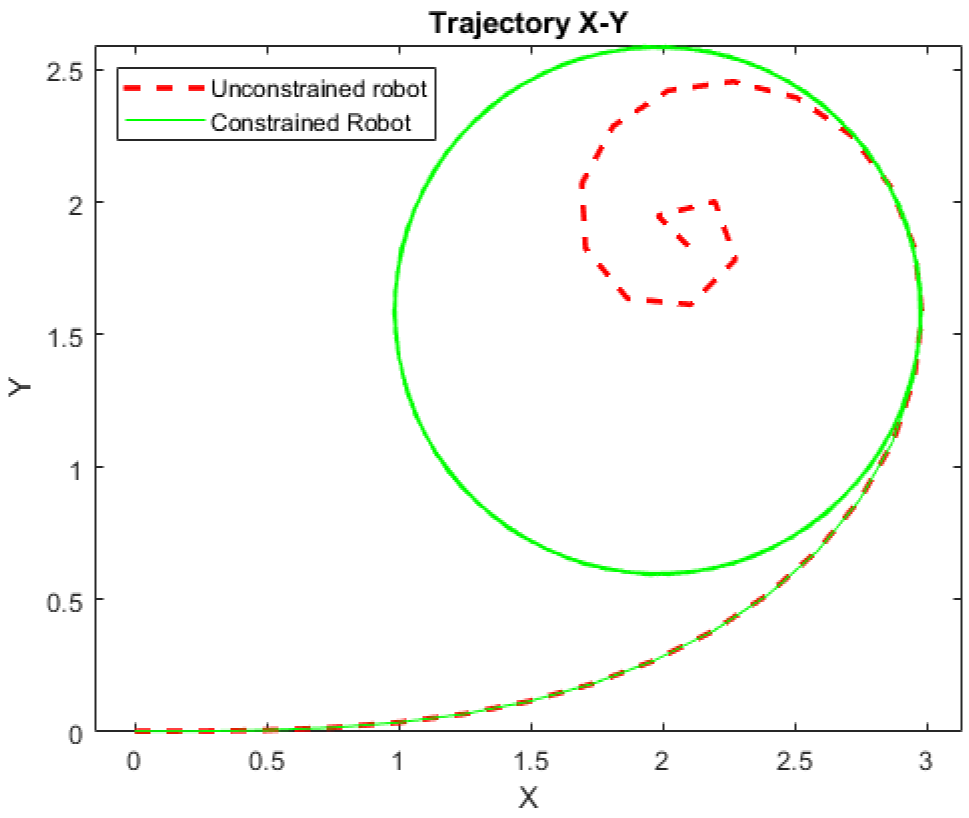
Now use the state of the constrained robot before termination of integration as initial condition for the second simulation. Modify the input vector to represent steering saturation, that is, set the steering rate to zero.

```
saturatedPsiDot = 0;             % Steering rate after saturation
cmds = [velo saturatedPsiDot];   % Command vector
tVec3 = te:sampleTime:timeEnd2;  % Time vector
pose3 = pose2(length(pose2),:);
[t3,pose3,te3,ye3,ie3] = ode45(@(t,y)derivative(carLike,y,cmds), tVec3,pose3, options);
```

Plot the Results

Plot the trajectory of the robot using `plot` and the data stored in `pose`.

```
figure(1)
plot(pose1(:,1),pose1(:,2),'--r','LineWidth',2);
hold on;
plot([pose2(:,1); pose3(:,1)],[pose2(:,2);pose3(:,2)],'g');
title('Trajectory X-Y')
xlabel('X')
ylabel('Y')
legend('Unconstrained robot','Constrained Robot','Location','northwest')
axis equal
```



The unconstrained robot follows a spiral trajectory with decreasing radius of curvature while the constrained robot follows a circular trajectory with constant radius of curvature after the steering limit is reached.

Define Event Function

Set the event function such that integration terminates when 4th state, theta, is equal to maximum steering angle.

```
function [state,isterminal,direction] = detectSteeringSaturation(t,y)
  maxSteerAngle = 0.785;               % Maximum steering angle (pi/4 radians)
  state(4) = (y(4) - maxSteerAngle);   % Saturation event occurs when the 4th state, theta, is e
  isterminal(4) = 1;                   % Integration is terminated when event occurs
  direction(4) = 0;                    % Bidirectional termination
```

```
end
```

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control* 1st ed. Cambridge, MA: Cambridge University Press, 2017.

Extended Capabilities

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

See Also

Classes
`bicycleKinematics` | `unicycleKinematics` | `differentialDriveKinematics`

Blocks
Ackermann Kinematic Model

Functions
`derivative`

Topics
"Mobile Robot Kinematics Equations"

Introduced in R2019b

analyticalInverseKinematics

Solve closed-form inverse kinematics

Description

The `analyticalInverseKinematics` object generates functions that computes all closed-form solutions for inverse kinematics (IK) for serial-chain manipulators. The object generates a custom function to find multiple distinct joint configurations that achieve the desired end-effector pose. The object supports six-degree-of-freedom (DOF) rigid body tree robot models with compatible kinematic parameters. These are the key elements of the solver:

- **Robot model** — Rigid body tree model that defines the kinematics of the robot. Specify this model as a `rigidBodyTree` object when creating the solver.
- **Kinematic group** — Base and end-effector body names for a 6-DOF serial chain that is part of the robot model. To set this parameter, use the `showdetails` function.
- **Kinematic group type** — Classification of joints connecting base to end effector.

To see all possible supported kinematic groups for your robot, use the `showdetails` object function. To set a specific group from the list, click the **Use this kinematic group** link for a kinematic group in the returned list.

To calculate inverse kinematics for a specific kinematic group, use the `generateIKFunction` object function. To ensure your robot model and kinematic group are compatible, check the IsValidGroupForIK property after selecting a kinematic group.

To generate numeric solutions, use the `inverseKinematics` and `generalizedInverseKinematics` objects.

Creation

Syntax

```
analyticalIK = analyticalInverseKinematics(robotRBT)
analyticalIK = analyticalInverseKinematics(
robotRBT,'KinematicGroup',kinGroup)
```

Description

`analyticalIK = analyticalInverseKinematics(robotRBT)` creates an analytical inverse kinematics solver for a rigid body tree robot model, specified as a `rigidBodyTree` object. The end effector is the final body listed in the Bodies property of the robot model. The `robotRBT` argument sets the RigidBodyTree property.

`analyticalIK = analyticalInverseKinematics(robotRBT,'KinematicGroup',kinGroup)` sets the KinematicGroup property to the `kinGroup` argument, specified as a structure.

Properties

`RigidBodyTree` — Rigid body tree robot model
`rigidBodyTree` object

Rigid body tree robot model, specified as a `rigidBodyTree` object. To use a provided robot model, see `loadrobot`. To import Unified Robot Description Format (URDF) models, see the `importrobot` function.

`KinematicGroup` — Base and end-effector body names
structure

Base and end-effector body names, specified as a structure. The structure contains these fields:

- `BaseName` — Name of the body in the robot model stored in the `RigidBodyTree` property that represents the base of the kinematic group. The default value is the base of the `RigidBodyTree` property.
- `EndEffectorBodyName` — Name of the body in the robot model stored in the `RigidBodyTree` property that represents the end of the kinematic group. The default value is the last body in the Bodies property of the robot model..

Example: `struct("BaseName","base","EndEffectoryBodyName","tool0")`

Data Types: `struct`

`KinematicGroupType` — Classification of the kinematic group
character vector

This property is read-only.

Classification of the kinematic group, stored as a character vector. Each character specifies the class of the corresponding joint type from the base to the end effector. These are the options for the characters:

- `R` — Revolute joint
- `P` — Prismatic joint
- `S` — Spherical joint, created by three consecutive revolute joints with intersecting axes

When created, the object automatically selects a kinematic group from the robot model, but other options may be available. To see valid kinematic groups for your model, use the `showdetails` object function.

Example: `'RRRSSS'`

Data Types: `char`

`KinematicGroupConfigIdx` — Mapping of IK solution configuration to rigid body tree configuration
six-element vector

This property is read-only.

Mapping of IK solution configuration to rigid body tree configuration, specified as a six-element vector. This mapping converts the indices of the IK solution that is output from the generateIKFunction function to the indices for the robot model stored in the RigidBodyTree property.

Example: [1 2 3 4 5 6]

Data Types: double

IsValidGroupForIK — Indication of whether closed-form solution is possible
1 (true) | 0 (false)

This property is read-only.

Indication of whether a closed-form solution is possible, stored as a logical, 1 (true or 0 (false). When this property is false, the generateIKFunction function cannot generate an IK solver for the current kinematic group. Use the showdetails object function to check if any valid groups exist. To select a valid group, specify a different base or end effector to the KinematicGroup property, or change kinematic parameters of your robot model stored in the RigidBodyTree property.

Data Types: logical

Object Functions

generateIKFunction	Generate function for closed-form inverse kinematics
showdetails	Display overview of available kinematic groups

Examples

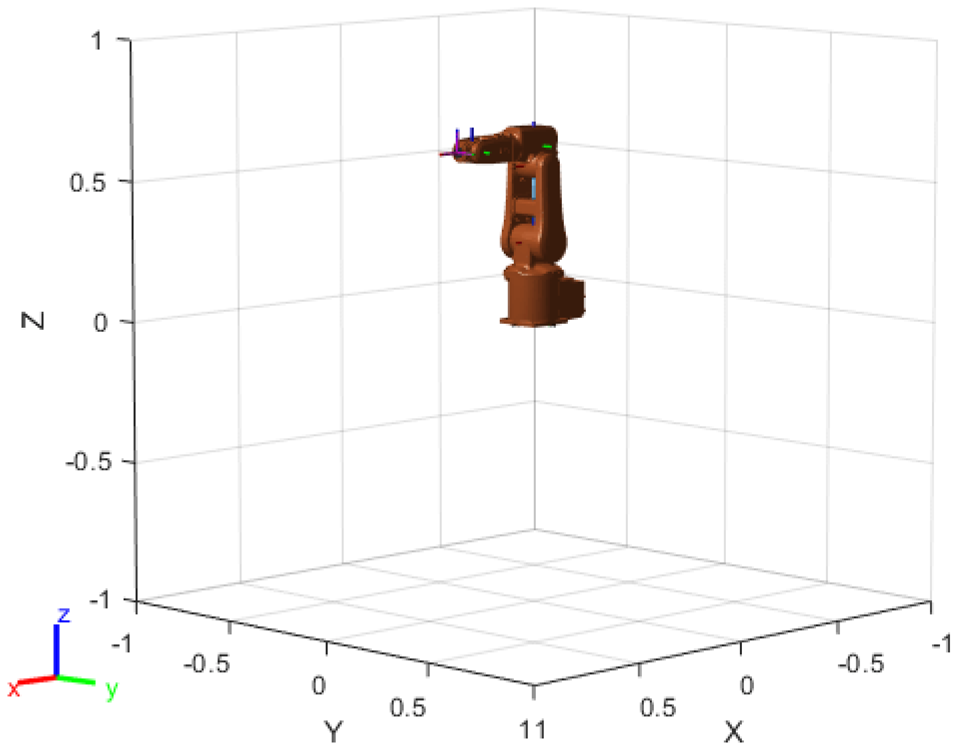
Solve Analytical Inverse Kinematics for Robot Manipulator

Generate closed-form inverse kinematics (IK) solutions for a desired end effector. Load the provided robot model and inspect details about the feasible kinematic groups of base and end-effector bodies. Generate a function for your desired kinematic group. Inspect the various configurations for a specific end-effector pose.

Robot Model

Load the ABB IRB 120 robot model into the workspace. Display the model.

```
robot = loadrobot('abbIrb120','DataFormat','row');
show(robot);
```



Analytical IK

Create the analytical IK solver. Show details for the robot model, which lists the different kinematic groups available for closed-form analytical IK solutions. Select the second kinematic group by clicking the **Use this kinematic group** link in the second row of the table.

```
aik = analyticalInverseKinematics(robot);
showdetails(aik)
```

```
--------------------
Robot: (8 bodies)

Index      Base Name   EE Body Name     Type                    Actions
-----      ---------   ------------     ----                    -------
    1      base_link         link_6   RRRSSS   Use this kinematic group
    2      base_link          tool0   RRRSSS   Use this kinematic group
```

Inspect the kinematic group, which lists the base and end-effector body names. For this robot, the group uses the 'base_link' and 'tool0' bodies, respectively.

```
aik.KinematicGroup
```

```
ans = struct with fields:
               BaseName: 'base_link'
    EndEffectorBodyName: 'tool0'
```

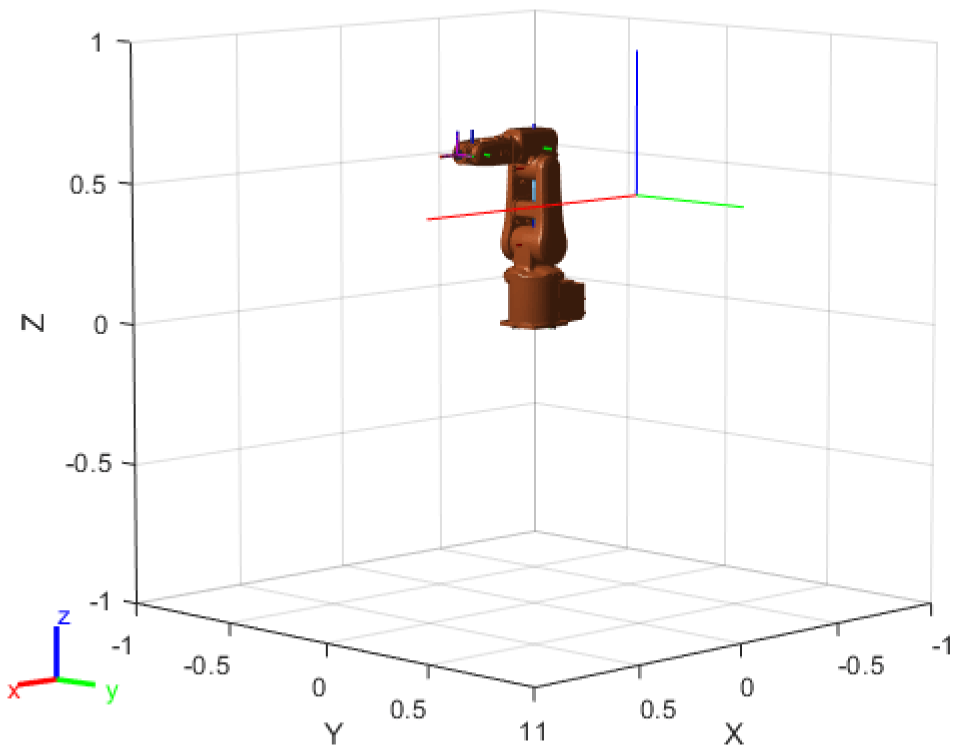
Generate Function

Generate the IK function for the selected kinematic group. Specify a name for the function, which is generated and saved in the current directory.

```
generateIKFunction(aik,'robotIK');
```

Specify a desired end-effector position. Convert the *xyz*-position to a homogeneous transformation.

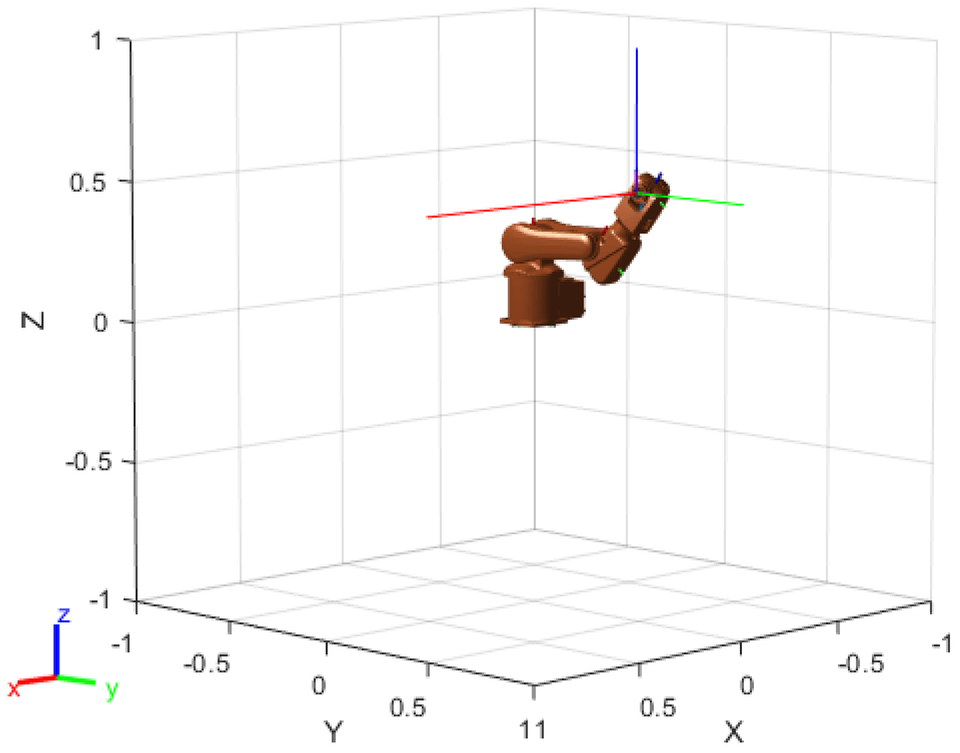
```
eePosition = [0 0.5 0.5];
eePose = trvec2tform(eePosition);
hold on
plotTransforms(eePosition,tform2quat(eePose))
hold off
```



Generate Configuration for IK Solution

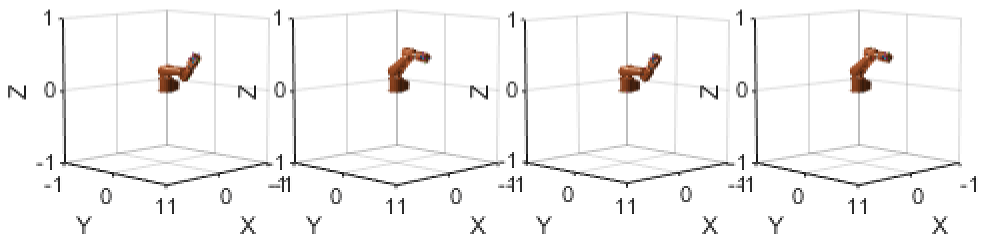
Specify the homogeneous transformation to the generated IK function, which generates all solutions for the desired end-effector pose. Display the first generated configuration to verify that the desired pose has been achieved.

```
ikConfig = robotIK(eePose); % Uses the generated file

show(robot,ikConfig(1,:));
hold on
plotTransforms(eePosition,tform2quat(eePose))
hold off
```



Display all of the closed-form IK solutions sequentially.

```
figure;
numSolutions = size(ikConfig,1);

for i = 1:size(ikConfig,1)
    subplot(1,numSolutions,i)
    show(robot,ikConfig(i,:));
end
```



Solve Analytical IK for Large-DOF Robot

Some manipulator robot models have large degrees-of-freedom (DOFs). To reach certain end-effector poses, however, only six DOFs are required. Use the `analyticalInverseKinematics` object, which supports six-DOF robots, to determine various valid kinematic groups for this large-DOF robot model. Use the `showdetails` object function to get information about the model.

Load Robot Model and Generate IK Solver

Load the robot model into the workspace, and create an `analyicalInverseKinematics` object. Use the `showdetails` object function to see the supported kinematic groups.

```
robot = loadrobot('willowgaragePR2','DataFormat','row');
aik = analyticalInverseKinematics(robot);
opts = showdetails(aik);
```

```
--------------------
Robot: (94 bodies)

Index                                         Base Name                                 EI
-----                                         ---------                                 --
    1                                  l_shoulder_pan_link                           l_wris
    2                                  r_shoulder_pan_link                           r_wris
    3                                  l_shoulder_pan_link                         l_gripper
    4                                  r_shoulder_pan_link                         r_gripper
```

```
     5                                l_shoulder_pan_link                              l_gripper
     6                                l_shoulder_pan_link                 l_gripper_motor_accelero
     7                                l_shoulder_pan_link                             l_gripper_
     8                                r_shoulder_pan_link                              r_gripper
     9                                r_shoulder_pan_link                 r_gripper_motor_accelero
    10                                r_shoulder_pan_link                             r_gripper_
```

Select a group programmatically using the output of the `showdetails` object function, `opts`. The selected group uses the left shoulder as the base with the left wrist as the end effector.

```
aik.KinematicGroup = opts(1).KinematicGroup;
disp(aik.KinematicGroup)
```

```
               BaseName: 'l_shoulder_pan_link'
    EndEffectorBodyName: 'l_wrist_roll_link'
```

Generate the IK function for the selected group.

```
generateIKFunction(aik,'willowRobotIK');
```

Solve Analytical IK

Define a target end-effector pose using a randomly-generated configuration.

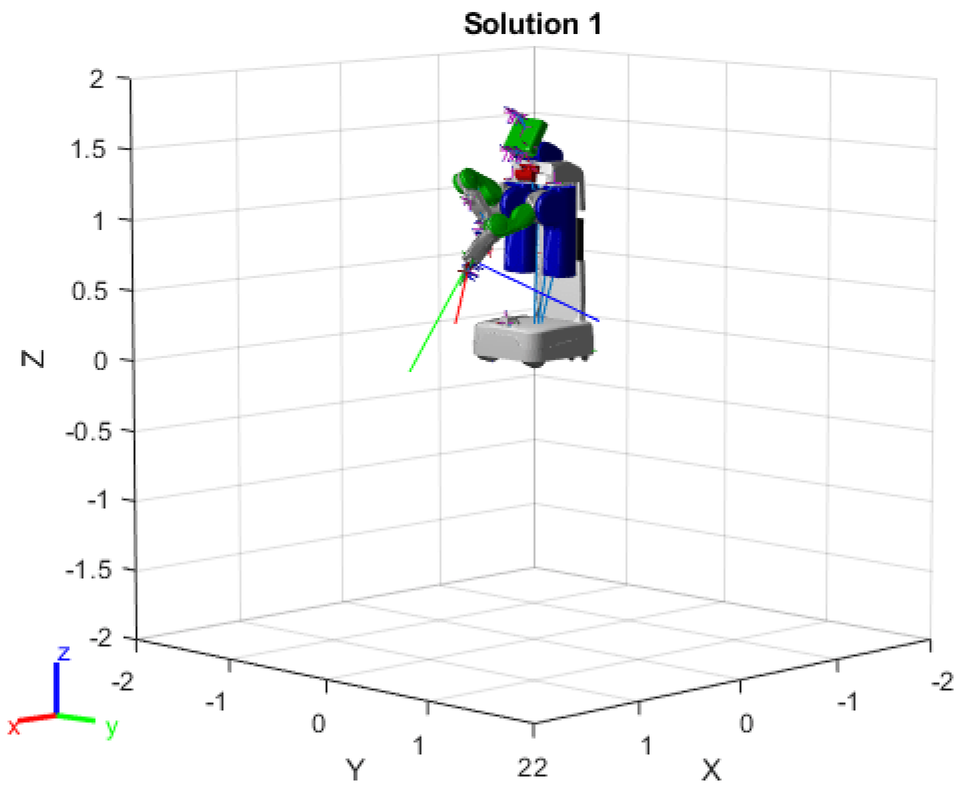
```
rng(0);
expConfig = randomConfiguration(robot);

eeBodyName = aik.KinematicGroup.EndEffectorBodyName;
baseName = aik.KinematicGroup.BaseName;
expEEPose = getTransform(robot,expConfig,eeBodyName,baseName);
```

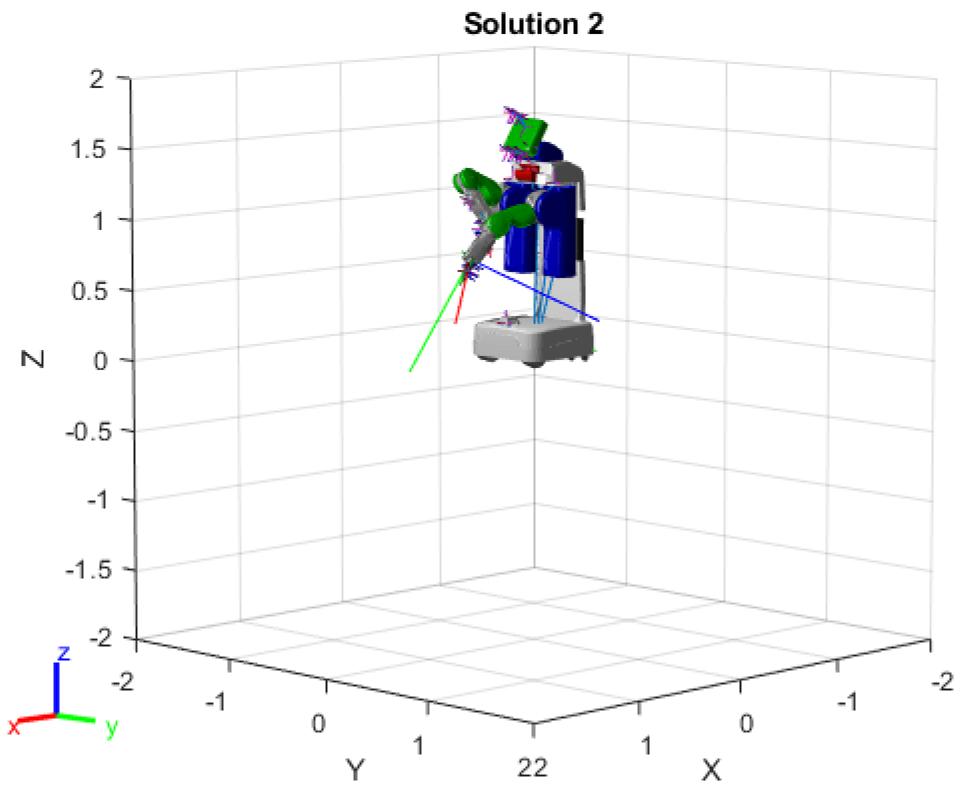
Solve for all robot configurations that achieve the defined end-effector pose using the generated IK function. To ignore joint limits, specify `false` as the second input argument.

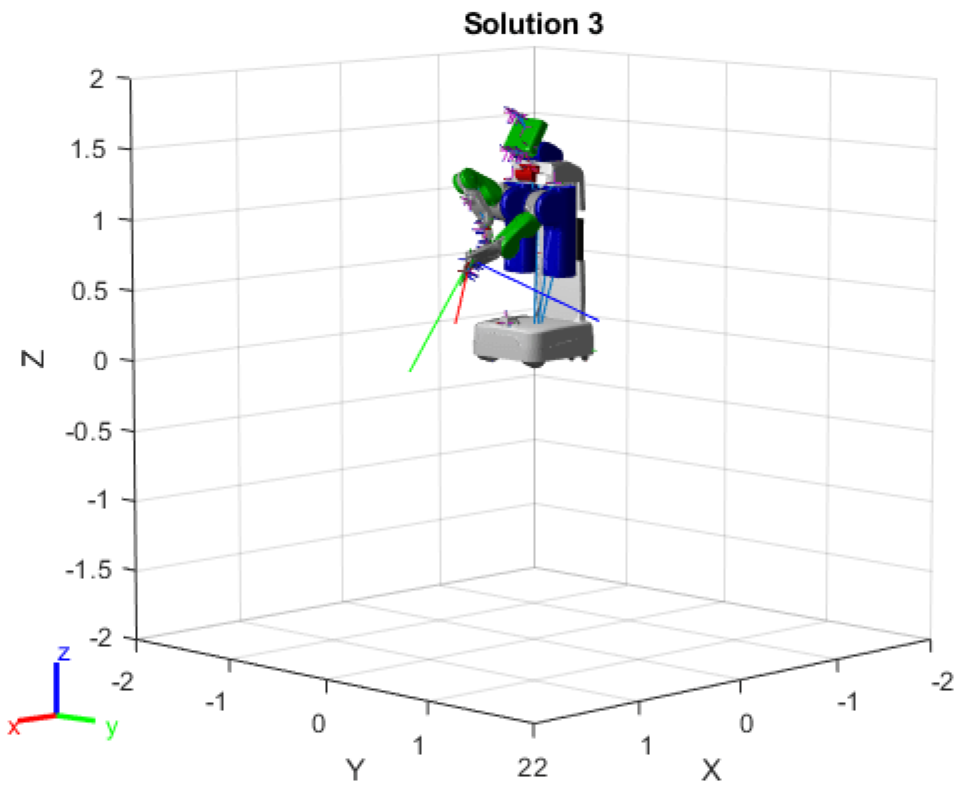
```
ikConfig = willowRobotIK(expEEPose,false);
```

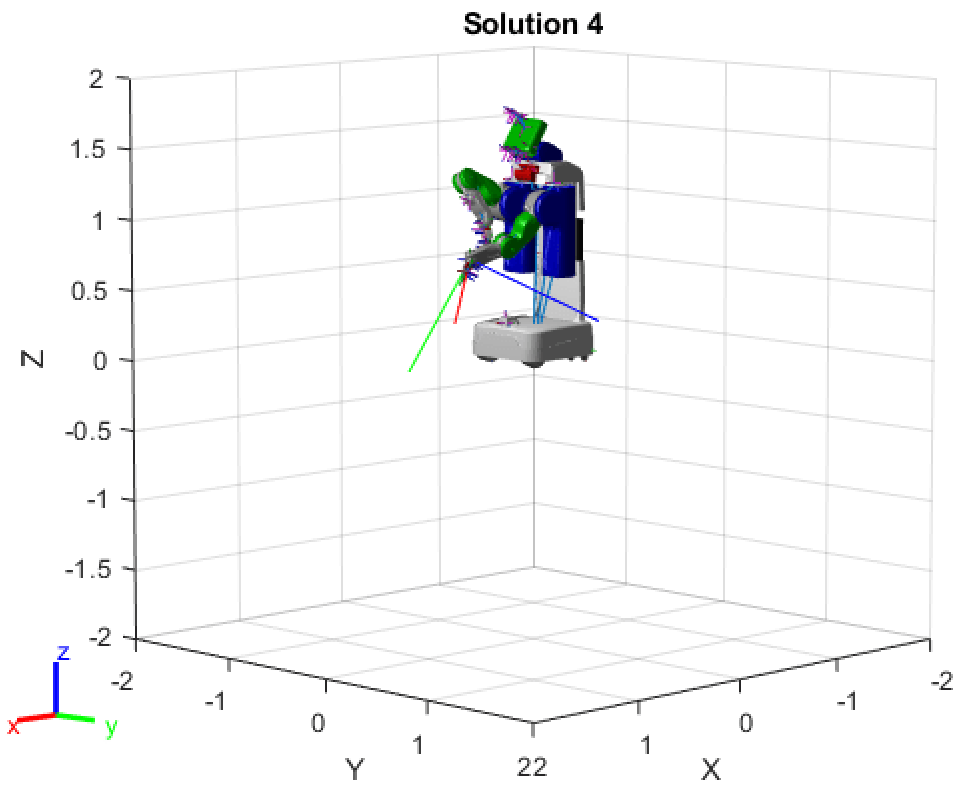
To display the target end-effector pose in the world frame, get the transformation from the base of the robot model, rather than the base of the kinematic group. Display all of the generated IK solutions by specifying the indices for your kinematic group IK solution in the configuration vector used with the `show` function.

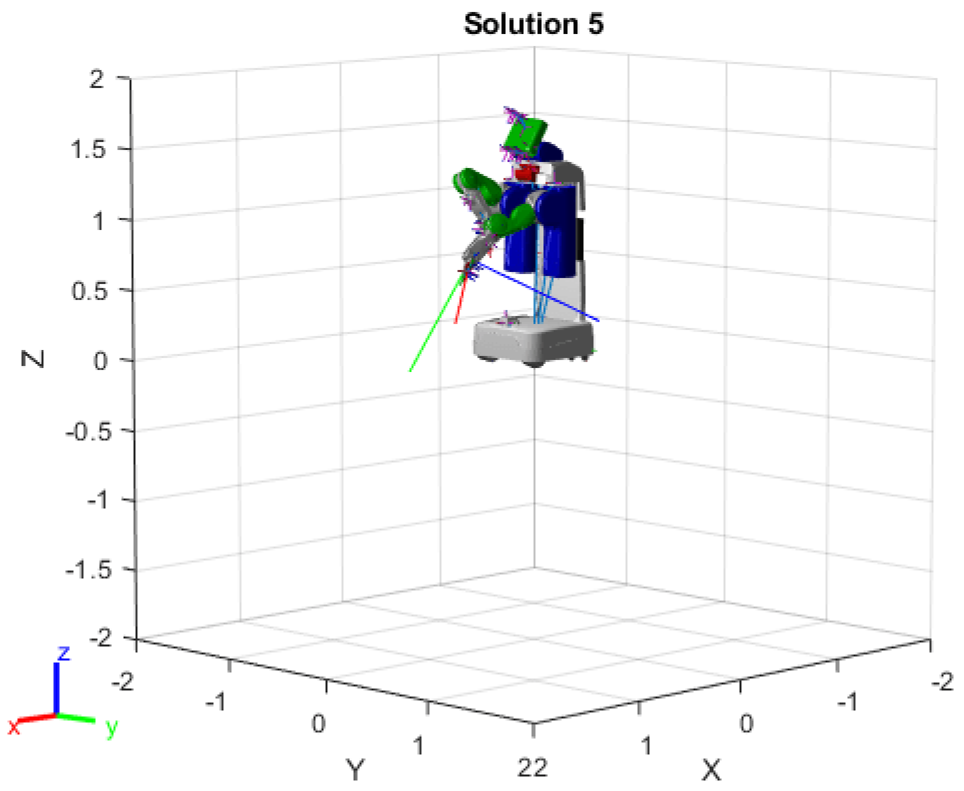
```
eeWorldPose = getTransform(robot,expConfig,eeBodyName);

generatedConfig = repmat(expConfig, size(ikConfig,1), 1);
generatedConfig(:,aik.KinematicGroupConfigIdx) = ikConfig;

for i = 1:size(ikConfig,1)
    figure;
    ax = show(robot,generatedConfig(i,:));
    hold all;
    plotTransforms(tform2trvec(eeWorldPose),tform2quat(eeWorldPose),'Parent',ax);
    title(['Solution ' num2str(i)]);
end
```

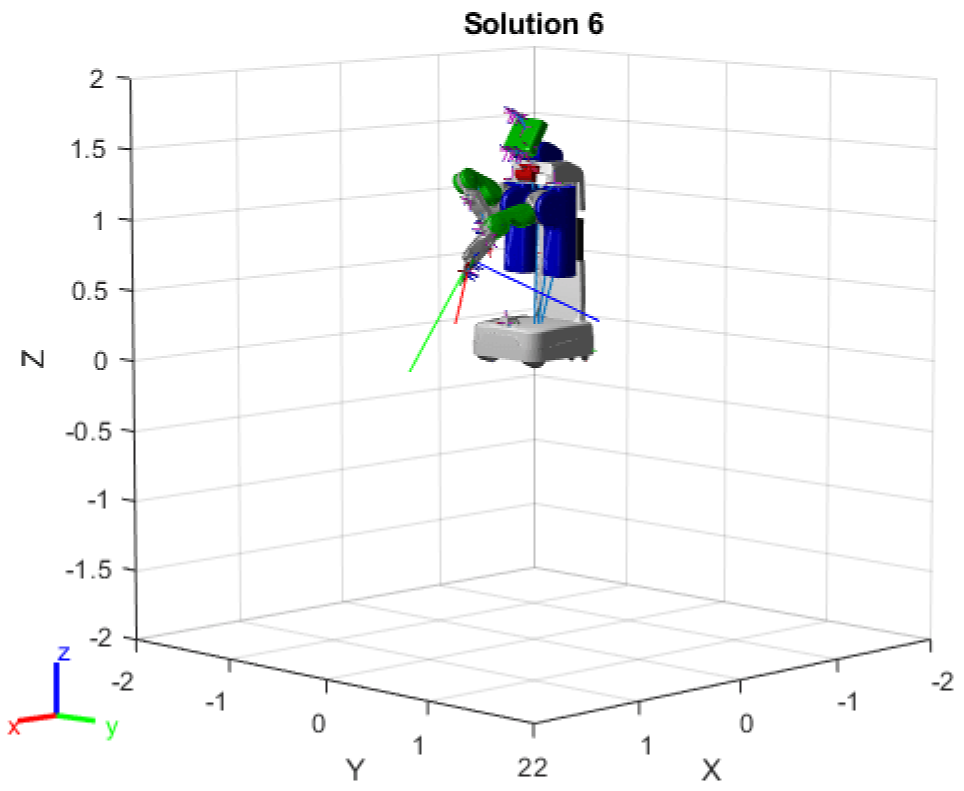

Solution 1
Z
Y
X
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1
0
1
22
1
0
-1
-2
z
x
y

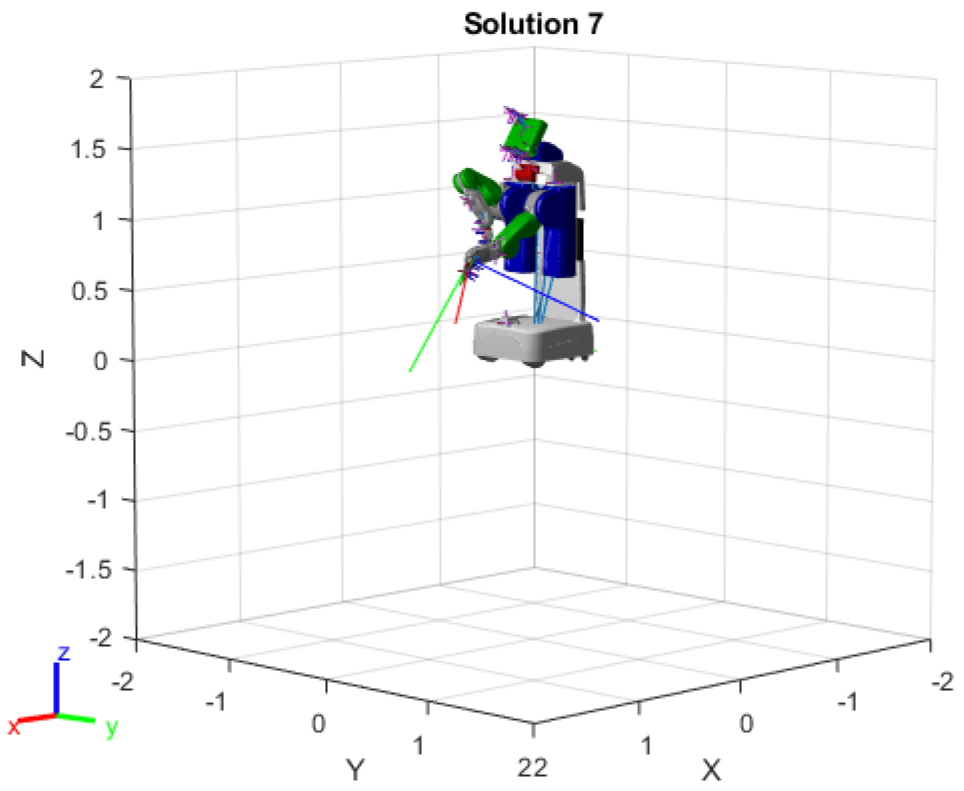

Solution 2
Z
Y
X
z
x
y

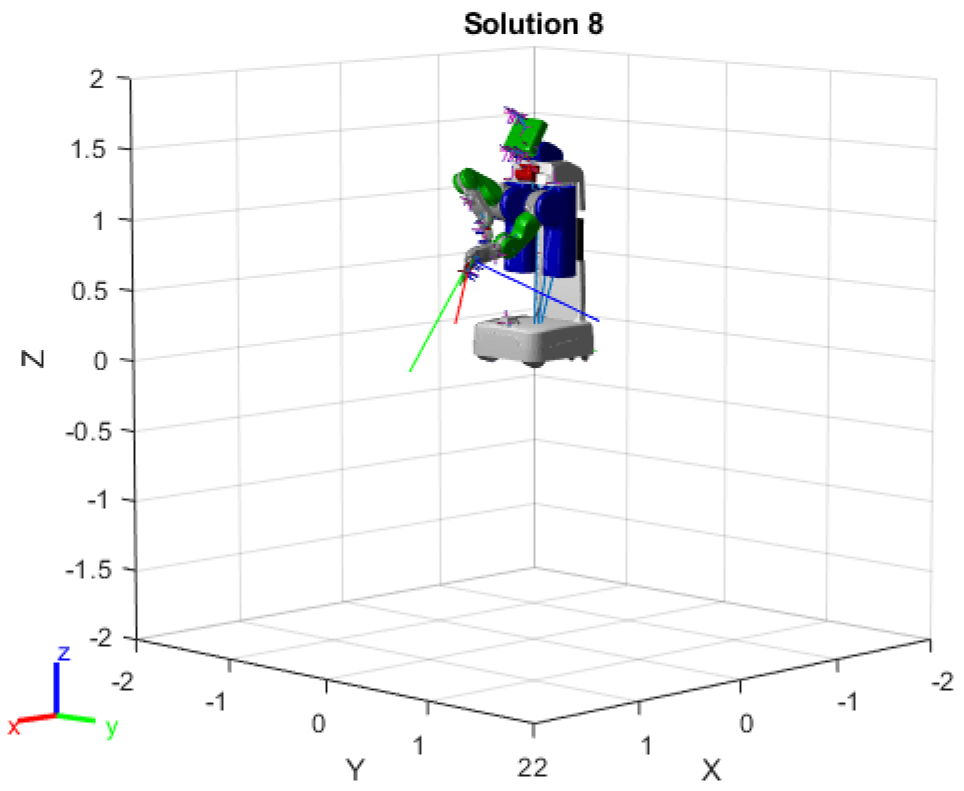

Solution 3
Z
Y
X
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1
0
1
22
1
0
-1
-2
z
x
y


Solution 4
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
z
x
y


Solution 5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
z
x
y


Solution 6
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
z
x
y


Solution 7
Z
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Y
-2
-1
0
1
2
X
2
1
0
-1
-2
z
x
y



Extended Capabilities

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

The `analyticalInverseKinematics` object only supports code generation for the function created by calling the `generateIKFunction`. Use the `analyticalInverseKinematics` object to modify parameters and setup the solver. Then, use `generateIKFunction` to create your custom IK function for your robot model. Call `codegen` on the output `ikFunction` that is generated.

See Also

Objects
`inverseKinematics` | `generalizedInverseKinematics` | `rigidBodyTree`

Functions
`loadrobot` | `importrobot` | `generateIKFunction` | `showdetails`

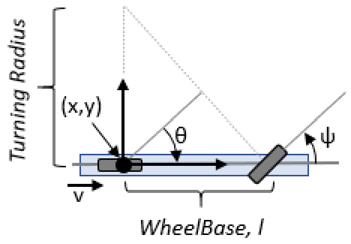
Introduced in R2020b

bicycleKinematics

Bicycle vehicle model

Description

`bicycleKinematics` creates a bicycle vehicle model to simulate simplified car-like vehicle dynamics. This model represents a vehicle with two axles separated by a distance, WheelBase. The state of the vehicle is defined as a three-element vector, [*x y theta*], with a global *xy*-position, specified in meters, and a vehicle heading angle, *theta*, specified in radians. The front wheel can be turned with steering angle *psi*. The vehicle heading, *theta*, is defined at the center of the rear axle. To compute the time derivative states of the model, use the `derivative` function with input commands and the current robot state.



Creation

Syntax

`kinematicModel = bicycleKinematics`

`kinematicModel = bicycleKinematics(Name,Value)`

Description

`kinematicModel = bicycleKinematics` creates a bicycle kinematic model object with default property values.

`kinematicModel = bicycleKinematics(Name,Value)` sets additional properties to the specified values. You can specify multiple properties in any order.

Properties

`WheelBase` — Distance between front and rear axles
`1` (default) | positive numeric scalar

The wheel base refers to the distance between the front and rear vehicle axles, specified in meters.

`VehicleSpeedRange` — Range of vehicle speeds
`[-Inf Inf]` (default) | positive numeric scalar

The vehicle speed range is a two-element vector that provides the minimum and maximum vehicle speeds, [*MinSpeed MaxSpeed*], specified in meters per second.

`MaxSteeringAngle` — Maximum steering angle
`pi/4` (default) | numeric scalar

The maximum steering angle, *psi*, refers to the maximum angle the vehicle can be steered to the right or left, specified in radians. A value of `pi/2` provides the vehicle with a minimum turning radius of 0. This property is used to validate the user-provided state input.

`MinimumTurningRadius` — Minimum vehicle turning radius
`1.0000` (default) | numeric scalar

This read-only property returns the minimum vehicle turning radius in meters. The minimum radius is computed using the wheel base and the maximum steering angle.

`VehicleInputs` — Type of motion inputs for vehicle
`"VehicleSpeedSteeringAngle"` (default) | character vector | string scalar

The `VehicleInputs` property specifies the format of the model input commands when using the `derivative` function. The property has two valid options, specified as a string or character vector:

- `"VehicleSpeedSteeringAngle"` — Vehicle speed and steering angle
- `"VehicleSpeedHeadingRate"` — Vehicle speed and heading angular velocity

Object Functions

derivative	Time derivative of vehicle state

Examples

Plot Path of Bicycle Kinematic Robot

Create a Robot

Define a robot and set the initial starting position and orientation.

```
kinematicModel = bicycleKinematics;
initialState = [0 0 0];
```

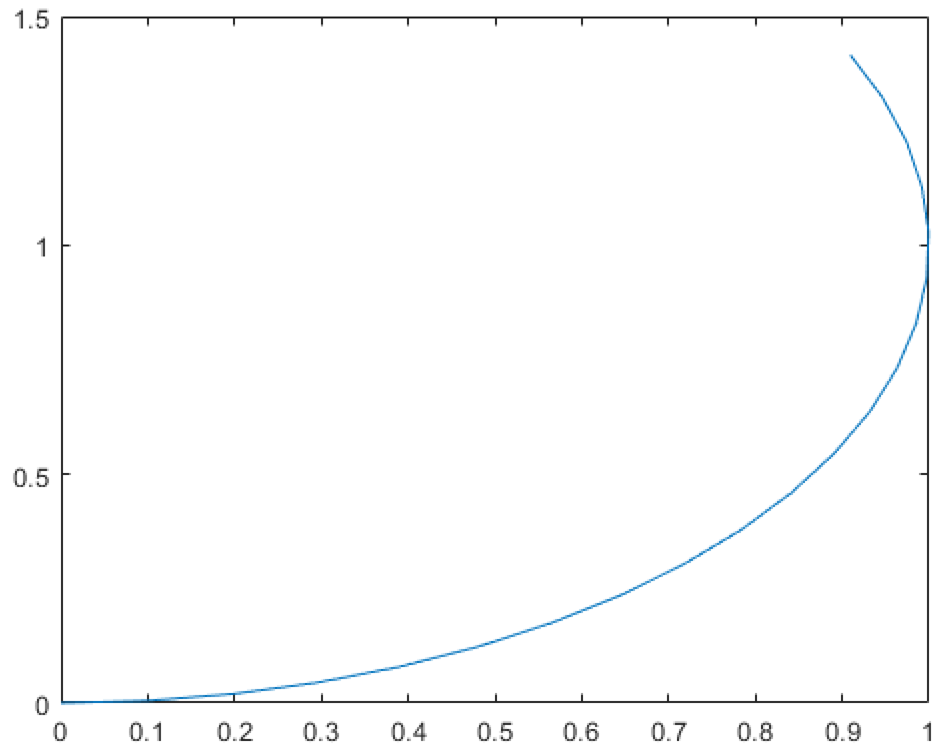
Simulate Robot Motion

Set the timespan of the simulation to 1 s with 0.05 s timesteps and the input commands to 2 m/s and left turn. Simulate the motion of the robot by using the `ode45` solver on the `derivative` function.

```
tspan = 0:0.05:1;
inputs = [2 pi/4]; %Turn left
[t,y] = ode45(@(t,y)derivative(kinematicModel,y,inputs),tspan,initialState);
```

Plot path

```
figure
plot(y(:,1),y(:,2))
```



References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control* 1st ed. Cambridge, MA: Cambridge University Press, 2017.

[2] Corke, Peter I. *Robotics, Vision and Control: Fundamental Algorithms in MATLAB*. Springer, 2011.

Extended Capabilities

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

See Also

Classes
`ackermannKinematics` | `unicycleKinematics` | `differentialDriveKinematics`

Blocks
Bicycle Kinematic Model

Functions
`derivative`

Topics
"Simulate Different Kinematic Models for Mobile Robots"
"Mobile Robot Kinematics Equations"

Introduced in R2019b

binaryOccupancyMap

Create occupancy grid with binary values

Description

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

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

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

The object keeps track of three reference frames: world, local, and, grid. The world frame origin is defined by `GridLocationInWorld`, which defines the bottom-left corner of the map relative to the world frame. The `LocalOriginInWorld` property specifies the location of the origin of the local frame relative to the world frame. The first grid location with index `(1,1)` begins in the top-left corner of the grid.

Note This object was previously named `robotics.BinaryOccupancyGrid`.

Creation

Syntax

```
map = binaryOccupancyMap
map = binaryOccupancyMap(width,height)
map = binaryOccupancyMap(width,height,resolution)

map = binaryOccupancyMap(rows,cols,resolution,"grid")

map = binaryOccupancyMap(p)
map = binaryOccupancyMap(p,resolution)
map = binaryOccupancyMap(p,resolution)

map = binaryOccupancyMap(sourcemap)
map = binaryOccupancyMap(sourcemap,resolution)
```

Description

`map = binaryOccupancyMap` creates a 2-D binary occupancy grid with a width and height of 10m. The default grid resolution is one cell per meter.

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

`map = binaryOccupancyMap(width,height,resolution)` creates a grid with the `Resolution` property specified in cells per meter. The map is in world coordinates by default.

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

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

`map = binaryOccupancyMap(p,resolution)` creates a map from a matrix with the `Resolution` property specified in cells per meter.

`map = binaryOccupancyMap(p,resolution)` creates an object with the `Resolution` property specified in cells per meter.

`map = binaryOccupancyMap(sourcemap)` creates an object using values from another `binaryOccupancyMap` object.

`map = binaryOccupancyMap(sourcemap,resolution)` creates an object using values from another `binaryOccupancyMap` object, but resamples the matrix to have the specified resolution.

Input Arguments

`width` — Map width
positive scalar

Map width, specified as a positive scalar in meters.

`height` — Map height
positive scalar

Map height, specified as a positive scalar in meters.

`p` — Map grid values
matrix

Map grid values, specified as a matrix.

`sourcemap` — Occupancy map object
`binaryOccupancyMap` object

Occupancy map object, specified as a `binaryOccupancyMap` object.

Properties

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

This property is read-only.

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

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

This property is read-only.

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

`XLocalLimits` — Minimum and maximum values of *x*-coordinates in local frame
two-element vector

This property is read-only.

Minimum and maximum values of *x*-coordinates in local frame, stored as a two-element horizontal vector of the form `[min max]`. Local frame is defined by `LocalOriginInWorld` property.

`YLocalLimits` — Minimum and maximum values of *y*-coordinates in local frame
two-element vector

This property is read-only.

Minimum and maximum values of *y*-coordinates in local frame, stored as a two-element horizontal vector of the form `[min max]`. Local frame is defined by `LocalOriginInWorld` property.

`XWorldLimits` — Minimum and maximum values of *x*-coordinates in world frame
two-element vector

This property is read-only.

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

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

This property is read-only.

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

`GridLocationInWorld` — Location of the grid in world coordinates
[0 0] (default) | two-element vector | `[xGrid yGrid]`

Location of the bottom-left corner of the grid in world coordinates, specified as a two-element vector, `[xGrid yGrid]`.

`LocalOriginInWorld` — Location of the local frame in world coordinates
[0 0] (default) | two-element vector | `[xWorld yWorld]`

Location of the origin of the local frame in world coordinates, specified as a two-element vector, `[xLocal yLocal]`. Use the `move` function to shift the local frame as your vehicle moves.

`GridOriginInLocal` — Location of the grid in local coordinates
[0 0] (default) | two-element vector | `[xLocal yLocal]`

Location of the bottom-left corner of the grid in local coordinates, specified as a two-element vector, `[xLocal yLocal]`.

`DefaultValue` — Default value for unspecified map locations
`0` (default) | `1`

Default value for unspecified map locations including areas outside the map, specified as `0` or `1`.

Object Functions

checkOccupancy	Check occupancy values for locations
getOccupancy	Get occupancy value of locations
grid2local	Convert grid indices to local coordinates
grid2world	Convert grid indices to world coordinates
inflate	Inflate each occupied grid location
insertRay	Insert ray from laser scan observation
local2grid	Convert local coordinates to grid indices
local2world	Convert local coordinates to world coordinates
move	Move map in world frame
occupancyMatrix	Convert occupancy grid to matrix
raycast	Compute cell indices along a ray
rayIntersection	Find intersection points of rays and occupied map cells
setOccupancy	Set occupancy value of locations
show	Show occupancy grid values
syncWith	Sync map with overlapping map
world2grid	Convert world coordinates to grid indices
world2local	Convert world coordinates to local coordinates

Examples

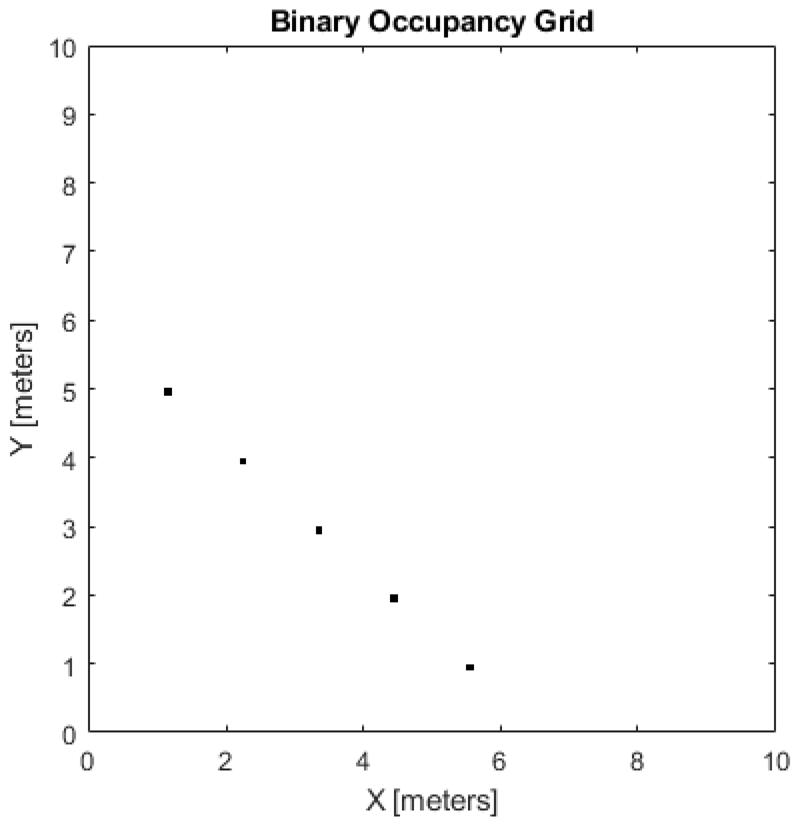
Create and Modify Binary Occupancy Grid

Create a 10m x 10m empty map.

```
map = binaryOccupancyMap(10,10,10);
```

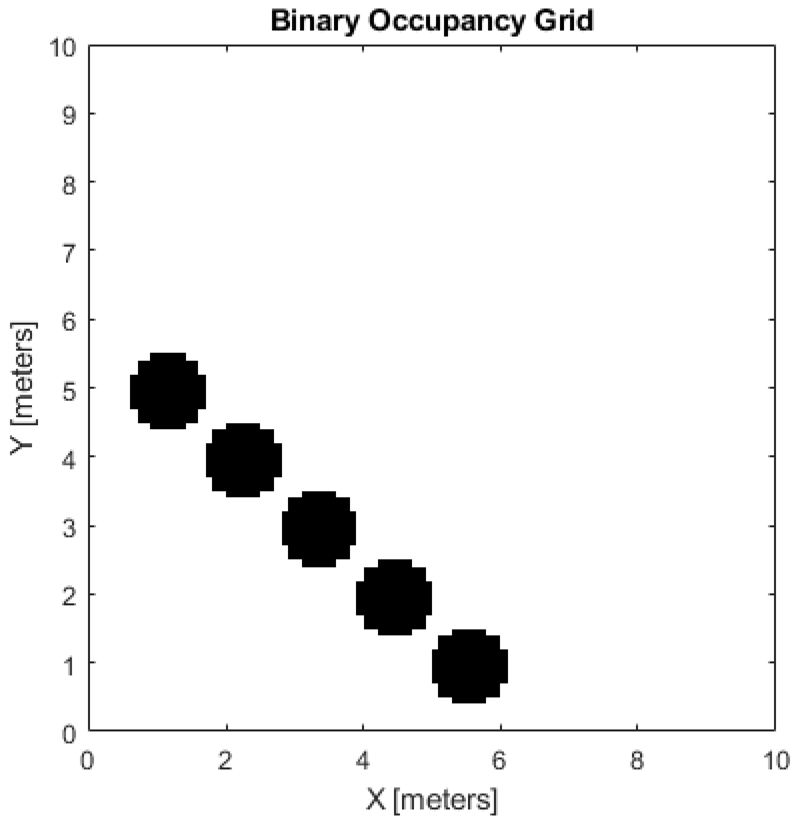
Set occupancy of world locations and show map.

```
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

setOccupancy(map, [x y], ones(5,1))
figure
show(map)
```



Inflate occupied locations by a given radius.

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



Get grid locations from world locations.

```
ij = world2grid(map, [x y]);
```

Set grid locations to free locations.

```
setOccupancy(map, ij, zeros(5,1), 'grid')
figure
show(map)
```

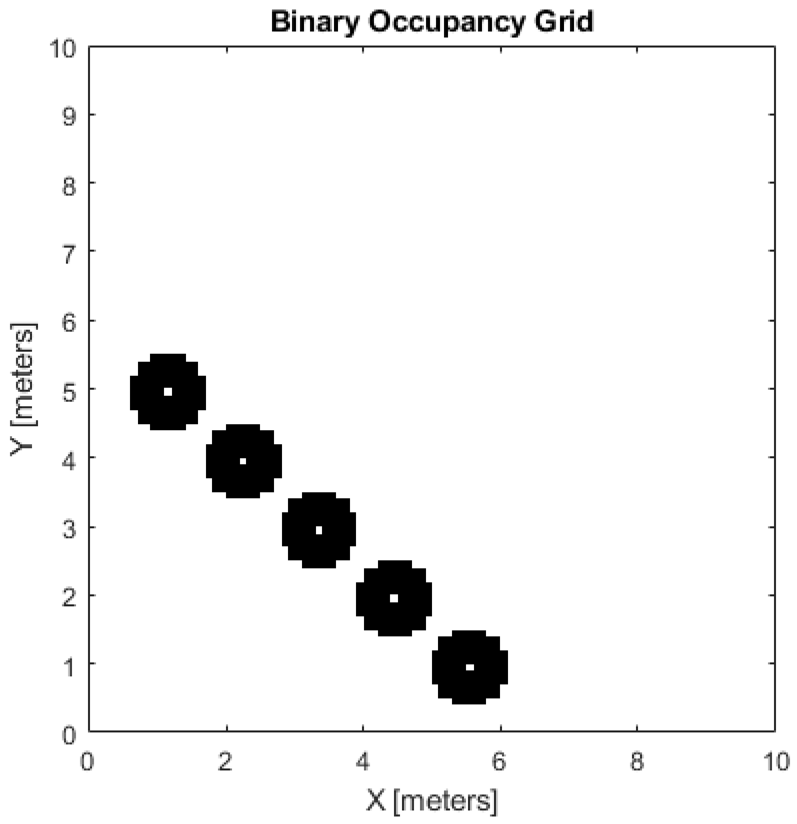


Image to Binary Occupancy Grid Example

This example shows how to convert an image to a binary occupancy grid for using with mapping and path planning.

Import image.

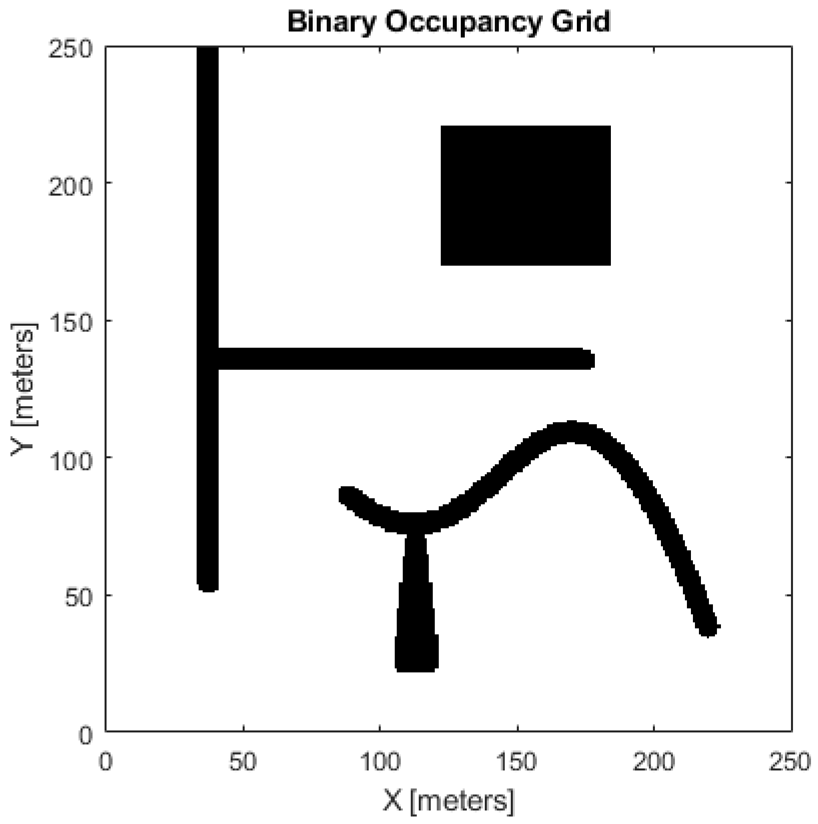
```
image = imread('imageMap.png');
```

Convert to grayscale and then black and white image based on given threshold value.

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

Use black and white image as matrix input for binary occupancy grid.

```
grid = binaryOccupancyMap(bwimage);

show(grid)
```

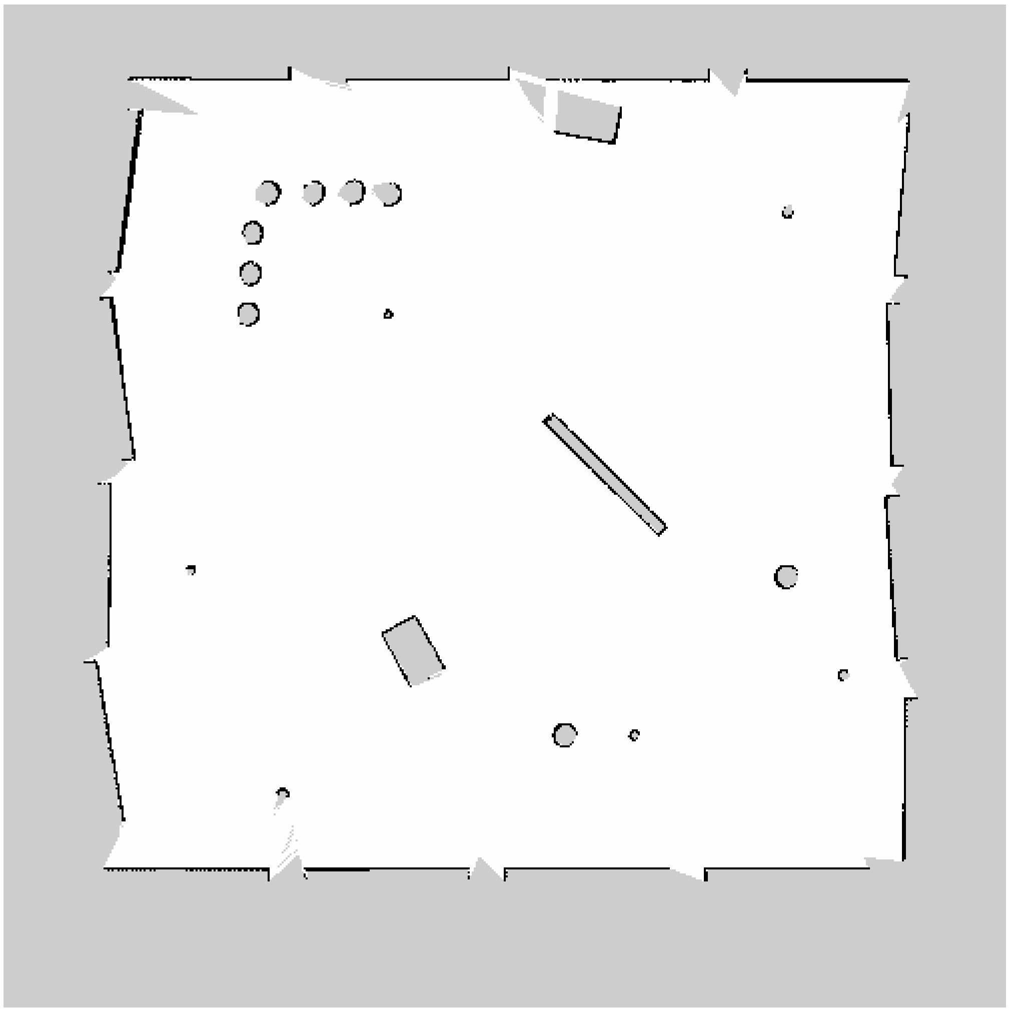


Convert PGM Image to Map

This example shows how to convert a `.pgm` file into a `binaryOccupancyMap` object for use in MATLAB.

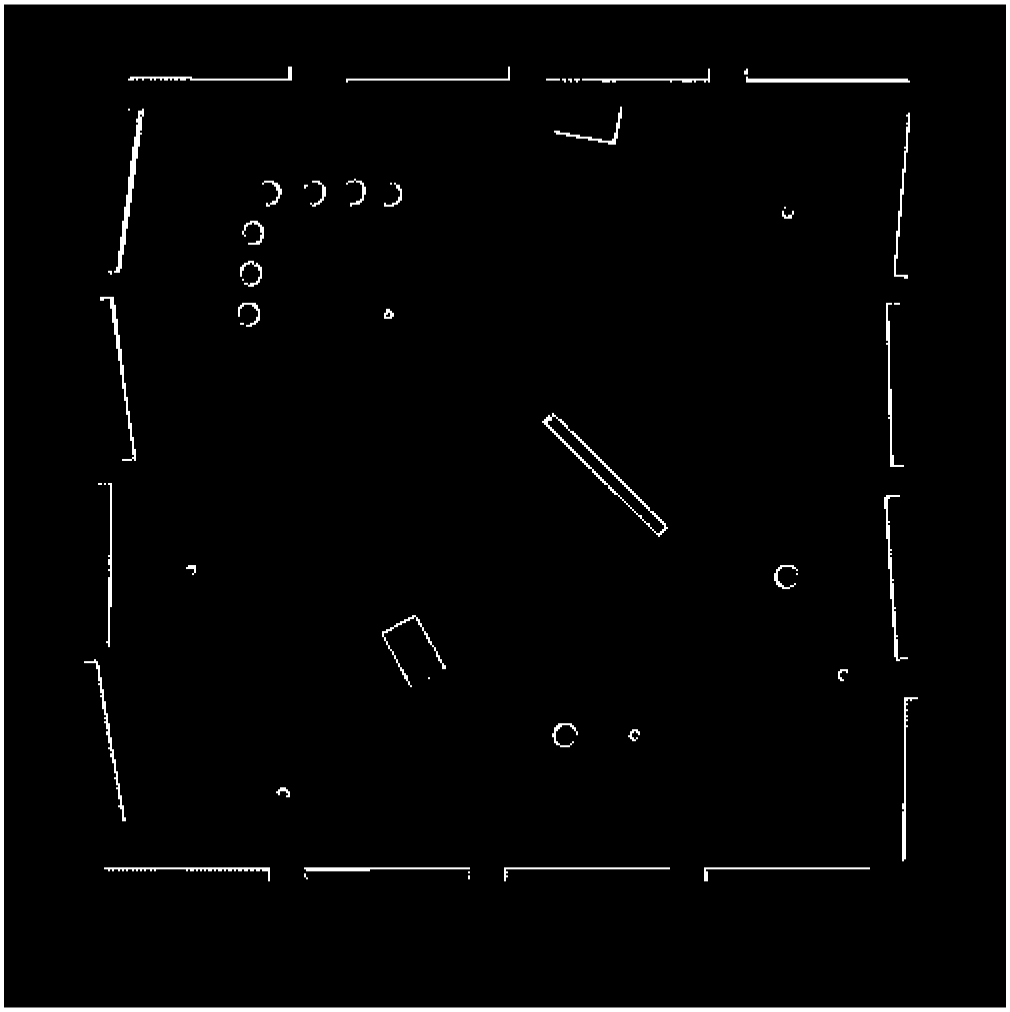
Import image using `imread`. The image is quite large and should be cropped to the relevant area.

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



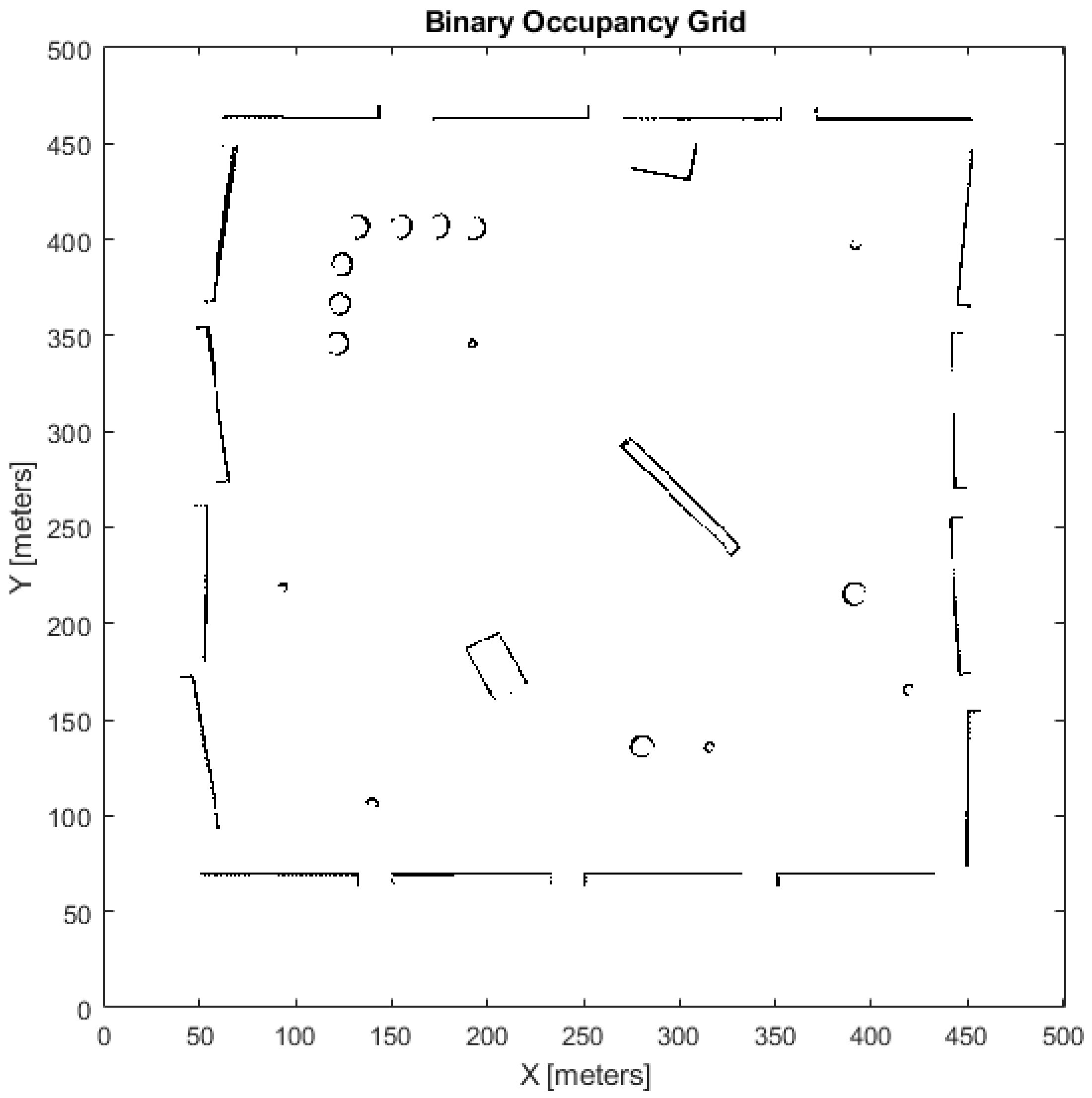
Unknown areas (gray) should be removed and treated as free space. Create a logical matrix based on a threshold. Depending on your image, this value could be different. Occupied space should be set as 1 (white in image).

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



Create `binaryOccupancyMap` object using adjusted map image.

```
map = binaryOccupancyMap(imageBW);
show(map)
```



Compatibility Considerations

`binaryOccupancyMap` was renamed

Behavior change in future release

The `binaryOccupancyMap` object was renamed from `robotics.BinaryOccupancyGrid`. Use `binaryOccupancyMap` for all object creation.

Extended Capabilities

C/C++ Code Generation

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

See Also

`mobileRobotPRM` | `controllerPurePursuit`

Topics

"Occupancy Grids"

Introduced in R2015a

collisionBox

Create box collision geometry

Description

Use `collisionBox` to create a box collision geometry centered at the origin.

Creation

Syntax

`BOX = collisionBox(X,Y,Z)`

Description

`BOX = collisionBox(X,Y,Z)` creates an axis-aligned box collision geometry centered at the origin with X, Y, and Z as its side lengths along the corresponding axes in the geometry-fixed frame. By default, the geometry-fixed frame collocates with the world frame.

Properties

X — Side length of box geometry
positive scalar

Side length of box geometry along the *x*-axis, specified as a positive scalar. Units are in meters.

Data Types: `double`

Y — Side length of box geometry
positive scalar

Side length of box geometry along the *y*-axis, specified as a positive scalar. Units are in meters.

Data Types: `double`

Z — Side length of box geometry
positive scalar

Side length of box geometry along the *z*-axis, specified as a positive scalar. Units are in meters.

Data Types: `double`

Pose — Pose
`eye(4)` (default) | real-valued matrix

Pose of the collision geometry relative to the world frame, specified as a 4-by-4 homogeneous matrix. You can change the pose after you create the collision geometry.

Data Types: `double`

Object Functions

show	Show collision geometry

Examples

Create and Visualize Box Collision Geometry

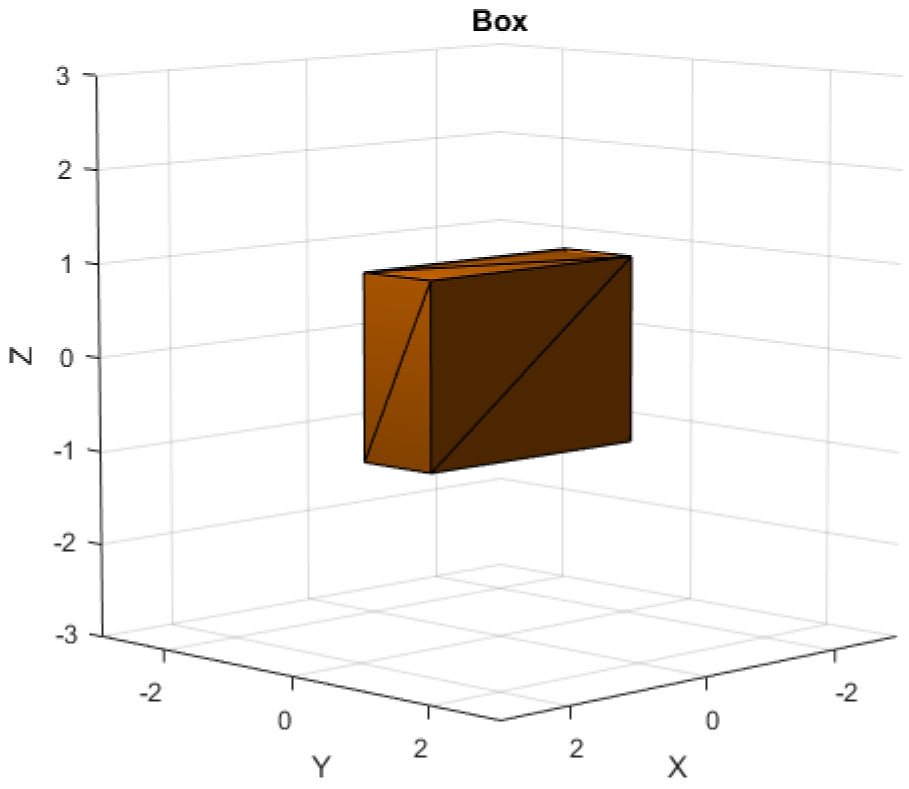
Create a box collision geometry centered at the origin. The side lengths in the *x*-, *y*-, and *z*-directions are 3, 1, and 2 meters, respectively.

```
box = collisionBox(3,1,2)
```

```
box = 
  collisionBox with properties:

        X: 3
        Y: 1
        Z: 2
     Pose: [4x4 double]
```

Visualize the box.

```
show(box)
title('Box')
```

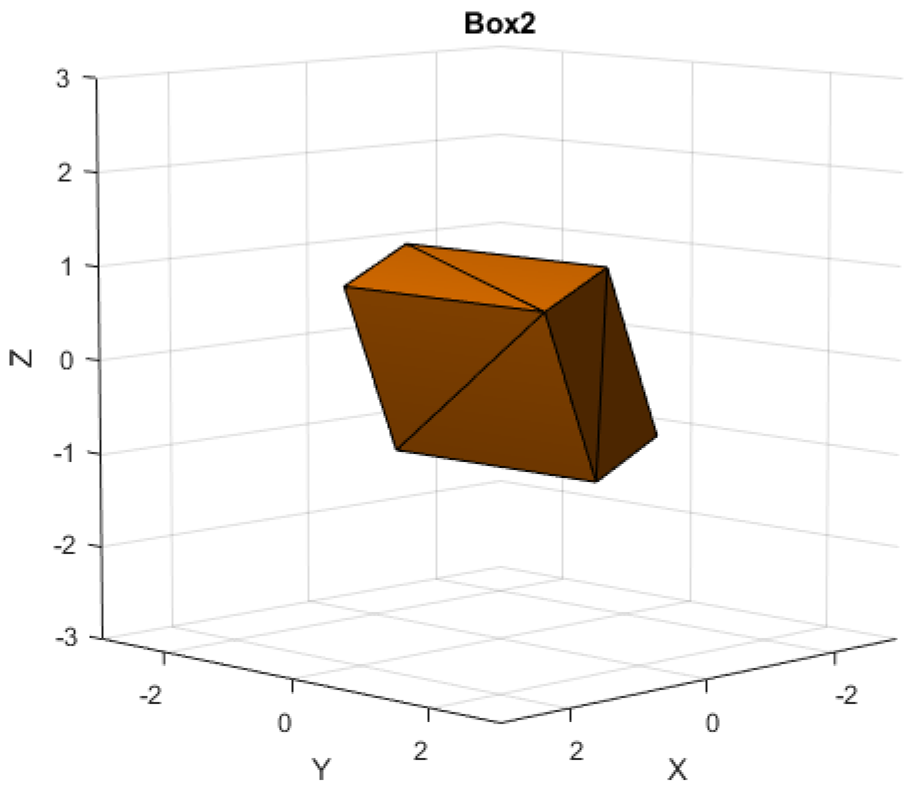


Create two homogeneous transformation matrices. The first matrix is a rotation about the *z*-axis by *π*/2 radians, and the second matrix is a rotation about the *x*-axis of *π*/8 radians.

```
matZ = axang2tform([0 0 1 pi/2]);
matX = axang2tform([1 0 0 pi/8]);
```

Create a second box collision geometry with the same dimensions as the first. Change its pose to the product of the two matrices. The product corresponds to first rotation about the z-axis followed by rotation about the x-axis. Visualize the result.

```
box2 = collisionBox(3,1,2);
box2.Pose = matZ*matX;
show(box2)
title('Box2')
```



Extended Capabilities

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

See Also
`collisionCylinder` | `collisionMesh` | `collisionSphere` | `checkCollision`

Introduced in R2019b

collisionCylinder

Create collision cylinder geometry

Description

Use `collisionCylinder` to create a cylinder collision geometry centered at the origin.

Creation

Syntax

`CYL = collisionCylinder(Radius,Length)`

Description

`CYL = collisionCylinder(Radius,Length)` creates a cylinder collision geometry with a specified Radius and Length. The cylinder is axis-aligned with its own body-fixed frame. The side of the cylinder lies along the *z*-axis. The origin of the body-fixed frame is at the center of the cylinder.

Properties

`Radius` — Radius
positive scalar

Radius of cylinder, specified as a positive scalar. Units are in meters.

Data Types: `double`

`Length` — Length
positive scalar

Length of cylinder, specified as a positive scalar. Units are in meters.

Data Types: `double`

`Pose` — Pose
`eye(4)` (default) | real-valued matrix

Pose of the collision geometry relative to the world frame, specified as a 4-by-4 homogeneous matrix. You can change the pose after you create the collision geometry.

Data Types: `double`

Object Functions

show	Show collision geometry

Examples

Create and Visualize Cylinder Collision Geometry

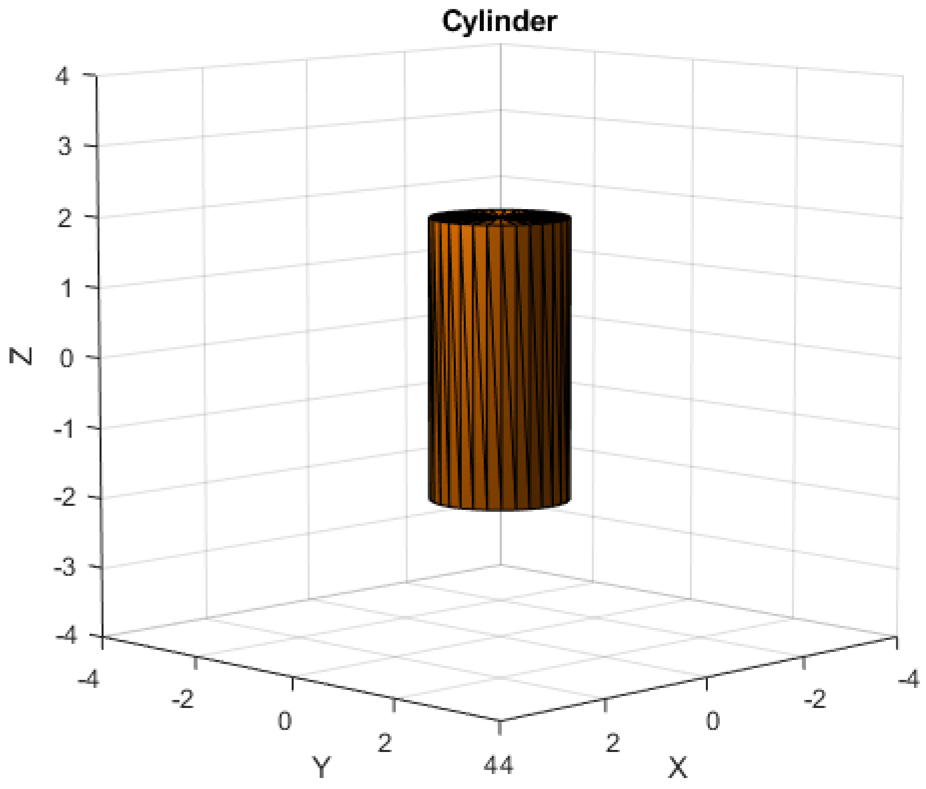
Create a cylinder collision geometry centered at the origin. The cylinder is 4 meters long with a radius of 1 meter.

```
rad = 1;
len = 4;
cyl = collisionCylinder(rad,len)
```

```
cyl = 
  collisionCylinder with properties:

    Radius: 1
    Length: 4
      Pose: [4x4 double]
```

Visualize the cylinder.

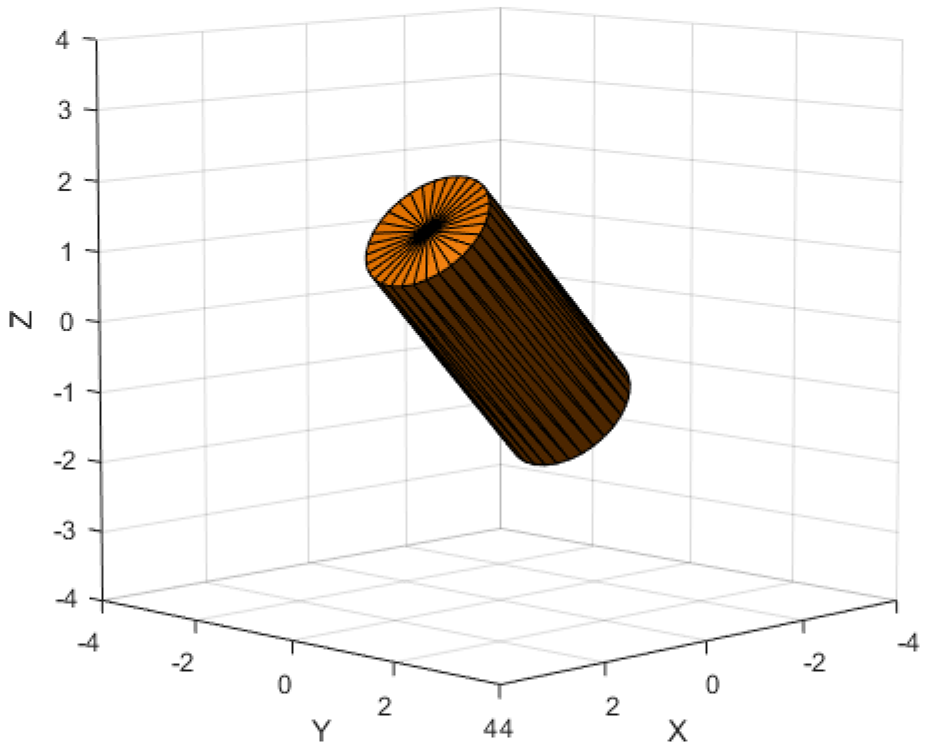
```
show(cyl)
title('Cylinder')
```



Create a homogeneous transformation that corresponds to a clockwise rotation of $\pi/4$ radians about the *y*-axis. Set the cylinder pose to the new matrix. Show the cylinder.

```
ang = pi/4;
mat = axang2tform([0 1 0 ang]);
```

```
cyl.Pose = mat;
show(cyl)
```



Extended Capabilities

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

See Also

`collisionBox` | `collisionMesh` | `collisionSphere` | `checkCollision`

Introduced in R2019b

collisionMesh

Create convex mesh collision geometry

Description

Use `collisionMesh` to create a collision geometry as a convex mesh.

Creation

Syntax

`MSH = collisionMesh(Vertices)`

Description

`MSH = collisionMesh(Vertices)` creates a convex mesh collision geometry from the list of 3-D Vertices. The vertices are specified relative to a frame of choice (collision geometry frame). By default, the collision geometry frame collocates with the world frame.

Properties

`Vertices` — Vertices
3-D real-valued array

Vertices of a mesh, specified as an *N*-by-3 array, where *N* is the number of vertices. Each row of `Vertices` represents the coordinates of a point in 3-D space. Note that some of the points can be inside the constructed convex mesh.

Data Types: `double`

Pose — Pose
`eye(4)` (default) | real-valued matrix

Pose of the collision geometry relative to the world frame, specified as a 4-by-4 homogeneous matrix. You can change the pose after you create the collision geometry.

Data Types: `double`

Object Functions

show	Show collision geometry

Examples

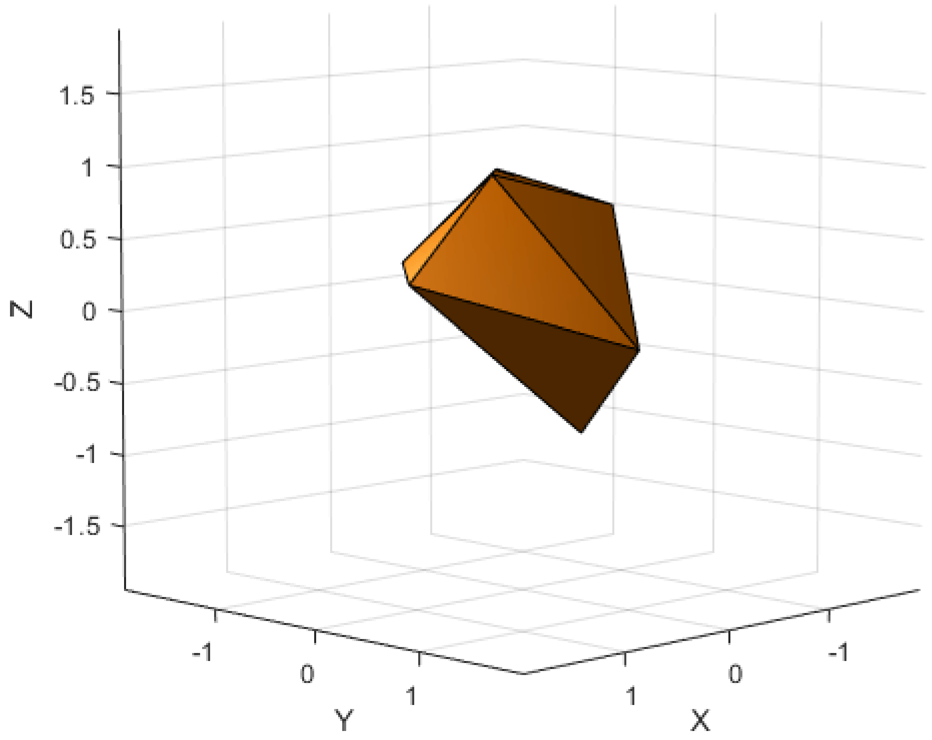
Create and Visualize Mesh Collision Geometry

Create an array consisting of the coordinates of ten points randomly chosen on the unit sphere. For reproducibility, set the random seed to the default value.

```
rng default
n = 10;
pts = zeros(n,3);
for k = 1:n
    ph = 2*pi*rand(1);
    th = pi*rand(1);
    pts(k,:) = [cos(th)*sin(ph) sin(th)*sin(ph) cos(ph)];
end
```

Create a convex mesh collision geometry from the array. Visualize the collision geometry.

```
m = collisionMesh(pts);
show(m)
```

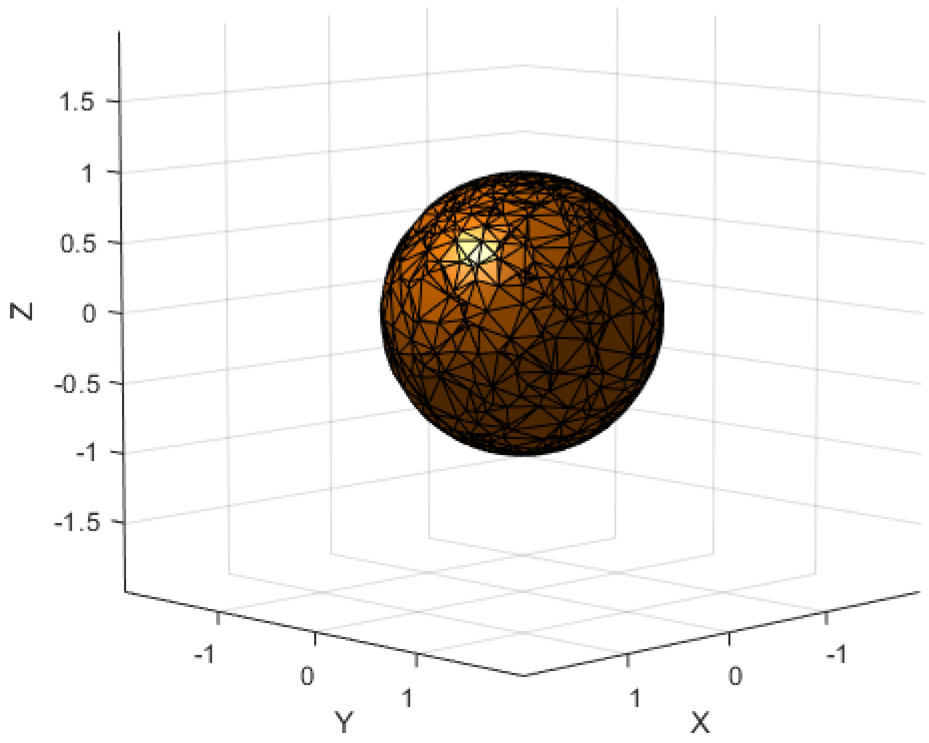


Create a second array similar to the first, but this time consisting of 1000 points randomly chosen on the unit sphere.

```
n = 1000;
pts2 = zeros(n,3);
for k = 1:n
    ph = 2*pi*rand(1);
    th = pi*rand(1);
    pts2(k,:) = [cos(th)*sin(ph) sin(th)*sin(ph) cos(ph)];
end
```

Create and visualize a mesh collision geometry from the array. Observe that choosing more points on the sphere results in a sphere-like mesh.

```
m2 = collisionMesh(pts2);
show(m2)
```



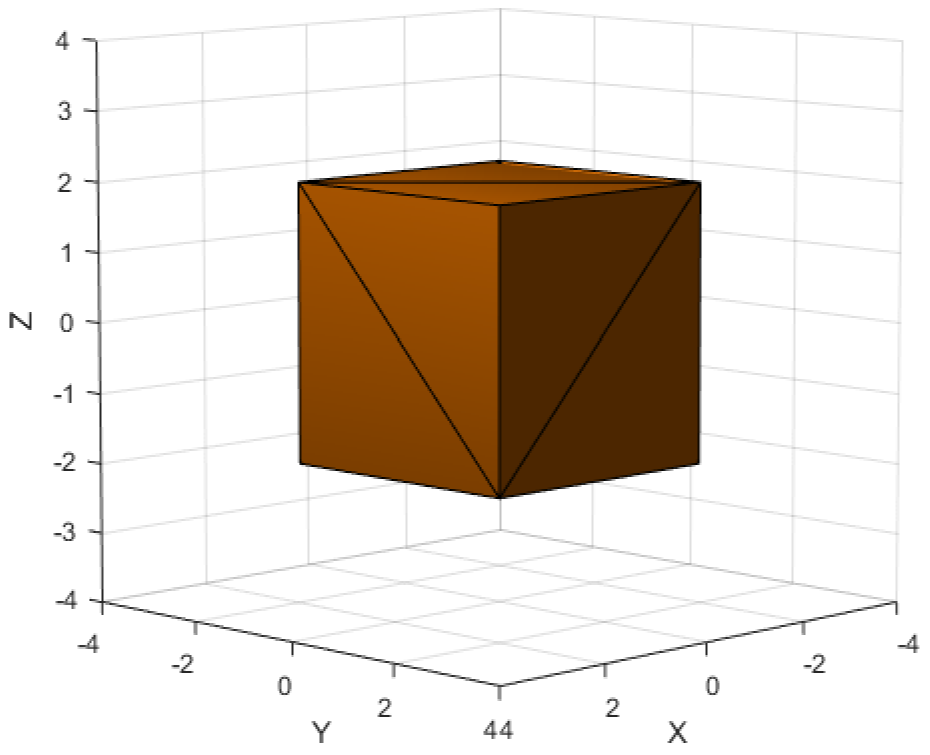
Create an array consisting of the coordinates of the eight corners of a cube. The cube is centered at the origin and has side length 4.

```
cubeCorners = [-2 -2 -2 ; -2 2 -2 ; 2 -2 -2 ; 2 2 -2 ;...
    -2 -2 2 ; -2 2 2 ; 2 -2 2 ; 2 2 2]
```

```
cubeCorners = 8×3

    -2    -2    -2
    -2     2    -2
     2    -2    -2
     2     2    -2
    -2    -2     2
    -2     2     2
     2    -2     2
     2     2     2
```

Append `cubeCorners` to `pts2`. Create and visualize the mesh collision geometry from the new array. Because the cube contains the sphere, the sphere points that are interior to the cube are disregarded when creating the geometry.

```
pts3 = [pts2;cubeCorners];
m3 = collisionMesh(pts3);
show(m3)
```



Extended Capabilities

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

See Also

`collisionBox` | `collisionCylinder` | `collisionSphere` | `checkCollision`

Introduced in R2019b

collisionSphere

Create sphere collision geometry

Description

Use `collisionSphere` to create a sphere collision geometry centered at the origin.

Creation

Syntax

```
sph = collisionSphere(Radius)
```

Description

`sph = collisionSphere(Radius)` creates a sphere collision geometry with a specified Radius. The origin of the geometry-fixed frame is at the center of the sphere.

Properties

`Radius` — Radius
positive scalar

Radius of sphere, specified as a positive scalar. Units are in meters.

Data Types: `double`

Pose — Pose
`eye(4)` (default) | real-valued matrix

Pose of the collision geometry relative to the world frame, specified as a 4-by-4 homogeneous matrix. You can change the pose after you create the collision geometry.

Data Types: `double`

Object Functions

show	Show collision geometry

Examples

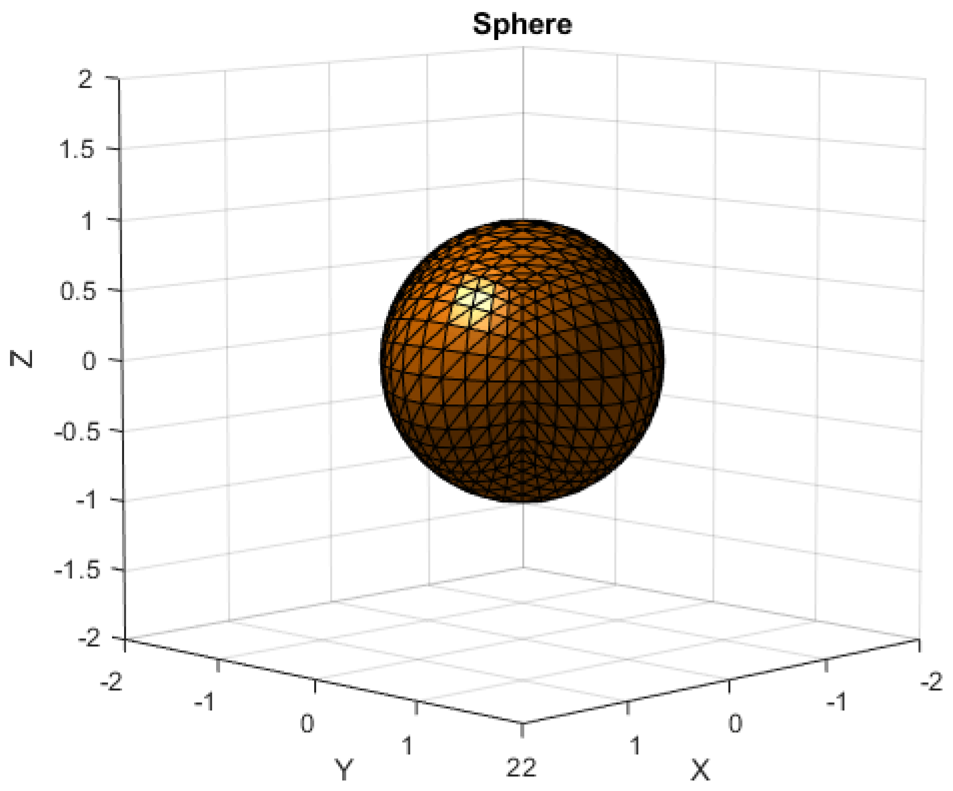
Create and Visualize Sphere Collision Geometry

Create a sphere collision geometry centered at the origin. The sphere has a radius of 1 meter.

```
rad = 1;
sph = collisionSphere(rad)
sph =
  collisionSphere with properties:

    Radius: 1
      Pose: [4x4 double]
```

Visualize the sphere.

```
show(sph)
title('Sphere')
```

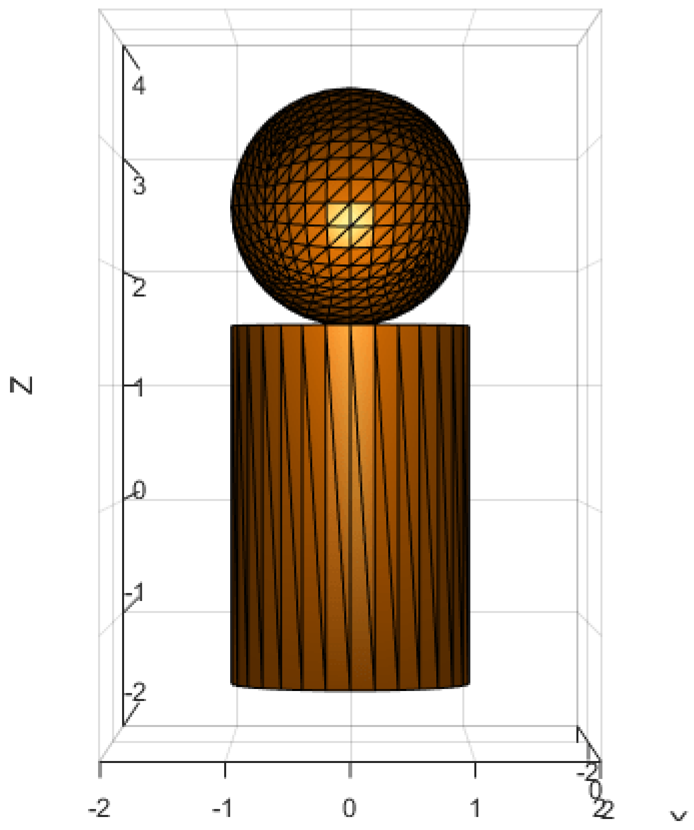


Create a cylinder collision geometry of radius 1 meter and length 3 meters.

```
cyl = collisionCylinder(1,3);
```

Create a homogeneous transformation that corresponds to a translation of 2.5 meters up the *z*-axis. Set the pose of the sphere to the matrix. Show the sphere and the cylinder.

```
mat = trvec2tform([0 0 2.5]);
sph.Pose = mat;
show(sph)
hold on
show(cyl)
view(90,0)
zlim([-2 4])
```



Extended Capabilities

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

See Also

`collisionCylinder` | `collisionMesh` | `collisionBox` | `checkCollision`

Introduced in R2019b

constraintAiming class

Create aiming constraint for pointing at a target location

Description

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

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

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

Construction

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

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

Input Arguments

`endeffector` — End-effector name
string scalar | character vector

End-effector name, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

Properties

`EndEffector` — Name of the end effector
string scalar | character vector

Name of the end effector, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

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

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

Data Types: `char` | `string`

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

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

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

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

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

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

Compatibility Considerations

`constraintAiming` was renamed
Behavior change in future release

The `constraintAiming` object was renamed from `robotics.AimingConstraint`. Use `constraintAiming` for all object creation.

Extended Capabilities

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

See Also

Classes
`generalizedInverseKinematics` | `constraintOrientationTarget` | `constraintPoseTarget` | `constraintPositionTarget`

Topics
“Plan a Reaching Trajectory With Multiple Kinematic Constraints”

Introduced in R2017a

constraintCartesianBounds

Create constraint to keep body origin inside Cartesian bounds

Description

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

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

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

Creation

Syntax

```
cartConst = constraintCartesianBounds(endeffector)
cartConst = constraintCartesianBounds(endeffector,Name,Value)
```

Description

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

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

Input Arguments

`endeffector` — End-effector name
string scalar | character vector

End-effector name, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

Properties

`EndEffector` — Name of the end effector
string scalar | character vector

Name of the end effector, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

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

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

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

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

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

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

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

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

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

Examples

Plan a Reaching Trajectory With Multiple Kinematic Constraints

This example shows how to use generalized inverse kinematics to plan a joint-space trajectory for a robotic manipulator. It combines multiple constraints to generate a trajectory that guides the gripper to a cup resting on a table. These constraints ensure that the gripper approaches the cup in a straight line and that the gripper remains at a safe distance from the table, without requiring the poses of the gripper to be determined in advance.

Set Up the Robot Model

This example uses a model of the KUKA LBR iiwa, a 7 degree-of-freedom robot manipulator. `importrobot` generates a `rigidBodyTree` model from a description stored in a Unified Robot Description Format (URDF) file.

```
lbr = importrobot('iiwa14.urdf'); % 14 kg payload version
lbr.DataFormat = 'row';
gripper = 'iiwa_link_ee_kuka';
```

Define dimensions for the cup.

```
cupHeight = 0.2;
cupRadius = 0.05;
cupPosition = [-0.5, 0.5, cupHeight/2];
```

Add a fixed body to the robot model representing the center of the cup.

```
body = rigidBody('cupFrame');
setFixedTransform(body.Joint, trvec2tform(cupPosition))
addBody(lbr, body, lbr.BaseName);
```

Define the Planning Problem

The goal of this example is to generate a sequence of robot configurations that satisfy the following criteria:

- Start in the home configuration
- No abrupt changes in robot configuration
- Keep the gripper at least 5 cm above the "table" (z = 0)
- The gripper should be aligned with the cup as it approaches
- Finish with the gripper 5 cm from the center of the cup

This example utilizes constraint objects to generate robot configurations that satisfy these criteria. The generated trajectory consists of five configuration waypoints. The first waypoint, `q0`, is set as the home configuration. Pre-allocate the rest of the configurations in `qWaypoints` using `repmat`.

```
numWaypoints = 5;
q0 = homeConfiguration(lbr);
qWaypoints = repmat(q0, numWaypoints, 1);
```

Create a `generalizedInverseKinematics` solver that accepts the following constraint inputs:

- Cartesian bounds - Limits the height of the gripper
- A position target - Specifies the position of the cup relative to the gripper.
- An aiming constraint - Aligns the gripper with the cup axis
- An orientation target - Maintains a fixed orientation for the gripper while approaching the cup
- Joint position bounds - Limits the change in joint positions between waypoints.

```
gik = generalizedInverseKinematics('RigidBodyTree', lbr, ...
    'ConstraintInputs', {'cartesian','position','aiming','orientation','joint'})
```

```
gik = 
  generalizedInverseKinematics with properties:
      NumConstraints: 5
    ConstraintInputs: {1x5 cell}
       RigidBodyTree: [1x1 rigidBodyTree]
     SolverAlgorithm: 'BFGSGradientProjection'
    SolverParameters: [1x1 struct]
```

Create Constraint Objects

Create the constraint objects that are passed as inputs to the solver. These object contain the parameters needed for each constraint. Modify these parameters between calls to the solver as necessary.

Create a Cartesian bounds constraint that requires the gripper to be at least 5 cm above the table (negative z direction). All other values are given as `inf` or `-inf`.

```
heightAboveTable = constraintCartesianBounds(gripper);
heightAboveTable.Bounds = [-inf, inf; ...
                           -inf, inf; ...
                           0.05, inf]
```

```
heightAboveTable = 
  constraintCartesianBounds with properties:

        EndEffector: 'iiwa_link_ee_kuka'
      ReferenceBody: ''
    TargetTransform: [4x4 double]
             Bounds: [3x2 double]
            Weights: [1 1 1]
```

Create a constraint on the position of the cup relative to the gripper, with a tolerance of 5 mm.

```
distanceFromCup = constraintPositionTarget('cupFrame');
distanceFromCup.ReferenceBody = gripper;
distanceFromCup.PositionTolerance = 0.005
```

```
distanceFromCup = 
  constraintPositionTarget with properties:

          EndEffector: 'cupFrame'
        ReferenceBody: 'iiwa_link_ee_kuka'
       TargetPosition: [0 0 0]
    PositionTolerance: 0.0050
              Weights: 1
```

Create an aiming constraint that requires the z-axis of the `iiwa_link_ee` frame to be approximately vertical, by placing the target far above the robot. The `iiwa_link_ee` frame is oriented such that this constraint aligns the gripper with the axis of the cup.

```
alignWithCup = constraintAiming('iiwa_link_ee');
alignWithCup.TargetPoint = [0, 0, 100]
```

```
alignWithCup = 
  constraintAiming with properties:
         EndEffector: 'iiwa_link_ee'
       ReferenceBody: ''
         TargetPoint: [0 0 100]
    AngularTolerance: 0
             Weights: 1
```

Create a joint position bounds constraint. Set the `Bounds` property of this constraint based on the previous configuration to limit the change in joint positions.

```
limitJointChange = constraintJointBounds(lbr)
```

```
limitJointChange = 
  constraintJointBounds with properties:

     Bounds: [7x2 double]
    Weights: [1 1 1 1 1 1 1]
```

Create an orientation constraint for the gripper with a tolerance of one degree. This constraint requires the orientation of the gripper to match the value specified by the `TargetOrientation` property. Use this constraint to fix the orientation of the gripper during the final approach to the cup.

```
fixOrientation = constraintOrientationTarget(gripper);
fixOrientation.OrientationTolerance = deg2rad(1)
```

```
fixOrientation = 
  constraintOrientationTarget with properties:

             EndEffector: 'iiwa_link_ee_kuka'
           ReferenceBody: ''
       TargetOrientation: [1 0 0 0]
    OrientationTolerance: 0.0175
                 Weights: 1
```

Find a Configuration That Points at the Cup

This configuration should place the gripper at a distance from the cup, so that the final approach can be made with the gripper properly aligned.

```
intermediateDistance = 0.3;
```

Constraint objects have a `Weights` property which determines how the solver treats conflicting constraints. Setting the weights of a constraint to zero disables the constraint. For this configuration, disable the joint position bounds and orientation constraint.

```
limitJointChange.Weights = zeros(size(limitJointChange.Weights));
fixOrientation.Weights = 0;
```

Set the target position for the cup in the gripper frame. The cup should lie on the z-axis of the gripper at the specified distance.

```
distanceFromCup.TargetPosition = [0,0,intermediateDistance];
```

Solve for the robot configuration that satisfies the input constraints using the `gik` solver. You must specify all the input constraints. Set that configuration as the second waypoint.

```
[qWaypoints(2,:),solutionInfo] = gik(q0, heightAboveTable, ...
                       distanceFromCup, alignWithCup, fixOrientation, ...
                       limitJointChange);
```

Find Configurations That Move Gripper to the Cup Along a Straight Line

Re-enable the joint position bound and orientation constraints.

```
limitJointChange.Weights = ones(size(limitJointChange.Weights));
fixOrientation.Weights = 1;
```

Disable the align-with-cup constraint, as the orientation constraint makes it redundant.

```
alignWithCup.Weights = 0;
```

Set the orientation constraint to hold the orientation based on the previous configuration (`qWaypoints(2,:)`). Get the transformation from the gripper to the base of the robot model. Convert the homogeneous transformation to a quaternion.

```
fixOrientation.TargetOrientation = ...
    tform2quat(getTransform(lbr,qWaypoints(2,:),gripper));
```

Define the distance between the cup and gripper for each waypoint

```
finalDistanceFromCup = 0.05;
distanceFromCupValues = linspace(intermediateDistance, finalDistanceFromCup, numWaypoints-1);
```

Define the maximum allowed change in joint positions between each waypoint.

```
maxJointChange = deg2rad(10);
```

Call the solver for each remaining waypoint.

```
for k = 3:numWaypoints
    % Update the target position.
    distanceFromCup.TargetPosition(3) = distanceFromCupValues(k-1);
    % Restrict the joint positions to lie close to their previous values.
    limitJointChange.Bounds = [qWaypoints(k-1,:)' - maxJointChange, ...
                               qWaypoints(k-1,:)' + maxJointChange];
    % Solve for a configuration and add it to the waypoints array.
    [qWaypoints(k,:),solutionInfo] = gik(qWaypoints(k-1,:), ...
                                         heightAboveTable, ...
                                         distanceFromCup, alignWithCup, ...
                                         fixOrientation, limitJointChange);
end
```

Visualize the Generated Trajectory

Interpolate between the waypoints to generate a smooth trajectory. Use `pchip` to avoid overshoots, which might violate the joint limits of the robot.

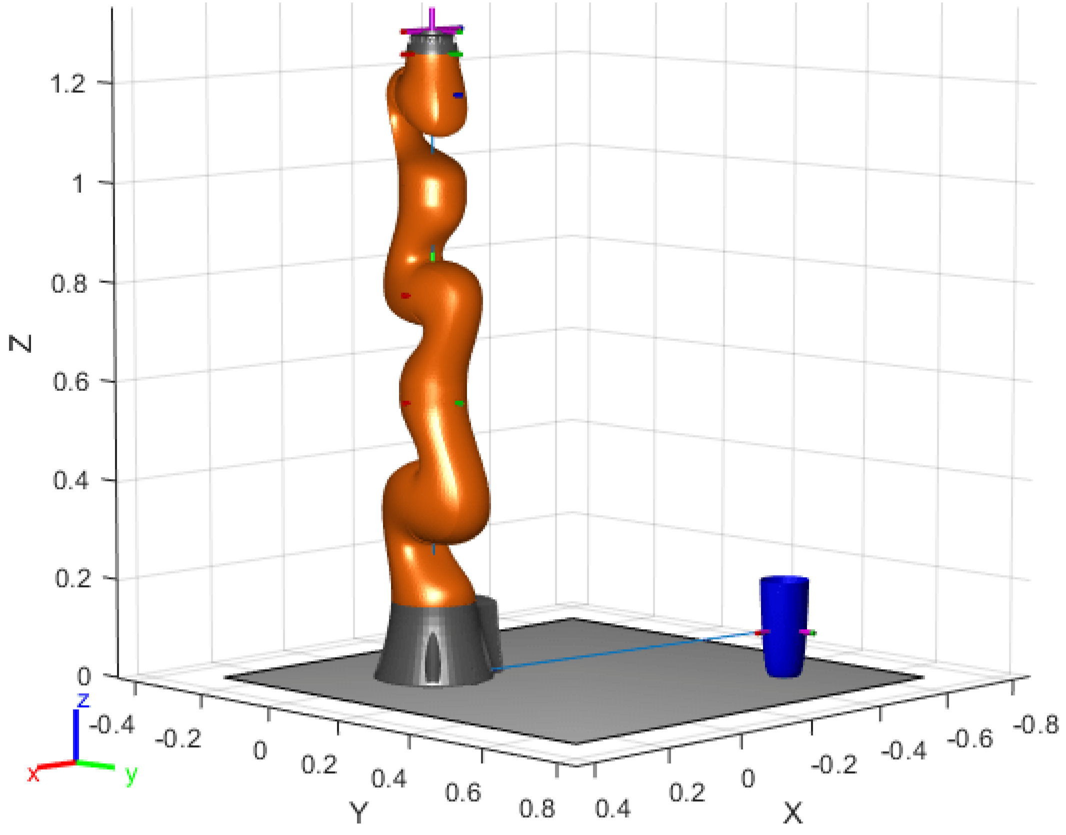
```
framerate = 15;
r = rateControl(framerate);
tFinal = 10;
tWaypoints = [0,linspace(tFinal/2,tFinal,size(qWaypoints,1)-1)];
numFrames = tFinal*framerate;
qInterp = pchip(tWaypoints,qWaypoints',linspace(0,tFinal,numFrames))';
```

Compute the gripper position for each interpolated configuration.

```
gripperPosition = zeros(numFrames,3);
for k = 1:numFrames
    gripperPosition(k,:) = tform2trvec(getTransform(lbr,qInterp(k,:), ...
                                                  gripper));
end
```

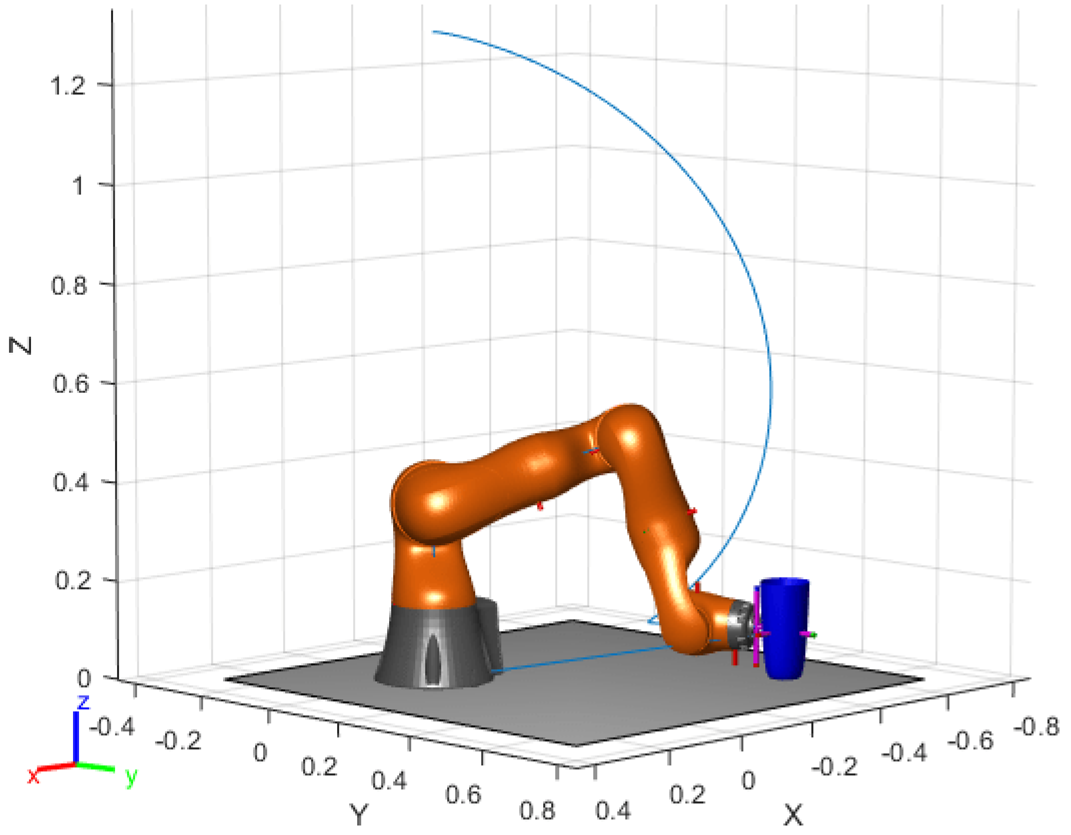
Show the robot in its initial configuration along with the table and cup

```
figure;
show(lbr, qWaypoints(1,:), 'PreservePlot', false);
hold on
exampleHelperPlotCupAndTable(cupHeight, cupRadius, cupPosition);
p = plot3(gripperPosition(1,1), gripperPosition(1,2), gripperPosition(1,3));
```



Animate the manipulator and plot the gripper position.

```
hold on
for k = 1:size(qInterp,1)
    show(lbr, qInterp(k,:), 'PreservePlot', false);
    p.XData(k) = gripperPosition(k,1);
    p.YData(k) = gripperPosition(k,2);
    p.ZData(k) = gripperPosition(k,3);
    waitfor(r);
end
hold off
```



If you want to save the generated configurations to a MAT-file for later use, execute the following:

```
>> save('lbr_trajectory.mat', 'tWaypoints', 'qWaypoints');
```

Compatibility Considerations

`constraintCartesianBounds` was renamed
Behavior change in future release

The `constraintCartesianBounds` object was renamed from `robotics.CartesianBounds`. Use `constraintCartesianBounds` for all object creation.

Extended Capabilities

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

See Also

Classes
`generalizedInverseKinematics` | `constraintOrientationTarget` | `constraintPoseTarget` | `constraintPositionTarget`

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

constraintJointBounds

Create constraint on joint positions of robot model

Description

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

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

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

Creation

Syntax

```
jointConst = constraintJointBounds(robot)
jointConst = constraintJointBounds(robot,Name,Value)
```

Description

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

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

Input Arguments

`robot` — Rigid body tree model
`rigidBodyTree` object

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

Properties

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

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

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

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

Examples

Plan a Reaching Trajectory With Multiple Kinematic Constraints

This example shows how to use generalized inverse kinematics to plan a joint-space trajectory for a robotic manipulator. It combines multiple constraints to generate a trajectory that guides the gripper to a cup resting on a table. These constraints ensure that the gripper approaches the cup in a straight line and that the gripper remains at a safe distance from the table, without requiring the poses of the gripper to be determined in advance.

Set Up the Robot Model

This example uses a model of the KUKA LBR iiwa, a 7 degree-of-freedom robot manipulator. `importrobot` generates a `rigidBodyTree` model from a description stored in a Unified Robot Description Format (URDF) file.

```
lbr = importrobot('iiwa14.urdf'); % 14 kg payload version
lbr.DataFormat = 'row';
gripper = 'iiwa_link_ee_kuka';
```

Define dimensions for the cup.

```
cupHeight = 0.2;
cupRadius = 0.05;
cupPosition = [-0.5, 0.5, cupHeight/2];
```

Add a fixed body to the robot model representing the center of the cup.

```
body = rigidBody('cupFrame');
setFixedTransform(body.Joint, trvec2tform(cupPosition))
addBody(lbr, body, lbr.BaseName);
```

Define the Planning Problem

The goal of this example is to generate a sequence of robot configurations that satisfy the following criteria:

- Start in the home configuration
- No abrupt changes in robot configuration
- Keep the gripper at least 5 cm above the "table" (z = 0)
- The gripper should be aligned with the cup as it approaches
- Finish with the gripper 5 cm from the center of the cup

This example utilizes constraint objects to generate robot configurations that satisfy these criteria. The generated trajectory consists of five configuration waypoints. The first waypoint, `q0`, is set as the home configuration. Pre-allocate the rest of the configurations in `qWaypoints` using `repmat`.

```
numWaypoints = 5;
q0 = homeConfiguration(lbr);
qWaypoints = repmat(q0, numWaypoints, 1);
```

Create a `generalizedInverseKinematics` solver that accepts the following constraint inputs:

- Cartesian bounds - Limits the height of the gripper
- A position target - Specifies the position of the cup relative to the gripper.
- An aiming constraint - Aligns the gripper with the cup axis
- An orientation target - Maintains a fixed orientation for the gripper while approaching the cup
- Joint position bounds - Limits the change in joint positions between waypoints.

```
gik = generalizedInverseKinematics('RigidBodyTree', lbr, ...
    'ConstraintInputs', {'cartesian','position','aiming','orientation','joint'})
```

```
gik = 
  generalizedInverseKinematics with properties:

      NumConstraints: 5
    ConstraintInputs: {1x5 cell}
       RigidBodyTree: [1x1 rigidBodyTree]
     SolverAlgorithm: 'BFGSGradientProjection'
    SolverParameters: [1x1 struct]
```

Create Constraint Objects

Create the constraint objects that are passed as inputs to the solver. These object contain the parameters needed for each constraint. Modify these parameters between calls to the solver as necessary.

Create a Cartesian bounds constraint that requires the gripper to be at least 5 cm above the table (negative z direction). All other values are given as `inf` or `-inf`.

```
heightAboveTable = constraintCartesianBounds(gripper);
heightAboveTable.Bounds = [-inf, inf; ...
                           -inf, inf; ...
                           0.05, inf]
```

```
heightAboveTable = 
  constraintCartesianBounds with properties:

        EndEffector: 'iiwa_link_ee_kuka'
      ReferenceBody: ''
    TargetTransform: [4x4 double]
             Bounds: [3x2 double]
            Weights: [1 1 1]
```

Create a constraint on the position of the cup relative to the gripper, with a tolerance of 5 mm.

```
distanceFromCup = constraintPositionTarget('cupFrame');
distanceFromCup.ReferenceBody = gripper;
distanceFromCup.PositionTolerance = 0.005
```

```
distanceFromCup = 
  constraintPositionTarget with properties:
          EndEffector: 'cupFrame'
        ReferenceBody: 'iiwa_link_ee_kuka'
       TargetPosition: [0 0 0]
    PositionTolerance: 0.0050
              Weights: 1
```

Create an aiming constraint that requires the z-axis of the `iiwa_link_ee` frame to be approximately vertical, by placing the target far above the robot. The `iiwa_link_ee` frame is oriented such that this constraint aligns the gripper with the axis of the cup.

```
alignWithCup = constraintAiming('iiwa_link_ee');
alignWithCup.TargetPoint = [0, 0, 100]
```

```
alignWithCup = 
  constraintAiming with properties:

         EndEffector: 'iiwa_link_ee'
       ReferenceBody: ''
         TargetPoint: [0 0 100]
    AngularTolerance: 0
             Weights: 1
```

Create a joint position bounds constraint. Set the `Bounds` property of this constraint based on the previous configuration to limit the change in joint positions.

```
limitJointChange = constraintJointBounds(lbr)
```

```
limitJointChange = 
  constraintJointBounds with properties:

     Bounds: [7x2 double]
    Weights: [1 1 1 1 1 1 1]
```

Create an orientation constraint for the gripper with a tolerance of one degree. This constraint requires the orientation of the gripper to match the value specified by the `TargetOrientation` property. Use this constraint to fix the orientation of the gripper during the final approach to the cup.

```
fixOrientation = constraintOrientationTarget(gripper);
fixOrientation.OrientationTolerance = deg2rad(1)
```

```
fixOrientation = 
  constraintOrientationTarget with properties:

             EndEffector: 'iiwa_link_ee_kuka'
           ReferenceBody: ''
       TargetOrientation: [1 0 0 0]
    OrientationTolerance: 0.0175
                 Weights: 1
```

Find a Configuration That Points at the Cup

This configuration should place the gripper at a distance from the cup, so that the final approach can be made with the gripper properly aligned.

```
intermediateDistance = 0.3;
```

Constraint objects have a `Weights` property which determines how the solver treats conflicting constraints. Setting the weights of a constraint to zero disables the constraint. For this configuration, disable the joint position bounds and orientation constraint.

```
limitJointChange.Weights = zeros(size(limitJointChange.Weights));
fixOrientation.Weights = 0;
```

Set the target position for the cup in the gripper frame. The cup should lie on the z-axis of the gripper at the specified distance.

```
distanceFromCup.TargetPosition = [0,0,intermediateDistance];
```

Solve for the robot configuration that satisfies the input constraints using the `gik` solver. You must specify all the input constraints. Set that configuration as the second waypoint.

```
[qWaypoints(2,:),solutionInfo] = gik(q0, heightAboveTable, ...
                       distanceFromCup, alignWithCup, fixOrientation, ...
                       limitJointChange);
```

Find Configurations That Move Gripper to the Cup Along a Straight Line

Re-enable the joint position bound and orientation constraints.

```
limitJointChange.Weights = ones(size(limitJointChange.Weights));
fixOrientation.Weights = 1;
```

Disable the align-with-cup constraint, as the orientation constraint makes it redundant.

```
alignWithCup.Weights = 0;
```

Set the orientation constraint to hold the orientation based on the previous configuration (`qWaypoints(2,:)`). Get the transformation from the gripper to the base of the robot model. Convert the homogeneous transformation to a quaternion.

```
fixOrientation.TargetOrientation = ...
    tform2quat(getTransform(lbr,qWaypoints(2,:),gripper));
```

Define the distance between the cup and gripper for each waypoint

```
finalDistanceFromCup = 0.05;
distanceFromCupValues = linspace(intermediateDistance, finalDistanceFromCup, numWaypoints-1);
```

Define the maximum allowed change in joint positions between each waypoint.

```
maxJointChange = deg2rad(10);
```

Call the solver for each remaining waypoint.

```
for k = 3:numWaypoints
    % Update the target position.
    distanceFromCup.TargetPosition(3) = distanceFromCupValues(k-1);
    % Restrict the joint positions to lie close to their previous values.
    limitJointChange.Bounds = [qWaypoints(k-1,:)' - maxJointChange, ...
                               qWaypoints(k-1,:)' + maxJointChange];
    % Solve for a configuration and add it to the waypoints array.
    [qWaypoints(k,:),solutionInfo] = gik(qWaypoints(k-1,:), ...
                                         heightAboveTable, ...
                                         distanceFromCup, alignWithCup, ...
                                         fixOrientation, limitJointChange);
end
```

Visualize the Generated Trajectory

Interpolate between the waypoints to generate a smooth trajectory. Use `pchip` to avoid overshoots, which might violate the joint limits of the robot.

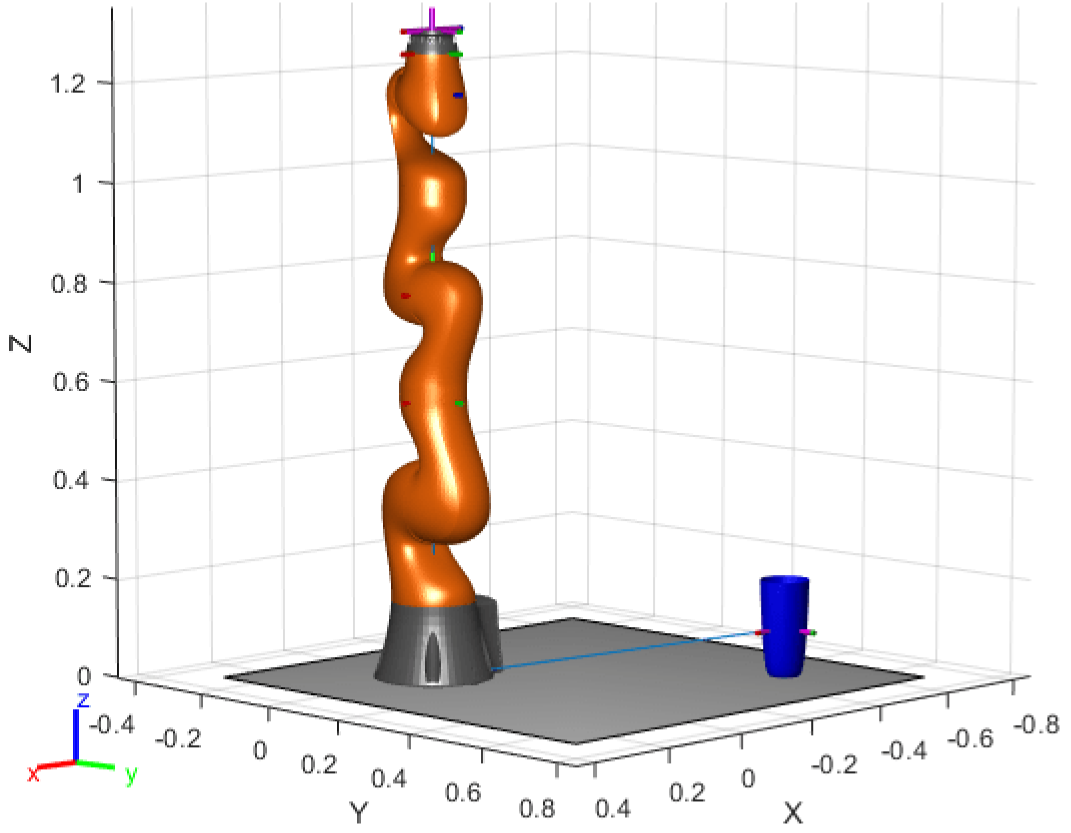
```
framerate = 15;
r = rateControl(framerate);
tFinal = 10;
tWaypoints = [0,linspace(tFinal/2,tFinal,size(qWaypoints,1)-1)];
numFrames = tFinal*framerate;
qInterp = pchip(tWaypoints,qWaypoints',linspace(0,tFinal,numFrames))';
```

Compute the gripper position for each interpolated configuration.

```
gripperPosition = zeros(numFrames,3);
for k = 1:numFrames
    gripperPosition(k,:) = tform2trvec(getTransform(lbr,qInterp(k,:), ...
                                                    gripper));
end
```

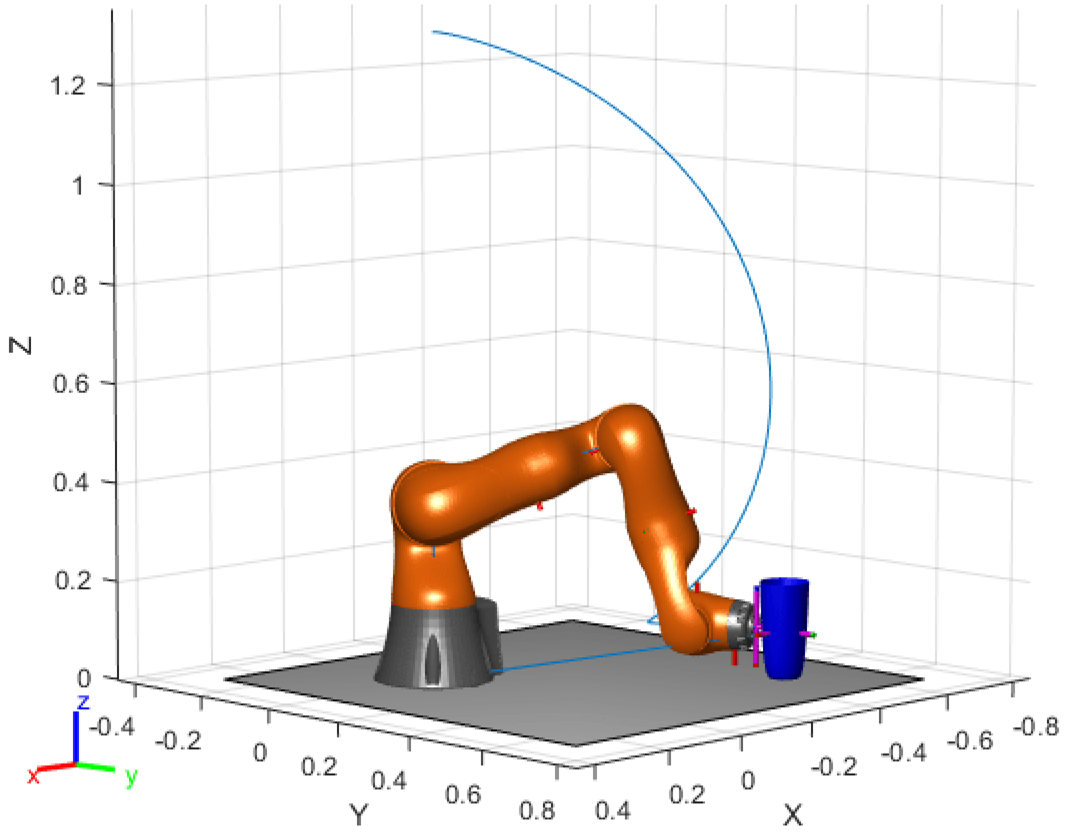
Show the robot in its initial configuration along with the table and cup

```
figure;
show(lbr, qWaypoints(1,:), 'PreservePlot', false);
hold on
exampleHelperPlotCupAndTable(cupHeight, cupRadius, cupPosition);
p = plot3(gripperPosition(1,1), gripperPosition(1,2), gripperPosition(1,3));
```



Animate the manipulator and plot the gripper position.

```
hold on
for k = 1:size(qInterp,1)
    show(lbr, qInterp(k,:), 'PreservePlot', false);
    p.XData(k) = gripperPosition(k,1);
    p.YData(k) = gripperPosition(k,2);
    p.ZData(k) = gripperPosition(k,3);
    waitfor(r);
end
hold off
```



If you want to save the generated configurations to a MAT-file for later use, execute the following:

```
>> save('lbr_trajectory.mat', 'tWaypoints', 'qWaypoints');
```

Compatibility Considerations

`constraintJointBounds` was renamed
Behavior change in future release

The `constraintJointBounds` object was renamed from `robotics.JointPositionBounds`. Use `constraintJointBounds` for all object creation.

Extended Capabilities

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

See Also

Classes
`generalizedInverseKinematics` | `constraintOrientationTarget` | `constraintPoseTarget` | `constraintPositionTarget`

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

constraintOrientationTarget

Create constraint on relative orientation of body

Description

The `constraintOrientationTarget` object describes a constraint that requires the orientation of one body (the end effector) to match a target orientation within an angular tolerance in any direction. The target orientation is specified relative to the body frame of the reference body.

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

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

Creation

Syntax

```
orientationConst = constraintOrientationTarget(endeffector)
orientationConst = constraintOrientationTarget(endeffector,Name,Value)
```

Description

`orientationConst = constraintOrientationTarget(endeffector)` returns an orientation target object that represents a constraint on a body of the robot model specified by `endeffector`.

`orientationConst = constraintOrientationTarget(endeffector,Name,Value)` returns an orientation target object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

Input Arguments

`endeffector` — End-effector name
string scalar | character vector

End-effector name, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

Properties

`EndEffector` — Name of the end effector
string scalar | character vector

Name of the end effector, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

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

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

Data Types: `char` | `string`

`TargetOrientation` — Target orientation of the end effector relative to the reference body
`[1 0 0 0]` (default) | four-element vector

Target orientation of the end effector relative to the reference body, specified as four-element vector that represents a unit quaternion. The orientation of the end effector relative to the reference body frame is the orientation that converts a direction specified in the end-effector frame to the same direction specified in the reference body frame.

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

Maximum allowed rotation angle in radians, specified as a numeric scalar. This value is the upper bound on the magnitude of the rotation required to make the end-effector orientation match the target orientation.

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

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

Examples

Plan a Reaching Trajectory With Multiple Kinematic Constraints

This example shows how to use generalized inverse kinematics to plan a joint-space trajectory for a robotic manipulator. It combines multiple constraints to generate a trajectory that guides the gripper to a cup resting on a table. These constraints ensure that the gripper approaches the cup in a straight line and that the gripper remains at a safe distance from the table, without requiring the poses of the gripper to be determined in advance.

Set Up the Robot Model

This example uses a model of the KUKA LBR iiwa, a 7 degree-of-freedom robot manipulator. `importrobot` generates a `rigidBodyTree` model from a description stored in a Unified Robot Description Format (URDF) file.

```
lbr = importrobot('iiwa14.urdf'); % 14 kg payload version
lbr.DataFormat = 'row';
gripper = 'iiwa_link_ee_kuka';
```

Define dimensions for the cup.

```
cupHeight = 0.2;
cupRadius = 0.05;
cupPosition = [-0.5, 0.5, cupHeight/2];
```

Add a fixed body to the robot model representing the center of the cup.

```
body = rigidBody('cupFrame');
setFixedTransform(body.Joint, trvec2tform(cupPosition))
addBody(lbr, body, lbr.BaseName);
```

Define the Planning Problem

The goal of this example is to generate a sequence of robot configurations that satisfy the following criteria:

- Start in the home configuration
- No abrupt changes in robot configuration
- Keep the gripper at least 5 cm above the "table" (z = 0)
- The gripper should be aligned with the cup as it approaches
- Finish with the gripper 5 cm from the center of the cup

This example utilizes constraint objects to generate robot configurations that satisfy these criteria. The generated trajectory consists of five configuration waypoints. The first waypoint, `q0`, is set as the home configuration. Pre-allocate the rest of the configurations in `qWaypoints` using `repmat`.

```
numWaypoints = 5;
q0 = homeConfiguration(lbr);
qWaypoints = repmat(q0, numWaypoints, 1);
```

Create a `generalizedInverseKinematics` solver that accepts the following constraint inputs:

- Cartesian bounds - Limits the height of the gripper
- A position target - Specifies the position of the cup relative to the gripper.
- An aiming constraint - Aligns the gripper with the cup axis
- An orientation target - Maintains a fixed orientation for the gripper while approaching the cup
- Joint position bounds - Limits the change in joint positions between waypoints.

```
gik = generalizedInverseKinematics('RigidBodyTree', lbr, ...
    'ConstraintInputs', {'cartesian','position','aiming','orientation','joint'})
```

```
gik = 
  generalizedInverseKinematics with properties:

      NumConstraints: 5
    ConstraintInputs: {1x5 cell}
       RigidBodyTree: [1x1 rigidBodyTree]
     SolverAlgorithm: 'BFGSGradientProjection'
    SolverParameters: [1x1 struct]
```

Create Constraint Objects

Create the constraint objects that are passed as inputs to the solver. These object contain the parameters needed for each constraint. Modify these parameters between calls to the solver as necessary.

Create a Cartesian bounds constraint that requires the gripper to be at least 5 cm above the table (negative z direction). All other values are given as `inf` or `-inf`.

```
heightAboveTable = constraintCartesianBounds(gripper);
heightAboveTable.Bounds = [-inf, inf; ...
                           -inf, inf; ...
                           0.05, inf]
```

```
heightAboveTable =
  constraintCartesianBounds with properties:

        EndEffector: 'iiwa_link_ee_kuka'
      ReferenceBody: ''
    TargetTransform: [4x4 double]
             Bounds: [3x2 double]
            Weights: [1 1 1]
```

Create a constraint on the position of the cup relative to the gripper, with a tolerance of 5 mm.

```
distanceFromCup = constraintPositionTarget('cupFrame');
distanceFromCup.ReferenceBody = gripper;
distanceFromCup.PositionTolerance = 0.005
```

```
distanceFromCup =
  constraintPositionTarget with properties:

          EndEffector: 'cupFrame'
        ReferenceBody: 'iiwa_link_ee_kuka'
       TargetPosition: [0 0 0]
    PositionTolerance: 0.0050
              Weights: 1
```

Create an aiming constraint that requires the z-axis of the `iiwa_link_ee` frame to be approximately vertical, by placing the target far above the robot. The `iiwa_link_ee` frame is oriented such that this constraint aligns the gripper with the axis of the cup.

```
alignWithCup = constraintAiming('iiwa_link_ee');
alignWithCup.TargetPoint = [0, 0, 100]
```

```
alignWithCup =
  constraintAiming with properties:

         EndEffector: 'iiwa_link_ee'
       ReferenceBody: ''
         TargetPoint: [0 0 100]
    AngularTolerance: 0
             Weights: 1
```

Create a joint position bounds constraint. Set the `Bounds` property of this constraint based on the previous configuration to limit the change in joint positions.

```
limitJointChange = constraintJointBounds(lbr)
```

```
limitJointChange = 
  constraintJointBounds with properties:

     Bounds: [7x2 double]
    Weights: [1 1 1 1 1 1 1]
```

Create an orientation constraint for the gripper with a tolerance of one degree. This constraint requires the orientation of the gripper to match the value specified by the `TargetOrientation` property. Use this constraint to fix the orientation of the gripper during the final approach to the cup.

```
fixOrientation = constraintOrientationTarget(gripper);
fixOrientation.OrientationTolerance = deg2rad(1)
```

```
fixOrientation = 
  constraintOrientationTarget with properties:

             EndEffector: 'iiwa_link_ee_kuka'
           ReferenceBody: ''
       TargetOrientation: [1 0 0 0]
    OrientationTolerance: 0.0175
                 Weights: 1
```

Find a Configuration That Points at the Cup

This configuration should place the gripper at a distance from the cup, so that the final approach can be made with the gripper properly aligned.

```
intermediateDistance = 0.3;
```

Constraint objects have a `Weights` property which determines how the solver treats conflicting constraints. Setting the weights of a constraint to zero disables the constraint. For this configuration, disable the joint position bounds and orientation constraint.

```
limitJointChange.Weights = zeros(size(limitJointChange.Weights));
fixOrientation.Weights = 0;
```

Set the target position for the cup in the gripper frame. The cup should lie on the z-axis of the gripper at the specified distance.

```
distanceFromCup.TargetPosition = [0,0,intermediateDistance];
```

Solve for the robot configuration that satisfies the input constraints using the `gik` solver. You must specify all the input constraints. Set that configuration as the second waypoint.

```
[qWaypoints(2,:),solutionInfo] = gik(q0, heightAboveTable, ...
                       distanceFromCup, alignWithCup, fixOrientation, ...
                       limitJointChange);
```

Find Configurations That Move Gripper to the Cup Along a Straight Line

Re-enable the joint position bound and orientation constraints.

```
limitJointChange.Weights = ones(size(limitJointChange.Weights));
fixOrientation.Weights = 1;
```

Disable the align-with-cup constraint, as the orientation constraint makes it redundant.

```
alignWithCup.Weights = 0;
```

Set the orientation constraint to hold the orientation based on the previous configuration (`qWaypoints(2,:)`). Get the transformation from the gripper to the base of the robot model. Convert the homogeneous transformation to a quaternion.

```
fixOrientation.TargetOrientation = ...
    tform2quat(getTransform(lbr,qWaypoints(2,:),gripper));
```

Define the distance between the cup and gripper for each waypoint

```
finalDistanceFromCup = 0.05;
distanceFromCupValues = linspace(intermediateDistance, finalDistanceFromCup, numWaypoints-1);
```

Define the maximum allowed change in joint positions between each waypoint.

```
maxJointChange = deg2rad(10);
```

Call the solver for each remaining waypoint.

```
for k = 3:numWaypoints
    % Update the target position.
    distanceFromCup.TargetPosition(3) = distanceFromCupValues(k-1);
    % Restrict the joint positions to lie close to their previous values.
    limitJointChange.Bounds = [qWaypoints(k-1,:)' - maxJointChange, ...
                               qWaypoints(k-1,:)' + maxJointChange];
    % Solve for a configuration and add it to the waypoints array.
    [qWaypoints(k,:),solutionInfo] = gik(qWaypoints(k-1,:), ...
                                         heightAboveTable, ...
                                         distanceFromCup, alignWithCup, ...
                                         fixOrientation, limitJointChange);
end
```

Visualize the Generated Trajectory

Interpolate between the waypoints to generate a smooth trajectory. Use `pchip` to avoid overshoots, which might violate the joint limits of the robot.

```
framerate = 15;
r = rateControl(framerate);
tFinal = 10;
tWaypoints = [0,linspace(tFinal/2,tFinal,size(qWaypoints,1)-1)];
numFrames = tFinal*framerate;
qInterp = pchip(tWaypoints,qWaypoints',linspace(0,tFinal,numFrames))';
```

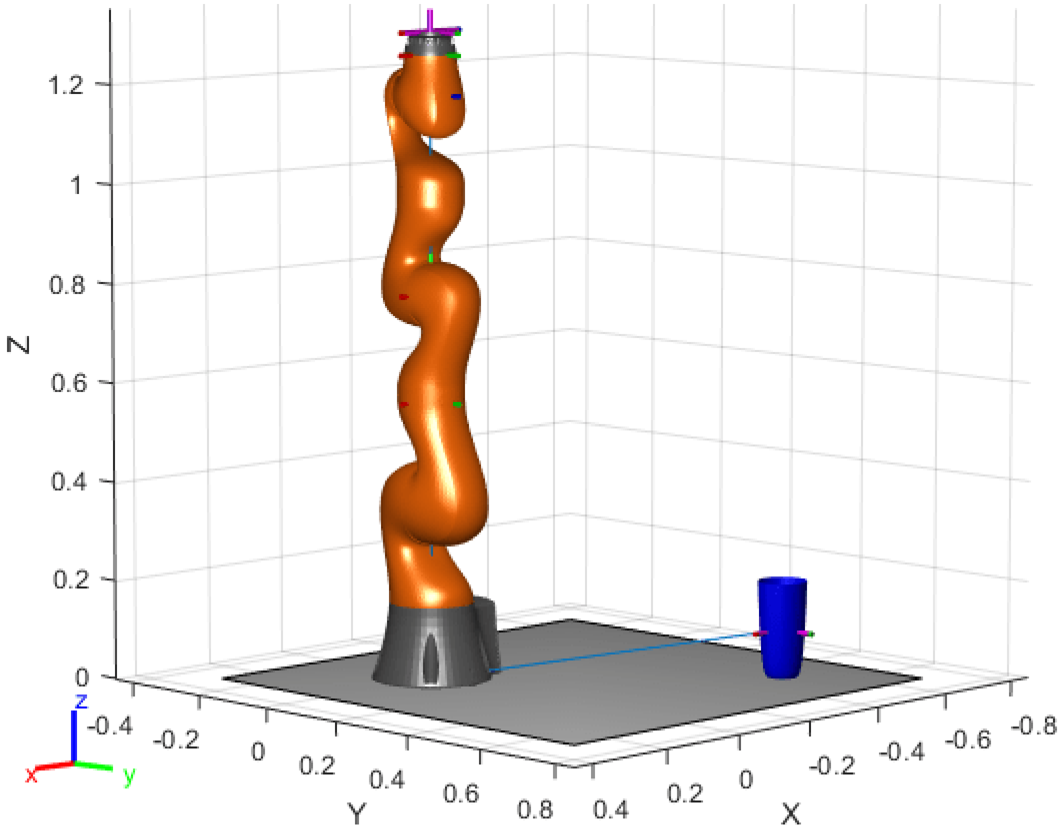
Compute the gripper position for each interpolated configuration.

```
gripperPosition = zeros(numFrames,3);
for k = 1:numFrames
    gripperPosition(k,:) = tform2trvec(getTransform(lbr,qInterp(k,:), ...
                                                    gripper));
end
```

Show the robot in its initial configuration along with the table and cup

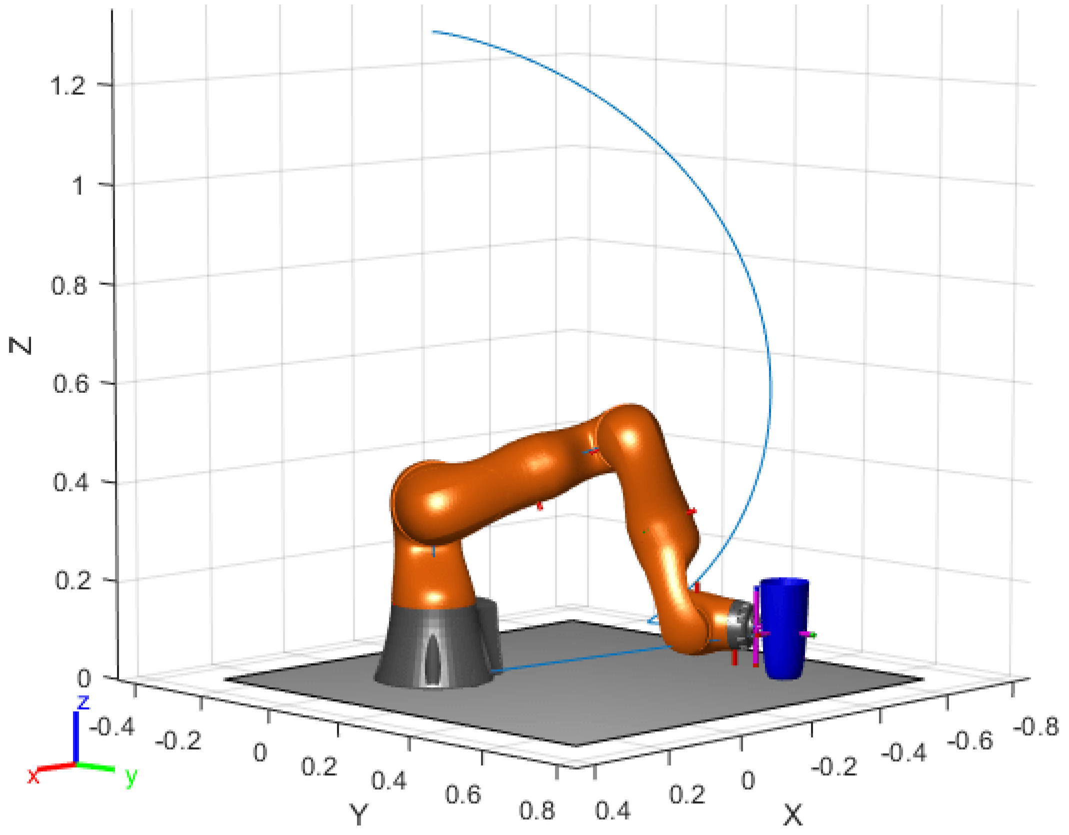
```
figure;
show(lbr, qWaypoints(1,:), 'PreservePlot', false);
```

```
hold on
exampleHelperPlotCupAndTable(cupHeight, cupRadius, cupPosition);
p = plot3(gripperPosition(1,1), gripperPosition(1,2), gripperPosition(1,3));
```



Animate the manipulator and plot the gripper position.

```
hold on
for k = 1:size(qInterp,1)
    show(lbr, qInterp(k,:), 'PreservePlot', false);
    p.XData(k) = gripperPosition(k,1);
    p.YData(k) = gripperPosition(k,2);
    p.ZData(k) = gripperPosition(k,3);
    waitfor(r);
end
hold off
```



If you want to save the generated configurations to a MAT-file for later use, execute the following:

```
>> save('lbr_trajectory.mat', 'tWaypoints', 'qWaypoints');
```

Compatibility Considerations

`constraintOrientationTarget` was renamed
Behavior change in future release

The `constraintOrientationTarget` object was renamed from `robotics.OrientationTarget`. Use `constraintOrientationTarget` for all object creation.

Extended Capabilities

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

See Also

Classes
`generalizedInverseKinematics` | `constraintPoseTarget` | `constraintPositionTarget` | `constraintJointBounds`

Topics

"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

constraintPoseTarget

Create constraint on relative pose of body

Description

The `constraintPoseTarget` object describes a constraint that requires the pose of one body (the end effector) to match a target pose within a distance and angular tolerance in any direction. The target pose is specified relative to the body frame of the reference body.

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

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

Creation

Syntax

```
poseConst = constraintPoseTarget(endeffector)
poseConst = constraintPoseTarget(endeffector,Name,Value)
```

Description

`poseConst = constraintPoseTarget(endeffector)` returns a pose target object that represents a constraint on the body of the robot model specified by `endeffector`.

`poseConst = constraintPoseTarget(endeffector,Name,Value)` returns a pose target object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

Input Arguments

`endeffector` — End-effector name
string scalar | character vector

End-effector name, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

Properties

`EndEffector` — Name of the end effector
string scalar | character vector

Name of the end effector, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

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

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

Example:

Data Types: `char` | `string`

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

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

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

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

Maximum allowed rotation angle in radians, specified as a numeric scalar. This value is the upper bound on the magnitude of the rotation required to make the end-effector orientation match the target orientation.

Example:

`PositionTolerance` — Maximum allowed distance from target
`0` (default) | numeric scalar in meters

Maximum allowed distance from target, specified as a numeric scalar in meters. This value is the upper bound on the distance between the end-effector origin and the target position.

Example:

`Weights` — Weights of the constraint
`[1 1]` (default) | two-element vector

Weights of the constraint, specified as a two-element vector. Each element of the vector corresponds to the weight for the `PositionTolerance` and `OrientationTolerance` respectively. These weights are used with the `Weights` of all the constraints specified in `generalizedInverseKinematics` to properly balance each constraint.

Example:

Examples

Plan a Reaching Trajectory With Multiple Kinematic Constraints

This example shows how to use generalized inverse kinematics to plan a joint-space trajectory for a robotic manipulator. It combines multiple constraints to generate a trajectory that guides the gripper to a cup resting on a table. These constraints ensure that the gripper approaches the cup in a straight line and that the gripper remains at a safe distance from the table, without requiring the poses of the gripper to be determined in advance.

Set Up the Robot Model

This example uses a model of the KUKA LBR iiwa, a 7 degree-of-freedom robot manipulator. `importrobot` generates a `rigidBodyTree` model from a description stored in a Unified Robot Description Format (URDF) file.

```
lbr = importrobot('iiwa14.urdf'); % 14 kg payload version
lbr.DataFormat = 'row';
gripper = 'iiwa_link_ee_kuka';
```

Define dimensions for the cup.

```
cupHeight = 0.2;
cupRadius = 0.05;
cupPosition = [-0.5, 0.5, cupHeight/2];
```

Add a fixed body to the robot model representing the center of the cup.

```
body = rigidBody('cupFrame');
setFixedTransform(body.Joint, trvec2tform(cupPosition))
addBody(lbr, body, lbr.BaseName);
```

Define the Planning Problem

The goal of this example is to generate a sequence of robot configurations that satisfy the following criteria:

- Start in the home configuration
- No abrupt changes in robot configuration
- Keep the gripper at least 5 cm above the "table" (z = 0)
- The gripper should be aligned with the cup as it approaches
- Finish with the gripper 5 cm from the center of the cup

This example utilizes constraint objects to generate robot configurations that satisfy these criteria. The generated trajectory consists of five configuration waypoints. The first waypoint, `q0`, is set as the home configuration. Pre-allocate the rest of the configurations in `qWaypoints` using `repmat`.

```
numWaypoints = 5;
q0 = homeConfiguration(lbr);
qWaypoints = repmat(q0, numWaypoints, 1);
```

Create a `generalizedInverseKinematics` solver that accepts the following constraint inputs:

- Cartesian bounds - Limits the height of the gripper
- A position target - Specifies the position of the cup relative to the gripper.
- An aiming constraint - Aligns the gripper with the cup axis

- An orientation target - Maintains a fixed orientation for the gripper while approaching the cup
- Joint position bounds - Limits the change in joint positions between waypoints.

```
gik = generalizedInverseKinematics('RigidBodyTree', lbr, ...
    'ConstraintInputs', {'cartesian','position','aiming','orientation','joint'})
```

```
gik = 
  generalizedInverseKinematics with properties:

      NumConstraints: 5
    ConstraintInputs: {1x5 cell}
       RigidBodyTree: [1x1 rigidBodyTree]
     SolverAlgorithm: 'BFGSGradientProjection'
    SolverParameters: [1x1 struct]
```

Create Constraint Objects

Create the constraint objects that are passed as inputs to the solver. These object contain the parameters needed for each constraint. Modify these parameters between calls to the solver as necessary.

Create a Cartesian bounds constraint that requires the gripper to be at least 5 cm above the table (negative z direction). All other values are given as `inf` or `-inf`.

```
heightAboveTable = constraintCartesianBounds(gripper);
heightAboveTable.Bounds = [-inf, inf; ...
                           -inf, inf; ...
                           0.05, inf]
```

```
heightAboveTable = 
  constraintCartesianBounds with properties:

        EndEffector: 'iiwa_link_ee_kuka'
      ReferenceBody: ''
    TargetTransform: [4x4 double]
             Bounds: [3x2 double]
            Weights: [1 1 1]
```

Create a constraint on the position of the cup relative to the gripper, with a tolerance of 5 mm.

```
distanceFromCup = constraintPositionTarget('cupFrame');
distanceFromCup.ReferenceBody = gripper;
distanceFromCup.PositionTolerance = 0.005
```

```
distanceFromCup = 
  constraintPositionTarget with properties:

          EndEffector: 'cupFrame'
        ReferenceBody: 'iiwa_link_ee_kuka'
       TargetPosition: [0 0 0]
    PositionTolerance: 0.0050
              Weights: 1
```

Create an aiming constraint that requires the z-axis of the `iiwa_link_ee` frame to be approximately vertical, by placing the target far above the robot. The `iiwa_link_ee` frame is oriented such that this constraint aligns the gripper with the axis of the cup.

```
alignWithCup = constraintAiming('iiwa_link_ee');
alignWithCup.TargetPoint = [0, 0, 100]
```

```
alignWithCup = 
  constraintAiming with properties:

         EndEffector: 'iiwa_link_ee'
       ReferenceBody: ''
         TargetPoint: [0 0 100]
    AngularTolerance: 0
             Weights: 1
```

Create a joint position bounds constraint. Set the `Bounds` property of this constraint based on the previous configuration to limit the change in joint positions.

```
limitJointChange = constraintJointBounds(lbr)
```

```
limitJointChange = 
  constraintJointBounds with properties:

     Bounds: [7x2 double]
    Weights: [1 1 1 1 1 1 1]
```

Create an orientation constraint for the gripper with a tolerance of one degree. This constraint requires the orientation of the gripper to match the value specified by the `TargetOrientation` property. Use this constraint to fix the orientation of the gripper during the final approach to the cup.

```
fixOrientation = constraintOrientationTarget(gripper);
fixOrientation.OrientationTolerance = deg2rad(1)
```

```
fixOrientation = 
  constraintOrientationTarget with properties:

             EndEffector: 'iiwa_link_ee_kuka'
           ReferenceBody: ''
       TargetOrientation: [1 0 0 0]
    OrientationTolerance: 0.0175
                 Weights: 1
```

Find a Configuration That Points at the Cup

This configuration should place the gripper at a distance from the cup, so that the final approach can be made with the gripper properly aligned.

```
intermediateDistance = 0.3;
```

Constraint objects have a `Weights` property which determines how the solver treats conflicting constraints. Setting the weights of a constraint to zero disables the constraint. For this configuration, disable the joint position bounds and orientation constraint.

```
limitJointChange.Weights = zeros(size(limitJointChange.Weights));
fixOrientation.Weights = 0;
```

Set the target position for the cup in the gripper frame. The cup should lie on the z-axis of the gripper at the specified distance.

```
distanceFromCup.TargetPosition = [0,0,intermediateDistance];
```

Solve for the robot configuration that satisfies the input constraints using the `gik` solver. You must specify all the input constraints. Set that configuration as the second waypoint.

```
[qWaypoints(2,:),solutionInfo] = gik(q0, heightAboveTable, ...
                       distanceFromCup, alignWithCup, fixOrientation, ...
                       limitJointChange);
```

Find Configurations That Move Gripper to the Cup Along a Straight Line

Re-enable the joint position bound and orientation constraints.

```
limitJointChange.Weights = ones(size(limitJointChange.Weights));
fixOrientation.Weights = 1;
```

Disable the align-with-cup constraint, as the orientation constraint makes it redundant.

```
alignWithCup.Weights = 0;
```

Set the orientation constraint to hold the orientation based on the previous configuration (`qWaypoints(2,:)`). Get the transformation from the gripper to the base of the robot model. Convert the homogeneous transformation to a quaternion.

```
fixOrientation.TargetOrientation = ...
    tform2quat(getTransform(lbr,qWaypoints(2,:),gripper));
```

Define the distance between the cup and gripper for each waypoint

```
finalDistanceFromCup = 0.05;
distanceFromCupValues = linspace(intermediateDistance, finalDistanceFromCup, numWaypoints-1);
```

Define the maximum allowed change in joint positions between each waypoint.

```
maxJointChange = deg2rad(10);
```

Call the solver for each remaining waypoint.

```
for k = 3:numWaypoints
    % Update the target position.
    distanceFromCup.TargetPosition(3) = distanceFromCupValues(k-1);
    % Restrict the joint positions to lie close to their previous values.
    limitJointChange.Bounds = [qWaypoints(k-1,:)' - maxJointChange, ...
                               qWaypoints(k-1,:)' + maxJointChange];
    % Solve for a configuration and add it to the waypoints array.
    [qWaypoints(k,:),solutionInfo] = gik(qWaypoints(k-1,:), ...
                                         heightAboveTable, ...
                                         distanceFromCup, alignWithCup, ...
                                         fixOrientation, limitJointChange);
end
```

Visualize the Generated Trajectory

Interpolate between the waypoints to generate a smooth trajectory. Use `pchip` to avoid overshoots, which might violate the joint limits of the robot.

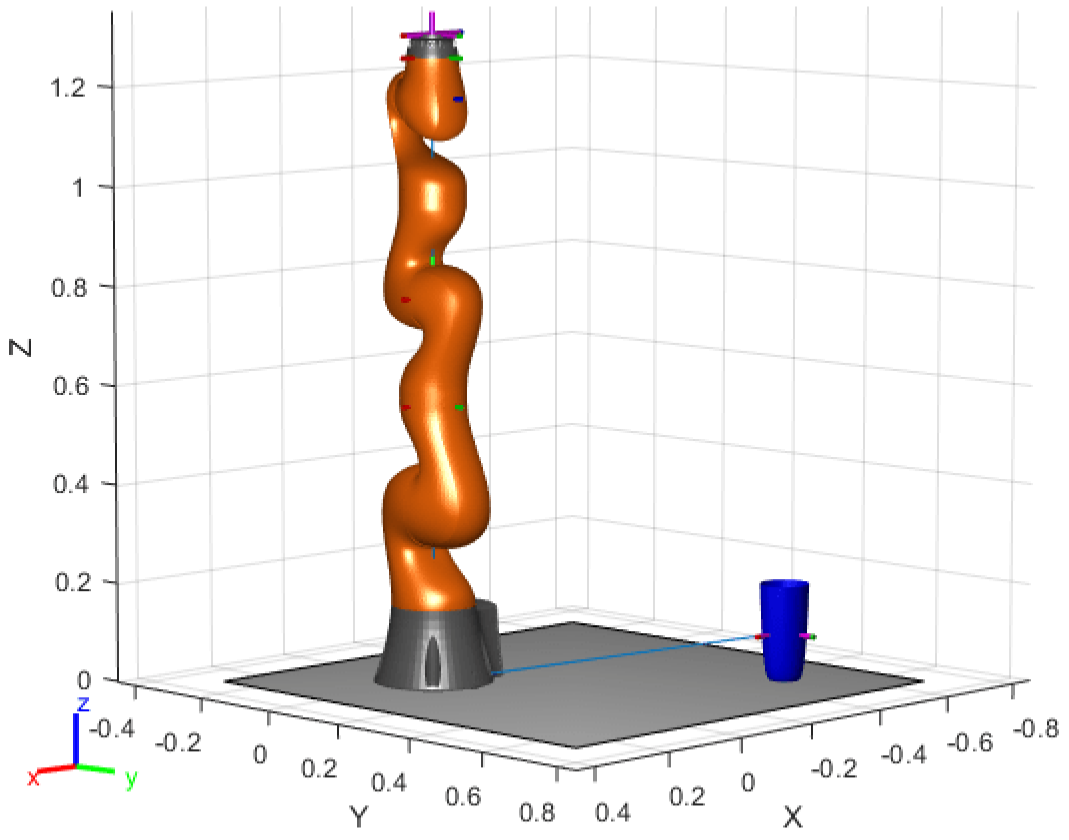
```
framerate = 15;
r = rateControl(framerate);
tFinal = 10;
tWaypoints = [0,linspace(tFinal/2,tFinal,size(qWaypoints,1)-1)];
numFrames = tFinal*framerate;
qInterp = pchip(tWaypoints,qWaypoints',linspace(0,tFinal,numFrames))';
```

Compute the gripper position for each interpolated configuration.

```
gripperPosition = zeros(numFrames,3);
for k = 1:numFrames
    gripperPosition(k,:) = tform2trvec(getTransform(lbr,qInterp(k,:), ...
                                                    gripper));
end
```

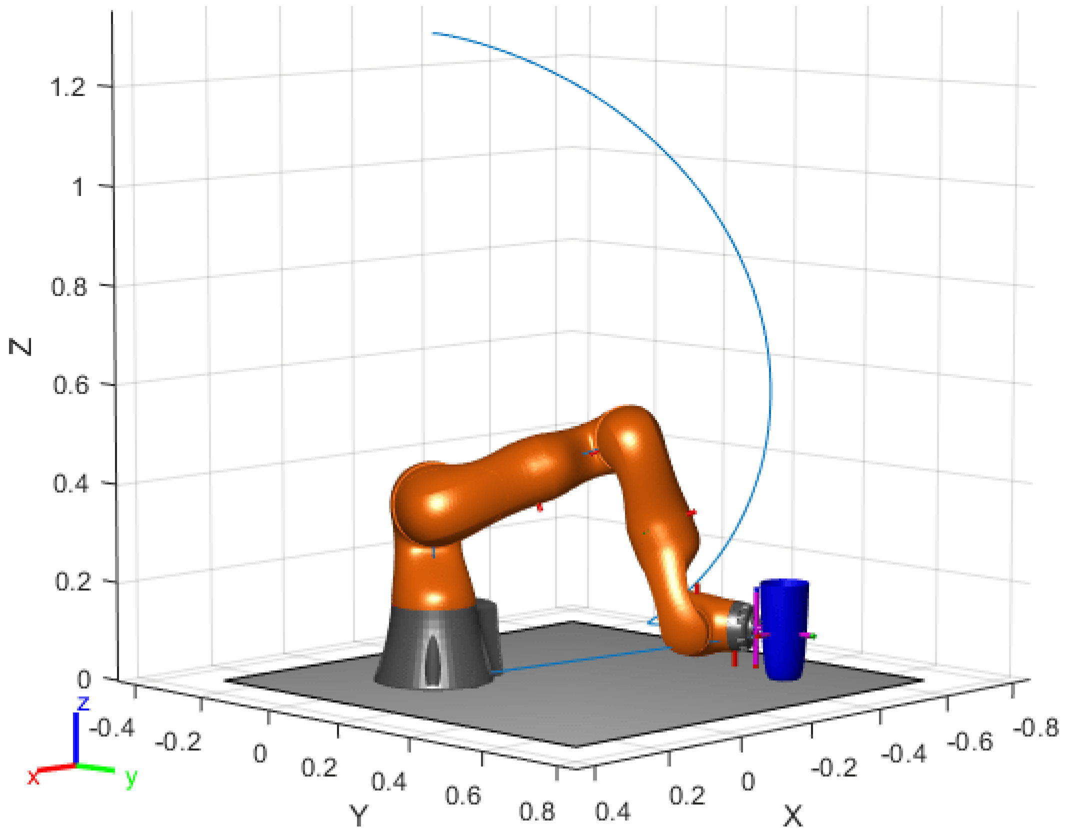
Show the robot in its initial configuration along with the table and cup

```
figure;
show(lbr, qWaypoints(1,:), 'PreservePlot', false);
hold on
exampleHelperPlotCupAndTable(cupHeight, cupRadius, cupPosition);
p = plot3(gripperPosition(1,1), gripperPosition(1,2), gripperPosition(1,3));
```



Animate the manipulator and plot the gripper position.

```
hold on
for k = 1:size(qInterp,1)
    show(lbr, qInterp(k,:), 'PreservePlot', false);
    p.XData(k) = gripperPosition(k,1);
    p.YData(k) = gripperPosition(k,2);
    p.ZData(k) = gripperPosition(k,3);
    waitfor(r);
end
hold off
```



If you want to save the generated configurations to a MAT-file for later use, execute the following:

```
>> save('lbr_trajectory.mat', 'tWaypoints', 'qWaypoints');
```

Compatibility Considerations

`constraintPoseTarget` was renamed
Behavior change in future release

The `constraintPoseTarget` object was renamed from `robotics.PoseTarget`. Use `constraintPoseTarget` for all object creation.

Extended Capabilities

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

See Also

Classes
`generalizedInverseKinematics` | `constraintPositionTarget` |
`constraintOrientationTarget` | `constraintCartesianBounds`

Topics
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

constraintPositionTarget

Create constraint on relative position of body

Description

The `constraintPositionTarget` object describes a constraint that requires the position of one body (the end effector) to match a target position within a distance tolerance in any direction. The target position is specified relative to the body frame of the reference body.

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

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

Creation

Syntax

```
positionConst = constraintPositionTarget(endeffector)
positionConst = constraintPositionTarget(endeffector,Name,Value)
```

Description

`positionConst = constraintPositionTarget(endeffector)` returns a position target object that represents a constraint on the body of the robot model specified by `endeffector`.

`positionConst = constraintPositionTarget(endeffector,Name,Value)` returns a position target object with each specified property name set to the specified value by one or more `Name,Value` pair arguments.

Input Arguments

`endeffector` — End-effector name
string scalar | character vector

End-effector name, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

Properties

`EndEffector` — Name of the end effector
string scalar | character vector

Name of the end effector, specified as a string scalar or character vector. When using this constraint with `generalizedInverseKinematics`, the name must match a body specified in the robot model (`rigidBodyTree`).

Example: `"left_palm"`

Data Types: `char` | `string`

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

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

Example:

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

Position of the target relative to the reference body, specified as an `[x y z]` vector. The target position is a point specified in the reference body frame.

Example:

`PositionTolerance` — Maximum allowed distance from target
`0` (default) | numeric scalar

Maximum allowed distance from target in meters, specified as a numeric scalar. This value is the upper bound on the distance between the end-effector origin and the target position.

Example:

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

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

Example:

Examples

Plan a Reaching Trajectory With Multiple Kinematic Constraints

This example shows how to use generalized inverse kinematics to plan a joint-space trajectory for a robotic manipulator. It combines multiple constraints to generate a trajectory that guides the gripper to a cup resting on a table. These constraints ensure that the gripper approaches the cup in a straight line and that the gripper remains at a safe distance from the table, without requiring the poses of the gripper to be determined in advance.

Set Up the Robot Model

This example uses a model of the KUKA LBR iiwa, a 7 degree-of-freedom robot manipulator. `importrobot` generates a `rigidBodyTree` model from a description stored in a Unified Robot Description Format (URDF) file.

```
lbr = importrobot('iiwa14.urdf'); % 14 kg payload version
lbr.DataFormat = 'row';
gripper = 'iiwa_link_ee_kuka';
```

Define dimensions for the cup.

```
cupHeight = 0.2;
cupRadius = 0.05;
cupPosition = [-0.5, 0.5, cupHeight/2];
```

Add a fixed body to the robot model representing the center of the cup.

```
body = rigidBody('cupFrame');
setFixedTransform(body.Joint, trvec2tform(cupPosition))
addBody(lbr, body, lbr.BaseName);
```

Define the Planning Problem

The goal of this example is to generate a sequence of robot configurations that satisfy the following criteria:

- Start in the home configuration
- No abrupt changes in robot configuration
- Keep the gripper at least 5 cm above the "table" (z = 0)
- The gripper should be aligned with the cup as it approaches
- Finish with the gripper 5 cm from the center of the cup

This example utilizes constraint objects to generate robot configurations that satisfy these criteria. The generated trajectory consists of five configuration waypoints. The first waypoint, `q0`, is set as the home configuration. Pre-allocate the rest of the configurations in `qWaypoints` using `repmat`.

```
numWaypoints = 5;
q0 = homeConfiguration(lbr);
qWaypoints = repmat(q0, numWaypoints, 1);
```

Create a `generalizedInverseKinematics` solver that accepts the following constraint inputs:

- Cartesian bounds - Limits the height of the gripper
- A position target - Specifies the position of the cup relative to the gripper.
- An aiming constraint - Aligns the gripper with the cup axis
- An orientation target - Maintains a fixed orientation for the gripper while approaching the cup
- Joint position bounds - Limits the change in joint positions between waypoints.

```
gik = generalizedInverseKinematics('RigidBodyTree', lbr, ...
    'ConstraintInputs', {'cartesian','position','aiming','orientation','joint'})
```

```
gik = 
  generalizedInverseKinematics with properties:
      NumConstraints: 5
    ConstraintInputs: {1x5 cell}
        RigidBodyTree: [1x1 rigidBodyTree]
     SolverAlgorithm: 'BFGSGradientProjection'
    SolverParameters: [1x1 struct]
```

Create Constraint Objects

Create the constraint objects that are passed as inputs to the solver. These object contain the parameters needed for each constraint. Modify these parameters between calls to the solver as necessary.

Create a Cartesian bounds constraint that requires the gripper to be at least 5 cm above the table (negative z direction). All other values are given as `inf` or `-inf`.

```
heightAboveTable = constraintCartesianBounds(gripper);
heightAboveTable.Bounds = [-inf, inf; ...
                           -inf, inf; ...
                           0.05, inf]
```

```
heightAboveTable = 
  constraintCartesianBounds with properties:

        EndEffector: 'iiwa_link_ee_kuka'
      ReferenceBody: ''
    TargetTransform: [4x4 double]
             Bounds: [3x2 double]
            Weights: [1 1 1]
```

Create a constraint on the position of the cup relative to the gripper, with a tolerance of 5 mm.

```
distanceFromCup = constraintPositionTarget('cupFrame');
distanceFromCup.ReferenceBody = gripper;
distanceFromCup.PositionTolerance = 0.005
```

```
distanceFromCup = 
  constraintPositionTarget with properties:

          EndEffector: 'cupFrame'
        ReferenceBody: 'iiwa_link_ee_kuka'
       TargetPosition: [0 0 0]
    PositionTolerance: 0.0050
              Weights: 1
```

Create an aiming constraint that requires the z-axis of the `iiwa_link_ee` frame to be approximately vertical, by placing the target far above the robot. The `iiwa_link_ee` frame is oriented such that this constraint aligns the gripper with the axis of the cup.

```
alignWithCup = constraintAiming('iiwa_link_ee');
alignWithCup.TargetPoint = [0, 0, 100]
```

```
alignWithCup = 
  constraintAiming with properties:
         EndEffector: 'iiwa_link_ee'
       ReferenceBody: ''
         TargetPoint: [0 0 100]
    AngularTolerance: 0
             Weights: 1
```

Create a joint position bounds constraint. Set the `Bounds` property of this constraint based on the previous configuration to limit the change in joint positions.

```
limitJointChange = constraintJointBounds(lbr)
```

```
limitJointChange = 
  constraintJointBounds with properties:

     Bounds: [7x2 double]
    Weights: [1 1 1 1 1 1 1]
```

Create an orientation constraint for the gripper with a tolerance of one degree. This constraint requires the orientation of the gripper to match the value specified by the `TargetOrientation` property. Use this constraint to fix the orientation of the gripper during the final approach to the cup.

```
fixOrientation = constraintOrientationTarget(gripper);
fixOrientation.OrientationTolerance = deg2rad(1)
```

```
fixOrientation = 
  constraintOrientationTarget with properties:

             EndEffector: 'iiwa_link_ee_kuka'
           ReferenceBody: ''
       TargetOrientation: [1 0 0 0]
    OrientationTolerance: 0.0175
                 Weights: 1
```

Find a Configuration That Points at the Cup

This configuration should place the gripper at a distance from the cup, so that the final approach can be made with the gripper properly aligned.

```
intermediateDistance = 0.3;
```

Constraint objects have a `Weights` property which determines how the solver treats conflicting constraints. Setting the weights of a constraint to zero disables the constraint. For this configuration, disable the joint position bounds and orientation constraint.

```
limitJointChange.Weights = zeros(size(limitJointChange.Weights));
fixOrientation.Weights = 0;
```

Set the target position for the cup in the gripper frame. The cup should lie on the z-axis of the gripper at the specified distance.

```
distanceFromCup.TargetPosition = [0,0,intermediateDistance];
```

Solve for the robot configuration that satisfies the input constraints using the `gik` solver. You must specify all the input constraints. Set that configuration as the second waypoint.

```
[qWaypoints(2,:),solutionInfo] = gik(q0, heightAboveTable, ...
                       distanceFromCup, alignWithCup, fixOrientation, ...
                       limitJointChange);
```

Find Configurations That Move Gripper to the Cup Along a Straight Line

Re-enable the joint position bound and orientation constraints.

```
limitJointChange.Weights = ones(size(limitJointChange.Weights));
fixOrientation.Weights = 1;
```

Disable the align-with-cup constraint, as the orientation constraint makes it redundant.

```
alignWithCup.Weights = 0;
```

Set the orientation constraint to hold the orientation based on the previous configuration (`qWaypoints(2,:)`). Get the transformation from the gripper to the base of the robot model. Convert the homogeneous transformation to a quaternion.

```
fixOrientation.TargetOrientation = ...
    tform2quat(getTransform(lbr,qWaypoints(2,:),gripper));
```

Define the distance between the cup and gripper for each waypoint

```
finalDistanceFromCup = 0.05;
distanceFromCupValues = linspace(intermediateDistance, finalDistanceFromCup, numWaypoints-1);
```

Define the maximum allowed change in joint positions between each waypoint.

```
maxJointChange = deg2rad(10);
```

Call the solver for each remaining waypoint.

```
for k = 3:numWaypoints
    % Update the target position.
    distanceFromCup.TargetPosition(3) = distanceFromCupValues(k-1);
    % Restrict the joint positions to lie close to their previous values.
    limitJointChange.Bounds = [qWaypoints(k-1,:)' - maxJointChange, ...
                               qWaypoints(k-1,:)' + maxJointChange];
    % Solve for a configuration and add it to the waypoints array.
    [qWaypoints(k,:),solutionInfo] = gik(qWaypoints(k-1,:), ...
                                        heightAboveTable, ...
                                        distanceFromCup, alignWithCup, ...
                                        fixOrientation, limitJointChange);
end
```

Visualize the Generated Trajectory

Interpolate between the waypoints to generate a smooth trajectory. Use `pchip` to avoid overshoots, which might violate the joint limits of the robot.

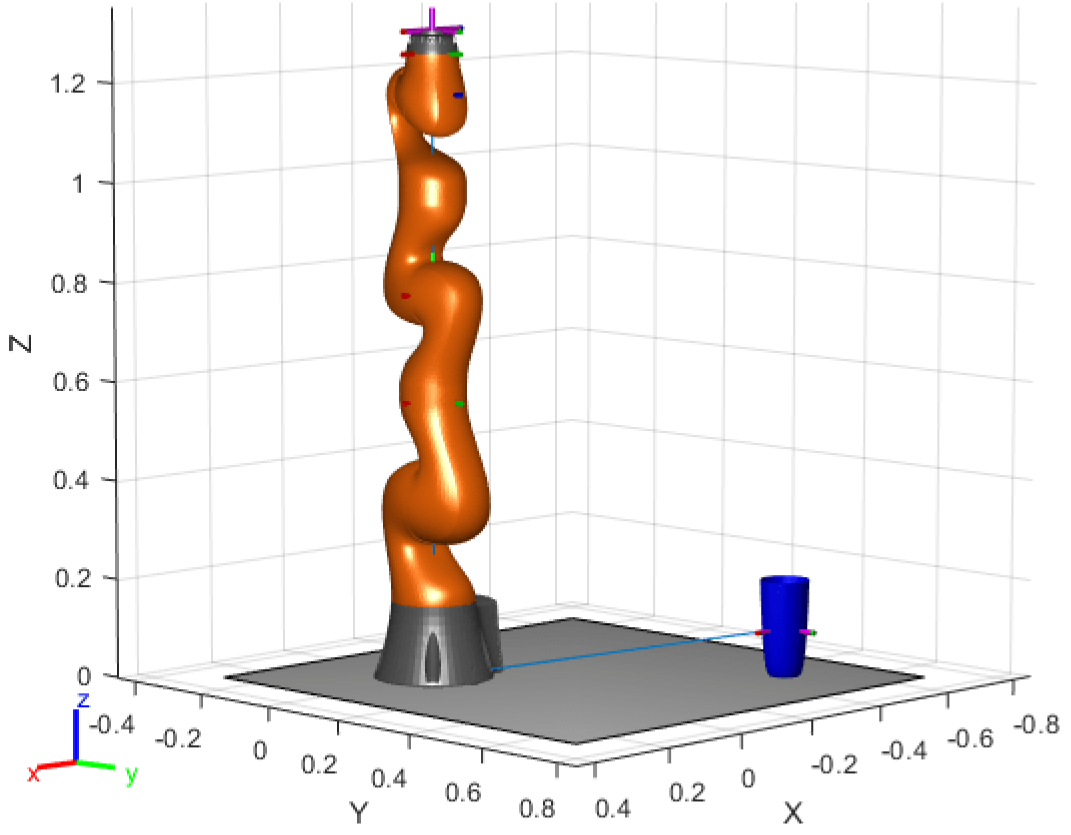
```
framerate = 15;
r = rateControl(framerate);
tFinal = 10;
tWaypoints = [0,linspace(tFinal/2,tFinal,size(qWaypoints,1)-1)];
numFrames = tFinal*framerate;
qInterp = pchip(tWaypoints,qWaypoints',linspace(0,tFinal,numFrames))';
```

Compute the gripper position for each interpolated configuration.

```
gripperPosition = zeros(numFrames,3);
for k = 1:numFrames
    gripperPosition(k,:) = tform2trvec(getTransform(lbr,qInterp(k,:), ...
                                                   gripper));
end
```

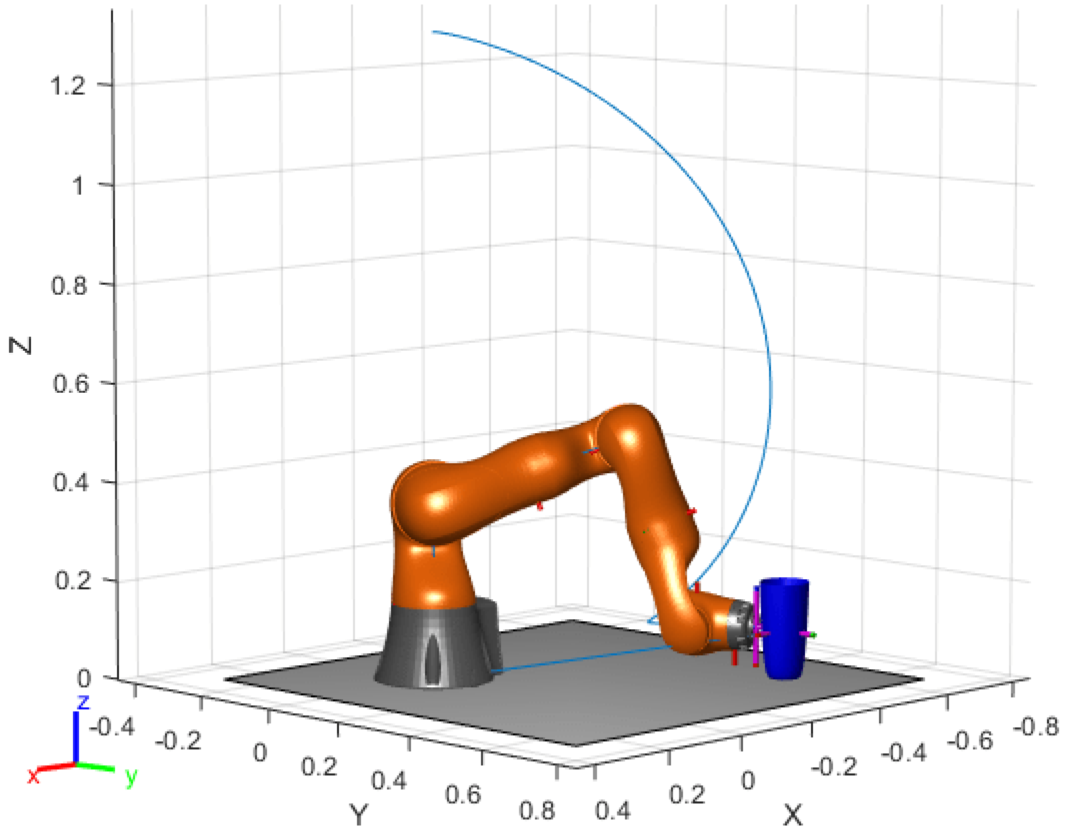
Show the robot in its initial configuration along with the table and cup

```
figure;
show(lbr, qWaypoints(1,:), 'PreservePlot', false);
hold on
exampleHelperPlotCupAndTable(cupHeight, cupRadius, cupPosition);
p = plot3(gripperPosition(1,1), gripperPosition(1,2), gripperPosition(1,3));
```



Animate the manipulator and plot the gripper position.

```
hold on
for k = 1:size(qInterp,1)
    show(lbr, qInterp(k,:), 'PreservePlot', false);
    p.XData(k) = gripperPosition(k,1);
    p.YData(k) = gripperPosition(k,2);
    p.ZData(k) = gripperPosition(k,3);
    waitfor(r);
end
hold off
```



If you want to save the generated configurations to a MAT-file for later use, execute the following:

```
>> save('lbr_trajectory.mat', 'tWaypoints', 'qWaypoints');
```

Compatibility Considerations

`constraintPositionTarget` was renamed
Behavior change in future release

The `constraintPositionTarget` object was renamed from `robotics.PositionTarget`. Use `constraintPositionTarget` for all object creation.

Extended Capabilities

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

See Also

Classes
`generalizedInverseKinematics` | `constraintOrientationTarget` | `constraintPoseTarget` | `constraintCartesianBounds`

Topics

"Plan a Reaching Trajectory With Multiple Kinematic Constraints"

Introduced in R2017a

controllerPurePursuit

Create controller to follow set of waypoints

Description

The `controllerPurePursuit` System object™ creates a controller object used to make a differential-drive vehicle follow a set of waypoints. The object computes the linear and angular velocities for the vehicle given the current pose. Successive calls to the object with updated poses provide updated velocity commands for the vehicle. Use the `MaxAngularVelocity` and `DesiredLinearVelocity` properties to update the velocities based on the vehicle's performance.

The `LookaheadDistance` property computes a look-ahead point on the path, which is a local goal for the vehicle. The angular velocity command is computed based on this point. Changing `LookaheadDistance` has a significant impact on the performance of the algorithm. A higher look-ahead distance results in a smoother trajectory for the vehicle, but can cause the vehicle to cut corners along the path. A low look-ahead distance can result in oscillations in tracking the path, causing unstable behavior. For more information on the pure pursuit algorithm, see “Pure Pursuit Controller”.

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

To compute linear and angular velocity control commands:

1. Create the `controllerPurePursuit` 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?

Creation

Syntax

`controller = controllerPurePursuit`

`controller = controllerPurePursuit(Name,Value)`

Description

`controller = controllerPurePursuit` creates a pure pursuit object that uses the pure pursuit algorithm to compute the linear and angular velocity inputs for a differential drive vehicle.

`controller = controllerPurePursuit(Name,Value)` creates a pure pursuit object with additional options specified by one or more `Name,Value` pairs. Name is the property name and Value is the corresponding value. Name must appear inside single quotes (`' '`). You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`. Properties not specified retain their default values.

Example: `controller = controllerPurePursuit('DesiredLinearVelocity', 0.5)`

Properties

`DesiredLinearVelocity` — Desired constant linear velocity
`0.1` (default) | scalar in meters per second

Desired constant linear velocity, specified as a scalar in meters per second. The controller assumes that the vehicle drives at a constant linear velocity and that the computed angular velocity is independent of the linear velocity.

Data Types: `double`

`LookaheadDistance` — Look-ahead distance
`1.0` (default) | scalar in meters

Look-ahead distance, specified as a scalar in meters. The look-ahead distance changes the response of the controller. A vehicle with a higher look-ahead distance produces smooth paths but takes larger turns at corners. A vehicle with a smaller look-ahead distance follows the path closely and takes sharp turns, but potentially creating oscillations in the path.

Data Types: `double`

`MaxAngularVelocity` — Maximum angular velocity
`1.0` (default) | scalar in radians per second

Maximum angular velocity, specified a scalar in radians per second. The controller saturates the absolute angular velocity output at the given value.

Data Types: `double`

`Waypoints` — Waypoints
[ ] (default) | *n*-by-2 array

Waypoints, specified as an *n*-by-2 array of `[x y]` pairs, where *n* is the number of waypoints. You can generate the waypoints from the `mobileRobotPRM` class or from another source.

Data Types: `double`

Usage

Syntax

```
[vel,angvel] = controller(pose)
[vel,angvel,lookaheadpoint] = controller(pose)
```

Description

`[vel,angvel] = controller(pose)` processes the vehicle's position and orientation, `pose`, and outputs the linear velocity, `vel`, and angular velocity, `angvel`.

`[vel,angvel,lookaheadpoint] = controller(pose)` returns the look-ahead point, which is a location on the path used to compute the velocity commands. This location on the path is computed using the `LookaheadDistance` property on the `controller` object.

Input Arguments

pose — Position and orientation of vehicle
3-by-1 vector in the form `[x y theta]`

Position and orientation of vehicle, specified as a 3-by-1 vector in the form `[x y theta]`. The vehicle pose is an *x* and *y* position with angular orientation θ (in radians) measured from the *x*-axis.

Output Arguments

vel — Linear velocity
scalar in meters per second

Linear velocity, specified as a scalar in meters per second.

Data Types: `double`

angvel — Angular velocity
scalar in radians per second

Angular velocity, specified as a scalar in radians per second.

Data Types: `double`

lookaheadpoint — Look-ahead point on path
`[x y]` vector

Look-ahead point on the path, returned as an `[x y]` vector. This value is calculated based on the `LookaheadDistance` property.

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to controllerPurePursuit

info	Characteristic information about controllerPurePursuit object

Common to All System Objects

step	Run System object algorithm
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object

Examples

Get Additional Pure Pursuit Object Information

Use the `info` method to get more information about a `controllerPurePursuit` object. The `info` function returns two fields, `RobotPose` and `LookaheadPoint`, which correspond to the current position and orientation of the robot and the point on the path used to compute outputs from the last call of the object.

Create a `controllerPurePursuit` object.

```
pp = controllerPurePursuit;
```

Assign waypoints.

```
pp.Waypoints = [0 0;1 1];
```

Compute control commands using the `pp` object with the initial pose `[x y theta]` given as the input.

```
[v,w] = pp([0 0 0]);
```

Get additional information.

```
s = info(pp)
```

```
s = struct with fields:
         RobotPose: [0 0 0]
    LookaheadPoint: [0.7071 0.7071]
```

Extended Capabilities

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

Usage notes and limitations:

Use in a MATLAB Function block is not supported.

For additional information about code generation for System objects, see “System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

`binaryOccupancyMap` | `occupancyMap` | `mobileRobotPRM`

Topics
“Path Following for a Differential Drive Robot”
“Pure Pursuit Controller”

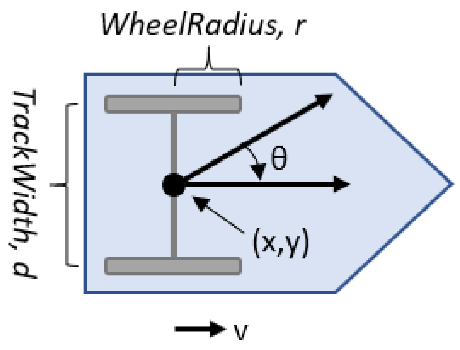
Introduced in R2019b

differentialDriveKinematics

Differential-drive vehicle model

Description

`differentialDriveKinematics` creates a differential-drive vehicle model to simulate simplified vehicle dynamics. This model approximates a vehicle with a single fixed axle and wheels separated by a specified track width. The wheels can be driven independently. Vehicle speed and heading is defined from the axle center. The state of the vehicle is defined as a three-element vector, *[x y theta]*, with a global *xy*-position, specified in meters, and a vehicle heading, *theta*, specified in radians. To compute the time derivative states for the model, use the `derivative` function with input commands and the current robot state.



Creation

Syntax

`kinematicModel = differentialDriveKinematics`

`kinematicModel = differentialDriveKinematics(Name,Value)`

Description

`kinematicModel = differentialDriveKinematics` creates a differential drive kinematic model object with default property values.

`kinematicModel = differentialDriveKinematics(Name,Value)` sets properties on the object to the specified value. You can specify multiple properties in any order.

Properties

`WheelRadius` — Wheel radius of vehicle
`0.05` (default) | positive numeric scalar

The wheel radius of the vehicle, specified in meters.

`WheelSpeedRange` — Range of vehicle wheel speeds

`[-Inf Inf]` (default) | two-element vector

The vehicle speed range is a two-element vector that provides the minimum and maximum vehicle speeds, [*MinSpeed MaxSpeed*], specified in meters per second.

`TrackWidth` — Distance between wheels on axle

`0.2` (default) | positive numeric scalar

The vehicle track width refers to the distance between the wheels, or the axle length, specified in meters.

`VehicleInputs` — Type of motion inputs for vehicle

`"WheelSpeeds"` (default) | character vector | string scalar

The `VehicleInputs` property specifies the format of the model input commands when using the `derivative` function. Options are specified as one of the following strings:

- `"WheelSpeeds"` — Angular speeds for each of the wheels, specified in radians per second.
- `"VehicleSpeedHeadingRate"` — Vehicle speed and heading angular velocity,specified in meters per second and radians per second respectively.

Object Functions

derivative	Time derivative of vehicle state

Examples

Plot Path of Differential-Drive Kinematic Robot

Create a Robot

Define a robot and set the initial starting position and orientation.

```
kinematicModel = differentialDriveKinematics;
initialState = [0 0 0];
```

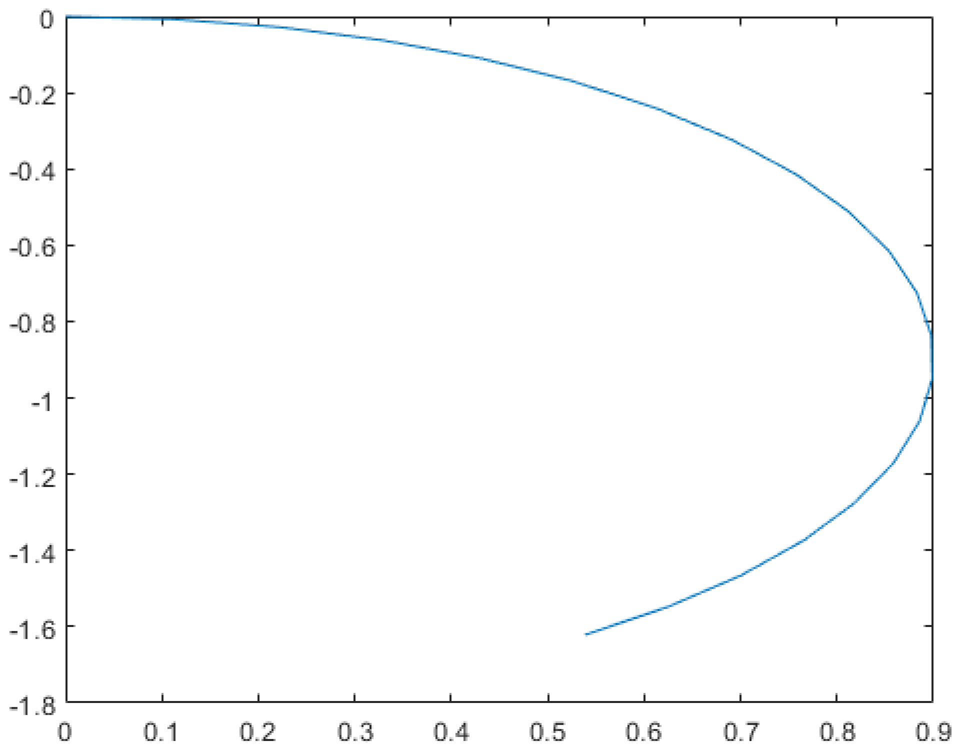
Simulate Robot Motion

Set the timespan of the simulation to 1 s with 0.05 s timesteps and the input commands to 2 m/s and left turn. Simulate the motion of the robot by using the `ode45` solver on the `derivative` function.

```
tspan = 0:0.05:1;
inputs = [50 40]; %Left wheel is spinning faster
[t,y] = ode45(@(t,y)derivative(kinematicModel,y,inputs),tspan,initialState);
```

Plot Path

```
figure
plot(y(:,1),y(:,2))
```



References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control* 1st ed. Cambridge, MA: Cambridge University Press, 2017.

Extended Capabilities

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

See Also

Classes
`ackermannKinematics` | `bicycleKinematics` | `unicycleKinematics`

Blocks
Differential Drive Kinematic Model

Functions
`derivative`

Topics
“Path Following for a Differential Drive Robot”
“Simulate Different Kinematic Models for Mobile Robots”

"Mobile Robot Kinematics Equations"

Introduced in R2019b

generalizedInverseKinematics

Create multiconstraint inverse kinematics solver

Description

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

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

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

- `constraintAiming`
- `constraintCartesianBounds`
- `constraintJointBounds`
- `constraintOrientationTarget`
- `constraintPoseTarget`
- `constraintPositionTarget`

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

For closed-form analytical inverse kinematics solutions, see `analyticalInverseKinematics`.

To solve the generalized inverse kinematics constraints:

1. Create the `generalizedInverseKinematics` object and set its properties.
2. Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects?

Creation

Syntax

```
gik = generalizedInverseKinematics
gik = generalizedInverseKinematics('RigidBodyTree',rigidbodytree,'
ConstraintInputs',inputTypes)
gik = generalizedInverseKinematics(Name,Value)
```

Description

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

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

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

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

`NumConstraints` — Number of constraint inputs
scalar

This property is read-only.

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

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

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

- `'orientation'` — `constraintOrientationTarget`
- `'position'` — `constraintPositionTarget`
- `'pose'` — `constraintPoseTarget`
- `'aiming'` — `constraintAiming`
- `'cartesian'` — `constraintCartesianBounds`
- `'joint'` — `constraintJointBounds`

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

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

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

Create the corresponding constraint objects.

```
positionTgt = constraintPositionTarget('left_palm');
aimConst = constraintAiming('right_palm');
```

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

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

`RigidBodyTree` — Rigid body tree model
`rigidBodyTree` object

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

Create IK solver and specify the rigid body tree.

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

Modify the rigid body tree model.

```
addBody(rigidbodytree,rigidBody('body1'),'base')
```

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

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

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

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

`SolverParameters` — Parameters associated with algorithm
structure

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

Usage

Syntax

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

Description

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

Input Arguments

`initialguess` — Initial guess of robot configuration

structure array | vector

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

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

`constraintObj,...,constraintObjN` — Constraint descriptions

constraint objects

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

- `constraintAiming`
- `constraintCartesianBounds`
- `constraintJointBounds`
- `constraintOrientationTarget`
- `constraintPoseTarget`
- `constraintPositionTarget`

Output Arguments

`configSol` — Robot configuration solution

structure array | vector

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

The structure array contains these fields:

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

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

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

Note For revolute joints, if the joint limits exceed a range of `2*pi`, where joint position wrapping occurs, then the returned joint position is the one closest to the joint's lower bound.

`solInfo` — Solution information
structure

Solution information, returned as a structure containing these fields:

- `Iterations` — Number of iterations run by the solver.
- `NumRandomRestarts` — Number of random restarts because the solver got stuck in a local minimum.
- `ConstraintViolation` — Information about the constraint, returned as a structure array. Each structure in the array has these fields:
  - `Type`: Type of the corresponding constraint input, as specified in the `ConstraintInputs` property.
  - `Violation`: Vector of constraint violations for the corresponding constraint type. `0` indicates that the constraint is satisfied.
- `ExitFlag` — Code that gives more details on the solver execution and what caused it to return. For the exit flags of each solver type, see “Exit Flags”.
- `Status` — Character vector describing whether the solution is within the tolerances defined by each constraint (`'success'`). If the solution is outside the tolerance, the best possible solution that the solver could find is given (`'best available'`).

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Common to All System Objects

step	Run System object algorithm
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object

Examples

Solve Generalized Inverse Kinematics for a Set of Constraints

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

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

```
load exampleRobots.mat lbr
```

Create the System object™ for solving generalized inverse kinematics.

```
gik = generalizedInverseKinematics;
```

Configure the System object to use the KUKA LBR robot.

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

Tell the solver to expect a `PositionTarget` object and a `constraintAiming` and `constraintPositionTarget` object as the constraint inputs.

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

Create the two constraint objects.

1. The origin of the body named `tool0` is located at `[0.0 0.5 0.5]` relative to the robot's base frame.
2. The *z*-axis of the body named `tool0` points toward the origin of the robot's base frame.

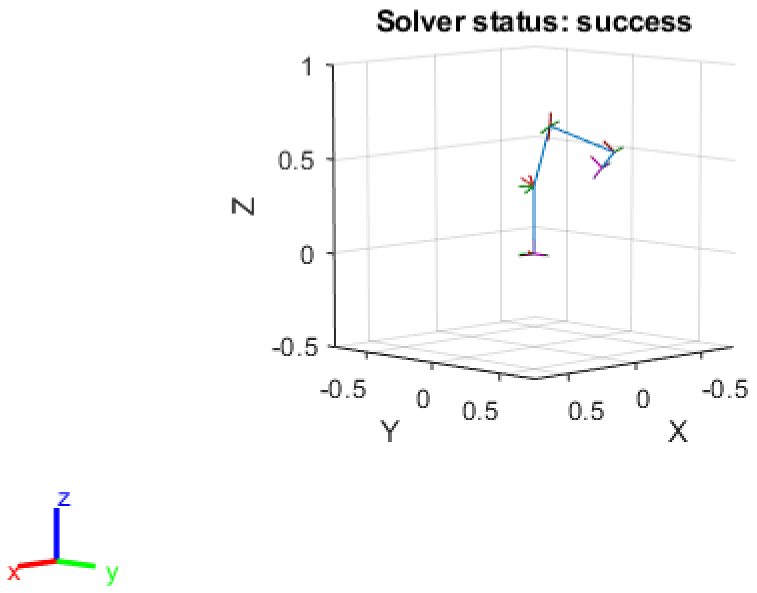
```
posTgt = constraintPositionTarget('tool0');
posTgt.TargetPosition = [0.0 0.5 0.5];

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

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

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

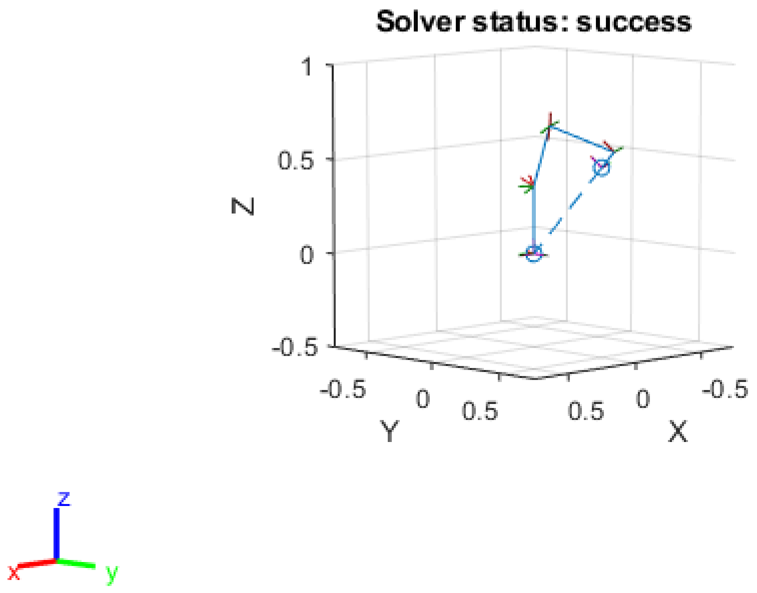
Visualize the configuration returned by the solver.

```
show(lbr,q);
title(['Solver status: ' solutionInfo.Status])
axis([-0.75 0.75 -0.75 0.75 -0.5 1])
```



Plot a line segment from the target position to the origin of the base. The origin of the `tool0` frame coincides with one end of the segment, and its `z`-axis is aligned with the segment.

```
hold on
plot3([0.0 0.0],[0.5 0.0],[0.5 0.0],'--o')
hold off
```



Compatibility Considerations

`generalizedInverseKinematics` was renamed
Behavior change in future release

The `generalizedInverseKienematics` object was renamed from `robotics.GeneralizedInverseKinematics`. Use `generalizedInverseKienematics` for all object creation.

Extended Capabilities

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

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

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

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

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

See Also

Objects
analyticalInverseKinematics | inverseKinematics | constraintPoseTarget | constraintPositionTarget | constraintAiming | constraintCartesianBounds | constraintJointBounds | constraintOrientationTarget

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

Introduced in R2017a

interactiveRigidBodyTree

Interact with rigid body tree robot models

Description

The `interactiveRigidBodyTree` object creates a figure that displays a robot model using a `rigidBodyTree` object and enables you to directly modify the robot configuration using an interactive marker. The `rigidBodyTree` object defines the geometry of the different connected rigid bodies in the robot model and the joint limits for these bodies.

To compute new configurations using inverse kinematics, click and drag the interactive marker in the figure. The marker supports dragging of the center marker, linear motion along specific axes, and rotation about each axes. You can change the end effector by right-clicking a different body and choosing **Set body as marker body**.

To save the current configuration of the robot model, use the `addConfiguration` object function. The StoredConfigurations property contains the saved configurations.

By default, the joint limits of the robot model are the only constraint on the robot. To add additional constraints, use the `addConstraint` object function. For a list of available constraint objects, see **Robot Constraints** in "Inverse Kinematics".

Creation

Syntax

```
viztree = interactiveRigidBodyTree(robot)
viztree = interactiveRigidBodyTree(robot,'Frames','off')
viztree = interactiveRigidBodyTree(___,Name,Value)
```

Description

`viztree = interactiveRigidBodyTree(robot)` creates an interactive rigid body tree object and associated figure for the specified robot model. The `robot` argument sets the `RigidBodyTree` property. To interact with the model, click and drag the interactive marker in the figure.

`viztree = interactiveRigidBodyTree(robot,'Frames','off')` turns off the frame axes plotted for each joint in the robot model.

`viztree = interactiveRigidBodyTree(___,Name,Value)` sets properties using one or more name-value pair arguments in addition to any of the input argument combinations in previous syntaxes. Enclose each property name in quotes. For example, `'RigidBodyTree',robot` creates an interactive rigid body tree object with the specified robot model.

Properties

`RigidBodyTree` — Rigid body tree robot model
`rigidBodyTree` object

Rigid body tree robot model, specified as a `rigidBodyTree` object. The robot model defines the geometry of the rigid bodies and the joints connecting them. To access provided robot models, use the `loadrobot` function. To import models from URDF files or Simscape™ Multibody™ models, use the `importrobot` function.

You can set this property when you create the object. After you create the object, this property is read-only.

`IKSolver` — Inverse kinematics solver
`generalizedInverseKinematics` System object with default properties (default) | `generalizedInverseKinematics` object

Inverse kinematics solver, specified as a `generalizedInverseKinematics` System object. By default, the solver uses the Levenberg-Marquardt algorithm with a maximum number of iterations of 2. Increasing the maximum number of iterations can decrease the frame rate in the figure.

You can set this property when you create the object. After you create the object, this property is read-only.

`MarkerBodyName` — Name of rigid body associated with interactive marker
`viztree.RigidBodyTree.BodyNames{end}` (default) | string scalar | character vector

Name of rigid body associated with interactive marker, specified as a string scalar or character vector. By default, this property is set to the body with the highest index in the `RigidBodyTree` property. To change this property using the figure, right-click a rigid body and select **Set body as marker body**.

Example: `"r_foot"`

Data Types: `char` | `string`

`MarkerPose` — Current pose of interactive marker
4-by-4 homogeneous transformation matrix

This property is read-only.

Current pose of interactive marker, specified as a 4-by-4 homogeneous transformation matrix.

Data Types: `double`

`MarkerBodyPose` — Current pose of rigid body associated with interactive marker
4-by-4 homogeneous transformation matrix

This property is read-only.

Current pose of the rigid body associated with the interactive marker, specified as a 4-by-4 homogeneous transformation matrix.

Data Types: `double`

`Constraints` — Constraints on inverse kinematics solver
`{}` (default) | cell array of constraint objects

Constraints on inverse kinematics solver, specified as a cell array of one or more constraint objects:

- `constraintAiming`

- `constraintCartesianBounds`
- `constraintJointBounds`
- `constraintOrientationTarget`
- `constraintPoseTarget`
- `constraintPositionTarget`

By default, the inverse kinematics solver respects only the joint limits of the RigidBodyTree property. To add or remove the constraints on the robot model, use the `addConstraint` and `removeConstraints` object functions respectively. Alternatively, you can assign a new cell array of constraint objects to the property.

Example: `{constraintAiming("head","ReferenceBody","right_hand")}`

Data Types: `cell`

`SolverPoseWeights` — Weights on orientation and position of target pose
`[1 1]` (default) | two-element vector `[`*`orientation position`*`]`

Weights on orientation and position of target pose, respectively, specified as a two-element vector, `[`*`orientation position`*`]`.

To increase priority for matching a desired orientation or position, increase the corresponding weight value.

Example: `[1 4]`

Data Types: `double`

`ShowMarker` — Visibility of interactive marker in figure
`true` or `1` (default) | `false` or `0`

Visibility of interactive marker in figure, specified as logical `1` (`true`) or `0` or (`false`). Set `ShowMarker` to `false` to hide the interactive marker in the figure.

Data Types: `logical`

`MarkerControlMethod` — Type of control for interactive marker
`"InverseKinematics"` (default) | `"JointControl"`

Type of control for interactive marker, specified as `"InverseKinematics"` or `"JointControl"`. By default, the figure computes all the joint configurations of the robot by using inverse kinematics with the end effector set to MarkerBodyName property value. To control the position of a specific joint on the selected rigid body, set this property to `"JointControl"`.

Data Types: `char` | `string`

`MarkerScaleFactor` — Relative scale of interactive marker
`1` (default) | positive real number

Relative scale of interactive marker, specified as a positive positive real number. To increase or decrease the size of the marker in the figure, adjust this property.

Data Types: `double`

`Configuration` — Current configuration of rigid body tree robot model
`homeConfiguration(viztree.RigidBodyTree)` (default) | *n*-element vector

Current configuration of rigid body tree robot model, specified as an *n*-element vector. `n` is the number of nonfixed joints in the RigidBodyTree property.

Example: `[1 pi 0 0.5 3.156]'`

Data Types: `double`

`StoredConfigurations` — Stored robot configurations
`[]` (default) | *n*-by-*p* matrix

Stored robot configurations, specified as an *n*-by-*p* matrix. Each column of the matrix is a stored robot configuration. *n* is the number of nonfixed joints in the `RigidBodyTree` property. *p* is the number of stored robot configurations. To add or remove stored configurations, use the `addConfiguration` or `removeConfigurations` object functions, respectively.

Data Types: `double`

Object Functions

addConfiguration	Store current configuration
addConstraint	Add inverse kinematics constraint
removeConfigurations	Remove configurations from StoredConfigurations property
removeConstraints	Remove inverse kinematics constraints
showFigure	Show interactive rigid body tree figure

Examples

Interactively Build and Play Back Series of Robot Configurations

Use the `interactiveRigidBodyTree` object to manually move around a robot in a figure. The object uses interactive markers in the figure to track the desired poses of different rigid bodies in the `rigidBodyTree` object.

Load Robot Model

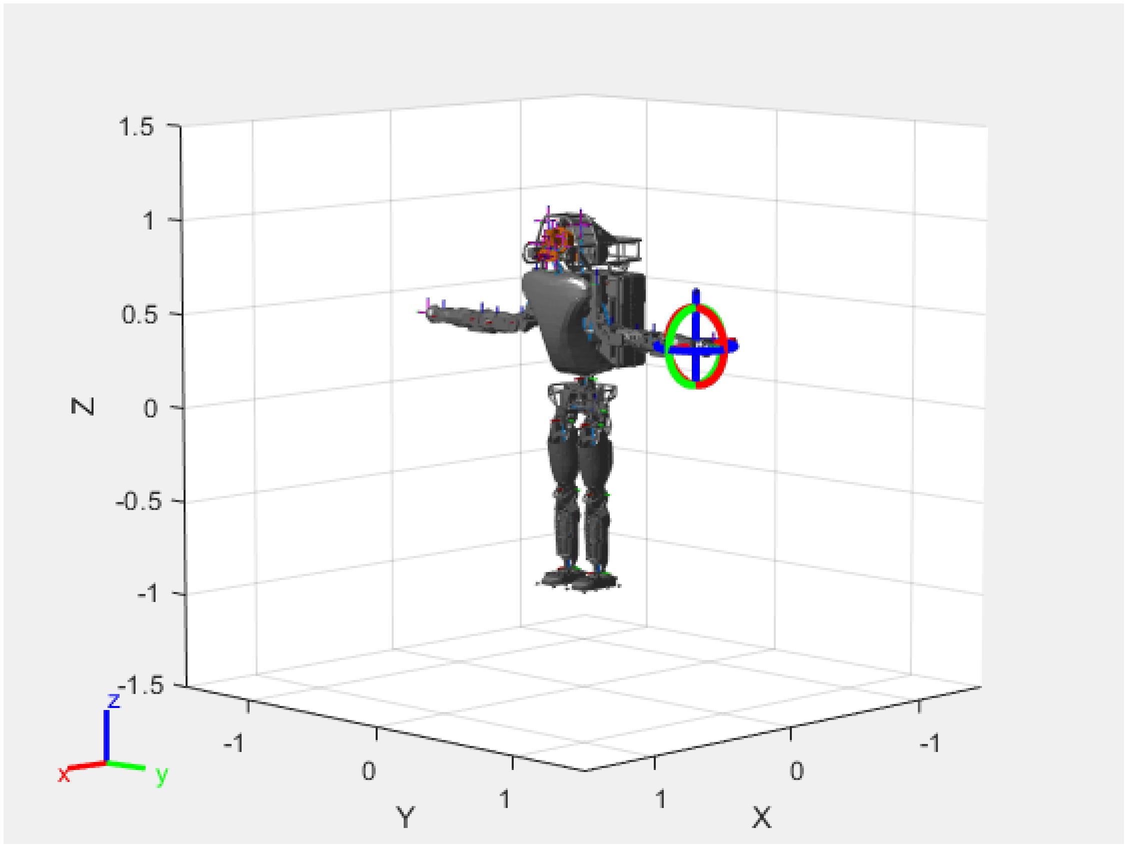
Use the `loadrobot` function to access provided robot models as `rigidBodyTree` objects.

```
robot = loadrobot("atlas");
```

Visualize Robot and Save Configurations

Create an interactive tree object and associated figure, specifying the loaded robot model and its left hand as the end effector.

```
viztree = interactiveRigidBodyTree(robot,"MarkerBodyName","l_hand");
```

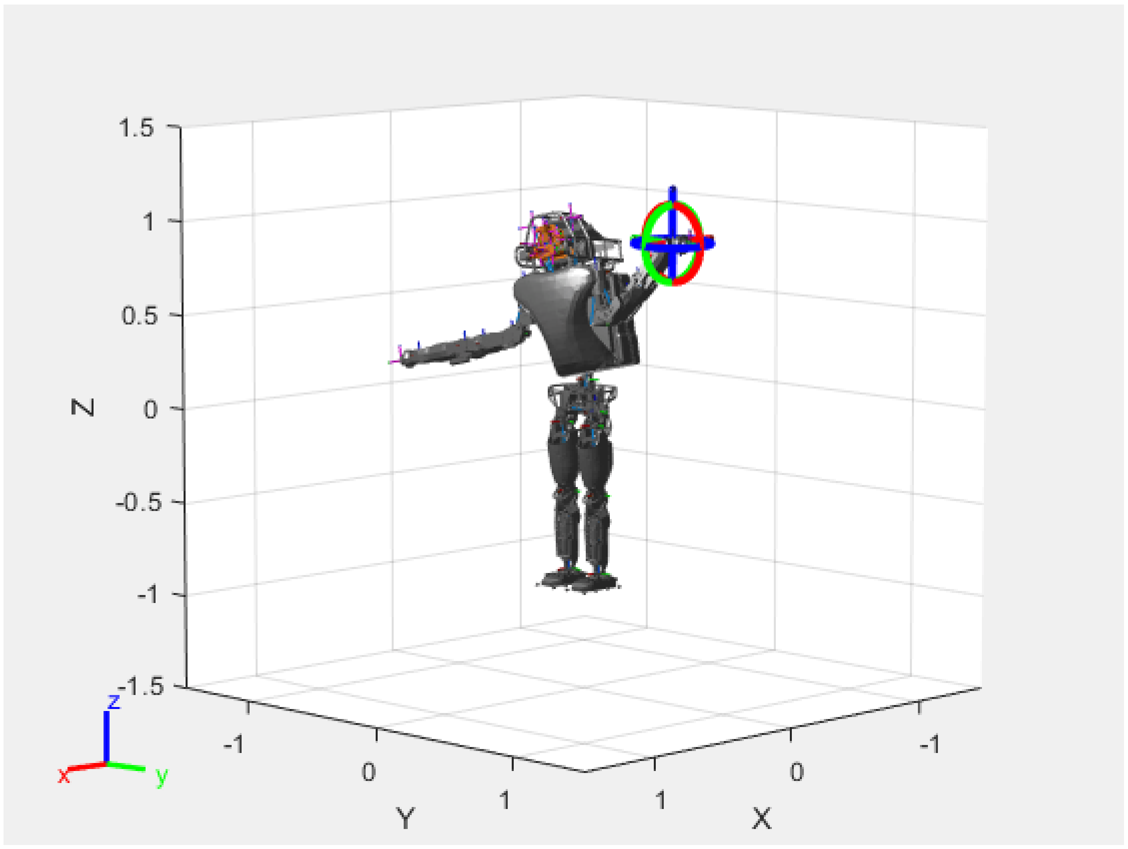


Click and drag the interactive marker to change the robot configuration. You can click and drag any of the axes for linear motion, rotate the body about an axis using the red, green, and blue circles, and drag the center of the interactive marker to position it in 3-D space.

The `interactiveRigidBodyTree` object uses inverse kinematics to determine a configuration that achieves the desired end-effector pose. If the associated rigid body cannot reach the marker, the figure renders the best configuration from the inverse kinematics solver.

Programmatically set the current configuration. Assign a vector of length equal to the number of nonfixed joints in the `RigidBodyTree` to the `Configuration` property.

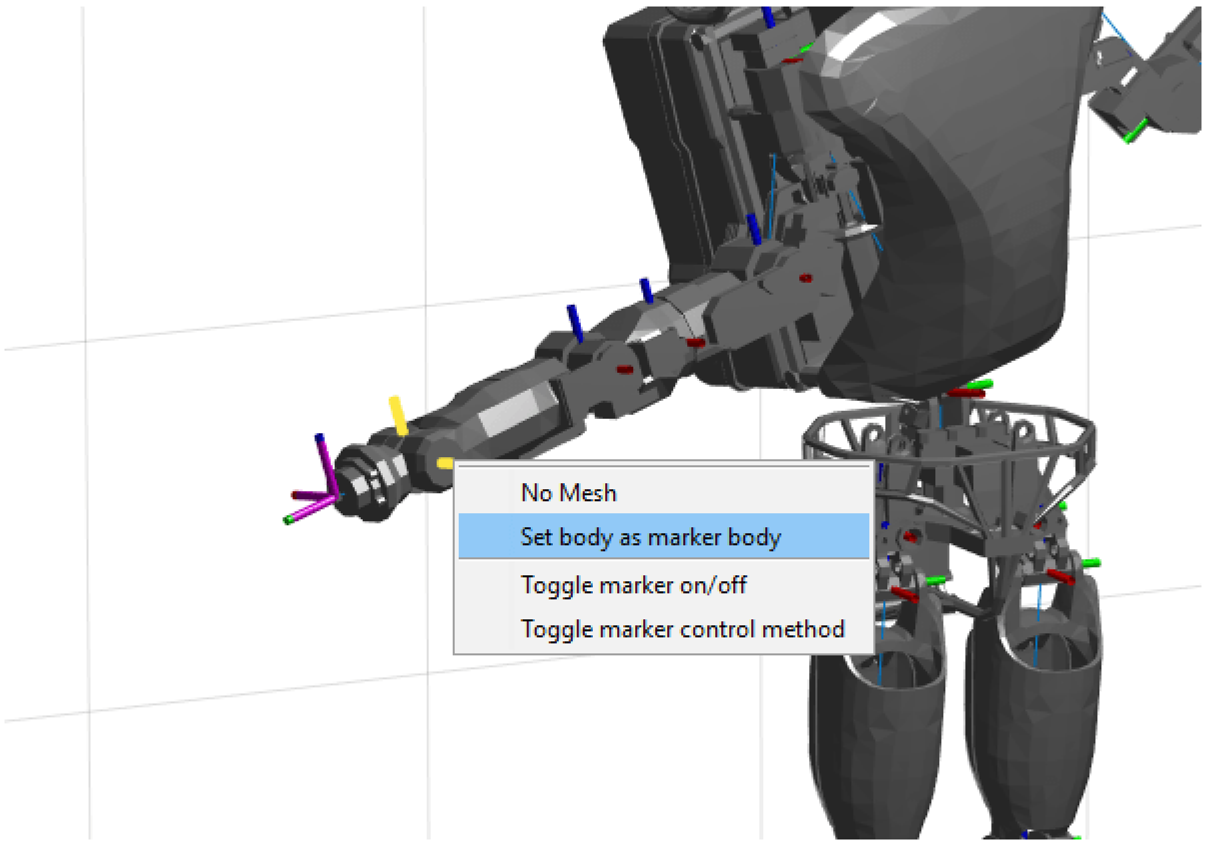
```
currConfig = homeConfiguration(viztree.RigidBodyTree);
currConfig(1:10) = [ 0.2201 -0.1319 0.2278 -0.3415 0.4996 ...
                     0.0747 0.0377 0.0718 -0.8117 -0.0427]';
viztree.Configuration = currConfig;
```



Save the current robot configuration in the `StoredConfigurations` property.

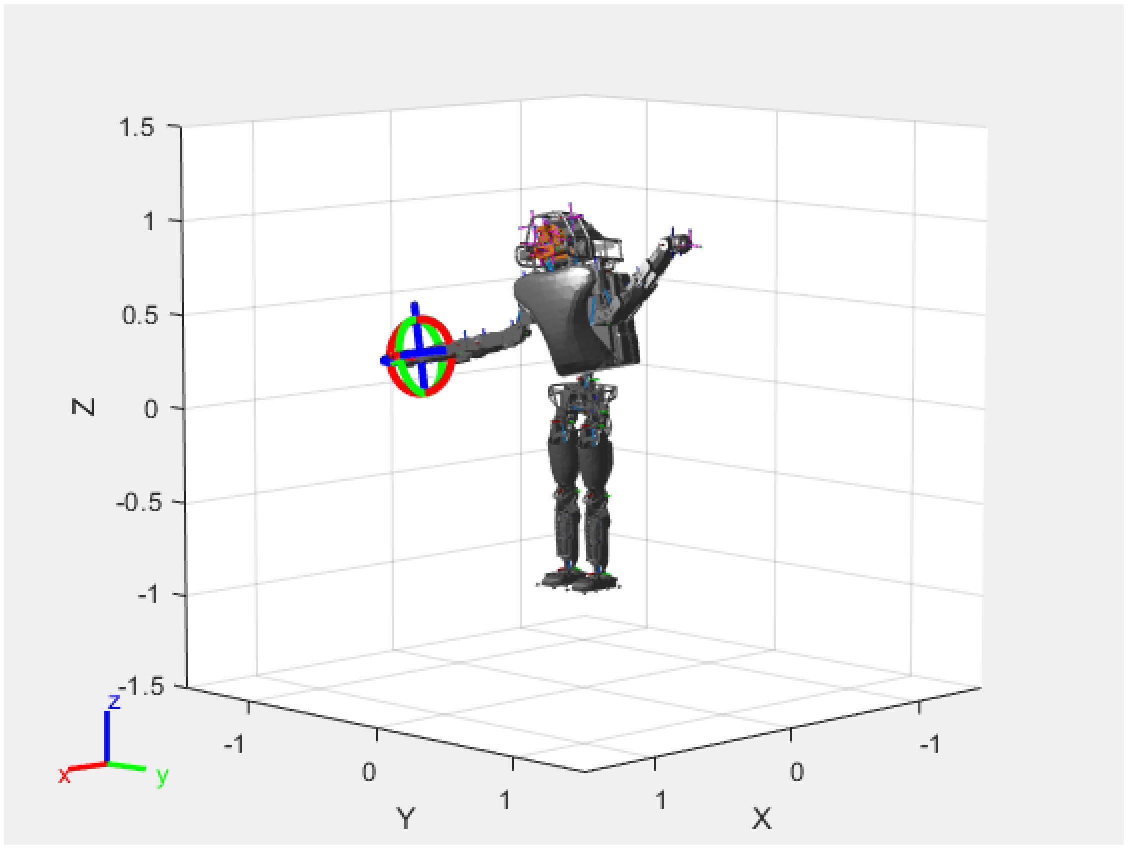
```
addConfiguration(viztree)
```

To switch the end effector to a different rigid body, right-click the desired body in the figure and select **Set body as marker body**. Use this process to select the right hand frame.



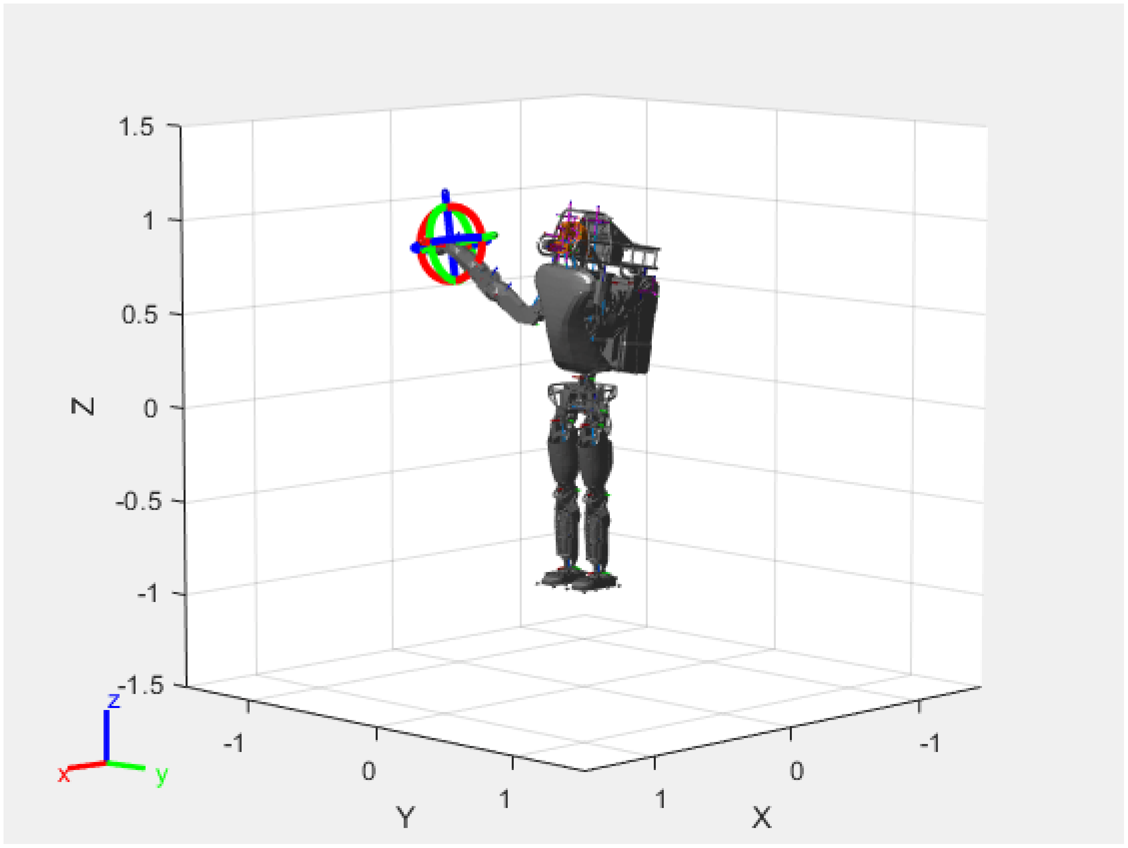
You can also set the `MarkerBodyName` property to the specific body name.

```
viztree.MarkerBodyName = "r_hand";
```



Move the right hand to a new position. Set the configuration programmatically. The marker moves to the new position of the end effector.

```
currConfig(1:18) = [-0.1350 -0.1498 -0.0167 -0.3415 0.4996 0.0747
                     0.0377 0.0718 -0.8117 -0.0427 0 0.4349
                    -0.5738 0.0563 -0.0095 0.0518 0.8762 -0.0895]';

viztree.Configuration = currConfig;
```



Save the current configuration.

```
addConfiguration(viztree)
```

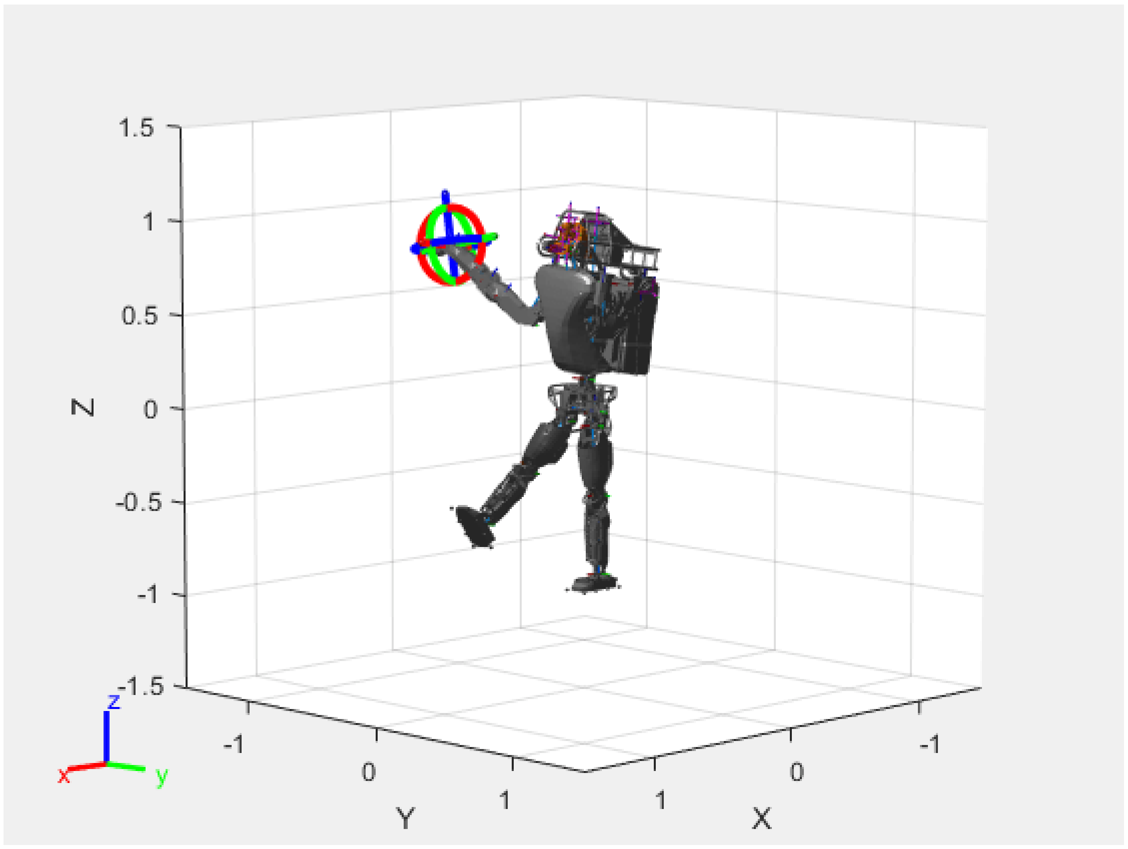
Add Constraints

By default, the robot model respects only the joint limits of the `rigidBodyJoint` objects associated with the `RigidBodyTree` property. To add constraints, generate **Robot Constraint** objects and specify them as a cell array in the `Constraints` property. To see a list of robotic constraints, see “Inverse Kinematics”. Specify a pose target for the pelvis to keep it fixed to the home position. Specify a position target for the right foot to be raised in front front and above its current position.

```
fixedWaist = constraintPoseTarget("pelvis");
raiseRightLeg = constraintPositionTarget("r_foot","TargetPosition",[1 0 0.5]);
```

Apply these constraints to the interactive rigid body tree object as a cell array. The right leg in the resulting figure changes position.

```
viztree.Constraints = {fixedWaist raiseRightLeg};
```



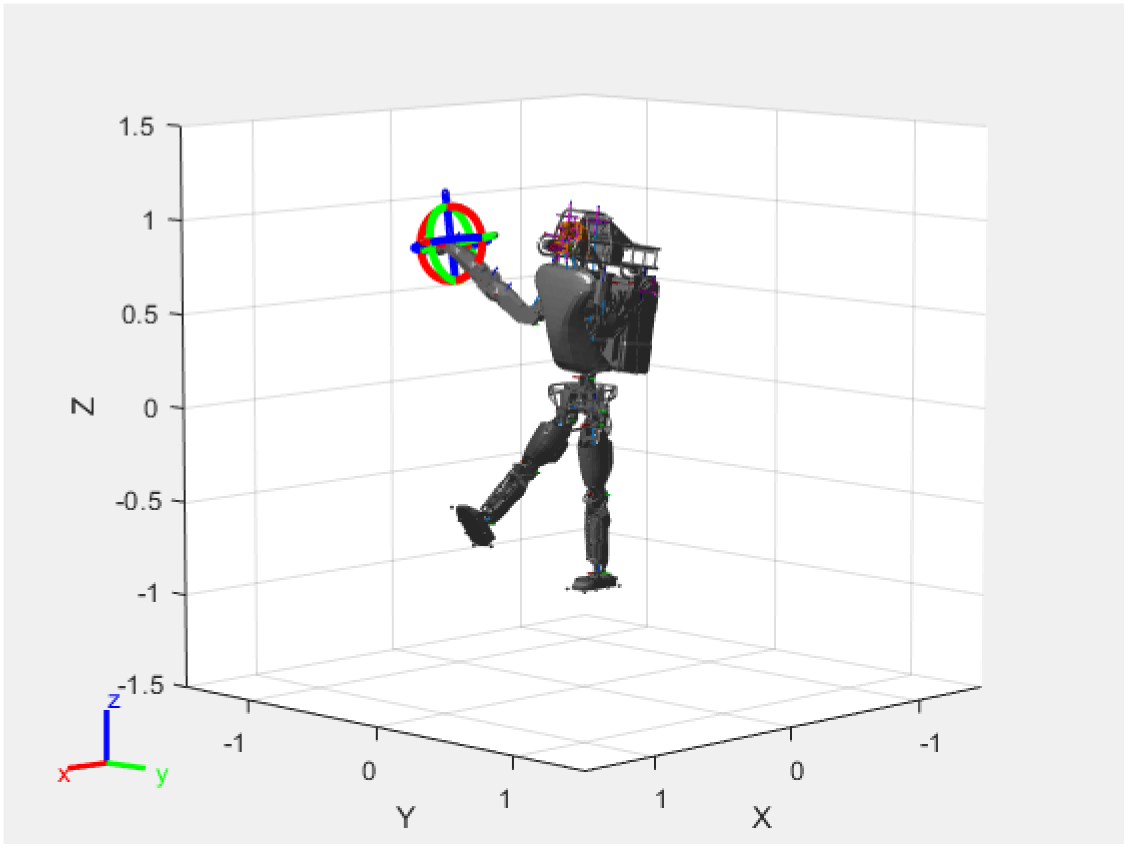
Notice the change in position of the right leg. Save this configuration as well.

```
addConfiguration(viztree)
```

Play Back Configurations

To play back configurations, iterate through the stored configurations index and set the current configuration equal to the stored configuration column vector at each iteration. Because configurations are stored as column vectors, use the second dimension of the matrix.

```
for i = 1:size(viztree.StoredConfigurations,2)
    viztree.Configuration = viztree.StoredConfigurations(:,i);
    pause(0.5)
end
```



Generate Robot Trajectory Using Interactive Rigid Body Tree Model

Use the `interactiveRigidBodyTree` object to visualize a robot model and interactively create waypoints and use them to generate a smooth trajectory using `cubicpolytraj`. For more information, see the `interactiveRigidBodyTree` object and `cubicpolytraj function.`

Load the Robot Model

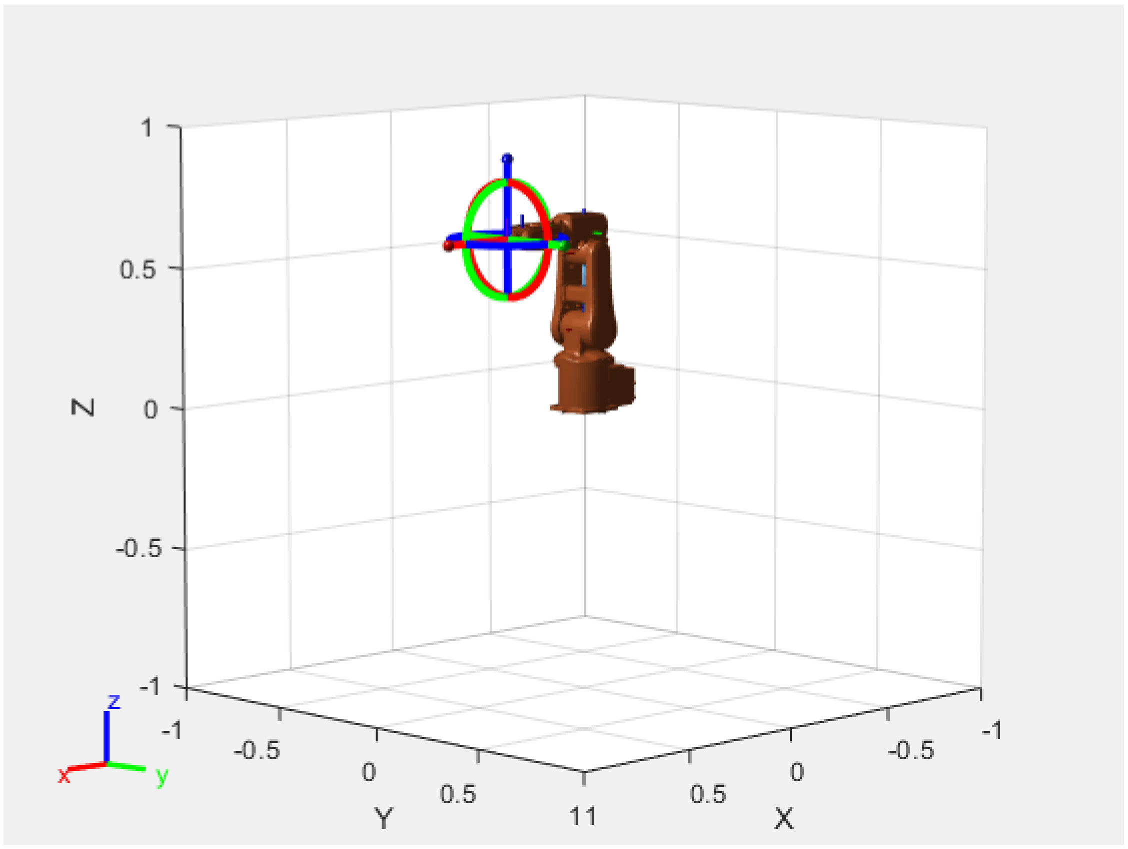
Use the `loadrobot` function to access provided robot models as `rigidBodyTree` objects.

```
robot = loadrobot('abbIrb120');
```

Visualize Robot and Save Configurations

Create an interactive tree object using the `interactiveRigidBodyTree` function. By default, the interactive marker is set to the body with the highest index in the `RigidBodyTree` property. To change this property using the figure, right-click a rigid body and select **Set body as marker body**. Alternatively, `MarkerBodyName` property for the `interactiveRigidBodyTree` can be set using name-value pairs.

```
iRBT = interactiveRigidBodyTree(robot);
```



Interactively Add Configurations

Click and drag the interactive marker to change the robot configuration. You can click and drag any of the axes for linear motion, rotate the body about an axis using the red, green, and blue circles, and drag the center of the interactive marker to position it in 3-D space.

The `interactiveRigidBodyTree` object uses inverse kinematics to determine a configuration that achieves the desired end-effector pose. If the associated rigid body cannot reach the marker, the figure renders the best configuration from the inverse kinematics solver.

When the robot is in a desired configuration use the `addConfiguration` object function to add the configuration to the `StoredConfiguration` property of the object.

In this example, 6 waypoints are created using the interactive marker and `addConfiguration` object function. They are saved in `wayPoints.mat`. Stored configurations can be accessed using `iRBT.StoredConfigurations`.

```
load("wayPts.mat");
```

Generate Smooth Trajectory Using the Waypoints

Use the `cubicpolytraj` function to generate smooth trajectory between the waypoints. Define time points that correspond to each waypoint. Define the time vector for generating the trajectory. The `cubicpolyTraj` function generates a configuration for each timestep in the timevector `tvec.`

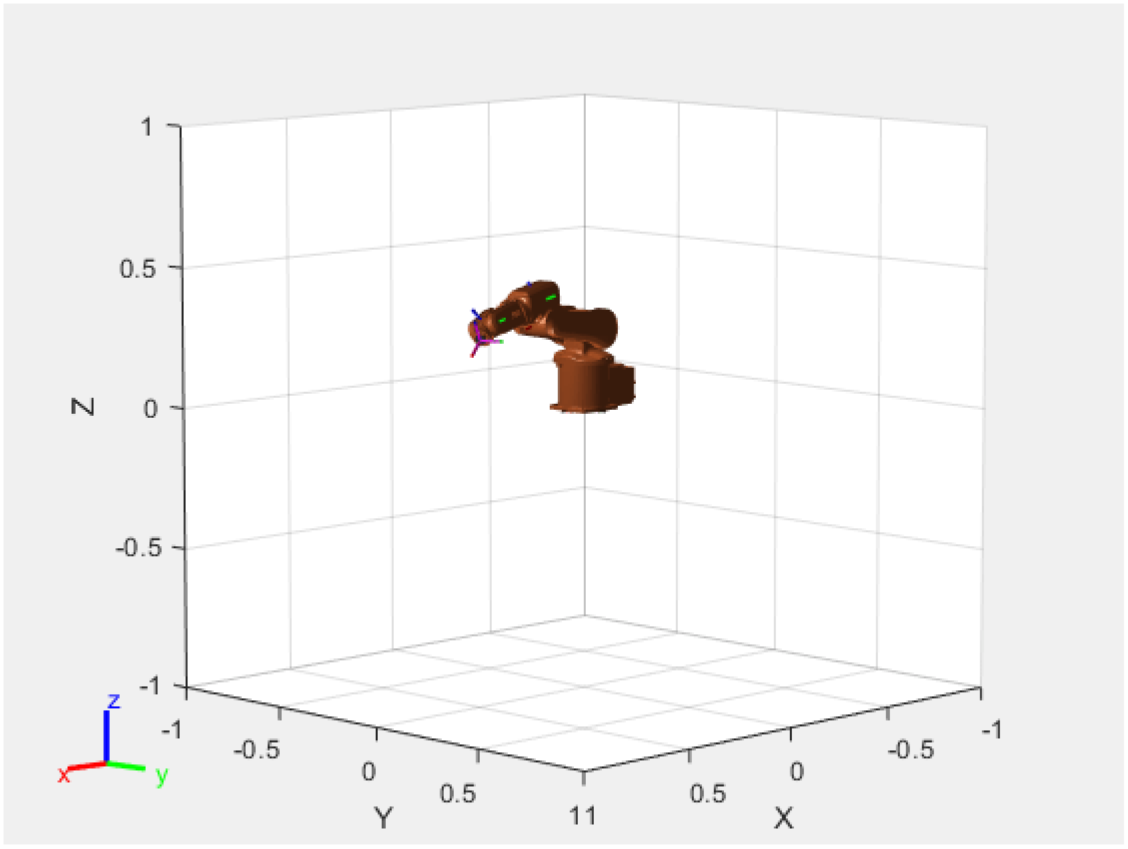
```
iRBT.StoredConfigurations = wayPts ;          % Waypoints
tpts = [0 2 4 6 8 10];                        % Time Points
```

```
tvec = 0:0.1:10;                                % Time Vector
[q,qd,qdd,pp] = cubicpolytraj(iRBT.StoredConfigurations,tpts,tvec);
```

Visualize Robot Motion on the Trajectory

Define the simulation frequency using a `rateControl` object. Use the `showFigure` function to visualize the robot model and use a `for` loop to play all the configurations of the robot.

```
r = rateControl(10);
iRBT.ShowMarker = false;  % Hide the marker


showFigure(iRBT)

for i = 1:size(q',1)
    iRBT.Configuration = q(:,i);
    waitfor(r);
end
```



Limitations

- If the `interactiveRigidBodyTree` object is deleted while the figure is still open, the interactivity of the figure is disabled and the title of the figure is updated.

Tips

- To maximize performance when visualizing complex robot models with complex meshes, ensure you enable hardware-accelerated OpenGL. By default, MATLAB® uses hardware-accelerated OpenGL if your graphics hardware supports it. For more information, see the `opengl` function.

See Also

Functions
`loadrobot` | `importrobot` | `homeConfiguration`

Objects
`rigidBodyTree` | `rigidBody` | `rigidBodyJoint` | `generalizedInverseKinematics`

Topics
"Rigid Body Tree Robot Model"
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"
"Trajectory Control Modeling with Inverse Kinematics"

Introduced in R2020a

inverseKinematics

Create inverse kinematic solver

Description

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

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

For closed-form analytical IK solutions, see `analyticalInverseKinematics`.

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

1. Create the `inverseKinematics` object and set its properties.
2. Call the object with arguments, as if it were a function.

To learn more about how System objects work, see What Are System Objects?

Creation

Syntax

```
ik = inverseKinematics
ik = inverseKinematics(Name,Value)
```

Description

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

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

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

RigidBodyTree — Rigid body tree model
rigidBodyTree object

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

Create IK solver and specify the rigid body tree.

```
ik = inverseKinematics('RigidBodyTree',rigidbodytree)
```

Modify the rigid body tree model.

```
addBody(rigidbodytree,rigidBody('body1'),'base')
```

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

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

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

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

SolverParameters — Parameters associated with algorithm
structure

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

Usage

Syntax

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

Description

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

Input Arguments

endeffector — End-effector name
character vector

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

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

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

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

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

`initialguess` — Initial guess of robot configuration
structure array | vector

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

To use the vector form, set the `DataFormat` property of the object assigned in the `RigidBodyTree` property to either `'row'` or `'column'` .

Output Arguments

`configSol` — Robot configuration solution
structure array | vector

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

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

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

Note For revolute joints, if the joint limits exceed a range of `2*pi`, where joint position wrapping occurs, then the returned joint position is the one closest to the joint's lower bound.

To use the vector form, set the `DataFormat` property of the object assigned in the `RigidBodyTree` property to either `'row'` or `'column'` .

`solInfo` — Solution information
structure

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

- `Iterations` — Number of iterations run by the algorithm.
- `NumRandomRestarts` — Number of random restarts because algorithm got stuck in a local minimum.

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

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

```
release(obj)
```

Common to All System Objects

step	Run System object algorithm
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object

Examples

Generate Joint Positions to Achieve End-Effector Position

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

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

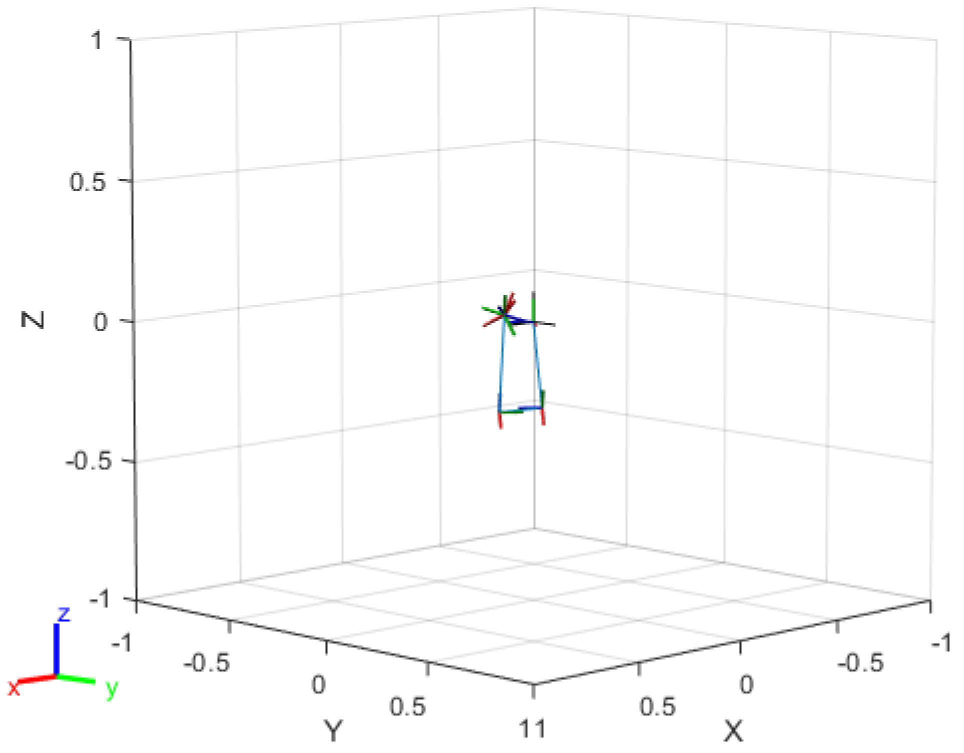
```
load exampleRobots.mat
showdetails(puma1)
```

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

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

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

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

```
show(puma1,randConfig);
```



Create an `inverseKinematics` object for the `puma1` model. Specify weights for the different components of the pose. Use a lower magnitude weight for the orientation angles than the position components. Use the home configuration of the robot as an initial guess.

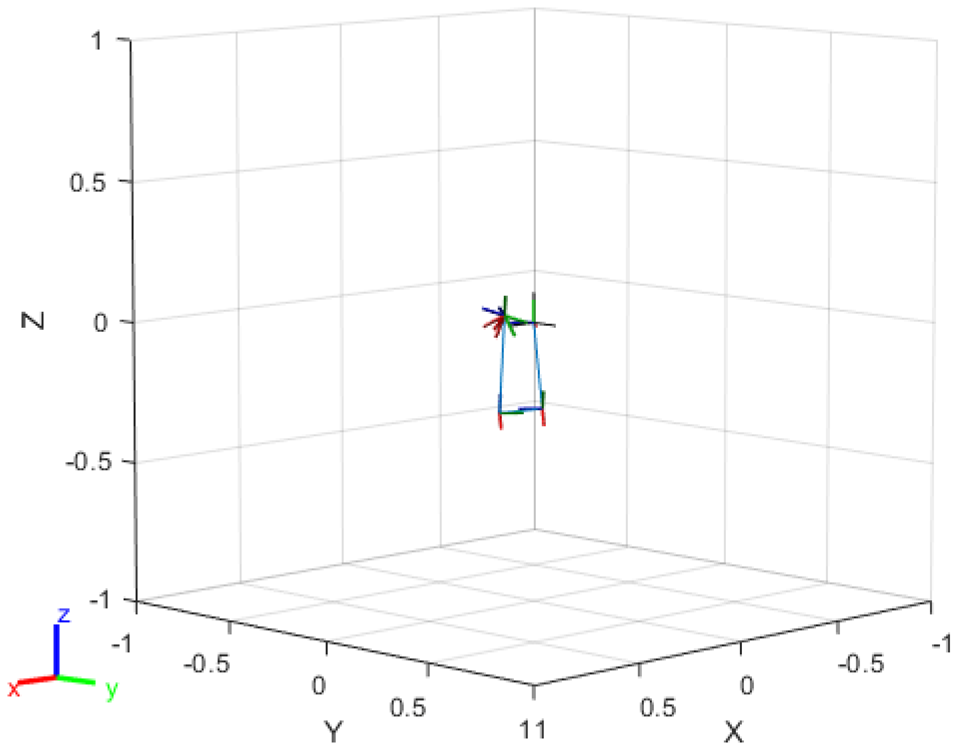
```
ik = inverseKinematics('RigidBodyTree',puma1);
weights = [0.25 0.25 0.25 1 1 1];
initialguess = puma1.homeConfiguration;
```

Calculate the joint positions using the `ik` object.

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

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

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



Compatibility Considerations

`inverseKinematics` was renamed
Behavior change in future release

The `inverseKinematics` object was renamed from `robotics.InverseKinematics`. Use `inverseKinematics` for all object creation.

References

[1] Badreddine, Hassan, Stefan Vandewalle, and Johan Meyers. "Sequential Quadratic Programming (SQP) for Optimal Control in Direct Numerical Simulation of Turbulent Flow." *Journal of Computational Physics*. 256 (2014): 1–16. doi:10.1016/j.jcp.2013.08.044.

[2] Bertsekas, Dimitri P. *Nonlinear Programming*. Belmont, MA: Athena Scientific, 1999.

[3] Goldfarb, Donald. "Extension of Davidon’s Variable Metric Method to Maximization Under Linear Inequality and Equality Constraints." *SIAM Journal on Applied Mathematics*. Vol. 17, No. 4 (1969): 739–64. doi:10.1137/0117067.

[4] Nocedal, Jorge, and Stephen Wright. *Numerical Optimization*. New York, NY: Springer, 2006.

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

[6] Zhao, Jianmin, and Norman I. Badler. "Inverse Kinematics Positioning Using Nonlinear Programming for Highly Articulated Figures." *ACM Transactions on Graphics* Vol. 13, No. 4 (1994): 313–36. doi:10.1145/195826.195827.

Extended Capabilities

C/C++ Code Generation

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

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

```
ik = inverseKinematics('RigidBodyTree',robotModel);
```

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

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

See Also

`analyticalInverseKinematics` | `rigidBodyJoint` | `rigidBody` | `rigidBodyTree` | `generalizedInverseKinematics`

Topics

“Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics”
“Inverse Kinematics Algorithms”

Introduced in R2016b

jointSpaceMotionModel

Model rigid body tree motion given joint-space inputs

Description

The `jointSpaceMotionModel` object models the closed-loop joint-space motion of a manipulator robot, specified as a `rigidBodyTree` object. The motion model behavior is defined by the MotionType property.

For more details about the equations of motion, see “Joint-Space Motion Model”.

Creation

Syntax

```
motionModel = jointSpaceMotionModel
motionModel = jointSpaceMotionModel("RigidBodyTree",tree)
motionModel = jointSpaceMotionModel(Name,Value)
```

Description

`motionModel = jointSpaceMotionModel` creates a motion model for a default two-joint manipulator.

`motionModel = jointSpaceMotionModel("RigidBodyTree",tree)` creates a motion model for the specified `rigidBodyTree` object.

`motionModel = jointSpaceMotionModel(Name,Value)` sets additional properties specified as name-value pairs. You can specify multiple properties in any order.

Properties

`RigidBodyTree` — Rigid body tree robot model
`rigidBodyTree` object

Rigid body tree robot model, specified as a `rigidBodyTree` object that defines the inertial and kinematic properties of the manipulator.

`NaturalFrequency` — Natural frequency of error dynamics
`[10 10]` (default) | *n*-element vector | scalar

Natural frequency of error dynamics, specified as a scalar or *n*-element vector in Hz, where *n* is the number of nonfixed joints in the associated `rigidBodyTree` object in the RigidBodyTree property.

Dependencies

To use this property, set the MotionType property to `"ComputedTorqueControl"` or `"IndependentJointMotion"`.

`DampingRatio` — Damping ratio of error dynamics

`[1 1]` (default) | *n*-element vector | scalar

Damping ratio of the second-order error dynamics, specified as a scalar or *n*-element vector of real values, where *n* is the number of nonfixed joints in the associated `rigidBodyTree` object in the RigidBodyTree property. If a scalar is specified, then `DampingRatio` becomes an *n*-element vector of value `s`, where `s` is the specified scalar.

Dependencies

To use this property, set the MotionType property to `"ComputedTorqueControl"` or `"IndependentJointMotion"`.

Kp — Proportional gain for PD control

`100*eye(2)` (default) | *n*-by-*n* | scalar

Proportional gain for proportional-derivative (PD) control, specified as a scalar or *n*-by-*n* matrix, where *n* is the number of nonfixed joints in the associated `rigidBodyTree` object in the RigidBodyTree property. You must set the MotionType property to `"PDControl"`. If a scalar is specified, then `Kp` becomes `s*eye(n)`, where `s` is the specified scalar.

Dependencies

To use this property, set the MotionType property to `"PDControl"`.

Kd — Derivative gain for PD control

`10*eye(2)` (default) | *n*-by-*n* | scalar

Derivative gain for PD control, specified as a scalar or *n*-by-*n* matrix, where *n* in the number of nonfixed joints in the `rigidBodyTree` object in the RigidBodyTree property. If a scalar is specified, then `Kp` becomes `s*eye(n)`, where `s` is the specified scalar.

Dependencies

To use this property, set the MotionType property to `"PDControl"`.

`MotionType` — Type of motion computed by the motion model

`"ComputedTorqueControl"` (default) | `"IndependentJointMotion"` | `"PDControl"`

Type of motion, specified as a string scalar or character vector that defines the closed-loop joint-space behavior that the object models. Options are:

- `"ComputedTorqueControl"` — Compensates for full-body dynamics and assigns the error dynamics specified in the NaturalFrequency and DampingRatio properties.
- `"IndependentJointMotion"` — Models each joint as an independent second-order system using the error dynamics specified by the `NaturalFrequency` and `DampingRatio` properties.
- `"PDControl"` — Uses proportional-derivative control on the joints based on the specified Kp and Kd properties.

Object Functions

derivative	Time derivative of manipulator model states
updateErrorDynamicsFromStep	Update values of NaturalFrequency and DampingRatio properties given desired step response

Examples

Create Joint-Space Motion Model

This example shows how to create and use a `jointSpaceMotionModel` object for a manipulator robot in joint-space.

Create the Robot

```
robot = loadrobot("kinovaGen3","DataFormat","column","Gravity",[0 0 -9.81]);
```

Set Up the Simulation

Set the timespan to be 1 s with a timestep size of 0.01 s. Set the initial state to be the robots, home configuration with a velocity of zero.

```
tspan = 0:0.01:1;
initialState = [homeConfiguration(robot); zeros(7,1)];
```

Define the a reference state with a target position, zero velocity, and zero acceleration.

```
targetState = [pi/4; pi/3; pi/2; -pi/3; pi/4; -pi/4; 3*pi/4; zeros(7,1); zeros(7,1)];
```

Create the Motion Model

Model the system with computed torque control and error dynamics defined by a moderately fast step response with 5% overshoot.

```
motionModel = jointSpaceMotionModel("RigidBodyTree",robot);
updateErrorDynamicsFromStep(motionModel,.3,.05);
```

Simulate the Robot

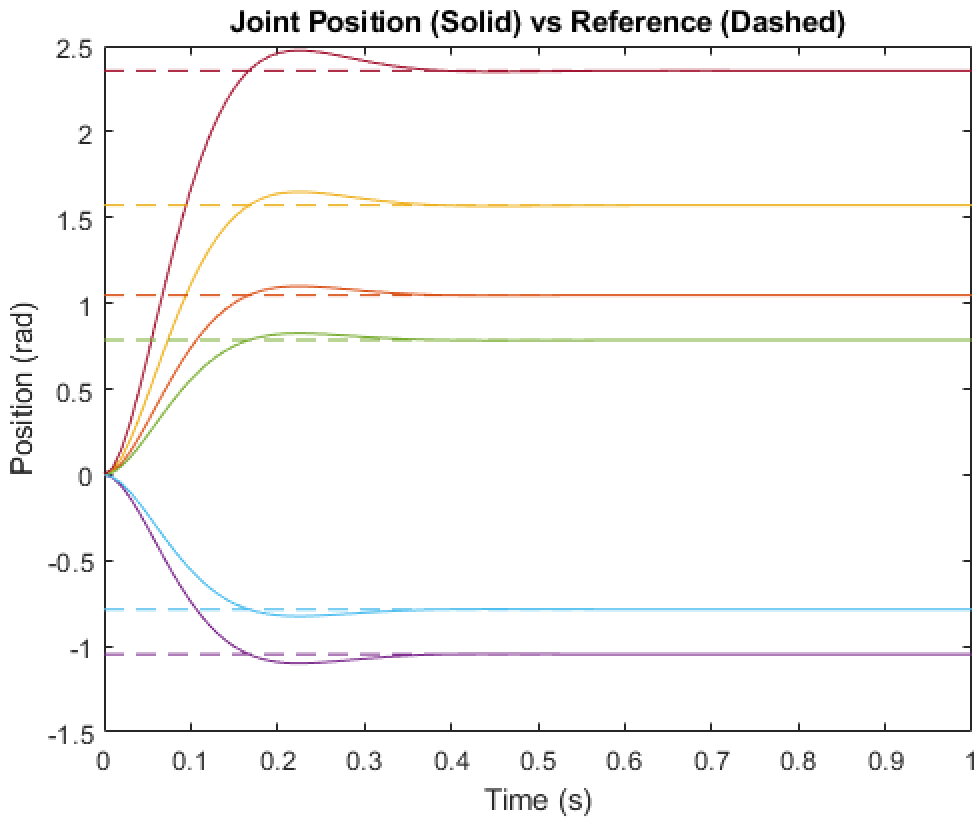
Use the derivative function of the model as the input to the `ode45` solver to simulate the behavior over 1 second.

```
[t,robotState] = ode45(@(t,state)derivative(motionModel,state,targetState),tspan,initialState);
```

Plot the Response

Plot the positions of all the joints actuating to their target state. Joints with a higher displacement between the starting position and the target position actuate to the target at a faster rate than those with a lower displacement. This leads to an overshoot, but all of the joints have the same settling time.

```
figure
plot(t,robotState(:,1:motionModel.NumJoints));
hold all;
plot(t,targetState(1:motionModel.NumJoints)*ones(1,length(t)),"--");
title("Joint Position (Solid) vs Reference (Dashed)");
xlabel("Time (s)")
ylabel("Position (rad)");
```



References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control*. Upper Saddle River, NJ: Pearson Education, 2005.

[2] Spong, Mark W., Seth Hutchinson, and Mathukumalli Vidyasagar. *Robot Modeling and Control*. Hoboken, NJ: Wiley, 2006.

Extended Capabilities

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

See Also

Classes
`taskSpaceMotionModel`

Blocks
Joint Space Motion Model

Functions
`derivative` | `updateErrorDynamicsFromStep`

Topics
"Simulate Joint-Space Trajectory Tracking in MATLAB"
"Plan and Execute Task- and Joint-Space Trajectories Using KINOVA Gen3 Manipulator"

Introduced in R2019b

lidarScan

Create object for storing 2-D lidar scan

Description

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

Creation

Syntax

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

Description

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

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

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

Properties

Ranges — Range readings from lidar in meters
vector

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

Data Types: `single` | `double`

`Angles` — Angle of readings from lidar in radians
vector

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

Data Types: `single` | `double`

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

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

Data Types: `single` | `double`

`Count` — Number of lidar readings
scalar

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

Data Types: `double`

Object Functions

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

Examples

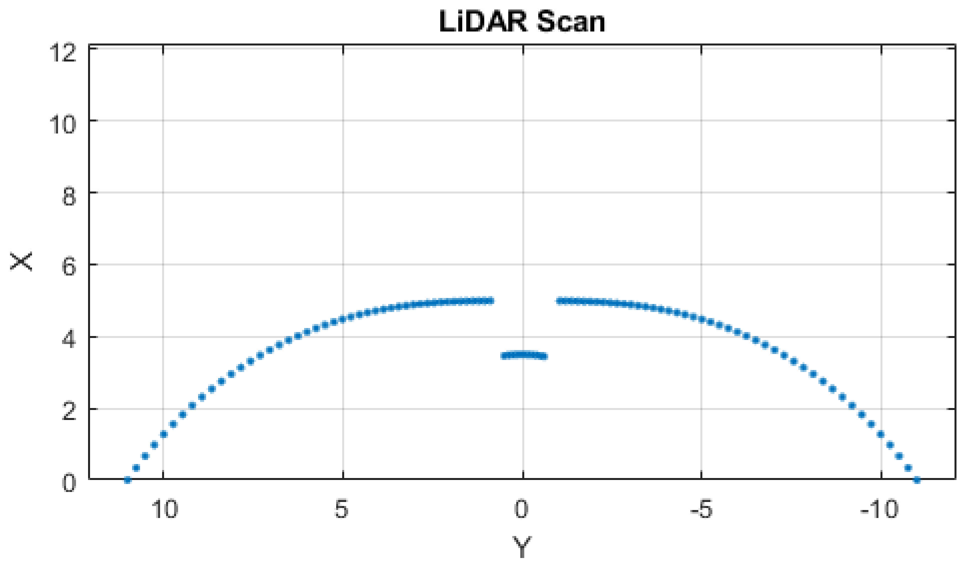
Plot Lidar Scan and Remove Invalid Points

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

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

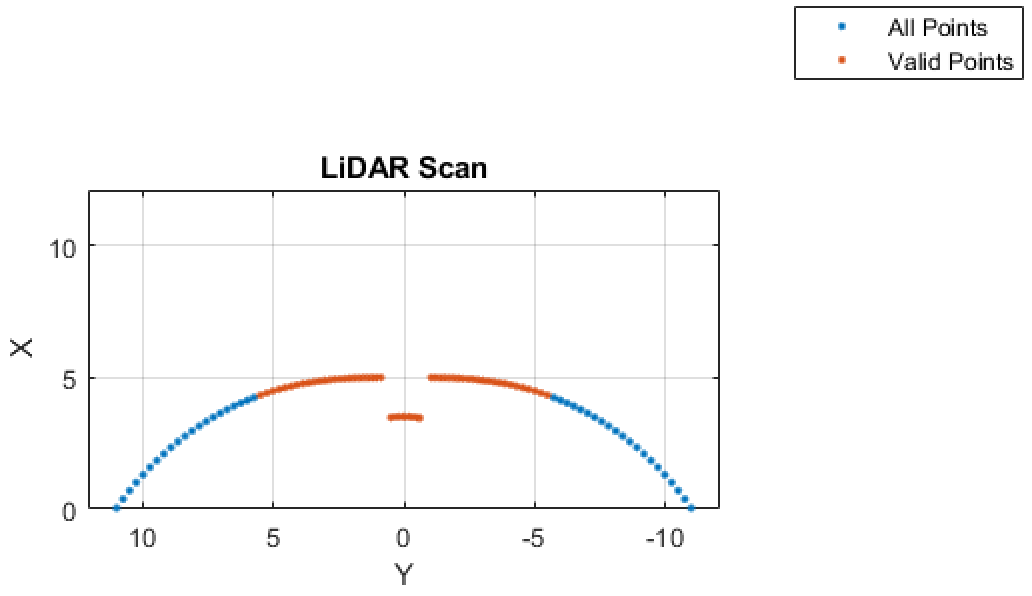
Create a lidar scan by specifying the ranges and angles. Plot all points of the lidar scan.

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



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

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



Transform Laser Scans

Create a `lidarScan` object. Specify the ranges and angles as vectors.

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

Translate the laser scan by an `[x y]` offset of `(0.5,0.2)`.

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

Rotate the laser scan by 20 degrees.

```
rotateScan = transformScan(refScan,[0,0,deg2rad(20)]);
```

Extended Capabilities

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

Usage notes and limitations:

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

See Also
`transformScan`

Introduced in R2019b

manipulatorCollisionBodyValidator

Validate states for collision bodies of rigid body tree

Description

The `manipulatorCollisionBodyValidator` object performs state and motion validity checks for a rigid body tree robot model. To check if the collision bodies collide either with other bodies (self-collisions) or the environment, use the `isStateValid` object function. To check if a motion between two states is valid, use the `isMotionValid` object function.

Creation

Syntax

```
manipSV = manipulatorCollisionBodyValidator
manipSV = manipulatorCollisionBodyValidator(ss)
manipSV = manipulatorCollisionBodyValidator(ss,Name=Value)
```

Description

`manipSV = manipulatorCollisionBodyValidator` creates a state validator with default values for a `manipulatorStateSpace` object.

`manipSV = manipulatorCollisionBodyValidator(ss)` creates a state validator for a `manipulatorStateSpace` object that represents a robot model state space and contains collision bodies for rigid body elements. Specify `ss` as a `manipulatorStateSpace` object.

`manipSV = manipulatorCollisionBodyValidator(ss,Name=Value)` specifies “Properties” on page 1-152 as name-value arguments

Properties

`ValidationDistance` — Distance resolution for motion validation
`0.01` (default) | positive scalar in meters

Distance resolution for motion validation, specified as a positive scalar. The validation distance determines the number of interpolated states between states specified to the `isMotionValid` object function. The object function validates each interpolated state by checking for collisions with the robot and the environment.

Data Types: `double`

`IgnoreSelfCollision` — Ignore self collisions toggle
`0` or `false` (default) | `1` or `true`

Ignore self collisions toggle, specified as a logical. If this property is set to `true`, the `isMotionValid` object function skips checking between bodies for collisions and only compares the bodies to the environment. Not checking for self-collisions can improve the speed of the planning phase, but your state space should contain joint limits that ensure self-collisions are not possible.

Data Types: `logical`

Environment — Collision objects in robot environment
`{}` (default) | cell array of collision body objects

Collision objects in the robot environment, specified as a cell array of collision objects of these types:

- `collisionBox`
- `collisionCylinder`
- `collisionMesh`
- `collisionSphere`

```
box = collisionBox(0.1,0.1,0.5); % XYZ Lengths
box.Pose = trvec2tform([0.2 0.2 0.5]); % XYZ Position
sphere = collisionSphere(0.25); % Radius
sphere.Pose = trvec2tform([-0.2 -0.2 0.5]); % XYZ Position
env = {box sphere};
manipSS = manipulatorCollisionBodyValidator(ss,Environment=env);
```

Data Types: `logical`

StateSpace — Manipulator state space
`manipulatorStateSpace` object

Manipulator state space, specified as a `manipulatorStateSpace` object, which is a subclass of `nav.StateSpace`.

Object Functions

isStateValid	Check if state is valid
isMotionValid	Check if path between states is valid

Examples

Validate State and Motion Manipulator State Space

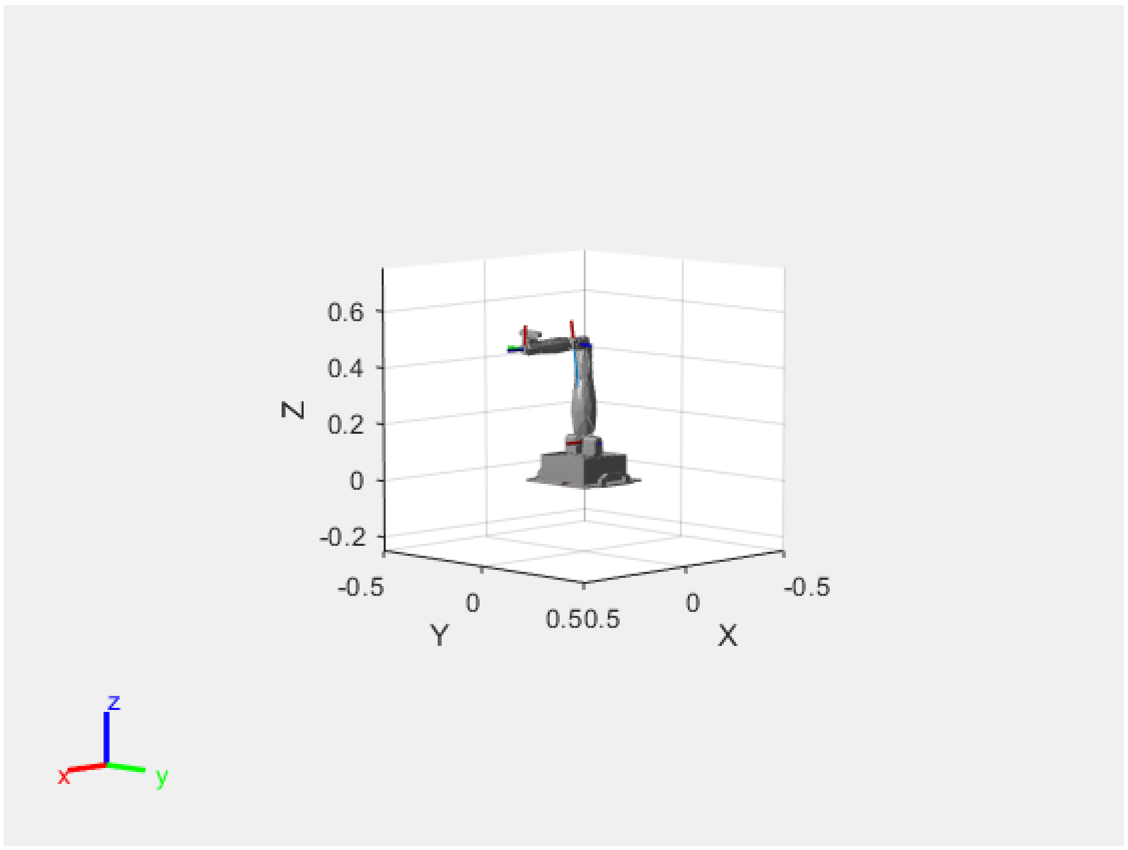
Generate states to form a path, validate motion between states, and check for self-collisions and environmental collisions with objects in your world. The `manipulatorStateSpace` object represents the joint configuration space of your rigid body tree robot model, and can sample states, calculate distances, and enforce state bounds. The `manipulatorCollisionBodyValidator` object validates the state and motion based on the collision bodies in your robot model and any obstacles in your environment.

Load Robot Model

Use the `loadrobot` function to access predefined robot models. This example uses the Quanser QArm™ robot and joint configurations are specified as row vectors.

```
robot = loadrobot("quanserQArm",DataFormat="row");
figure(Visible="on")
show(robot);
```

```
xlim([-0.5 0.5])
ylim([-0.5 0.5])
zlim([-0.25 0.75])
hold on
```



Configure State Space and State Validation

Create the state space and state validator from the robot model.

```
ss = manipulatorStateSpace(robot);
sv = manipulatorCollisionBodyValidator(ss);
```

Set the validation distance to `0.05`, which is based on the distance normal between two states. You can configure the validator to ignore self collisions to improve the speed of validation, but must consider whether your robot model has the proper joint limit settings set to ensure it does not collide with itself.

```
sv.ValidationDistance = 0.05;
sv.IgnoreSelfCollision = true;
```

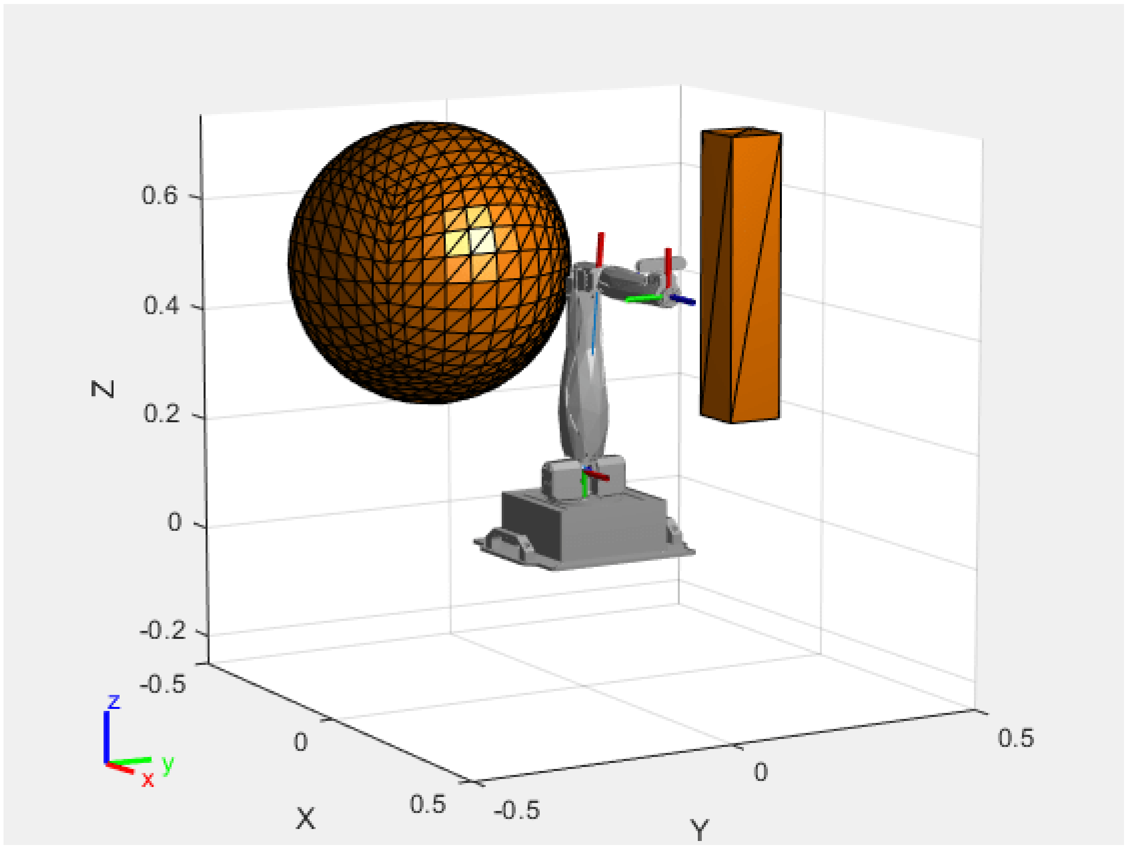
Place collision objects in the robot environment. Set the `Environment` property of the collision validator object using a cell array of objects.

```
box = collisionBox(0.1,0.1,0.5); % XYZ Lengths
box.Pose = trvec2tform([0.2 0.2 0.5]); % XYZ Position
sphere = collisionSphere(0.25); % Radius
sphere.Pose = trvec2tform([-0.2 -0.2 0.5]); % XYZ Position
```

```
env = {box sphere};
sv.Environment = env;
```

Visualize the environment.

```
for i = 1:length(env)
    show(env{i})
end
view(60,10)
```



Plan Path

Start with the home configuration as the first point on the path.

```
rng(0); % Repeatable results
start = homeConfiguration(robot);
path = start;
idx = 1;
```

Plan a path using these steps, in a loop:

- Sample a nearby goal configuration, using the Gaussian distribution, by specifying the standard deviation for each joint angle.
- Check if the sampled goal state is valid.
- If the sampled goal state is valid, check if the motion between states is valid and, if so, add it to the path.

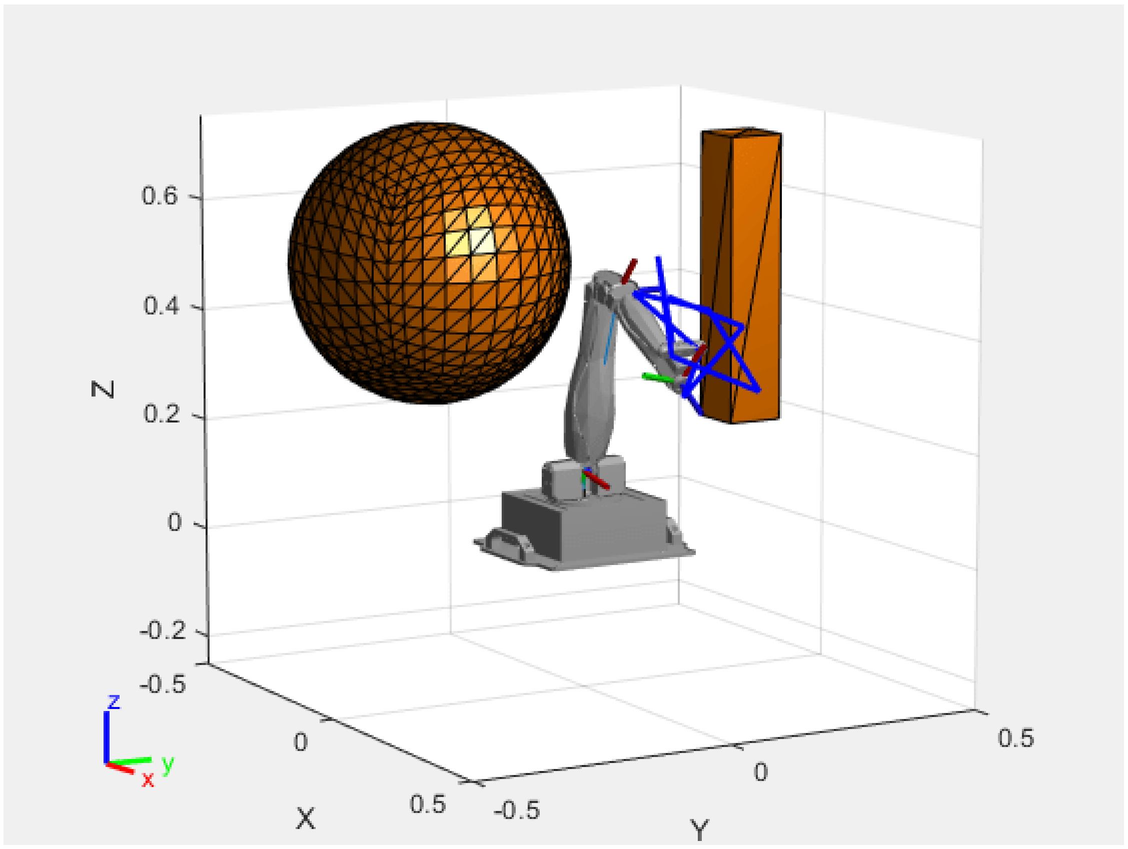
```
for i = 2:25
    goal = sampleGaussian(ss,start,0.25*ones(4,1));
    validState = isStateValid(sv,goal);

    if validState % If state is valid, check motion between states.
        [validMotion,~] = isMotionValid(sv,path(idx,:),goal);

        if validMotion % If motion is valid, add to path.
            path = [path; goal];
            idx = idx + 1;
        end
    end
end
```

Visualize Path

After generating the path of valid motions, visualize the robot motion. Because you sampled random states near the home configuration, you should see the arm move around that initial configuration.

To visualize the path of the end effector in 3-D, get the transformation, relative to the base world frame at each point. Store the points as an *xyz* translation vector. Plot the path of the end effector.

```
eePose = nan(3,size(path,1));

for i = 1:size(path,1)
    show(robot,path(i,:),PreservePlot=false);
    eePos(i,:) = tform2trvec(getTransform(robot,path(i,:),"END-EFFECTOR")); % XYZ translation ve
    plot3(eePos(:,1),eePos(:,2),eePos(:,3),"-b",LineWidth=2)
    drawnow
end
```



See Also

Objects
`rigidBodyTree` | `manipulatorStateSpace` | `workspaceGoalRegion` | `manipulatorRRT`

Functions
`isStateValid` | `isMotionValid` | `sampleUniform` | `sampleGaussian` | `interpolate` | `distance` | `enforceStateBounds`

Introduced in R2021b

manipulatorRRT

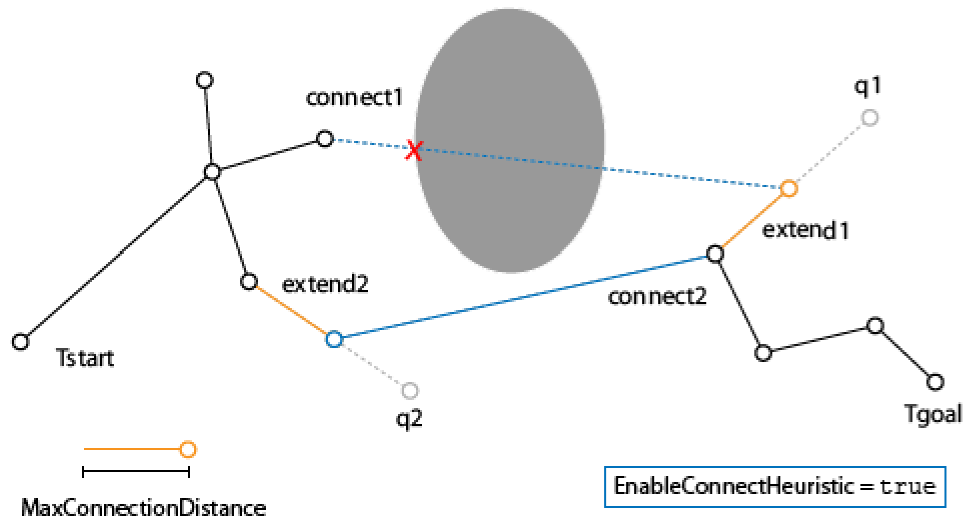
Plan motion for rigid body tree using bidirectional RRT

Description

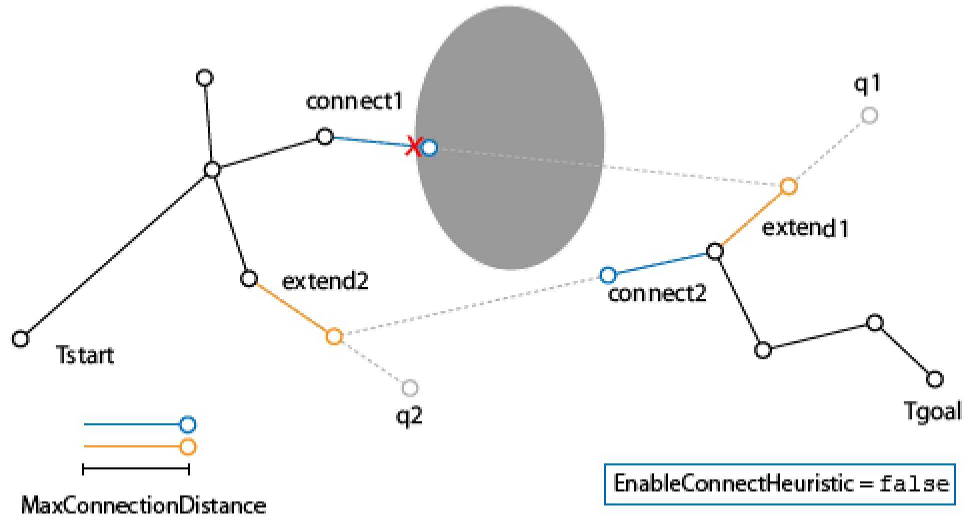
The `manipulatorRRT` object is a single-query planner for manipulator arms that uses the bidirectional rapidly exploring random trees (RRT) algorithm with an optional connect heuristic to potentially increase speed.

The bidirectional RRT planner creates two trees with root nodes at the specified start and goal configurations. To extend each tree, the planner generates a random configuration and, if valid, takes a step from the nearest node based on the MaxConnectionDistance property. After each extension, the planner attempts to connect between the two trees using the new extension and the closest node on the opposite tree. Invalid configurations or connections that collide with the environment are not added to the tree.

For a greedier search, enabling the EnableConnectHeuristic property disables the limit on the `MaxConnectionDistance` property when connecting between the two trees.



Setting the `EnableConnectHueristic` property to `false` limits the extension distance when connecting between the two trees to the value of the `MaxConnectionDistance` property.



The object uses a `rigidBodyTree` robot model to generate the random configurations and intermediate states between nodes. Collision objects are specified in the robot model to validate the configurations and check for collisions with the environment or the robot itself.

To plan a path between a start and a goal configuration, use the `plan` object function. After planning, you can interpolate states along the path using the `interpolate` object function. To attempt to shorten the path by trimming edges, use the `shorten` object function.

To specify a region to sample end-effector poses near the goal configuration, create a `workspaceGoalRegion` object and specify it as the `goalRegion` input to the `plan` object function. To change the probability of sampling additional goal configurations, specify the WorkspaceGoalRegionBias property.

For more information about the computational complexity, see Planning Complexity on page 1-167.

Creation

Syntax

```
rrt = manipulatorRRT(robotRBT,{})
rrt = manipulatorRRT(robotRBT,collisionObjects)
```

Description

`rrt = manipulatorRRT(robotRBT,{})` creates a bidirectional RRT planner for the specified `rigidBodyTree` robot model. The empty cell array indicates that there are no obstacles in the environment.

`rrt = manipulatorRRT(robotRBT,collisionObjects)` creates a planner for a robot model with collision objects placed in the environment. The planner checks for collisions with these objects.

Properties

`MaxConnectionDistance` — Maximum length between planned configurations
`0.1` (default) | positive scalar

Maximum length between planned configurations, specified as a positive scalar. The object computes the length of the motion as the Euclidean distance between the two joint configurations. During the extension process, this is the maximum distance a configuration can change.

When revolute joints have infinite limits, differences between two joint positions are calculated using the `angdiff` function.

If the `EnableConnectheuristic` property is set to `true`, the object ignores this distance when connecting the two trees during the connect stage.

Data Types: `double`

`ValidationDistance` — Distance resolution for validating motion between configurations
`0.01` (default) | positive scalar

Distance resolution for validating motion between configurations, specified as a positive scalar. The validation distance determines the number of interpolated nodes between two adjacent nodes in the tree. The object validates each interpolated node by checking for collisions with the robot and the environment.

Data Types: `double`

`MaxIterations` — Maximum number of random configurations generated
`10000` (default) | positive integer

Maximum number of random configurations generated, specified as a positive integer.

Data Types: `double`

`EnableConnectHeuristic` — Directly join trees during connect phase
`true` or `1` (default) | `false` or `0`

Directly join trees during the connect phase of the planner, specified as a logical `1` (`true`) or `0` (`false`). Setting this property to `true` causes the object to ignore the `MaxConnectionDistance` property when attempting to connect the two trees together.

Data Types: `logical`

`WorkspaceGoalRegionBias` — Probability to sample additional goal state from workspace goal region
0.50 (default) | positive value in the range [0,1)

Probability to sample a goal state from the workspace goal region, specified as a positive value in the range [0,1). The bias defines the probability to add additional goal states to the tree from the `workspaceGoalRegion` object. When this value is set to zero, the `workspaceGoalRegion` object still samples a single goal for the planner to plan to.

Increasing this value increases the likelihood of reaching a goal state in the goal region, but may lead to longer planning times because each new goal state adds additional complexity for planning.

Dependency

You must use the `goalRegion` input when calling the `plan` object function.

Data Types: `double`

`IgnoreSelfCollision` — Ignore self collisions during planning
`0` or `false` (default) | `1` or `true`

Ignore self collisions during planning, specified as a logical. If this property is set to `true`, the `plan` function skips checking between bodies for collisions and only compares the bodies to the environment. By not checking for self-collisions, you may improve the speed of the planning phase.

Data Types: `logical`

Object Functions

plan	Plan path using RRT for manipulators
interpolate	Interpolate states along path from RRT
shorten	Trim edges to shorten path from RRT

Examples

Plan Path for Manipulator Robot Using RRT

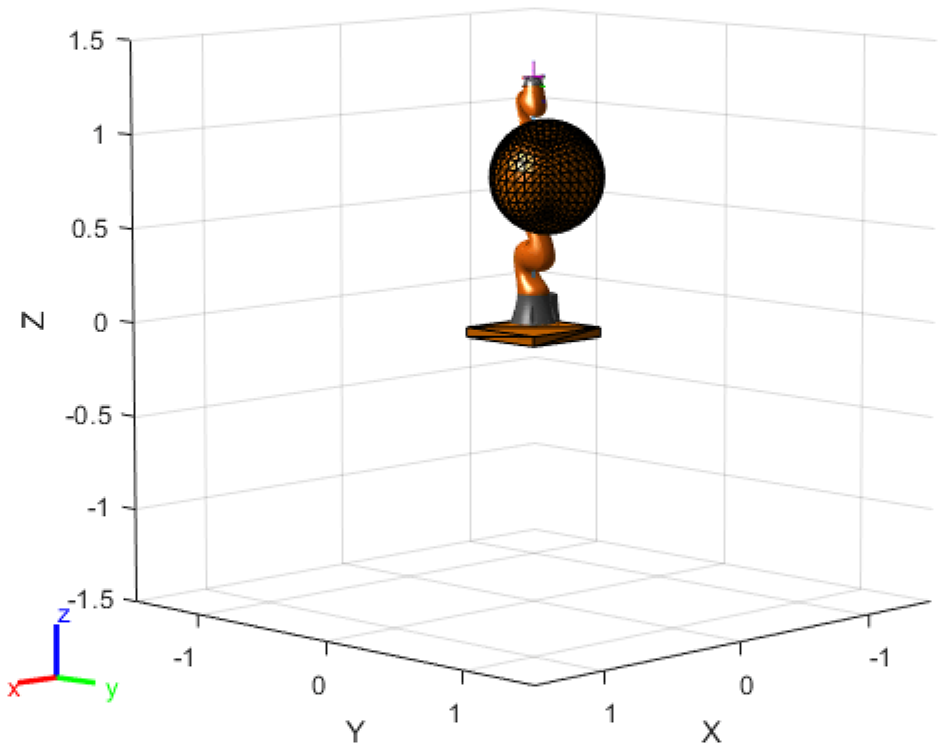
Use the `manipulatorRRT` object to plan a path for a rigid body tree robot model in an environment with obstacles. Visualize the planned path with interpolated states.

Load a robot model into the workspace. Use the KUKA LBR iiwa© manipulator arm.

```
robot = loadrobot("kukaIiwa14","DataFormat","row");
```

Generate the environment for the robot. Create collision objects and specify their poses relative to the robot base. Visualize the environment.

```
env = {collisionBox(0.5, 0.5, 0.05) collisionSphere(0.3)};
env{1}.Pose(3, end) = -0.05;
env{2}.Pose(1:3, end) = [0.1 0.2 0.8];

show(robot);
hold on
show(env{1})
show(env{2})
```



Create the RRT planner for the robot model.

```
rrt = manipulatorRRT(robot,env);
```

Specify a start and a goal configuration.

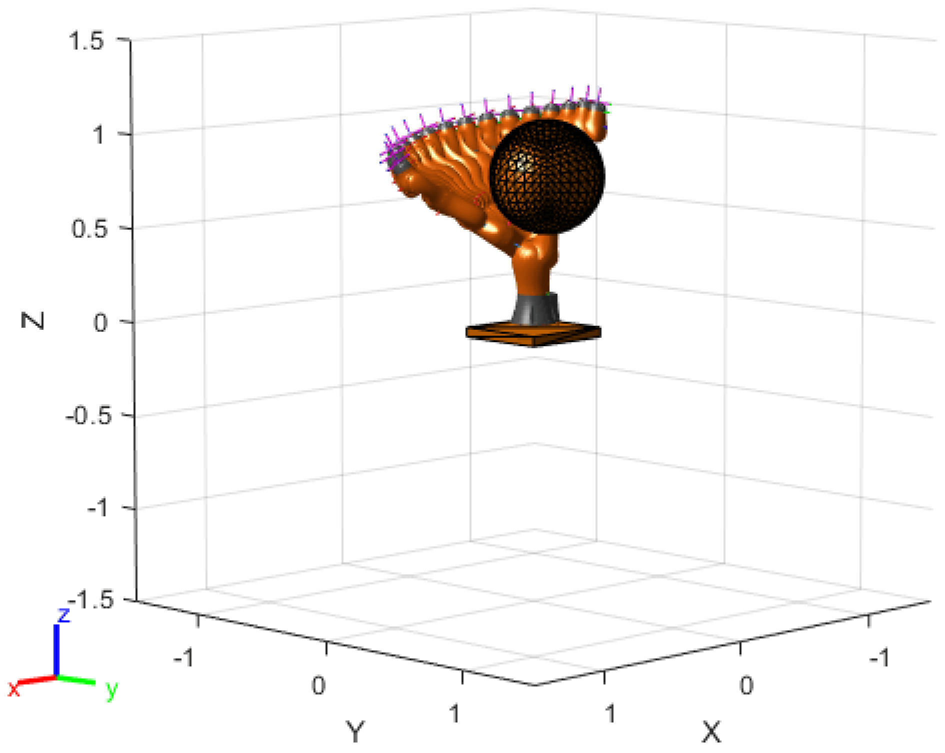
```
startConfig = [0.08 -0.65 0.05 0.02 0.04 0.49 0.04];
goalConfig =  [2.97 -1.05 0.05 0.02 0.04 0.49 0.04];
```

Plan the path. Due to the randomness of the RRT algorithm, set the `rng` seed for repeatability.

```
rng(0)
path = plan(rrt,startConfig,goalConfig);
```

Visualize the path. To add more intermediate states, interpolate the path. By default, the `interpolate` object function uses the value of `ValidationDistance` property to determine the number of intermediate states. The `for` loop shows every 20th element of the interpolated path.

```
interpPath = interpolate(rrt,path);
clf
for i = 1:20:size(interpPath,1)
    show(robot,interpPath(i,:));
    hold on
end
show(env{1})
show(env{2})
hold off
```

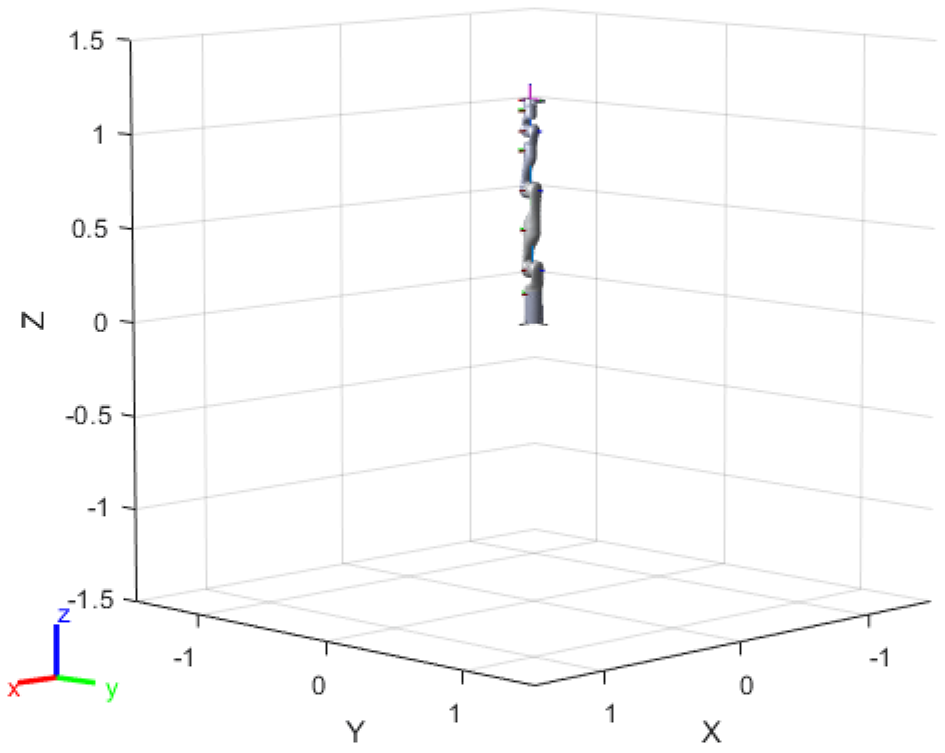


Plan Path To A Workspace Goal Region

Specify a goal region in your workspace and plan a path within those bounds. The `workspaceGoalRegion` object defines the bounds on the XYZ-position and ZYX Euler orientation of the robot end effector. The `manipulatorRRT` object plans a path based on that goal region and samples random poses within the bounds.

Load an existing robot model as a `rigidBodyTree` object.

```
robot = loadrobot("kinovaGen3", "DataFormat", "row");
ax = show(robot);
```



Create Path Planner

Create a rapidly-exploring random tree (RRT) path planner for the robot. This example uses an empty environment, but this workflow also works well with cluttered environments. You can add collision objects to the environment like the `collisionBox` or `collisionMesh` object.

```
planner = manipulatorRRT(robot,{});
```

Define Goal Region

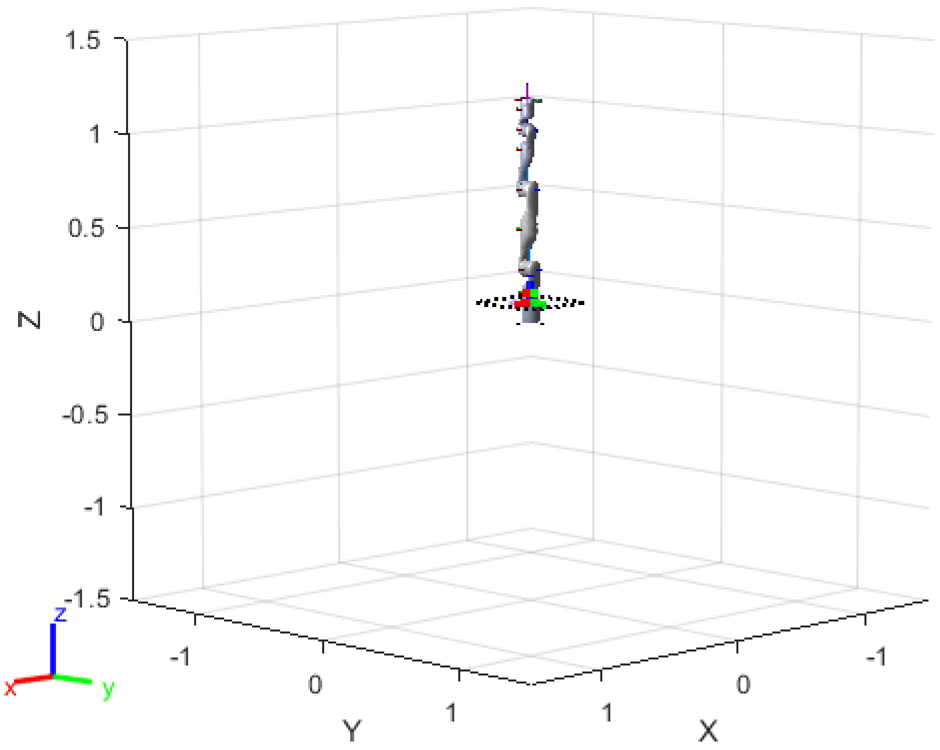
Create a workspace goal region using the end-effector body name of the robot.

Define the goal region parameters for your workspace. The goal region includes a reference pose, XYZ-position bounds, and orientation limits on the ZYX Euler angles. This example specifies bounds on the XY-plane in meters and allows rotation about the Z-axis in radians.

```
goalRegion = workspaceGoalRegion(robot.BodyNames{end});
goalRegion.ReferencePose = trvec2tform([0.5 0.5 0.2]);
goalRegion.Bounds(1, :) = [-0.2 0.2];    % X Bounds
goalRegion.Bounds(2, :) = [-0.2 0.2];    % Y Bounds
goalRegion.Bounds(4, :) = [-pi/2 pi/2];  % Rotation about the Z-axis
```

You can also apply a fixed offset to all poses sampled within the region. This offset can account for grasping tools or variations in dimensions within your workspace. For this example, apply a fixed transformation that places the end effector 5 cm above the workspace.

```
goalRegion.EndEffectorOffsetPose = trvec2tform([0 0 0.05]);
hold on
show(goalRegion);
```



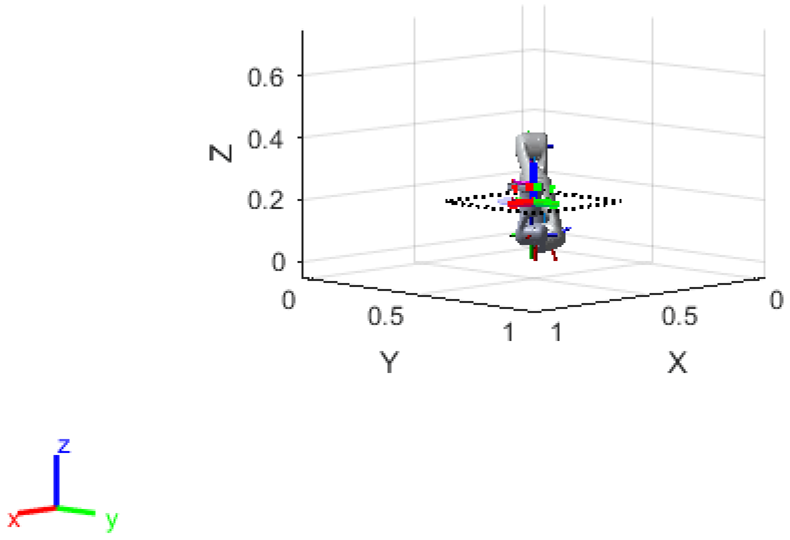
Plan Path To Goal Region

Plan a path to the goal region from the robot's home configuration. Due to the randomness in the RRT algorithm, this example sets the `rng` seed to ensure repeatable results.

```
rng(0)
path = plan(planner,homeConfiguration(robot),goalRegion);
```

Show the robot executing the path. To visualize a more realistic path, interpolate points between path configurations.

```
interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot,interpConfigurations(i,:),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1],...
        'CameraViewAngle',5)

    drawnow
end
hold off
```



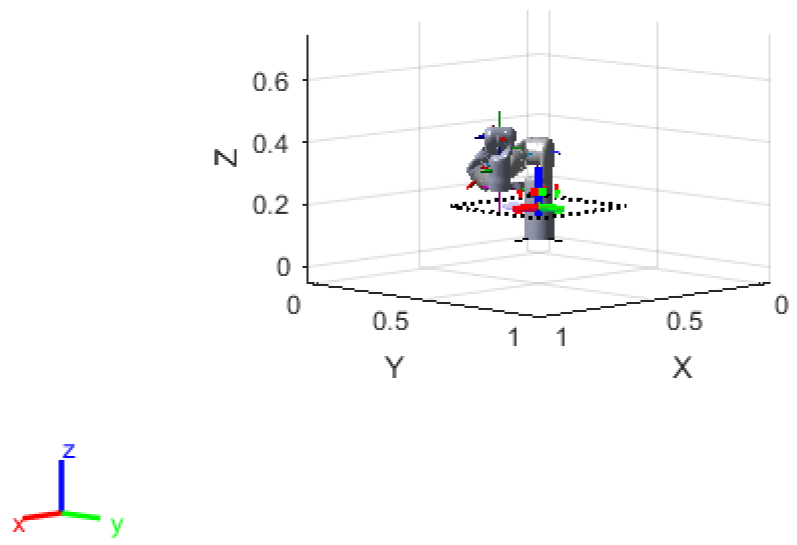
Adjust End-effector Pose

Notice that the robot arm approaches the workspace from the bottom. To flip the orientation of the final position, add a `pi` rotation to the Y-axis for the reference pose.

```
goalRegion.EndEffectorOffsetPose = ...
    goalRegion.EndEffectorOffsetPose*eul2tform([0 pi 0],"ZYX");
```

Replan the path and visualize the robot motion again. The robot now approaches from the top.

```
hold on
show(goalRegion);
path = plan(planner,homeConfiguration(robot),goalRegion);

interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot, interpConfigurations(i, :),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1])
    drawnow;
end
hold off
```



Tips

Planning Complexity

- When planning the motion between nodes in the tree, a set of configurations are generated and validated. This computation time of the planner is proportional to the number of configurations generated. The number of configurations between nodes is controlled by the ratio of the MaxConnectionDistance and ValidationDistance properties. To improve planning time, consider increasing the validation distance or decreasing the max connection distance.
- Validating each configuration has a complexity of O(mn+m^2), where m is the number of collision bodies in the `rigidBodyTree` object and n is the number of collision objects in `worldObjects`. Using large numbers of meshes to represent your robot or environment increases the time for validating each configuration.

Infinite Joint Limits

- If your `rigidBodyTree` robot model has joint limits that have infinite range (e.g. revolute joint with limits of `[-Inf Inf]`), the `manipulatorRRT` object uses limits of `[-1e10 1e10]` to perform uniform random sampling in the joint limits.

References

[1] Kuffner, J. J., and S. M. LaValle. “RRT-Connect: An Efficient Approach to Single-Query Path Planning.” In *Proceedings 2000 ICRA. Millennium Conference. IEEE International Conference*

on Robotics and Automation. Symposia Proceedings (Cat. No.00CH37065), 2:995–1001. San Francisco, CA, USA: IEEE, 2000. https://doi:10.1109/ROBOT.2000.844730.

Extended Capabilities

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

See Also

Objects
`rigidBodyTree` | `interactiveRigidBodyTree` | `analyticalInverseKinematics`

Functions
`plan` | `interpolate` | `shorten`

Topics
“Pick and Place Using RRT for Manipulators”
“Pick-and-Place Workflow Using RRT Planner and Stateflow for MATLAB”

Introduced in R2020b

manipulatorStateSpace

State space for rigid body tree robot models

Description

The `manipulatorStateSpace` object represents the joint configuration state space of a rigid body tree robot model. For a given `rigidBodyTree` object, the nonfixed joints in the rigid body tree model form the state space. When sampling the state or specifying bounds, the values of the state vector correspond to joint positions that define a joint configuration with dimension equal to the `NumStateVariables` property.

Typically, the manipulator state space works with sampling-based path planners like the `plannerRRT` and `plannerBiRRT` objects. To sample and validate paths for manipulators, combine the state space with a state validator `manipulatorCollisionBodyValidator` object. Because the `manipulatorStateSpace` object derives from the `nav.StateSpace` class, and is specified in the `StateSpace` property of the path planners.

To plan paths for manipulators using only Robotics System Toolbox, see the `manipulatorRRT` object.

Creation

Syntax

```
manipSS = manipulatorStateSpace
manipSS = manipulatorStateSpace(robot)
manipSS = manipulatorStateSpace(robot,numStateVariables)
```

Description

`manipSS = manipulatorStateSpace` creates a default state space for a rigid body tree with two revolute joints.

`manipSS = manipulatorStateSpace(robot)` creates a state space for the specified `rigidBodyTree` object, `robot`.

`manipSS = manipulatorStateSpace(robot,numStateVariables)` specifies the number of state variables, which is the number of nonfixed joints in the robot model. You must use this syntax for code generation.

Properties

`RigidBodyTree` — Rigid body tree robot model
`rigidBodyTree` object

Rigid body tree robot model, specified as a `rigidBodyTree` object. After you create the `manipulatorStateSpace` object, this property is read-only.

Name — Name of state space object
"manipulatorStateSpace" (default) | string scalar | character vector

This property is read-only.

Name of the state space object, specified as a string scalar or character vector.

Example: "customManipulatorState"

NumStateVariables — Dimension of state space
2 (default) | positive numeric integer

Dimension of the state space, specified as a positive numeric integer. This property is the dimension of the state space and should match the size of the robot model joint configuration. To get a joint configuration, see the `homeConfiguration` or `randomConfiguration` function.

After you create the object, this property is read-only.

StateBounds — Minimum and maximum bounds of joint positions
n-by-2 matrix

Min and max bounds of the joint positions, specified as an *n*-by-2 matrix with rows of form `[min max]`. *n* is the number of state variables in the joint configuration space, specified in the `NumStateVariables` property. You must specify the `[min max]` joint positions in meters for prismatic joints and in radians for revolute joints.

Example: `[-10 10; -10 10; -pi pi]`

Data Types: `double`

Object Functions

distance	Distance between states
enforceStateBounds	Limit state to state space bounds
sampleUniform	Sample state using uniform distribution
sampleGaussian	Sample state using Gaussian distribution
interpolate	Interpolate between states

Examples

Validate State and Motion Manipulator State Space

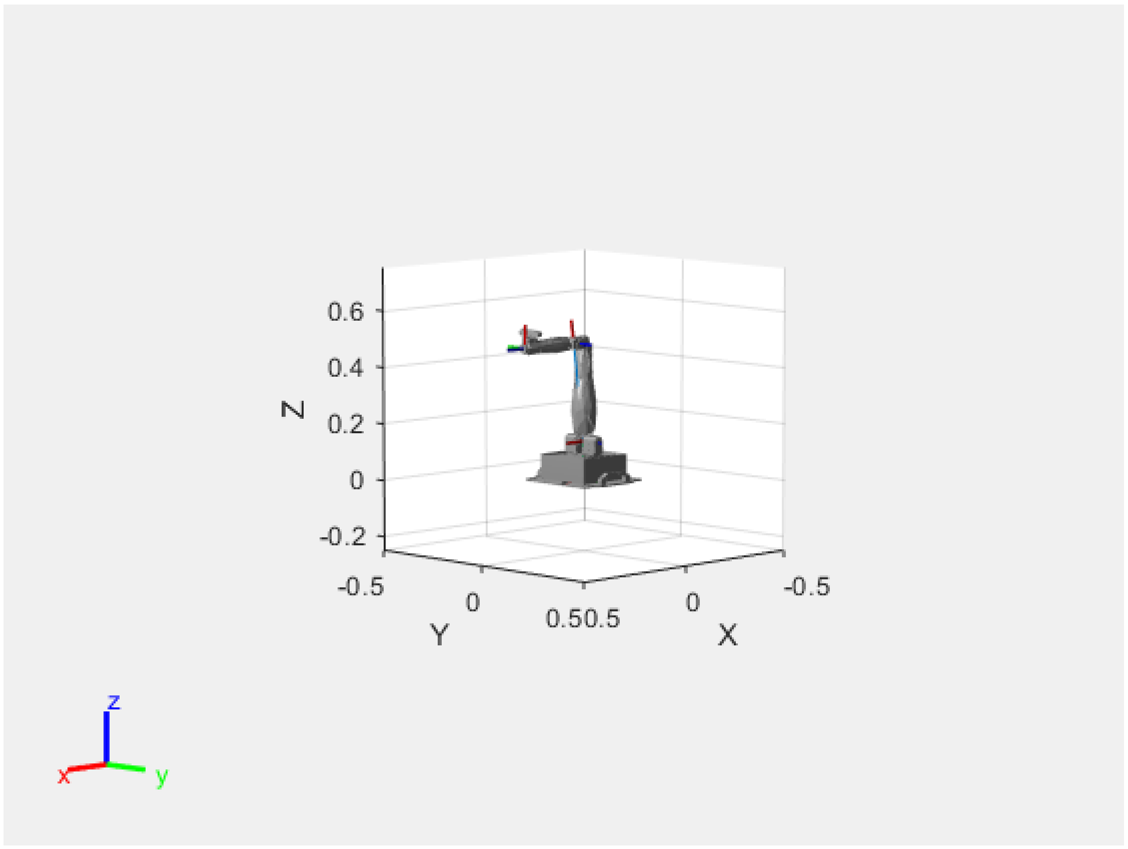
Generate states to form a path, validate motion between states, and check for self-collisions and environmental collisions with objects in your world. The `manipulatorStateSpace` object represents the joint configuration space of your rigid body tree robot model, and can sample states, calculate distances, and enforce state bounds. The `manipulatorCollisionBodyValidator` object validates the state and motion based on the collision bodies in your robot model and any obstacles in your environment.

Load Robot Model

Use the `loadrobot` function to access predefined robot models. This example uses the Quanser QArm™ robot and joint configurations are specified as row vectors.

```
robot = loadrobot("quanserQArm",DataFormat="row");
figure(Visible="on")
```

```
show(robot);
xlim([-0.5 0.5])
ylim([-0.5 0.5])
zlim([-0.25 0.75])
hold on
```



Configure State Space and State Validation

Create the state space and state validator from the robot model.

```
ss = manipulatorStateSpace(robot);
sv = manipulatorCollisionBodyValidator(ss);
```

Set the validation distance to `0.05`, which is based on the distance normal between two states. You can configure the validator to ignore self collisions to improve the speed of validation, but must consider whether your robot model has the proper joint limit settings set to ensure it does not collide with itself.

```
sv.ValidationDistance = 0.05;
sv.IgnoreSelfCollision = true;
```

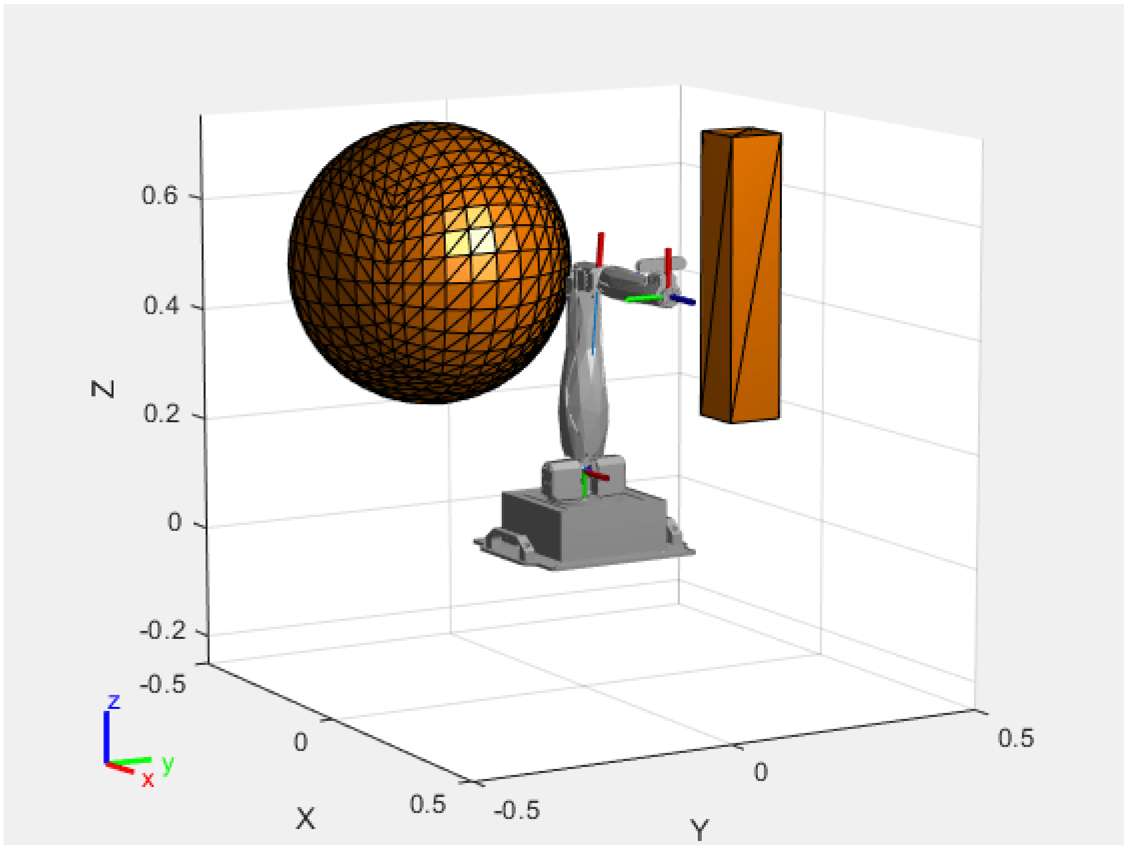
Place collision objects in the robot environment. Set the `Environment` property of the collision validator object using a cell array of objects.

```
box = collisionBox(0.1,0.1,0.5); % XYZ Lengths
box.Pose = trvec2tform([0.2 0.2 0.5]); % XYZ Position
sphere = collisionSphere(0.25); % Radius
sphere.Pose = trvec2tform([-0.2 -0.2 0.5]); % XYZ Position
```

```
env = {box sphere};
sv.Environment = env;
```

Visualize the environment.

```
for i = 1:length(env)
    show(env{i})
end
view(60,10)
```



Plan Path

Start with the home configuration as the first point on the path.

```
rng(0); % Repeatable results
start = homeConfiguration(robot);
path = start;
idx = 1;
```

Plan a path using these steps, in a loop:

- Sample a nearby goal configuration, using the Gaussian distribution, by specifying the standard deviation for each joint angle.
- Check if the sampled goal state is valid.
- If the sampled goal state is valid, check if the motion between states is valid and, if so, add it to the path.

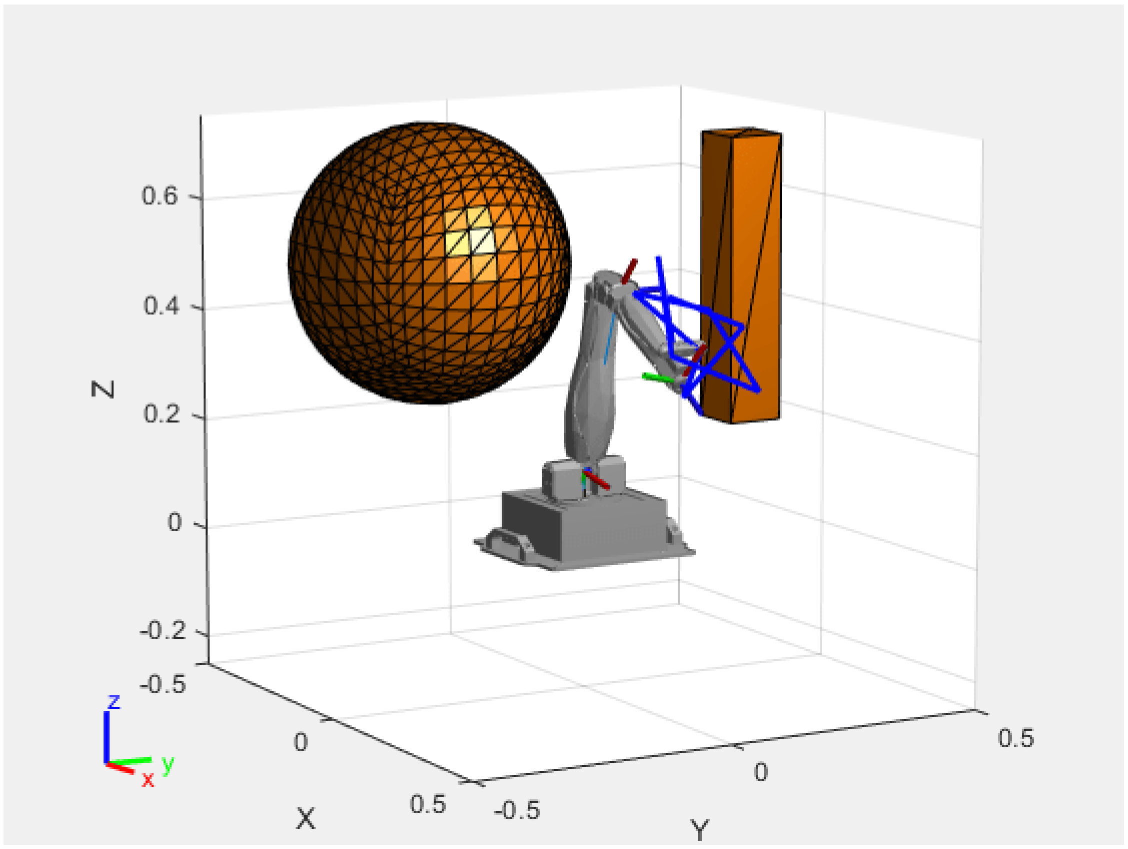
```
for i = 2:25
    goal = sampleGaussian(ss,start,0.25*ones(4,1));
    validState = isStateValid(sv,goal);

    if validState % If state is valid, check motion between states.
        [validMotion,~] = isMotionValid(sv,path(idx,:),goal);

        if validMotion % If motion is valid, add to path.
            path = [path; goal];
            idx = idx + 1;
        end
    end
end
```

Visualize Path

After generating the path of valid motions, visualize the robot motion. Because you sampled random states near the home configuration, you should see the arm move around that initial configuration.

To visualize the path of the end effector in 3-D, get the transformation, relative to the base world frame at each point. Store the points as an *xyz* translation vector. Plot the path of the end effector.

```
eePose = nan(3,size(path,1));

for i = 1:size(path,1)
    show(robot,path(i,:),PreservePlot=false);
    eePos(i,:) = tform2trvec(getTransform(robot,path(i,:),"END-EFFECTOR")); % XYZ translation ve
    plot3(eePos(:,1),eePos(:,2),eePos(:,3),"-b",LineWidth=2)
    drawnow
end
```



Extended Capabilities

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

See Also

Objects
`rigidBodyTree` | `manipulatorCollisionBodyValidator` | `manipulatorRRT` | `workspaceGoalRegion`

Functions
`isStateValid` | `isMotionValid` | `sampleUniform` | `sampleGaussian` | `interpolate` | `distance` | `enforceStateBounds`

Introduced in R2021b

mobileRobotPRM

Create probabilistic roadmap path planner

Description

The `mobileRobotPRM` object is a roadmap path planner object for the environment map specified in the `Map` property. The object uses the map to generate a roadmap, which is a network graph of possible paths in the map based on free and occupied spaces. You can customize the number of nodes, `NumNodes`, and the connection distance, `ConnectionDistance`, to fit the complexity of the map and find an obstacle-free path from a start to an end location.

After the map is defined, the `mobileRobotPRM` path planner generates the specified number of nodes throughout the free spaces in the map. A connection between nodes is made when a line between two nodes contains no obstacles and is within the specified connection distance.

After defining a start and end location, to find an obstacle-free path using this network of connections, use the `findpath` method. If `findpath` does not find a connected path, it returns an empty array. By increasing the number of nodes or the connection distance, you can improve the likelihood of finding a connected path, but tuning these properties is necessary. To see the roadmap and the generated path, use the visualization options in `show`. If you change any of the `mobileRobotPRM` properties, call `update`, `show`, or `findpath` to recreate the roadmap.

Creation

Syntax

```
planner = mobileRobotPRM

planner = mobileRobotPRM(map)
planner = mobileRobotPRM(map,numnodes)
```

Description

`planner = mobileRobotPRM` creates an empty roadmap with default properties. Before you can use the roadmap, you must specify a `binaryOccupancyMap` object in the `Map` property.

`planner = mobileRobotPRM(map)` creates a roadmap with `map` set as the `Map` property, where `map` is a `binaryOccupancyMap` object.

`planner = mobileRobotPRM(map,numnodes)` sets the maximum number of nodes, `numnodes`, to the `NumNodes` property.

Input Arguments

map — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object is a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

`numnodes` — Maximum number of nodes in roadmap
50 (default) | scalar

Maximum number of nodes in roadmap, specified as a scalar. By increasing this value, the complexity and computation time for the path planner increases.

Properties

`ConnectionDistance` — Maximum distance between two connected nodes
`inf` (default) | scalar in meters

Maximum distance between two connected nodes, specified as the comma-separated pair consisting of `"ConnectionDistance"` and a scalar in meters. This property controls whether nodes are connected based on their distance apart. Nodes are connected only if no obstacles are directly in the path. By decreasing this value, the number of connections is lowered, but the complexity and computation time decreases as well.

`Map` — Map representation
`binaryOccupancyMap` object | `occupancyMap` object

Map representation, specified as the comma-separated pair consisting of `"Map"` and a `binaryOccupancyMap` or `occupancyMap` object. This object represents the environment of the robot. The object is a matrix grid with values indicating the occupancy of locations in the map.

`NumNodes` — Number of nodes in the map
50 (default) | scalar

Number of nodes in the map, specified as the comma-separated pair consisting of `"NumNodes"` and a scalar. By increasing this value, the complexity and computation time for the path planner increases.

Object Functions

findpath	Find path between start and goal points on roadmap
show	Show map, roadmap, and path
update	Create or update roadmap

Compatibility Considerations

`mobileRobotPRM` was renamed
Behavior change in future release

The `mobileRobotPRM` object was renamed from `robotics.PRM`. Use `mobileRobotPRM` for all object creation.

Extended Capabilities

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

Usage notes and limitations:

The `map` input must be specified on creation of the `mobileRobotPRM` object.

See Also
`binaryOccupancyMap` | `occupancyMap` | `controllerPurePursuit`

Topics
"Path Planning in Environments of Different Complexity"
"Probabilistic Roadmaps (PRM)"

Introduced in R2019b

quaternion

Create a quaternion array

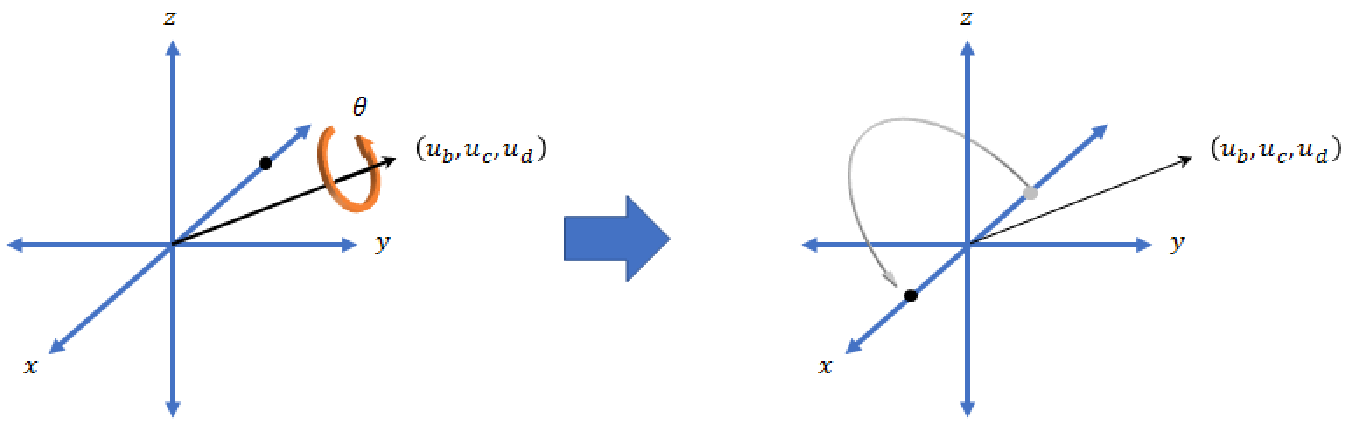
Description

A quaternion is a four-part hyper-complex number used in three-dimensional rotations and orientations.

A quaternion number is represented in the form $a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, where a, b, c, and d parts are real numbers, and i, j, and k are the basis elements, satisfying the equation: $\mathrm{i}^2 = \mathrm{j}^2 = \mathrm{k}^2 = \mathrm{ijk} = -1$.

The set of quaternions, denoted by **H**, is defined within a four-dimensional vector space over the real numbers, $\mathbf{R}^4$. Every element of **H** has a unique representation based on a linear combination of the basis elements, i, j, and k.

All rotations in 3-D can be described by an axis of rotation and angle about that axis. An advantage of quaternions over rotation matrices is that the axis and angle of rotation is easy to interpret. For example, consider a point in $\mathbf{R}^3$. To rotate the point, you define an axis of rotation and an angle of rotation.



The quaternion representation of the rotation may be expressed as $q = \cos\left(\theta/2\right) + \sin\left(\theta/2\right)(u_b\mathrm{i} + u_c\mathrm{j} + u_d\mathrm{k})$, where θ is the angle of rotation and [u_b, u_c, and u_d] is the axis of rotation.

Creation

Syntax

```
quat = quaternion()
quat = quaternion(A,B,C,D)
quat = quaternion(matrix)
quat = quaternion(RV,'rotvec')
quat = quaternion(RV,'rotvecd')
quat = quaternion(RM,'rotmat',PF)
quat = quaternion(E,'euler',RS,PF)
quat = quaternion(E,'eulerd',RS,PF)
```

Description

`quat = quaternion()` creates an empty quaternion.

`quat = quaternion(A,B,C,D)` creates a quaternion array where the four quaternion parts are taken from the arrays `A`, `B`, `C`, and `D`. All the inputs must have the same size and be of the same data type.

`quat = quaternion(matrix)` creates an *N*-by-1 quaternion array from an *N*-by-4 matrix, where each column becomes one part of the quaternion.

`quat = quaternion(RV,'rotvec')` creates an *N*-by-1 quaternion array from an *N*-by-3 matrix of rotation vectors, `RV`. Each row of `RV` represents a rotation vector in radians.

`quat = quaternion(RV,'rotvecd')` creates an *N*-by-1 quaternion array from an *N*-by-3 matrix of rotation vectors, `RV`. Each row of `RV` represents a rotation vector in degrees.

`quat = quaternion(RM,'rotmat',PF)` creates an *N*-by-1 quaternion array from the 3-by-3-by-*N* array of rotation matrices, `RM`. `PF` can be either `'point'` if the Euler angles represent point rotations or `'frame'` for frame rotations.

`quat = quaternion(E,'euler',RS,PF)` creates an *N*-by-1 quaternion array from the *N*-by-3 matrix, `E`. Each row of `E` represents a set of Euler angles in radians. The angles in `E` are rotations about the axes in sequence `RS`.

`quat = quaternion(E,'eulerd',RS,PF)` creates an *N*-by-1 quaternion array from the *N*-by-3 matrix, `E`. Each row of `E` represents a set of Euler angles in degrees. The angles in `E` are rotations about the axes in sequence `RS`.

Input Arguments

`A,B,C,D` — Quaternion parts
comma-separated arrays of the same size

Parts of a quaternion, specified as four comma-separated scalars, matrices, or multi-dimensional arrays of the same size.

Example: `quat = quaternion(1,2,3,4)` creates a quaternion of the form 1 + 2i + 3j + 4k.

Example: `quat = quaternion([1,5],[2,6],[3,7],[4,8])` creates a 1-by-2 quaternion array where `quat(1,1) = 1 + 2i + 3j + 4k` and `quat(1,2) = 5 + 6i + 7j + 8k`

Data Types: `single` | `double`

`matrix` — Matrix of quaternion parts
N-by-4 matrix

Matrix of quaternion parts, specified as an *N*-by-4 matrix. Each row represents a separate quaternion. Each column represents a separate quaternion part.

Example: `quat = quaternion(rand(10,4))` creates a 10-by-1 quaternion array.

Data Types: `single` | `double`

RV — Matrix of rotation vectors
N-by-3 matrix

Matrix of rotation vectors, specified as an *N*-by-3 matrix. Each row of `RV` represents the [X Y Z] elements of a rotation vector. A rotation vector is a unit vector representing the axis of rotation scaled by the angle of rotation in radians or degrees.

To use this syntax, specify the first argument as a matrix of rotation vectors and the second argument as the `'rotvec'` or `'rotvecd'`.

Example: `quat = quaternion(rand(10,3),'rotvec')` creates a 10-by-1 quaternion array.

Data Types: `single` | `double`

RM — Rotation matrices
3-by-3 matrix | 3-by-3-by-*N* array

Array of rotation matrices, specified by a 3-by-3 matrix or 3-by-3-by-*N* array. Each page of the array represents a separate rotation matrix.

Example: `quat = quaternion(rand(3),'rotmat','point')`

Example: `quat = quaternion(rand(3),'rotmat','frame')`

Data Types: `single` | `double`

PF — Type of rotation matrix
`'point'` | `'frame'`

Type of rotation matrix, specified by `'point'` or `'frame'`.

Example: `quat = quaternion(rand(3),'rotmat','point')`

Example: `quat = quaternion(rand(3),'rotmat','frame')`

Data Types: `char` | `string`

E — Matrix of Euler angles
N-by-3 matrix

Matrix of Euler angles, specified by an *N*-by-3 matrix. If using the `'euler'` syntax, specify `E` in radians. If using the `'eulerd'` syntax, specify `E` in degrees.

Example: `quat = quaternion(E,'euler','YZY','point')`

Example: `quat = quaternion(E,'euler','XYZ','frame')`

Data Types: `single` | `double`

RS — Rotation sequence
character vector | scalar string

Rotation sequence, specified as a three-element character vector:

- `'YZY'`
- `'YXY'`
- `'ZYZ'`

- `'ZXZ'`
- `'XYX'`
- `'XZX'`
- `'XYZ'`
- `'YZX'`
- `'ZXY'`
- `'XZY'`
- `'ZYX'`
- `'YXZ'`

Assume you want to determine the new coordinates of a point when its coordinate system is rotated using frame rotation. The point is defined in the original coordinate system as:

```
point = [sqrt(2)/2,sqrt(2)/2,0];
```

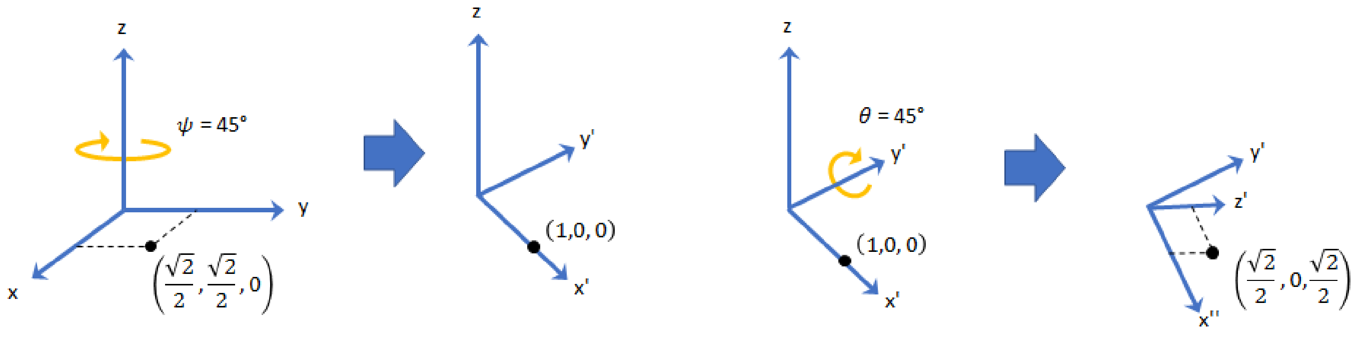
In this representation, the first column represents the *x*-axis, the second column represents the *y*-axis, and the third column represents the *z*-axis.

You want to rotate the point using the Euler angle representation [45,45,0]. Rotate the point using two different rotation sequences:

- If you create a quaternion rotator and specify the 'ZYX' sequence, the frame is first rotated 45° around the *z*-axis, then 45° around the new *y*-axis.

  ```
  quatRotator = quaternion([45,45,0],'eulerd','ZYX','frame');
  newPointCoordinate = rotateframe(quatRotator,point)
  ```

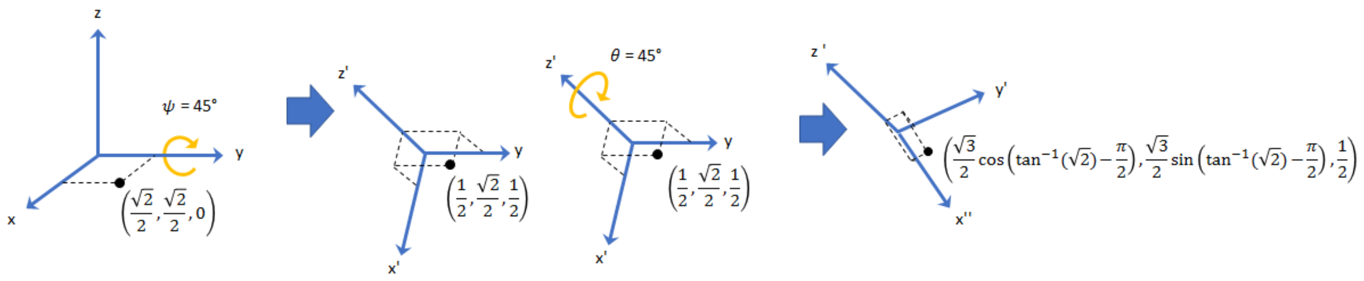
  ```
  newPointCoordinate =

      0.7071   -0.0000    0.7071
  ```


z
ψ = 45°
y
x
$\left(\frac{\sqrt{2}}{2},\frac{\sqrt{2}}{2},0\right)$
z
y'
(1,0,0)
x'
z
θ = 45°
y'
(1,0,0)
x'
y'
z'
$\left(\frac{\sqrt{2}}{2},0,\frac{\sqrt{2}}{2}\right)$
x''

- If you create a quaternion rotator and specify the 'YZX' sequence, the frame is first rotated 45° around the *y*-axis, then 45° around the new *z*-axis.

  ```
  quatRotator = quaternion([45,45,0],'eulerd','YZX','frame');
  newPointCoordinate = rotateframe(quatRotator,point)
  ```

  ```
  newPointCoordinate =

      0.8536    0.1464    0.5000
  ```


z
ψ = 45°
y
x
$\left(\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}, 0\right)$
z'
y
x'
$\left(\frac{1}{2}, \frac{\sqrt{2}}{2}, \frac{1}{2}\right)$
z'
θ = 45°
y
x'
$\left(\frac{1}{2}, \frac{\sqrt{2}}{2}, \frac{1}{2}\right)$
z'
y'
x''
$\left(\frac{\sqrt{3}}{2}\cos\left(\tan^{-1}(\sqrt{2}) - \frac{\pi}{2}\right), \frac{\sqrt{3}}{2}\sin\left(\tan^{-1}(\sqrt{2}) - \frac{\pi}{2}\right), \frac{1}{2}\right)$

Data Types: `char` | `string`

Object Functions

angvel	Angular velocity from quaternion array
classUnderlying	Class of parts within quaternion
compact	Convert quaternion array to N-by-4 matrix
conj	Complex conjugate of quaternion
'	Complex conjugate transpose of quaternion array
dist	Angular distance in radians
euler	Convert quaternion to Euler angles (radians)
eulerd	Convert quaternion to Euler angles (degrees)
exp	Exponential of quaternion array
.\,ldivide	Element-wise quaternion left division
log	Natural logarithm of quaternion array
meanrot	Quaternion mean rotation
-	Quaternion subtraction
*	Quaternion multiplication
norm	Quaternion norm
normalize	Quaternion normalization
ones	Create quaternion array with real parts set to one and imaginary parts set to zero
parts	Extract quaternion parts
.^,power	Element-wise quaternion power
prod	Product of a quaternion array
randrot	Uniformly distributed random rotations
./,rdivide	Element-wise quaternion right division
rotateframe	Quaternion frame rotation
rotatepoint	Quaternion point rotation
rotmat	Convert quaternion to rotation matrix
rotvec	Convert quaternion to rotation vector (radians)
rotvecd	Convert quaternion to rotation vector (degrees)
slerp	Spherical linear interpolation
.*,times	Element-wise quaternion multiplication
'	Transpose a quaternion array
-	Quaternion unary minus
zeros	Create quaternion array with all parts set to zero

Examples

Create Empty Quaternion

```
quat = quaternion()
quat = 

  0x0 empty quaternion array
```

By default, the underlying class of the quaternion is a double.

```
classUnderlying(quat)
```

```
ans = 
'double'
```

Create Quaternion by Specifying Individual Quaternion Parts

You can create a quaternion array by specifying the four parts as comma-separated scalars, matrices, or multidimensional arrays of the same size.

Define quaternion parts as scalars.

```
A = 1.1;
B = 2.1;
C = 3.1;
D = 4.1;
quatScalar = quaternion(A,B,C,D)
```

```
quatScalar = quaternion
     1.1 + 2.1i + 3.1j + 4.1k
```

Define quaternion parts as column vectors.

```
A = [1.1;1.2];
B = [2.1;2.2];
C = [3.1;3.2];
D = [4.1;4.2];
quatVector = quaternion(A,B,C,D)
```

```
quatVector = 2x1 quaternion array
     1.1 + 2.1i + 3.1j + 4.1k
     1.2 + 2.2i + 3.2j + 4.2k
```

Define quaternion parts as matrices.

```
A = [1.1,1.3; ...
     1.2,1.4];
B = [2.1,2.3; ...
     2.2,2.4];
C = [3.1,3.3; ...
     3.2,3.4];
D = [4.1,4.3; ...
     4.2,4.4];
quatMatrix = quaternion(A,B,C,D)
```

```
quatMatrix = 2x2 quaternion array
     1.1 + 2.1i + 3.1j + 4.1k     1.3 + 2.3i + 3.3j + 4.3k
     1.2 + 2.2i + 3.2j + 4.2k     1.4 + 2.4i + 3.4j + 4.4k
```

Define quaternion parts as three dimensional arrays.

```
A = randn(2,2,2);
B = zeros(2,2,2);
C = zeros(2,2,2);
D = zeros(2,2,2);
quatMultiDimArray = quaternion(A,B,C,D)
```

```
quatMultiDimArray = 2x2x2 quaternion array
quatMultiDimArray(:,:,1) =

     0.53767 +       0i +       0j +       0k     -2.2588 +       0i +       0j +       0k
      1.8339 +       0i +       0j +       0k     0.86217 +       0i +       0j +       0k


quatMultiDimArray(:,:,2) =

     0.31877 +       0i +       0j +       0k    -0.43359 +       0i +       0j +       0k
     -1.3077 +       0i +       0j +       0k     0.34262 +       0i +       0j +       0k
```

Create Quaternion by Specifying Quaternion Parts Matrix

You can create a scalar or column vector of quaternions by specify an *N*-by-4 matrix of quaternion parts, where columns correspond to the quaternion parts A, B, C, and D.

Create a column vector of random quaternions.

```
quatParts = rand(3,4)
```

```
quatParts = 3×4

    0.8147    0.9134    0.2785    0.9649
    0.9058    0.6324    0.5469    0.1576
    0.1270    0.0975    0.9575    0.9706
```

```
quat = quaternion(quatParts)
```

```
quat = 3x1 quaternion array
     0.81472 + 0.91338i +  0.2785j + 0.96489k
     0.90579 + 0.63236i + 0.54688j + 0.15761k
     0.12699 + 0.09754i + 0.95751j + 0.97059k
```

To retrieve the `quatParts` matrix from quaternion representation, use `compact`.

```
retrievedquatParts = compact(quat)
```

```
retrievedquatParts = 3×4

    0.8147    0.9134    0.2785    0.9649
    0.9058    0.6324    0.5469    0.1576
    0.1270    0.0975    0.9575    0.9706
```

Create Quaternion by Specifying Rotation Vectors

You can create an *N*-by-1 quaternion array by specifying an *N*-by-3 matrix of rotation vectors in radians or degrees. Rotation vectors are compact spatial representations that have a one-to-one relationship with normalized quaternions.

Rotation Vectors in Radians

Create a scalar quaternion using a rotation vector and verify the resulting quaternion is normalized.

```
rotationVector = [0.3491,0.6283,0.3491];
quat = quaternion(rotationVector,'rotvec')
```

```
quat = quaternion
     0.92124 + 0.16994i + 0.30586j + 0.16994k
```

```
norm(quat)
```

```
ans = 1.0000
```

You can convert from quaternions to rotation vectors in radians using the `rotvec` function. Recover the `rotationVector` from the quaternion, `quat`.

```
rotvec(quat)
```

```
ans = 1×3

    0.3491    0.6283    0.3491
```

Rotation Vectors in Degrees

Create a scalar quaternion using a rotation vector and verify the resulting quaternion is normalized.

```
rotationVector = [20,36,20];
quat = quaternion(rotationVector,'rotvecd')
```

```
quat = quaternion
     0.92125 + 0.16993i + 0.30587j + 0.16993k
```

```
norm(quat)
```

```
ans = 1
```

You can convert from quaternions to rotation vectors in degrees using the `rotvecd` function. Recover the `rotationVector` from the quaternion, `quat`.

```
rotvecd(quat)
```

```
ans = 1×3

   20.0000   36.0000   20.0000
```

Create Quaternion by Specifying Rotation Matrices

You can create an N-by-1 quaternion array by specifying a 3-by-3-by-N array of rotation matrices. Each page of the rotation matrix array corresponds to one element of the quaternion array.

Create a scalar quaternion using a 3-by-3 rotation matrix. Specify whether the rotation matrix should be interpreted as a frame or point rotation.

```
rotationMatrix = [1 0         0; ...
                  0 sqrt(3)/2 0.5; ...
                  0 -0.5      sqrt(3)/2];
quat = quaternion(rotationMatrix,'rotmat','frame')
```

```
quat = quaternion
     0.96593 + 0.25882i +       0j +       0k
```

You can convert from quaternions to rotation matrices using the `rotmat` function. Recover the `rotationMatrix` from the quaternion, `quat`.

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

```
ans = 3×3

    1.0000         0         0
         0    0.8660    0.5000
         0   -0.5000    0.8660
```

Create Quaternion by Specifying Euler Angles

You can create an *N*-by-1 quaternion array by specifying an *N*-by-3 array of Euler angles in radians or degrees.

Euler Angles in Radians

Use the `euler` syntax to create a scalar quaternion using a 1-by-3 vector of Euler angles in radians. Specify the rotation sequence of the Euler angles and whether the angles represent a frame or point rotation.

```
E = [pi/2,0,pi/4];
quat = quaternion(E,'euler','ZYX','frame')
```

```
quat = quaternion
     0.65328 +  0.2706i +  0.2706j + 0.65328k
```

You can convert from quaternions to Euler angles using the `euler` function. Recover the Euler angles, `E`, from the quaternion, `quat`.

```
euler(quat,'ZYX','frame')
```

```
ans = 1×3

    1.5708         0    0.7854
```

Euler Angles in Degrees

Use the `eulerd` syntax to create a scalar quaternion using a 1-by-3 vector of Euler angles in degrees. Specify the rotation sequence of the Euler angles and whether the angles represent a frame or point rotation.

```
E = [90,0,45];
quat = quaternion(E,'eulerd','ZYX','frame')
```

```
quat = quaternion
     0.65328 +  0.2706i +  0.2706j + 0.65328k
```

You can convert from quaternions to Euler angles in degrees using the `eulerd` function. Recover the Euler angles, `E`, from the quaternion, `quat`.

```
eulerd(quat,'ZYX','frame')
```

```
ans = 1×3

   90.0000         0   45.0000
```

Quaternion Algebra

Quaternions form a noncommutative associative algebra over the real numbers. This example illustrates the rules of quaternion algebra.

Addition and Subtraction

Quaternion addition and subtraction occur part-by-part, and are commutative:

```
Q1 = quaternion(1,2,3,4)
```

```
Q1 = quaternion
     1 + 2i + 3j + 4k
```

```
Q2 = quaternion(9,8,7,6)
```

```
Q2 = quaternion
     9 + 8i + 7j + 6k
```

```
Q1plusQ2 = Q1 + Q2
```

```
Q1plusQ2 = quaternion
     10 + 10i + 10j + 10k
```

```
Q2plusQ1 = Q2 + Q1
```

```
Q2plusQ1 = quaternion
     10 + 10i + 10j + 10k
```

```
Q1minusQ2 = Q1 - Q2
```

```
Q1minusQ2 = quaternion
    -8 - 6i - 4j - 2k
```

```
Q2minusQ1 = Q2 - Q1
```

```
Q2minusQ1 = quaternion
     8 + 6i + 4j + 2k
```

You can also perform addition and subtraction of real numbers and quaternions. The first part of a quaternion is referred to as the *real* part, while the second, third, and fourth parts are referred to as the *vector*. Addition and subtraction with real numbers affect only the real part of the quaternion.

```
Q1plusRealNumber = Q1 + 5
```

```
Q1plusRealNumber = quaternion
     6 + 2i + 3j + 4k
```

```
Q1minusRealNumber = Q1 - 5
```

```
Q1minusRealNumber = quaternion
    -4 + 2i + 3j + 4k
```

Multiplication

Quaternion multiplication is determined by the products of the basis elements and the distributive law. Recall that multiplication of the basis elements, *i*, *j*, and *k*, are not commutative, and therefore quaternion multiplication is not commutative.

```
Q1timesQ2 = Q1 * Q2
```

```
Q1timesQ2 = quaternion
    -52 + 16i + 54j + 32k
```

```
Q2timesQ1 = Q2 * Q1
```

```
Q2timesQ1 = quaternion
    -52 + 36i + 14j + 52k
```

```
isequal(Q1timesQ2,Q2timesQ1)
```

```
ans = logical
   0
```

You can also multiply a quaternion by a real number. If you multiply a quaternion by a real number, each part of the quaternion is multiplied by the real number individually:

```
Q1times5 = Q1*5
```

```
Q1times5 = quaternion
      5 + 10i + 15j + 20k
```

Multiplying a quaternion by a real number is commutative.

```
isequal(Q1*5,5*Q1)
```

```
ans = logical
   1
```

Conjugation

The complex conjugate of a quaternion is defined such that each element of the vector portion of the quaternion is negated.

```
Q1
```

```
Q1 = quaternion
     1 + 2i + 3j + 4k
```

```
conj(Q1)
```

```
ans = quaternion
     1 - 2i - 3j - 4k
```

Multiplication between a quaternion and its conjugate is commutative:

```
isequal(Q1*conj(Q1),conj(Q1)*Q1)
```

```
ans = logical
   1
```

Quaternion Array Manipulation

You can organize quaternions into vectors, matrices, and multidimensional arrays. Built-in MATLAB® functions have been enhanced to work with quaternions.

Concatenate

Quaternions are treated as individual objects during concatenation and follow MATLAB rules for array manipulation.

```
Q1 = quaternion(1,2,3,4);
Q2 = quaternion(9,8,7,6);

qVector = [Q1,Q2]
```

```
qVector = 1x2 quaternion array
     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
```

```
Q3 = quaternion(-1,-2,-3,-4);
Q4 = quaternion(-9,-8,-7,-6);

qMatrix = [qVector;Q3,Q4]
```

```
qMatrix = 2x2 quaternion array
     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
```

```
    -1 - 2i - 3j - 4k    -9 - 8i - 7j - 6k
```

```
qMultiDimensionalArray(:,:,1) = qMatrix;
qMultiDimensionalArray(:,:,2) = qMatrix
```

```
qMultiDimensionalArray = 2x2x2 quaternion array
qMultiDimensionalArray(:,:,1) =

     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k    -9 - 8i - 7j - 6k


qMultiDimensionalArray(:,:,2) =

     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k    -9 - 8i - 7j - 6k
```

Indexing

To access or assign elements in a quaternion array, use indexing.

```
qLoc2 = qMultiDimensionalArray(2)
```

```
qLoc2 = quaternion
    -1 - 2i - 3j - 4k
```

Replace the quaternion at index two with a quaternion one.

```
qMultiDimensionalArray(2) = ones('quaternion')
```

```
qMultiDimensionalArray = 2x2x2 quaternion array
qMultiDimensionalArray(:,:,1) =

     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
     1 + 0i + 0j + 0k    -9 - 8i - 7j - 6k


qMultiDimensionalArray(:,:,2) =

     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k    -9 - 8i - 7j - 6k
```

Reshape

To reshape quaternion arrays, use the `reshape` function.

```
qMatReshaped = reshape(qMatrix,4,1)
```

```
qMatReshaped = 4x1 quaternion array
     1 + 2i + 3j + 4k
    -1 - 2i - 3j - 4k
     9 + 8i + 7j + 6k
    -9 - 8i - 7j - 6k
```

Transpose

To transpose quaternion vectors and matrices, use the `transpose` function.

```
qMatTransposed = transpose(qMatrix)
```

```
qMatTransposed = 2x2 quaternion array
     1 + 2i + 3j + 4k    -1 - 2i - 3j - 4k
     9 + 8i + 7j + 6k    -9 - 8i - 7j - 6k
```

Permute

To permute quaternion vectors, matrices, and multidimensional arrays, use the `permute` function.

```
qMultiDimensionalArray
```

```
qMultiDimensionalArray = 2x2x2 quaternion array
qMultiDimensionalArray(:,:,1) =

     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
     1 + 0i + 0j + 0k    -9 - 8i - 7j - 6k


qMultiDimensionalArray(:,:,2) =

     1 + 2i + 3j + 4k     9 + 8i + 7j + 6k
    -1 - 2i - 3j - 4k    -9 - 8i - 7j - 6k
```

```
qMatPermute = permute(qMultiDimensionalArray,[3,1,2])
```

```
qMatPermute = 2x2x2 quaternion array
qMatPermute(:,:,1) =

     1 + 2i + 3j + 4k     1 + 0i + 0j + 0k
     1 + 2i + 3j + 4k    -1 - 2i - 3j - 4k


qMatPermute(:,:,2) =

     9 + 8i + 7j + 6k    -9 - 8i - 7j - 6k
     9 + 8i + 7j + 6k    -9 - 8i - 7j - 6k
```

Extended Capabilities

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

See Also

Introduced in R2018a

rateControl

Execute loop at fixed frequency

Description

The `rateControl` object enables you to run a loop at a fixed frequency. It also collects statistics about the timing of the loop iterations. Use `waitfor` in the loop to pause code execution until the next time step. The loop operates every `DesiredPeriod` seconds, unless the enclosed code takes longer to operate. The object uses the `OverrunAction` property to determine how it handles longer loop operation times. The default setting, `'slip'`, immediately executes the loop if `LastPeriod` is greater than `DesiredPeriod`. Using `'drop'` causes the `waitfor` method to wait until the next multiple of `DesiredPeriod` is reached to execute the next loop.

Tip The scheduling resolution of your operating system and the level of other system activity can affect rate execution accuracy. As a result, accurate rate timing is limited to 100 Hz for execution of MATLAB code. To improve performance and execution speeds, use code generation.

Creation

Syntax

```
rateObj = rateControl(desiredRate)
```

Description

`rateObj = rateControl(desiredRate)` creates an object that operates loops at a fixed-rate based on your system time and directly sets the `DesireRate` property.

Properties

`DesiredRate` — Desired execution rate
scalar

Desired execution rate of loop, specified as a scalar in Hz. When using `waitfor`, the loop operates every `DesiredRate` seconds, unless the loop takes longer. It then begins the next loop based on the specified `OverrunAction`.

`DesiredPeriod` — Desired time period between executions
scalar

Desired time period between executions, specified as a scalar in seconds. This property is equal to the inverse of `DesiredRate`.

`TotalElapsedTime` — Elapsed time since construction or reset
scalar

Elapsed time since construction or reset, specified as a scalar in seconds.

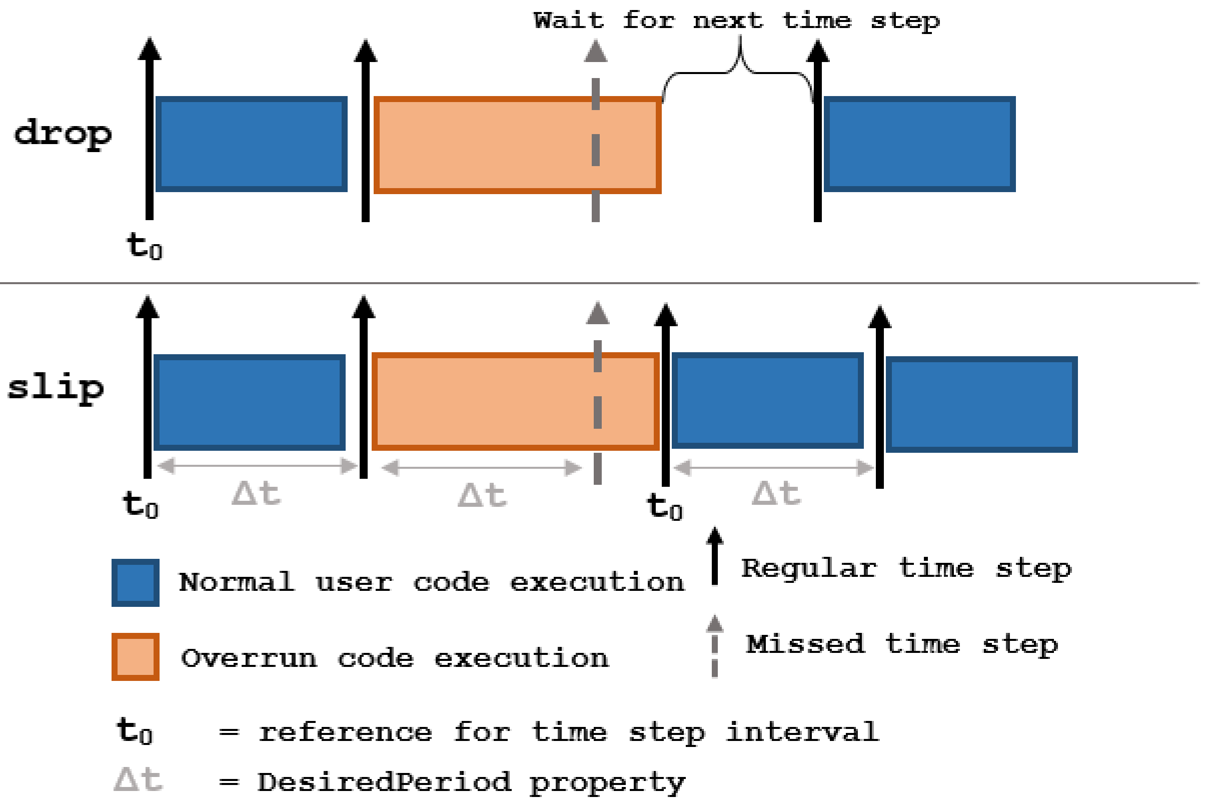
`LastPeriod` — Elapsed time between last two calls to `waitfor`
`NaN` (default) | scalar

Elapsed time between last two calls to `waitfor`, specified as a scalar. By default, `LastPeriod` is set to `NaN` until `waitfor` is called for the first time. After the first call, `LastPeriod` equals `TotalElapsedTime`.

`OverrunAction` — Method for handling overruns
`'slip'` (default) | `'drop'`

Method for handling overruns, specified as one of these character vectors:

- `'drop'` — waits until the next time interval equal to a multiple of `DesiredPeriod`
- `'slip'` — immediately executes the loop again



Each code section calls `waitfor` at the end of execution.

Object Functions

waitfor	Pause code execution to achieve desired execution rate
statistics	Statistics of past execution periods
reset	Reset Rate object

Examples

Run Loop at Fixed Rate

Create a rate object that runs at 1 Hz.

```
r = rateControl(1);
```

Start a loop using the `rateControl` object inside to control the loop execution. Reset the object prior to the loop execution to reset timer. Print the iteration and time elapsed.

```
reset(r)
for i = 1:10
    time = r.TotalElapsedTime;
    fprintf('Iteration: %d - Time Elapsed: %f\n',i,time)
    waitfor(r);
end
```

```
Iteration: 1 - Time Elapsed: 0.004098
Iteration: 2 - Time Elapsed: 1.004890
Iteration: 3 - Time Elapsed: 2.009797
Iteration: 4 - Time Elapsed: 3.024798
Iteration: 5 - Time Elapsed: 4.004382
Iteration: 6 - Time Elapsed: 5.009306
Iteration: 7 - Time Elapsed: 6.002341
Iteration: 8 - Time Elapsed: 7.013342
Iteration: 9 - Time Elapsed: 8.004305
Iteration: 10 - Time Elapsed: 9.000212
```

Each iteration executes at a 1-second interval.

Get Statistics From Rate Object Execution

Create a `rateControl` object for running at 20 Hz.

```
r = rateControl(20);
```

Start a loop and control operation using the `rateControl` object.

```
for i = 1:30
    % Your code goes here
    waitfor(r);
end
```

Get `Rate` object statistics after loop operation.

```
stats = statistics(r)
```

```
stats = struct with fields:
              Periods: [0.0558 0.0610 0.0355 0.0551 0.0611 0.0494 0.2308 ... ]
           NumPeriods: 30
        AveragePeriod: 0.0551
    StandardDeviation: 0.0352
          NumOverruns: 1
```

Run Loop At Fixed Rate and Reset Rate Object

Create a `rateControl` object for running at 20 Hz.

```
r = rateControl(2);
```

Start a loop and control operation using the `Rate` object.

```
for i = 1:30
    % Your code goes here
    waitfor(r);
end
```

Display the `rateControl` object properties after loop operation.

```
disp(r)
```

```
  rateControl with properties:

         DesiredRate: 2
       DesiredPeriod: 0.5000
       OverrunAction: 'slip'
    TotalElapsedTime: 15.0135
          LastPeriod: 0.4916
```

Reset the object to restart the time statistics.

```
reset(r);
disp(r)
```

```
  rateControl with properties:

         DesiredRate: 2
       DesiredPeriod: 0.5000
       OverrunAction: 'slip'
    TotalElapsedTime: 0.0040
          LastPeriod: NaN
```

Compatibility Considerations

`rateControl` was renamed

Behavior change in future release

The `rateControl` object was renamed from `robotics.Rate`. Use `rateControl` for all object creation.

See Also

`rosrate` | `waitfor` | `statistics` | `reset`

Topics

"Execute Code at a Fixed-Rate"

Introduced in R2016a

resamplingPolicyPF

Create resampling policy object with resampling settings

Description

The `resamplingPolicyPF` object stores settings for when resampling should occur when using a particle filter for state estimation. The object contains the method that triggers resampling and the relevant threshold for this resampling. Use this object as the `ResamplingPolicy` property of the `stateEstimatorPF` object.

Creation

Syntax

```
policy = resamplingPolicyPF
```

Description

`policy = resamplingPolicyPF` creates a `resamplingPolicyPF` object `policy`, which contains properties to be modified to control when resampling should be triggered. Use this object as the `ResamplingPolicy` property of the `stateEstimatorPF` object.

Properties

`TriggerMethod` — Method for determining if resampling should occur
`'ratio'` (default) | character vector

Method for determining if resampling should occur, specified as a character vector. Possible choices are `'ratio'` and `'interval'`. The `'interval'` method triggers resampling at regular intervals of operating the particle filter. The `'ratio'` method triggers resampling based on the ratio of effective total particles.

`SamplingInterval` — Fixed interval between resampling
1 (default) | scalar

Fixed interval between resampling, specified as a scalar. This interval determines during which correction steps the resampling is executed. For example, a value of 2 means the resampling is executed every second correction step. A value of `inf` means that resampling is never executed.

This property only applies with the `TriggerMethod` is set to `'interval'`.

`MinEffectiveParticleRatio` — Minimum desired ratio of effective to total particles
0.5 (default) | scalar

Minimum desired ratio of effective to total particles, specified as a scalar. The effective number of particles is a measure of how well the current set of particles approximates the posterior distribution. A lower effective particle ratio means less particles are contributing to the estimation and resampling might be required. If the ratio of effective particles to total particles falls below the `MinEffectiveParticleRatio`, a resampling step is triggered.

See Also
`stateEstimatorPF` | `correct`

Topics
"Track a Car-Like Robot Using Particle Filter"

Introduced in R2019b

rigidBody

Create a rigid body

Description

The `rigidBody` object represents a rigid body. A rigid body is the building block for any tree-structured robot manipulator. Each `rigidBody` has a `rigidBodyJoint` object attached to it that defines how the rigid body can move. Rigid bodies are assembled into a tree-structured robot model using `rigidBodyTree`.

Set a joint object to the `Joint` property before calling `addBody` to add the rigid body to the robot model. When a rigid body is in a rigid body tree, you cannot directly modify its properties because it corrupts the relationships between bodies. Use `replaceJoint` to modify the entire tree structure.

Creation

Syntax

```
body = rigidBody(name)
```

Description

`body = rigidBody(name)` creates a rigid body with the specified name. By default, the body comes with a fixed joint.

Input Arguments

`name` — Name of rigid body
string scalar | character vector

Name of the rigid body, specified as a string scalar or character vector. This name must be unique to the body so that it can be accessed in a `rigidBodyTree` object.

Properties

`Name` — Name of rigid body
string scalar | character vector

Name of the rigid body, specified as a string scalar or character vector. This name must be unique to the body so that it can be found in a `rigidBodyTree` object.

Data Types: `char` | `string`

`Joint` — `rigidBodyJoint` object
handle

`rigidBodyJoint` object, specified as a handle. By default, the joint is `'fixed'` type.

`Mass` — Mass of rigid body
1 kg (default) | numeric scalar

Mass of rigid body, specified as a numeric scalar in kilograms.

`CenterOfMass` — Center of mass position of rigid body
`[0 0 0]` m (default) | `[x y z]` vector

Center of mass position of rigid body, specified as an `[x y z]` vector. The vector describes the location of the center of mass relative to the body frame in meters.

`Inertia` — Inertia of rigid body
`[1 1 1 0 0 0]` kg•m^2 (default) | `[Ixx Iyy Izz Iyz Ixz Ixy]` vector

Inertia of rigid body, specified as a `[Ixx Iyy Izz Iyz Ixz Ixy]` vector relative to the body frame in kilogram square meters. The first three elements of the vector are the diagonal elements of the inertia tensor. The last three elements are the off-diagonal elements of the inertia tensor. The inertia tensor is a positive semi-definite symmetric matrix:

$$\begin{pmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{pmatrix}$$

`Parent` — Rigid body parent
`rigidBody` object handle

Rigid body parent, specified as a `rigidBody` object handle. The rigid body joint defines how this body can move relative to the parent. This property is empty until the rigid body is added to a `rigidBodyTree` robot model.

`Children` — Rigid body children
cell array of `rigidBody` object handles

Rigid body children, specified as a cell array of `rigidBody` object handles. These rigid body children are all attached to this rigid body object. This property is empty until the rigid body is added to a `rigidBodyTree` robot model, and at least one other body is added to the tree with this body as its parent.

`Visuals` — Visual geometries
cell array of string scalars | cell array of character vectors

Visual geometries, specified as a cell array of string scalars or character vectors. Each character vector describes a type and source of a visual geometry. For example, if a mesh file, `link_0.stl`, is attached to the rigid body, the visual would be `Mesh:link_0.stl`. Visual geometries are added to the rigid body using `addVisual`.

`Collisions` — Collision geometries
cell array of character vectors

Collision geometries, specified as a cell array of character vectors. Each character vector describes the type of collision object and relevant parameters of the collision geometry. To modify the collision geometries for a rigid body, use the `addCollision` and `clearCollision` functions.

Object Functions

copy	Create a deep copy of rigid body
addCollision	Add collision geometry to rigid body
addVisual	Add visual geometry data to rigid body
clearCollision	Clear all attached collision geometries
clearVisual	Clear all visual geometries

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `rigidBody` object contains a `rigidBodyJoint` object and must be added to the `rigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = rigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = rigidBody('b1');
```

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

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

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

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

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

```
showdetails(rbtree)
```

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

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

Build Manipulator Robot Using Denavit-Hartenberg Parameters

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

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix[1] on page 1-

0 . The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

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

Create a rigid body tree object to build the robot.

```
robot = rigidBodyTree;
```

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

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

```
body1 = rigidBody('body1');
jnt1 = rigidBodyJoint('jnt1','revolute');

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

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

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

```
body2 = rigidBody('body2');
jnt2 = rigidBodyJoint('jnt2','revolute');
body3 = rigidBody('body3');
jnt3 = rigidBodyJoint('jnt3','revolute');
body4 = rigidBody('body4');
jnt4 = rigidBodyJoint('jnt4','revolute');
body5 = rigidBody('body5');
jnt5 = rigidBodyJoint('jnt5','revolute');
body6 = rigidBody('body6');
jnt6 = rigidBodyJoint('jnt6','revolute');

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

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

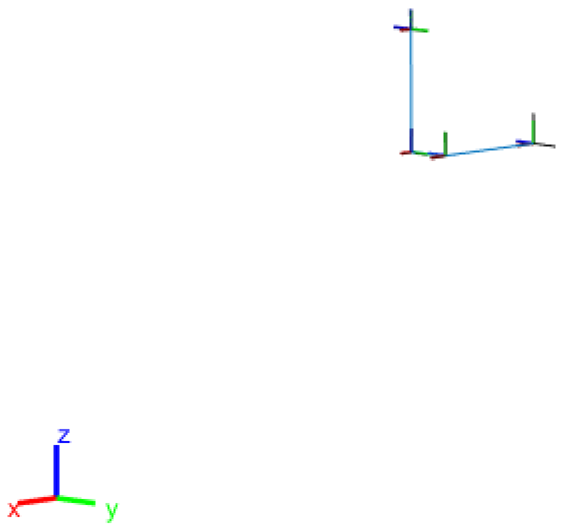
```
addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

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

```
showdetails(robot)
```

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

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1         body1         jnt1     revolute             base(0)   body2(2)
   2         body2         jnt2     revolute            body1(1)   body3(3)
   3         body3         jnt3     revolute            body2(2)   body4(4)
   4         body4         jnt4     revolute            body3(3)   body5(5)
   5         body5         jnt5     revolute            body4(4)   body6(6)
   6         body6         jnt6     revolute            body5(5)
--------------------
```

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



References

[1] Corke, P. I., and B. Armstrong-Helouvry. “A Search for Consensus among Model Parameters Reported for the PUMA 560 Robot.” *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, IEEE Comput. Soc. Press, 1994, pp. 1608–13. *DOI.org (Crossref)*, doi:10.1109/ROBOT.1994.351360.

Compatibility Considerations

`rigidBody` was renamed
Behavior change in future release

The `rigidBody` object was renamed from `robotics.RigidBody`. Use `rigidBody` for all object creation.

References

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

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

Extended Capabilities

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

See Also

`rigidBodyJoint` | `rigidBodyTree` | `addBody` | `replaceJoint` | `addCollision` | `addVisual` | `clearCollision` | `clearVisual`

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

Introduced in R2016b

rigidBodyJoint

Create a joint

Description

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

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

The different joint types supported are:

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

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

Creation

Syntax

```
jointObj = rigidBodyJoint(jname)
jointObj = rigidBodyJoint(jname,jtype)
```

Description

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

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

Input Arguments

`jname` — Joint name
string scalar | character vector

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

Example: `"elbow_right"`

Data Types: `char` | `string`

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

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

The different joint types supported are:

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

Example: `"prismatic"`

Data Types: `char` | `string`

Properties

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

This property is read-only.

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

The different joint types supported are:

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

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

Example: `"prismatic"`

Data Types: `char` | `string`

`Name` — Joint name
string scalar | character vector

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

Example: `"elbow_right"`

Data Types: `char` | `string`

`PositionLimits` — Position limits of joint
vector

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

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

Example: `[-pi/2, pi/2]`

`HomePosition` — Home position of joint
scalar

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

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

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

Example: `pi/2` radians for a `revolute` joint

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

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

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

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

Example: `[1 0 0]` for motion around the *x*-axis for a `revolute` joint

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

This property is read-only.

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

Example: `eye(4)`

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

This property is read-only.

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

Example: eye(4)

Object Functions

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

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `rigidBody` object contains a `rigidBodyJoint` object and must be added to the `rigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = rigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = rigidBody('b1');
```

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

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

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

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

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

```
showdetails(rbtree)
```

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

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

Build Manipulator Robot Using Denavit-Hartenberg Parameters

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

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix[1] on page 1-0 . The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

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

Create a rigid body tree object to build the robot.

```
robot = rigidBodyTree;
```

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

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

```
body1 = rigidBody('body1');
jnt1 = rigidBodyJoint('jnt1','revolute');

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

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

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

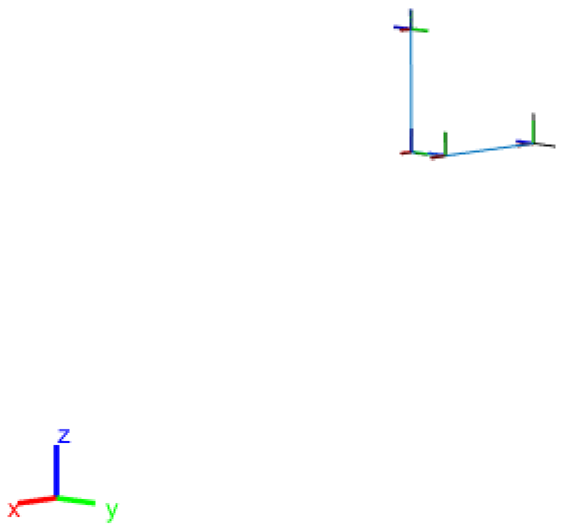
```
body2 = rigidBody('body2');
jnt2 = rigidBodyJoint('jnt2','revolute');
body3 = rigidBody('body3');
jnt3 = rigidBodyJoint('jnt3','revolute');
body4 = rigidBody('body4');
jnt4 = rigidBodyJoint('jnt4','revolute');
body5 = rigidBody('body5');
jnt5 = rigidBodyJoint('jnt5','revolute');
body6 = rigidBody('body6');
jnt6 = rigidBodyJoint('jnt6','revolute');

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

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

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

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

```
showdetails(robot)
```

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

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1         body1         jnt1     revolute             base(0)   body2(2)
   2         body2         jnt2     revolute            body1(1)   body3(3)
   3         body3         jnt3     revolute            body2(2)   body4(4)
   4         body4         jnt4     revolute            body3(3)   body5(5)
   5         body5         jnt5     revolute            body4(4)   body6(6)
   6         body6         jnt6     revolute            body5(5)
--------------------
```

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



References

[1] Corke, P. I., and B. Armstrong-Helouvry. “A Search for Consensus among Model Parameters Reported for the PUMA 560 Robot.” *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, IEEE Comput. Soc. Press, 1994, pp. 1608–13. *DOI.org (Crossref)*, doi:10.1109/ROBOT.1994.351360.

Modify a Robot Rigid Body Tree Model

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

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

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

```
showdetails(puma1)
```

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

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
```

```
   1           L1         jnt1     revolute             base(0)   L2(2)
   2           L2         jnt2     revolute               L1(1)   L3(3)
   3           L3         jnt3     revolute               L2(2)   L4(4)
   4           L4         jnt4     revolute               L3(3)   L5(5)
   5           L5         jnt5     revolute               L4(4)   L6(6)
   6           L6         jnt6     revolute               L5(5)
--------------------
```

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

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

```
childBody = 
  rigidBody with properties:

            Name: 'L4'
           Joint: [1x1 rigidBodyJoint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 rigidBody]
        Children: {[1x1 rigidBody]}
         Visuals: {}
      Collisions: {}
```

```
body3Copy = copy(body3);
```

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

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

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

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

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

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

```
subtree = 
  rigidBodyTree with properties:
     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

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

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

showdetails(puma1)
```

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

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

Compatibility Considerations

`rigidBodyJoint` was renamed
Behavior change in future release

The `rigidBodyJoint` object was renamed from `robotics.Joint`. Use `rigidBodyJoint` for all object creation.

References

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

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

Extended Capabilities

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

See Also

`rigidBody` | `rigidBodyTree`

Topics

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

Introduced in R2016b

rigidBodyTree

Create tree-structured robot

Description

The rigidBodyTree is a representation of the connectivity of rigid bodies with joints. Use this class to build robot manipulator models in MATLAB. If you have a robot model specified using the Unified Robot Description Format (URDF), use importrobot to import your robot model.

A rigid body tree model is made up of rigid bodies as rigidBody objects. Each rigid body has a rigidBodyJoint object associated with it that defines how it can move relative to its parent body. Use setFixedTransform to define the fixed transformation between the frame of a joint and the frame of one of the adjacent bodies. You can add, replace, or remove rigid bodies from the model using the methods of the RigidBodyTree class.

Robot dynamics calculations are also possible. Specify the Mass, CenterOfMass, and Inertia properties for each rigidBody in the robot model. You can calculate forward and inverse dynamics with or without external forces and compute dynamics quantities given robot joint motions and joint inputs. To use the dynamics-related functions, set the DataFormat property to "row" or "column".

For a given rigid body tree model, you can also use the robot model to calculate joint angles for desired end-effector positions using the robotics inverse kinematics algorithms. Specify your rigid body tree model when using inverseKinematics or generalizedInverseKinematics.

The show method supports visualization of body meshes. Meshes are specified as .stl files and can be added to individual rigid bodies using addVisual. Also, by default, the importrobot function loads all the accessible .stl files specified in your URDF robot model.

Creation

Syntax

```
robot = rigidBodyTree
robot = rigidBodyTree("MaxNumBodies",N,"DataFormat",dataFormat)
```

Description

robot = rigidBodyTree creates a tree-structured robot object. Add rigid bodies to it using addBody.

robot = rigidBodyTree("MaxNumBodies",N,"DataFormat",dataFormat) specifies an upper bound on the number of bodies allowed in the robot when generating code. You must also specify the DataFormat property as a name-value pair.

Properties

NumBodies — Number of bodies
integer

This property is read-only.

Number of bodies in the robot model (not including the base), returned as an integer.

`Bodies` — List of rigid bodies
cell array of handles

This property is read-only.

List of rigid bodies in the robot model, returned as a cell array of handles. Use this list to access specific `RigidBody` objects in the model. You can also call `getBody` to get a body by its name.

`BodyNames` — Names of rigid bodies
cell array of string scalars | cell array of character vectors

This property is read-only.

Names of rigid bodies, returned as a cell array of character vectors.

`BaseName` — Name of robot base
`'base'` (default) | string scalar | character vector

Name of robot base, returned as a string scalar or character vector.

`Gravity` — Gravitational acceleration experienced by robot
`[0 0 0]` m/s^2 (default) | `[x y z]` vector

Gravitational acceleration experienced by robot, specified as an `[x y z]` vector in meters per second squared. Each element corresponds to the acceleration of the base robot frame in that direction.

`DataFormat` — Input/output data format for kinematics and dynamics functions
`"struct"` (default) | `"row"` | `"column"`

Input/output data format for kinematics and dynamics functions, specified as `"struct"`, `"row"`, or `"column"`. To use dynamics functions, you must use either `"row"` or `"column"`.

Object Functions

addBody	Add body to robot
addSubtree	Add subtree to robot
centerOfMass	Center of mass position and Jacobian
checkCollision	Check if robot is in collision
copy	Copy robot model
externalForce	Compose external force matrix relative to base
forwardDynamics	Joint accelerations given joint torques and states
geometricJacobian	Geometric Jacobian for robot configuration
gravityTorque	Joint torques that compensate gravity
getBody	Get robot body handle by name
getTransform	Get transform between body frames
homeConfiguration	Get home configuration of robot
inverseDynamics	Required joint torques for given motion
massMatrix	Joint-space mass matrix
randomConfiguration	Generate random configuration of robot
removeBody	Remove body from robot

replaceBody	Replace body on robot
replaceJoint	Replace joint on body
show	Show robot model in figure
showdetails	Show details of robot model
subtree	Create subtree from robot model
velocityProduct	Joint torques that cancel velocity-induced forces
writeAsFunction	Create rigidBodyTree code generating function

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `rigidBody` object contains a `rigidBodyJoint` object and must be added to the `rigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = rigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = rigidBody('b1');
```

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

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

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

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

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

```
showdetails(rbtree)
```

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

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

Build Manipulator Robot Using Denavit-Hartenberg Parameters

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

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix[1] on page 1-

0 . The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

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

Create a rigid body tree object to build the robot.

```
robot = rigidBodyTree;
```

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

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

```
body1 = rigidBody('body1');
jnt1 = rigidBodyJoint('jnt1','revolute');

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

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

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

```
body2 = rigidBody('body2');
jnt2 = rigidBodyJoint('jnt2','revolute');
body3 = rigidBody('body3');
jnt3 = rigidBodyJoint('jnt3','revolute');
body4 = rigidBody('body4');
jnt4 = rigidBodyJoint('jnt4','revolute');
body5 = rigidBody('body5');
jnt5 = rigidBodyJoint('jnt5','revolute');
body6 = rigidBody('body6');
jnt6 = rigidBodyJoint('jnt6','revolute');

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

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

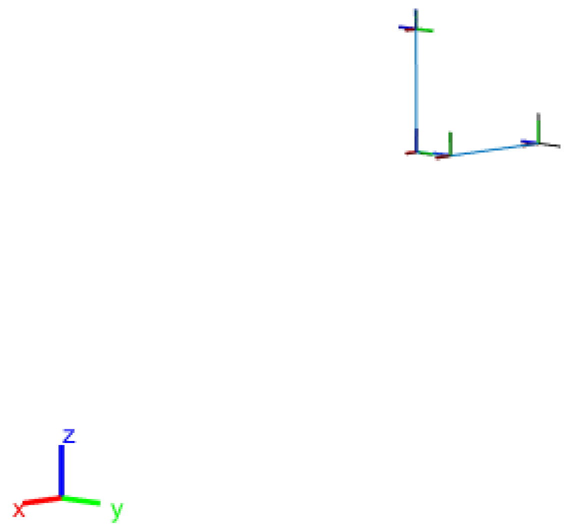
```
addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

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

```
showdetails(robot)
```

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

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1        body1         jnt1     revolute             base(0)   body2(2)
   2        body2         jnt2     revolute            body1(1)   body3(3)
   3        body3         jnt3     revolute            body2(2)   body4(4)
   4        body4         jnt4     revolute            body3(3)   body5(5)
   5        body5         jnt5     revolute            body4(4)   body6(6)
   6        body6         jnt6     revolute            body5(5)
--------------------
```

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



References

[1] Corke, P. I., and B. Armstrong-Helouvry. “A Search for Consensus among Model Parameters Reported for the PUMA 560 Robot.” *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, IEEE Comput. Soc. Press, 1994, pp. 1608–13. *DOI.org (Crossref)*, doi:10.1109/ROBOT.1994.351360.

Modify a Robot Rigid Body Tree Model

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

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

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

```
showdetails(puma1)
```

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

 Idx     Body Name     Joint Name     Joint Type     Parent Name(Idx)    Children Name(s)
 ---     ---------     ----------     ----------     ----------------    ----------------
```

```
   1           L1          jnt1     revolute             base(0)   L2(2)
   2           L2          jnt2     revolute               L1(1)   L3(3)
   3           L3          jnt3     revolute               L2(2)   L4(4)
   4           L4          jnt4     revolute               L3(3)   L5(5)
   5           L5          jnt5     revolute               L4(4)   L6(6)
   6           L6          jnt6     revolute               L5(5)
--------------------
```

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

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

```
childBody = 
  rigidBody with properties:

            Name: 'L4'
           Joint: [1x1 rigidBodyJoint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 rigidBody]
        Children: {[1x1 rigidBody]}
         Visuals: {}
      Collisions: {}
```

```
body3Copy = copy(body3);
```

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

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

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

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

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

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

```
subtree = 
  rigidBodyTree with properties:
     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

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

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

showdetails(puma1)
```

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

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

Specify Dynamics Properties to Rigid Body Tree

To use dynamics functions to calculate joint torques and accelerations, specify the dynamics properties for the `rigidBodyTree` object and `rigidBody`.

Create a rigid body tree model. Create two rigid bodies to attach to it.

```
robot = rigidBodyTree('DataFormat','row');
body1 = rigidBody('body1');
body2 = rigidBody('body2');
```

Specify joints to attach to the bodies. Set the fixed transformation of `body2` to `body1`. This transform is 1m in the *x*-direction.

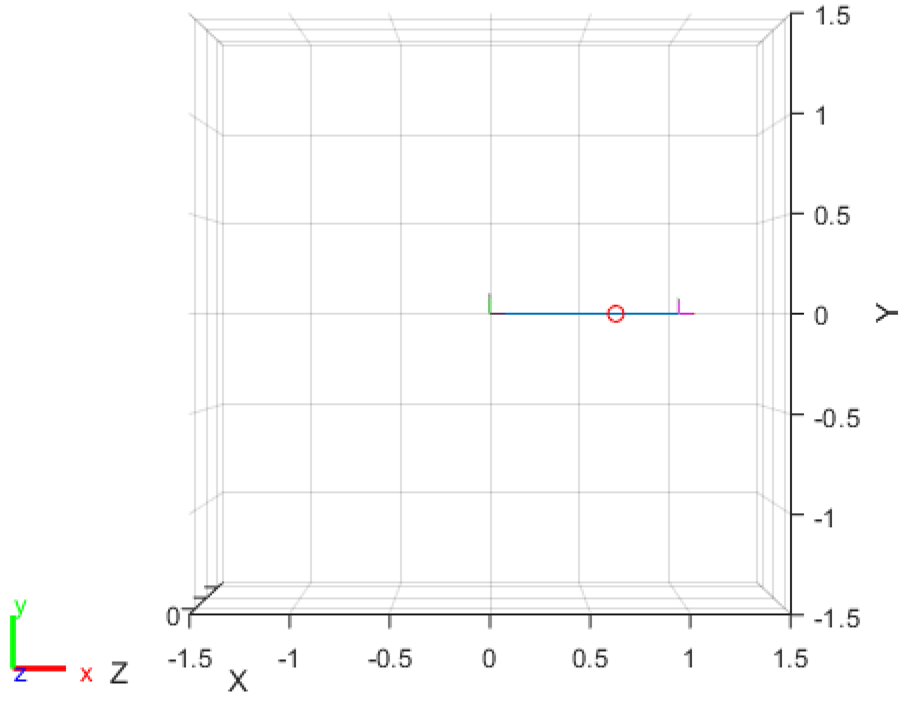
```
joint1 = rigidBodyJoint('joint1','revolute');
joint2 = rigidBodyJoint('joint2');
setFixedTransform(joint2,trvec2tform([1 0 0]))
body1.Joint = joint1;
body2.Joint = joint2;
```

Specify dynamics properties for the two bodies. Add the bodies to the robot model. For this example, basic values for a rod (`body1`) with an attached spherical mass (`body2`) are given.

```
body1.Mass = 2;
body1.CenterOfMass = [0.5 0 0];
body1.Inertia = [0.001 0.67 0.67 0 0 0];

body2.Mass = 1;
body2.CenterOfMass = [0 0 0];
body2.Inertia = 0.0001*[4 4 4 0 0 0];

addBody(robot,body1,'base');
addBody(robot,body2,'body1');
```

Compute the center of mass position of the whole robot. Plot the position on the robot. Move the view to the *xy* plane.

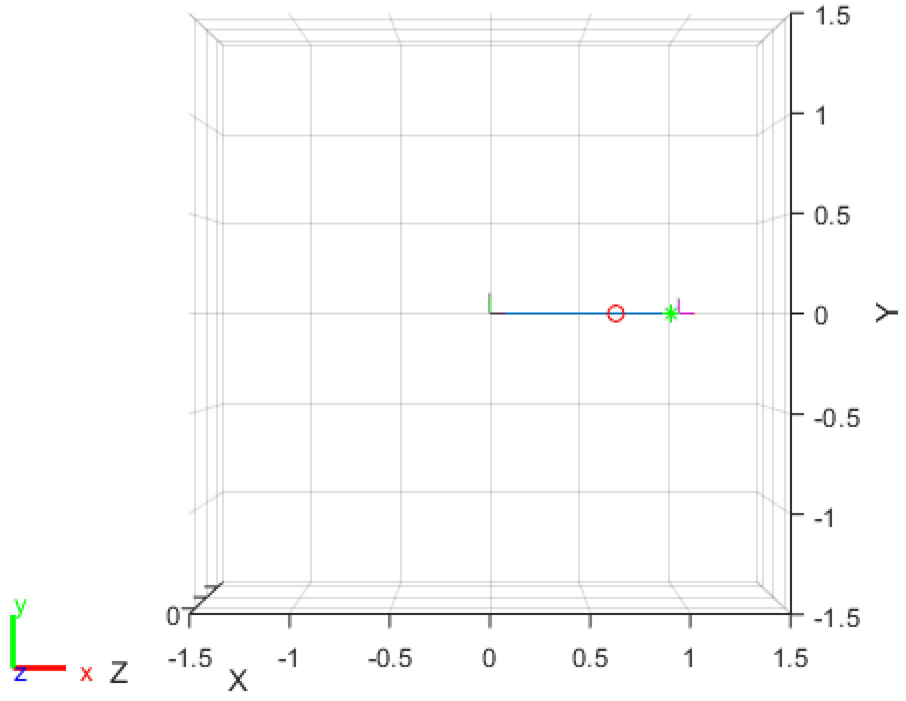
```
comPos = centerOfMass(robot);

show(robot);
hold on
plot(comPos(1),comPos(2),'or')
view(2)
```



Change the mass of the second body. Notice the change in center of mass.

```
body2.Mass = 20;
replaceBody(robot,'body2',body2)

comPos2 = centerOfMass(robot);
```

```
plot(comPos2(1),comPos2(2),'*g')
hold off
```



Compute Forward Dynamics Due to External Forces on Rigid Body Tree Model

Calculate the resultant joint accelerations for a given robot configuration with applied external forces and forces due to gravity. A wrench is applied to a specific body with the gravity being specified for the whole robot.

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

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the gravity. By default, gravity is assumed to be zero.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for the `lbr` robot.

```
q = homeConfiguration(lbr);
```

Specify the wrench vector that represents the external forces experienced by the robot. Use the `externalForce` function to generate the external force matrix. Specify the robot model, the end effector that experiences the wrench, the wrench vector, and the current robot configuration. `wrench` is given relative to the `'tool0'` body frame, which requires you to specify the robot configuration, `q`.

```
wrench = [0 0 0.5 0 0 0.3];
fext = externalForce(lbr,'tool0',wrench,q);
```

Compute the resultant joint accelerations due to gravity, with the external force applied to the end-effector `'tool0'` when `lbr` is at its home configuration. The joint velocities and joint torques are assumed to be zero (input as an empty vector `[]`).

```
qddot = forwardDynamics(lbr,q,[],[],fext);
```

Compute Inverse Dynamics from Static Joint Configuration

Use the `inverseDynamics` function to calculate the required joint torques to statically hold a specific robot configuration. You can also specify the joint velocities, joint accelerations, and external forces using other syntaxes.

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

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Generate a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Compute the required joint torques for `lbr` to statically hold that configuration.

```
tau = inverseDynamics(lbr,q);
```

Compute Joint Torque to Counter External Forces

Use the `externalForce` function to generate force matrices to apply to a rigid body tree model. The force matrix is an *m*-by-6 vector that has a row for each joint on the robot to apply a six-element wrench. Use the `externalForce` function and specify the end effector to properly assign the wrench to the correct row of the matrix. You can add multiple force matrices together to apply multiple forces to one robot.

To calculate the joint torques that counter these external forces, use the `inverseDynamics` function.

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

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for `lbr`.

```
q = homeConfiguration(lbr);
```

Set external force on `link1`. The input wrench vector is expressed in the base frame.

```
fext1 = externalForce(lbr,'link_1',[0 0 0.0 0.1 0 0]);
```

Set external force on the end effector, `tool0`. The input wrench vector is expressed in the `tool0` frame.

```
fext2 = externalForce(lbr,'tool0',[0 0 0.0 0.1 0 0],q);
```

Compute the joint torques required to balance the external forces. To combine the forces, add the force matrices together. Joint velocities and accelerations are assumed to be zero (input as `[]`).

```
tau = inverseDynamics(lbr,q,[],[],fext1+fext2);
```

Display Robot Model with Visual Geometries

You can import robots that have `.stl` files associated with the Unified Robot Description format (URDF) file to describe the visual geometries of the robot. Each rigid body has an individual visual geometry specified. The `importrobot` function parses the URDF file to get the robot model and visual geometries. The function assumes that visual geometry and collision geometry of the robot are the same and assigns the visual geometries as collision geometries of corresponsing bodies.

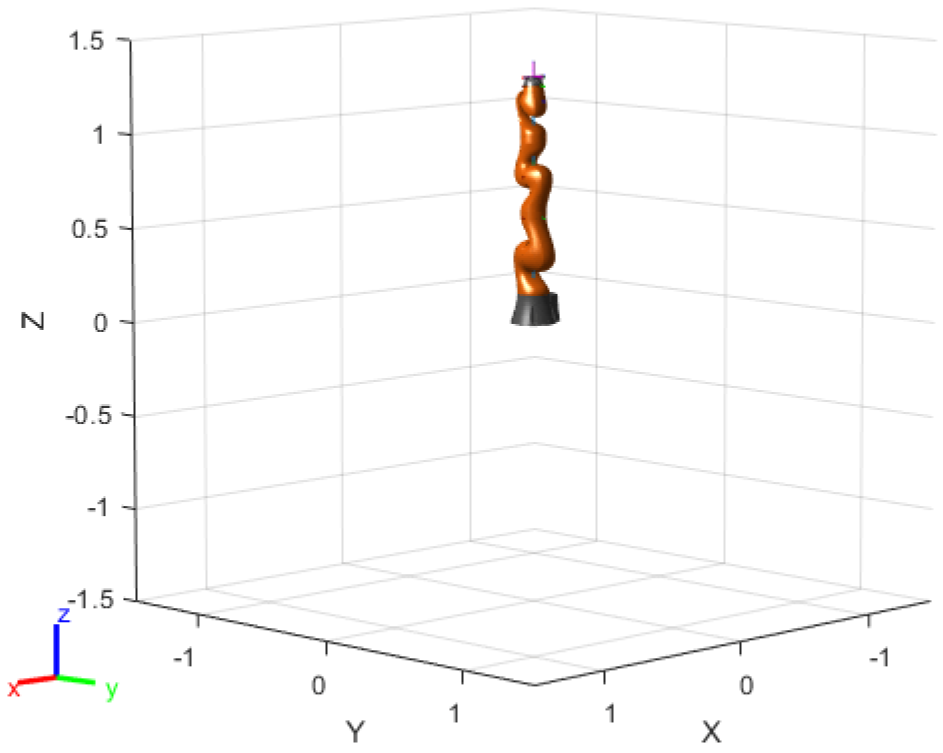
Use the `show` function to display the visual and collosion geometries of the robot model in a figure. You can then interact with the model by clicking components to inspect them and right-clicking to toggle visibility.

Import a robot model as a URDF file. The `.stl` file locations must be properly specified in this URDF. To add other `.stl` files to individual rigid bodies, see `addVisual`.

```
robot = importrobot('iiwa14.urdf');
```

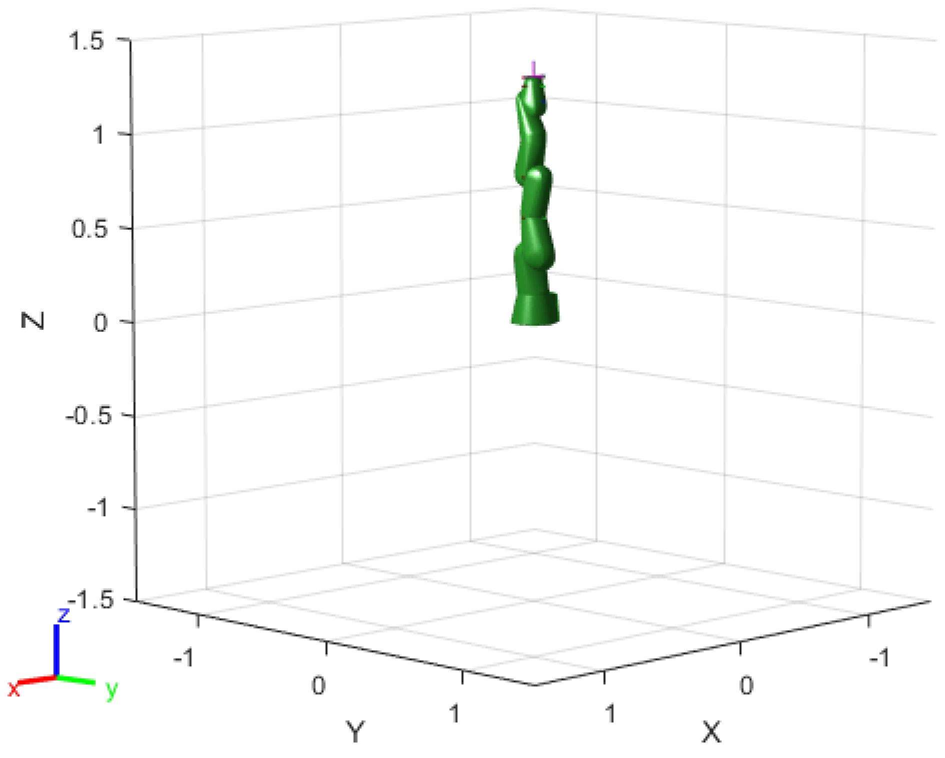
Visualize the robot with the associated visual model. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each visual geometry.

```
show(robot,'visuals','on','collision','off');
```



Visualize the robot with the associated collision geometries. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each collision geometry.

```
show(robot,'visuals','off','collision','on');
```



Compatibility Considerations

`rigidBodyTree` was renamed
Behavior change in future release

The `rigidBodyTree` object was renamed from `robotics.RigidBodyTree`. Use `rigidBodyTree` for all object creation.

References

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

[2] Siciliano, Bruno, Lorenzo Sciavicco, Luigi Villani, and Giuseppe Oriolo. *Robotics: Modelling, Planning and Control*. London: Springer, 2009.

Extended Capabilities

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

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`importrobot` | `inverseKinematics` | `generalizedInverseKinematics` | `rigidBodyJoint` | `rigidBody`

Topics

"Build a Robot Step by Step"
"Solve Inverse Kinematics for a Four-Bar Linkage"
"Rigid Body Tree Robot Model"
"Robot Dynamics"

Introduced in R2016b

rigidBodyTreeImportInfo

Object for storing `rigidBodyTree` import information

Description

The `rigidBodyTreeImportInfo` object is created by the `importrobot` function when converting a Simulink® model using Simscape Multibody components. Get import information for specific bodies, joints, or blocks using the object functions. Changes to the Simulink model are not reflected in this object after initially calling `importrobot`.

Creation

`[robot,importInfo] = importrobot(model)` imports a Simscape Multibody model and returns an equivalent `rigidBodyTree` object, `robot`, and info about the import in `importInfo`. Only fixed, prismatic, and revolute joints are supported in the output `rigidBodyTree` object.

If you are importing a model that uses other joint types, constraint blocks, or variable inertias, use the "Simscape Multibody Model Import" on page 2-0 name-value pairs to disable errors.

Properties

`SourceModelName` — Name of source model from Simscape Multibody
character vector

This property is read-only.

Name of the source model from Simscape Multibody, specified as a character vector. This property matches the name of the input `model` when calling `importrobot`.

Example: `'sm_import_humanoid_urdf'`

Data Types: `char`

`RigidBodyTree` — Robot model
`rigidBodyTree` object

This property is read-only.

Robot model, returned as a `rigidBodyTree` object.

`BlockConversionInfo` — List of blocks that were converted
structure

This property is read-only.

List of blocks that were converted from Simscape Multibody blocks to preserve compatibility, specified as a structure with the nested fields:

- `AddedBlocks`

  - `ImplicitJoints` — Cell array of implicit joints added during the conversion process.
- `ConvertedBlocks`
  - `Joints` — Cell array of joint blocks that were converted to fixed joints.
  - `JointSourceType` — `containers.Map` object that associates converted joint blocks to their original joint type.
- `RemovedBlocks`
  - `ChainClosureJoints`— Cell array of joint blocks removed to open closed chains.
  - `SMConstraints` — Cell array of constraint blocks that were removed.
  - `VariableInertias` — Cell array of variable inertia blocks that were removed.

Object Functions

bodyInfo	Import information for body
bodyInfoFromBlock	Import information for block name
bodyInfoFromJoint	Import information for given joint name
showdetails	Display details of imported robot

Compatibility Considerations

`rigidBodyTreeImportInfo` was renamed
Behavior change in future release

The `rigidBodyTreeImportInfo` object was renamed from `robotics.RigidBodyTreeImportInfo`. Use `rigidBodyTreeImportInfo` for all object creation.

See Also

`importrobot` | `rigidBodyTree`

Topics
"Rigid Body Tree Robot Model"

Introduced in R2018b

stateEstimatorPF

Create particle filter state estimator

Description

The `stateEstimatorPF` object is a recursive, Bayesian state estimator that uses discrete particles to approximate the posterior distribution of the estimated state.

The particle filter algorithm computes the state estimate recursively and involves two steps: prediction and correction. The prediction step uses the previous state to predict the current state based on a given system model. The correction step uses the current sensor measurement to correct the state estimate. The algorithm periodically redistributes, or resamples, the particles in the state space to match the posterior distribution of the estimated state.

The estimated state consists of state variables. Each particle represents a discrete state hypothesis of these state variables. The set of all particles is used to help determine the final state estimate.

You can apply the particle filter to arbitrary nonlinear system models. Process and measurement noise can follow arbitrary non-Gaussian distributions.

For more information on the particle filter workflow and setting specific parameters, see:

- “Particle Filter Workflow”
- “Particle Filter Parameters”

Creation

Syntax

`pf = stateEstimatorPF`

Description

`pf = stateEstimatorPF` creates an object that enables the state estimation for a simple system with three state variables. Use the `initialize` method to initialize the particles with a known mean and covariance or uniformly distributed particles within defined bounds. To customize the particle filter’s system and measurement models, modify the `StateTransitionFcn` and `MeasurementLikelihoodFcn` properties.

After you create the object, use `initialize` to initialize the `NumStateVariables` and `NumParticles` properties. The `initialize` function sets these two properties based on your inputs.

Properties

`NumStateVariables` — Number of state variables
3 (default) | scalar

This property is read-only.

Number of state variables, specified as a scalar. This property is set based on the inputs to the `initialize` method. The number of states is implicit based on the specified matrices for initial state and covariance.

`NumParticles` — Number of particles used in the filter
1000 (default) | scalar

This property is read-only.

Number of particles using in the filter, specified as a scalar. You can specify this property only by calling the `initialize` method.

`StateTransitionFcn` — Callback function for determining the state transition between particle filter steps
function handle

Callback function for determining the state transition between particle filter steps, specified as a function handle. The state transition function evolves the system state for each particle. The function signature is:

```
function predictParticles = stateTransitionFcn(pf,prevParticles,varargin)
```

The callback function accepts at least two input arguments: the `stateEstimatorPF` object, `pf`, and the particles at the previous time step, `prevParticles`. These specified particles are the `predictParticles` returned from the previous call of the object. `predictParticles` and `prevParticles` are the same size: `NumParticles`-by-`NumStateVariables`.

You can also use `varargin` to pass in a variable number of arguments from the `predict` function. When you call:

```
predict(pf,arg1,arg2)
```

MATLAB essentially calls `stateTranstionFcn` as:

```
stateTransitionFcn(pf,prevParticles,arg1,arg2)
```

`MeasurementLikelihoodFcn` — Callback function calculating the likelihood of sensor measurements
function handle

Callback function calculating the likelihood of sensor measurements, specified as a function handle. Once a sensor measurement is available, this callback function calculates the likelihood that the measurement is consistent with the state hypothesis of each particle. You must implement this function based on your measurement model. The function signature is:

```
function likelihood = measurementLikelihoodFcn(PF,predictParticles,measurement,varargin)
```

The callback function accepts at least three input arguments:

1. `pf` – The associated `stateEstimatorPF` object
2. `predictParticles` – The particles that represent the predicted system state at the current time step as an array of size `NumParticles`-by-`NumStateVariables`
3. `measurement` – The state measurement at the current time step

You can also use `varargin` to pass in a variable number of arguments. These arguments are passed by the `correct` function. When you call:

```
correct(pf,measurement,arg1,arg2)
```

MATLAB essentially calls `measurementLikelihoodFcn` as:

```
measurementLikelihoodFcn(pf,predictParticles,measurement,arg1,arg2)
```

The callback needs to return exactly one output, `likelihood`, which is the likelihood of the given `measurement` for each particle state hypothesis.

`IsStateVariableCircular` — Indicator if state variables have a circular distribution
[0 0 0] (default) | logical array

Indicator if state variables have a circular distribution, specified as a logical array. Circular (or angular) distributions use a probability density function with a range of `[-pi,pi]`. If the object has multiple state variables, then `IsStateVariableCircular` is a row vector. Each vector element indicates if the associated state variable is circular. If the object has only one state variable, then `IsStateVariableCircular` is a scalar.

`ResamplingPolicy` — Policy settings that determine when to trigger resampling
object

Policy settings that determine when to trigger resampling, specified as an object. You can trigger resampling either at fixed intervals, or you can trigger it dynamically, based on the number of effective particles. See `resamplingPolicyPF` for more information.

`ResamplingMethod` — Method used for particle resampling
`'multinomial'` (default) | `'residual'` | `'stratified'` | `'systematic'`

Method used for particle resampling, specified as `'multinomial'`, `'residual'`, `'stratified'`, and `'systematic'`.

`StateEstimationMethod` — Method used for state estimation
`'mean'` (default) | `'maxweight'`

Method used for state estimation, specified as `'mean'` and `'maxweight'`.

`Particles` — Array of particle values
`NumParticles`-by-`NumStateVariables` matrix

Array of particle values, specified as a `NumParticles`-by-`NumStateVariables` matrix. Each row corresponds to the state hypothesis of a single particle.

`Weights` — Particle weights
`NumParticles`-by-1 vector

Particle weights, specified as a `NumParticles`-by-1 vector. Each weight is associated with the particle in the same row in the `Particles` property.

`State` — Best state estimate
vector

This property is read-only.

Best state estimate, returned as a vector with length `NumStateVariables`. The estimate is extracted based on the `StateEstimationMethod` property.

`State Covariance` — Corrected system covariance
N-by-*N* matrix | `[]`

This property is read-only.

Corrected system variance, returned as an *N*-by-*N* matrix, where *N* is equal to the `NumStateVariables` property. The corrected state is calculated based on the `StateEstimationMethod` property and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the property is set to `[]`.

Object Functions

initialize	Initialize the state of the particle filter
getStateEstimate	Extract best state estimate and covariance from particles
predict	Predict state of robot in next time step
correct	Adjust state estimate based on sensor measurement

Examples

Particle Filter Prediction and Correction

Create a `stateEstimatorPF` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = stateEstimatorPF
```

```
pf = 
  stateEstimatorPF with properties:

           NumStateVariables: 3
                NumParticles: 1000
          StateTransitionFcn: @nav.algs.gaussianMotion
    MeasurementLikelihoodFcn: @nav.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
            ResamplingPolicy: [1x1 resamplingPolicyPF]
            ResamplingMethod: 'multinomial'
       StateEstimationMethod: 'mean'
            StateOrientation: 'row'
                   Particles: [1000x3 double]
                     Weights: [1000x1 double]
                       State: 'Use the getStateEstimate function to see the value.'
             StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

```
stateEst = getStateEstimate(pf)
```

```
stateEst = 1×3

    4.1562    0.9185    9.0202
```

Estimate Robot Position in a Loop Using Particle Filter

Use the `stateEstimatorPF` object to track a robot as it moves in a 2-D space. The measured position has random noise added. Using `predict` and `correct`, track the robot based on the measurement and on an assumed motion model.

Initialize the particle filter and specify the default state transition function, the measurement likelihood function, and the resampling policy.

```
pf = stateEstimatorPF;
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Sample 1000 particles with an initial position of [0 0] and unit covariance.

```
initialize(pf,1000,[0 0],eye(2));
```

Prior to estimation, define a sine wave path for the dot to follow. Create an array to store the predicted and estimated position. Define the amplitude of noise.

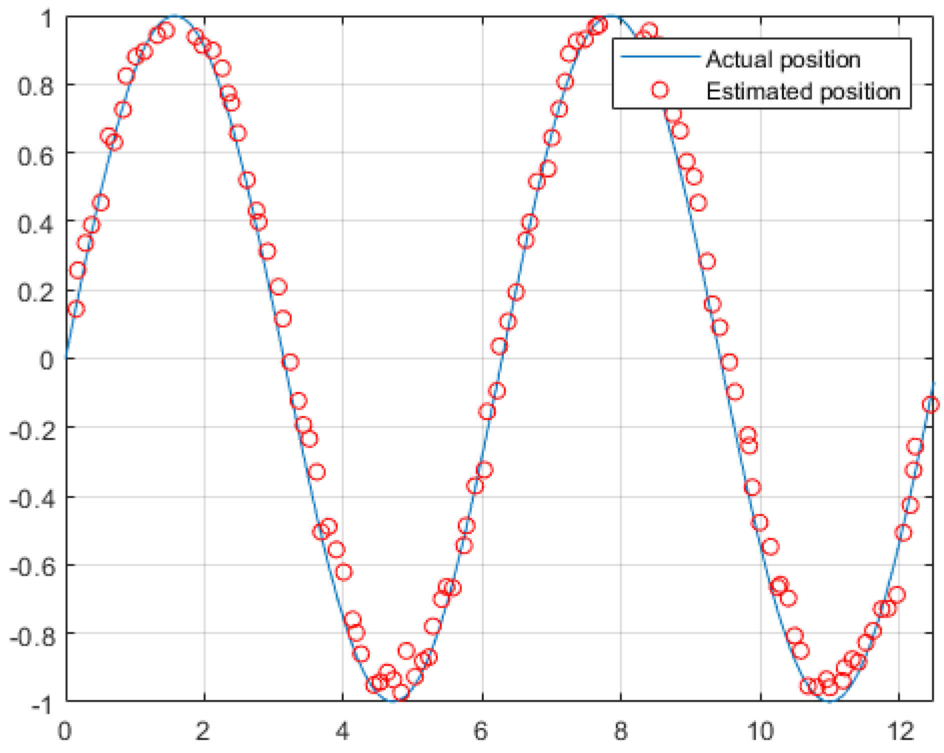
```
t = 0:0.1:4*pi;
dot = [t; sin(t)]';
robotPred = zeros(length(t),2);
robotCorrected = zeros(length(t),2);
noise = 0.1;
```

Begin the loop for predicting and correcting the estimated position based on measurements. The resampling of particles occurs based on the`ResamplingPolicy` property. The robot moves based on a sine wave function with random noise added to the measurement.

```
for i = 1:length(t)
    % Predict next position. Resample particles if necessary.
    [robotPred(i,:),robotCov] = predict(pf);
    % Generate dot measurement with random noise. This is
    % equivalent to the observation step.
    measurement(i,:) = dot(i,:) + noise*(rand([1 2])-noise/2);
    % Correct position based on the given measurement to get best estimation.
    % Actual dot position is not used. Store corrected position in data array.
    [robotCorrected(i,:),robotCov] = correct(pf,measurement(i,:));
end
```

Plot the actual path versus the estimated position. Actual results may vary due to the randomness of particle distributions.

```
plot(dot(:,1),dot(:,2),robotCorrected(:,1),robotCorrected(:,2),'or')
xlim([0 t(end)])
ylim([-1 1])
legend('Actual position','Estimated position')
grid on
```



The figure shows how close the estimate state matches the actual position of the robot. Try tuning the number of particles or specifying a different initial position and covariance to see how it affects tracking over time.

Compatibility Considerations

`stateEstimatorPF` was renamed

Behavior change in future release

The `stateEstimatorPF` object was renamed from `robotics.ParticleFilter`. Use `stateEstimatorPF` for all object creation.

References

[1] Arulampalam, M.S., S. Maskell, N. Gordon, and T. Clapp. "A Tutorial on Particle Filters for Online Nonlinear/Non-Gaussian Bayesian Tracking." *IEEE Transactions on Signal Processing.* Vol. 50, No. 2, Feb 2002, pp. 174-188.

[2] Chen, Z. "Bayesian Filtering: From Kalman Filters to Particle Filters, and Beyond." *Statistics*. Vol. 182, No. 1, 2003, pp. 1-69.

Extended Capabilities

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

See Also

`resamplingPolicyPF` | `initialize` | `getStateEstimate` | `predict` | `correct`

Topics
“Track a Car-Like Robot Using Particle Filter”
“Particle Filter Parameters”
“Particle Filter Workflow”

Introduced in R2016a

taskSpaceMotionModel

Model rigid body tree motion given task-space reference inputs

Description

The `taskSpaceMotionModel` object models the closed-loop task-space motion of a manipulator, specified as a rigid body tree object. The motion model behavior is defined by the MotionType property.

For more details about the equations of motion, see "Task-Space Motion Model".

Creation

Syntax

`motionModel = taskSpaceMotionModel`

`motionModel = taskSpaceMotionModel("RigidBodyTree",tree)`

`motionModel = taskSpaceMotionControlModel(Name,Value)`

Description

`motionModel = taskSpaceMotionModel` creates a motion model for a default two-joint manipulator.

`motionModel = taskSpaceMotionModel("RigidBodyTree",tree)` creates a motion model for the specified `rigidBodyTree` object.

`motionModel = taskSpaceMotionControlModel(Name,Value)` sets additional properties specified as name-value pairs. You can specify multiple properties in any order.

Properties

`RigidBodyTree` — Rigid body tree robot model
`rigidBodyTree` object

Rigid body tree robot model, specified as a `rigidBodyTree` object that defines the inertial and kinematic properties of the manipulator.

`EndEffectorName` — End effector body
`'tool'` (default) | string scalar | character vector

This property defines the body that will be used as the end effector, and for which the task space motion is defined. The property must correspond to a body name in the `rigidBodyTree` object of the RigidBodyTree property. If the rigid body tree is updated without also updating the end effector, the body with the highest index becomes the end-effector body by default.

Kp — Proportional gain for PD Control
`500*eye(6)` (default) | 6-by-6 matrix

Proportional gain for PD control, specified as a 6-by-6 matrix.

Kd — Derivative gain for PD control
`100*eye(6)` (default) | 6-by-6 matrix

Derivative gain for proportional-derivative (PD) control, specified as a 6-by-6 matrix.

`JointDamping` — Joint damping constant
`ones(1,n)` (default) | *n*-element vector

Joint damping constant, specified as an *n*-element vector, where *n* is the number of non-fixed joints in the robot model specified by the Rigid Body Tree property. Joint damping units are N/(m/s) or N/(rad/s) for prismatic and revolute joints, respectively.

`MotionType` — Type of motion computed by the motion model
`"PDControl"` (default)

Type of motion, specified as `"PDControl"`, which uses proportional-derivative (PD) control mapped to the joints via a Jacobian-Transpose controller. The control is based on the specified Kp and Kd properties.

Object Functions

derivative	Time derivative of manipulator model states
updateErrorDynamicsFromStep	Update values of NaturalFrequency and DampingRatio properties given desired step response

Examples

Create Task-Space Motion Model

This example shows how to create and use a `taskSpaceMotionModel` object for a manipulator robot arm in task-space.

Create the Robot

```
robot = loadrobot("kinovaGen3","DataFormat","column","Gravity",[0 0 -9.81]);
```

Set Up the Simulation

Set the time span to be 1 second with a timestep size of 0.02 seconds. Set the initial state to the home configuration of the robot, with a velocity of zero.

```
tspan = 0:0.02:1;
initialState = [homeConfiguration(robot);zeros(7,1)];
```

Define a reference state with a target position and zero velocity.

```
refPose = trvec2tform([0.6 -.1 0.5]);
refVel = zeros(6,1);
```

Create the Motion Model

Model the behavior as a system under proportional-derivative (PD) control.

```
motionModel = taskSpaceMotionModel("RigidBodyTree",robot,"EndEffectorName","EndEffector_Link");
```

Simulate the Robot

Simulate the behavior over 1 second using a stiff solver to more efficiently capture the robot dynamics. Using `ode15s` enables higher precision around the areas with a high rate of change.

```
[t,robotState] = ode15s(@(t,state)derivative(motionModel,state,refPose,refVel),tspan,initialState
```

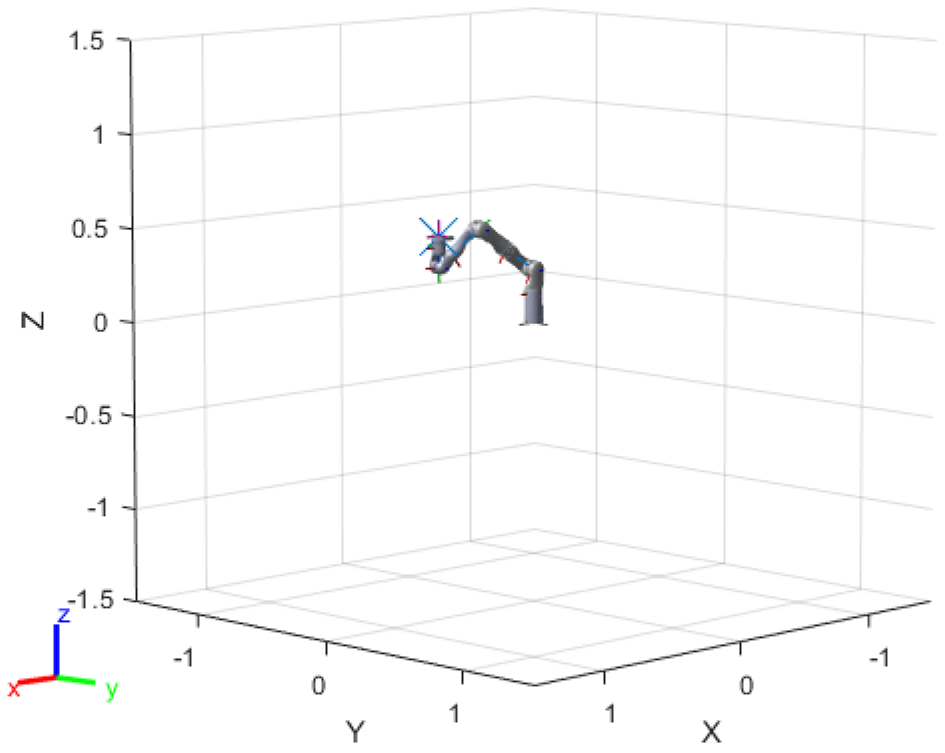
Plot the Response

Plot the robot's initial position and mark the target with an X.

```
figure
show(robot,initialState(1:7));
hold all
plot3(refPose(1,4),refPose(2,4),refPose(3,4),"x","MarkerSize",20)
```

Observe the response by plotting the robot in a 5 Hz loop.

```
r = rateControl(5);
for i = 1:size(robotState,1)
    show(robot,robotState(i,1:7)',"PreservePlot",false);
    waitfor(r);
end
```



References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control*. Upper Saddle River, NJ: Pearson Education, 2005.

[2] Spong, Mark W., Seth Hutchinson, and Mathukumalli Vidyasagar. *Robot Modeling and Control*. Hoboken, NJ: Wiley, 2006.

Extended Capabilities

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

See Also

Classes
`jointSpaceMotionModel`

Blocks
Task Space Motion Model

Functions
`derivative`

Topics
"Plan and Execute Task- and Joint-Space Trajectories Using KINOVA Gen3 Manipulator"

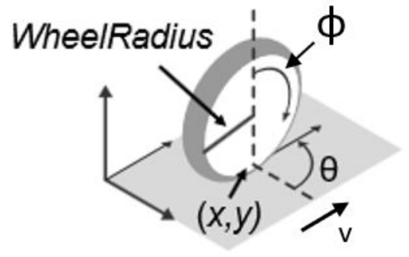
Introduced in R2019b

unicycleKinematics

Unicycle vehicle model

Description

`unicycleKinematics` creates a unicycle vehicle model to simulate simplified car-like vehicle dynamics. The state of the vehicle is defined as a three-element vector, *[x y theta]*, with a global *xy*-position, specified in meters, and a vehicle heading angle, *theta*, specified in radians. This model approximates a unicycle vehicle with a given wheel radius, WheelRadius, that can spin in place according to a heading angle, *theta*. To compute the time derivative states for the model, use the `derivative` function with input commands and the current robot state.



Creation

Syntax

`kinematicModel = unicycleKinematics`

`kinematicModel = unicycleKinematics(Name,Value)`

Description

`kinematicModel = unicycleKinematics` creates a unicycle kinematic model object with default property values.

`kinematicModel = unicycleKinematics(Name,Value)` sets additional properties to the specified values. You can specify multiple properties in any order.

Properties

`WheelRadius` — Wheel radius of vehicle
`0.1` (default) | positive numeric scalar

The wheel radius of the vehicle, specified in meters.

`WheelSpeedRange` — Range of vehicle wheel speeds
`[-Inf Inf]` (default) | two-element vector

The vehicle speed range is a two-element vector that provides the minimum and maximum vehicle speeds, [*MinSpeed MaxSpeed*], specified in meters per second.

`VehicleInputs` — Type of motion inputs for vehicle
`"WheelSpeedHeadingRate"` (default) | character vector | string scalar

The `VehicleInputs` property specifies the format of the model input commands when using the `derivative` function. Options are specified as one of the following strings:

- `"WheelSpeedHeadingRate"` — Wheel speed and heading angular velocity, specified in radians per second.
- `"VehicleSpeedHeadingRate"` — Vehicle speed and heading angular velocity, specified in radians per second.

Object Functions

derivative	Time derivative of vehicle state

Examples

Plot Path of Unicycle Kinematic Robot

Create a Robot

Define a robot and set the initial starting position and orientation.

```
kinematicModel = unicycleKinematics;
initialState = [0 0 0];
```

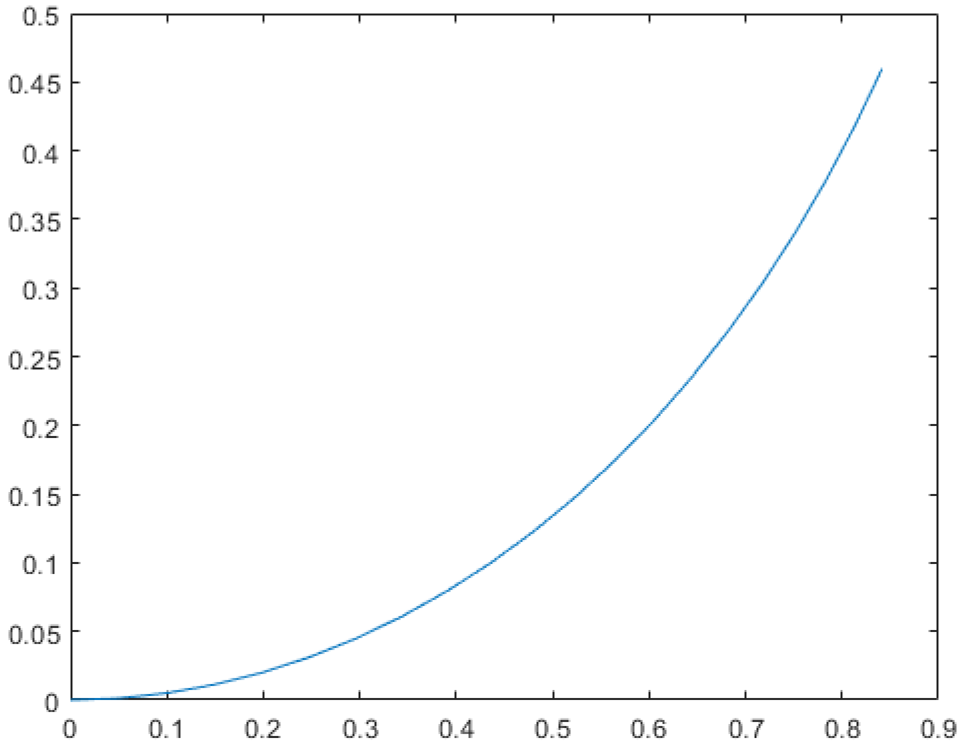
Simulate Robot Motion

Set the timespan of the simulation to 1 s with 0.05 s timesteps and the input commands to 10 m/s and left turn. Simulate the motion of the robot by using the `ode45` solver on the `derivative` function.

```
tspan = 0:0.05:1;
inputs = [10 1]; %Constant speed and turning left
[t,y] = ode45(@(t,y)derivative(kinematicModel,y,inputs),tspan,initialState);
```

Plot path

```
figure
plot(y(:,1),y(:,2))
```



References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control* 1st ed. Cambridge, MA: Cambridge University Press, 2017.

Extended Capabilities

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

See Also

Classes
`bicycleKinematics` | `ackermannKinematics` | `differentialDriveKinematics`

Blocks
Unicycle Kinematic Model

Functions
`derivative`

Topics
“Simulate Different Kinematic Models for Mobile Robots”
“Mobile Robot Kinematics Equations”

Introduced in R2019b

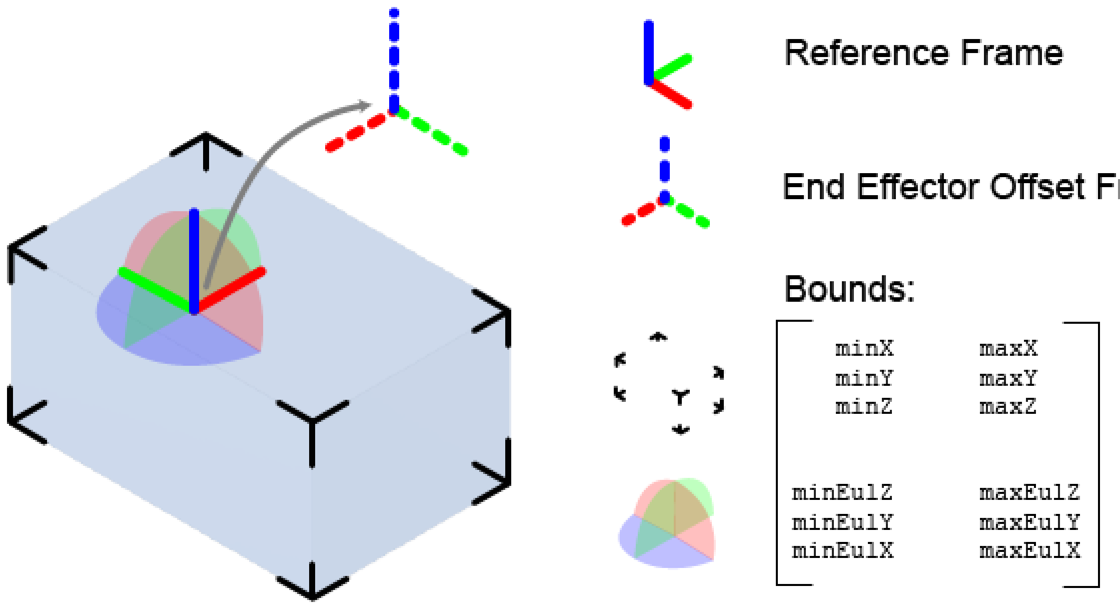
workspaceGoalRegion

Define workspace region of end-effector goal poses

Description

The `workspaceGoalRegion` object defines a region for valid end-effector goal poses. To sample poses within the bounds of the goal region, use the `sample` object function. You can also visualize the bounds you define using the `show` object function.

The object is typically used with rapidly exploring random tree (RRT) planners like the `manipulatorRRT` object. The `sample` generates alternative goal states to increase the likelihood of finding valid paths.



The key elements of the goal region are defined as object properties:

- ReferencePose — Pose of the reference frame in the world frame. The bounds and offset pose are relative to this frame.
- EndEffectorOffsetPose — Offset pose applied to any pose sampled in the reference frame. Use this offset if the end effector needs to be positioned differently based on grasping or other geometric restrictions.
- Bounds — Bounds of the region as a 6-by-2 matrix with the minimum and maximum values for the *XYZ*-position and *ZYX* Euler angle orientation, in respective column vectors.

Creation

Syntax

```
goalRegion = workspaceGoalRegion(EndEffectorName)
goalRegion = workspaceGoalRegion(EndEffectorName,Name,Value)
```

Description

`goalRegion = workspaceGoalRegion(EndEffectorName)` creates a default workspace goal region object for the specified end-effector name. Sets the `EndEffectorName` property.

`goalRegion = workspaceGoalRegion(EndEffectorName,Name,Value)` sets additional properties on page 1-249 on the object using name-value pairs. For example, `workSpaceGoalRegion("endEffector","Bounds",limits)` creates a workspace goal region with the Bounds property specified as a matrix.

Properties

`EndEffectorName` — Name of end effector
string scalar

Name of the end effector, specified as a string scalar.

Example: `"eeTool"`

Data Types: `string`

`ReferencePose` — Pose of reference frame
`eye(4)` (default) | 4-by-4 homogeneous transform

Pose of the reference frame, specified as a 4-by-4 homogeneous transformation matrix. The `Bounds` property defines the limits of the goal region relative to this reference frame.

Example: `trvect2tform([1 2 3])`

Data Types: `double`

`EndEffectorOffsetPose` — End-effector offset pose applied to poses sampled in reference frame
`eye(4)` (default) | 4-by-4 homogeneous transform

End-effector offset pose applied to poses sampled in the reference frame, specified as a 4-by-4 homogeneous transformation matrix. This offset is applied to all poses sampled. Use this offset if the end effector needs to be positioned differently based on grasping or other geometric restrictions.

Example: `trvect2tform([0.5 1 0])`

Example: `eul2tform([pi/2 0 -pi/4])`

Data Types: `double`

`Bounds` — Position and orientation bounds
`zeros(6,2)` (default) | 6-by-2 matrix

Position and orientation bounds on pose samples, specified as a 6-by-2 matrix with the minimum and maximum values in column vectors.

```
wgr.Bounds = [ minX  maxX;
               minY  maxY;
               minZ  maxZ;
               minEulZ  maxEulZ;
               minEulY  maxEulY;
               minEulX  maxEulX ];
```

The first three rows are the *XYZ*-position bounds. The last three rows are the orientation bounds, which are specified as intrinsic *ZYX* Euler angles. Orientation is based on the right-hand rule, with counterclockwise rotations about the respective axes being positive and measured in radians. During sampling, a pose is uniformly sampled within each of these bounds to obtain a sample pose in the reference frame.

Data Types: `double`

Object Functions

sample	Sample end-effector poses in world frame
show	Visualize workspace bounds, reference frame, and offset frame

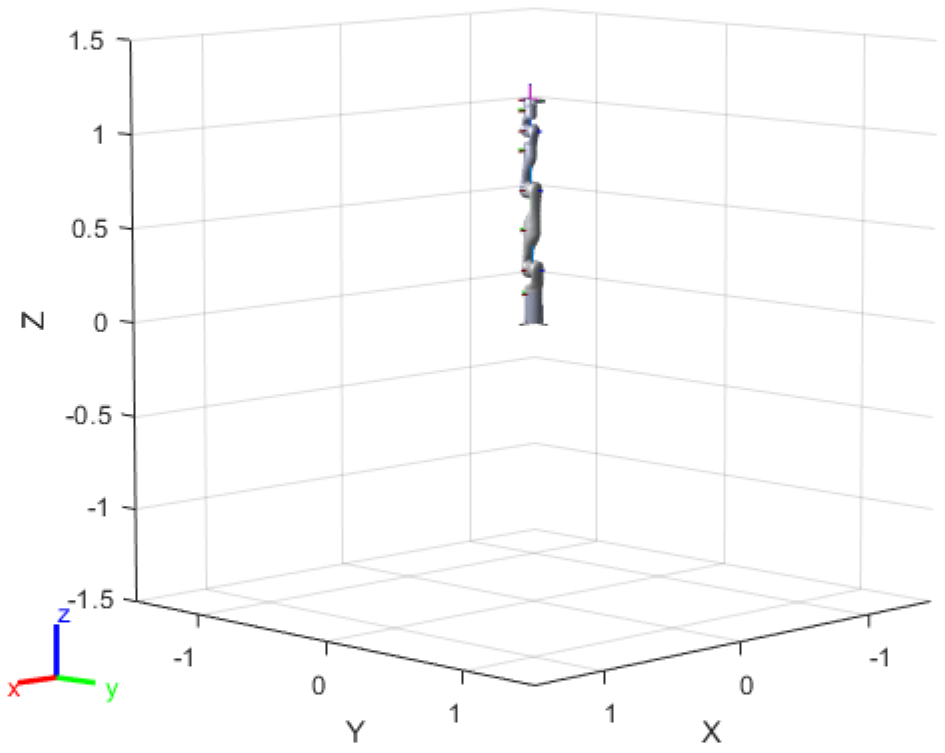
Examples

Plan Path To A Workspace Goal Region

Specify a goal region in your workspace and plan a path within those bounds. The `workspaceGoalRegion` object defines the bounds on the XYZ-position and ZYX Euler orientation of the robot end effector. The `manipulatorRRT` object plans a path based on that goal region and samples random poses within the bounds.

Load an existing robot model as a `rigidBodyTree` object.

```
robot = loadrobot("kinovaGen3", "DataFormat", "row");
ax = show(robot);
```



Create Path Planner

Create a rapidly-exploring random tree (RRT) path planner for the robot. This example uses an empty environment, but this workflow also works well with cluttered environments. You can add collision objects to the environment like the `collisionBox` or `collisionMesh` object.

```
planner = manipulatorRRT(robot,{});
```

Define Goal Region

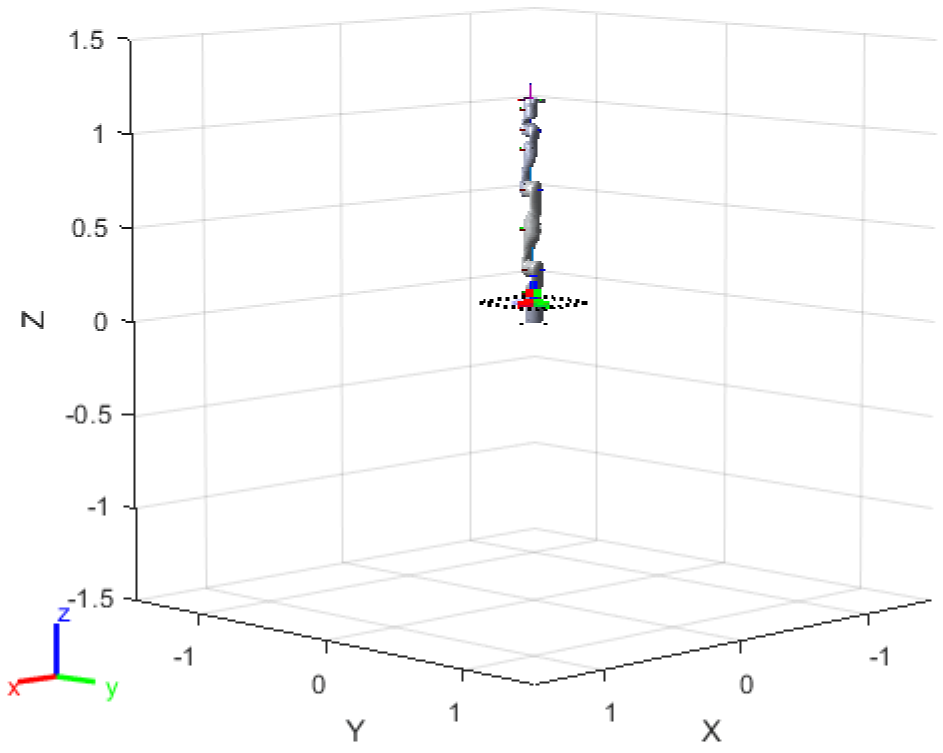
Create a workspace goal region using the end-effector body name of the robot.

Define the goal region parameters for your workspace. The goal region includes a reference pose, XYZ-position bounds, and orientation limits on the ZYX Euler angles. This example specifies bounds on the XY-plane in meters and allows rotation about the Z-axis in radians.

```
goalRegion = workspaceGoalRegion(robot.BodyNames{end});
goalRegion.ReferencePose = trvec2tform([0.5 0.5 0.2]);
goalRegion.Bounds(1, :) = [-0.2 0.2];    % X Bounds
goalRegion.Bounds(2, :) = [-0.2 0.2];    % Y Bounds
goalRegion.Bounds(4, :) = [-pi/2 pi/2];  % Rotation about the Z-axis
```

You can also apply a fixed offset to all poses sampled within the region. This offset can account for grasping tools or variations in dimensions within your workspace. For this example, apply a fixed transformation that places the end effector 5 cm above the workspace.

```
goalRegion.EndEffectorOffsetPose = trvec2tform([0 0 0.05]);
hold on
show(goalRegion);
```



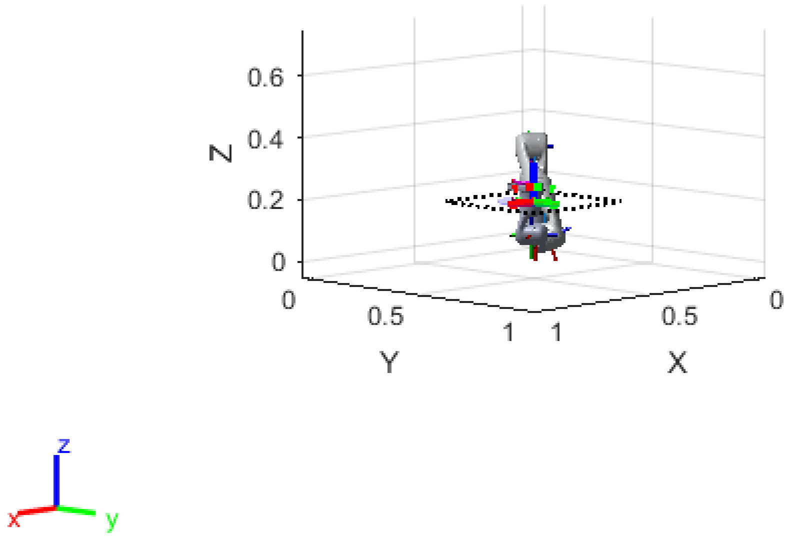
Plan Path To Goal Region

Plan a path to the goal region from the robot's home configuration. Due to the randomness in the RRT algorithm, this example sets the `rng` seed to ensure repeatable results.

```
rng(0)
path = plan(planner,homeConfiguration(robot),goalRegion);
```

Show the robot executing the path. To visualize a more realistic path, interpolate points between path configurations.

```
interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot,interpConfigurations(i,:),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1],...
        'CameraViewAngle',5)

    drawnow
end
hold off
```



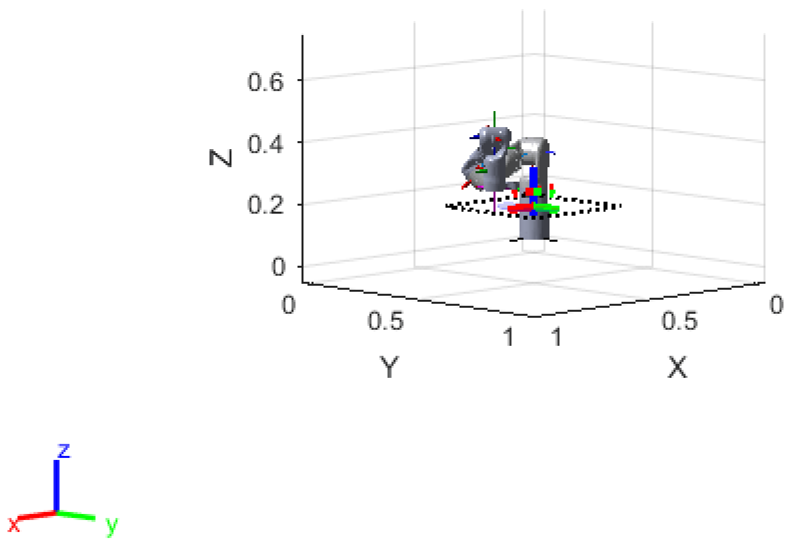
Adjust End-effector Pose

Notice that the robot arm approaches the workspace from the bottom. To flip the orientation of the final position, add a `pi` rotation to the Y-axis for the reference pose.

```
goalRegion.EndEffectorOffsetPose = ...
    goalRegion.EndEffectorOffsetPose*eul2tform([0 pi 0],"ZYX");
```

Replan the path and visualize the robot motion again. The robot now approaches from the top.

```
hold on
show(goalRegion);
path = plan(planner,homeConfiguration(robot),goalRegion);

interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot, interpConfigurations(i, :),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1])
    drawnow;
end
hold off
```



References

[1] Berenson, Dmitry, Siddhartha S. Srinivasa, Dave Ferguson, Alvaro Collet, and James J. Kuffner. "Manipulation Planning with Workspace Goal Regions." In *2009 IEEE International Conference on Robotics and Automation (ICRA)*, 618–24. Kobe, Japan: Institute of Electrical and Electronics Engineers, 2009. https://doi.org/10.1109/ROBOT.2009.5152401.

Extended Capabilities

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

See Also

`manipulatorRRT` | `sample` | `show`

Introduced in R2021a

Functions

angdiff

Difference between two angles

Syntax

```
delta = angdiff(alpha,beta)
```

```
delta = angdiff(alpha)
```

Description

`delta = angdiff(alpha,beta)` calculates the difference between the angles `alpha` and `beta`. This function subtracts `alpha` from `beta` with the result wrapped on the interval `[-pi,pi]`. You can specify the input angles as single values or as arrays of angles that have the same number of values.

`delta = angdiff(alpha)` returns the angular difference between adjacent elements of `alpha` along the first dimension whose size does not equal 1. If `alpha` is a vector of length *n*, the first entry is subtracted from the second, the second from the third, etc. The output, `delta`, is a vector of length *n-1*. If `alpha` is an *m*-by-*n* matrix with *m* greater than 1, the output, `delta`, will be a matrix of size *m-1*-by-*n*. If `alpha` is a scalar, `delta` returns as an empty vector.

Examples

Calculate Difference Between Two Angles

```
d = angdiff(pi,2*pi)
```

```
d = 3.1416
```

Calculate Difference Between Two Angle Arrays

```
d = angdiff([pi/2 3*pi/4 0],[pi pi/2 -pi])
```

```
d = 1×3

    1.5708   -0.7854   -3.1416
```

Calculate Angle Differences of Adjacent Elements

```
angles = [pi pi/2 pi/4 pi/2];
d = angdiff(angles)
```

```
d = 1×3
```

```
   -1.5708   -0.7854    0.7854
```

Input Arguments

`alpha` — Angle in radians
scalar | vector | matrix | multidimensional array

Angle in radians, specified as a scalar, vector, matrix, or multidimensional array. This is the angle that is subtracted from `beta` when specified. If `alpha` is a scalar, `delta` returns as an empty vector.

Example: `pi/2`

`beta` — Angle in radians
scalar | vector | matrix | multidimensional array

Angle in radians, specified as a scalar, vector, matrix, or multidimensional array of the same size as `alpha`. This is the angle that `alpha` is subtracted from when specified.

Example: `pi/2`

Output Arguments

`delta` — Difference between two angles
scalar | vector | matrix | multidimensional array

Angular difference between two angles, returned as a scalar, vector, or array. `delta` is wrapped to the interval `[-pi,pi]`. If `alpha` is a scalar, `delta` returns as an empty vector.

Extended Capabilities

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

Introduced in R2015a

angvel

Angular velocity from quaternion array

Syntax

```
AV = angvel(Q,dt,'frame')
AV = angvel(Q,dt,'point')
[AV,qf] = angvel(Q,dt,fp,qi)
```

Description

`AV = angvel(Q,dt,'frame')` returns the angular velocity array from an array of quaternions, `Q`. The quaternions in `Q` correspond to frame rotation. The initial quaternion is assumed to represent zero rotation.

`AV = angvel(Q,dt,'point')` returns the angular velocity array from an array of quaternions, `Q`. The quaternions in `Q` correspond to point rotation. The initial quaternion is assumed to represent zero rotation.

`[AV,qf] = angvel(Q,dt,fp,qi)` allows you to specify the initial quaternion, `qi`, and the type of rotation, `fp`. It also returns the final quaternion, `qf`.

Examples

Generate Angular Velocity From Quaternion Array

Create an array of quaternions.

```
eulerAngles = [(0:10:90).',zeros(numel(0:10:90),2)];
q = quaternion(eulerAngles,'eulerd','ZYX','frame');
```

Specify the time step and generate the angular velocity array.

```
dt = 1;
av = angvel(q,dt,'frame') % units in rad/s
```

```
av = 10×3

         0         0         0
         0         0    0.1743
         0         0    0.1743
         0         0    0.1743
         0         0    0.1743
         0         0    0.1743
         0         0    0.1743
         0         0    0.1743
         0         0    0.1743
         0         0    0.1743
```

Input Arguments

`Q` — Quaternions
N-by-1 vector of quaternions

Quaternions, specified as an *N*-by-1 vector of quaternions.

Data Types: `quaternion`

`dt` — Time step
nonnegative scalar

Time step, specified as a nonnegative scalar.

Data Types: `single` | `double`

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

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

`qi` — Initial quaternion
quaternion

Initial quaternion, specified as a quaternion.

Data Types: `quaternion`

Output Arguments

`AV` — Angular velocity
N-by-3 real matrix

Angular velocity, returned as an *N*-by-3 real matrix. *N* is the number of quaternions given in the input *Q*. Each row of the matrix corresponds to an angular velocity vector.

`qf` — Final quaternion
quaternion

Final quaternion, returned as a quaternion. `qf` is the same as the last quaternion in the *Q* input.

Data Types: `quaternion`

Extended Capabilities

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

See Also
`quaternion`

Introduced in R2020a

axang2quat

Convert axis-angle rotation to quaternion

Syntax

```
quat = axang2quat(axang)
```

Description

`quat = axang2quat(axang)` converts a rotation given in axis-angle form, `axang`, to quaternion, `quat`.

Examples

Convert Axis-Angle Rotation to Quaternion

```
axang = [1 0 0 pi/2];
quat = axang2quat(axang)
```

```
quat = 1×4

    0.7071    0.7071         0         0
```

Input Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Output Arguments

quat — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with w as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Extended Capabilities

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

See Also
`quat2axang`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

axang2rotm

Convert axis-angle rotation to rotation matrix

Syntax

```
rotm = axang2rotm(axang)
```

Description

`rotm = axang2rotm(axang)` converts a rotation given in axis-angle form, `axang`, to an orthonormal rotation matrix, `rotm`. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Examples

Convert Axis-Angle Rotation to Rotation Matrix

```
axang = [0 1 0 pi/2];
rotm = axang2rotm(axang)
```

```
rotm = 3×3

    0.0000         0    1.0000
         0    1.0000         0
   -1.0000         0    0.0000
```

Input Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also

`rotm2axang`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

axang2tform

Convert axis-angle rotation to homogeneous transformation

Syntax

```
tform = axang2tform(axang)
```

Description

`tform = axang2tform(axang)` converts a rotation given in axis-angle form, `axang`, to a homogeneous transformation matrix, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Axis-Angle Rotation to Homogeneous Transformation

```
axang = [1 0 0 pi/2];
tform = axang2tform(axang)
```

```
tform = 4×4

    1.0000         0         0         0
         0    0.0000   -1.0000         0
         0    1.0000    0.0000         0
         0         0         0    1.0000
```

Input Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the transformation matrix, premultiply it with the coordinates to be formed (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also

`tform2axang`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

bsplinepolytraj

Generate polynomial trajectories using B-splines

Syntax

```
[q,qd,qdd,pp] = bsplinepolytraj(controlPoints,tInterval,tSamples)
```

Description

`[q,qd,qdd,pp] = bsplinepolytraj(controlPoints,tInterval,tSamples)` generates a piecewise cubic B-spline trajectory that falls in the control polygon defined by `controlPoints`. The trajectory is uniformly sampled between the start and end times given in `tInterval`. The function returns the positions, velocities, and accelerations at the input time samples, `tSamples`. The function also returns the piecewise polynomial `pp` form of the polynomial trajectory with respect to time.

Examples

Compute B-Spline Trajectory for 2-D Planar Motion

Use the `bsplinepolytraj` function with a given set of 2-D *xy* control points. The B-spline uses these control points to create a trajectory inside the polygon. Time points for the waypoints are also given.

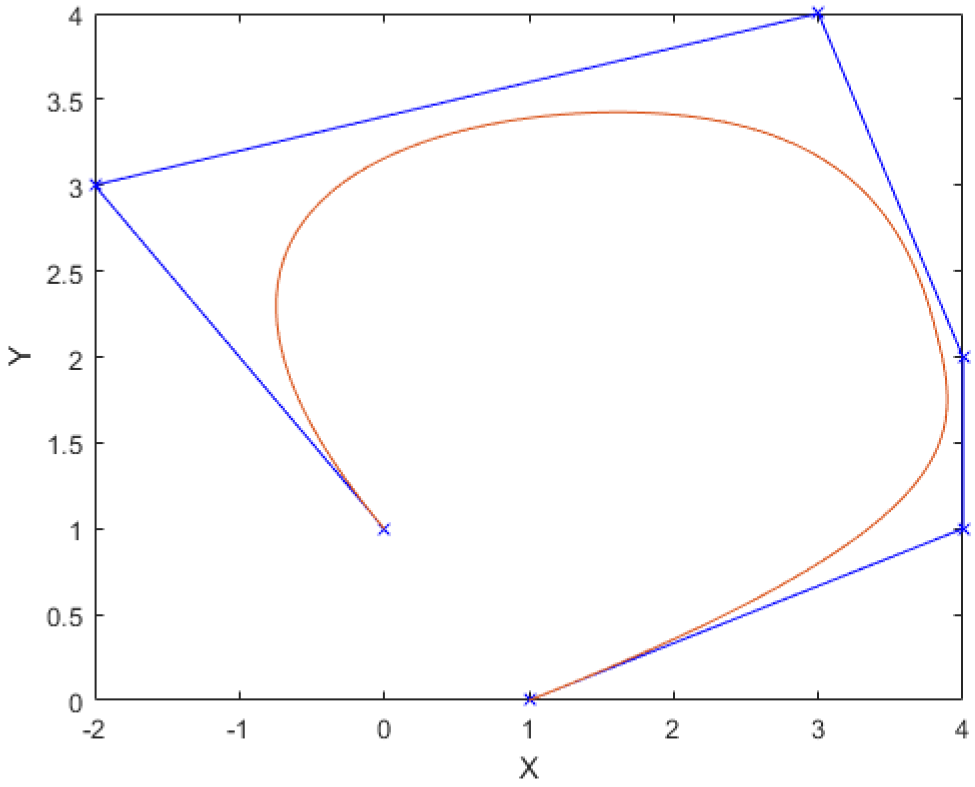
```
cpts = [1 4 4 3 -2 0; 0 1 2 4 3 1];
tpts = [0 5];
```

Compute the B-spline trajectory. The function outputs the trajectory positions (`q`), velocity (`qd`), acceleration (`qdd`), time vector (`tvec`), and polynomial coefficients (`pp`) of the polynomial that achieves the waypoints using trapezoidal velocities.

```
tvec = 0:0.01:5;
[q, qd, qdd, pp] = bsplinepolytraj(cpts,tpts,tvec);
```

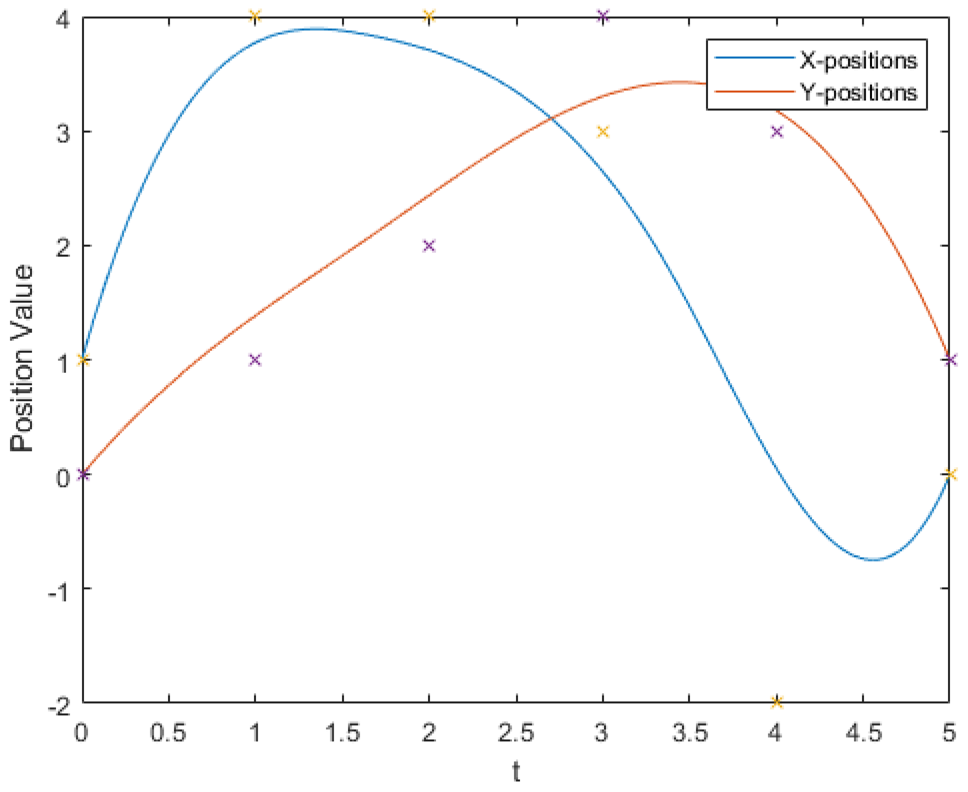
Plot the results. Show the control points and the resulting trajectory inside them.

```
figure
plot(cpts(1,:),cpts(2,:),'xb-')
hold all
plot(q(1,:), q(2,:))
xlabel('X')
ylabel('Y')
hold off
```



Plot the position of each element of the B-spline trajectory. These trajectories are cubic piecewise polynomials parameterized in time.

```
figure
plot(tvec,q)
hold all
plot([0:length(cpts)-1],cpts,'x')
xlabel('t')
ylabel('Position Value')
legend('X-positions','Y-positions')
hold off
```



Interpolate with B-Spline

Create waypoints to interpolate with a B-Spline.

```
wpts1 = [0 1 2.1 8 4 3];
wpts2 = [0 1 1.3 .8 .3 .3];
wpts = [wpts1; wpts2];
L = length(wpts) - 1;
```

Form matrices used to compute interior points of control polygon

```
r = zeros(L+1, size(wpts,1));
A = eye(L+1);
for i= 1:(L-1)
    A(i+1,(i):(i+2)) = [1 4 1];
    r(i+1,:) = 6*wpts(:,i+1)';
end
```

Override end points and choose `r0` and `rL`.

```
A(2,1:3) = [3/2 7/2 1];
A(L,(L-1):(L+1)) = [1 7/2 3/2];

r(1,:) = (wpts(:,1) + (wpts(:,2) - wpts(:,1))/2)';
r(end,:) = (wpts(:,end-1) + (wpts(:,end) - wpts(:,end-1))/2)';
```

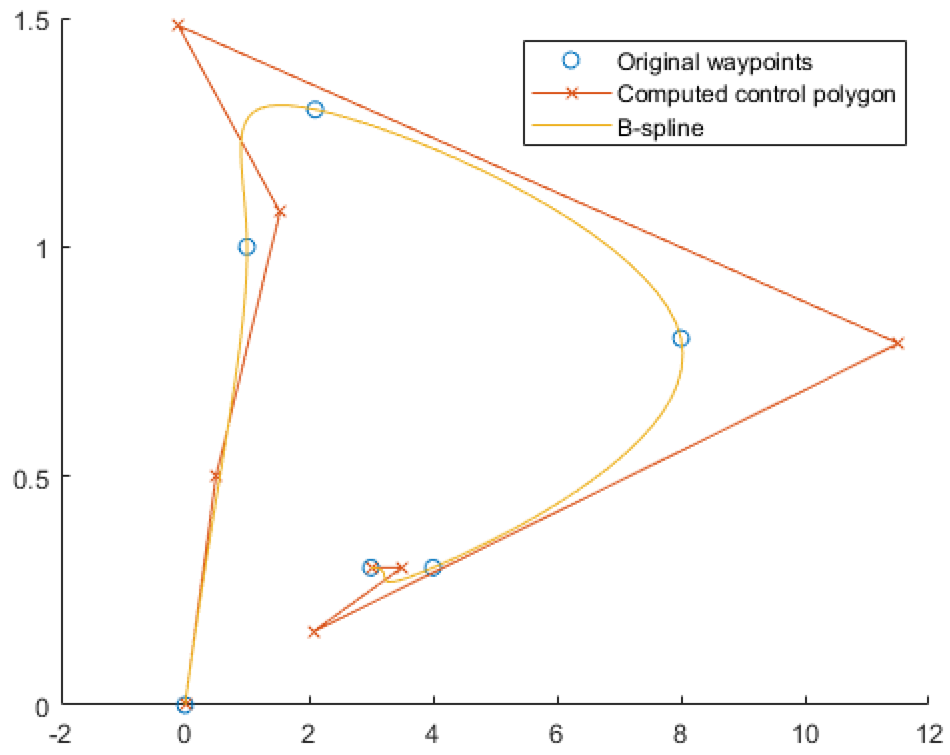
```
dInterior = (A\r)';
```

Construct a complete control polygon and use `bsplinepolytraj` to compute a polynomial with the new control points

```
cpts = [wpts(:,1) dInterior wpts(:,end)];
t = 0:0.01:1;
q = bsplinepolytraj(cpts, [0 1], t);
```

Plot the results. Show the original waypoints, the computed polygon, and the interpolated B-spline.

```
figure;
hold all
plot(wpts1, wpts2, 'o');
plot(cpts(1,:), cpts(2,:), 'x-');
plot(q(1,:), q(2,:));
legend('Original waypoints', 'Computed control polygon', 'B-spline');
```



[1] Farin, Section 9.1

Input Arguments

`controlPoints` — Points for control polygon

n-by-*p* matrix

Points for control polygon of B-spline trajectory, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of control points.

Example: `[1 4 4 3 -2 0; 0 1 2 4 3 1]`

Data Types: `single` | `double`

`tInterval` — Start and end times for trajectory
two-element vector

Start and end times for the trajectory, specified as a two-element vector.

Example: `[0 10]`

Data Types: `single` | `double`

`tSamples` — Time samples for trajectory
vector

Time samples for the trajectory, specified as a vector. The output position, `q`, velocity, `qd`, and accelerations, `qdd`, are sampled at these time intervals.

Example: `0:0.01:10`

Data Types: `single` | `double`

Output Arguments

q — Positions of trajectory
vector

Positions of the trajectory at the given time samples in `tSamples`, returned as a vector.

Data Types: `single` | `double`

qd — Velocities of trajectory
vector

Velocities of the trajectory at the given time samples in `tSamples`, returned as a vector.

Data Types: `single` | `double`

qdd — Accelerations of trajectory
vector

Accelerations of the trajectory at the given time samples in `tSamples`, returned as a vector.

Data Types: `single` | `double`

pp — Piecewise-polynomial
structure

Piecewise-polynomial, returned as a structure that defines the polynomial for each section of the piecewise trajectory. You can build your own piecewise polynomials using `mkpp`, or evaluate the polynomial at specified times using `ppval`. The structure contains the fields:

- `form`: `'pp'`.
- `breaks`: *p*-element vector of times when the piecewise trajectory changes forms. *p* is the number of waypoints.

- `coefs`: *n*(*p*–1)-by-`order` matrix for the coefficients for the polynomials. *n*(*p*–1) is the dimension of the trajectory times the number of `pieces`. Each set of *n* rows defines the coefficients for the polynomial that described each variable trajectory.
- `pieces`: *p*–1. The number of breaks minus 1.
- `order`: Degree of the polynomial + 1. For example, cubic polynomials have an order of 4.
- `dim`: *n*. The dimension of the control point positions.

References

[1] Farin, Gerald E. *Curves and Surfaces for Computer Aided Geometric Design: A Practical Guide*. San Diego, CA: Academic Press, 1993.

Extended Capabilities

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

See Also
`cubicpolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

cart2hom

Convert Cartesian coordinates to homogeneous coordinates

Syntax

```
hom = cart2hom(cart)
```

Description

`hom = cart2hom(cart)` converts a set of points in Cartesian coordinates to homogeneous coordinates.

Examples

Convert 3-D Cartesian Points to Homogeneous Coordinates

```
c = [0.8147 0.1270 0.6324; 0.9058 0.9134 0.0975];
h = cart2hom(c)
```

```
h = 2×4

    0.8147    0.1270    0.6324    1.0000
    0.9058    0.9134    0.0975    1.0000
```

Input Arguments

`cart` — Cartesian coordinates
n-by-(*k*–1) matrix

Cartesian coordinates, specified as an *n*-by-(*k*–1) matrix, containing *n* points. Each row of `cart` represents a point in (*k*–1)-dimensional space. *k* must be greater than or equal to 2.

Example: `[0.8147 0.1270 0.6324; 0.9058 0.9134 0.0975]`

Output Arguments

`hom` — Homogeneous points
n-by-*k* matrix

Homogeneous points, returned as an *n*-by-*k* matrix, containing *n* points. *k* must be greater than or equal to 2.

Example: `[0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5]`

Extended Capabilities

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

See Also

`hom2cart`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

checkCollision

Check if two geometries are in collision

Syntax

```
collisionStatus = checkCollision(geom1,geom2)
[collisionStatus,sepdist,witnesspts] = checkCollision(geom1,geom2)
```

Description

`collisionStatus = checkCollision(geom1,geom2)` returns the collision status between the two convex geometries `geom1` and `geom2`. If the two geometries are in collision at their specified poses, `checkCollision` is equal to `1`. If no collision is found, `collisionStatus` is equal to `0`.

`[collisionStatus,sepdist,witnesspts] = checkCollision(geom1,geom2)` also returns the minimal distance and witness points of each geometry, `sepdist` and `witnesspts`, respectively, when no collision is found between the two geometries.

Examples

Check Geometry Collision Status

This example shows how to check the collision status of two collision geometries.

Create a box collision geometry.

```
bx = collisionBox(1,2,3);
```

Create a cylinder collision geometry.

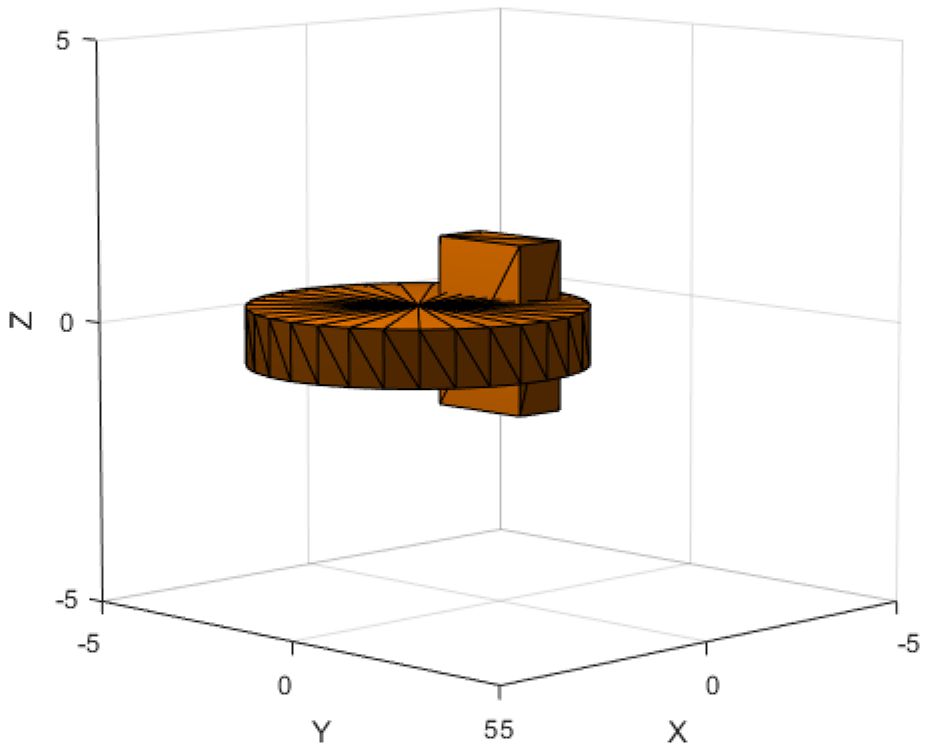
```
cy = collisionCylinder(3,1);
```

Translate the cylinder along the *x*-axis by 2.

```
T = trvec2tform([2 0 0]);
cy.Pose = T;
```

Plot the two geometries.

```
show(cy)
hold on
show(bx)
xlim([-5 5])
ylim([-5 5])
zlim([-5 5])
hold off
```



Check the collision status. Confirm the status is consistent with the plot.

```
[areIntersecting,dist,witnessPoints] = checkCollision(bx,cy)
```

```
areIntersecting = 1

dist = NaN

witnessPoints = 3×2

   NaN   NaN
   NaN   NaN
   NaN   NaN
```

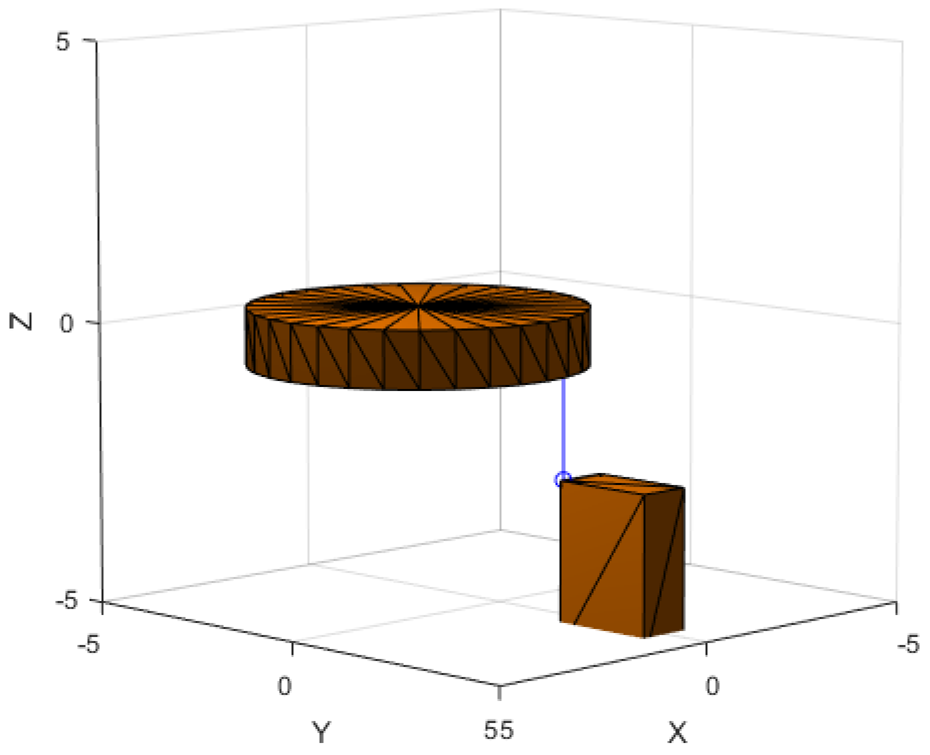
Translate the box along the *x*-axis by 3 and down the *z*-axis by 4. Confirm the box and cylinder are not colliding.

```
T = trvec2tform([0 3 -4]);
bx.Pose = T;
[areIntersecting,dist,witnessPoints] = checkCollision(bx,cy)
```

```
areIntersecting = 0

dist = 2

witnessPoints = 3×2

    0.4286    0.4286
    2.0000    2.0000
   -2.5000   -0.5000
```

Plot the box, cylinder, and the line segment representing the minimum distance between the two geometries.

```
show(cy)
hold on
show(bx)
wp = witnessPoints;
plot3([wp(1,1) wp(1,2)], [wp(2,1) wp(2,2)], [wp(3,1) wp(3,2)], 'bo-')
xlim([-5 5])
ylim([-5 5])
zlim([-5 5])
hold off
```



Input Arguments

geom1 — Collision geometry
collision geometry object

Collision geometry, specified as one of the following:

- `collisionBox`

- `collisionCylinder`
- `collisionMesh`
- `collisionSphere`

`geom2` — Collision geometry
collision geometry object

Collision geometry, specified as one of the following:

- `collisionBox`
- `collisionCylinder`
- `collisionMesh`
- `collisionSphere`

Output Arguments

`collisionStatus` — Collision status
`0` | `1`

Collision status, returned as `0` or `1`. If the two geometries are in collision, `collisionStatus` is equal to `1`. Otherwise, the value is `0`.

Data Types: `double`

`sepdist` — Minimal distance
real number | `NaN`

Minimal distance between two collision geometries, returned as a real number or `NaN`. The line segment that connects the witness points (`witnesspts`) realizes the minimal distance between the two geometries. When the two geometries are in collision, `sepdist` is set to `NaN`.

Data Types: `double` | `NaN`

`witnesspts` — Witness points
3-by-2 matrix

Witness points on each geometry, returned as a 3-by-2 matrix. Each column corresponds to the witness point on `geom1` and `geom2`, respectively. The line segment that connects the two witness points has length `septdist`. When the two geometries are in collision, `witnesspts` is set to `nan(3,2)`.

Data Types: `double` | `NaN`

Limitations

- Collision checking results are no longer reliable when the minimal distance falls below 10^{-5} m.

References

[1] E. G. Gilbert, D. W. Johnson, and S. S. Keerthi. *A fast procedure for computing the distance between complex objects in three-dimensional space.* in IEEE Journal on Robotics and Automation, vol. 4, no. 2, pp. 193-203, April 1988, doi: 10.1109/56.2083.

Extended Capabilities

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

See Also

`collisionBox` | `collisionCylinder` | `collisionMesh` | `collisionSphere`

Introduced in R2019b

classUnderlying

Class of parts within quaternion

Syntax

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

Description

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

Examples

Get Underlying Class of Quaternion

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

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

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

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

```
classUnderlying(qSingle)
```

```
ans =
'single'
```

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

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

```
classUnderlying(qDouble)
```

```
ans =
'double'
```

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

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

```
aS = single
    1
```

```
bS = single
    2

cS = single
    3

dS = single
    4
```

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

```
aD = 1

bD = 2

cD = 3

dD = 4
```

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

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

```
ans =
'single'
```

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `char`

Extended Capabilities

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

See Also

Functions
`compact` | `parts`

Objects
`quaternion`

Introduced in R2018a

compact

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

Syntax

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

Description

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

Examples

Convert Quaternion Array to Compact Representation of Parts

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

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

```
randomParts = 1×4

    0.5377    1.8339   -2.2588    0.8622
```

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

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

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

```
quatParts = 1×4

    0.5377    1.8339   -2.2588    0.8622
```

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

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

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

```
quatArrayParts = compact(quatArray)
```

```
quatArrayParts = 4×4
```

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

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `single` | `double`

Extended Capabilities

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

See Also

Functions
`parts` | `classUnderlying`

Objects
`quaternion`

Introduced in R2018a

conj

Complex conjugate of quaternion

Syntax

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

Description

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

If $q = a + b\text{i} + c\text{j} + d\text{k}$, the complex conjugate of q is $q^* = a - b\text{i} - c\text{j} - d\text{k}$. Considered as a rotation operator, the conjugate performs the opposite rotation. For example,

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

```
ans =

     0     1     0
```

Examples

Complex Conjugate of Quaternion

Create a quaternion scalar and get the complex conjugate.

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

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

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

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

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

```
q*qConj
```

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

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

Functions
`norm` | `.*,times`

Objects
`quaternion`

Introduced in R2018a

ctranspose, '

Complex conjugate transpose of quaternion array

Syntax

```
quatTransposed = quat'
```

Description

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

Examples

Vector Complex Conjugate Transpose

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

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

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

```
quatTransposed = quat'
```

```
quatTransposed = 1x4 quaternion array
      0.53767 -  0.31877i -   3.5784j -   0.7254k       1.8339 +   1.3077i -   2.7694j + 0.06305
```

Matrix Complex Conjugate Transpose

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

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

```
quat = 2x2 quaternion array
      0.53767 -   2.2588i +  0.31877j -  0.43359k       3.5784 -   1.3499i +   0.7254j +  0.7147
       1.8339 +  0.86217i -   1.3077j +  0.34262k       2.7694 +   3.0349i - 0.063055j -  0.2049
```

```
quatTransposed = quat'
```

```
quatTransposed = 2x2 quaternion array
      0.53767 +   2.2588i -  0.31877j +  0.43359k       1.8339 -  0.86217i +   1.3077j -  0.3426
       3.5784 +   1.3499i -   0.7254j -  0.71474k       2.7694 -   3.0349i + 0.063055j +  0.2049
```

Input Arguments

`quat` — Quaternion to transpose
scalar | vector | matrix

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

Data Types: `quaternion`

Output Arguments

`quatTransposed` — Conjugate transposed quaternion
scalar | vector | matrix

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

Functions
`transpose, '`

Objects
`quaternion`

Introduced in R2018a

cubicpolytraj

Generate third-order polynomial trajectories

Syntax

```
[q,qd,qdd,pp] = cubicpolytraj(wayPoints,timePoints,tSamples)
[q,qd,qdd,pp] = cubicpolytraj( ___ ,Name,Value)
```

Description

`[q,qd,qdd,pp] = cubicpolytraj(wayPoints,timePoints,tSamples)` generates a third-order polynomial that achieves a given set of input waypoints with corresponding time points. The function outputs positions, velocities, and accelerations at the given time samples, `tSamples`. The function also returns the piecewise polynomial `pp` form of the polynomial trajectory with respect to time.

`[q,qd,qdd,pp] = cubicpolytraj( ___ ,Name,Value)` specifies additional parameters as `Name,Value` pair arguments using any combination of the previous syntaxes.

Examples

Compute Cubic Trajectory for 2-D Planar Motion

Use the `cubicpolytraj` function with a given set of 2-D *xy* waypoints. Time points for the waypoints are also given.

```
wpts = [1 4 4 3 -2 0; 0 1 2 4 3 1];
tpts = 0:5;
```

Specify a time vector for sampling the trajectory. Sample at a smaller interval than the specified time points.

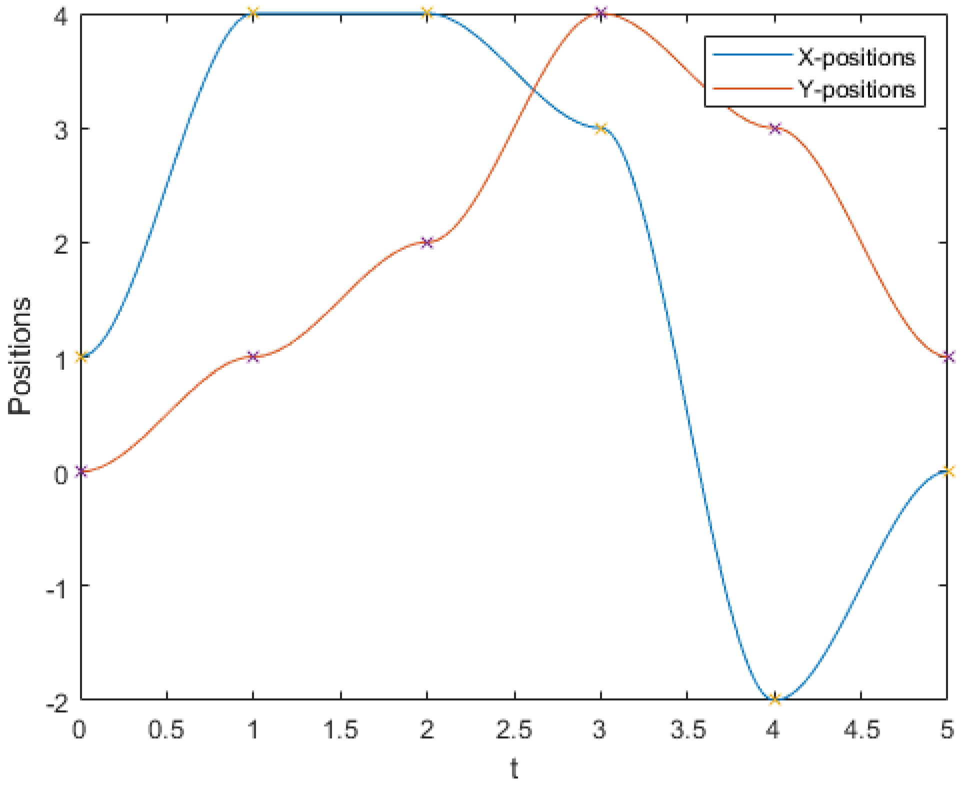
```
tvec = 0:0.01:5;
```

Compute the cubic trajectory. The function outputs the trajectory positions (`q`), velocity (`qd`), acceleration (`qdd`), and polynomial coefficients (`pp`) of the cubic polynomial.

```
[q, qd, qdd, pp] = cubicpolytraj(wpts, tpts, tvec);
```

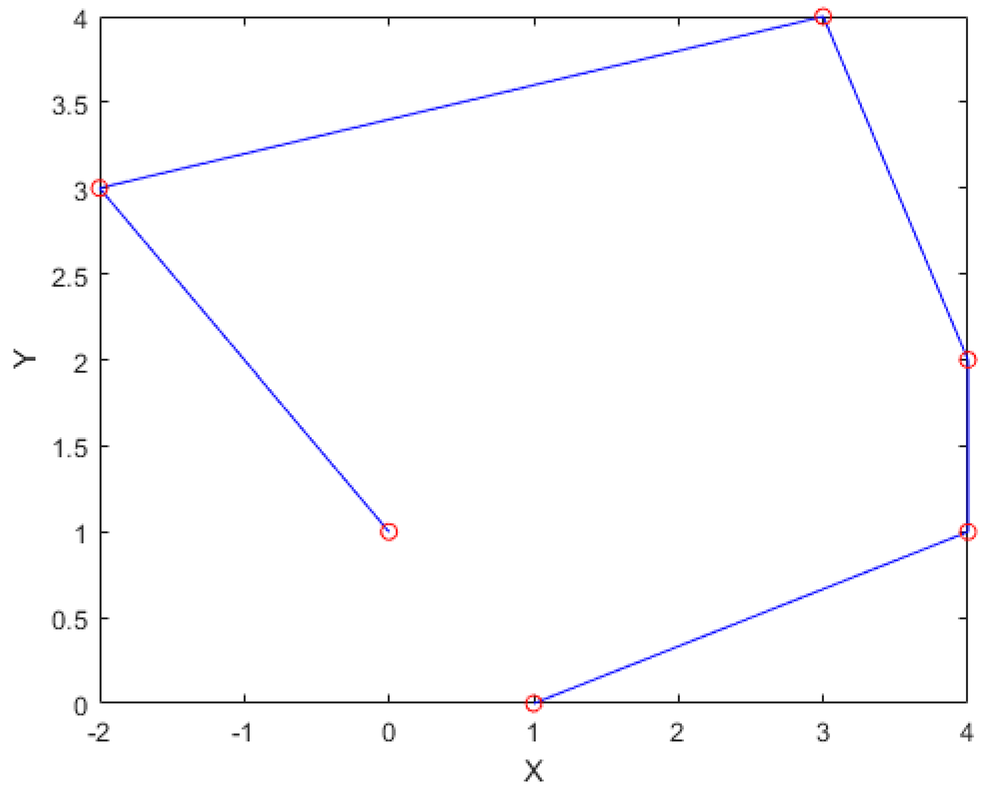
Plot the cubic trajectories for the *x*- and *y*-positions. Compare the trajectory with each waypoint.

```
plot(tvec, q)
hold all
plot(tpts, wpts, 'x')
xlabel('t')
ylabel('Positions')
legend('X-positions','Y-positions')
hold off
```



You can also verify the actual positions in the 2-D plane. Plot the separate rows of the q vector and the waypoints as *x*- and *y* -positions.

```
figure
plot(q(1,:),q(2,:),'-b',wpts(1,:),wpts(2,:),'or')
xlabel('X')
ylabel('Y')
```



Input Arguments

`wayPoints` — Waypoints for trajectory
n-by-*p* matrix

Points for waypoints of trajectory, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of waypoints.

Example: `[1 4 4 3 -2 0; 0 1 2 4 3 1]`

Data Types: `single` | `double`

`timePoints` — Time points for waypoints of trajectory
p-element vector

Time points for waypoints of trajectory, specified as a *p*-element vector.

Example: `[0 2 4 5 8 10]`

Data Types: `single` | `double`

`tSamples` — Time samples for trajectory
m-element vector

Time samples for the trajectory, specified as an *m*-element vector. The output position, `q`, velocity, `qd`, and accelerations, `qdd`, are sampled at these time intervals.

Example: `0:0.01:10`

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: `'VelocityBoundaryCondition',[1 0 -1 -1 0 0; 1 1 1 -1 -1 -1]`

`VelocityBoundaryCondition` — Velocity boundary conditions for each waypoint
`zeroes(n,p)` (default) | *n*-by-*p* matrix

Velocity boundary conditions for each waypoint, specified as the comma-separated pair consisting of `'VelocityBoundaryCondition'` and an *n*-by-*p* matrix. Each row corresponds to the velocity at all *p* waypoints for the respective variable in the trajectory.

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

Data Types: `single` | `double`

Output Arguments

q — Positions of trajectory
m-element vector

Positions of the trajectory at the given time samples in `tSamples`, returned as an *m*-element vector, where *m* is the length of `tSamples`.

Data Types: `single` | `double`

qd — Velocities of trajectory
vector

Velocities of the trajectory at the given time samples in `tSamples`, returned as a vector.

Data Types: `single` | `double`

qdd — Accelerations of trajectory
vector

Accelerations of the trajectory at the given time samples in `tSamples`, returned as a vector.

Data Types: `single` | `double`

pp — Piecewise-polynomial
structure

Piecewise-polynomial, returned as a structure that defines the polynomial for each section of the piecewise trajectory. You can build your own piecewise polynomials using `mkpp`, or evaluate the polynomial at specified times using `ppval`. The structure contains the fields:

- `form`: `'pp'`.
- `breaks`: *p*-element vector of times when the piecewise trajectory changes forms. *p* is the number of waypoints.

- `coefs`: *n*(*p*–1)-by-`order` matrix for the coefficients for the polynomials. *n*(*p*–1) is the dimension of the trajectory times the number of `pieces`. Each set of *n* rows defines the coefficients for the polynomial that described each variable trajectory.
- `pieces`: *p*–1. The number of breaks minus 1.
- `order`: Degree of the polynomial + 1. For example, cubic polynomials have an order of 4.
- `dim`: *n*. The dimension of the control point positions.

Extended Capabilities

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

See Also

`bsplinepolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

dist

Angular distance in radians

Syntax

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

Description

`distance = dist(quatA,quatB)` returns the angular distance in radians between two quaternions, `quatA` and `quatB`.

Examples

Calculate Quaternion Distance

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

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

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

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

```
qArray = 5x1 quaternion array
       0.92388 +         0i +   0.38268j +         0k
       0.70711 +         0i +   0.70711j +         0k
    6.1232e-17 +         0i +         1j +         0k
       0.70711 +         0i -   0.70711j +         0k
       0.92388 +         0i -   0.38268j +         0k
```

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

```
quaternionDistance = 5×1

   45.0000
   90.0000
  180.0000
   90.0000
   45.0000
```

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

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

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

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

```
ans = 4×1

    6.0000
    6.0827
    6.0827
    6.0287
```

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

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

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

```
qNegative = -qPositive
```

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

Find the distance between the quaternion and its negative.

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

```
ans = 0
```

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

Input Arguments

`quatA`,`quatB` — Quaternions to calculate distance between

scalar | vector | matrix | multidimensional array

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

- `size(quatA) == size(quatB)`, or
- `numel(quatA) == 1`, or
- `numel(quatB) == 1`, or

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

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

Data Types: `quaternion`

Output Arguments

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

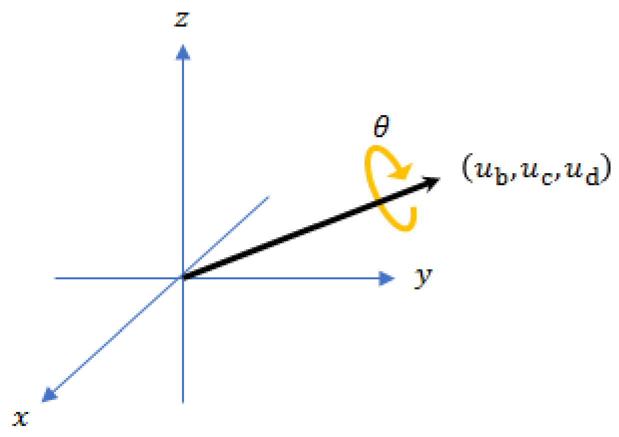
Angular distance in radians, returned as an array. The dimensions are the maximum of the union of `size(quatA)` and `size(quatB)`.

Data Types: `single` | `double`

Algorithms

The `dist` function returns the angular distance between two quaternions.

A quaternion may be defined by an axis (u_b,u_c,u_d) and angle of rotation θ_q:
$q = \cos\left(\theta_q/2\right) + \sin\left(\theta_q/2\right)(u_b\mathrm{i} + u_c\mathrm{j} + u_d\mathrm{k})$.



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

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

The angular distance between two quaternions can be expressed as $\theta_z = 2\cos^{-1}(\mathrm{real}(z))$.

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

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

Extended Capabilities

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

See Also

Functions
`parts` | `conj`

Objects
`quaternion`

Introduced in R2018a

eul2quat

Convert Euler angles to quaternion

Syntax

```
quat = eul2quat(eul)
quat = eul2quat(eul,sequence)
```

Description

`quat = eul2quat(eul)` converts a given set of Euler angles, `eul`, to the corresponding quaternion, `quat`. The default order for Euler angle rotations is `"ZYX"`.

`quat = eul2quat(eul,sequence)` converts a set of Euler angles into a quaternion. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Convert Euler Angles to Quaternion

```
eul = [0 pi/2 0];
qZYX = eul2quat(eul)
```

```
qZYX = 1×4

    0.7071         0    0.7071         0
```

Convert Euler Angles to Quaternion Using Default ZYZ Axis Order

```
eul = [pi/2 0 0];
qZYZ = eul2quat(eul,'ZYZ')
```

```
qZYZ = 1×4

    0.7071         0         0    0.7071
```

Input Arguments

eul — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, specified as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

`sequence` — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these string scalars:

- `"ZYX"` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `"ZYZ"` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `"XYZ"` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Data Types: `string` | `char`

Output Arguments

`quat` — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Extended Capabilities

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

See Also

`quat2eul` | `quaternion`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

eul2rotm

Convert Euler angles to rotation matrix

Syntax

```
rotm = eul2rotm(eul)
rotm = eul2rotm(eul,sequence)
```

Description

`rotm = eul2rotm(eul)` converts a set of Euler angles, `eul`, to the corresponding rotation matrix, `rotm`. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying). The default order for Euler angle rotations is `"ZYX"`.

`rotm = eul2rotm(eul,sequence)` converts Euler angles to a rotation matrix, `rotm`. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Convert Euler Angles to Rotation Matrix

```
eul = [0 pi/2 0];
rotmZYX = eul2rotm(eul)
```

```
rotmZYX = 3×3

    0.0000         0    1.0000
         0    1.0000         0
   -1.0000         0    0.0000
```

Convert Euler Angles to Rotation Matrix Using ZYZ Axis Order

```
eul = [0 pi/2 pi/2];
rotmZYZ = eul2rotm(eul,'ZYZ')
```

```
rotmZYZ = 3×3

    0.0000   -0.0000    1.0000
    1.0000    0.0000         0
   -0.0000    1.0000    0.0000
```

Input Arguments

`eul` — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, specified as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

`sequence` — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these string scalars:

- `"ZYX"` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `"ZYZ"` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `"XYZ"` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Data Types: `string` | `char`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also

`rotm2eul`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

eul2tform

Convert Euler angles to homogeneous transformation

Syntax

```
eul = eul2tform(eul)
tform = eul2tform(eul,sequence)
```

Description

`eul = eul2tform(eul)` converts a set of Euler angles, `eul`, into a homogeneous transformation matrix, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying). The default order for Euler angle rotations is `"ZYX"`.

`tform = eul2tform(eul,sequence)` converts Euler angles to a homogeneous transformation. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Convert Euler Angles to Homogeneous Transformation Matrix

```
eul = [0 pi/2 0];
tformZYX = eul2tform(eul)

tformZYX = 4×4

    0.0000         0    1.0000         0
         0    1.0000         0         0
   -1.0000         0    0.0000         0
         0         0         0    1.0000
```

Convert Euler Angles to Homogeneous Transformation Matrix Using ZYZ Axis Order

```
eul = [0 pi/2 pi/2];
tformZYZ = eul2tform(eul,'ZYZ')

tformZYZ = 4×4

    0.0000   -0.0000    1.0000         0
    1.0000    0.0000         0         0
   -0.0000    1.0000    0.0000         0
         0         0         0    1.0000
```

Input Arguments

`eul` — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, specified as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

`sequence` — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these string scalars:

- `"ZYX"` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `"ZYZ"` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `"XYZ"` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Data Types: `string` | `char`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also

`tform2eul`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

euler

Convert quaternion to Euler angles (radians)

Syntax

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

Description

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

Examples

Convert Quaternion to Euler Angles in Radians

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

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

```
eulerAnglesRandians = 1×3

         0         0    1.5708
```

Input Arguments

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

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

Data Types: `quaternion`

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

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

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

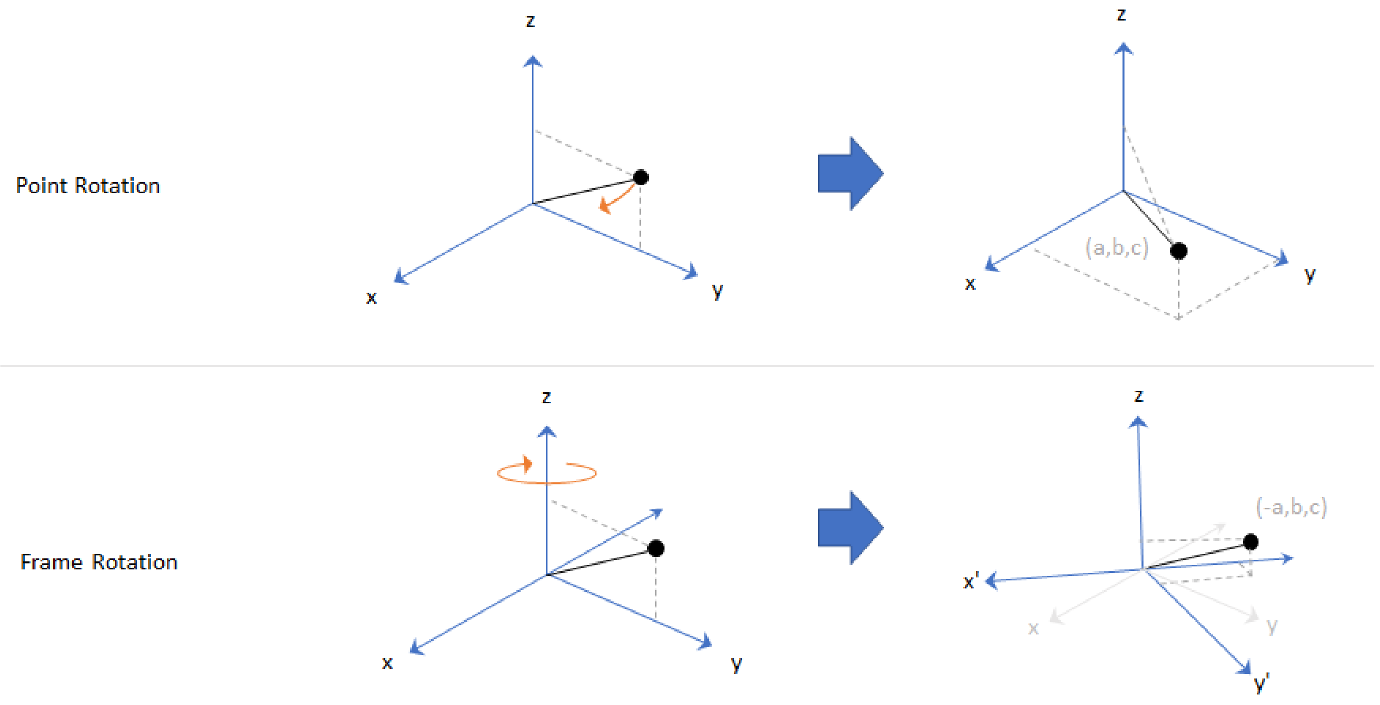
1. The first rotation is about the y-axis.
2. The second rotation is about the new z-axis.
3. The third rotation is about the new x-axis.

Data Types: `char` | `string`

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

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

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



Data Types: `char` | `string`

Output Arguments

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

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

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

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

Data Types: `single` | `double`

Extended Capabilities

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

See Also

Functions
`eulerd` | `rotateframe` | `rotatepoint`

Objects
`quaternion`

Introduced in R2018a

eulerd

Convert quaternion to Euler angles (degrees)

Syntax

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

Description

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

Examples

Convert Quaternion to Euler Angles in Degrees

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

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

```
eulerAnglesDegrees = 1×3

         0         0   90.0000
```

Input Arguments

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

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

Data Types: `quaternion`

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

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

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

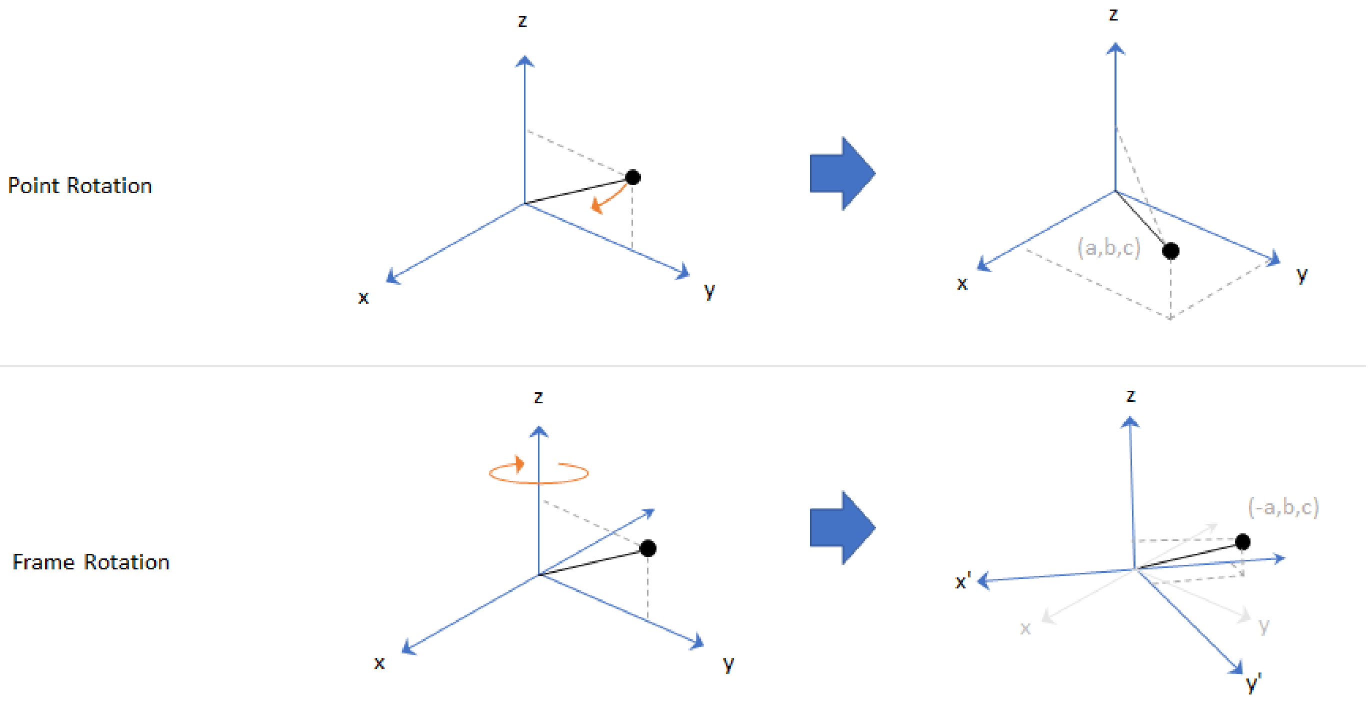
1. The first rotation is about the *y*-axis.
2. The second rotation is about the new *z*-axis.
3. The third rotation is about the new *x*-axis.

Data Types: `char` | `string`

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

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

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



Data Types: `char` | `string`

Output Arguments

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

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

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

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

Data Types: `single` | `double`

Extended Capabilities

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

See Also

Functions
`euler` | `rotateframe` | `rotatepoint`

Objects
`quaternion`

Introduced in R2018b

exp

Exponential of quaternion array

Syntax

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

Description

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

Examples

Exponential of Quaternion Array

Create a 4-by-1 quaternion array A.

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

```
A = 4x1 quaternion array
     16 +  2i +  3j + 13k
      5 + 11i + 10j +  8k
      9 +  7i +  6j + 12k
      4 + 14i + 15j +  1k
```

Compute the exponential of A.

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

```
B = 4x1 quaternion array
     5.3525e+06 + 1.0516e+06i + 1.5774e+06j + 6.8352e+06k
        -57.359 -     89.189i -     81.081j -     64.865k
        -6799.1 +     2039.1i +     1747.8j +     3495.6k
          -6.66 +     36.931i +     39.569j +     2.6379k
```

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

B — Result
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Algorithms

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

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

Extended Capabilities

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

See Also

Functions
`.^,power` | `log`

Objects
`quaternion`

Introduced in R2018b

gazebogenmsg

Generate dependencies for Gazebo custom message support

Syntax

```
gazebogenmsg(folderpath)
gazebogenmsg(folderpath,Name,Value)
```

Description

`gazebogenmsg(folderpath)` generates dependencies for Gazebo custom message support using the protocol buffer (protobuf) files (`.proto`) in the specified folder `folderpath`. It then outputs the generated dependency files to the same folder. The function expects one or more `.proto` files in the same folder. See “Algorithms” on page 2-60 for more information about using Simulink to communicate with Gazebo, as well as sending and receiving custom messages.

`gazebogenmsg(folderpath,Name,Value)` specifies options using one or more name-value pair arguments.

For example, `'GazeboVersion','Gazebo 10'` sets the Gazebo message version to Gazebo 10.

Examples

Generate Dependencies for User-Defined Gazebo Custom Message

Create a folder in a local directory.

```
folderPath = fullfile(pwd,'customMessage')
```

```
folderPath = 
'C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage'
```

```
mkdir(folderPath)
```

Create a `.proto` file inside the folder and define protobuf custom message fields.

```
messageDefinition = {'message MyPose'
                     '{'
                     '    required double x = 1;'
                     '    required double y = 2;'
                     '    required double z = 3;'
                     '}'};
fileID = fopen(fullfile(folderPath,'MyPose.proto'),'w');
fprintf(fileID,'%s\n',messageDefinition{:});
fclose(fileID);
```

Use the `gazebogenmsg` function to generate dependences in the created folder.

```
gazebogenmsg(folderPath)
```

```
Validating ...
Selected compiler details: "Microsoft Visual C++ 2019 16.0"
```

```
[libprotobuf WARNING] No syntax specified for the proto file: MyPose.proto. Please use 'syntax =
Building shared library ...
Microsoft (R) C/C++ Optimizing Compiler Version 19.15.26726 for x64
Copyright (C) Microsoft Corporation.  All rights reserved.

MyPose.pb.cc
Microsoft (R) Incremental Linker Version 14.15.26726.0
Copyright (C) Microsoft Corporation.  All rights reserved.

/out:MyPose.pb.dll
/dll
/implib:MyPose.pb.lib
/LIBPATH:B:\matlab\toolbox\shared\robotics\externalDependency\libprotobuf\lib
libprotobuf3.lib
/OUT:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\instal
/IMPLIB:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\ins
C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\install\MyP
   Creating library C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\custo
Building MEX for "MyPose.proto" file ...
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building custom message utilities  ...
DONE.

To use the gazebo custom messages, execute following commands:

addpath('C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\ins
savepath
```

Use the following commands to add and save the install path.

```
addpath(fullfile(folderPath,'install'))
```

```
savepath
```

Create a Gazebo plugin package `'MyPlugin'` inside the custom message folder using the `packageGazeboPlugin` function.

```
packageGazeboPlugin(fullfile(folderPath,'MyPlugin'),folderPath)
```

Generate Dependencies for Built-in Gazebo Message

Create a folder in a local directory.

```
folderPath = fullfile(pwd,'customMessage');
mkdir(folderPath)
cd(folderPath)
```

Use the `gazebogenmsg` function to generate dependencies for a built-in gazebo message in the specified folder.

```
gazebogenmsg(folderPath,"GazeboMessageList","gazebo.msgs.Image");
```

```
Validating ...
Selected compiler details: "Microsoft Visual C++ 2019 16.0"
Building shared library ...
Microsoft (R) C/C++ Optimizing Compiler Version 19.15.26726 for x64
Copyright (C) Microsoft Corporation.  All rights reserved.

image.pb.cc
Microsoft (R) Incremental Linker Version 14.15.26726.0
Copyright (C) Microsoft Corporation.  All rights reserved.

/out:image.pb.dll
/dll
/implib:image.pb.lib
/LIBPATH:B:\matlab\toolbox\shared\robotics\externalDependency\libprotobuf\lib
libprotobuf3.lib
/OUT:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\instal
/IMPLIB:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\ins
C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\install\ima
   Creating library C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\custo
Building MEX for "image.proto" file ...
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building custom message utilities  ...
DONE.

To use the gazebo custom messages, execute following commands:

addpath('C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\in
savepath
```

Use the following commands to add and save the install path.

```
addpath(fullfile(folderPath,'install'))
```

```
savepath
```

Create a Gazebo plugin package using the `packageGazeboPlugin` function.

```
packageGazeboPlugin
```

Input Arguments

`folderpath` — Path of custom message folder
string scalar | character vector

Path of the custom message folder, specified as a string scalar or character vector. The folder must contain one or more `.proto` files. The path also specifies the location in which to output the generated dependency files.

Example: `gazebogenmsg('C:\GazeboCustomMsg')`

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: `'GazeboMessageList','gazebo.msgs.IMU'` generates dependences for the built-in Gazebo message `gazebo.msgs.IMU`.

`GazeboVersion` — Gazebo message version
`'Gazebo 9'` (default) | `'Gazebo 10'`

Gazebo message version, specified as the comma-separated pair consisting of `'GazeboVersion'` and either `'Gazebo 9'` or `'Gazebo 10'`.

Example: `'GazeboVersion','Gazebo 10'`

Data Types: `char` | `string`

`GazeboMessageList` — Gazebo built-in messages
string scalar | character vector

Gazebo built-in messages, specified as the comma-separated pair consisting of `'GazeboMessageList'` and one or more built-in messages from the list of valid Gazebo messages.

To get a list of valid Gazebo messages, press **Tab** after entering the `'GazeboMessageList'` argument name. You can select a valid Gazebo message value from the list.

Example: `'GazeboMessageList','gazebo.msgs.Altimeter'`

Data Types: `char` | `string`

Limitations

- The `gazebogenmsg` function supports the **proto2** version of the protobuf language. The function does not support the proto2 fields `map`, `group`, `extend`, `extensions`, and `reserved`.
- You can run the Simulink model multiple times but you need to restart MATLAB to run `gazebogenmsg` function again.
- `gazebogenmsg` function not supported with MATLAB Compiler™.

Tips

Supported Compilers

Windows: Microsoft Visual C++ 14.0 and later

Linux: g++ 6.0.0 and later

Mac: Xcode Clang++ 10.0.0 and later

Algorithms

1. Add and save the install path by running the command presented at the end of `gazebogenmsg` function output.

2. Use the `packageGazeboPlugin` function to package the plugin.
3. Copy, install and run the plugin on the Gazebo machine.
4. Use the Gazebo Publish Simulink block to send the custom messages to the Gazebo machine.
5. Use the Gazebo Subscribe Simulink block to receive the custom messages from the Gazebo machine.

References

[1] Google Developers. “Language Guide | Protocol Buffers.” Accessed July 17, 2020. https://developers.google.com/protocol-buffers/docs/proto.

See Also

`packageGazeboPlugin` | Gazebo Publish | Gazebo Subscribe

Topics

“Perform Co-Simulation between Simulink and Gazebo”

Introduced in R2020b

gzinit

Initialize connection settings for Gazebo Co-Simulation MATLAB interface

Syntax

```
gzinit
gzinit(HostIP)
gzinit(HostIP,HostPort)
gzinit(HostIP,HostPort,Timeout)
```

Description

`gzinit` initializes connection settings and checks connectivity with the Gazebo plugin running on `localhost` and port `14581`. This syntax sets response timeout to 1 second.

`gzinit(HostIP)` specifies the host name or IP address of the Gazebo plugin `HostIP`.

`gzinit(HostIP,HostPort)` specifies the port number `HostPort`.

`gzinit(HostIP,HostPort,Timeout)` specifies the response timeout `Timeout` in seconds.

Examples

Perform Co-Simulation Between MATLAB and Gazebo

Set up a simulation between MATLAB and Gazebo, receive data from Gazebo, and send commands to Gazebo.

Download the Linux virtual machine (VM) with Gazebo installed from Virtual Machine with ROS and Gazebo.

Set up `multiSensorPluginTest.world` by following the Gazebo simulation environment setup and launch steps in “Perform Co-Simulation between Simulink and Gazebo”.

Configure and Perform Gazebo Co-Simulation

Initialize connection settings and check connectivity with the Gazebo plugin running on `192.168.198.129` and port `14581.`

```
gzinit("192.168.198.129",14581)
```

Assign and Retrieve Gazebo Model Information

List the models available in the Gazebo world.

```
modelList = gzmodel("list")
```

```
modelList = 1×11 string
    "ground_plane"    "unit_box"    "camera0"    "camera1"    "depth_camera0"    "depth_camera1"
```

Assign values to the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[status,message] = gzmodel("set","unit_box","Position",[2 2 0.5],"SelfCollide","on")
```

```
status = 1×2 logical array

   1   1


message = 1×2 string
    "Position parameter set successfully."    "SelfCollide parameter set successfully."
```

Retrieve the values of the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[position,selfcollide] = gzmodel("get","unit_box","Position","SelfCollide")
```

```
position = 1×3

                         2                         2           0.4999999999951


selfcollide = logical
   1
```

Assign and Retrieve Gazebo Model Link Information

List the links available in the `unit_box` model.

```
linkList = gzlink("list","unit_box")
```

```
linkList = 
"link"
```

Assign values to the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[status,message] = gzlink("set","unit_box","link","Mass",2,"Gravity","off")
```

```
status = 1×2 logical array

   1   1


message = 1×2 string
    "Mass parameter set successfully."    "Gravity parameter set successfully."
```

Retrieve the values of the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[mass,gravity] = gzlink("get","unit_box","link","Mass","Gravity")
```

```
mass = 
     2


gravity = logical
   0
```

Assign and Retrieve Gazebo Model Joint Information

List the joints available in the `unit_box` model.

```
jointList = gzjoint("list","unit_box")
```

```
jointList = 
"joint"
```

Assign a value to the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
[status,message] = gzjoint("set","unit_box","joint","Axis","0","Damping",0.25)
```

```
status = logical
   1


message = 
"Damping parameter set successfully."
```

Retrieve the value of the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
damping = gzjoint("get","unit_box","joint","Axis0","Damping")
```

```
damping = 
                      0.25
```

Reset all Gazebo model configurations.

```
gzworld("reset")
```

Input Arguments

`HostIP` — Host name or IP address of machine with Gazebo plugin
`localhost` (default) | string scalar | character vector

The host name or IP address of the machine with the Gazebo plugin, specified as a string scalar or character vector.

Example: `gzinit("172.18.250.191")`

`HostPort` — Port number of machine with Gazebo plugin
`14581` (default) | positive integer

Port number of the machine with the Gazebo plugin, specified as a positive integer. The port number must be the same as the value of `'portNumber'` in the Gazebo `'.world'` file.

Example: `gzinit("172.18.250.191",14581)`

`Timeout` — Response timeout
`1` (default) | positive numeric scalar

Response timeout, specified as a positive numeric scalar. This value determines how long the client will wait for a response from the server, in seconds. Set a higher `Timeout` value for a network with poor connectivity.

Example: `gzinit("172.18.250.191",14581,10)`

Limitations

- `gzinit` function not supported with MATLAB Compiler.

See Also

`gzlink` | `gzjoint` | `gzmodel` | `gzworld`

Introduced in R2021a

gzjoint

Assign and retrieve Gazebo model joint information

Syntax

```
List = gzjoint("list",modelname)
[Status,Message] = gzjoint("set",modelname,jointname,Name,Value)
[Output1,...,OutputN] = gzjoint("get",modelname,jointname,params)
```

Description

`List = gzjoint("list",modelname)` returns and displays a list of joint names `List` of the specified Gazebo model `modelname`.

`[Status,Message] = gzjoint("set",modelname,jointname,Name,Value)` assigns values to the joint parameters using one or more name-value pair arguments for the specified Gazebo model `modelname` and the joint `jointname`. The function returns the status of the value assignments `Status` and the message of their success and failure `Message`. For example, `gzjoint("set","unit_box","joint","Position",[2 2 0.5])` sets the position of the joint in the model `unit_box`.

`[Output1,...,OutputN] = gzjoint("get",modelname,jointname,params)` retrieves values of the joint parameters using one or more parameter names, `params`, for the specified Gazebo model `modelname` and the joint `jointname`. The function returns one or more outputs, `Output1,...,OutputN`, corresponding to the specified parameter names.

Examples

Perform Co-Simulation Between MATLAB and Gazebo

Set up a simulation between MATLAB and Gazebo, receive data from Gazebo, and send commands to Gazebo.

Download the Linux virtual machine (VM) with Gazebo installed from Virtual Machine with ROS and Gazebo.

Set up `multiSensorPluginTest.world` by following the Gazebo simulation environment setup and launch steps in “Perform Co-Simulation between Simulink and Gazebo”.

Configure and Perform Gazebo Co-Simulation

Initialize connection settings and check connectivity with the Gazebo plugin running on `192.168.198.129` and port `14581.`

```
gzinit("192.168.198.129",14581)
```

Assign and Retrieve Gazebo Model Information

List the models available in the Gazebo world.

```
modelList = gzmodel("list")
```

```
modelList = 1×11 string
    "ground_plane"    "unit_box"    "camera0"    "camera1"    "depth_camera0"    "depth_camera1"
```

Assign values to the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[status,message] = gzmodel("set","unit_box","Position",[2 2 0.5],"SelfCollide","on")
```

```
status = 1×2 logical array

   1   1


message = 1×2 string
    "Position parameter set successfully."    "SelfCollide parameter set successfully."
```

Retrieve the values of the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[position,selfcollide] = gzmodel("get","unit_box","Position","SelfCollide")
```

```
position = 1×3

                         2                         2           0.4999999999951


selfcollide = logical
   1
```

Assign and Retrieve Gazebo Model Link Information

List the links available in the `unit_box` model.

```
linkList = gzlink("list","unit_box")
```

```
linkList = 
"link"
```

Assign values to the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[status,message] = gzlink("set","unit_box","link","Mass",2,"Gravity","off")
```

```
status = 1×2 logical array

   1   1


message = 1×2 string
    "Mass parameter set successfully."    "Gravity parameter set successfully."
```

Retrieve the values of the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[mass,gravity] = gzlink("get","unit_box","link","Mass","Gravity")
```

```
mass =
     2


gravity = logical
   0
```

Assign and Retrieve Gazebo Model Joint Information

List the joints available in the `unit_box` model.

```
jointList = gzjoint("list","unit_box")
```

```
jointList = 
"joint"
```

Assign a value to the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
[status,message] = gzjoint("set","unit_box","joint","Axis","0","Damping",0.25)
```

```
status = logical
   1


message = 
"Damping parameter set successfully."
```

Retrieve the value of the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
damping = gzjoint("get","unit_box","joint","Axis0","Damping")
```

```
damping = 
                      0.25
```

Reset all Gazebo model configurations.

```
gzworld("reset")
```

Input Arguments

`modelname` — Gazebo model name
string scalar | character vector

Gazebo model name, specified as a string scalar or character vector.

Data Types: `char` | `string`

`jointname` — Associated joint name
string scalar | character vector

Associated joint name, specified as a string scalar or character vector.

Data Types: `char` | `string`

`params` — Gazebo model joint parameters
string scalars | character vectors

Gazebo model joint parameters, specified as a comma-separated list of string scalars or character vectors. Specify the list of parameters you want to retrieve the values, from these tables.

Gazebo model joint axis parameters for `Axis0` or `Axis1`, specified as the comma-separated arguments consisting of `"Axis0"` or `"Axis1"`, respectively, and one or more of the options in this table.

Option Name	Description
`"Angle"`	Get the angle parameter of the Gazebo model joint axis for `Axis0` or `Axis1`.
`"Damping"`	Get the damping parameter of the Gazebo model joint axis for `Axis0` or `Axis1`.
`"Friction"`	Get the friction parameter of the Gazebo model joint axis for `Axis0` or `Axis1`.
`"XYZ"`	Get the position of the Gazebo model joint axis for `Axis0` or `Axis1`.

Gazebo model joint parameters:

Parameters	Description
`"CFM"`	Get the CFM parameter of the Gazebo model joint.
`"FudgeFactor"`	Get the fudge factor parameter of the Gazebo model joint.
`"Orientation"`	Get the orientation parameter of the Gazebo model joint.
`"Position"`	Get the position of the Gazebo model joint.
`"SuspensionCFM"`	Get the suspension CFM parameter of the Gazebo model joint.
`"SuspensionERP"`	Get the suspension ERP parameter of the Gazebo model joint.

Example: `[ang,damp,cfm,pos] = gzjoint("get","unit_box","joint","Axis0","Angle","Damping","CFM","Position")`

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: For example, `gzjoint("set","unit_box","joint","Position",[2 2 0.5])` sets the position of the joint in the model `unit_box`.

`Axis` — Gazebo model joint axis parameters
`"0"` | `"1"`

Gazebo model joint axis parameters, specified as the comma-separated pair consisting of `'Axis'` and either `"0"` or `"1"`. Then, specify one or more of the options in this table as the comma-separated pair consisting of an option name and its value.

Option Name	Description
`"Angle"`	Set the angle parameter of the Gazebo model joint axis as a numeric scalar in radians.
`"Damping"`	Set the damping parameter of the Gazebo model joint axis as a numeric scalar in newton meter second per radians.
`"Friction"`	Set the friction parameter of the Gazebo model joint axis as a numeric scalar in newton.
`"XYZ"`	Set the position of the Gazebo model joint axis as a three-element vector of the form `[X Y Z]` in meters.

Example: `[status,message] = gzjoint("set","unit_box","joint","Axis","0","Damping",0.25)`

Data Types: `single` | `double`

`CFM` — Gazebo model joint constraint force mixing (CFM) parameter
numeric scalar

Gazebo model joint CFM parameter, specified as the comma-separated pair consisting of `'CFM'` and a numeric scalar.

Example: `[status,message] = gzjoint("set","unit_box","joint","CFM",1);`

Data Types: `single` | `double`

`FudgeFactor` — Gazebo model joint fudge factor parameter
numeric scalar

Gazebo model joint fudge factor parameter, specified as the comma-separated pair consisting of `'FudgeFactor'` and a numeric scalar.

Example: `[status,message] = gzjoint("set","unit_box","joint","FudgeFactor",1);`

Data Types: `single` | `double`

`Orientation` — Gazebo model joint orientation parameter
four-element vector

Gazebo model joint orientation parameter, specified as the comma-separated pair consisting of `'Orientation'` and a four-element quaternion vector of the form [*w x y z*].

Example: `[status,message] = gzjoint("set","unit_box","joint","Orientation",[1 0 0 0]);`

Data Types: `single` | `double`

`Position` — Gazebo model joint position
three-element vector

Gazebo model joint position parameter, specified as the comma-separated pair consisting of `'Position'` and a three-element vector of the form [*x y z*] in meters.

Example: `[status,message] = gzjoint("set","unit_box","joint","Position",[0 0 0]);`

Data Types: `single` | `double`

`SuspensionCFM` — Gazebo model joint suspension CFM parameter
numeric scalar

Gazebo model joint suspension CFM parameter, specified as the comma-separated pair consisting of `'SuspensionCFM'` and a numeric scalar.

Example: `[status,message] = gzjoint("set","unit_box","joint","SuspensionCFM",1);`

Data Types: `single` | `double`

`SuspensionERP` — Gazebo model joint suspension error reduction parameter (ERP) parameter
numeric scalar

Gazebo model joint suspension ERP parameter, specified as the comma-separated pair consisting of `'SuspensionERP'` and a numeric scalar.

Example: `[status,message] = gzjoint("set","unit_box","joint","SuspensionERP",1);`

Data Types: `single` | `double`

Output Arguments

`List` — List of joints in model
cell array of character vectors

List of joints in the model, returned as a cell array of character vectors.

`Status` — Status of values assigned to parameters
logical array

Status of the values assigned to the parameters, returned as a logical array.

`Message` — Success or failure message
string array

Success or failure message, returned as a string array.

`Output1,...,OutputN` — Values of specified parameters
numeric scalar | numeric vector

Values of specified parameters, returned as a numeric scalar or numeric vector based on the specified parameters. The following tables shows the returned data type of parameter values.

Gazebo model joint axis parameters for `Axis0` or `Axis1`:

Option Name	Description
`"Angle"`	Gazebo model joint axis angle parameter for `Axis0` or `Axis1`, returns a numeric scalar in radians.
`"Damping"`	Gazebo model joint axis damping parameter for `Axis0` or `Axis1`, returns a numeric scalar in newton meter second per radians.
`"Friction"`	Gazebo model joint axis friction parameter for `Axis0` or `Axis1`, returns a numeric scalar in newton.
`"XYZ"`	Gazebo model joint axis position parameter for `Axis0` or `Axis1`, returns a three-element vector of the form `[X Y Z]` in meters.

Gazebo model joint parameters:

Parameters	Description
`"CFM"`	Gazebo model joint CFM parameter, returns a numeric scalar.
`"FudgeFactor"`	Gazebo model joint fudge factor parameter, returns a numeric scalar.
`"Orientation"`	Gazebo model joint orientation parameter, returns a four-element quaternion vector of the form [*w x y z*].
`"Position"`	Gazebo model joint position parameter, returns a three-element vector of the form `[x y z]` in meters.
`"SuspensionCFM"`	Gazebo model joint suspension CFM parameter, returns a numeric scalar.
`"SuspensionERP"`	Gazebo model joint suspension ERP parameter, returns a numeric scalar.

Limitations

- `gzjoint` function not supported with MATLAB Compiler.

See Also

`gzinit` | `gzlink` | `gzmodel` | `gzworld`

Introduced in R2021a

gzlink

Assign and retrieve Gazebo model link information

Syntax

```
List = gzlink("list",modelname)
[Status,Message] = gzlink("set",modelname,linkname,Name,Value)
[Output1,...,OutputN] = gzlink("get",modelname,linkname,params)
```

Description

`List = gzlink("list",modelname)` returns and displays a list of link names `List` in the specified Gazebo model `modelname`.

`[Status,Message] = gzlink("set",modelname,linkname,Name,Value)` assigns values to the link parameters using one or more name-value pair arguments for the specified Gazebo model `modelname` and the link `linkname`. The function returns the status of the value assignments `Status` and the message of their success and failure `Message`. For example, `gzlink("set","unit_box","link","Position",[2 2 0.5])` sets the position of the link in the model `unit_box`.

`[Output1,...,OutputN] = gzlink("get",modelname,linkname,params)` retrieves values of the link parameters using one or more parameter name, `params`, for the specified Gazebo model `modelname` and the link `linkname`. The function returns one or more outputs, `Output1,...,OutputN`, corresponding to the specified parameter names.

Examples

Perform Co-Simulation Between MATLAB and Gazebo

Set up a simulation between MATLAB and Gazebo, receive data from Gazebo, and send commands to Gazebo.

Download the Linux virtual machine (VM) with Gazebo installed from Virtual Machine with ROS and Gazebo.

Set up `multiSensorPluginTest.world` by following the Gazebo simulation environment setup and launch steps in “Perform Co-Simulation between Simulink and Gazebo”.

Configure and Perform Gazebo Co-Simulation

Initialize connection settings and check connectivity with the Gazebo plugin running on `192.168.198.129` and port `14581.`

```
gzinit("192.168.198.129",14581)
```

Assign and Retrieve Gazebo Model Information

List the models available in the Gazebo world.

```
modelList = gzmodel("list")
```

```
modelList = 1×11 string
    "ground_plane"    "unit_box"    "camera0"    "camera1"    "depth_camera0"    "depth_camera1"
```

Assign values to the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[status,message] = gzmodel("set","unit_box","Position",[2 2 0.5],"SelfCollide","on")
```

```
status = 1×2 logical array

   1   1

message = 1×2 string
    "Position parameter set successfully."    "SelfCollide parameter set successfully."
```

Retrieve the values of the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[position,selfcollide] = gzmodel("get","unit_box","Position","SelfCollide")
```

```
position = 1×3

                         2                         2           0.4999999999951

selfcollide = logical
   1
```

Assign and Retrieve Gazebo Model Link Information

List the links available in the `unit_box` model.

```
linkList = gzlink("list","unit_box")
```

```
linkList = 
"link"
```

Assign values to the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[status,message] = gzlink("set","unit_box","link","Mass",2,"Gravity","off")
```

```
status = 1×2 logical array

   1   1

message = 1×2 string
    "Mass parameter set successfully."    "Gravity parameter set successfully."
```

Retrieve the values of the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[mass,gravity] = gzlink("get","unit_box","link","Mass","Gravity")
```

```
mass = 
     2

gravity = logical
   0
```

Assign and Retrieve Gazebo Model Joint Information

List the joints available in the `unit_box` model.

```
jointList = gzjoint("list","unit_box")
```

```
jointList = 
"joint"
```

Assign a value to the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
[status,message] = gzjoint("set","unit_box","joint","Axis","0","Damping",0.25)
```

```
status = logical
   1

message = 
"Damping parameter set successfully."
```

Retrieve the value of the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
damping = gzjoint("get","unit_box","joint","Axis0","Damping")
```

```
damping = 
                      0.25
```

Reset all Gazebo model configurations.

```
gzworld("reset")
```

Input Arguments

`modelname` — Gazebo model name
string scalar | character vector

Gazebo model name, specified as a string scalar or character vector.

Data Types: `char` | `string`

`linkname` — Associated link name
string scalar | character vector

Associated link name, specified as a string scalar or character vector.

Data Types: `char` | `string`

`params` — Gazebo model link parameters
string scalars | character vectors

Gazebo model link parameters, specified as a comma-separated list of string scalars or character vectors. Specify the list of parameters you want to retrieve the values, from this table.

Parameters	Description
`"Canonical"`	Get the canonical parameter of the Gazebo model link.
`"EnableWind"`	Get the wind parameter of the Gazebo model link.
`"Gravity"`	Get the gravity parameter of the Gazebo model link.
`"IsStatic"`	Get the IsStatic parameter of the Gazebo model link.
`"Kinematic"`	Get the kinematic parameter of the Gazebo model link.
`"Mass"`	Get the mass parameter of the Gazebo model link.
`"Orientation"`	Get the orientation parameter of the Gazebo model link.
`"Position"`	Get the position parameter of the Gazebo model link.
`"PrincipalMoments"`	Get the principal moments parameter of the Gazebo model link.
`"ProductOfInertia"`	Get the product of inertia parameter of the Gazebo model link.
`"SelfCollide"`	Get the SelfCollide parameter of the Gazebo model link.

Example: `[mass,gravity] = gzlink("get","unit_box","link","Mass","Gravity")`

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: For example, `gzlink("set","unit_box","link","Position",[2 2 0.5])` sets the position of the link in the model `unit_box`.

`Canonical` — Gazebo model link canonical parameter
`'on'` | `'off'`

Gazebo model link canonical parameter, specified as the comma-separated pair consisting of `'Canonical'` and either `'on'` or `'off'`.

Example: `[status,message] = gzlink("set","unit_box","link","Canonical","off");`

Data Types: `char` | `string`

`EnableWind` — Gazebo model link wind parameter
`'on'` | `'off'`

Gazebo model link wind parameter, specified as the comma-separated pair consisting of `'EnableWind'` and either `'on'` or `'off'`.

Example: `[status,message] = gzlink("set","unit_box","link","EnableWind","off");`

Data Types: `char` | `string`

`Gravity` — Gazebo model link gravity parameter
`'on'` | `'off'`

Gazebo model link gravity parameter, specified as the comma-separated pair consisting of `'Gravity'` and either `'on'` or `'off'`.

Example: `[status,message] = gzlink("set","unit_box","link","Gravity","off");`

Data Types: `char` | `string`

`IsStatic` — Gazebo model link IsStatic parameter
`'on'` | `'off'`

Gazebo model link IsStatic parameter, specified as the comma-separated pair consisting of `'IsStatic'` and either `'on'` or `'off'`.

Example: `[status,message] = gzlink("set","unit_box","link","IsStatic","off");`

Data Types: `char` | `string`

`Kinematic` — Gazebo model link kinematic parameter
`'on'` | `'off'`

Gazebo model link kinematic parameter, specified as the comma-separated pair consisting of `'Kinematic'` and either `'on'` or `'off'`.

Example: `[status,message] = gzlink("set","unit_box","link","Kinematic","off");`

Data Types: `char` | `string`

`Mass` — Gazebo model link mass parameter
numeric scalar

Gazebo model link mass parameter, specified as the comma-separated pair consisting of `'Mass'` and a numeric scalar in kilograms.

Example: `[status,message] = gzlink("set","unit_box","link","Mass",1);`

Data Types: `single` | `double`

`Orientation` — Gazebo model link orientation parameter
four-element vector

Gazebo model link orientation parameter, specified as the comma-separated pair consisting of `'Orientation'` and a four-element quaternion vector of the form [*w x y z*].

Example: `[status,message] = gzlink("set","unit_box","link","Orientation",[1 0 0 0]);`

Data Types: `single` | `double`

`Position` — Gazebo model link position
three-element vector

Gazebo model link position parameter, specified as the comma-separated pair consisting of `'Position'` and a three-element vector of the form [*x y z*] in meters.

Example: `[status,message] = gzlink("set","unit_box","link","Position",[0 0 0]);`

Data Types: `single` | `double`

`PrincipalMoments` — Gazebo model link principal moments
three-element vector

Gazebo model link principal moments parameter, specified as the comma-separated pair consisting of `'PrincipalMoments'` and a three-element vector of the form [*ixx iyy izz*] in kilogram square meters.

Example: `[status,message] = gzlink("set","unit_box","link","PrincipalMoments",[0 0 0]);`

Data Types: `single` | `double`

`ProductOfInertia` — Gazebo model link product of inertia
three-element vector

Gazebo model link product of inertia parameter, specified as the comma-separated pair consisting of `'ProductOfInertia'` and a three-element vector of the form [*ixy ixz iyz*] in kilogram square meters.

Example: `[status,message] = gzlink("set","unit_box","link","ProductOfInertia",[0 0 0]);`

Data Types: `single` | `double`

`SelfCollide` — Gazebo model link SelfCollide parameter
`'on'` | `'off'`

Gazebo model link SelfCollide parameter, specified as the comma-separated pair consisting of `'SelfCollide'` and either `'on'` or `'off'`.

Example: `[status,message] = gzlink("set","unit_box","link","SelfCollide","off");`

Data Types: `char` | `string`

Output Arguments

`List` — List of links in model
cell array of character vectors

List of links in the model, returned as a cell array of character vectors.

`Status` — Status of values assigned to parameters
logical array

Status of the values assigned to the parameters, returned as a logical array.

`Message` — Success or failure message
string array

Success or failure message, returned as a string array.

`Output1,...,OutputN` — Values of specified parameters
logical scalar | numeric scalar | numeric vector

Values of specified parameters, returned as a logical or numeric vector based on the specified parameters. The following table shows the returned data type of parameter values.

Parameters	Description
`"Canonical"`	Gazebo model link canonical parameter, returns a logical scalar.
`"EnableWind"`	Gazebo model link wind parameter, returns a logical scalar.
`"Gravity"`	Gazebo model link gravity parameter, returns a logical scalar.
`"IsStatic"`	Gazebo model link IsStatic parameter, returns a logical scalar.
`"Kinematic"`	Gazebo model link kinematic parameter, returns a logical scalar.
`"Mass"`	Gazebo model link mass parameter, returns a numeric scalar in kilograms.
`"Orientation"`	Gazebo model link orientation parameter, returns a four-element quaternion vector of the form [*w x y z*].
`"Position"`	Gazebo model link position parameter, returns a three-element vector of the form [*x y z*] in meters.
`"PrincipalMoments"`	Gazebo model link principal moments parameter, returns a three-element vector of the form [*ixx iyy izz*] in kilogram square meters.
`"ProductOfInertia"`	Gazebo model link product of inertia parameter, returns a three-element vector of the form [*ixy ixz iyz*] in kilogram square meters.
`"SelfCollide"`	Gazebo model link SelfCollide parameter, returns a logical scalar.

Limitations

- `gzlink` function not supported with MATLAB Compiler.

See Also

`gzinit` | `gzjoint` | `gzmodel` | `gzworld`

Introduced in R2021a

gzmodel

Assign and retrieve Gazebo model information

Syntax

```
List = gzmodel("list")
[Links,Joints] = gzmodel("info",modelname)
[Status,Message] = gzmodel("set",modelname,Name,Value)
[Output1,...,OutputN] = gzmodel("get",modelname,params)
sdfString = gzmodel("importSDF",modelname)
```

Description

`List = gzmodel("list")` returns and displays a list of model names `List` available in the Gazebo world.

If you do not define the output argument, the model names are returned in the MATLAB Command Window.

`[Links,Joints] = gzmodel("info",modelname)` returns and displays a list of link names `Links` and joint names `Joints` of the specified Gazebo model `modelname`.

If you do not define the output argument, the model info is returned in the MATLAB Command Window.

`[Status,Message] = gzmodel("set",modelname,Name,Value)` assigns values to the model parameters using one or more name-value pair arguments for the specified Gazebo model `modelname`. The function returns the status of the value assignments `Status` and the message of their success and failure `Message`. For example, `gzmodel("set","unit_box","Position",[2 2 0.5])` sets the position of the model `unit_box`.

If you do not define the output argument, the status and message are returned in the MATLAB Command Window.

`[Output1,...,OutputN] = gzmodel("get",modelname,params)` retrieves values of the model parameters using one or more parameter name, `params`, for the specified Gazebo model `modelname`. The function returns one or more outputs `Output1,...,OutputN`, corresponding to the specified parameter names.

If you do not define the output argument, the model parameters are returned in the MATLAB Command Window.

`sdfString = gzmodel("importSDF",modelname)` returns the Simulation Description Format (SDF) of the specified Gazebo model as a string.

If you do not define the output argument, the SDF model description are returned in the MATLAB Command Window.

Examples

Perform Co-Simulation Between MATLAB and Gazebo

Set up a simulation between MATLAB and Gazebo, receive data from Gazebo, and send commands to Gazebo.

Download the Linux virtual machine (VM) with Gazebo installed from Virtual Machine with ROS and Gazebo.

Set up `multiSensorPluginTest.world` by following the Gazebo simulation environment setup and launch steps in “Perform Co-Simulation between Simulink and Gazebo”.

Configure and Perform Gazebo Co-Simulation

Initialize connection settings and check connectivity with the Gazebo plugin running on `192.168.198.129` and port `14581.`

```
gzinit("192.168.198.129",14581)
```

Assign and Retrieve Gazebo Model Information

List the models available in the Gazebo world.

```
modelList = gzmodel("list")
```

```
modelList = 1×11 string
    "ground_plane"    "unit_box"    "camera0"    "camera1"    "depth_camera0"    "depth_camera1"
```

Assign values to the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[status,message] = gzmodel("set","unit_box","Position",[2 2 0.5],"SelfCollide","on")
```

```
status = 1×2 logical array

   1   1


message = 1×2 string
    "Position parameter set successfully."    "SelfCollide parameter set successfully."
```

Retrieve the values of the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[position,selfcollide] = gzmodel("get","unit_box","Position","SelfCollide")
```

```
position = 1×3

                         2                          2            0.4999999999951


selfcollide = logical
   1
```

Assign and Retrieve Gazebo Model Link Information

List the links available in the `unit_box` model.

```
linkList = gzlink("list","unit_box")
linkList = 
"link"
```

Assign values to the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[status,message] = gzlink("set","unit_box","link","Mass",2,"Gravity","off")
```

```
status = 1×2 logical array

   1   1


message = 1×2 string
    "Mass parameter set successfully."    "Gravity parameter set successfully."
```

Retrieve the values of the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[mass,gravity] = gzlink("get","unit_box","link","Mass","Gravity")
```

```
mass = 
     2


gravity = logical
   0
```

Assign and Retrieve Gazebo Model Joint Information

List the joints available in the `unit_box` model.

```
jointList = gzjoint("list","unit_box")
```

```
jointList = 
"joint"
```

Assign a value to the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
[status,message] = gzjoint("set","unit_box","joint","Axis","0","Damping",0.25)
```

```
status = logical
   1


message = 
"Damping parameter set successfully."
```

Retrieve the value of the joint parameter `Damping` of the axis `Axis0` for the joint `joint` in the `unit_box` model.

```
damping = gzjoint("get","unit_box","joint","Axis0","Damping")
```

```
damping = 
                      0.25
```

Reset all Gazebo model configurations.

```
gzworld("reset")
```

Input Arguments

`modelname` — Gazebo model name
string scalar | character vector

Gazebo model name, specified as a string scalar or character vector.

Data Types: `char` | `string`

`params` — Gazebo model parameters
string scalars | character vectors

Gazebo model parameters, specified as a comma-separated list of string scalars or character vectors. Specify the list of parameters you want to retrieve the values, from this table.

Parameters	Description
`"EnableWind"`	Get the wind parameter of the Gazebo model.
`"IsStatic"`	Get the IsStatic parameter of the Gazebo model.
`"Orientation"`	Get the orientation parameter of the Gazebo model.
`"Position"`	Get the position parameter of the Gazebo model.
`"SelfCollide"`	Get the SelfCollide parameter of the Gazebo model.

Example: `[position,selfcollide] = gzmodel("get","unit_box","Position","SelfCollide")`

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: For example, `gzmodel("set","unit_box","Position",[2 2 0.5])` sets the position of the model `unit_box`.

`EnableWind` — Gazebo model wind parameter
`'on'` | `'off'`

Gazebo model wind parameter, specified as the comma-separated pair consisting of `'EnableWind'` and either `'on'` or `'off'`.

Example: `[status,message] = gzmodel("set","unit_box","EnableWind","off");`

Data Types: `char` | `string`

`IsStatic` — Gazebo model IsStatic parameter
`'on'` | `'off'`

Gazebo model IsStatic parameter, specified as the comma-separated pair consisting of `'IsStatic'` and either `'on'` or `'off'`.

Example: `[status,message] = gzmodel("set","unit_box","IsStatic","off");`

Data Types: `char` | `string`

`Orientation` — Gazebo model orientation parameter
four-element vector

Gazebo model orientation parameter, specified as the comma-separated pair consisting of `'Orientation'` and a four-element quaternion vector of the form [*w x y z*].

Example: `[status,message] = gzmodel("set","unit_box","Orientation",[1 0 0 0]);`

Data Types: `single` | `double`

`Position` — Gazebo model position
three-element vector

Gazebo model position parameter, specified as the comma-separated pair consisting of `'Position'` and a three-element vector of the form [*x y z*] in meters.

Example: `[status,message] = gzmodel("set","unit_box","Position",[0 0 0]);`

Data Types: `single` | `double`

`SelfCollide` — Gazebo model SelfCollide parameter
`'on'` | `'off'`

Gazebo model SelfCollide parameter, specified as the comma-separated pair consisting of `'SelfCollide'` and either `'on'` or `'off'`.

Example: `[status,message] = gzmodel("set","unit_box","SelfCollide","off");`

Data Types: `char` | `string`

Output Arguments

`List` — List of models
cell array of character vectors

List of models, returned as a cell array of character vectors.

`Links` — List of links in model
cell array of character vectors

List of links in the model, returned as a cell array of character vectors.

`Joints` — List of joints in model
cell array of character vectors

List of joints in the model, returned as a cell array of character vectors.

`Status` — Status of values assigned to parameters
logical array

Status of the values assigned to the parameters, returned as a logical array.

`Message` — Success or failure message
string array

Success or failure message, returned as a string array.

`Output1,...,OutputN` — Values of specified parameters
logical scalar | numeric vector

Values of specified parameters, returned as a logical or numeric vector based on the specified parameters. The following table shows the returned data type of parameter values.

Parameters	Description
`"EnableWind"`	Gazebo model wind parameter, returns a logical scalar.
`"IsStatic"`	Gazebo model IsStatic parameter, returns a logical scalar.
`"Orientation"`	Gazebo model orientation parameter, returns a four-element quaternion vector of the form [*w x y z*].
`"Position"`	Gazebo model position parameter, returns a three-element vector of the form [*x y z*] in meters.
`"SelfCollide"`	Gazebo model SelfCollide parameter, returns a logical scalar.

Limitations

- `gzmodel` function not supported with MATLAB Compiler.

See Also

`gzinit` | `gzlink` | `gzjoint` | `gzworld`

Introduced in R2021a

gzworld

Interact with Gazebo world

Syntax

```
gzworld("reset")
```

Description

`gzworld("reset")` resets all Gazebo model configurations and Gazebo simulation time.

Examples

Perform Co-Simulation Between MATLAB and Gazebo

Set up a simulation between MATLAB and Gazebo, receive data from Gazebo, and send commands to Gazebo.

Download the Linux virtual machine (VM) with Gazebo installed from Virtual Machine with ROS and Gazebo.

Set up `multiSensorPluginTest.world` by following the Gazebo simulation environment setup and launch steps in “Perform Co-Simulation between Simulink and Gazebo”.

Configure and Perform Gazebo Co-Simulation

Initialize connection settings and check connectivity with the Gazebo plugin running on `192.168.198.129` and port `14581`.

```
gzinit("192.168.198.129",14581)
```

Assign and Retrieve Gazebo Model Information

List the models available in the Gazebo world.

```
modelList = gzmodel("list")
```

```
modelList = 1×11 string
    "ground_plane"    "unit_box"    "camera0"    "camera1"    "depth_camera0"    "depth_camera1"
```

Assign values to the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[status,message] = gzmodel("set","unit_box","Position",[2 2 0.5],"SelfCollide","on")
```

```
status = 1×2 logical array

   1   1
```

```
message = 1×2 string
    "Position parameter set successfully."    "SelfCollide parameter set successfully."
```

Retrieve the values of the `Position` and `SelfCollide` parameters of the `unit_box` model.

```
[position,selfcollide] = gzmodel("get","unit_box","Position","SelfCollide")
```

```
position = 1×3

                         2                         2          0.4999999999951

selfcollide = logical
   1
```

Assign and Retrieve Gazebo Model Link Information

List the links available in the `unit_box` model.

```
linkList = gzlink("list","unit_box")
```

```
linkList = 
"link"
```

Assign values to the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[status,message] = gzlink("set","unit_box","link","Mass",2,"Gravity","off")
```

```
status = 1×2 logical array

   1   1

message = 1×2 string
    "Mass parameter set successfully."    "Gravity parameter set successfully."
```

Retrieve the values of the link parameters `Mass` and `Gravity` of the link `link` in the `unit_box` model.

```
[mass,gravity] = gzlink("get","unit_box","link","Mass","Gravity")
```

```
mass = 
     2

gravity = logical
   0
```

Assign and Retrieve Gazebo Model Joint Information

List the joints available in the `unit_box` model.

```
jointList = gzjoint("list","unit_box")
```

```
jointList = 
"joint"
```

Assign a value to the joint parameter Damping of the axis Axis0 for the joint joint in the unit_box model.

```
[status,message] = gzjoint("set","unit_box","joint","Axis","0","Damping",0.25)
```

```
status = logical
   1


message = 
"Damping parameter set successfully."
```

Retrieve the value of the joint parameter Damping of the axis Axis0 for the joint joint in the unit_box model.

```
damping = gzjoint("get","unit_box","joint","Axis0","Damping")
```

```
damping = 
                      0.25
```

Reset all Gazebo model configurations.

```
gzworld("reset")
```

Limitations

- gzworld function not supported with MATLAB Compiler.

See Also

gzinit | gzlink | gzjoint | gzmodel

Introduced in R2021a

hom2cart

Convert homogeneous coordinates to Cartesian coordinates

Syntax

```
cart = hom2cart(hom)
```

Description

`cart = hom2cart(hom)` converts a set of homogeneous points to Cartesian coordinates.

Examples

Convert Homogeneous Points to 3-D Cartesian Points

```
h = [0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5];
c = hom2cart(h)
```

```
c = 2×3

    0.5570    1.9150    0.3152
    1.0938    1.9298    1.9412
```

Input Arguments

hom — Homogeneous points
n-by-*k* matrix

Homogeneous points, specified as an *n*-by-*k* matrix, containing *n* points. *k* must be greater than or equal to 2.

Example: `[0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5]`

Output Arguments

`cart` — Cartesian coordinates
n-by-(*k*–1) matrix

Cartesian coordinates, returned as an *n*-by-(*k*–1) matrix, containing *n* points. Each row of `cart` represents a point in (*k*–1)-dimensional space. *k* must be greater than or equal to 2.

Example: `[0.8147 0.1270 0.6324; 0.9058 0.9134 0.0975]`

Extended Capabilities

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

See Also

`cart2hom`

Topics

"Coordinate Transformations in Robotics"

Introduced in R2015a

importrobot

Import rigid body tree model from URDF, SDF file, text, or Simscape Multibody model

Syntax

```
robot = importrobot(filename)
robot = importrobot(URDFtext)
robot = importrobot(SDFtext)
robot = importrobot( ___ ,format)
robot = importrobot( ___ ,Name,Value)

[robot,importInfo] = importrobot(model)
[robot,importInfo] = importrobot( ___ ,Name,Value)
```

Description

URDF or SDF Import

`robot = importrobot(filename)` returns a `rigidBodyTree` object by parsing the Unified Robot Description Format (URDF) or Simulation Description Format (SDF) file specified by `filename`.

`robot = importrobot(URDFtext)` parses the URDF text. Specify `URDFtext` as a string scalar or character vector.

`robot = importrobot(SDFtext)` parses the SDF text. Specify `SDFtext` as a string scalar or character vector.

`robot = importrobot( ___ ,format)` explicitly specifies the type of the robot description in addition to any combination of input arguments from previous syntaxes. If the format of the text file does not match the format specified in the `format` argument, the function returns an error.

`robot = importrobot( ___ ,Name,Value)` specifies options using one or more name-value pair arguments in addition to any combination of input arguments from previous syntaxes. Use the “URDF or SDF Import” on page 2-0 name-value pairs to import a model from URDF, SDF file, or text.

Simscape Multibody Model Import

`[robot,importInfo] = importrobot(model)` imports a Simscape Multibody model and returns an equivalent `rigidBodyTree` object and information about the import in `importInfo`. Only fixed, prismatic, and revolute joints are supported in the output `rigidBodyTree` object.

`[robot,importInfo] = importrobot( ___ ,Name,Value)` specifies options using one or more name-value pair arguments in addition to the Simscape Multibody model from the previous syntax. Use the “Simscape Multibody Model Import” on page 2-0 name-value pairs to import a model that uses other joint types, constraint blocks, or variable inertias.

Examples

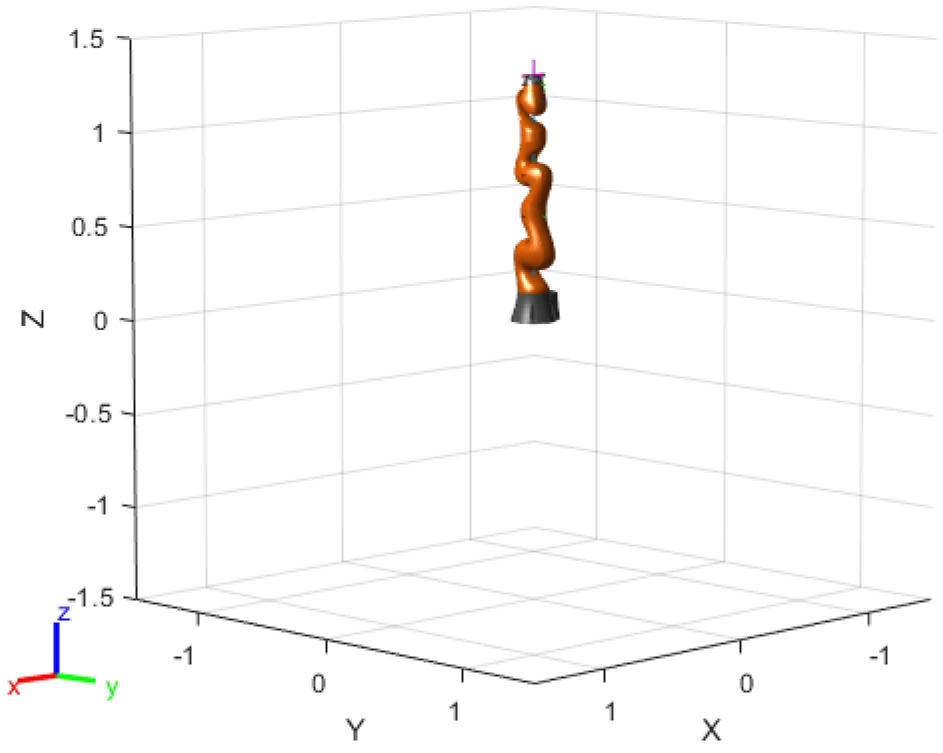
Import Robot from URDF File

Import a URDF file as a `rigidBodyTree` object.

```
robot = importrobot('iiwa14.urdf')
```

```
robot = 
  rigidBodyTree with properties:

     NumBodies: 10
        Bodies: {1x10 cell}
          Base: [1x1 rigidBody]
     BodyNames: {1x10 cell}
      BaseName: 'world'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

```
show(robot)
```



```
ans = 
  Axes (Primary) with properties:

             XLim: [-1.5000 1.5000]
             YLim: [-1.5000 1.5000]
           XScale: 'linear'
           YScale: 'linear'
    GridLineStyle: '-'
```

```
         Position: [0.1300 0.1100 0.7750 0.8150]
            Units: 'normalized'

  Show all properties
```

Import Robot from URDF Character Vector

Specify the URDF character vector. This character vector is a minimalist description for creating a valid robot model.

```
URDFtext = '<?xml version="1.0" ?><robot name="min"><link name="L0"/></robot>';
```

Import the robot model. The description creates a `rigidBodyTree` object that has only a robot base link named `'L0'`.

```
robot = importrobot(URDFtext)
```

```
robot = 
  rigidBodyTree with properties:

     NumBodies: 0
        Bodies: {1x0 cell}
          Base: [1x1 rigidBody]
     BodyNames: {1x0 cell}
      BaseName: 'L0'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Display Robot Model with Visual Geometries

You can import robots that have `.stl` files associated with the Unified Robot Description format (URDF) file to describe the visual geometries of the robot. Each rigid body has an individual visual geometry specified. The `importrobot` function parses the URDF file to get the robot model and visual geometries. The function assumes that visual geometry and collision geometry of the robot are the same and assigns the visual geometries as collision geometries of corresponsing bodies.

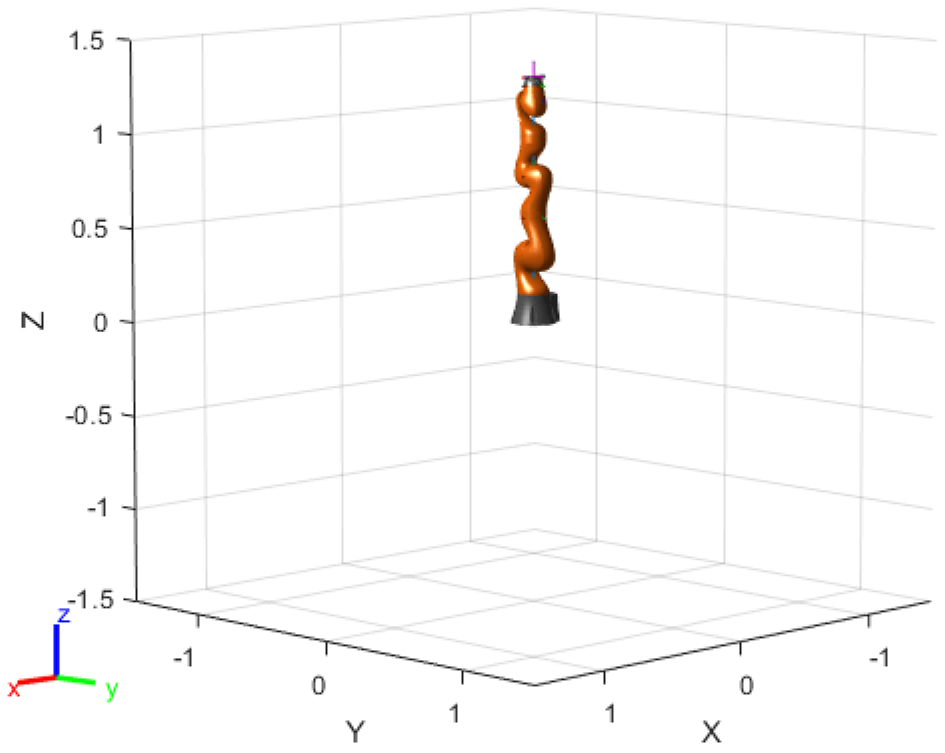
Use the `show` function to display the visual and collosion geometries of the robot model in a figure. You can then interact with the model by clicking components to inspect them and right-clicking to toggle visibility.

Import a robot model as a URDF file. The `.stl` file locations must be properly specified in this URDF. To add other `.stl` files to individual rigid bodies, see `addVisual`.

```
robot = importrobot('iiwa14.urdf');
```

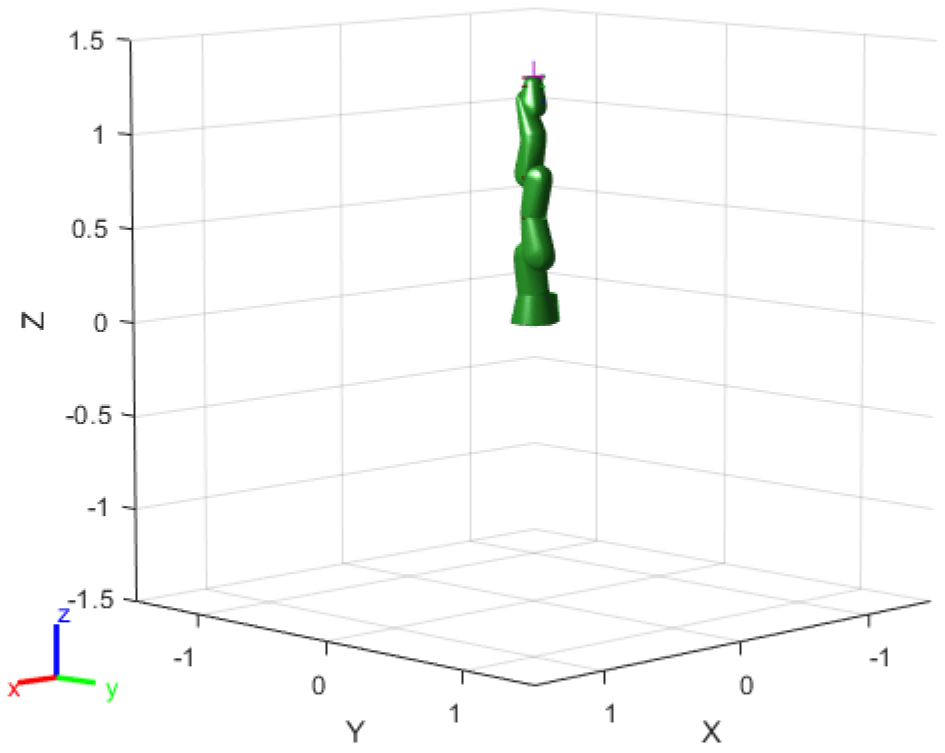
Visualize the robot with the associated visual model. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each visual geometry.

```
show(robot,'visuals','on','collision','off');
```



Visualize the robot with the associated collision geometries. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each collision geometry.

```
show(robot,'visuals','off','collision','on');
```



Import Simscape™ Multibody™ model to `RigidBodyTree` Object

Import an existing Simscape™ Multibody™ robot model into the Robotics System Toolbox™ as a `rigidBodyTree` object.

Open the Simscape™ Multibody™ model. This is a model for a humanoid robot.

```
open_system('example_smhumanoidrobot.slx')
```

Import the model.

```
[robot,importInfo] = importrobot(gcs)
```

```
robot = 
  rigidBodyTree with properties:

     NumBodies: 21
        Bodies: {1x21 cell}
          Base: [1x1 rigidBody]
     BodyNames: {1x21 cell}
      BaseName: 'Base'
       Gravity: [0 0 -9.8066]
    DataFormat: 'struct'
```

```
importInfo = 
  rigidBodyTreeImportInfo with properties:

        SourceModelName: 'example_smhumanoidrobot'
          RigidBodyTree: [1x1 rigidBodyTree]
    BlockConversionInfo: [1x1 struct]
```

Display details about the created `rigidBodyTree` object.

```
showdetails(importInfo)
```

```
--------------------
Robot: (21 bodies)

 Idx     Body Name     Simulink Source Blocks     Joint Name     Simulink Source Blocks   Joint T
 ---     ---------     ----------------------     ----------     ----------------------   -------
   1        Body01    Info | List | Highlight        Joint01    Info | List | Highlight     revol
   2        Body02    Info | List | Highlight        Joint02    Info | List | Highlight     revol
   3        Body03    Info | List | Highlight        Joint03    Info | List | Highlight     revol
   4        Body04    Info | List | Highlight        Joint04    Info | List | Highlight     revol
   5        Body05    Info | List | Highlight        Joint05    Info | List | Highlight     revol
   6        Body06    Info | List | Highlight        Joint06    Info | List | Highlight     revol
   7        Body07    Info | List | Highlight        Joint07    Info | List | Highlight     revol
   8        Body08    Info | List | Highlight        Joint08    Info | List | Highlight     revol
   9        Body09    Info | List | Highlight        Joint09    Info | List | Highlight     revol
  10        Body10    Info | List | Highlight        Joint10    Info | List | Highlight     revol
  11        Body11    Info | List | Highlight        Joint11    Info | List | Highlight     revol
  12        Body12    Info | List | Highlight        Joint12    Info | List | Highlight     revol
  13        Body13    Info | List | Highlight        Joint13    Info | List | Highlight     revol
  14        Body14    Info | List | Highlight        Joint14    Info | List | Highlight     revol
  15        Body15    Info | List | Highlight        Joint15    Info | List | Highlight     revol
  16        Body16    Info | List | Highlight        Joint16    Info | List | Highlight     revol
  17        Body17    Info | List | Highlight        Joint17    Info | List | Highlight     revol
  18        Body18    Info | List | Highlight        Joint18    Info | List | Highlight     revol
  19        Body19    Info | List | Highlight        Joint19    Info | List | Highlight        fi
  20        Body20    Info | List | Highlight        Joint20    Info | List | Highlight        fi
  21        Body21    Info | List | Highlight        Joint21    Info | List | Highlight        fi
--------------------
```

Input Arguments

`filename` — Name of URDF or SDF file
string scalar | character vector

Name of the URDF or SDF file, specified as a string scalar or character vector. This file must be a valid URDF robot description or SDF model description.

Included Robot Models with Mesh Data

Robot Model	Description
`"iiwa7.urdf"`	KUKA LBR iiwa 7 R800 7-axis robot
`"iiwa14.urdf"`	URDF version of KUKA LBR iiwa 14 R820 7-axis robot
`"iiwa14.sdf"`	SDF version of KUKA LBR iiwa 14 R820 7-axis robot
`"sawyer.urdf"`	Rethink Robotics Sawyer 7-axis robot

To download the mesh data for the included robot models without the mesh data, install Robotics System Toolbox Robot Library Data support package. See “Get and Manage Add-Ons”.

Included Robot Models without Mesh Data

Robot Model	Description
`"abbIrb120.urdf"`	ABB IRB 120 6-axis robot
`"abbIrb120T.urdf"`	ABB IRB 120T 6-axis robot
`"abbIrb1600.urdf"`	ABB IRB 1600 6-axis robot
`"abbYuMi.urdf"`	ABB YuMi 2-armed robot
`"amrPioneer3AT.urdf"`	Adept MobileRobots Pioneer 3-AT mobile robot
`"amrPioneer3DX.urdf"`	Adept MobileRobots Pioneer 3-DX mobile robot
`"amrPioneerLX.urdf"`	Adept MobileRobots Pioneer LX mobile robot
`"atlas.urdf"`	Boston Dynamics ATLAS® Humanoid robot
`"clearpathHusky.urdf"`	Clearpath Robotics Husky mobile robot
`"clearpathJackal.urdf"`	Clearpath Robotics Jackal mobile robot
`"clearpathTurtleBot2.urdf"`	Clearpath Robotics TurtleBot 2 mobile robot
`"fanucLRMate200ib.urdf"`	FANUC LR Mate 200iB 6-axis robot
`"fanucM16ib.urdf"`	FANUC M-16iB 6-axis robot
`"frankaEmikaPanda.urdf"`	Franka Emika Panda 7-axis robot
`"kinovaGen3.urdf"`	Version 1 of KINOVA® Gen3 7-axis robot
`"kinovaGen3V12.urdf"`	Version 2 of KINOVA® Gen3 7-axis robot
`"kinovaJacoJ2N6S200.urdf"`	KINOVA JACO® 2-fingered 6 DOF robot with non-spherical wrist
`"kinovaJacoJ2N6S300.urdf"`	KINOVA JACO® 3-fingered 6 DOF robot with non-spherical wrist
`"kinovaJacoJ2N7S300.urdf"`	KINOVA JACO® 3-fingered 7 DOF robot with non-spherical wrist
`"kinovaJacoJ2S6S300.urdf"`	KINOVA JACO® 3-fingered 6 DOF robot with spherical wrist
`"kinovaJacoJ2S7S300.urdf"`	KINOVA JACO® 3-fingered 7 DOF robot with spherical wrist
`"kinovaJacoTwoArmExample.urdf"`	Two KINOVA JACO® 3-fingered 6 DOF robots with non-spherical wrist
`"kinovaMicoM1N4S200.urdf"`	KINOVA MICO® 2-fingered 4 DOF robot
`"kinovaMicoM1N6S200.urdf"`	KINOVA MICO® 2-fingered 6 DOF robot
`"kinovaMicoM1N6S300.urdf"`	KINOVA MICO® 3-fingered 6 DOF robot
`"kinovaMovo.urdf"`	KINOVA MOVO® 2-armed mobile robot
`"kukaIiwa7.urdf"`	KUKA LBR iiwa 7 R800 7-axis robot
`"kukaIiwa14.urdf"`	KUKA LBR iiwa 14 R820 7-axis robot
`"quanserQArm.urdf"`	Quanser QArm 4 DOF robot
`"quanserQBot2e.urdf"`	Quanser QBot 2e mobile robot
`"quanserQCar.urdf"`	Quanser QCar mobile robot

Robot Model	Description
`"rethinkBaxter.urdf"`	Rethink Robotics Baxter 2-armed robot
`"rethinkSawyer.urdf"`	Rethink Robotics Sawyer 7-axis robot
`"robotisOP2.urdf"`	ROBOTIS OP2 Humanoid robot
`"robotisOpenManipulator.urdf"`	ROBOTIS OpenMANIPULATOR 4-axis robot with gripper
`"robotisTurtleBot3Burger.urdf"`	ROBOTIS TurtleBot 3 Burger robot
`"robotisTurtleBot3Waffle.urdf"`	ROBOTIS TurtleBot 3 Waffle robot
`"robotisTurtleBot3WaffleForOpenManipulator.urdf"`	ROBOTIS TurtleBot 3 Waffle robot with OpenMANIPULATOR
`"robotisTurtleBot3WafflePi.urdf"`	ROBOTIS TurtleBot 3 Waffle Pi robot
`"robotisTurtleBot3WafflePiForOpenManipulator.urdf"`	ROBOTIS TurtleBot 3 Waffle Pi robot with OpenMANIPULATOR
`"universalUR3.urdf"`	Universal Robots UR3 6-axis robot
`"universalUR5.urdf"`	Universal Robots UR5 6-axis robot
`"universalUR10.urdf"`	Universal Robots UR10 6-axis robot
`"valkyrie.urdf"`	NASA Valkyrie Humanoid robot
`"willowgaragePR2.urdf"`	Willow Garage PR2 mobile robot
`"yaskawaMotomanMH5.urdf"`	Yaskawa Motoman MH5 6-axis robot

Example: `"robot_file.urdf"`

Example: `"robot_file.sdf"`

Data Types: `char` | `string`

`URDFtext` — URDF robot text
string scalar | character vector

URDF robot text, specified as a string scalar or character vector.

Example: `"<?xml version="1.0" ?><robot name="min"><link name="L0"/></robot>"`

Example: `"robot_file.txt","urdf"`

Data Types: `char` | `string`

`SDFtext` — SDF model text
string scalar | character vector

SDF model text, specified as a string scalar or character vector.

Example: `"<?xml version="1.0" ?><sdf version="1.6"><model name="min"><link name="L0"/></model></sdf>"`

Example: `"robot_file.txt","sdf"`

Data Types: `char` | `string`

`format` — File format of robot description text file
`'urdf'` | `'sdf'`

File format of robot description text file, specified as a string scalar or character vector. Use this argument to specify explicitly the required format for the robot description file.

Example: `"robot_file.txt","urdf"`

Example: `"robot_file.txt","sdf"`

Data Types: `char` | `string`

`model` — Simscape Multibody model
model handle | string scalar | character vector

Simscape Multibody model, specified as a model handle, string scalar, or character vector.

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: `"MeshPath",{"../arm_meshes","../body_meshes"}`

URDF or SDF Import

`MeshPath` — Relative search paths for mesh files
string scalar | character vector | cell array of string scalars or character vectors

Relative search paths for mesh files, specified as a string scalar, character vector, or cell array of string scalars or character vectors. Mesh files must still be specified inside the URDF or SDF file, but `MeshPath` defines the relative paths for these specified files.

Data Types: `char` | `string` | `cell`

`DataFormat` — Input/output data format for kinematics and dynamics functions
`"struct"` (default) | `"row"` | `"column"`

Input/output data format for the kinematics and dynamics functions of the robot model, specified as the comma-separated pair consisting of `'DataFormat'` and `"struct"`, `"row"`, or `"column"`. To use dynamics functions, you must specify either `"row"` or `"column"`. This name-value pair sets the DataFormat property of the `rigidBodyTree` robot model.

Data Types: `char` | `string`

`SDFModel` — Select model from SDF that contain multiple models
string scalar | character vector

Select a model from the SDF file or text that contain multiple models, specified as a string scalar or character vector.

Note This name-value pair only applies to the SDF model and text.

Data Types: `char` | `string`

Simscape Multibody Model Import

`BreakChains` — Indicates whether to break closed chains
`"error"` (default) | `"remove-joints"`

Indicates whether to break closed chains in the given `model` input, specified as `"error"` or `"remove-joints"`. If you specify `"remove-joints"`, the resulting `robot` output has chain closure joints removed. Otherwise, the function throws an error.

Data Types: `char` | `string`

`ConvertJoints` — Indicates whether to convert unsupported joints to fixed
`"error"` (default) | `"convert-to-fixed"`

Indicates whether to convert unsupported joints to fixed joints in the given `model` input, specified as `"error"` or `"convert-to-fixed"`. If you specify `"convert-to-fixed"`, the resulting `robot` output has any unsupported joints converted to fixed joints. Only fixed, prismatic, and revolute joints are supported in the output `rigidBodyTree` object. Otherwise, if the `model` contains unsupported joints, the function throws an error.

Data Types: `char` | `string`

`SMContraints` — Indicates whether to remove constraint blocks
`"error"` (default) | `"remove"`

Indicates whether to remove constraint blocks in the given `model` input, specified as `"error"` or `"remove"`. If you specify `"remove"`, the resulting `robot` output has the constraints removed. Otherwise, if the `model` contains constraint blocks, the function throws an error.

Data Types: `char` | `string`

`VariableInertias` — Indicates whether to remove variable inertia blocks
`"error"` (default) | `"remove"`

Indicates whether to remove variable inertia blocks in the given `model` input, specified as `"error"` or `"remove"`. If you specify `"remove"`, the resulting `robot` output has the variable inertias removed. Otherwise, if the `model` contains variable inertia blocks, the function throws an error.

Data Types: `char` | `string`

`DataFormat` — Input/output data format for kinematics and dynamics functions
`"struct"` (default) | `"row"` | `"column"`

Input/output data format for the kinematics and dynamics functions of the robot model, specified as the comma-separated pair consisting of `'DataFormat'` and `"struct"`, `"row"`, or `"column"`. To use dynamics functions, you must specify either `"row"` or `"column"`. This name-value pair sets the DataFormat property of the `rigidBodyTree` robot model.

Data Types: `char` | `string`

Output Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, returned as a `rigidBodyTree` object.

Note If the gravity is not specified in the URDF file, the default `Gravity` property is set to `[0 0 0]`. Simscape Multibody uses a default of `[0 0 -9.80665]`m/s^2 when using `smimport` to import a URDF.

`importInfo` — Object for storing import information
`rigidBodyTreeImportInfo` object

Object for storing import information, returned as a `rigidBodyTreeImportInfo` object. This object contains the relationship between the input `model` and the resulting `robot` output.

Use `showdetails` to list all the import info for each body in the `robot`. Links to display the rigid body info, their corresponding blocks in the model, and highlighting specific blocks in the model are output to the command window.

Use `bodyInfo`, `bodyInfoFromBlock`, or `bodyInfoFromJoint` to get information about specific components in either the `robot` output or the `model` input.

Tips

When importing a robot model with visual meshes, the `importrobot` function searches for the `.stl` or `.dae` files to assign to each rigid body using these rules:

- The function searches the raw mesh path for a specified rigid body from the URDF or SDF file. References to ROS packages have the `package:\\<pkg_name>` removed.
- Absolute paths are checked directly with no modification.
- Relative paths are checked using the following directories in order:
  - User-specified `MeshPath`
  - Current folder
  - MATLAB path
  - The folder containing the URDF or SDF file
  - One level above the folder containing the URDF or SDF file
- The file name from the mesh path in the URDF or SDF file is appended to the `MeshPath` input argument.

If the mesh file is still not found, the parser ignores the mesh file and returns a `rigidBodyTree` object without visual.

See Also

`rigidBodyTree` | `rigidBodyTreeImportInfo`

Topics
"Rigid Body Tree Robot Model"

Introduced in R2017a

loadrobot

Load rigid body tree robot model

Syntax

```
robotRBT = loadrobot(robotname)
[robotRBT,robotData] = loadrobot(robotname)
[robotRBT,robotData] = loadrobot(robotname,Name,Value)
```

Description

`robotRBT = loadrobot(robotname)` loads a robot model as a `rigidBodyTree` object specified by robot model name `robotname`.

To import your own robot model as a Unified Robot Description Format (URDF) file or Simscape Multibody model, see the `importrobot` function.

`[robotRBT,robotData] = loadrobot(robotname)` returns additional information about the robot model as a structure, `robotData`.

`[robotRBT,robotData] = loadrobot(robotname,Name,Value)` specifies additional options using one or more name-value pair arguments. For example, `'Gravity',[0 0 –9.81]` sets the gravity property to –9.81 m/s^2 in the *z*-direction for the robot model.

Examples

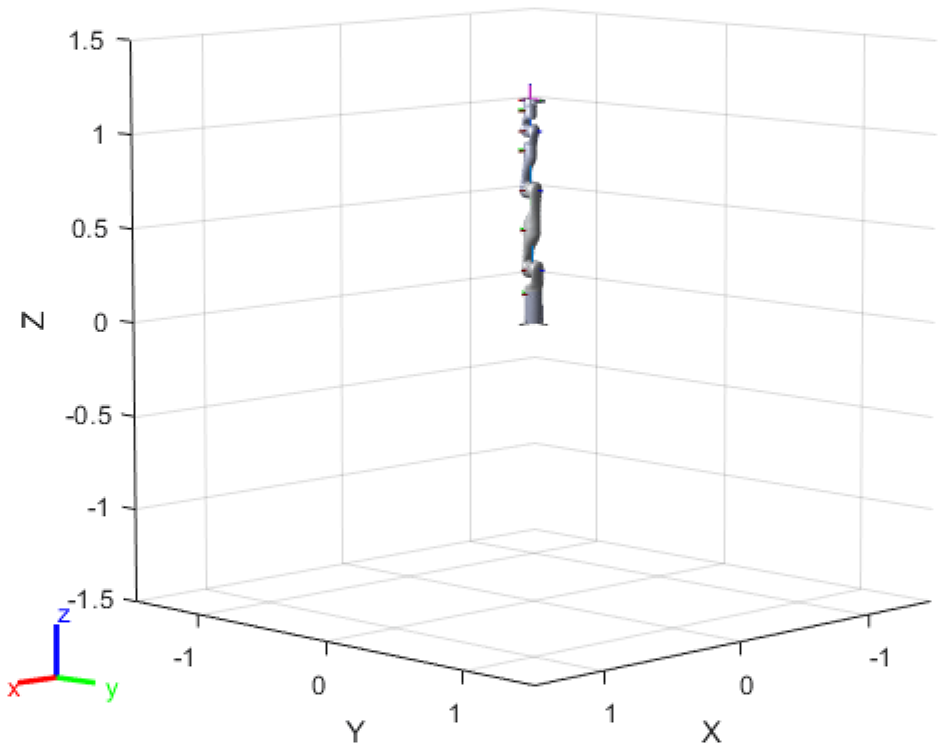
Load Provided Robot Model

This example shows how to load an included robot model using `loadrobot`. Specify one of the select robot names to get a `rigidBodyTree` robot model that contains kinematic and dynamic constraints and visual meshes for the specified robot geometry.

```
gen3 = loadrobot("kinovaGen3");
```

Show the robot model in a figure.

```
show(gen3);
```



Input Arguments

robotname — Name of robot model
"abbIrb120" | "abbIrb120T" | "abbIrb1600" | ...

Name of robot model, specified as one of these valid robot model names:

Robot Model	Description
"abbIrb120"	ABB IRB 120 6-axis robot
"abbIrb120T"	ABB IRB 120T 6-axis robot
"abbIrb1600"	ABB IRB 1600 6-axis robot
"abbYuMi"	ABB YuMi 2-armed robot
"amrPioneer3AT"	Adept MobileRobots Pioneer 3-AT mobile robot
"amrPioneer3DX"	Adept MobileRobots Pioneer 3-DX mobile robot
"amrPioneerLX"	Adept MobileRobots Pioneer LX mobile robot
"atlas"	Boston Dynamics ATLAS® Humanoid robot
"clearpathHusky"	Clearpath Robotics Husky mobile robot
"clearpathJackal"	Clearpath Robotics Jackal mobile robot
"clearpathTurtleBot2"	Clearpath Robotics TurtleBot 2 mobile robot

Robot Model	Description
"fanucLRMate200ib"	FANUC LR Mate 200iB 6-axis robot
"fanucM16ib"	FANUC M-16iB 6-axis robot
"frankaEmikaPanda"	Franka Emika Panda 7-axis robot
"kinovaGen3"	KINOVA® Gen3 7-axis robot
"kinovaJacoJ2N6S200"	KINOVA JACO® 2-fingered 6 DOF robot with non-spherical wrist
"kinovaJacoJ2N6S300"	KINOVA JACO® 3-fingered 6 DOF robot with non-spherical wrist
"kinovaJacoJ2N7S300"	KINOVA JACO® 3-fingered 7 DOF robot with non-spherical wrist
"kinovaJacoJ2S6S300"	KINOVA JACO® 3-fingered 6 DOF robot with spherical wrist
"kinovaJacoJ2S7S300"	KINOVA JACO® 3-fingered 7 DOF robot with spherical wrist
"kinovaJacoTwoArmExample"	Two KINOVA JACO® 3-fingered 6 DOF robots with non-spherical wrist
"kinovaMicoM1N4S200"	KINOVA MICO® 2-fingered 4 DOF robot
"kinovaMicoM1N6S200"	KINOVA MICO® 2-fingered 6 DOF robot
"kinovaMicoM1N6S300"	KINOVA MICO® 3-fingered 6 DOF robot
"kinovaMovo"	KINOVA MOVO® 2-armed mobile robot
"kukaIiwa7"	KUKA LBR iiwa 7 R800 7-axis robot
"kukaIiwa14"	KUKA LBR iiwa 14 R820 7-axis robot
"quanserQArm"	Quanser QArm 4 DOF robot
"quanserQBot2e"	Quanser QBot 2e mobile robot
"quanserQCar"	Quanser QCar mobile robot
"rethinkBaxter"	Rethink Robotics Baxter 2-armed robot
"rethinkSawyer"	Rethink Robotics Sawyer 7-axis robot
"robotisOP2"	ROBOTIS OP2 Humanoid robot
"robotisOpenManipulator"	ROBOTIS OpenMANIPULATOR 4-axis robot with gripper
"robotisTurtleBot3Burger"	ROBOTIS TurtleBot 3 Burger robot
"robotisTurtleBot3Waffle"	ROBOTIS TurtleBot 3 Waffle robot
"robotisTurtleBot3WaffleForOpenManipulator"	ROBOTIS TurtleBot 3 Waffle robot with OpenMANIPULATOR
"robotisTurtleBot3WafflePi"	ROBOTIS TurtleBot 3 Waffle Pi robot
"robotisTurtleBot3WafflePiForOpenManipulator"	ROBOTIS TurtleBot 3 Waffle Pi robot with OpenMANIPULATOR
"universalUR3"	Universal Robots UR3 6-axis robot
"universalUR5"	Universal Robots UR5 6-axis robot

Robot Model	Description
`"universalUR10"`	Universal Robots UR10 6-axis robot
`"valkyrie"`	NASA Valkyrie Humanoid robot
`"willowgaragePR2"`	Willow Garage PR2 mobile robot
`"yaskawaMotomanMH5"`	Yaskawa Motoman MH5 6-axis robot

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: `'Gravity',[0 0 -9.81]` sets the gravity property to -9.81 m/s^2 in the *z*-direction for the robot model.

`DataFormat` — Input/output data format for kinematics and dynamics functions

`"struct"` (default) | `"row"` | `"column"`

Input/output data format for the kinematics and dynamics functions of the robot model, specified as the comma-separated pair consisting of `'DataFormat'` and `"struct"`, `"row"`, or `"column"`. To use dynamics functions, you must specify either `"row"` or `"column"`. This name-value pair sets the DataFormat property of the `rigidBodyTree` robot model.

`Gravity` — Gravitational acceleration experienced by robot

`[0 0 0]` m/s^2 (default) | three-element vector of the form `[x y z]`

Gravitational acceleration experienced by robot, specified as the comma-separated pair consisting of `'Gravity'` and a three-element vector of the form `[x y z]` in m/s^2. Each element corresponds to the acceleration of the base robot frame in the *x*-, *y*-, and *z*-direction, respectively. This name-value pair sets the Gravity property of the `rigidBodyTree` robot model.

`Version` — URDF version of robot model

`1` (default) | numeric scalar

URDF version of the robot model, specified as a numeric scalar.

Robot Model	Versions
`"kinovaGen3"`	`1` –– Loads the `kinovaGen3.urdf` robot model
	`2` –– Loads the `kinovaGen3V12.urdf` robot model

Example: `loadrobot("kinovaGen3","Version",2)`

Output Arguments

`robotRBT` — Rigid body tree robot model

`rigidBodyTree` object

Rigid body tree robot model, returned as a `rigidBodyTree` object. This model contains all the kinematic and dynamic constraints based on the robot source files specified in `robotData`. Some models also contain visual meshes for visualizing robot trajectories.

`robotData` — Robot model information
structure

Robot model information, returned as a structure containing these fields. Whether the function returns a value for a field is based on the type of robot specified by the `robotname` input. Non-relevant fields for that robot are empty.

This table describes the fields of the robot model information structure.

Field	Description
`RobotName` (relevant for all robot types)	Name of the returned robot model
`FilePath` (relevant for all robot types)	File path of the URDF file that is used to create the rigid body tree model
`Source` (relevant for all robot types)	URL source of the robot model
`Version` (relevant for all robot types)	Version number of the robot model.
`WheelRadius`	Wheel radius of the robot in meters
`WheelBase`	Distance between front and rear axles in meters
`TrackWidth`	Distance between wheels on axle in meters
`MaxTranslationalVelocity`	Maximum linear velocity of the robot in m/s
`MaxRotationalVelocity`	Maximum angular velocity of the robot in rad/s
`DriveType`	All robots are modeled with a fixed base, but this field describes the actual drive type of the robot base. The drive type can be any one of the following based on the specified robot: • `FixedBase` –– Drive type of robots with a fixed base • `Differential-Drive` –– Drive type of robots with a differential-drive mobile base • `Omni-Wheel` –– Drive type of robots with an omni-wheel mobile base
`ManipulatorMotionModel`	Motion model of a manipulator robot • `jointSpaceMotionModel` object –– Joint-space motion model of the manipulator robot

Field	Description
`MobileBaseMotionModel`	Kinematic motion model of the mobile base. The motion model can be any one of the following based on the specified robot: • `differentialDriveKinematics` object -- Differential-drive kinematic motion model for robots with a differential-drive mobile base • `unicycleKinematics` object -- Unicycle kinematic motion model for robots with an omni-wheel mobile base

Data Types: `struct`

See Also

`rigidBodyTree` | `importrobot` | `inverseKinematics`

Introduced in R2019b

ldivide, .\

Element-wise quaternion left division

Syntax

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

Description

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

Examples

Divide a Quaternion Array by a Real Scalar

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

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

```
A = 2x1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k
```

```
B = 2;
C = A.\B
```

```
C = 2x1 quaternion array
     0.066667 -  0.13333i -      0.2j -  0.26667k
     0.057471 - 0.068966i -  0.08046j - 0.091954k
```

Divide a Quaternion Array by Another Quaternion Array

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

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

```
A = 2x2 quaternion array
     1 + 2i + 3j + 4k     4 + 5i + 6j + 7k
     2 + 3i + 4j + 5k     5 + 6i + 7j + 8k
```

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

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

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

```
C = 2x2 quaternion array
          2.7 -      1.9i -      0.9j -      1.7k       1.5159 -  0.37302i -  0.15079j -  0.0238
       2.2778 +  0.46296i -  0.57407j + 0.092593k       1.2471 +  0.91379i -  0.33908j -   0.109
```

Input Arguments

A — Divisor

scalar | vector | matrix | multidimensional array

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

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

Data Types: quaternion | single | double

B — Dividend

scalar | vector | matrix | multidimensional array

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

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

Data Types: quaternion | single | double

Output Arguments

C — Result

scalar | vector | matrix | multidimensional array

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

Data Types: quaternion

Algorithms

Quaternion Division

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

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

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

Quaternion Division by a Quaternion Scalar

Given two quaternions A and B of compatible sizes, then

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

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`.*,times` | `conj` | `norm` | `./,ldivide`

Objects

`quaternion`

Introduced in R2018b

log

Natural logarithm of quaternion array

Syntax

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

Description

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

Examples

Logarithmic Values of Quaternion Array

Create a 3-by-1 quaternion array A.

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

```
A = 3x1 quaternion array
     0.53767 + 0.86217i - 0.43359j +  2.7694k
      1.8339 + 0.31877i + 0.34262j -  1.3499k
     -2.2588 -  1.3077i +  3.5784j +  3.0349k
```

Compute the logarithmic values of A.

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

```
B = 3x1 quaternion array
      1.0925 + 0.40848i - 0.20543j +  1.3121k
      0.8436 + 0.14767i + 0.15872j - 0.62533k
      1.6807 - 0.53829i +   1.473j +  1.2493k
```

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `quaternion`

Algorithms

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

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

Extended Capabilities

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

See Also

Functions
`exp` | `.^,power`

Objects
`quaternion`

Introduced in R2018b

meanrot

Quaternion mean rotation

Syntax

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

Description

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

- If `quat` is a vector, `meanrot(quat)` returns the average rotation of the elements.
- If `quat` is a matrix, `meanrot(quat)` returns a row vector containing the average rotation of each column.
- If `quat` is a multidimensional array, then `mearot(quat)` operates along the first array dimension whose size does not equal 1, treating the elements as vectors. This dimension becomes 1 while the sizes of all other dimensions remain the same.

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

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

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

Examples

Quaternion Mean Rotation

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

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

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

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

```
quatAverage = meanrot(quat)
quatAverage = quaternion
      0.88863 - 0.062598i +  0.27822j +  0.35918k
```

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

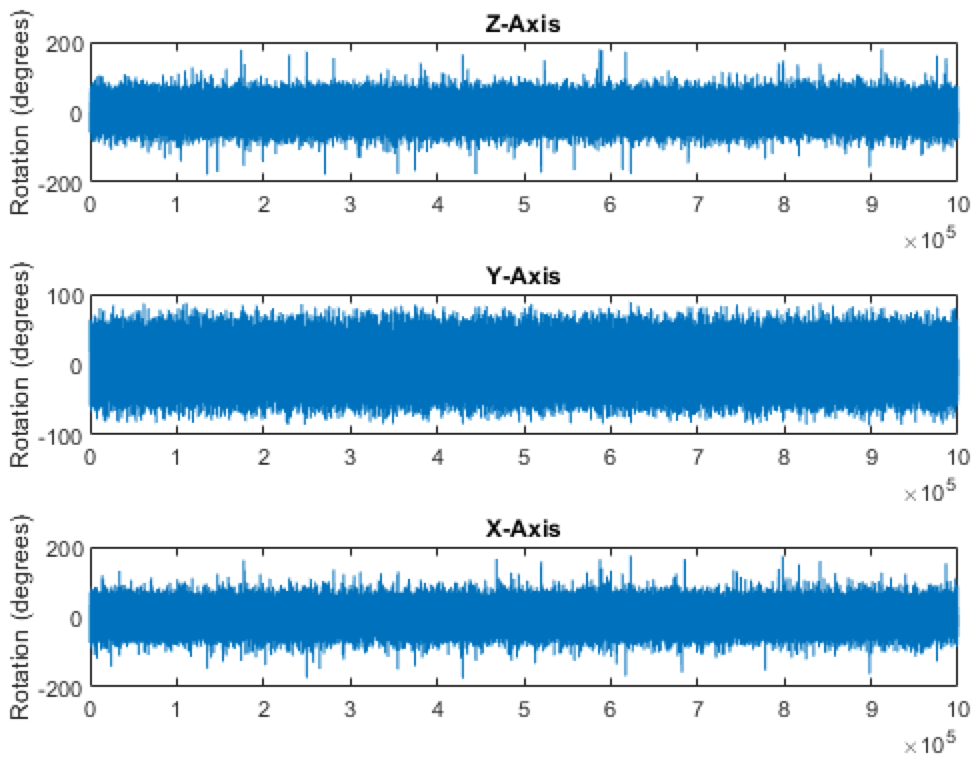
```
eulerAverage = 1×3

   45.7876   32.6452    6.0407
```

Average Out Rotational Noise

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

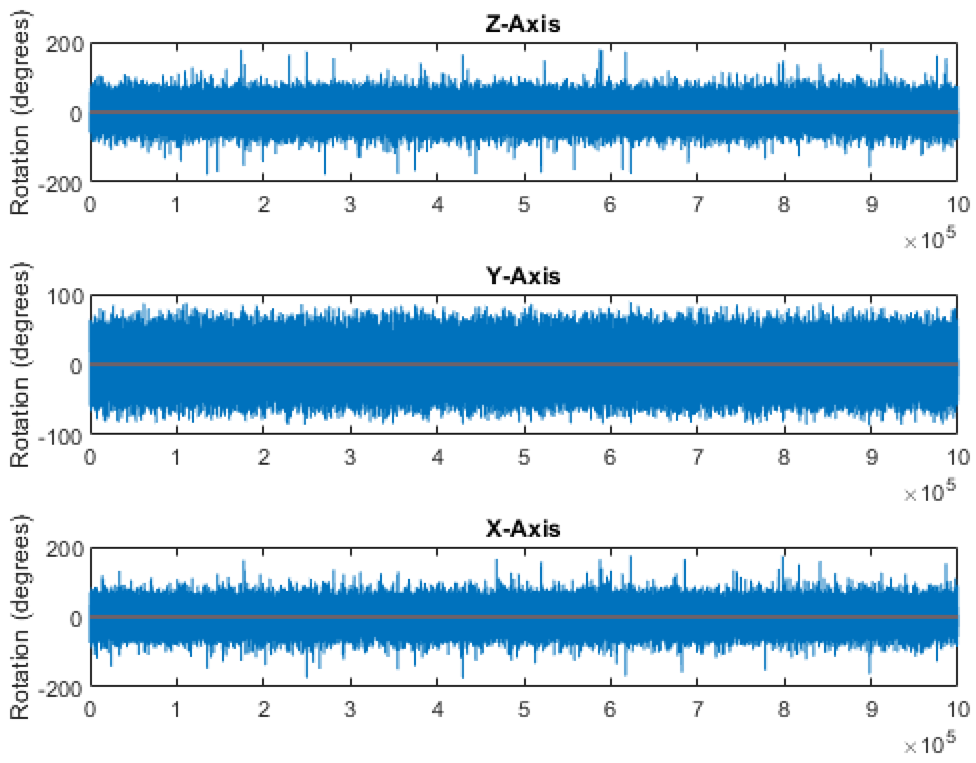
Create a vector of 1e6 quaternions whose distance, as defined by the `dist` function, from quaternion(1,0,0,0) is normally distributed. Plot the Euler angles corresponding to the noisy quaternion vector.

```
nrows = 1e6;
ax = 2*rand(nrows,3) - 1;
ax = ax./sqrt(sum(ax.^2,2));
ang = 0.5*randn(size(ax,1),1);
q = quaternion(ax.*ang ,'rotvec');

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

figure(1)

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

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

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



Use `meanrot` to determine the average quaternion given the vector of quaternions. Convert to Euler angles and plot the results.

```
qAverage = meanrot(q);

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

figure(1)

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

subplot(3,1,2)
plot(ones(nrows,1)*qAverageInEulerAngles(:,2))
title('Y-Axis')

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



The `meanrot` Algorithm and Limitations

The `meanrot` Algorithm

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

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

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

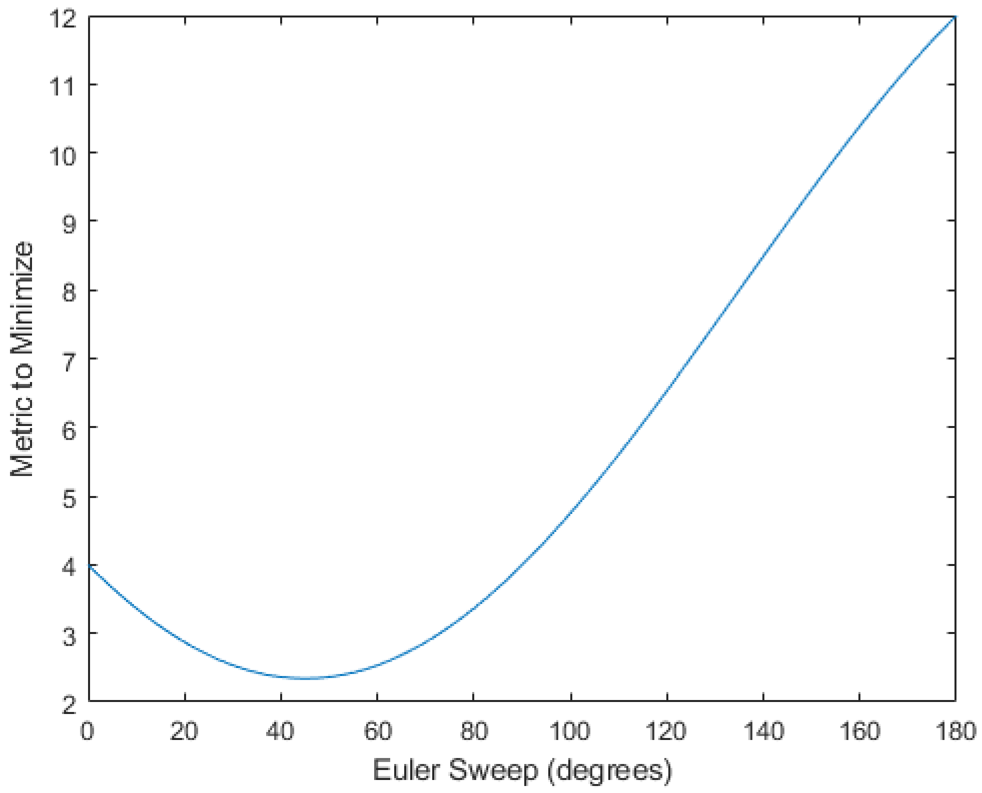
Create a quaternion sweep, `qSweep`, that represents rotations from 0 to 180 degrees about the *x*-axis.

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

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

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

```
rSweep = rotmat(qSweep,'frame');

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

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



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

ans = 45
```

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

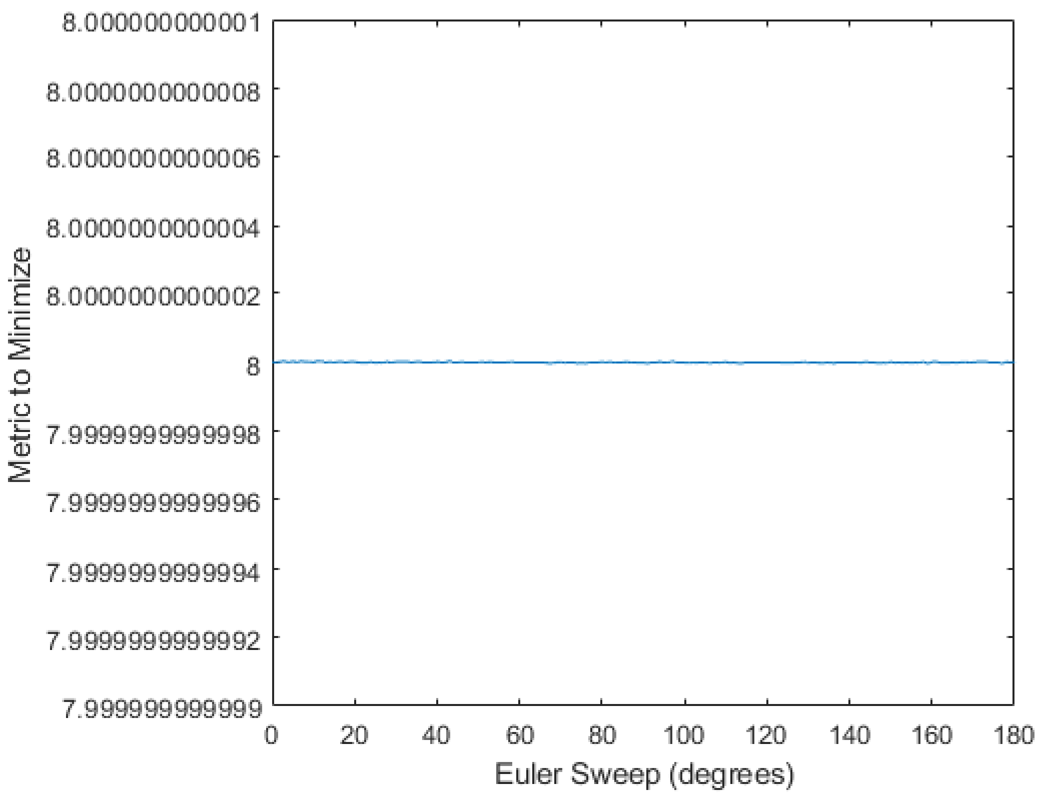
```
eulerd(meanrot([q0,q90]),'ZYX','frame')

ans = 1×3
```

```
         0         0   45.0000
```

Limitations

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

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

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

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



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

```
ans = 159
```

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

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

```
q0_q180 = 1×3

         0         0   90.0000
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

dim — Dimension to operate along
positive integer scalar

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

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

Data Types: `double` | `single`

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

`NaN` condition, specified as one of these values:

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

Data Types: `char` | `string`

Output Arguments

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

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

Data Types: `single` | `double`

Algorithms

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

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

References

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

Extended Capabilities

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

See Also

Functions
`dist` | `slerp`

Objects
`quaternion`

Introduced in R2018b

minjerkpolytraj

Generate minimum jerk trajectory through waypoints

Syntax

```
[q,qd,qdd,qddd,pp,tPoints,tSamples] = minjerkpolytraj(waypoints,timePoints,
numSamples)
[q,qd,qdd,qddd,pp,tPoints,tSamples] = minjerkpolytraj( ___ ,Name=Value)
[q,qd,qdd,qddd,pp,tPoints,tSamples] = minjerkpolytraj( ___
,TimeAllocation=true)
```

Description

`[q,qd,qdd,qddd,pp,tPoints,tSamples] = minjerkpolytraj(waypoints,timePoints, numSamples)` generates a minimum jerk polynomial trajectory that achieves a given set of input waypoints with their corresponding time points. The function returns positions, velocities, accelerations, and jerks at the given number of samples `numSamples`. The function also returns the piecewise polynomial `pp` form of the polynomial trajectory with respect to time, as well as the time points `tPoints` and the sample times `tSamples`.

`[q,qd,qdd,qddd,pp,tPoints,tSamples] = minjerkpolytraj( ___ ,Name=Value)` specifies options using one or more name-value pair arguments in addition to the input arguments from the previous syntax. For example, `minjerkpolytraj(waypoints,timePoints,numSamples,VelocityBoundaryCondition=[1 0 -1 -1; 1 1 1 -1])` generates a two-dimensional minimum jerk trajectory and specifies the velocity boundary conditions in each dimension for each waypoint.

`[q,qd,qdd,qddd,pp,tPoints,tSamples] = minjerkpolytraj( ___ ,TimeAllocation=true)` optimizes a combination of jerk and total segment time cost. In this case, the function treats `timePoints` as an initial guess for the time of arrival at the waypoints.

Examples

Compute Minimum Jerk Trajectory for 2-D Planar Motion

Use the `minjerkpolytraj` function with a given set of 2-D *xy* waypoints. Time points for the waypoints are also given.

```
wpts = [1 4 4 3 -2 0; 0 1 2 4 3 1];
tpts = 0:5;
```

Specify the number of samples in the output trajectory.

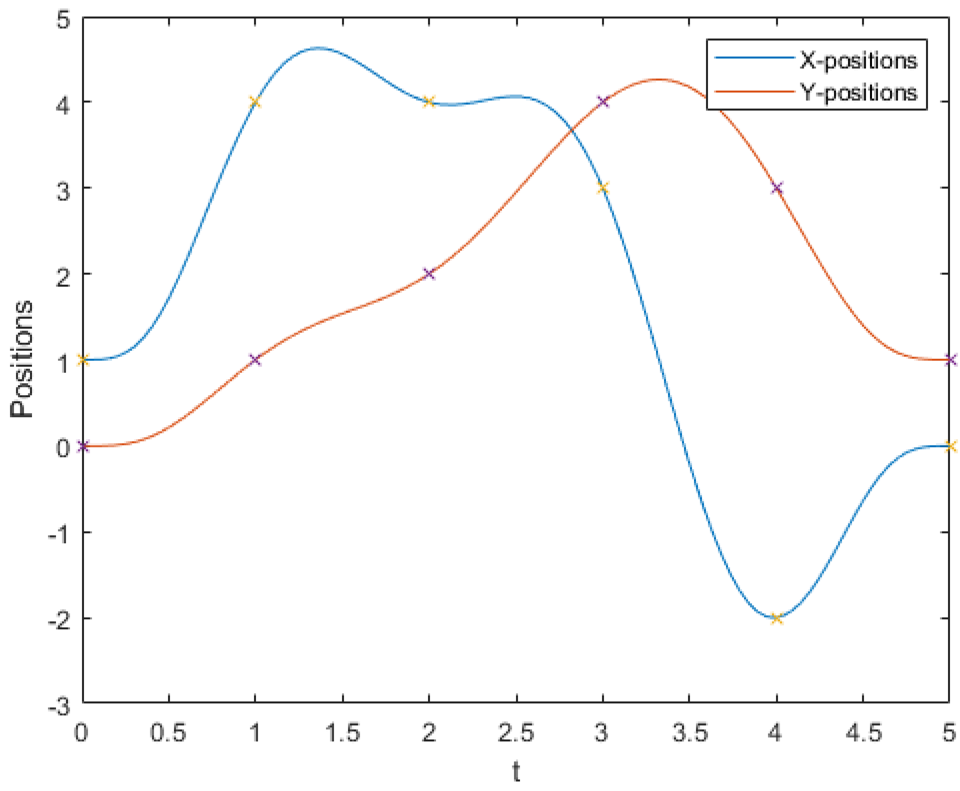
```
numsamples = 100;
```

Compute minimum jerk trajectories. The function outputs the trajectory positions (`q`), velocity (`qd`), acceleration (`qdd`), and jerks (`qddd`) at the given number of samples.

```
[q,qd,qdd,qddd,pp,timepoints,tsamples] = minjerkpolytraj(wpts,tpts,numsamples);
```

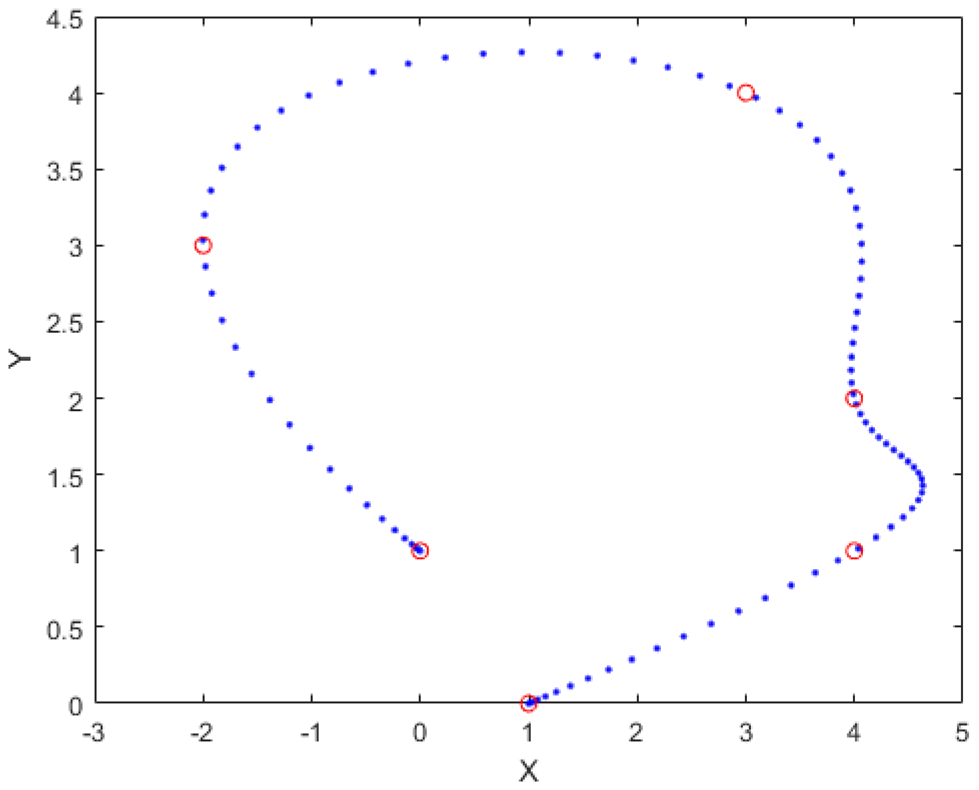
Plot the trajectories for the *x*- and *y*-positions. Compare the trajectory with each waypoint.

```
plot(tsamples,q)
hold on
plot(timepoints,wpts,'x')
xlabel('t')
ylabel('Positions')
legend('X-positions','Y-positions')
hold off
```



You can also verify the actual positions in the 2-D plane. Plot the separate rows of the `q` vector and the waypoints as *x*- and *y*- positions.

```
figure
plot(q(1,:),q(2,:),'.b',wpts(1,:),wpts(2,:),'or')
xlabel('X')
ylabel('Y')
```



Input Arguments

`waypoints` — Waypoints for trajectory
n-by-*p* matrix

Waypoints for the trajectory, specified as an *n*-by-*p* matrix. *n* is the dimension of the trajectory, and *p* is the number of waypoints.

Example: `[2 5 8 4; 3 4 10 12]`

Data Types: `single` | `double`

`timePoints` — Time points for waypoints of trajectory
p-element row vector

Time points for the waypoints of the trajectory, specified as a *p*-element row vector. *p* is the number of waypoints.

Example: `[1 2 3 5]`

Data Types: `single` | `double`

`numSamples` — Number of samples in output trajectory
positive integer

Number of samples in the output trajectory, specified as a positive integer.

Example: `50`

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Example:
`minjerkpolytraj(waypoints,timePoints,numSamples,VelocityBoundaryCondition=[1 0 -1 -1; 1 1 1 -1])` generates a two-dimensional minimum jerk trajectory and specifies the velocity boundary conditions in each dimension for each waypoint.

`VelocityBoundaryCondition` — Velocity boundary conditions for each waypoint
n-by-*p* matrix

Velocity boundary conditions for each waypoint, specified as an *n*-by-*p* matrix. Each row sets the velocity boundary for the corresponding dimension of the trajectory at each of *p* waypoints. By default, the function uses a value of `0` at the boundary waypoints and `NaN` at the intermediate waypoints.

Example: `VelocityBoundaryCondition=[1 0 -1 -1; 1 1 1 -1]`

Data Types: `single` | `double`

`AccelerationBoundaryCondition` — Acceleration boundary conditions for each waypoint
n-by-*p* matrix

Acceleration boundary conditions for each waypoint, specified as an *n*-by-*p* matrix. Each row sets the acceleration boundary for the corresponding dimension of the trajectory at each of *p* waypoints. By default, the function uses a value of `0` at the boundary waypoints and `NaN` at the intermediate waypoints.

Example: `AccelerationBoundaryCondition=[1 0 -1 -1; 1 1 1 -1]`

Data Types: `single` | `double`

`JerkBoundaryCondition` — Jerk boundary conditions for each waypoint
n-by-*p* matrix

Jerk boundary conditions for each waypoint, specified as an *n*-by-*p* matrix. Each row sets the jerk boundary for the corresponding dimension of the trajectory at each of *p* waypoints. By default, the function uses a value of `0` at the boundary waypoints and `NaN` at the intermediate waypoints.

Example: `JerkBoundaryCondition=[1 0 -1 -1; 1 1 1 -1]`

Data Types: `single` | `double`

`TimeAllocation` — Time allocation flag
`false` or `0` (default) | `true` or `1`

Time allocation flag, specified as a logical `0` (`false`) or `1` (`true`). Enable this flag to optimize a combination of jerk and total segment time cost.

Note If singularity occurs when the time allocation flag is enabled, reduce the `MaxSegmentTime` to `MinSegmentTime` ratio.

Example: `TimeAllocation=true`

Data Types: `logical`

`TimeWeight` — Weight for time allocation
`100` (default) | positive scalar

Weight for time allocation, specified as a positive scalar.

Example: `TimeWeight=120`

Data Types: `single` | `double`

`MinSegmentTime` — Minimum time segment length
`0.1` (default) | positive scalar | (*p*—1)-element row vector

Minimum time segment length, specified as a positive scalar or (*p*—1)-element row vector.

Example: `MinSegmentTime=0.2`

Data Types: `single` | `double`

`MaxSegmentTime` — Maximum time segment length
`5` (default) | positive scalar | (*p*—1)-element row vector

Maximum time segment length, specified as a positive scalar or (*p*—1)-element row vector

Example: `MaxSegmentTime=10`

Data Types: `single` | `double`

Output Arguments

q — Positions of trajectory
n-by-*m* matrix

Positions of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

qd — Velocities of trajectory
n-by-*m* matrix

Velocities of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

qdd — Accelerations of trajectory
n-by-*m* matrix

Accelerations of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

qddd — Jerks of trajectory
n-by-*m* matrix

Jerks of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

pp — Piecewise polynomial
structure

Piecewise-polynomial, returned as a structure that defines the polynomial for each section of the piecewise trajectory. You can build your own piecewise polynomials using `mkpp`, or evaluate the polynomial at specified times using `ppval`. The structure contains the fields:

- `form`: `'pp'`.
- `breaks`: *p*-element vector of times when the piecewise trajectory changes forms. *p* is the number of waypoints.
- `coefs`: *n*(*p*–1)-by-`order` matrix for the coefficients for the polynomials. *n*(*p*–1) is the dimension of the trajectory times the number of `pieces`. Each set of *n* rows defines the coefficients for the polynomial that described each variable trajectory.
- `pieces`: *p*–1. The number of breaks minus 1.
- `order`: Degree of the polynomial + 1. The order of polynomial is 8.
- `dim`: *n*. The dimension of the control point positions.

`tPoints` — Time points for waypoints of trajectory
p-element row vector

Time points for the waypoints of the trajectory, returned as a *p*-element row vector. *p* is the number of waypoints.

`tSamples` — Time samples for trajectory
m-element row vector

Time samples for the trajectory, returned as an *m*-element row vector. Each element of the output position `q`, velocity `qd`, acceleration `qdd`, and jerk `qddd` has been sampled at the corresponding time in this vector.

References

[1] Bry, Adam, Charles Richter, Abraham Bachrach, and Nicholas Roy. “Aggressive Flight of Fixed-Wing and Quadrotor Aircraft in Dense Indoor Environments.” *The International Journal of Robotics Research*, 34, no. 7 (June 2015): 969–1002.

[2] Richter, Charles, Adam Bry, and Nicholas Roy. “Polynomial Trajectory Planning for Aggressive Quadrotor Flight in Dense Indoor Environments." *Paper presented at the International Symposium of Robotics Research (ISRR 2013)*, 2013.

Extended Capabilities

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

See Also

Functions
`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `trapveltraj` | `minsnappolytraj`

Introduced in R2021b

minsnappolytraj

Generate minimum snap trajectory through waypoints

Syntax

```
[q,qd,qdd,qddd,qdddd,pp,tPoints,tSamples] = minsnappolytraj(waypoints,
timePoints,numSamples)
[q,qd,qdd,qddd,qdddd,pp,tPoints,tSamples] = minsnappolytraj( ___ ,Name=Value)
[q,qd,qdd,qddd,qdddd,pp,tPoints,tSamples] = minsnappolytraj( ___
,TimeAllocation=true)
```

Description

`[q,qd,qdd,qddd,qdddd,pp,tPoints,tSamples] = minsnappolytraj(waypoints, timePoints,numSamples)` generates a minimum snap polynomial trajectory that achieves a given set of input waypoints with their corresponding time points. The function returns positions, velocities, accelerations, jerks, and snaps at the given number of samples `numSamples`. The function also returns the piecewise polynomial `pp` form of the polynomial trajectory with respect to time, as well as the time points `tPoints`, and the sample times `tSamples`.

`[q,qd,qdd,qddd,qdddd,pp,tPoints,tSamples] = minsnappolytraj( ___ ,Name=Value)` specifies options using one or more name-value pair arguments in addition to the input arguments from the previous syntax. For example, `minsnappolytraj(waypoints,timePoints,numSamples,VelocityBoundaryCondition=[1 0 -1 -1; 1 1 1 -1])` generates a two-dimensional minimum snap trajectory and specifies the velocity boundary conditions in each dimension for each waypoint.

`[q,qd,qdd,qddd,qdddd,pp,tPoints,tSamples] = minsnappolytraj( ___ ,TimeAllocation=true)` optimizes a combination of snap and the total segment time cost. In this case, the function treats `timePoints` as an initial guess for the time of arrival at the waypoints.

Examples

Compute Minimum Snap Trajectory for 2-D Planar Motion

Use the `minsnappolytraj` function with a given set of 2-D *xy* waypoints. Time points for the waypoints are also given.

```
wpts = [1 4 4 3 -2 0; 0 1 2 4 3 1];
tpts = 0:5;
```

Specify the number of samples in the output trajectory.

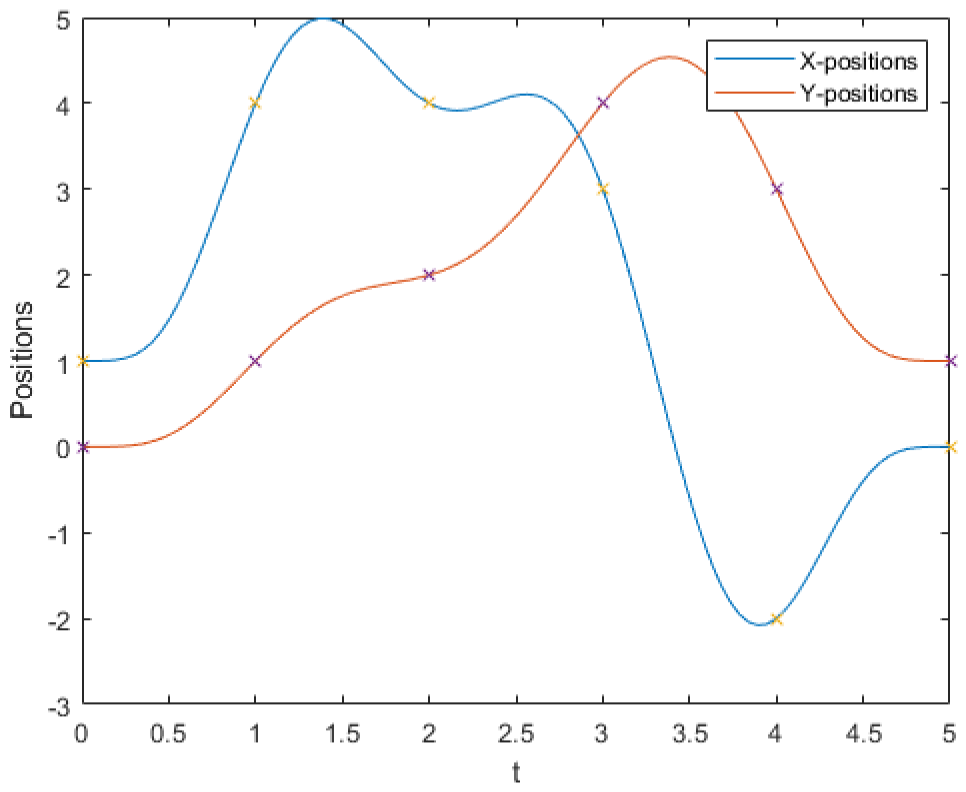
```
numsamples = 100;
```

Compute minimum snap trajectories. The function outputs the trajectory positions (`q`), velocity (`qd`), acceleration (`qdd`), jerks (`qddd`), and snaps (`qdddd`) at the given number of samples.

```
[q,qd,qdd,qddd,qdddd,pp,timepoints,tsamples] = minsnappolytraj(wpts,tpts,numsamples);
```

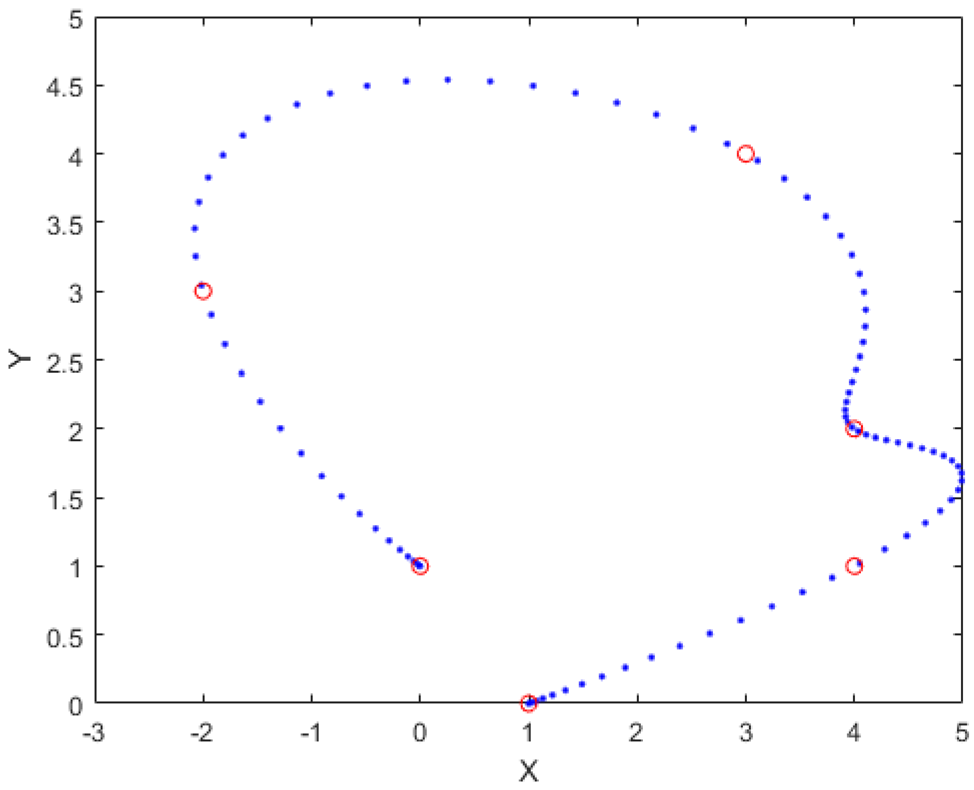
Plot the trajectories for the *x*- and *y*-positions. Compare the trajectory with each waypoint.

```
plot(tsamples,q)
hold on
plot(timepoints,wpts,'x')
xlabel('t')
ylabel('Positions')
legend('X-positions','Y-positions')
hold off
```



You can also verify the actual positions in the 2-D plane. Plot the separate rows of the `q` vector and the waypoints as *x*- and *y*- positions.

```
figure
plot(q(1,:),q(2,:),'.b',wpts(1,:),wpts(2,:),'or')
xlabel('X')
ylabel('Y')
```



Input Arguments

`waypoints` — Waypoints for trajectory
n-by-*p* matrix

Waypoints for the trajectory, specified as an *n*-by-*p* matrix. *n* is the dimension of the trajectory, and *p* is the number of waypoints.

Example: `[2 5 8 4; 3 4 10 12]`

Data Types: `single` | `double`

`timePoints` — Time points for waypoints of trajectory
p-element row vector

Time points for the waypoints of the trajectory, specified as a *p*-element row vector. *p* is the number of waypoints.

Example: `[1 2 3 5]`

Data Types: `single` | `double`

`numSamples` — Number of samples in output trajectory
positive integer

Number of samples in the output trajectory, specified as a positive integer.

Example: `50`

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Example: `minsnappolytraj(waypoints,timePoints,numSamples,VelocityBoundaryCondition=[1 0 -1 -1; 1 1 1 -1])` generates a two-dimensional minimum snap trajectory and specifies the velocity boundary conditions in each dimension for each waypoint.

`VelocityBoundaryCondition` — Velocity boundary conditions for each waypoint
n-by-*p* matrix

Velocity boundary conditions for each waypoint, specified as an *n*-by-*p* matrix. Each row sets the velocity boundary for the corresponding dimension of the trajectory at each of *p* waypoints. By default, the function uses a value of `0` at the boundary waypoints and `NaN` at the intermediate waypoints.

Example: `VelocityBoundaryCondition=[1 0 -1 -1; 1 1 1 -1]`

Data Types: `single` | `double`

`AccelerationBoundaryCondition` — Acceleration boundary conditions for each waypoint
n-by-*p* matrix

Acceleration boundary conditions for each waypoint, specified as an *n*-by-*p* matrix. Each row sets the acceleration boundary for the corresponding dimension of the trajectory at each of *p* waypoints. By default, the function uses a value of `0` at the boundary waypoints and `NaN` at the intermediate waypoints.

Example: `AccelerationBoundaryCondition=[1 0 -1 -1; 1 1 1 -1]`

Data Types: `single` | `double`

`JerkBoundaryCondition` — Jerk boundary conditions for each waypoint
n-by-*p* matrix

Jerk boundary conditions for each waypoint, specified as an *n*-by-*p* matrix. Each row sets the jerk boundary for the corresponding dimension of the trajectory at each of *p* waypoints. By default, the function uses a value of `0` at the boundary waypoints and `NaN` at the intermediate waypoints.

Example: `JerkBoundaryCondition=[1 0 -1 -1; 1 1 1 -1]`

Data Types: `single` | `double`

`SnapBoundaryCondition` — Snap boundary conditions for each waypoint
n-by-*p* matrix

Snap boundary conditions for each waypoint, specified as an *n*-by-*p* matrix. Each row sets the snap boundary for the corresponding dimension of the trajectory at each of *p* waypoints. By default, the function uses a value of `0` at the boundary waypoints and `NaN` at the intermediate waypoints.

Example: `SnapBoundaryCondition=[1 0 -1 -1; 1 1 1 -1]`

Data Types: `single` | `double`

`TimeAllocation` — Time allocation flag
`false` or `0` (default) | `true` or `1`

Time allocation flag, specified as a logical `0` (`false`) or `1` (`true`). Enable this flag to optimize a combination of snap and total segment time cost.

Note If singularity occurs when the time allocation flag is enabled, reduce the `MaxSegmentTime` to `MinSegmentTime` ratio.

Example: `TimeAllocation=true`

Data Types: `logical`

`TimeWeight` — Weight for time allocation
`100` (default) | positive scalar

Weight for time allocation, specified as a positive scalar.

Example: `TimeWeight=120`

Data Types: `single` | `double`

`MinSegmentTime` — Minimum time segment length
`0.1` (default) | positive scalar | (*p*–1)-element row vector

Minimum time segment length, specified as a positive scalar or (*p*–1)-element row vector.

Example: `MinSegmentTime=0.2`

Data Types: `single` | `double`

`MaxSegmentTime` — Maximum time segment length
`1` (default) | positive scalar | (*p*–1)-element row vector

Maximum time segment length, specified as a positive scalar or (*p*–1)-element row vector

Example: `MaxSegmentTime=5`

Data Types: `single` | `double`

Output Arguments

q — Positions of trajectory
n-by-*m* matrix

Positions of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

qd — Velocities of trajectory
n-by-*m* matrix

Velocities of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

qdd — Accelerations of trajectory
n-by-*m* matrix

Accelerations of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

qddd — Jerks of trajectory
n-by-*m* matrix

Jerks of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

qdddd — Snaps of trajectory
n-by-*m* matrix

Snaps of the trajectory at the given time samples in `tSamples`, returned as an *n*-by-*m* matrix. *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

pp — Piecewise polynomial
structure

Piecewise-polynomial, returned as a structure that defines the polynomial for each section of the piecewise trajectory. You can build your own piecewise polynomials using `mkpp`, or evaluate the polynomial at specified times using `ppval`. The structure contains the fields:

- `form`: `'pp'`.
- `breaks`: *p*-element vector of times when the piecewise trajectory changes forms. *p* is the number of waypoints.
- `coefs`: *n*(*p*–`1`)-by-`order` matrix for the coefficients for the polynomials. *n*(*p*–`1`) is the dimension of the trajectory times the number of `pieces`. Each set of *n* rows defines the coefficients for the polynomial that described each variable trajectory.
- `pieces`: *p*–`1`. The number of breaks minus 1.
- `order`: Degree of the polynomial + `1`. The order of polynomial is 10.
- `dim`: *n*. The dimension of the control point positions.

`tPoints` — Time points for waypoints of trajectory
p-element row vector

Time points for the waypoints of the trajectory, returned as a *p*-element row vector. *p* is the number of waypoints.

`tSamples` — Time samples for trajectory
m-element row vector

Time samples for the trajectory, returned as an *m*-element row vector. Each element of the output position `q`, velocity `qd`, acceleration `qdd`, jerk `qddd`, and snap `qdddd` has been sampled at the corresponding time in this vector.

References

[1] Bry, Adam, Charles Richter, Abraham Bachrach, and Nicholas Roy. “Aggressive Flight of Fixed-Wing and Quadrotor Aircraft in Dense Indoor Environments.” *The International Journal of Robotics Research*, 34, no. 7 (June 2015): 969–1002.

[2] Richter, Charles, Adam Bry, and Nicholas Roy. “Polynomial Trajectory Planning for Aggressive Quadrotor Flight in Dense Indoor Environments." *Paper presented at the International Symposium of Robotics Research (ISRR 2013)*, 2013.

Extended Capabilities

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

See Also

Functions
`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `trapveltraj` | `minjerkpolytraj`

Introduced in R2021b

minus, -

Quaternion subtraction

Syntax

```
C = A - B
```

Description

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

Examples

Subtract a Quaternion from a Quaternion

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

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

Q1minusQ2 = Q1 - Q2
```

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

Subtract a Real Number from a Quaternion

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

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

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

```
Qminus1 = Q - 1
```

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

Input Arguments

A — Input
scalar | vector | matrix | multidimensional array

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

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

B — Input
scalar | vector | matrix | multidimensional array

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

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

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

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

Objects
`quaternion`

Introduced in R2018a

mtimes, *

Quaternion multiplication

Syntax

```
quatC = A*B
```

Description

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

You can use quaternion multiplication to compose rotation operators:

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

Examples

Multiply Quaternion Scalar and Quaternion Vector

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

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

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

```
b = quaternion(randn(1,4))
```

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

```
C = A*b
```

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

Input Arguments

A — Input
scalar | vector | matrix | multidimensional array

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

If B is nonscalar, then A must be scalar.

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

B — Input
scalar | vector | matrix | multidimensional array

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

If A is nonscalar, then B must be scalar.

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

Output Arguments

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

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

Data Types: `quaternion`

Algorithms

Quaternion Multiplication by a Real Scalar

Given a quaternion

$$q = a_\mathrm{q} + b_\mathrm{q}\mathrm{i} + c_\mathrm{q}\mathrm{j} + d_\mathrm{q}\mathrm{k},$$

the product of q and a real scalar β is

$$\beta q = \beta a_\mathrm{q} + \beta b_\mathrm{q}\mathrm{i} + \beta c_\mathrm{q}\mathrm{j} + \beta d_\mathrm{q}\mathrm{k}$$

Quaternion Multiplication by a Quaternion Scalar

The definition of the basis elements for quaternions,

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

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

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

j	j	−k	−1	i
k	k	j	−i	−1

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

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

$$\begin{aligned} z = pq &= (a_p + b_p\mathrm{i} + c_p\mathrm{j} + d_p\mathrm{k})(a_q + b_q\mathrm{i} + c_q\mathrm{j} + d_q\mathrm{k}) \\ &= a_pa_q + a_pb_q\mathrm{i} + a_pc_q\mathrm{j} + a_pd_q\mathrm{k} \\ &+ b_pa_q\mathrm{i} + b_pb_q\mathrm{i}^2 + b_pc_q\mathrm{ij} + b_pd_q\mathrm{ik} \\ &+ c_pa_q\mathrm{j} + c_pb_q\mathrm{ji} + c_pc_q\mathrm{j}^2 + c_pd_q\mathrm{jk} \\ &+ d_pa_qk + d_pb_q\mathrm{ki} + d_pc_q\mathrm{kj} + d_pd_q\mathrm{k}^2 \end{aligned}$$

You can simplify the equation using the quaternion multiplication table:

$$\begin{aligned} z = pq &= a_pa_q + a_pb_q\mathrm{i} + a_pc_q\mathrm{j} + a_pd_q\mathrm{k} \\ &+ b_pa_q\mathrm{i} - b_pb_q + b_pc_q\mathrm{k} - b_pd_q\mathrm{j} \\ &+ c_pa_q\mathrm{j} - c_pb_q\mathrm{k} - c_pc_q + c_pd_q\mathrm{i} \\ &+ d_pa_qk + d_pb_q\mathrm{j} - d_pc_q\mathrm{i} - d_pd_q \end{aligned}$$

References

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

Extended Capabilities

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

See Also

Functions
`.*,times`

Objects
`quaternion`

Introduced in R2018a

norm

Quaternion norm

Syntax

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

Description

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

Given a quaternion of the form $Q = a + b\text{i} + c\text{j} + d\text{k}$, the norm of the quaternion is defined as $\text{norm}(Q) = \sqrt{a^2 + b^2 + c^2 + d^2}$.

Examples

Calculate Quaternion Norm

Create a scalar quaternion and calculate its norm.

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

```
ans = 5.4772
```

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

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

```
ans = 5.4772
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `single` | `double`

Extended Capabilities

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

See Also

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

Objects
`quaternion`

Introduced in R2018a

normalize

Quaternion normalization

Syntax

`quatNormalized = normalize(quat)`

Description

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

Given a quaternion of the form $Q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, the normalized quaternion is defined as $Q/\sqrt{a^2 + b^2 + c^2 + d^2}$.

Examples

Normalize Elements of Quaternion Vector

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

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

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

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

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

Objects
`quaternion`

Introduced in R2018a

ones

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

Syntax

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

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

Description

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

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

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

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

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

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

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

Examples

Quaternion Scalar One

Create a quaternion scalar one.

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

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

Square Matrix of Quaternion Ones

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

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

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

Multidimensional Array of Quaternion Ones

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

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

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

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


quatOnesSyntax1(:,:,2) =

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

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

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

```
ans = logical
   1
```

Underlying Class of Quaternion Ones

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

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

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

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

Verify the underlying class using the `classUnderlying` function.

```
classUnderlying(quatOnes)
```

```
ans =
'single'
```

Input Arguments

`n` — Size of square quaternion matrix
integer value

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

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

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

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

`sz` — Output size
row vector of integer values

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

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

`prototype` — Quaternion prototype
variable

Quaternion prototype, specified as a variable.

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

Data Types: `quaternion`

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

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

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

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

Output Arguments

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

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

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

Functions
`zeros`

Objects
`quaternion`

Introduced in R2018a

packageGazeboPlugin

Create Gazebo plugin package for Simulink

Syntax

```
packageGazeboPlugin
packageGazeboPlugin(packagePath)
packageGazeboPlugin(packagePath,customMessagePath)
outputPath = packageGazeboPlugin( ___ )
```

Description

`packageGazeboPlugin` creates a Gazebo plugin package as a zip archive. The function creates a folder containing plugin source code, named `GazeboPlugin`, in the current working directory and compresses it as `GazeboPlugin.zip`. Gazebo uses this plugin package to communicate with Simulink for synchronized stepping, as well as sending and receiving messages.

`packageGazeboPlugin(packagePath)` creates a Gazebo plugin at the specified location `packagePath`. `packagePath` must be a valid file name or a file path with the desired package folder name. The function creates the plugin folder with the specified name in the location specified in the `packagePath` argument and compresses it.

`packageGazeboPlugin(packagePath,customMessagePath)` creates a Gazebo plugin with custom message support using the specified custom message dependencies in `customMessagePath`. The dependencies must be specified as a valid path to a folder that contains the custom message dependencies.

`outputPath = packageGazeboPlugin( ___ )` returns the path of the plugin folder in addition to any combination of input arguments from a previous syntax.

Examples

Generate Dependencies for User-Defined Gazebo Custom Message

Create a folder in a local directory.

```
folderPath = fullfile(pwd,'customMessage')
```

```
folderPath = 
'C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage'
```

```
mkdir(folderPath)
```

Create a `.proto` file inside the folder and define protobuf custom message fields.

```
messageDefinition = {'message MyPose'
                     '{'
                     '    required double x = 1;'
                     '    required double y = 2;'
                     '    required double z = 3;'
```

```
                      '}'};
fileID = fopen(fullfile(folderPath,'MyPose.proto'),'w');
fprintf(fileID,'%s\n',messageDefinition{:});
fclose(fileID);
```

Use the `gazebogenmsg` function to generate dependences in the created folder.

```
gazebogenmsg(folderPath)
```

```
Validating ...
Selected compiler details: "Microsoft Visual C++ 2019 16.0"
[libprotobuf WARNING] No syntax specified for the proto file: MyPose.proto. Please use 'syntax =
Building shared library ...
Microsoft (R) C/C++ Optimizing Compiler Version 19.15.26726 for x64
Copyright (C) Microsoft Corporation.  All rights reserved.

MyPose.pb.cc
Microsoft (R) Incremental Linker Version 14.15.26726.0
Copyright (C) Microsoft Corporation.  All rights reserved.

/out:MyPose.pb.dll
/dll
/implib:MyPose.pb.lib
/LIBPATH:B:\matlab\toolbox\shared\robotics\externalDependency\libprotobuf\lib
libprotobuf3.lib
/OUT:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\instal
/IMPLIB:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\ins
C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\install\MyP
   Creating library C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\custo
Building MEX for "MyPose.proto" file ...
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building custom message utilities  ...
DONE.

To use the gazebo custom messages, execute following commands:

addpath('C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex62907275\customMessage\ins
savepath
```

Use the following commands to add and save the install path.

```
addpath(fullfile(folderPath,'install'))
```

```
savepath
```

Create a Gazebo plugin package `'MyPlugin'` inside the custom message folder using the `packageGazeboPlugin` function.

```
packageGazeboPlugin(fullfile(folderPath,'MyPlugin'),folderPath)
```

Generate Dependencies for Built-in Gazebo Message

Create a folder in a local directory.

```
folderPath = fullfile(pwd,'customMessage');
mkdir(folderPath)
cd(folderPath)
```

Use the `gazebogenmsg` function to generate dependencies for a built-in gazebo message in the specified folder.

```
gazebogenmsg(folderPath,"GazeboMessageList","gazebo.msgs.Image");
```

```
Validating ...
Selected compiler details: "Microsoft Visual C++ 2019 16.0"
Building shared library ...
Microsoft (R) C/C++ Optimizing Compiler Version 19.15.26726 for x64
Copyright (C) Microsoft Corporation.  All rights reserved.

image.pb.cc
Microsoft (R) Incremental Linker Version 14.15.26726.0
Copyright (C) Microsoft Corporation.  All rights reserved.

/out:image.pb.dll
/dll
/implib:image.pb.lib
/LIBPATH:B:\matlab\toolbox\shared\robotics\externalDependency\libprotobuf\lib
libprotobuf3.lib
/OUT:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\instal
/IMPLIB:C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\ins
C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\install\imag
   Creating library C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\custo
Building MEX for "image.proto" file ...
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building with 'Microsoft Visual C++ 2019'.
MEX completed successfully.
Building custom message utilities  ...
DONE.

To use the gazebo custom messages, execute following commands:

addpath('C:\TEMP\Bdoc21b_1757077_3096\ib2EDA31\1\tp85146263\robotics-ex40128733\customMessage\ins
savepath
```

Use the following commands to add and save the install path.

```
addpath(fullfile(folderPath,'install'))
```

```
savepath
```

Create a Gazebo plugin package using the `packageGazeboPlugin` function.

```
packageGazeboPlugin
```

Input Arguments

`packagePath` — Name or path of Gazebo plugin package folder
string scalar | character vector

Name or path of the Gazebo plugin package folder, specified as a string scalar or a character vector.

When specified as a folder name, the function creates a plugin folder and a compressed plugin file with the specified name in the current directory.

Example: `packageGazeboPlugin('MyPlugin')`

When specified as a file path, the function creates a plugin folder and a compressed plugin file with the specified file name in the specified folder.

Example: `packageGazeboPlugin('C:\GazeboPlugin\MyPlugin')`

Data Types: `char` | `string`

`customMessagePath` — Path of Gazebo custom message folder
string scalar | character vector

Path of the Gazebo custom message folder, specified as a string scalar or a character vector.

To create a Gazebo plugin with custom message support, specify the `customMessagePath` as a valid path to the folder that contains the desired custom message dependencies.

When the `packagePath` argument is specified as a folder name, the function creates a plugin folder and a compressed plugin file with the specified package name in the current directory.

Example: `packageGazeboPlugin('MyPlugin','C:\GazeboCustomMsg')`

When the `packagePath` argument is specified as a file path inside the custom message folder, the function creates a plugin folder and a compressed plugin file with the specified file name in the specified folder.

Example: `packageGazeboPlugin('C:\GazeboCustomMsg \MyPlugin','C:\GazeboCustomMsg')`

Data Types: `char` | `string`

Output Arguments

`outputPath` — Path of plugin folder
character vector

Path of the plugin folder, returned as a character vector.

Limitations

- `packageGazeboPlugin` function not supported with MATLAB Compiler.

See Also

`gazebogenmsg`

Topics
"Perform Co-Simulation between Simulink and Gazebo"

Introduced in R2020b

parts

Extract quaternion parts

Syntax

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

Description

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

Examples

Convert Quaternion to Matrix of Quaternion Parts

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

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

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

```
quat = 2x1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k
```

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

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

```
qA = 2×1

     1
     5


qB = 2×1

     2
     6


qC = 2×1

     3
     7


qD = 2×1
```

```
     4
     8
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

Quaternion, specified as a quaternion or array of quaternions.

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `single` | `double`

Extended Capabilities

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

See Also

Functions
`classUnderlying` | `compact`

Objects
`quaternion`

Introduced in R2018a

plotTransforms

Plot 3-D transforms from translations and rotations

Syntax

```
ax = plotTransforms(translations,rotations)
ax = plotTransforms(translations,rotations,Name,Value)
```

Description

`ax = plotTransforms(translations,rotations)` draws transform frames in a 3-D figure window using the specified translations and rotations. The *z*-axis always points upward.

`ax = plotTransforms(translations,rotations,Name,Value)` specifies additional options using name-value pair arguments. Specify multiple name-value pairs to set multiple options.

Input Arguments

`translations` — *xyz*-positions
`[x y z]` vector | matrix of `[x y z]` vectors

xyz-positions specified as a vector or matrix of `[x y z]` vectors. Each row represents a new frame to plot with a corresponding orientation in `rotations`.

Example: `[1 1 1; 2 2 2]`

`rotations` — Rotations of *xyz*-positions
`quaternion` array | matrix of `[w x y z]` quaternion vectors

Rotations of *xyz*-positions specified as a `quaternion` array or *n*-by-4 matrix of `[w x y z]` quaternion vectors. Each element of the array or each row of the matrix represents the rotation of the *xyz*-positions specified in `translations`.

Example: `[1 1 1 0; 1 3 5 0]`

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: `'FrameSize',5`

`FrameSize` — Size of frames and attached meshes
positive numeric scalar

Size of frame and attached meshes, specified as positive numeric scalar.

`InertialZDirection` — Direction of positive *z*-axis of inertial frame
`"up"` (default) | `"down"`

Direction of the positive *z*-axis of inertial frame, specified as either `"up"` or `"down"`. In the plot, the positive *z*-axis always points up.

`MeshFilePath` — File path of mesh file attached to frames
character vector | string scalar

File path of mesh file attached to frames, specified as either a character vector or string scalar. The mesh is attached to each plotted frame at the specified position and orientation. Provided `.stl` are

- `"fixedwing.stl"`
- `"multirotor.stl"`
- `"groundvehicle.stl"`

Example: `'fixedwing.stl'`

`MeshColor` — Color of attached mesh
`"red"` (default) | RGB triplet | string scalar

Color of attached mesh, specified as an RGB triple or string scalar.

Example: `[0 0 1]` or `"green"`

`Parent` — Axes used to plot transforms
`Axes` object | `UIAxes` object

Axes used to plot the pose graph, specified as the comma-separated pair consisting of `'Parent'` and either an `Axes` or `UIAxes` object. See `axes` or `uiaxes`.

Output Arguments

ax — Axes used to plot transforms
`Axes` object | `UIAxes` object

Axes used to plot the pose graph, specified as the comma-separated pair consisting of `'Parent'` and either an `Axes` or `UIAxes`object. See `axes` or `uiaxes`.

See Also
`quaternion` | `hom2cart` | `eul2quat` | `tform2quat` | `rotm2quat`

Introduced in R2018b

power, .^

Element-wise quaternion power

Syntax

`C = A.^b`

Description

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

Examples

Raise a Quaternion to a Real Scalar Power

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

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

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

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

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

Raise a Quaternion Array to Powers from a Multidimensional Array

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

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

```
A = 2x1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k
```

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

```
b = 2×3

     1     0     2
     3     2     1
```

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

```
C = 2x3 quaternion array
        1 +    2i +    3j +    4k        1 +    0i +    0j +    0k      -28 +    4i +    6j +
    -2110 -  444i -  518j -  592k     -124 +   60i +   70j +   80k        5 +    6i +    7j +
```

Input Arguments

A — Base
scalar | vector | matrix | multidimensional array

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

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

b — Exponent
scalar | vector | matrix | multidimensional array

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

Data Types: `single` | `double`

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Algorithms

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

$$A = \|A\|(\cos\theta + \widehat{u}\sin\theta)$$

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

Quaternion A raised by a real exponent b is given by

$$P = A\,.\,\hat{}\,b = \|A\|^b(\cos(b\theta) + \widehat{u}\sin(b\theta))$$

Extended Capabilities

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

See Also

Functions
`log` | `exp`

Objects
`quaternion`

Introduced in R2018b

prod

Product of a quaternion array

Syntax

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

Description

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

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

Examples

Product of Quaternions in Each Column

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

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

```
A = 3x3 quaternion array
      0.53767 +   2.7694i +    1.409j -  0.30344k      0.86217 +   0.7254i -   1.2075j +   0.888
       1.8339 -   1.3499i +   1.4172j +  0.29387k      0.31877 - 0.063055i +  0.71724j -   1.147
      -2.2588 +   3.0349i +   0.6715j -  0.78728k      -1.3077 +  0.71474i +   1.6302j -   1.068
```

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

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

```
B = 1x3 quaternion array
    -19.837 -  9.1521i +  15.813j -  19.918k     -5.4708 - 0.28535i +   3.077j -  1.2295k
```

Product of Specified Dimension of Quaternion Array

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

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

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

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

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

B = 2x2 quaternion array
     -2.4847 +  1.1659i - 0.37547j +  2.8068k     0.28786 - 0.29876i - 0.51231j -  4.2972k
     0.38986 -  3.6606i -  2.0474j -   6.047k      -1.741 - 0.26782i +  5.4346j +  4.1452k
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

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

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

Data Types: `quaternion`

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

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

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

Output Arguments

quatProd — Quaternion product
positive integer

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

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

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

Functions
`mtimes` | `.*,times`

Objects
`quaternion`

Introduced in R2018a

quat2axang

Convert quaternion to axis-angle rotation

Syntax

`axang = quat2axang(quat)`

Description

`axang = quat2axang(quat)` converts a quaternion, `quat`, to the equivalent axis-angle rotation, `axang`.

Examples

Convert Quaternion to Axis-Angle Rotation

```
quat = [0.7071 0.7071 0 0];
axang = quat2axang(quat)
```

```
axang = 1×4

    1.0000         0         0    1.5708
```

Input Arguments

`quat` — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Output Arguments

`axang` — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, returned as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Extended Capabilities

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

See Also

`axang2quat` | `quaternion`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

quat2eul

Convert quaternion to Euler angles

Syntax

```
eul = quat2eul(quat)
eul = quat2eul(quat,sequence)
```

Description

`eul = quat2eul(quat)` converts a quaternion rotation, `quat`, to the corresponding Euler angles, `eul`. The default order for Euler angle rotations is `"ZYX"`.

`eul = quat2eul(quat,sequence)` converts a quaternion into Euler angles. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Convert Quaternion to Euler Angles

```
quat = [0.7071 0.7071 0 0];
eulZYX = quat2eul(quat)
```

```
eulZYX = 1×3

         0         0    1.5708
```

Convert Quaternion to Euler Angles Using ZYZ Axis Order

```
quat = [0.7071 0.7071 0 0];
eulZYZ = quat2eul(quat,'ZYZ')
```

```
eulZYZ = 1×3

    1.5708   -1.5708   -1.5708
```

Input Arguments

quat — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with w as the scalar number.

Example: `[0.7071 0.7071 0 0]`

`sequence` — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these string scalars:

- `"ZYX"` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `"ZYZ"` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `"XYZ"` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Data Types: `string` | `char`

Output Arguments

`eul` — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, returned as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

Extended Capabilities

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

See Also
`eul2quat` | `quaternion`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

quat2rotm

Convert quaternion to rotation matrix

Syntax

`rotm = quat2rotm(quat)`

Description

`rotm = quat2rotm(quat)` converts a quaternion `quat` to an orthonormal rotation matrix, `rotm`. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Examples

Convert Quaternion to Rotation Matrix

```
quat = [0.7071 0.7071 0 0];
rotm = quat2rotm(quat)
```

```
rotm = 3×3

    1.0000         0         0
         0   -0.0000   -1.0000
         0    1.0000   -0.0000
```

Input Arguments

`quat` — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also

`rotm2quat` | `quaternion`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

quat2tform

Convert quaternion to homogeneous transformation

Syntax

```
tform = quat2tform(quat)
```

Description

`tform = quat2tform(quat)` converts a quaternion, `quat`, to a homogeneous transformation matrix, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Quaternion to Homogeneous Transformation

```
quat = [0.7071 0.7071 0 0];
tform = quat2tform(quat)
```

```
tform = 4×4

    1.0000         0         0         0
         0   -0.0000   -1.0000         0
         0    1.0000   -0.0000         0
         0         0         0    1.0000
```

Input Arguments

`quat` — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form *q* = [*w x y z*], with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, returned as a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also

`tform2quat` | `quaternion`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

rdivide, ./

Element-wise quaternion right division

Syntax

`C = A./B`

Description

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

Examples

Divide a Quaternion Array by a Real Scalar

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

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

```
A = 2x1 quaternion array
     1 + 2i + 3j + 4k
     5 + 6i + 7j + 8k
```

```
B = 2;
C = A./B
```

```
C = 2x1 quaternion array
     0.5 +   1i + 1.5j +   2k
     2.5 +   3i + 3.5j +   4k
```

Divide a Quaternion Array by Another Quaternion Array

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

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

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

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

```
B = 2x2 quaternion array
     1 + 2i + 3j + 4k     2 + 3i + 4j + 5k
     3 + 4i + 5j + 6k     4 + 5i + 6j + 7k
```

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

```
C = 2x2 quaternion array
          2.7 -      0.1i -      2.1j -      1.7k       2.2778 + 0.092593i -  0.46296j -  0.5740
       1.8256 - 0.081395i +  0.45349j -  0.24419k       1.4524 -      0.5i +   1.0238j -   0.261
```

Input Arguments

A — Dividend
scalar | vector | matrix | multidimensional array

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

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

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

B — Divisor
scalar | vector | matrix | multidimensional array

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

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

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

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Algorithms

Quaternion Division

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

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

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

Quaternion Division by a Quaternion Scalar

Given two quaternions *A* and *B* of compatible sizes,

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

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

`conj` | `./,ldivide` | `norm` | `.*,times`

Objects

`quaternion`

Introduced in R2018b

quinticpolytraj

Generate fifth-order trajectories

Syntax

```
[q,qd,qdd,pp] = quinticpolytraj(wayPoints,timePoints,tSamples)
[q,qd,qdd,pp] = quinticpolytraj(___,Name,Value)
```

Description

`[q,qd,qdd,pp] = quinticpolytraj(wayPoints,timePoints,tSamples)` generates a fifth-order polynomial that achieves a given set of input waypoints with corresponding time points. The function outputs positions, velocities, and accelerations at the given time samples, `tSamples`. The function also returns the piecewise polynomial `pp` form of the polynomial trajectory with respect to time.

`[q,qd,qdd,pp] = quinticpolytraj(___,Name,Value)` specifies additional parameters as `Name,Value` pair arguments using any combination of the previous syntaxes.

Examples

Compute Quintic Trajectory for 2-D Planar Motion

Use the `quinticpolytraj` function with a given set of 2-D *xy* waypoints. Time points for the waypoints are also given.

```
wpts = [1 4 4 3 -2 0; 0 1 2 4 3 1];
tpts = 0:5;
```

Specify a time vector for sampling the trajectory. Sample at a smaller interval than the specified time points.

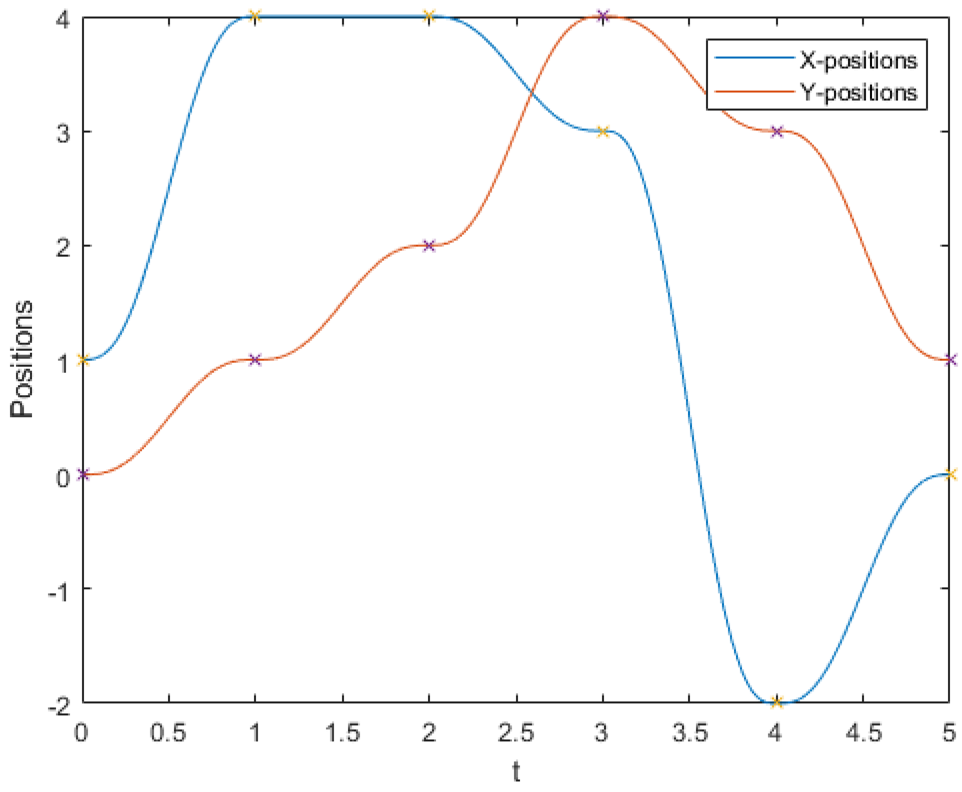
```
tvec = 0:0.01:5;
```

Compute the quintic trajectory. The function outputs the trajectory positions (`q`), velocity (`qd`), acceleration (`qdd`), and polynomial coefficients (`pp`) of the quintic polynomial.

```
[q, qd, qdd, pp] = quinticpolytraj(wpts, tpts, tvec);
```

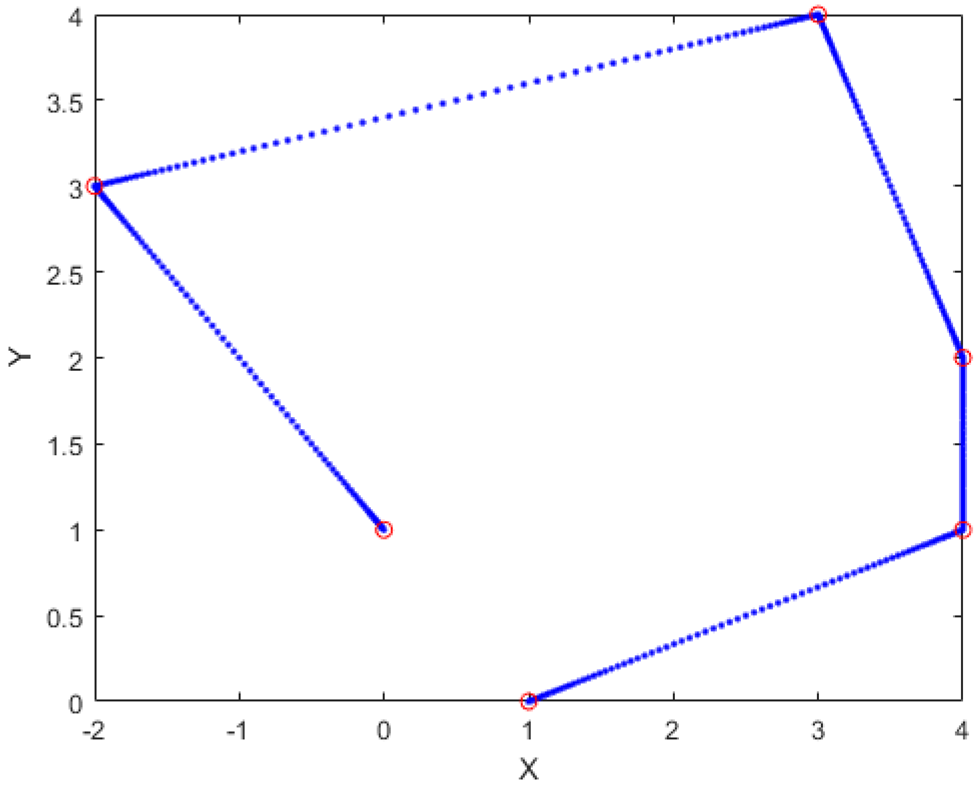
Plot the quintic trajectories for the *x*- and *y*-positions. Compare the trjactory with each waypoint.

```
plot(tvec, q)
hold all
plot(tpts, wpts, 'x')
xlabel('t')
ylabel('Positions')
legend('X-positions','Y-positions')
hold off
```



You can also verify the actual positions in the 2-D plane. Plot the separate rows of the `q` vector and the waypoints as *x*- and *y*- positions.

```
figure
plot(q(1,:),q(2,:),'.b',wpts(1,:),wpts(2,:),'or')
xlabel('X')
ylabel('Y')
```



Input Arguments

`wayPoints` — Waypoints for trajectory

n-by-*p* matrix

Points for waypoints of trajectory, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of waypoints.

Example: `[1 4 4 3 -2 0; 0 1 2 4 3 1]`

Data Types: `single` | `double`

`timePoints` — Time points for waypoints of trajectory

p-element vector

Time points for waypoints of trajectory, specified as a *p*-element vector.

Example: `[0 2 4 5 8 10]`

Data Types: `single` | `double`

`tSamples` — Time samples for trajectory

m-element vector

Time samples for the trajectory, specified as an *m*-element vector. The output position, `q`, velocity, `qd`, and accelerations, `qdd`, are sampled at these time intervals.

Example: `0:0.01:10`

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: `'VelocityBoundaryCondition',[1 0 -1 -1 0 0; 1 1 1 -1 -1 -1]`

`VelocityBoundaryCondition` — Velocity boundary conditions for each waypoint
`zeroes(n,p)` (default) | *n*-by-*p* matrix

Velocity boundary conditions for each waypoint, specified as the comma-separated pair consisting of `'VelocityBoundaryCondition'` and an *n*-by-*p* matrix. Each row corresponds to the velocity at all of *p* waypoints for the respective variable in the trajectory.

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

Data Types: `single` | `double`

`AccelerationBoundaryCondition` — Acceleration boundary conditions for each waypoint
`zeroes(n,p)` (default) | *n*-by-*p* matrix

Acceleration boundary conditions for each waypoint, specified as the comma-separated pair consisting of `'VelocityBoundaryCondition'` and an *n*-by-*p* matrix. Each row corresponds to the acceleration at all of *p* waypoints for the respective variable in the trajectory.

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

Data Types: `single` | `double`

Output Arguments

q — Positions of trajectory
m-element vector

Positions of the trajectory at the given time samples in `tSamples`, returned as an *m*-element vector, where *m* is the length of `tSamples`.

Data Types: `single` | `double`

qd — Velocities of trajectory
vector

Velocities of the trajectory at the given time samples in `tSamples`, returned as a vector.

Data Types: `single` | `double`

qdd — Accelerations of trajectory
vector

Accelerations of the trajectory at the given time samples in `tSamples`, returned as a vector.

Data Types: `single` | `double`

pp — Piecewise-polynomial
structure

Piecewise-polynomial, returned as a structure that defines the polynomial for each section of the piecewise trajectory. You can build your own piecewise polynomials using `mkpp`, or evaluate the polynomial at specified times using `ppval`. The structure contains the fields:

- `form`: `'pp'`.
- `breaks`: *p*-element vector of times when the piecewise trajectory changes forms. *p* is the number of waypoints.
- `coefs`: *n*(*p*–1)-by-`order` matrix for the coefficients for the polynomials. *n*(*p*–1) is the dimension of the trajectory times the number of `pieces`. Each set of *n* rows defines the coefficients for the polynomial that described each variable trajectory.
- `pieces`: *p*–1. The number of breaks minus 1.
- `order`: Degree of the polynomial + 1. For example, cubic polynomials have an order of 4.
- `dim`: *n*. The dimension of the control point positions.

Extended Capabilities

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

See Also

`bsplinepolytraj` | `cubicpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

randrot

Uniformly distributed random rotations

Syntax

```
R = randrot
R = randrot(m)
R = randrot(m1,...,mN)
R = randrot([m1,...,mN])
```

Description

`R = randrot` returns a unit quaternion drawn from a uniform distribution of random rotations.

`R = randrot(m)` returns an `m`-by-`m` matrix of unit quaternions drawn from a uniform distribution of random rotations.

`R = randrot(m1,...,mN)` returns an `m1`-by-...-by-`mN` array of random unit quaternions, where `m1`, ..., `mN` indicate the size of each dimension. For example, `randrot(3,4)` returns a 3-by-4 matrix of random unit quaternions.

`R = randrot([m1,...,mN])` returns an `m1`-by-...-by-`mN` array of random unit quaternions, where `m1`,..., `mN` indicate the size of each dimension. For example, `randrot([3,4])` returns a 3-by-4 matrix of random unit quaternions.

Examples

Matrix of Random Rotations

Generate a 3-by-3 matrix of uniformly distributed random rotations.

```
r = randrot(3)
```

```
r = 3x3 quaternion array
      0.17446 +  0.59506i -  0.73295j +  0.27976k      0.69704 - 0.060589i +  0.68679j -  0.19695
      0.21908 -  0.89875i -    0.298j +  0.23548k    -0.049744 +  0.59691i +  0.56459j +  0.56780
       0.6375 +  0.49338i -  0.24049j +  0.54068k       0.2979 -  0.53568i +  0.31819j +  0.7232
```

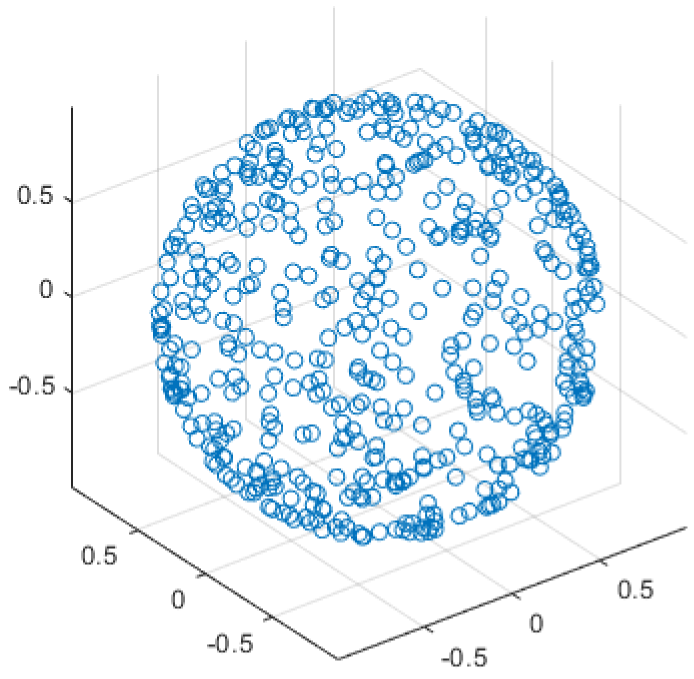
Create Uniform Distribution of Random Rotations

Create a vector of 500 random quaternions. Use rotatepoint on page 2-192 to visualize the distribution of the random rotations applied to point (1, 0, 0).

```
q = randrot(500,1);
```

```
pt = rotatepoint(q, [1 0 0]);
```

```
figure
scatter3(pt(:,1), pt(:,2), pt(:,3))
axis equal
```



Input Arguments

m — Size of square matrix
integer

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

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

m1,...,mN — Size of each dimension
two or more integer values

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

Example: randrot(2,3) returns a 2-by-3 matrix of random quaternions.

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

[m1,...,mN] — Vector of size of each dimension
row vector of integer values

Vector of size of each dimension, specified as a row vector of two or more integer values. If the size of any dimension is `0` or negative, then `R` is returned as an empty array.

Example: `randrot([2,3])` returns a 2-by-3 matrix of random quaternions.

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

Output Arguments

`R` — Random quaternions
scalar | vector | matrix | multidimensional array

Random quaternions, returned as a quaternion or array of quaternions.

Data Types: `quaternion`

References

[1] Shoemake, K. "Uniform Random Rotations." *Graphics Gems III* (K. David, ed.). New York: Academic Press, 1992.

Extended Capabilities

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

See Also

`quaternion`

Introduced in R2019a

readBinaryOccupancyGrid

Read binary occupancy grid

Syntax

```
map = readBinaryOccupancyGrid(msg)
map = readBinaryOccupancyGrid(msg,thresh)
map = readBinaryOccupancyGrid(msg,thresh,val)
```

Description

`map = readBinaryOccupancyGrid(msg)` returns a `binaryOccupancyMap` object by reading the data inside a ROS message, `msg`, which must be a `'nav_msgs/OccupancyGrid'` message. All message data values greater than or equal to the occupancy threshold are set to occupied, `1`, in the map. All other values, including unknown values (`-1`) are set to unoccupied, `0`, in the map.

Note The `msg` input is an `'nav_msgs/OccupancyGrid'` ROS message. For more info, see `OccupancyGrid`.

`map = readBinaryOccupancyGrid(msg,thresh)` specifies a threshold, `thresh`, for occupied values. All values greater than or equal to the threshold are set to occupied, `1`. All other values are set to unoccupied, `0`.

`map = readBinaryOccupancyGrid(msg,thresh,val)` specifies a value to set for unknown values (`-1`). By default, all unknown values are set to unoccupied, `0`.

Input Arguments

`msg` — `'nav_msgs/OccupancyGrid'` ROS message
`OccupancyGrid` object handle

`'nav_msgs/OccupancyGrid'` ROS message, specified as a `OccupancyGrid` object handle.

`thresh` — Threshold for occupied values
50 (default) | scalar

Threshold for occupied values, specified as a scalar. Any value greater than or equal to the threshold is set to occupied, `1`. All other values are set to unoccupied, `0`.

Data Types: `double`

`val` — Value to replace unknown values
0 (default) | 1

Value to replace unknown values, specified as either `0` or `1`. Unknown message values (`-1`) are set to the given value.

Data Types: `double` | `logical`

Output Arguments

`map` — Binary occupancy grid
`binaryOccupancyMap` object handle

Binary occupancy grid, returned as a `binaryOccupancyMap` object handle. `map` is converted from a `'nav_msgs/OccupancyGrid'` message on the ROS network. The object is a grid of binary values, where `1` indicates an occupied location and `0` indications an unoccupied location.

See Also

Objects
`OccupancyGrid` | `occupancyMap` | `binaryOccupancyMap`

Functions
`rosReadOccupancyGrid` | `rosWriteBinaryOccupancyGrid` | `rosWriteOccupancyGrid`

Introduced in R2015a

roboticsAddons

Install add-ons for robotics

Syntax

```
roboticsAddons
```

Description

`roboticsAddons` allows you to download and install add-ons for Robotics System Toolbox. Use this function to open the Add-ons Explorer to browse the available add-ons.

Examples

Install Add-ons for Robotics System Toolbox™

To install add-ons for Robotics System Toolbox, run the function.

```
roboticsAddons
```

This function opens the Add-on Explorer with the Robotics System Toolbox set as the filter. Select the desired add-on and choose your install action.

See Also

Topics
"Install Robotics System Toolbox Add-ons"
"ROS Custom Message Support" (ROS Toolbox)
"Get and Manage Add-Ons"

Introduced in R2016a

roboticsSupportPackages

Download and install support packages for Robotics System Toolbox

Note `roboticsSupportPackages` has been removed. Use `roboticsAddons` instead.

Syntax

`roboticsSupportPackages`

Description

`roboticsSupportPackages` opens the Support Package Installer to download and install support packages for Robotics System Toolbox. For more details, see “Install Robotics System Toolbox Add-ons”.

Examples

Open Robotics System Toolbox Support Package Installer

```
roboticsSupportPackages
```

Introduced in R2015a

rotateframe

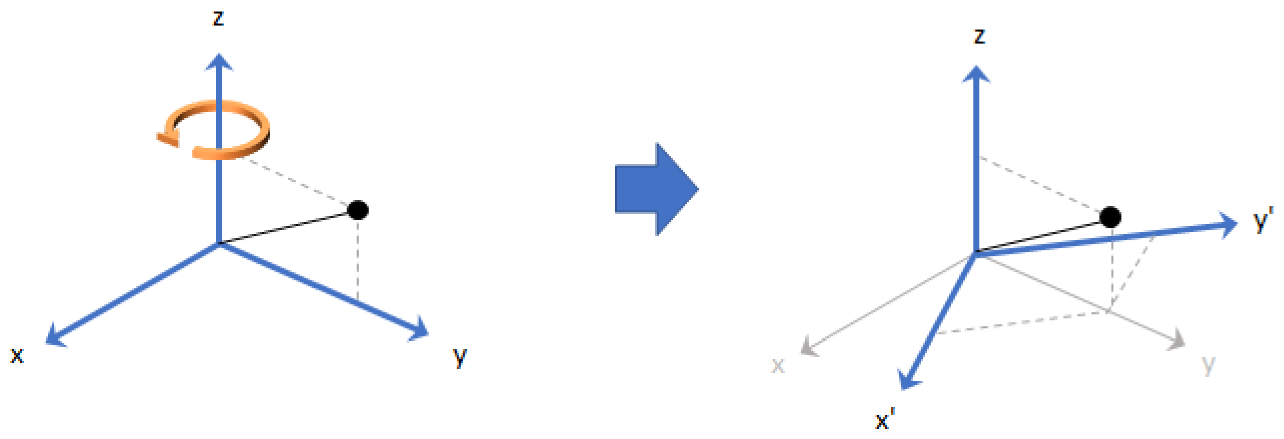
Quaternion frame rotation

Syntax

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

Description

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

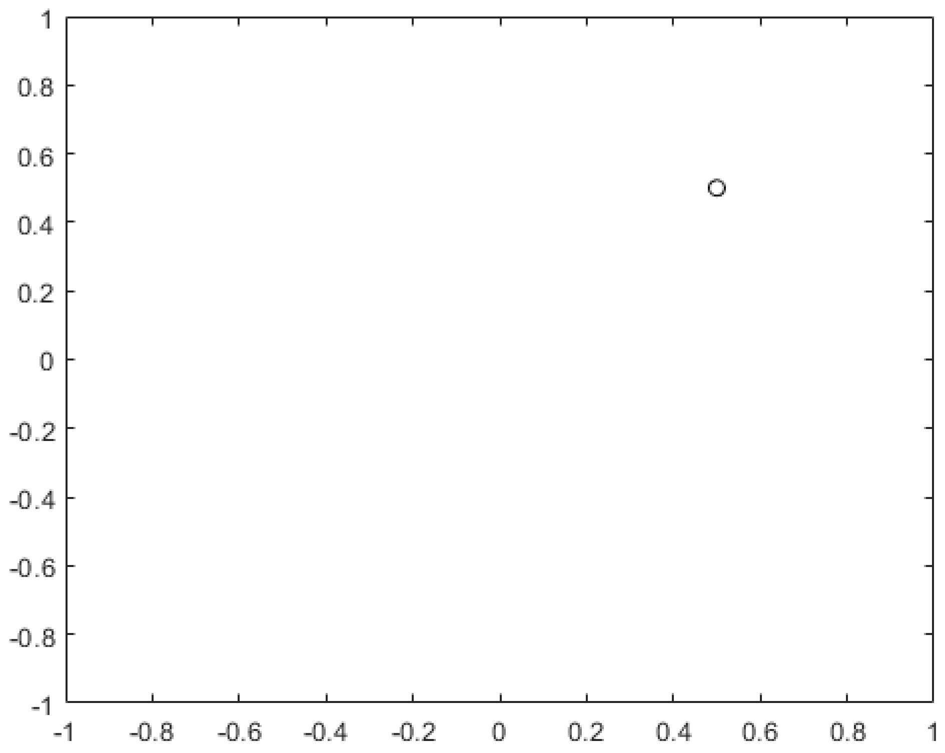


Examples

Rotate Frame Using Quaternion Vector

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

```
x = 0.5;
y = 0.5;
z = 0;
plot(x,y,'ko')
hold on
axis([-1 1 -1 1])
```



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

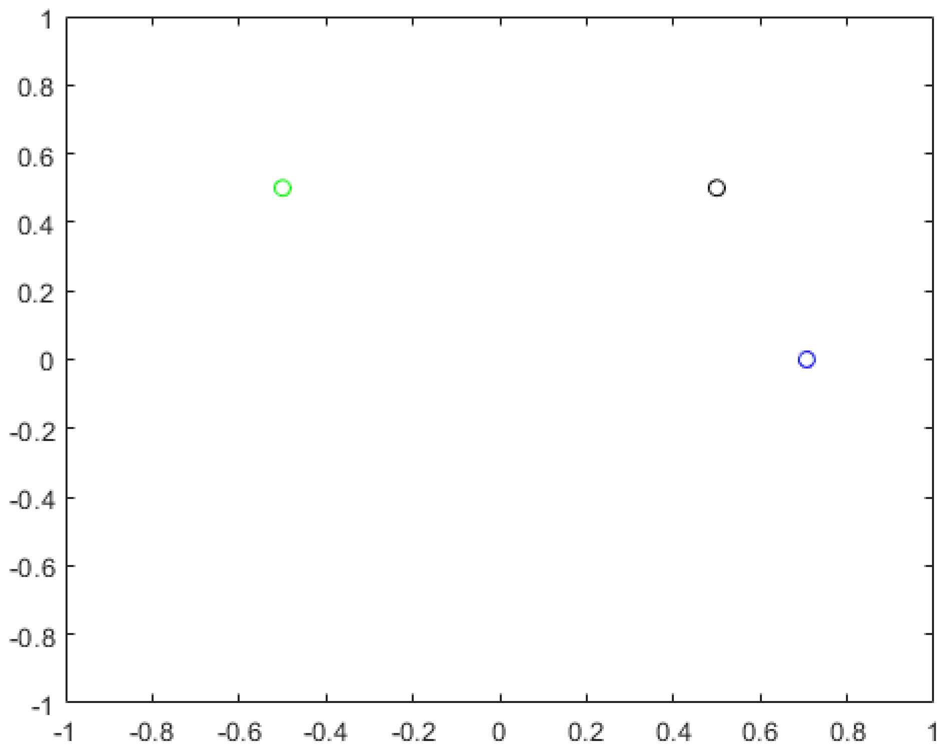
```
quat = quaternion([0,0,pi/4; ...
                   0,0,-pi/2],'euler','XYZ','frame');
```

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

```
rereferencedPoint = 2×3

    0.7071   -0.0000         0
   -0.5000    0.5000         0
```

Plot the rereferenced points.

```
plot(rereferencedPoint(1,1),rereferencedPoint(1,2),'bo')
plot(rereferencedPoint(2,1),rereferencedPoint(2,2),'go')
```



Rereference Group of Points using Quaternion

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

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

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

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

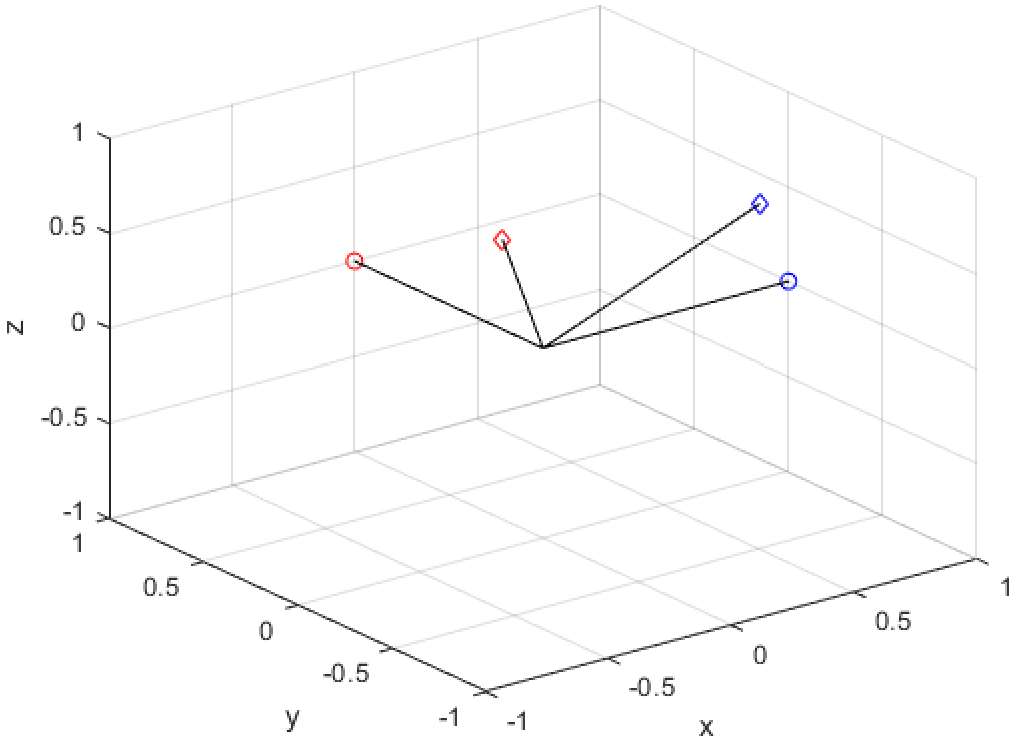
```
rP = 2×3

    0.6124   -0.3536    0.7071
    0.5000    0.8660   -0.0000
```

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

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

```
hold on
```

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

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

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



Input Arguments

quat — Quaternion that defines rotation
scalar | vector

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

Data Types: `quaternion`

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

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

Data Types: `single` | `double`

Output Arguments

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

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

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

Data Types: `single` | `double`

Algorithms

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

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

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

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

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

the `rotateframe` function performs the following operations:

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

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

2. Normalizes the quaternion, q:

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

3. Applies the rotation:

   $$v_q = q^* u_q q$$

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

Extended Capabilities

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

See Also

Functions
`rotatepoint`

Objects
`quaternion`

Introduced in R2018a

rotatepoint

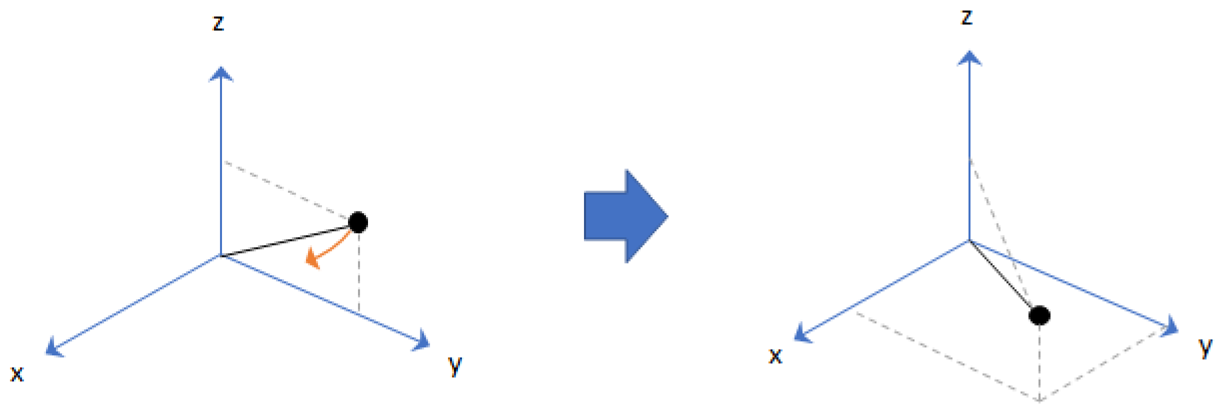
Quaternion point rotation

Syntax

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

Description

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

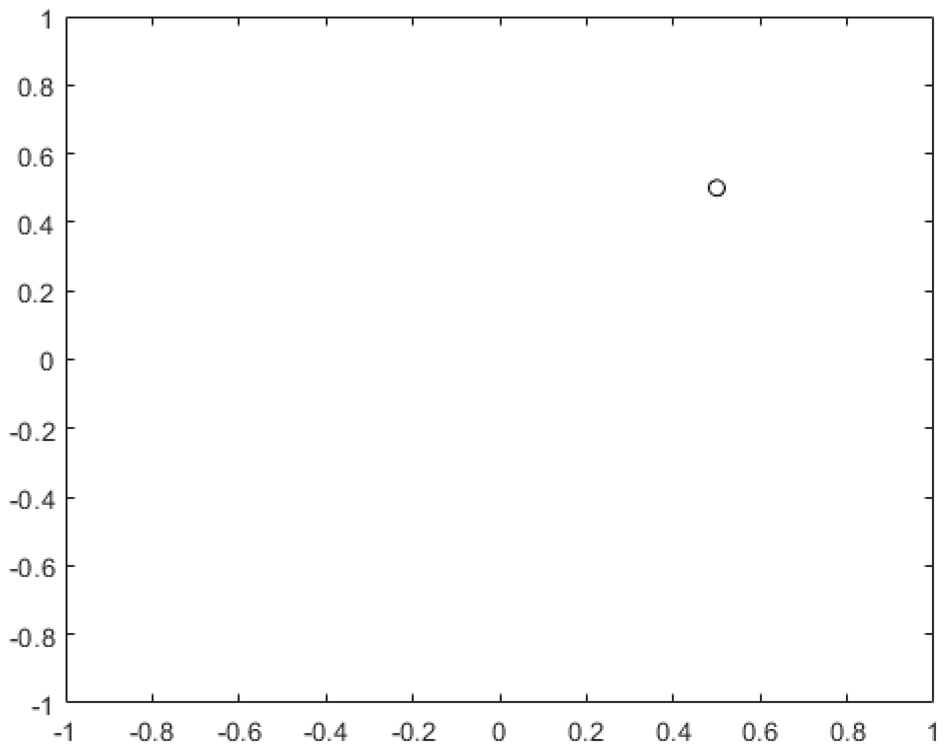


Examples

Rotate Point Using Quaternion Vector

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

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

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



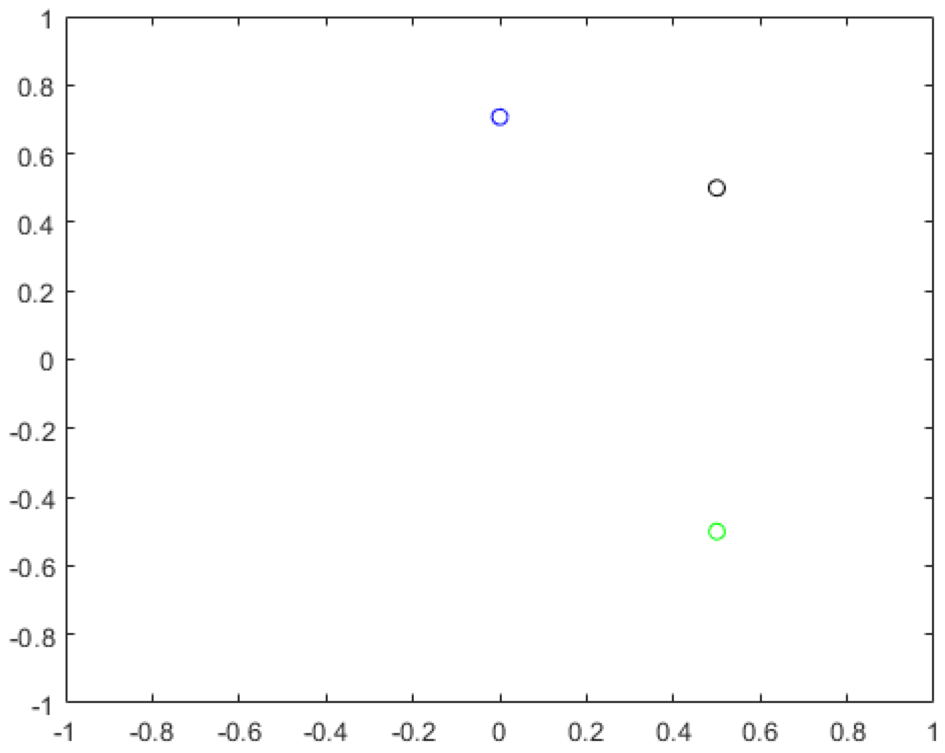
Create a quaternion vector specifying two separate rotations, one to rotate the point 45 and another to rotate the point -90 degrees about the *z*-axis. Use `rotatepoint` to perform the rotation.

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

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

```
rotatedPoint = 2×3

   -0.0000    0.7071         0
    0.5000   -0.5000         0
```

Plot the rotated points.

```
plot(rotatedPoint(1,1),rotatedPoint(1,2),'bo')
plot(rotatedPoint(2,1),rotatedPoint(2,2),'go')
```



Rotate Group of Points Using Quaternion

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

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

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

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

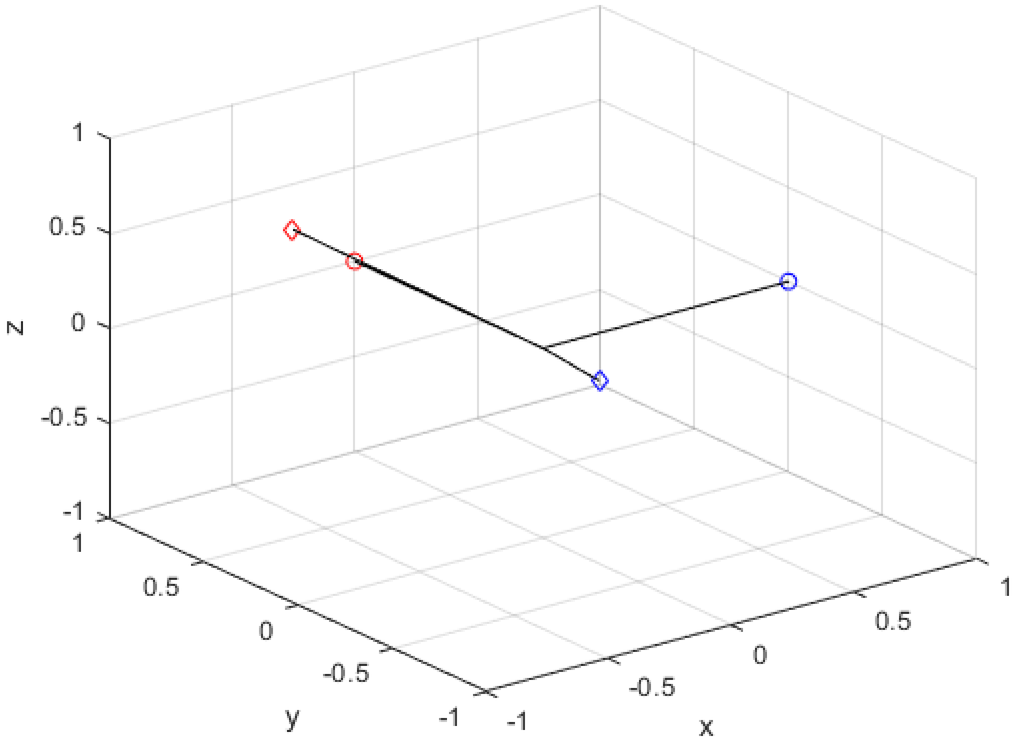
```
rP = 2×3

    0.6124    0.5000   -0.6124
   -0.3536    0.8660    0.3536
```

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

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

```
hold on
```

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

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

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



Input Arguments

quat — Quaternion that defines rotation

scalar | vector

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

Data Types: `quaternion`

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

Three-dimensional Cartesian points, specified as a 1-by-3 vector or *N*-by-3 matrix.

Data Types: `single` | `double`

Output Arguments

`rotationResult` — Repositioned Cartesian points
vector | matrix

Rotated Cartesian points defined using the quaternion rotation, returned as a vector or matrix the same size as `cartesianPoints`.

Data Types: `single` | `double`

Algorithms

Quaternion point rotation rotates a point specified in $\mathbf{R}^3$ according to a specified quaternion:

$$L_q(u) = quq^*$$

where q is the quaternion, * represents conjugation, and u is the point to rotate, specified as a quaternion.

For convenience, the `rotatepoint` function takes in a point in $\mathbf{R}^3$ and returns a point in $\mathbf{R}^3$. Given a function call with some arbitrary quaternion, $q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, and arbitrary coordinate, $[x,y,z]$, for example,

```
rereferencedPoint = rotatepoint(q,[x,y,z])
```

the `rotatepoint` function performs the following operations:

1. Converts point $[x,y,z]$ to a quaternion:

   $$u_q = 0 + xi + yj + zk$$

2. Normalizes the quaternion, q:

   $$q_n = \frac{q}{\sqrt{a^2 + b^2 + c^2 + d^2}}$$

3. Applies the rotation:

   $$v_q = qu_qq^*$$

4. Converts the quaternion output, v_q, back to $\mathbf{R}^3$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`rotateframe`

Objects
`quaternion`

Introduced in R2018a

rotm2axang

Convert rotation matrix to axis-angle rotation

Syntax

```
axang = rotm2axang(rotm)
```

Description

`axang = rotm2axang(rotm)` converts a rotation given as an orthonormal rotation matrix, `rotm`, to the corresponding axis-angle representation, `axang`. The input rotation matrix must be in the premultiply form for rotations.

Examples

Convert Rotation Matrix to Axis-Angle Rotation

```
rotm = [1 0 0 ; 0 -1 0; 0 0 -1];
axang = rotm2axang(rotm)
```

```
axang = 1×4

    1.0000         0         0    3.1416
```

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and must be orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: `[0 0 1; 0 1 0; -1 0 0]`

Output Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, returned as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axis, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`axang2rotm`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

rotm2eul

Convert rotation matrix to Euler angles

Syntax

```
eul = rotm2eul(rotm)
eul = rotm2eul(rotm,sequence)
```

Description

`eul = rotm2eul(rotm)` converts a rotation matrix, `rotm`, to the corresponding Euler angles, `eul`. The input rotation matrix must be in the premultiply form for rotations. The default order for Euler angle rotations is `"ZYX"`.

For more details on Euler angle rotations, see “Euler Angles”.

`eul = rotm2eul(rotm,sequence)` converts a rotation matrix to Euler angles. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Convert Rotation Matrix to Euler Angles

```
rotm = [0 0 1; 0 1 0; -1 0 0];
eulZYX = rotm2eul(rotm)
```

```
eulZYX = 1×3

         0    1.5708         0
```

Convert Rotation Matrix to Euler Angles Using ZYZ Axis Order

```
rotm = [0 0 1; 0 -1 0; -1 0 0];
eulZYZ = rotm2eul(rotm,'ZYZ')
```

```
eulZYZ = 1×3

   -3.1416   -1.5708   -3.1416
```

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: `[0 0 1; 0 1 0; -1 0 0]`

`sequence` — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these string scalars:

- `"ZYX"` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `"ZYZ"` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `"XYZ"` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Data Types: `string` | `char`

Output Arguments

`eul` — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, returned as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`eul2rotm`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

rotm2quat

Convert rotation matrix to quaternion

Syntax

```
quat = rotm2quat(rotm)
```

Description

`quat = rotm2quat(rotm)` converts a rotation matrix, `rotm`, to the corresponding unit quaternion representation, `quat`. The input rotation matrix must be in the premultiply form for rotations.

Examples

Convert Rotation Matrix to Quaternion

```
rotm = [0 0 1; 0 1 0; -1 0 0];
quat = rotm2quat(rotm)
```

```
quat = 1×4

    0.7071         0    0.7071         0
```

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: `[0 0 1; 0 1 0; -1 0 0]`

Output Arguments

quat — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with w as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`quat2rotm`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

rotm2tform

Convert rotation matrix to homogeneous transformation

Syntax

```
tform = rotm2tform(rotm)
```

Description

`tform = rotm2tform(rotm)` converts the rotation matrix, `rotm`, into a homogeneous transformation matrix, `tform`. The input rotation matrix must be in the premultiply form for rotations. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Rotation Matrix to Homogeneous Transformation

```
rotm = [1 0 0 ; 0 -1 0; 0 0 -1];
tform = rotm2tform(rotm)
```

```
tform = 4×4

     1     0     0     0
     0    -1     0     0
     0     0    -1     0
     0     0     0     1
```

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

Example: `[0 0 1; 0 1 0; -1 0 0]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`tform2rotm`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

rotmat

Convert quaternion to rotation matrix

Syntax

`rotationMatrix = rotmat(quat,rotationType)`

Description

`rotationMatrix = rotmat(quat,rotationType)` converts the quaternion, `quat`, to an equivalent rotation matrix representation.

Examples

Convert Quaternion to Rotation Matrix for Point Rotation

Define a quaternion for use in point rotation.

```
theta = 45;
gamma = 30;
quat = quaternion([0,theta,gamma],'eulerd','ZYX','point')
```

```
quat = quaternion
       0.8924 +  0.23912i +  0.36964j + 0.099046k
```

Convert the quaternion to a rotation matrix.

```
rotationMatrix = rotmat(quat,'point')
```

```
rotationMatrix = 3×3

    0.7071   -0.0000    0.7071
    0.3536    0.8660   -0.3536
   -0.6124    0.5000    0.6124
```

To verify the rotation matrix, directly create two rotation matrices corresponding to the rotations about the *y*- and *x*-axes. Multiply the rotation matrices and compare to the output of `rotmat`.

```
theta = 45;
gamma = 30;

ry = [cosd(theta)   0           sind(theta) ; ...
      0             1           0           ; ...
     -sind(theta)   0           cosd(theta)];

rx = [1             0           0           ;      ...
      0             cosd(gamma) -sind(gamma) ;     ...
      0             sind(gamma) cosd(gamma)];

rotationMatrixVerification = rx*ry
rotationMatrixVerification = 3×3

    0.7071         0    0.7071
    0.3536    0.8660   -0.3536
   -0.6124    0.5000    0.6124
```

Convert Quaternion to Rotation Matrix for Frame Rotation

Define a quaternion for use in frame rotation.

```
theta = 45;
gamma = 30;
quat = quaternion([0,theta,gamma],'eulerd','ZYX','frame')
```

```
quat = quaternion
       0.8924 +  0.23912i +  0.36964j - 0.099046k
```

Convert the quaternion to a rotation matrix.

```
rotationMatrix = rotmat(quat,'frame')
```

```
rotationMatrix = 3×3

    0.7071   -0.0000   -0.7071
    0.3536    0.8660    0.3536
    0.6124   -0.5000    0.6124
```

To verify the rotation matrix, directly create two rotation matrices corresponding to the rotations about the *y*- and *x*-axes. Multiply the rotation matrices and compare to the output of `rotmat`.

```
theta = 45;
gamma = 30;

ry = [cosd(theta)   0           -sind(theta) ; ...
      0             1           0            ; ...
     sind(theta)   0           cosd(theta)];

rx = [1             0           0            ;      ...
      0             cosd(gamma) sind(gamma) ;     ...
      0             -sind(gamma) cosd(gamma)];

rotationMatrixVerification = rx*ry
```

```
rotationMatrixVerification = 3×3

    0.7071         0   -0.7071
    0.3536    0.8660    0.3536
    0.6124   -0.5000    0.6124
```

Convert Quaternion Vector to Rotation Matrices

Create a 3-by-1 normalized quaternion vector.

```
qVec = normalize(quaternion(randn(3,4)));
```

Convert the quaternion array to rotation matrices. The pages of `rotmatArray` correspond to the linear index of `qVec`.

```
rotmatArray = rotmat(qVec,'frame');
```

Assume `qVec` and `rotmatArray` correspond to a sequence of rotations. Combine the quaternion rotations into a single representation, then apply the quaternion rotation to arbitrarily initialized Cartesian points.

```
loc = normalize(randn(1,3));
quat = prod(qVec);
rotateframe(quat,loc)
```

```
ans = 1×3

    0.9524    0.5297    0.9013
```

Combine the rotation matrices into a single representation, then apply the rotation matrix to the same initial Cartesian points. Verify the quaternion rotation and rotation matrix result in the same orientation.

```
totalRotMat = eye(3);
for i = 1:size(rotmatArray,3)
    totalRotMat = rotmatArray(:,:,i)*totalRotMat;
end
totalRotMat*loc'
```

```
ans = 3×1

    0.9524
    0.5297
    0.9013
```

Input Arguments

quat — Quaternion to convert
scalar | vector | matrix | multidimensional array

Quaternion to convert, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

`rotationType` — Type or rotation
`'frame'` | `'point'`

Type of rotation represented by the `rotationMatrix` output, specified as `'frame'` or `'point'`.

Data Types: `char` | `string`

Output Arguments

`rotationMatrix` — Rotation matrix representation
3-by-3 matrix | 3-by-3-by-*N* multidimensional array

Rotation matrix representation, returned as a 3-by-3 matrix or 3-by-3-by-*N* multidimensional array.

- If `quat` is a scalar, `rotationMatrix` is returned as a 3-by-3 matrix.
- If `quat` is non-scalar, `rotationMatrix` is returned as a 3-by-3-by-*N* multidimensional array, where `rotationMatrix(:,:,i)` is the rotation matrix corresponding to `quat(i)`.

The data type of the rotation matrix is the same as the underlying data type of `quat`.

Data Types: `single` | `double`

Algorithms

Given a quaternion of the form

$$q = a + bi + cj + dk\,,$$

the equivalent rotation matrix for frame rotation is defined as

$$\begin{bmatrix} 2a^2-1+2b^2 & 2bc+2ad & 2bd-2ac \\ 2bc-2ad & 2a^2-1+2c^2 & 2cd+2ab \\ 2bd+2ac & 2cd-2ab & 2a^2-1+2d^2 \end{bmatrix}.$$

The equivalent rotation matrix for point rotation is the transpose of the frame rotation matrix:

$$\begin{bmatrix} 2a^2-1+2b^2 & 2bc-2ad & 2bd+2ac \\ 2bc+2ad & 2a^2-1+2c^2 & 2cd-2ab \\ 2bd-2ac & 2cd+2ab & 2a^2-1+2d^2 \end{bmatrix}.$$

References

[1] Kuipers, Jack B. *Quaternions and Rotation Sequences: A Primer with Applications to Orbits, Aerospace, and Virtual Reality*. Princeton, NJ: Princeton University Press, 2007.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`rotvec` | `rotvecd` | `euler` | `eulerd`

Objects
`quaternion`

Introduced in R2018a

rottraj

Generate trajectories between orientation rotation matrices

Syntax

```
[R,omega,alpha] = rottraj(r0,rF,tInterval,tSamples)
[R,omega,alpha] = rottraj(r0,rF,tInterval,tSamples,Name,Value)
```

Description

`[R,omega,alpha] = rottraj(r0,rF,tInterval,tSamples)` generates a trajectory that interpolates between two orientations, `r0` and `rF`, with points based on the time interval and given time samples.

`[R,omega,alpha] = rottraj(r0,rF,tInterval,tSamples,Name,Value)` specifies additional parameters using `Name,Value` pair arguments.

Examples

Interpolate Trajectory Between Quaternions

Define two quaternion waypoints to interpolate between.

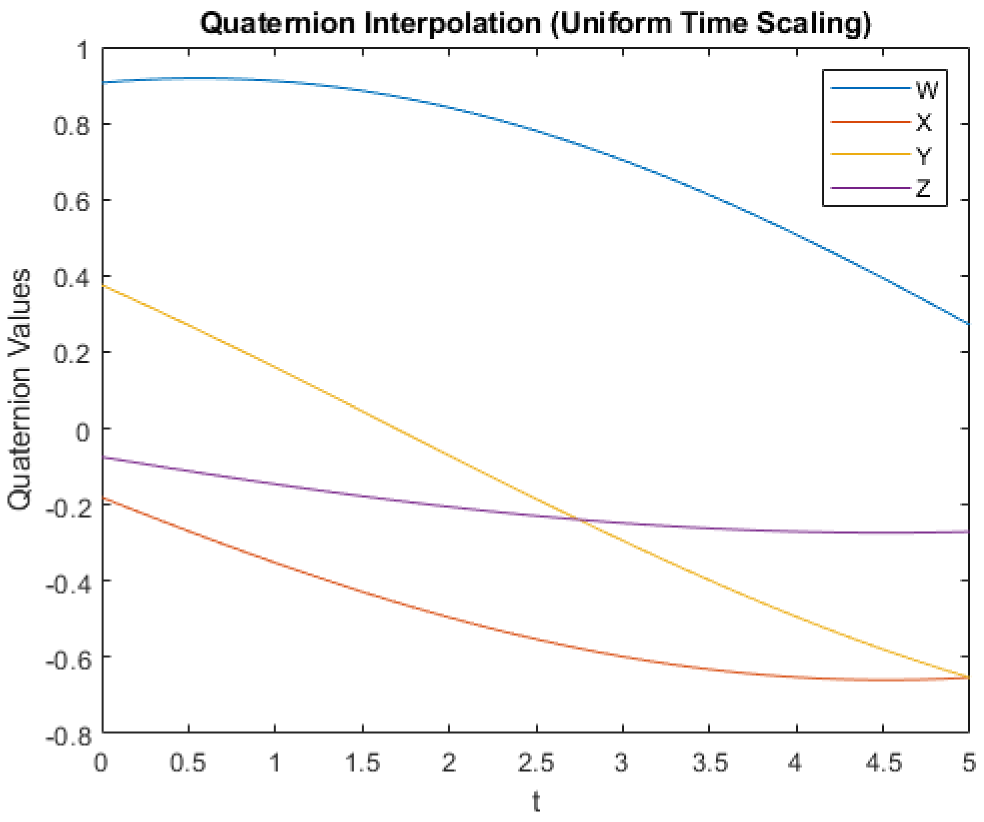
```
q0 = quaternion([0 pi/4 -pi/8],'euler','ZYX','point');
qF = quaternion([3*pi/2 0 -3*pi/4],'euler','ZYX','point');
```

Specify a vector of times to sample the quaternion trajectory.

```
tvec = 0:0.01:5;
```

Generate the trajectory. Plot the results.

```
[qInterp1,w1,a1] = rottraj(q0,qF,[0 5],tvec);

plot(tvec,compact(qInterp1))
title('Quaternion Interpolation (Uniform Time Scaling)')
xlabel('t')
ylabel('Quaternion Values')
legend('W','X','Y','Z')
```



Interpolate Trajectory Between Rotation Matrices

Define two rotation matrix waypoints to interpolate between.

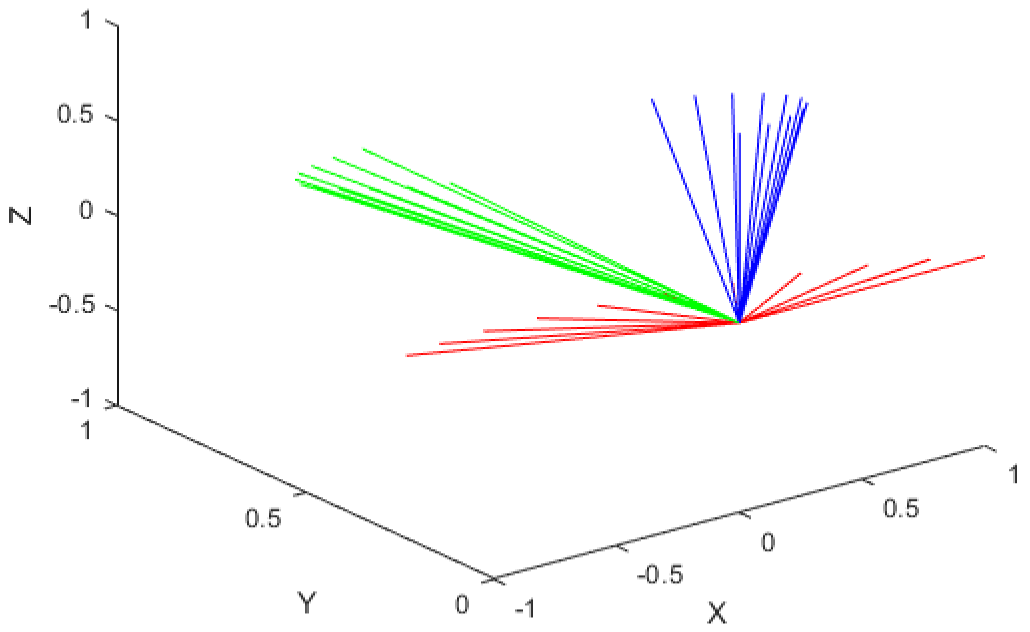
```
r0 = [1 0 0; 0 1 0; 0 0 1];
rF = [0 0 1; 1 0 0; 0 0 0];
```

Specify a vector of times to sample the quaternion trajectory.

```
tvec = 0:0.1:1;
```

Generate the trajectory. Plot the results using `plotTransforms`. Convert the rotation matrices to quaternions and specify zero translation. The figure shows all the intermediate rotations of the coordinate frame.

```
[rInterp1,w1,a1] = rottraj(r0,rF,[0 1],tvec);

rotations = rotm2quat(rInterp1);
zeroVect = zeros(length(rotations),1);
translations = [zeroVect,zeroVect,zeroVect];

plotTransforms(translations,rotations)
xlabel('X')
ylabel('Y')
zlabel('Z')
```



Input Arguments

`r0` — Initial orientation

3-by-3 rotation matrix | `quaternion` object

Initial orientation, specified as a 3-by-3 rotation matrix or `quaternion` object. The function generates a trajectory that starts at the initial orientation, `r0`, and goes to the final orientation, `rF`.

Example: `quaternion([0 pi/4 -pi/8],'euler','ZYX','point');`

Data Types: `single` | `double`

`rF` — Final orientation

3-by-3 rotation matrix | `quaternion` object

Final orientation, specified as a 3-by-3 rotation matrix or `quaternion` object. The function generates a trajectory that starts at the initial orientation, `r0`, and goes to the final orientation, `rF`.

Example: `quaternion([3*pi/2 0 -3*pi/4],'euler','ZYX','point')`

Data Types: `single` | `double`

`tInterval` — Start and end times for trajectory

two-element vector

Start and end times for the trajectory, specified as a two-element vector.

Example: `[0 10]`

Data Types: `single` | `double`

`tSamples` — Time samples for trajectory

m-element vector

Time samples for the trajectory, specified as an *m*-element vector.

Example: `0:0.01:10`

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: `'TimeScaling',[0 1 2; 0 1 0; 0 0 0]`

`TimeScaling` — Time scaling vector and first two derivatives

3-by-*m* vector

Time scaling vector and the first two derivatives, specified as the comma-separated pair of `'TimeScaling'` and a 3-by-*m* vector, where *m* is the length of `tSamples`. By default, the time scaling is a linear time scaling between the time points in `tInterval`.

For a nonlinear time scaling, specify the values of the time points in the first row. The second and third rows are the velocity and acceleration of the time points, respectively. For example, to follow the path with a linear velocity to the halfway point, and then jump to the end, the time-scaling would be:

```
s(1,:) = [0 0.25 0.5 1 1 1] % Position
s(2,:) = [1    1   1 0 0 0] % Velocity
s(3,:) = [0    0   0 0 0 0] % Acceleration
```

Data Types: `single` | `double`

Output Arguments

`R` — Orientation trajectory

3-by-3-by-*m* rotation matrix array | `quaternion` object array

Orientation trajectory, returned as a 3-by-3-by-*m* rotation matrix array or `quaternion` object array, where *m* is the number of points in `tSamples`. The output type depends on the inputs from `r0` and `rF`.

`omega` — Orientation angular velocity

3-by-*m* matrix

Orientation angular velocity, returned as a 3-by-*m* matrix, where *m* is the number of points in `tSamples`.

`alpha` — Orientation angular acceleration

3-by-*m* matrix

Orientation angular acceleration, returned as a 3-by-*m* matrix, where *m* is the number of points in `tSamples`

Limitations

- When specifying your `r0` and `rF` input arguments as a 3-by-3 rotation matrix, they are converted to a `quaternion` object before interpolating the trajectory . If your rotation matrix does not follow a right-handed coordinate system or does not have a direct conversion to quaternions, this conversion may result in different initial and final rotations in the output trajectory.

References

[1] Dam, Erik B., Martin Koch, and Martin Lillholm. *Quaternions, Interpolation and Animation*. Technical Report DIKU-TR-98/5 (July 1998). http://web.mit.edu/2.998/www/QuaternionReport1.pdf

[2] Graf, Basile. *Quaternions and Dynamics*. arXiv:0811.2889 [math.DS] (2008). https://arxiv.org/pdf/0811.2889.pdf

[3] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control*. Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `transformtraj` | `trapveltraj` | `quaternion`

Introduced in R2019a

rotvec

Convert quaternion to rotation vector (radians)

Syntax

```
rotationVector = rotvec(quat)
```

Description

`rotationVector = rotvec(quat)` converts the quaternion array, `quat`, to an *N*-by-3 matrix of equivalent rotation vectors in radians. The elements of `quat` are normalized before conversion.

Examples

Convert Quaternion to Rotation Vector in Radians

Convert a random quaternion scalar to a rotation vector in radians

```
quat = quaternion(randn(1,4));
rotvec(quat)
```

```
ans = 1×3

    1.6866   -2.0774    0.7929
```

Input Arguments

`quat` — Quaternion to convert
scalar | vector | matrix | multidimensional array

Quaternion to convert, specified as scalar quaternion, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

Output Arguments

`rotationVector` — Rotation vector (radians)
N-by-3 matrix

Rotation vector representation, returned as an *N*-by-3 matrix of rotations vectors, where each row represents the [X Y Z] angles of the rotation vectors in radians. The *i*th row of `rotationVector` corresponds to the element `quat(i)`.

The data type of the rotation vector is the same as the underlying data type of `quat`.

Data Types: `single` | `double`

Algorithms

All rotations in 3-D can be represented by a three-element axis of rotation and a rotation angle, for a total of four elements. If the rotation axis is constrained to be unit length, the rotation angle can be distributed over the vector elements to reduce the representation to three elements.

Recall that a quaternion can be represented in axis-angle form

$$q = \cos\left(\theta/2\right) + \sin\left(\theta/2\right)(\mathrm{xi} + y\mathrm{j} + z\mathrm{k}),$$

where θ is the angle of rotation and $[x,y,z]$ represent the axis of rotation.

Given a quaternion of the form

$$q = a + bi + cj + dk\,,$$

you can solve for the rotation angle using the axis-angle form of quaternions:

$$\theta = 2\cos^{-1}(a)\,.$$

Assuming a normalized axis, you can rewrite the quaternion as a rotation vector without loss of information by distributing θ over the parts b, c, and d. The rotation vector representation of q is

$$q_{\mathrm{rv}} = \frac{\theta}{\sin\left(\theta/2\right)}[b, c, d]\,.$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`rotvecd` | `euler` | `eulerd`

Objects
`quaternion`

Introduced in R2018a

rotvecd

Convert quaternion to rotation vector (degrees)

Syntax

```
rotationVector = rotvecd(quat)
```

Description

`rotationVector = rotvecd(quat)` converts the quaternion array, `quat`, to an *N*-by-3 matrix of equivalent rotation vectors in degrees. The elements of `quat` are normalized before conversion.

Examples

Convert Quaternion to Rotation Vector in Degrees

Convert a random quaternion scalar to a rotation vector in degrees.

```
quat = quaternion(randn(1,4));
rotvecd(quat)
```

```
ans = 1×3

   96.6345 -119.0274   45.4312
```

Input Arguments

`quat` — Quaternion to convert
scalar | vector | matrix | multidimensional array

Quaternion to convert, specified as scalar, vector, matrix, or multidimensional array of quaternions.

Data Types: `quaternion`

Output Arguments

`rotationVector` — Rotation vector (degrees)
N-by-3 matrix

Rotation vector representation, returned as an *N*-by-3 matrix of rotation vectors, where each row represents the [*x y z*] angles of the rotation vectors in degrees. The *i*th row of `rotationVector` corresponds to the element `quat(i)`.

The data type of the rotation vector is the same as the underlying data type of `quat`.

Data Types: `single` | `double`

Algorithms

All rotations in 3-D can be represented by four elements: a three-element axis of rotation and a rotation angle. If the rotation axis is constrained to be unit length, the rotation angle can be distributed over the vector elements to reduce the representation to three elements.

Recall that a quaternion can be represented in axis-angle form

$$q = \cos\left(\theta/2\right) + \sin\left(\theta/2\right)(\mathrm{xi} + y\mathrm{j} + z\mathrm{k}),$$

where θ is the angle of rotation in degrees, and [x,y,z] represent the axis of rotation.

Given a quaternion of the form

$$q = a + bi + cj + dk\,,$$

you can solve for the rotation angle using the axis-angle form of quaternions:

$$\theta = 2\cos^{-1}(a)\,.$$

Assuming a normalized axis, you can rewrite the quaternion as a rotation vector without loss of information by distributing θ over the parts b, c, and d. The rotation vector representation of q is

$$q_{\mathrm{rv}} = \frac{\theta}{\sin\left(\theta/2\right)}[b, c, d]\,.$$

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`rotvec` | `euler` | `eulerd`

Objects
`quaternion`

Introduced in R2018b

slerp

Spherical linear interpolation

Syntax

```
q0 = slerp(q1,q2,T)
```

Description

`q0 = slerp(q1,q2,T)` spherically interpolates between `q1` and `q2` by the interpolation coefficient `T`. The function always chooses the shorter interpolation path between `q1` and `q2`.

Examples

Interpolate Between Two Quaternions

Create two quaternions with the following interpretation:

1. `a` = 45 degree rotation around the *z*-axis
2. `c` = -45 degree rotation around the *z*-axis

```
a = quaternion([45,0,0],'eulerd','ZYX','frame');
c = quaternion([-45,0,0],'eulerd','ZYX','frame');
```

Call `slerp` with the quaternions `a` and `c` and specify an interpolation coefficient of 0.5.

```
interpolationCoefficient = 0.5;

b = slerp(a,c,interpolationCoefficient);
```

The output of `slerp`, `b`, represents an average rotation of `a` and `c`. To verify, convert `b` to Euler angles in degrees.

```
averageRotation = eulerd(b,'ZYX','frame')
```

```
averageRotation = 1×3

     0     0     0
```

The interpolation coefficient is specified as a normalized value between `0` and `1`, inclusive. An interpolation coefficient of `0` corresponds to the `a` quaternion, and an interpolation coefficient of `1` corresponds to the `c` quaternion. Call `slerp` with coefficients `0` and `1` to confirm.

```
b = slerp(a,c,[0,1]);
eulerd(b,'ZYX','frame')
```

```
ans = 2×3

   45.0000         0         0
```

```
  -45.0000         0         0
```

You can create smooth paths between quaternions by specifying arrays of equally spaced interpolation coefficients.

```
path = 0:0.1:1;

interpolatedQuaternions = slerp(a,c,path);
```

For quaternions that represent rotation only about a single axis, specifying interpolation coefficients as equally spaced results in quaternions equally spaced in Euler angles. Convert `interpolatedQuaternions` to Euler angles and verify that the difference between the angles in the path is constant.

```
k = eulerd(interpolatedQuaternions,'ZYX','frame');
abc = abs(diff(k))
```

```
abc = 10×3

    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
    9.0000         0         0
```

Alternatively, you can use the `dist` function to verify that the distance between the interpolated quaternions is consistent. The `dist` function returns angular distance in radians; convert to degrees for easy comparison.

```
def = rad2deg(dist(interpolatedQuaternions(2:end),interpolatedQuaternions(1:end-1)))
```

```
def = 1×10

    9.0000    9.0000    9.0000    9.0000    9.0000    9.0000    9.0000    9.0000    9.0000    9.0
```

SLERP Minimizes Great Circle Path

The SLERP algorithm interpolates along a great circle path connecting two quaternions. This example shows how the SLERP algorithm minimizes the great circle path.

Define three quaternions:

1. `q0` - quaternion indicating no rotation from the global frame
2. `q179` - quaternion indicating a 179 degree rotation about the *z*-axis
3. `q180` - quaternion indicating a 180 degree rotation about the *z*-axis

4 `q181` - quaternion indicating a 181 degree rotation about the *z*-axis

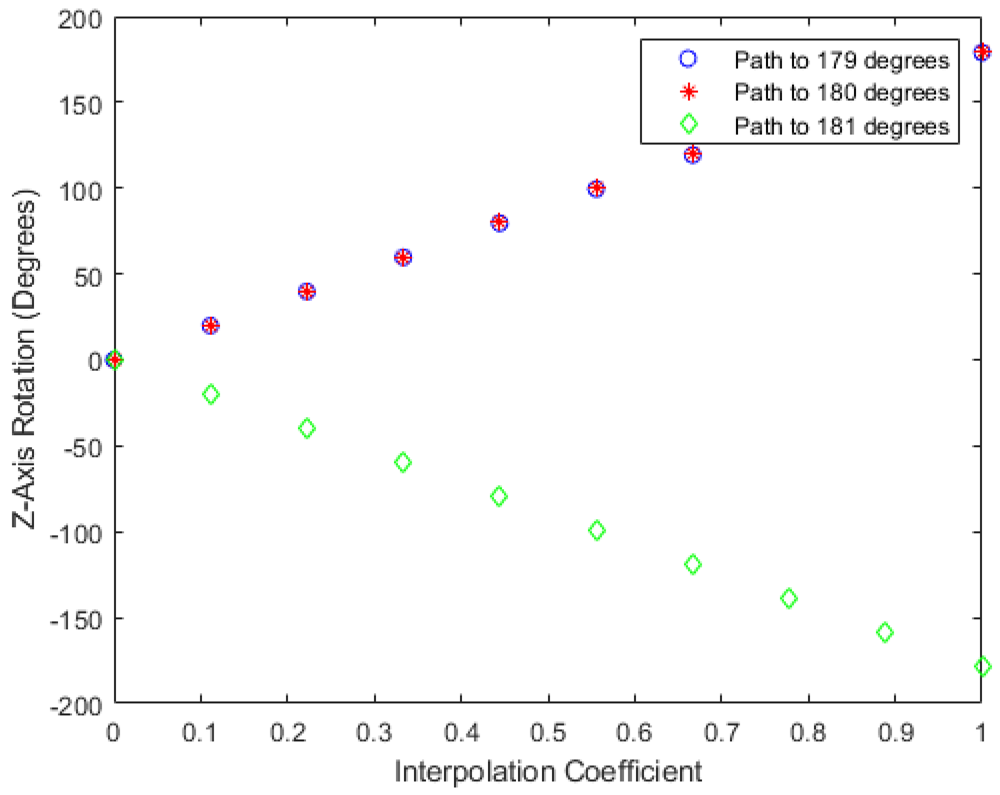
```
q0 = ones(1,'quaternion');

q179 = quaternion([179,0,0],'eulerd','ZYX','frame');

q180 = quaternion([180,0,0],'eulerd','ZYX','frame');

q181 = quaternion([181,0,0],'eulerd','ZYX','frame');
```

Use `slerp` to interpolate between `q0` and the three quaternion rotations. Specify that the paths are traveled in 10 steps.

```
T = linspace(0,1,10);

q179path = slerp(q0,q179,T);
q180path = slerp(q0,q180,T);
q181path = slerp(q0,q181,T);
```

Plot each path in terms of Euler angles in degrees.

```
q179pathEuler = eulerd(q179path,'ZYX','frame');
q180pathEuler = eulerd(q180path,'ZYX','frame');
q181pathEuler = eulerd(q181path,'ZYX','frame');

plot(T,q179pathEuler(:,1),'bo', ...
     T,q180pathEuler(:,1),'r*', ...
     T,q181pathEuler(:,1),'gd');
legend('Path to 179 degrees', ...
       'Path to 180 degrees', ...
       'Path to 181 degrees')
xlabel('Interpolation Coefficient')
ylabel('Z-Axis Rotation (Degrees)')
```



The path between `q0` and `q179` is clockwise to minimize the great circle distance. The path between `q0` and `q181` is counterclockwise to minimize the great circle distance. The path between `q0` and `q180` can be either clockwise or counterclockwise, depending on numerical rounding.

Show Interpolated Quaternions on Sphere

Create two quaternions.

```
q1 = quaternion([75,-20,-10],'eulerd','ZYX','frame');
q2 = quaternion([-45,20,30],'eulerd','ZYX','frame');
```

Define the interpolation coefficient.

```
T = 0:0.01:1;
```

Obtain the interpolated quaternions.

```
quats = slerp(q1,q2,T);
```

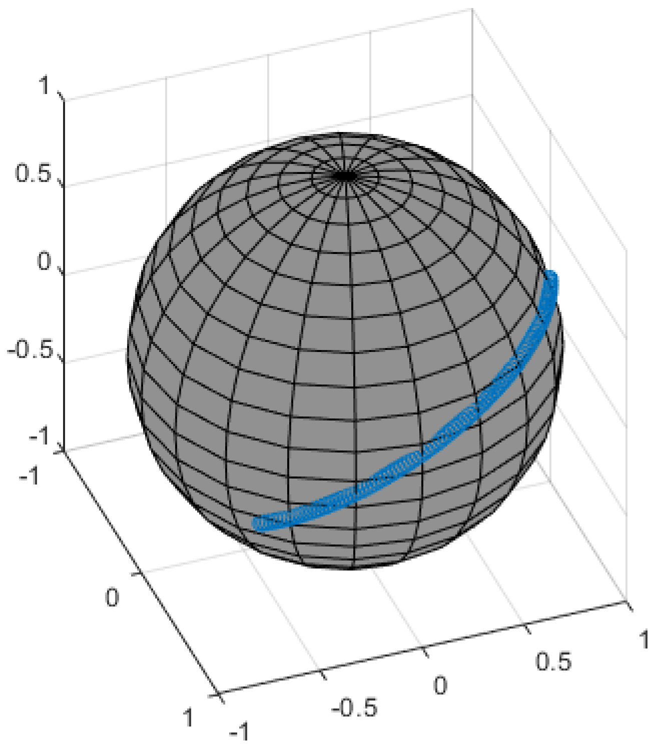
Obtain the corresponding rotate points.

```
pts = rotatepoint(quats,[1 0 0]);
```

Show the interpolated quaternions on a unit sphere.

```
figure
[X,Y,Z] = sphere;
```

```
surf(X,Y,Z,'FaceColor',[0.57 0.57 0.57])
hold on;

scatter3(pts(:,1),pts(:,2),pts(:,3))
view([69.23 36.60])
axis equal
```



Note that the interpolated quaternions follow the shorter path from `q1` to `q2`.

Input Arguments

q1 — Quaternion

scalar | vector | matrix | multidimensional array

Quaternion to interpolate, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

`q1`, `q2`, and `T` must have compatible sizes. In the simplest cases, they can be the same size or any one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are either the same or one of them is 1.

Data Types: `quaternion`

q2 — Quaternion

scalar | vector | matrix | multidimensional array

Quaternion to interpolate, specified as a scalar, vector, matrix, or multidimensional array of quaternions.

`q1`, `q2`, and `T` must have compatible sizes. In the simplest cases, they can be the same size or any one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are either the same or one of the dimension sizes is 1.

Data Types: `quaternion`

`T` — Interpolation coefficient
scalar | vector | matrix | multidimensional array

Interpolation coefficient, specified as a scalar, vector, matrix, or multidimensional array of numbers with each element in the range [0,1].

`q1`, `q2`, and `T` must have compatible sizes. In the simplest cases, they can be the same size or any one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are either the same or one of the dimension sizes is 1.

Data Types: `single` | `double`

Output Arguments

`q0` — Interpolated quaternion
scalar | vector | matrix | multidimensional array

Interpolated quaternion, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Quaternion **s**pherical **l**inear int**erp**olation (SLERP) is an extension of linear interpolation along a plane to spherical interpolation in three dimensions. The algorithm was first proposed in [1]. Given two quaternions, q_1 and q_2, SLERP interpolates a new quaternion, q_0, along the great circle that connects q_1 and q_2. The interpolation coefficient, T, determines how close the output quaternion is to either q_1 and q_2.

The SLERP algorithm can be described in terms of sinusoids:

$$q_0 = \frac{\sin((1 - T)\theta)}{\sin(\theta)} q_1 + \frac{\sin(T\theta)}{\sin(\theta)} q_2$$

where q_1 and q_2 are normalized quaternions, and θ is half the angular distance between q_1 and q_2.

References

[1] Shoemake, Ken. "Animating Rotation with Quaternion Curves." *ACM SIGGRAPH Computer Graphics* Vol. 19, Issue 3, 1985, pp. 345–354.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`dist` | `meanrot`

Objects
`quaternion`

Introduced in R2018b

tform2axang

Convert homogeneous transformation to axis-angle rotation

Syntax

```
axang = tform2axang(tform)
```

Description

`axang = tform2axang(tform)` converts the rotational component of a homogeneous transformation, `tform`, to an axis-angle rotation, `axang`. The translational components of `tform` are ignored. The input homogeneous transformation must be in the premultiply form for transformations.

Examples

Convert Homogeneous Transformation to Axis-Angle Rotation

```
tform = [1 0 0 0; 0 0 -1 0; 0 1 0 0; 0 0 0 1];
axang = tform2axang(tform)
```

```
axang = 1×4

    1.0000         0         0    1.5708
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

axang — Rotation given in axis-angle form
n-by-4 matrix

Rotation given in axis-angle form, specified as an *n*-by-4 matrix of *n* axis-angle rotations. The first three elements of every row specify the rotation axes, and the last element defines the rotation angle (in radians).

Example: `[1 0 0 pi/2]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`axang2tform`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

tform2eul

Extract Euler angles from homogeneous transformation

Syntax

```
eul = tform2eul(tform)
eul = tform2eul(tform, sequence)
```

Description

`eul = tform2eul(tform)` extracts the rotational component from a homogeneous transformation, `tform`, and returns it as Euler angles, `eul`. The translational components of `tform` are ignored. The input homogeneous transformation must be in the premultiply form for transformations. The default order for Euler angle rotations is `"ZYX"`.

`eul = tform2eul(tform, sequence)` extracts the Euler angles, `eul`, from a homogeneous transformation, `tform`, using the specified rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Extract Euler Angles from Homogeneous Transformation Matrix

```
tform = [1 0 0 0.5; 0 -1 0 5; 0 0 -1 -1.2; 0 0 0 1];
eulZYX = tform2eul(tform)
```

```
eulZYX = 1×3

         0         0    3.1416
```

Extract Euler Angles from Homogeneous Transformation Matrix Using ZYZ Rotation

```
tform = [1 0 0 0.5; 0 -1 0 5; 0 0 -1 -1.2; 0 0 0 1];
eulZYZ = tform2eul(tform,'ZYZ')
```

```
eulZYZ = 1×3

         0   -3.1416    3.1416
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

`sequence` — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these string scalars:

- `"ZYX"` (default) – The order of rotation angles is *z*-axis, *y*-axis, *x*-axis.
- `"ZYZ"` – The order of rotation angles is *z*-axis, *y*-axis, *z*-axis.
- `"XYZ"` – The order of rotation angles is *x*-axis, *y*-axis, *z*-axis.

Data Types: `string` | `char`

Output Arguments

`eul` — Euler rotation angles
n-by-3 matrix

Euler rotation angles in radians, returned as an *n*-by-3 array of Euler rotation angles. Each row represents one Euler angle set.

Example: `[0 0 1.5708]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`eul2tform`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

tform2quat

Extract quaternion from homogeneous transformation

Syntax

```
quat = tform2quat(tform)
```

Description

`quat = tform2quat(tform)` extracts the rotational component from a homogeneous transformation, `tform`, and returns it as a quaternion, `quat`. The translational components of `tform` are ignored. The input homogeneous transformation must be in the premultiply form for transformations.

Examples

Extract Quaternion from Homogeneous Transformation

```
tform = [1 0 0 0; 0 -1 0 0; 0 0 -1 0; 0 0 0 1];
quat = tform2quat(tform)
```

```
quat = 1×4

     0     1     0     0
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

`quat` — Unit quaternion
n-by-4 matrix

Unit quaternion, returned as an *n*-by-4 matrix containing *n* quaternions. Each quaternion, one per row, is of the form $q = [w\ x\ y\ z]$, with w as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`quat2tform`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

tform2rotm

Extract rotation matrix from homogeneous transformation

Syntax

```
rotm = tform2rotm(tform)
```

Description

`rotm = tform2rotm(tform)` extracts the rotational component from a homogeneous transformation, `tform`, and returns it as an orthonormal rotation matrix, `rotm`. The translational components of `tform` are ignored. The input homogeneous transformation must be in the pre-multiply form for transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Examples

Convert Homogeneous Transformation to Rotation Matrix

```
tform = [1 0 0 0; 0 -1 0 0; 0 0 -1 0; 0 0 0 1];
rotm = tform2rotm(tform)
```

```
rotm = 3×3

     1     0     0
     0    -1     0
     0     0    -1
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the pre-multiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1; 0 1 0; -1 0 0]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`rotm2tform`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

tform2trvec

Extract translation vector from homogeneous transformation

Syntax

```
trvec = tform2trvec(tform)
```

Description

`trvec = tform2trvec(tform)` extracts the Cartesian representation of translation vector, `trvec` , from a homogeneous transformation, `tform`. The rotational components of `tform` are ignored. The input homogeneous transformation must be in the premultiply form for transformations.

Examples

Extract Translation Vector from Homogeneous Transformation

```
tform = [1 0 0 0.5; 0 -1 0 5; 0 0 -1 -1.2; 0 0 0 1];
trvec = tform2trvec(tform)
```

```
trvec = 1×3

    0.5000    5.0000   -1.2000
```

Input Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation, specified by a 4-by-4-by-*n* matrix of *n* homogeneous transformations. The input homogeneous transformation must be in the premultiply form for transformations.

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Output Arguments

`trvec` — Cartesian representation of a translation vector
n-by-3 matrix

Cartesian representation of a translation vector, returned as an *n*-by-3 matrix containing *n* translation vectors. Each vector is of the form $t = [x\ y\ z]$.

Example: `[0.5 6 100]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`trvec2tform`

Topics
"Coordinate Transformations in Robotics"

Introduced in R2015a

times, .*

Element-wise quaternion multiplication

Syntax

`quatC = A.*B`

Description

`quatC = A.*B` returns the element-by-element quaternion multiplication of quaternion arrays.

You can use quaternion multiplication to compose rotation operators:

- To compose a sequence of frame rotations, multiply the quaternions in the same order as the desired sequence of rotations. For example, to apply a *p* quaternion followed by a *q* quaternion, multiply in the order *pq*. The rotation operator becomes $(pq)^{*}v(pq)$, where *v* represents the object to rotate in quaternion form. * represents conjugation.
- To compose a sequence of point rotations, multiply the quaternions in the reverse order of the desired sequence of rotations. For example, to apply a *p* quaternion followed by a *q* quaternion, multiply in the reverse order, *qp*. The rotation operator becomes $(qp)v(qp)^{*}$.

Examples

Multiply Two Quaternion Vectors

Create two vectors, `A` and `B`, and multiply them element by element.

```
A = quaternion([1:4;5:8]);
B = A;
C = A.*B
```

```
C = 2x1 quaternion array
     -28 +   4i +   6j +   8k
    -124 +  60i +  70j +  80k
```

Multiply Two Quaternion Arrays

Create two 3-by-3 arrays, `A` and `B`, and multiply them element by element.

```
A = reshape(quaternion(randn(9,4)),3,3);
B = reshape(quaternion(randn(9,4)),3,3);
C = A.*B
```

```
C = 3x3 quaternion array
     0.60169 +  2.4332i -  2.5844j + 0.51646k    -0.49513 +  1.1722i +  4.4401j -   1.217k      2
     -4.2329 +  2.4547i +  3.7768j + 0.77484k    -0.65232 - 0.43112i -  1.4645j - 0.90073k     -
     -4.4159 +  2.1926i +  1.9037j -  4.0303k     -2.0232 +  0.4205i - 0.17288j +  3.8529k     -
```

Note that quaternion multiplication is not commutative:

```
isequal(C,B.*A)
```

```
ans = logical
   0
```

Multiply Quaternion Row and Column Vectors

Create a row vector a and a column vector b, then multiply them. The 1-by-3 row vector and 4-by-1 column vector combine to produce a 4-by-3 matrix with all combinations of elements multiplied.

```
a = [zeros('quaternion'),ones('quaternion'),quaternion(randn(1,4))]
```

```
a = 1x3 quaternion array
           0 +       0i +       0j +       0k             1 +       0i +       0j +       0k     0
```

```
b = quaternion(randn(4,4))
```

```
b = 4x1 quaternion array
      0.31877 +   3.5784i +   0.7254j -  0.12414k
      -1.3077 +   2.7694i - 0.063055j +   1.4897k
     -0.43359 -   1.3499i +  0.71474j +    1.409k
      0.34262 +   3.0349i -  0.20497j +   1.4172k
```

```
a.*b
```

```
ans = 4x3 quaternion array
            0 +        0i +        0j +        0k      0.31877 +   3.5784i +   0.7254j -  0.1241
            0 +        0i +        0j +        0k      -1.3077 +   2.7694i - 0.063055j +   1.489
            0 +        0i +        0j +        0k     -0.43359 -   1.3499i +  0.71474j +    1.40
            0 +        0i +        0j +        0k      0.34262 +   3.0349i -  0.20497j +   1.417
```

Input Arguments

A — Array to multiply
scalar | vector | matrix | multidimensional array

Array to multiply, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of them is 1.

Data Types: quaternion | single | double

B — Array to multiply
scalar | vector | matrix | multidimensional array

Array to multiply, specified as a quaternion, an array of quaternions, a real scalar, or an array of real numbers.

A and B must have compatible sizes. In the simplest cases, they can be the same size or one can be a scalar. Two inputs have compatible sizes if, for every dimension, the dimension sizes of the inputs are the same or one of them is 1.

Data Types: `quaternion` | `single` | `double`

Output Arguments

`quatC` — Quaternion product
scalar | vector | matrix | multidimensional array

Quaternion product, returned as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Algorithms

Quaternion Multiplication by a Real Scalar

Given a quaternion,

$$q = a_{\mathrm{q}} + b_{\mathrm{q}}\mathrm{i} + c_{\mathrm{q}}\mathrm{j} + d_{\mathrm{q}}\mathrm{k},$$

the product of q and a real scalar β is

$$\beta q = \beta a_{\mathrm{q}} + \beta b_{\mathrm{q}}\mathrm{i} + \beta c_{\mathrm{q}}\mathrm{j} + \beta d_{\mathrm{q}}\mathrm{k}$$

Quaternion Multiplication by a Quaternion Scalar

The definition of the basis elements for quaternions,

$$\mathrm{i}^2 = \mathrm{j}^2 = \mathrm{k}^2 = \mathrm{ijk} = -1\,,$$

can be expanded to populate a table summarizing quaternion basis element multiplication:

	1	**i**	**j**	**k**
1	1	i	j	k
i	i	−1	k	−j
j	j	−k	−1	i
k	k	j	−i	−1

When reading the table, the rows are read first, for example: ij = k and ji = −k.

Given two quaternions, $q = a_{\mathrm{q}} + b_{\mathrm{q}}\mathrm{i} + c_{\mathrm{q}}\mathrm{j} + d_{\mathrm{q}}\mathrm{k}$, and $p = a_{\mathrm{p}} + b_{\mathrm{p}}\mathrm{i} + c_{\mathrm{p}}\mathrm{j} + d_{\mathrm{p}}\mathrm{k}$, the multiplication can be expanded as:

$$
\begin{aligned}
z = pq = &\left(a_\mathrm{p} + b_\mathrm{p}\mathrm{i} + c_\mathrm{p}\mathrm{j} + d_\mathrm{p}\mathrm{k}\right)\left(a_\mathrm{q} + b_\mathrm{q}\mathrm{i} + c_\mathrm{q}\mathrm{j} + d_\mathrm{q}\mathrm{k}\right) \\
&= a_\mathrm{p}a_\mathrm{q} + a_\mathrm{p}b_\mathrm{q}\mathrm{i} + a_\mathrm{p}c_\mathrm{q}\mathrm{j} + a_\mathrm{p}d_\mathrm{q}\mathrm{k} \\
&+ b_\mathrm{p}a_\mathrm{q}\mathrm{i} + b_\mathrm{p}b_\mathrm{q}\mathrm{i}^2 + b_\mathrm{p}c_\mathrm{q}\mathrm{ij} + b_\mathrm{p}d_\mathrm{q}\mathrm{ik} \\
&+ c_\mathrm{p}a_\mathrm{q}\mathrm{j} + c_\mathrm{p}b_\mathrm{q}\mathrm{ji} + c_\mathrm{p}c_\mathrm{q}\mathrm{j}^2 + c_\mathrm{p}d_\mathrm{q}\mathrm{jk} \\
&+ d_\mathrm{p}a_\mathrm{q}k + d_\mathrm{p}b_\mathrm{q}\mathrm{ki} + d_\mathrm{p}c_\mathrm{q}\mathrm{kj} + d_\mathrm{p}d_\mathrm{q}\mathrm{k}^2
\end{aligned}
$$

You can simplify the equation using the quaternion multiplication table.

$$
\begin{aligned}
z = pq \ = &\ a_\mathrm{p}a_\mathrm{q} + a_\mathrm{p}b_\mathrm{q}\mathrm{i} + a_\mathrm{p}c_\mathrm{q}\mathrm{j} + a_\mathrm{p}d_\mathrm{q}\mathrm{k} \\
&+ b_\mathrm{p}a_\mathrm{q}\mathrm{i} - b_\mathrm{p}b_\mathrm{q} + b_\mathrm{p}c_\mathrm{q}\mathrm{k} - b_\mathrm{p}d_\mathrm{q}\mathrm{j} \\
&+ c_\mathrm{p}a_\mathrm{q}\mathrm{j} - c_\mathrm{p}b_\mathrm{q}\mathrm{k} - c_\mathrm{p}c_\mathrm{q} + c_\mathrm{p}d_\mathrm{q}\mathrm{i} \\
&+ d_\mathrm{p}a_\mathrm{q}k + d_\mathrm{p}b_\mathrm{q}\mathrm{j} - d_\mathrm{p}c_\mathrm{q}\mathrm{i} - d_\mathrm{p}d_\mathrm{q}
\end{aligned}
$$

References

[1] Kuipers, Jack B. *Quaternions and Rotation Sequences: A Primer with Applications to Orbits, Aerospace, and Virtual Reality*. Princeton, NJ: Princeton University Press, 2007.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`prod | mtimes, *`

Objects
`quaternion`

Introduced in R2018a

transformScan

Transform laser scan based on relative pose

Syntax

```
transScan = transformScan(scan,relPose)
```

```
[transRanges,transAngles] = transformScan(ranges,angles,relPose)
```

Description

`transScan = transformScan(scan,relPose)` transforms the laser scan specified in `scan` by using the specified relative pose, `relPose`.

`[transRanges,transAngles] = transformScan(ranges,angles,relPose)` transforms the laser scan specified in `ranges` and `angles` by using the specified relative pose, `relPose`.

Examples

Transform Laser Scans

Create a `lidarScan` object. Specify the ranges and angles as vectors.

```
refRanges = 5*ones(1,300);
refAngles = linspace(-pi/2,pi/2,300);
refScan = lidarScan(refRanges,refAngles);
```

Translate the laser scan by an `[x y]` offset of `(0.5,0.2)`.

```
transformedScan = transformScan(refScan,[0.5 0.2 0]);
```

Rotate the laser scan by 20 degrees.

```
rotateScan = transformScan(refScan,[0,0,deg2rad(20)]);
```

Input Arguments

`scan` — Lidar scan readings
`lidarScan` object

Lidar scan readings, specified as a `lidarScan` object.

`ranges` — Range values from scan data
vector

Range values from scan data, specified as a vector in meters. These range values are distances from a sensor at specified `angles`. The vector must be the same length as the corresponding `angles` vector.

`angles` — Angle values from scan data
vector

Angle values from scan data, specified as a vector in radians. These angle values are the specific angles of the specified `ranges`. The vector must be the same length as the corresponding `ranges` vector.

`relPose` — Relative pose of current scan
`[x y theta]`

Relative pose of current scan, specified as `[x y theta]`, where `[x y]` is the translation in meters and `theta` is the rotation in radians.

Output Arguments

`transScan` — Transformed lidar scan readings
`lidarScan` object

Transformed lidar scan readings, specified as a `lidarScan` object.

`transRanges` — Range values of transformed scan
vector

Range values of transformed scan, returned as a vector in meters. These range values are distances from a sensor at specified `transAngles`. The vector is the same length as the corresponding `transAngles` vector.

`transAngles` — Angle values from scan data
vector

Angle values of transformed scan, returned as a vector in radians. These angle values are the specific angles of the specified `transRanges`. The vector is the same length as the corresponding `ranges` vector.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`transformScan`

Introduced in R2017a

transformtraj

Generate trajectories between two transformations

Syntax

```
[tforms,vel,acc] = transformtraj(T0,TF,tInterval,tSamples)
[tforms,vel,acc] = transformtraj(T0,TF,tInterval,tSamples,Name,Value)
```

Description

`[tforms,vel,acc] = transformtraj(T0,TF,tInterval,tSamples)` generates a trajectory that interpolates between two 4-by-4 homogeneous transformations, `T0` and `TF`, with points based on the time interval and given time samples.

`[tforms,vel,acc] = transformtraj(T0,TF,tInterval,tSamples,Name,Value)` specifies additional parameters using `Name,Value` pair arguments.

Examples

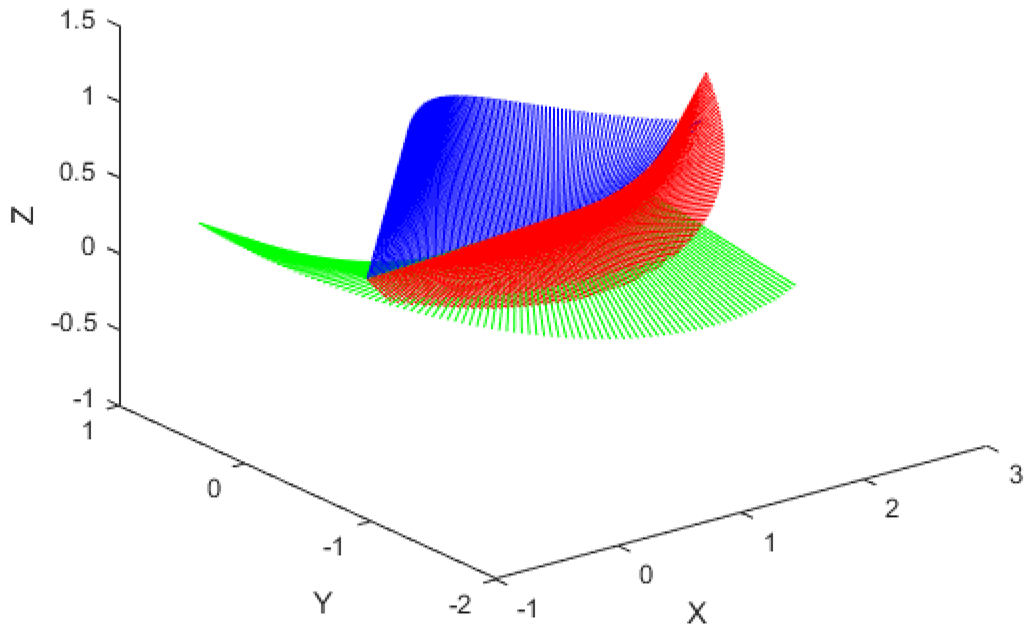
Interpolate Between Homogenous Transformations

Build transformations from two orientations and positions. Specifiy the time interval and vector of times for interpolating.

```
t0 = axang2tform([0 1 1 pi/4])*trvec2tform([0 0 0]);
tF = axang2tform([1 0 1 6*pi/5])*trvec2tform([1 1 1]);
tInterval = [0 1];
tvec = 0:0.01:1;
```

Interpolate between the points. Plot the trajectory using `plotTransforms`. Convert the transformations to quaternion rotations and linear transitions. The figure shows all the intermediate transformations of the coordinate frame.

```
[tfInterp, v1, a1] = transformtraj(t0,tF,tInterval,tvec);

rotations = tform2quat(tfInterp);
translations = tform2trvec(tfInterp);

plotTransforms(translations,rotations)
xlabel('X')
ylabel('Y')
zlabel('Z')
```



Input Arguments

T0 — Initial transformation

4-by-4 homogeneous transformation

Initial transformation, specified as a 4-by-4 homogeneous transformation. The function generates a trajectory that starts at the initial transformation, `T0`, and goes to the final transformation, `TF`.

Data Types: `single` | `double`

TF — Final transformation

4-by-4 homogeneous transformation

Final transformation, specified as a 4-by-4 homogeneous transformation. The function generates a trajectory that starts at the initial transformation, `T0`, and goes to the final transformation, `TF`.

Data Types: `single` | `double`

`tInterval` — Start and end times for trajectory

two-element vector

Start and end times for the trajectory, specified as a two-element vector in seconds.

Example: `[0 10]`

Data Types: `single` | `double`

tSamples — Time samples for trajectory
m-element vector

Time samples for the trajectory, specified as an *m*-element vector in seconds.

Example: `0:0.01:10`

Data Types: `single` | `double`

tSamples — Time samples for trajectory
m-element vector

Time samples for the trajectory, specified as an *m*-element vector.

Example: `0:0.01:10`

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: `'TimeScaling',[0 1 2; 0 1 0; 0 0 0]`

TimeScaling — Time scaling vector and first two derivatives
3-by-*m* vector

Time scaling vector and the first two derivatives, specified as a 3-by-*m* vector, where *m* is the length of `tSamples`. By default, the time scaling is a linear time scaling between the time points in `tInterval`.

For a nonlinear time scaling, specify the values of the time points as positions in meters in the first row. The second and third rows are the velocity and acceleration of the time points in m/s and m/s^2, respectively. For example, to follow the path with a linear velocity to the halfway point, and then jump to the end, the time-scaling would be:

```
s(1,:) = [0 0.25 0.5 1 1 1] % Position
s(2,:) = [1    1   1 0 0 0] % Velocity
s(3,:) = [0    0   0 0 0 0] % Acceleration
```

Data Types: `single` | `double`

Output Arguments

tforms — Transformation trajectory
4-by-4-by-*m* homogeneous transformation matrix array

Transformation trajectory, returned as a 4-by-4-by-*m* homogeneous transformation matrix array, where *m* is the number of points in `tSamples`.

vel — Transformation velocities
6-by-*m* matrix

Transformation velocities, returned as a 6-by-*m* matrix in m/s, where *m* is the number of points in `tSamples`. The first three elements are the angular velocities, and the second three elements are the velocities in time.

`acc` — Transformation accelerations
6-by-*m* matrix

Transformation accelerations, returned as a 6-by-*m* matrix in m/s^2, where *m* is the number of points in `tSamples`. The first three elements are the angular accelerations, and the second three elements are the accelerations in time.

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control*. Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

transpose, .'

Transpose a quaternion array

Syntax

```
Y = quat.'
```

Description

`Y = quat.'` returns the non-conjugate transpose of the quaternion array, `quat`.

Examples

Vector Transpose

Create a vector of quaternions and compute its nonconjugate transpose.

```
quat = quaternion(randn(4,4))
```

```
quat = 4x1 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k
       1.8339 -   1.3077i +   2.7694j - 0.063055k
      -2.2588 -  0.43359i -   1.3499j +  0.71474k
      0.86217 +  0.34262i +   3.0349j -  0.20497k
```

```
quatTransposed = quat.'
```

```
quatTransposed = 1x4 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k       1.8339 -   1.3077i +   2.7694j - 0.06305
```

Matrix Transpose

Create a matrix of quaternions and compute its nonconjugate transpose.

```
quat = [quaternion(randn(2,4)),quaternion(randn(2,4))]
```

```
quat = 2x2 quaternion array
      0.53767 -   2.2588i +  0.31877j -  0.43359k       3.5784 -   1.3499i +   0.7254j +  0.7147
       1.8339 +  0.86217i -   1.3077j +  0.34262k       2.7694 +   3.0349i - 0.063055j -  0.2049
```

```
quatTransposed = quat.'
```

```
quatTransposed = 2x2 quaternion array
      0.53767 -   2.2588i +  0.31877j -  0.43359k       1.8339 +  0.86217i -   1.3077j +  0.3426
       3.5784 -   1.3499i +   0.7254j +  0.71474k       2.7694 +   3.0349i - 0.063055j -  0.2049
```

Input Arguments

quat — Quaternion array to transpose
vector | matrix

Quaternion array to transpose, specified as a vector or matrix of quaternions. `transpose` is defined for 1-D and 2-D arrays. For higher-order arrays, use `permute`.

Data Types: `quaternion`

Output Arguments

Y — Transposed quaternion array
vector | matrix

Transposed quaternion array, returned as an *N*-by-*M* array, where `quat` was specified as an *M*-by-*N* array.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`ctranspose, '`

Objects
`quaternion`

Introduced in R2018a

trapveltraj

Generate trajectories with trapezoidal velocity profiles

Syntax

```
[q,qd,qdd,tSamples,pp] = trapveltraj(wayPoints,numSamples)
[q,qd,qdd,tSamples,pp] = trapveltraj(wayPoints,numSamples,Name,Value)
```

Description

`[q,qd,qdd,tSamples,pp] = trapveltraj(wayPoints,numSamples)` generates a trajectory through a given set of input waypoints that follow a trapezoidal velocity profile. The function outputs positions, velocities, and accelerations at the given time samples, `tSamples`, based on the specified number of samples, `numSamples`. The function also returns the piecewise polynomial `pp` form of the polynomial trajectory with respect to time.

`[q,qd,qdd,tSamples,pp] = trapveltraj(wayPoints,numSamples,Name,Value)` specifies additional parameters using `Name,Value` pair arguments.

Examples

Compute Trapezoidal Velocity Trajectory for 2-D Planar Motion

Use the `trapveltraj` function with a given set of 2-D *xy* waypoints. Time points for the waypoints are also given.

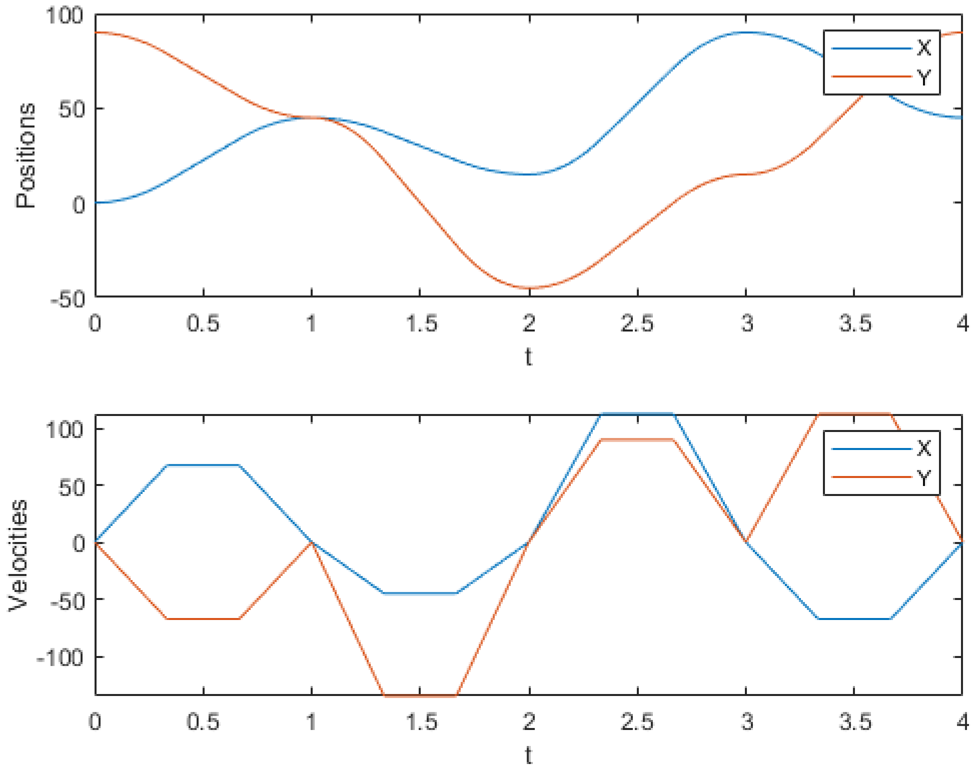
```
wpts = [0 45 15 90 45; 90 45 -45 15 90];
```

Compute the trajectory for a given number of samples (501). The function outputs the trajectory positions (`q`), velocity (`qd`), acceleration (`qdd`), time vector (`tvec`), and polynomial coefficients (`pp`) of the polynomial that achieves the waypoints using trapezoidal velocities.

```
[q, qd, qdd, tvec, pp] = trapveltraj(wpts, 501);
```

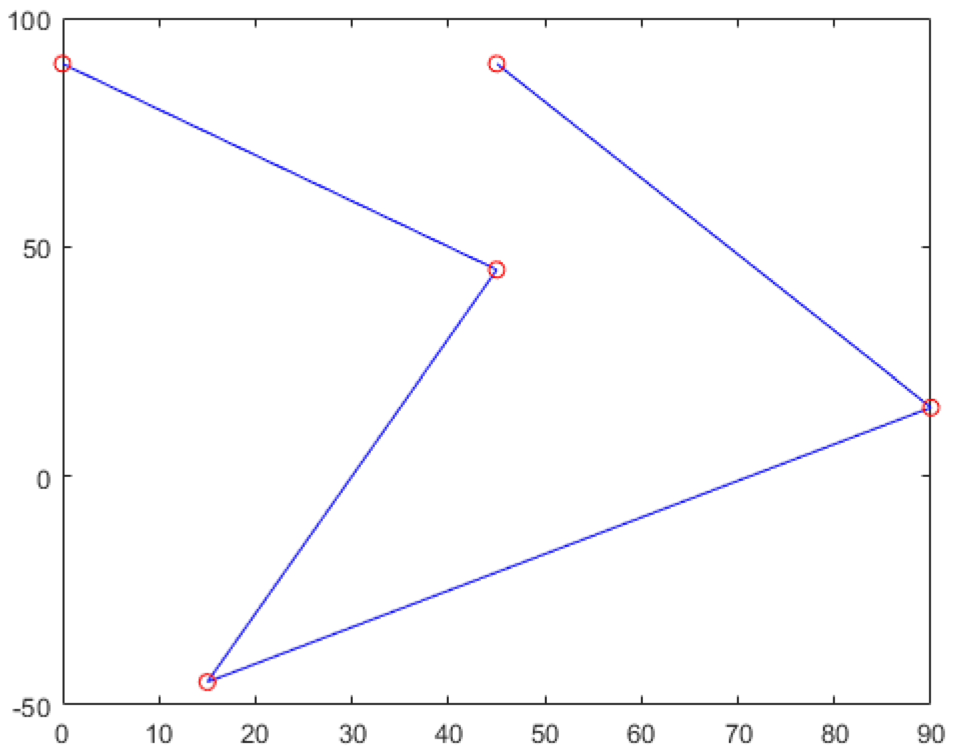
Plot the trajectories for the *x*- and *y*-positions and the trapezoial velocity profile between each waypoint.

```
subplot(2,1,1)
plot(tvec, q)
xlabel('t')
ylabel('Positions')
legend('X','Y')
subplot(2,1,2)
plot(tvec, qd)
xlabel('t')
ylabel('Velocities')
legend('X','Y')
```



You can also verify the actual positions in the 2-D plane. Plot the separate rows of the q vector and the waypoints as *x*- and *y*-positions.

```
figure
plot(q(1,:),q(2,:),'-b',wpts(1,:),wpts(2,:),'or')
```



Input Arguments

`wayPoints` — Waypoints for trajectory

n-by-*p* matrix

Points for waypoints of trajectory, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of waypoints.

Example: `[1 4 4 3 -2 0; 0 1 2 4 3 1]`

Data Types: `single` | `double`

`numSamples` — Number of samples in output trajectory

positive integer

Number of samples in output trajectory, specified as a positive integer.

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`.

Note Due to the nature of the trapezoidal velocity profile, you can only set at most two of the following parameters.

Example: `'PeakVelocity',5`

`PeakVelocity` — Peak velocity of the velocity profile

scalar | *n*-element vector | *n*-by-(*p*–1) matrix

Peak velocity of the profile segment, specified as the comma-separated pair consisting of `'PeakVelocity'` and a scalar, vector, or matrix. This peak velocity is the highest velocity achieved during the trapezoidal velocity profile.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p*–1) matrix is applied to each element of the trajectory for each waypoint.

Data Types: `single` | `double`

`Acceleration` — Acceleration of velocity profile

scalar | *n*-element vector | *n*-by-(*p*–1) matrix

Acceleration of the velocity profile, specified as the comma-separated pair consisting of `'Acceleration'` and a scalar, vector, or matrix. This acceleration defines the constant acceleration from zero velocity to the `PeakVelocity` value.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p*–1) matrix is applied to each element of the trajectory for each waypoint.

Data Types: `single` | `double`

`EndTime` — Duration of each trajectory segment

scalar | *n*-element vector | *n*-by-(*p*–1) matrix

Duration of each of the *p*–1 trajectory segments, specified as the comma-separated pair consisting of `'EndTime'` and a scalar, vector, or matrix.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p*–1) matrix is applied to each element of the trajectory for each waypoint.

Data Types: `single` | `double`

`AccelTime` — Duration of acceleration phase of velocity profile

scalar | *n*-element vector | *n*-by-(*p*–1) matrix

Duration of acceleration phase of velocity profile, specified as the comma-separated pair consisting of `'AccelTime'` and a scalar, vector, or matrix.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p*–1) matrix is applied to each element of the trajectory for each waypoint.

Data Types: `single` | `double`

Output Arguments

q — Positions of trajectory
n-by-*m* matrix

Positions of the trajectory at the given time samples in `tSamples`, returned as *n*-by-*m* matrix, where *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

Data Types: `single` | `double`

qd — Velocities of trajectory
n-by-*m* matrix

Velocities of the trajectory at the given time samples in `tSamples`, returned as *n*-by-*m* matrix, where *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

Data Types: `single` | `double`

qdd — Accelerations of trajectory
n-by-*m* matrix

Accelerations of the trajectory at the given time samples in `tSamples`, returned as *n*-by-*m* matrix, where *n* is the dimension of the trajectory, and *m* is equal to `numSamples`.

Data Types: `single` | `double`

`tSamples` — Time samples for trajectory
m-element vector

Time samples for the trajectory, returned as an *m*-element vector. The output position, `q`, velocity, `qd`, and accelerations, `qdd` are sampled at these time intervals.

Example: `0:0.01:10`

Data Types: `single` | `double`

pp — Piecewise polynomials
cell array or structures

Piecewise polynomials, returned as a cell array of structures that defines the polynomial for each section of the piecewise trajectory. If all the elements of the trajectory share the same breaks, the cell array is a single piecewise polynomial structure. Otherwise, the cell array has *n* elements, which correspond to each of the different trajectory elements (dimensions). Each structure contains the fields:

- `form`: `'pp'`.
- `breaks`: *p*-element vector of times when the piecewise trajectory changes forms. *p* is the number of waypoints.
- `coefs`: *n*(*p*–1)-by-`order` matrix for the coefficients for the polynomials. *n*(*p*–1) is the dimension of the trajectory times the number of `pieces`. Each set of *n* rows defines the coefficients for the polynomial that described each variable trajectory.
- `pieces`: *p*–1. The number of breaks minus 1.
- `order`: Degree of the polynomial + 1. For example, cubic polynomials have an order of 4.
- `dim`: *n*. The dimension of the control point positions.

You can build your own piecewise polynomials using `mkpp`, or evaluate the polynomial at specified times using `ppval`.

pp — Piecewise-polynomial
structure

Piecewise-polynomial, returned as a structure that defines the polynomial for each section of the piecewise trajectory. You can build your own piecewise polynomials using `mkpp`, or evaluate the polynomial at specified times using `ppval`. The structure contains the fields:

- `form`: `'pp'`.
- `breaks`: *p*-element vector of times when the piecewise trajectory changes forms. *p* is the number of waypoints.
- `coefs`: *n*(*p*–1)-by-`order` matrix for the coefficients for the polynomials. *n*(*p*–1) is the dimension of the trajectory times the number of `pieces`. Each set of *n* rows defines the coefficients for the polynomial that described each variable trajectory.
- `pieces`: *p*–1. The number of breaks minus 1.
- `order`: Degree of the polynomial + 1. For example, cubic polynomials have an order of 4.
- `dim`: *n*. The dimension of the control point positions.

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning and Control*. Cambridge: Cambridge University Press, 2017.

[2] Spong, Mark W., Seth Hutchinson, and M. Vidyasagar. *Robot Modeling and Control*. John Wiley & Sons, 2006.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Topics
“Design Trajectory with Velocity Limits Using Trapezoidal Velocity Profile”

Introduced in R2019a

trvec2tform

Convert translation vector to homogeneous transformation

Syntax

`tform = trvec2tform(trvec)`

Description

`tform = trvec2tform(trvec)` converts the Cartesian representation of a translation vector, `trvec`, to the corresponding homogeneous transformation, `tform`. When using the transformation matrix, premultiply it with the coordinates to be transformed (as opposed to postmultiplying).

Examples

Convert Translation Vector to Homogeneous Transformation

```
trvec = [0.5 6 100];
tform = trvec2tform(trvec)
```

```
tform = 4×4

    1.0000         0         0    0.5000
         0    1.0000         0    6.0000
         0         0    1.0000  100.0000
         0         0         0    1.0000
```

Input Arguments

`trvec` — Cartesian representation of a translation vector

n-by-3 matrix

Cartesian representation of a translation vector, specified as an *n*-by-3 matrix containing *n* translation vectors. Each vector is of the form $t = [x\ y\ z]$.

Example: `[0.5 6 100]`

Output Arguments

`tform` — Homogeneous transformation

4-by-4-by-*n* matrix

Homogeneous transformation matrix, returned as a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Example: `[0 0 1 0; 0 1 0 0; -1 0 0 0; 0 0 0 1]`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`tform2trvec`

Topics
“Coordinate Transformations in Robotics”

Introduced in R2015a

uminus, -

Quaternion unary minus

Syntax

`mQuat = -quat`

Description

`mQuat = -quat` negates the elements of `quat` and stores the result in `mQuat`.

Examples

Negate Elements of Quaternion Matrix

Unary minus negates each part of a the quaternion. Create a 2-by-2 matrix, `Q`.

```
Q = quaternion(randn(2),randn(2),randn(2),randn(2))
```

```
Q = 2x2 quaternion array
      0.53767 +  0.31877i +   3.5784j +   0.7254k      -2.2588 -  0.43359i -   1.3499j +  0.7147
       1.8339 -   1.3077i +   2.7694j - 0.063055k      0.86217 +  0.34262i +   3.0349j -  0.2049
```

Negate the parts of each quaternion in `Q`.

```
R = -Q
```

```
R = 2x2 quaternion array
     -0.53767 -  0.31877i -   3.5784j -   0.7254k       2.2588 +  0.43359i +   1.3499j -  0.7147
      -1.8339 +   1.3077i -   2.7694j + 0.063055k     -0.86217 -  0.34262i -   3.0349j +  0.2049
```

Input Arguments

`quat` — Quaternion array
scalar | vector | matrix | multidimensional array

Quaternion array, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `quaternion`

Output Arguments

`mQuat` — Negated quaternion array
scalar | vector | matrix | multidimensional array

Negated quaternion array, returned as the same size as `quat`.

Data Types: `quaternion`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`minus, -`

Objects
`quaternion`

Introduced in R2018a

updateErrorDynamicsFromStep

Update values of `NaturalFrequency` and `DampingRatio` properties given desired step response

Syntax

```
updateErrorDynamicsFromStep(motionModel,settlingTime,overshoot)
updateErrorDynamicsFromStep(motionModel,settlingTime,overshoot,jointIndex)
```

Description

`updateErrorDynamicsFromStep(motionModel,settlingTime,overshoot)` updates the values of the `NaturalFrequency` and `DampingRatio` properties of the given `jointSpaceMotionModel` object given the desired step response.

`updateErrorDynamicsFromStep(motionModel,settlingTime,overshoot,jointIndex)` updates the `NaturalFrequency` and `DampingRatio` properties for a specific joint. In this case, the values of `SettlingTime` and `Overshoot` must be provided as scalars because they apply to a single joint.

Examples

Create Joint-Space Motion Model

This example shows how to create and use a `jointSpaceMotionModel` object for a manipulator robot in joint-space.

Create the Robot

```
robot = loadrobot("kinovaGen3","DataFormat","column","Gravity",[0 0 -9.81]);
```

Set Up the Simulation

Set the timespan to be 1 s with a timestep size of 0.01 s. Set the initial state to be the robots, home configuration with a velocity of zero.

```
tspan = 0:0.01:1;
initialState = [homeConfiguration(robot); zeros(7,1)];
```

Define the a reference state with a target position, zero velocity, and zero acceleration.

```
targetState = [pi/4; pi/3; pi/2; -pi/3; pi/4; -pi/4; 3*pi/4; zeros(7,1); zeros(7,1)];
```

Create the Motion Model

Model the system with computed torque control and error dynamics defined by a moderately fast step response with 5% overshoot.

```
motionModel = jointSpaceMotionModel("RigidBodyTree",robot);
updateErrorDynamicsFromStep(motionModel,.3,.05);
```

Simulate the Robot

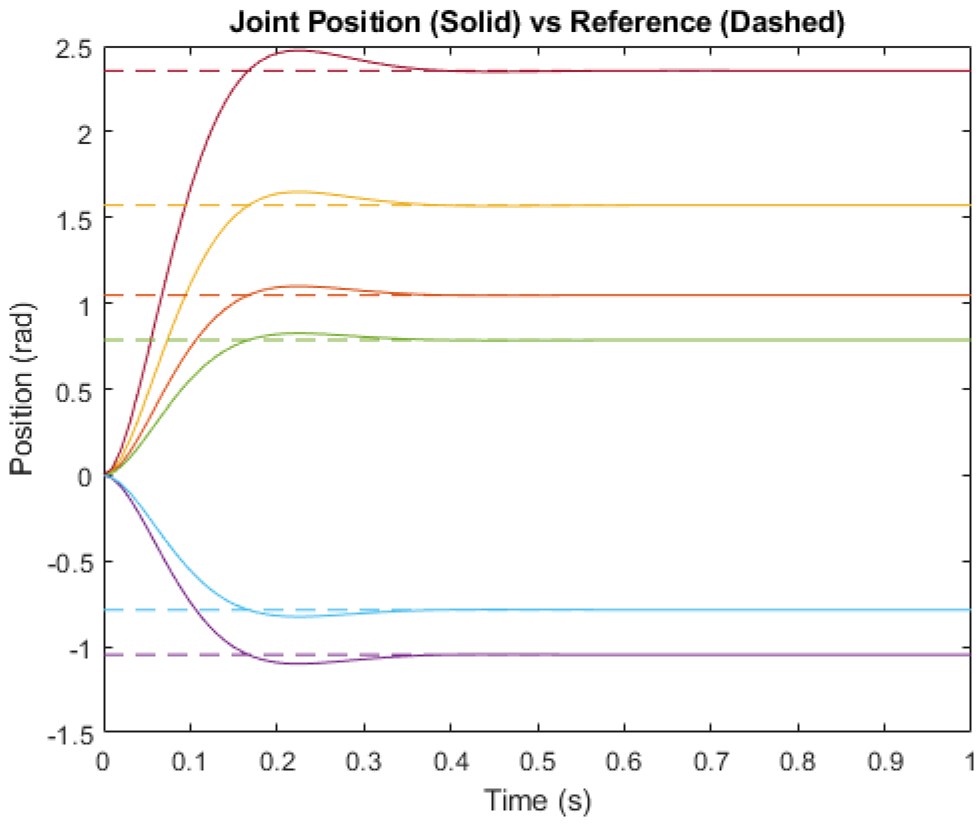
Use the derivative function of the model as the input to the `ode45` solver to simulate the behavior over 1 second.

```
[t,robotState] = ode45(@(t,state)derivative(motionModel,state,targetState),tspan,initialState);
```

Plot the Response

Plot the positions of all the joints actuating to their target state. Joints with a higher displacement between the starting position and the target position actuate to the target at a faster rate than those with a lower displacement. This leads to an overshoot, but all of the joints have the same settling time.

```
figure
plot(t,robotState(:,1:motionModel.NumJoints));
hold all;
plot(t,targetState(1:motionModel.NumJoints)*ones(1,length(t)),"--");
title("Joint Position (Solid) vs Reference (Dashed)");
xlabel("Time (s)")
ylabel("Position (rad)");
```



Input Arguments

`motionModel` — `jointSpaceMotionModel` object
`jointSpaceMotionModel` object

The `jointSpaceMotionModel` object, which defines the properties of the motion model.

`settlingTime` — Settling time of system
n-element vector

Settling time required to reach a 2% tolerance band in seconds, specified as a scalar or an *n*-element vector. *n* is the number of nonfixed joints in the `rigidBodyTree` of the `jointSpaceMotionModel` in the `motionModel` argument.

`overshoot` — Overshoot of system
n-element vector

The overshoot relative to a unit step, specified as a scalar or an *n*-element vector. *n* is the number of nonfixed joints in the `rigidBodyTree` of the `jointSpaceMotionModel` in the `motionModel` argument.

`jointIndex` — Joint index
scalar

The index of the joint for which `NaturalFrequency` and `DampingRatio` is updated given the unit-step error dynamics. In this case, settling time and overshoot must be specified as scalars.

References

[1] Ogata, Katsuhiko. *Modern Control Engineering* 4th ed. Englewood Cliffs, NJ: Prentice-Hall, 2002.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
`jointSpaceMotionModel` | `taskSpaceMotionModel`

Introduced in R2019b

writeBinaryOccupancyGrid

Write values from grid to ROS message

Syntax

`writeBinaryOccupancyGrid(msg,map)`

Description

`writeBinaryOccupancyGrid(msg,map)` writes occupancy values and other information to the ROS message, `msg`, from the binary occupancy grid, `map`.

Note The `msg` input is an `'nav_msgs/OccupancyGrid'` ROS message. For more info, see `OccupancyGrid`.

Input Arguments

`map` — Binary occupancy grid
`binaryOccupancyMap` object handle

Binary occupancy grid, specified as a `binaryOccupancyMap` object handle. `map` is converted to a `'nav_msgs/OccupancyGrid'` message on the ROS network. `map` is an object with a grid of binary values, where `1` indicates an occupied location and `0` indications an unoccupied location.

`msg` — `'nav_msgs/OccupancyGrid'` ROS message
`OccupancyGrid` object handle

`'nav_msgs/OccupancyGrid'` ROS message, specified as a `OccupancyGrid` object handle.

See Also

Functions
`rosReadBinaryOccupancyGrid` | `rosReadOccupancyMap3D` | `rosReadOccupancyGrid` | `rosWriteOccupancyGrid`

Introduced in R2015a

zeros

Create quaternion array with all parts set to zero

Syntax

```
quatZeros = zeros('quaternion')
quatZeros = zeros(n,'quaternion')
quatZeros = zeros(sz,'quaternion')
quatZeros = zeros(sz1,...,szN,'quaternion')

quatZeros = zeros(___,'like',prototype,'quaternion')
```

Description

`quatZeros = zeros('quaternion')` returns a scalar quaternion with all parts set to zero.

`quatZeros = zeros(n,'quaternion')` returns an `n`-by-`n` matrix of quaternions.

`quatZeros = zeros(sz,'quaternion')` returns an array of quaternions where the size vector, `sz`, defines `size(quatZeros)`.

`quatZeros = zeros(sz1,...,szN,'quaternion')` returns a `sz1`-by-...-by-`szN` array of quaternions where `sz1,…,szN` indicates the size of each dimension.

`quatZeros = zeros(___,'like',prototype,'quaternion')` specifies the underlying class of the returned quaternion array to be the same as the underlying class of the quaternion prototype.

Examples

Quaternion Scalar Zero

Create a quaternion scalar zero.

```
quatZeros = zeros('quaternion')
```

```
quatZeros = quaternion
     0 + 0i + 0j + 0k
```

Square Matrix of Quaternions

Create an n-by-n array of quaternion zeros.

```
n = 3;
quatZeros = zeros(n,'quaternion')
```

```
quatZeros = 3x3 quaternion array
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
```

Multidimensional Array of Quaternion Zeros

Create a multidimensional array of quaternion zeros by defining array dimensions in order. In this example, you create a 3-by-1-by-2 array. You can specify dimensions using a row vector or comma-separated integers.

Specify the dimensions using a row vector and display the results:

```
dims = [3,1,2];
quatZerosSyntax1 = zeros(dims,'quaternion')
```

```
quatZerosSyntax1 = 3x1x2 quaternion array
quatZerosSyntax1(:,:,1) =

     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k


quatZerosSyntax1(:,:,2) =

     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k
```

Specify the dimensions using comma-separated integers, and then verify the equivalence of the two syntaxes:

```
quatZerosSyntax2 = zeros(3,1,2,'quaternion');
isequal(quatZerosSyntax1,quatZerosSyntax2)
```

```
ans = logical
   1
```

Underlying Class of Quaternion Zeros

A quaternion is a four-part hyper-complex number used in three-dimensional representations. You can specify the underlying data type of the parts as `single` or `double`. The default is `double`.

Create a quaternion array of zeros with the underlying data type set to `single`.

```
quatZeros = zeros(2,'like',single(1),'quaternion')
```

```
quatZeros = 2x2 quaternion array
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
     0 + 0i + 0j + 0k     0 + 0i + 0j + 0k
```

Verify the underlying class using the `classUnderlying` function.

```
classUnderlying(quatZeros)
```

```
ans =
'single'
```

Input Arguments

`n` — Size of square quaternion matrix
integer value

Size of square quaternion matrix, specified as an integer value. If `n` is `0` or negative, then `quatZeros` is returned as an empty matrix.

Example: `zeros(4,'quaternion')` returns a 4-by-4 matrix of quaternion zeros.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`sz` — Output size
row vector of integer values

Output size, specified as a row vector of integer values. Each element of `sz` indicates the size of the corresponding dimension in `quatZeros`. If the size of any dimension is `0` or negative, then `quatZeros` is returned as an empty array.

Example: `zeros([1,4,2],'quaternion')` returns a 1-by-4-by-2 array of quaternion zeros.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`prototype` — Quaternion prototype
variable

Quaternion prototype, specified as a variable.

Example: `zeros(2,'like',quat,'quaternion')` returns a 2-by-2 matrix of quaternions with the same underlying class as the prototype quaternion, `quat`.

Data Types: `quaternion`

`sz1,...,szN` — Size of each dimension
two or more integer values

Size of each dimension, specified as two or more integers.

- If the size of any dimension is `0`, then `quatZeros` is returned as an empty array.
- If the size of any dimension is negative, then it is treated as `0`.

Example: `zeros(2,3,'quaternion')` returns a 2-by-3 matrix of quaternion zeros.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

`quatZeros` — Quaternion zeros
scalar | vector | matrix | multidimensional array

Quaternion zeros, returned as a quaternion or array of quaternions.

Given a quaternion of the form $Q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, a quaternion zero is defined as $Q = 0 + 0\mathrm{i} + 0\mathrm{j} + 0\mathrm{k}$.

Data Types: `quaternion`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Functions
`ones`

Objects
`quaternion`

Introduced in R2018a

3

Methods

generateIKFunction

Generate function for closed-form inverse kinematics

Syntax

```
ikFunction = generateIKFunction(analyticalIK,functionName)
```

Description

`ikFunction = generateIKFunction(analyticalIK,functionName)` generates a function with a specified name, `functionName`, that computes the closed-form solutions for inverse kinematics (IK) for a selected kinematic group to achieve a desired end-effector pose. To generate a list of configurations that achieve the desired end-effector pose, use the generated function `ikFunction`. The specified `analyticalInverseKinematics` object `analyticalIK` must contain a valid kinematic group. For information on determining valid kinematic groups, see the `showdetails` function.

For the syntax of the generated function, see the `ikFunction` output argument.

Examples

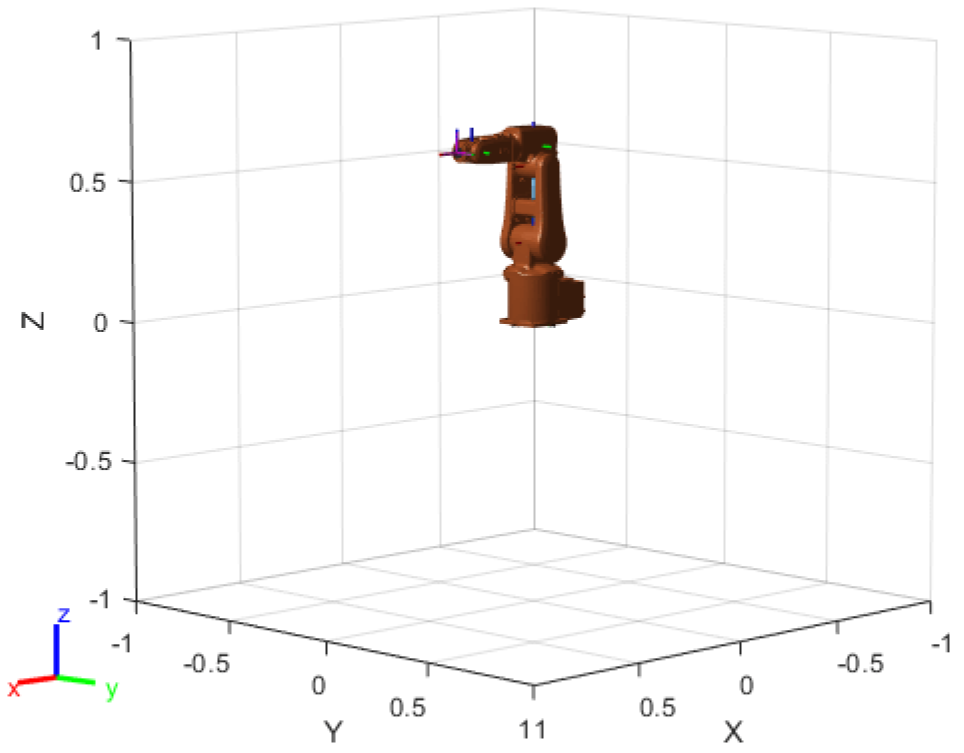
Solve Analytical Inverse Kinematics for Robot Manipulator

Generate closed-form inverse kinematics (IK) solutions for a desired end effector. Load the provided robot model and inspect details about the feasible kinematic groups of base and end-effector bodies. Generate a function for your desired kinematic group. Inspect the various configurations for a specific end-effector pose.

Robot Model

Load the ABB IRB 120 robot model into the workspace. Display the model.

```
robot = loadrobot('abbIrb120','DataFormat','row');
show(robot);
```



Analytical IK

Create the analytical IK solver. Show details for the robot model, which lists the different kinematic groups available for closed-form analytical IK solutions. Select the second kinematic group by clicking the **Use this kinematic group** link in the second row of the table.

```
aik = analyticalInverseKinematics(robot);
showdetails(aik)
```

```
--------------------
Robot: (8 bodies)

Index      Base Name   EE Body Name     Type                     Actions
-----      ---------   ------------     ----                     -------
    1      base_link         link_6   RRRSSS   Use this kinematic group
    2      base_link          tool0   RRRSSS   Use this kinematic group
```

Inspect the kinematic group, which lists the base and end-effector body names. For this robot, the group uses the `'base_link'` and `'tool0'` bodies, respectively.

```
aik.KinematicGroup
```

```
ans = struct with fields:
               BaseName: 'base_link'
    EndEffectorBodyName: 'tool0'
```

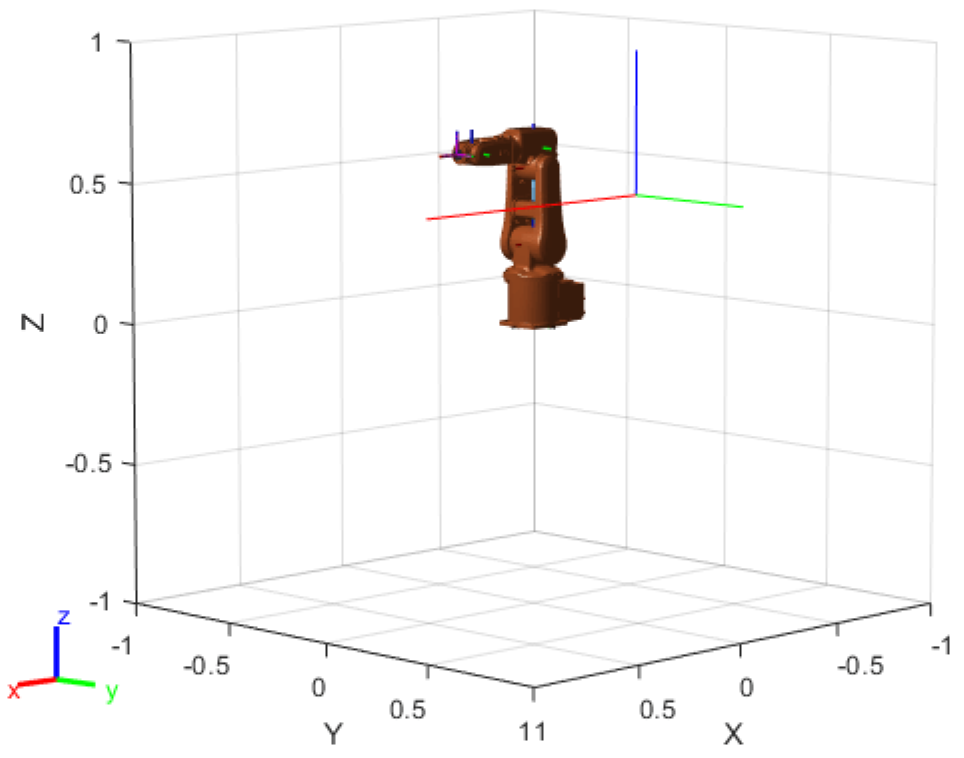
Generate Function

Generate the IK function for the selected kinematic group. Specify a name for the function, which is generated and saved in the current directory.

```
generateIKFunction(aik,'robotIK');
```

Specify a desired end-effector position. Convert the *xyz*-position to a homogeneous transformation.

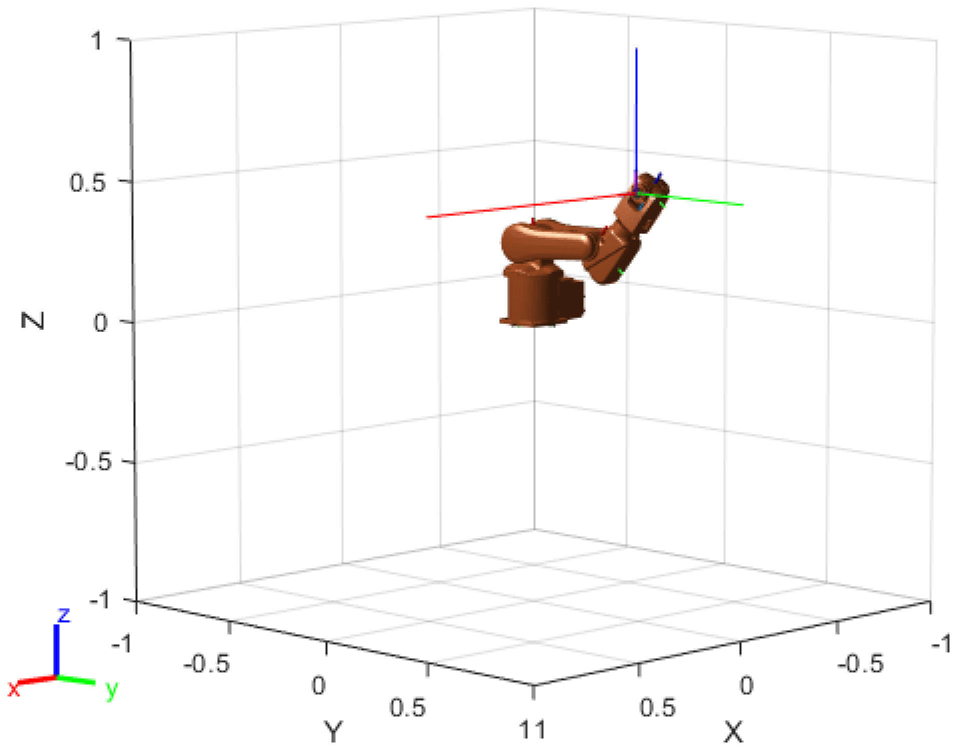
```
eePosition = [0 0.5 0.5];
eePose = trvec2tform(eePosition);
hold on
plotTransforms(eePosition,tform2quat(eePose))
hold off
```



Generate Configuration for IK Solution

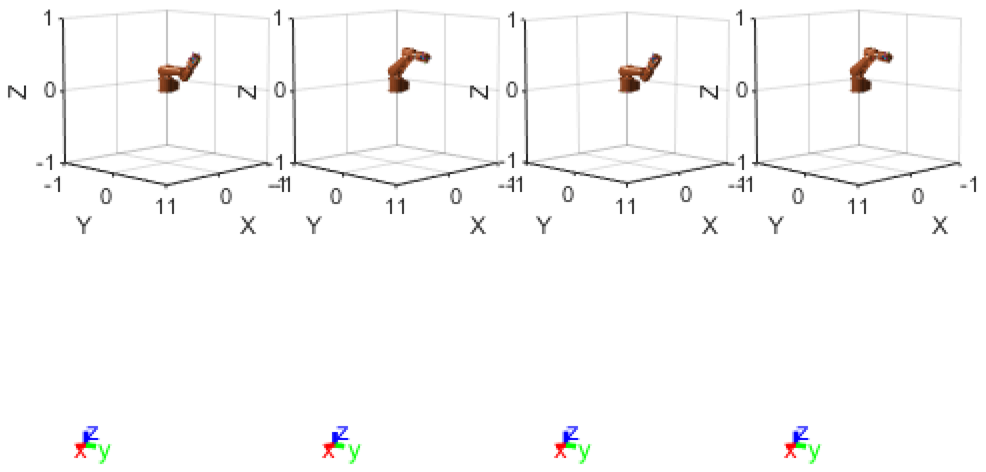
Specify the homogeneous transformation to the generated IK function, which generates all solutions for the desired end-effector pose. Display the first generated configuration to verify that the desired pose has been achieved.

```
ikConfig = robotIK(eePose); % Uses the generated file

show(robot,ikConfig(1,:));
hold on
plotTransforms(eePosition,tform2quat(eePose))
hold off
```



Display all of the closed-form IK solutions sequentially.

```
figure;
numSolutions = size(ikConfig,1);

for i = 1:size(ikConfig,1)
    subplot(1,numSolutions,i)
    show(robot,ikConfig(i,:));
end
```



Solve Analytical IK for Large-DOF Robot

Some manipulator robot models have large degrees-of-freedom (DOFs). To reach certain end-effector poses, however, only six DOFs are required. Use the `analyticalInverseKinematics` object, which supports six-DOF robots, to determine various valid kinematic groups for this large-DOF robot model. Use the `showdetails` object function to get information about the model.

Load Robot Model and Generate IK Solver

Load the robot model into the workspace, and create an `analyicalInverseKinematics` object. Use the `showdetails` object function to see the supported kinematic groups.

```
robot = loadrobot('willowgaragePR2','DataFormat','row');
aik = analyticalInverseKinematics(robot);
opts = showdetails(aik);
```

```
--------------------
Robot: (94 bodies)

Index                                     Base Name                                 EE
-----                                     ---------                                 --
    1                             l_shoulder_pan_link                             l_wris
    2                             r_shoulder_pan_link                             r_wris
    3                             l_shoulder_pan_link                            l_gripper
    4                             r_shoulder_pan_link                            r_gripper
```

```
     5                               l_shoulder_pan_link                                 l_gripper
     6                               l_shoulder_pan_link                     l_gripper_motor_accelero
     7                               l_shoulder_pan_link                                l_gripper_
     8                               r_shoulder_pan_link                                 r_gripper
     9                               r_shoulder_pan_link                     r_gripper_motor_accelero
    10                               r_shoulder_pan_link                                r_gripper_
```

Select a group programmatically using the output of the `showdetails` object function, `opts`. The selected group uses the left shoulder as the base with the left wrist as the end effector.

```
aik.KinematicGroup = opts(1).KinematicGroup;
disp(aik.KinematicGroup)
```

```
                BaseName: 'l_shoulder_pan_link'
    EndEffectorBodyName: 'l_wrist_roll_link'
```

Generate the IK function for the selected group.

```
generateIKFunction(aik,'willowRobotIK');
```

Solve Analytical IK

Define a target end-effector pose using a randomly-generated configuration.

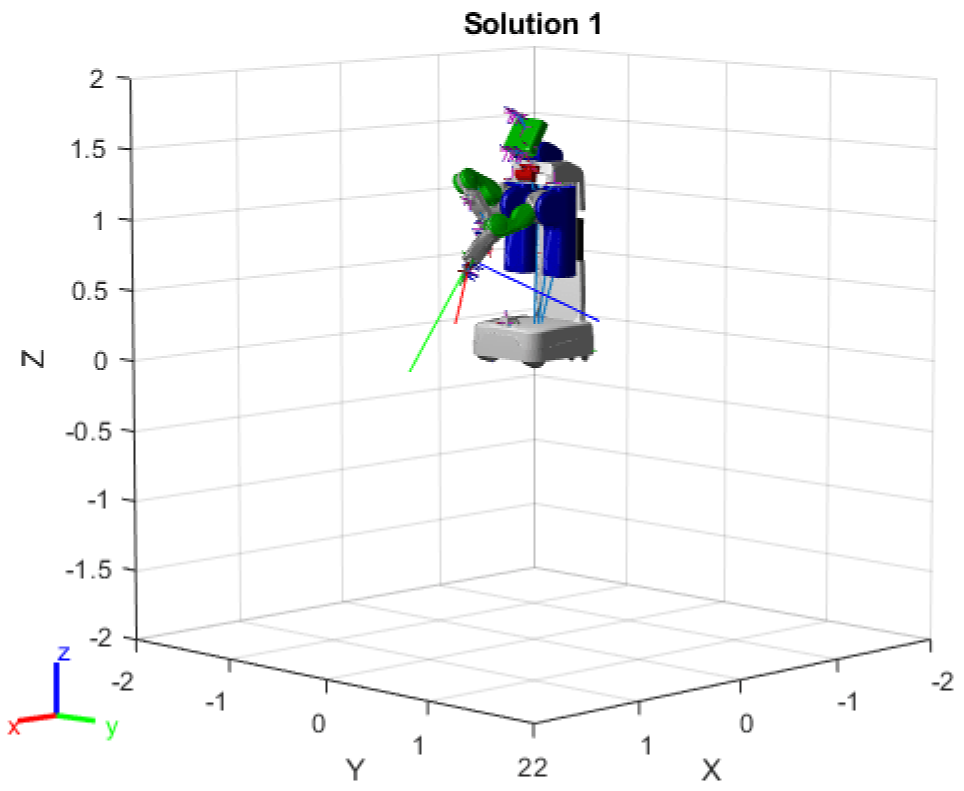
```
rng(0);
expConfig = randomConfiguration(robot);

eeBodyName = aik.KinematicGroup.EndEffectorBodyName;
baseName = aik.KinematicGroup.BaseName;
expEEPose = getTransform(robot,expConfig,eeBodyName,baseName);
```

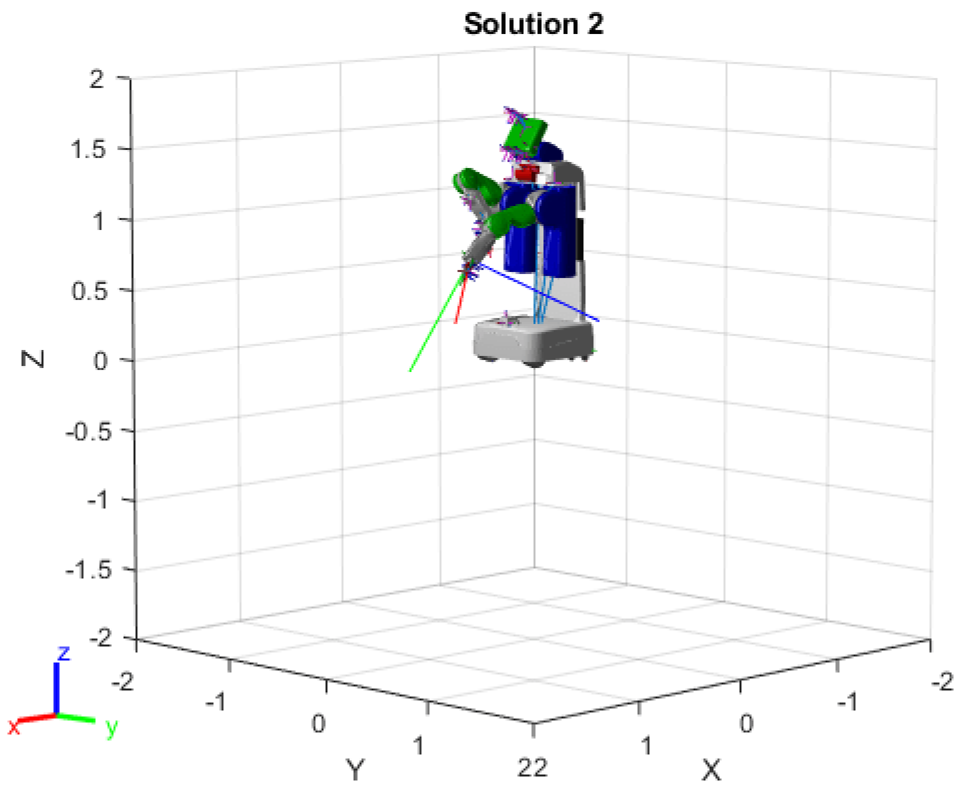
Solve for all robot configurations that achieve the defined end-effector pose using the generated IK function. To ignore joint limits, specify `false` as the second input argument.

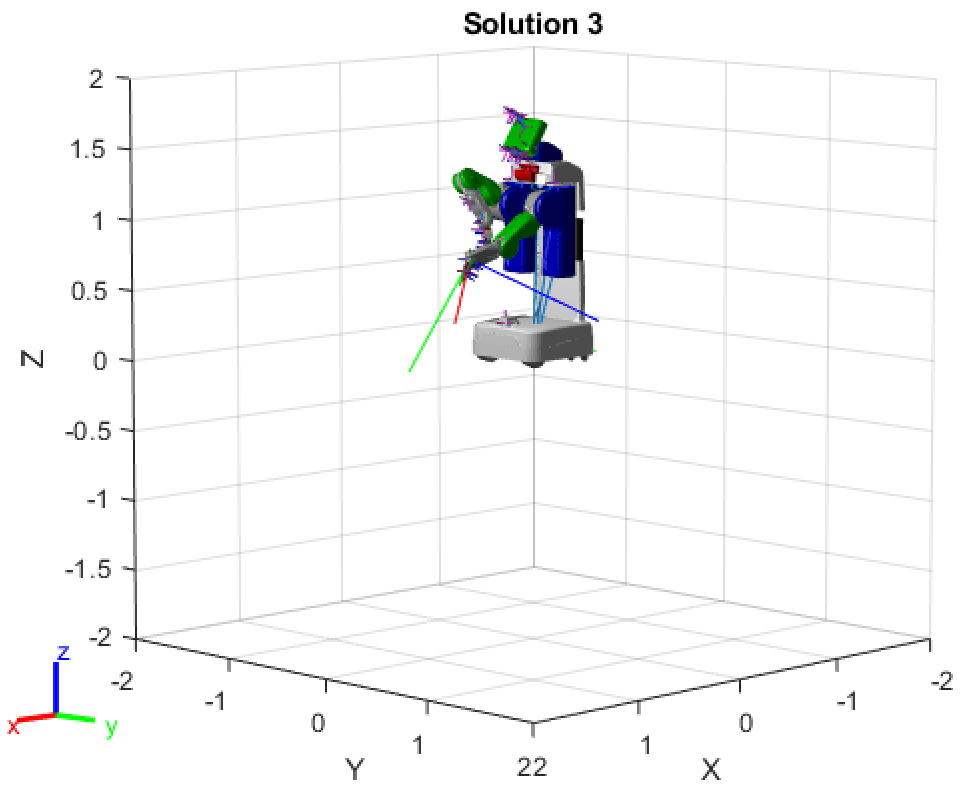
```
ikConfig = willowRobotIK(expEEPose,false);
```

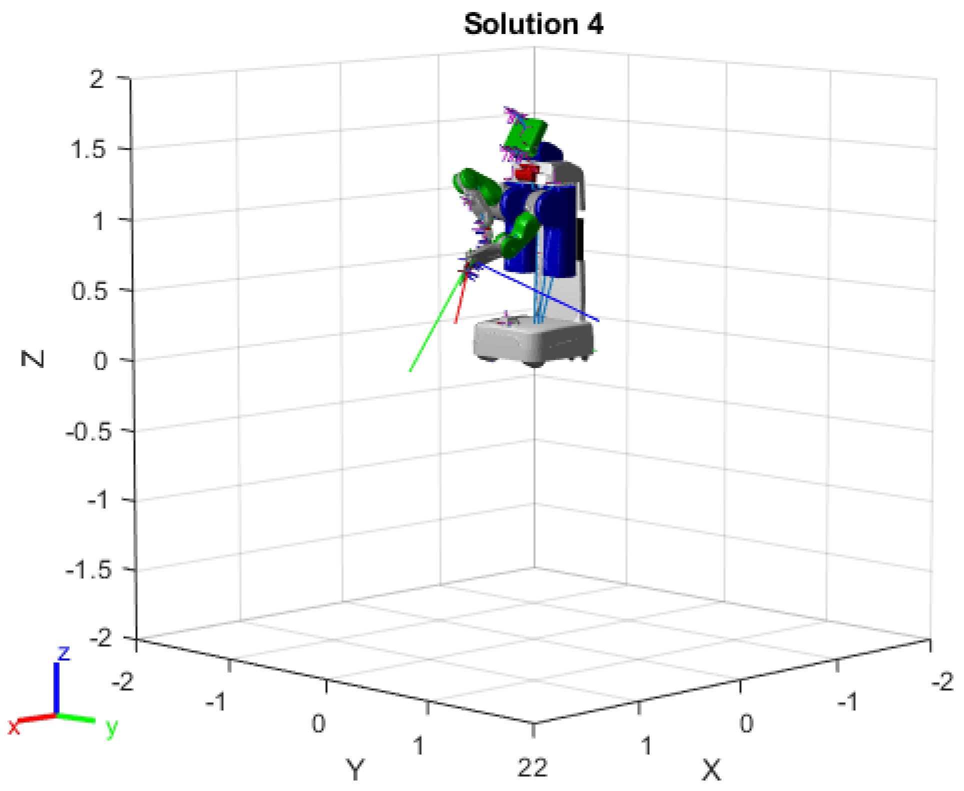
To display the target end-effector pose in the world frame, get the transformation from the base of the robot model, rather than the base of the kinematic group. Display all of the generated IK solutions by specifying the indices for your kinematic group IK solution in the configuration vector used with the `show` function.

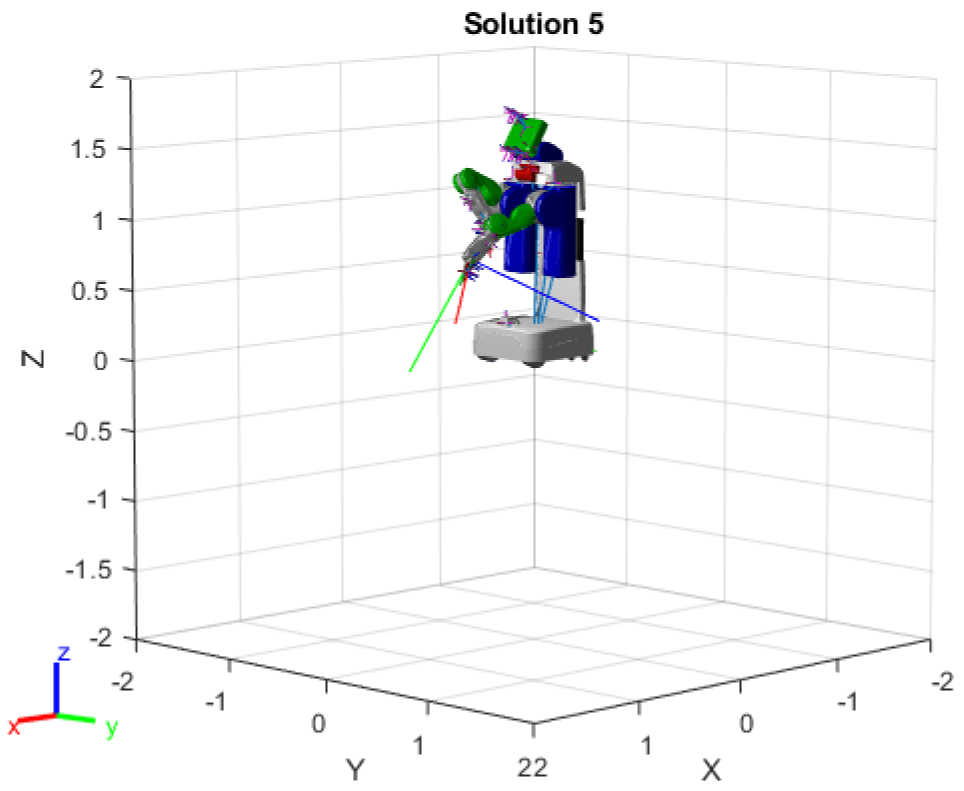
```
eeWorldPose = getTransform(robot,expConfig,eeBodyName);

generatedConfig = repmat(expConfig, size(ikConfig,1), 1);
generatedConfig(:,aik.KinematicGroupConfigIdx) = ikConfig;

for i = 1:size(ikConfig,1)
    figure;
    ax = show(robot,generatedConfig(i,:));
    hold all;
    plotTransforms(tform2trvec(eeWorldPose),tform2quat(eeWorldPose),'Parent',ax);
    title(['Solution ' num2str(i)]);
end
```

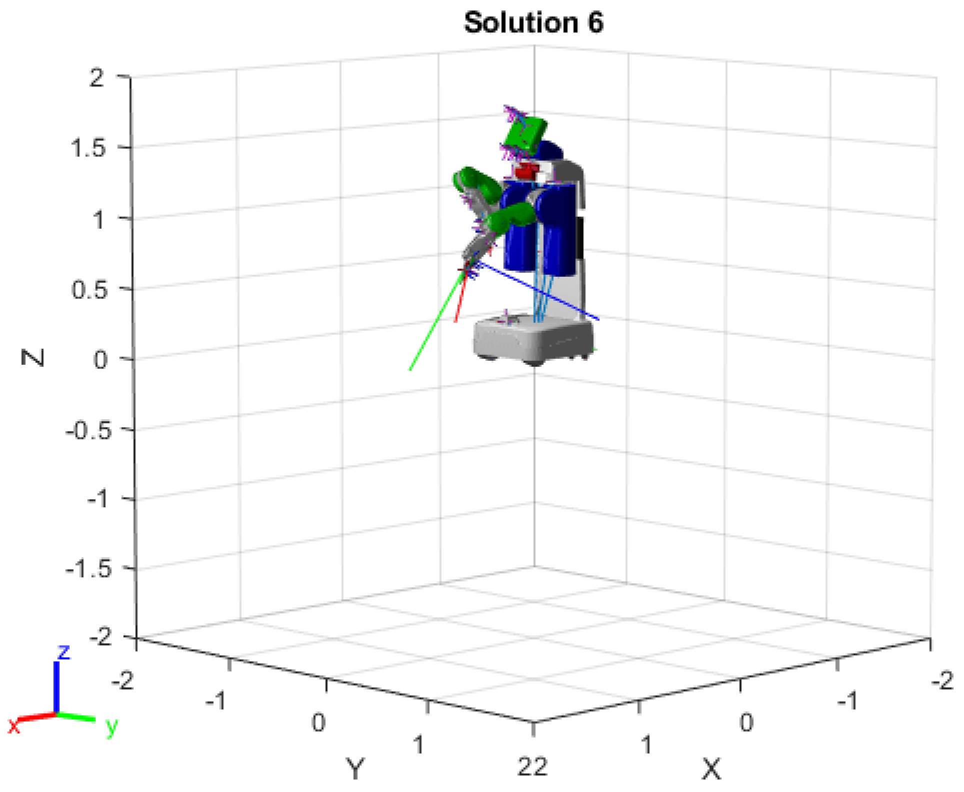

Solution 1
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
z
x
y

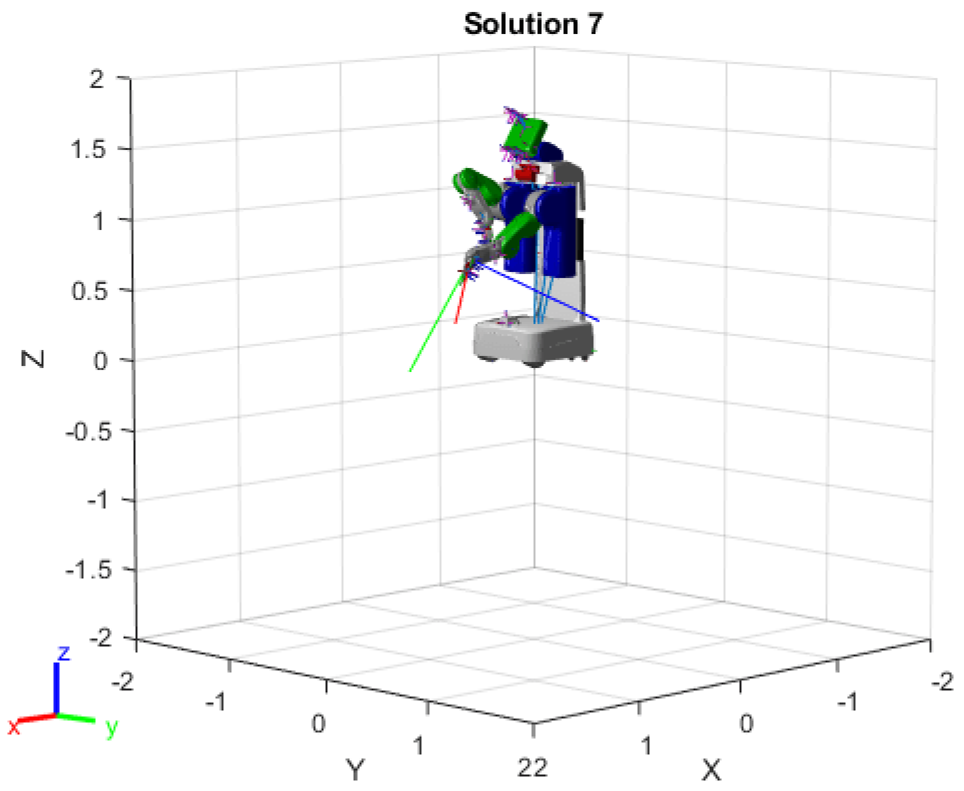

Solution 2
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
x
y
z

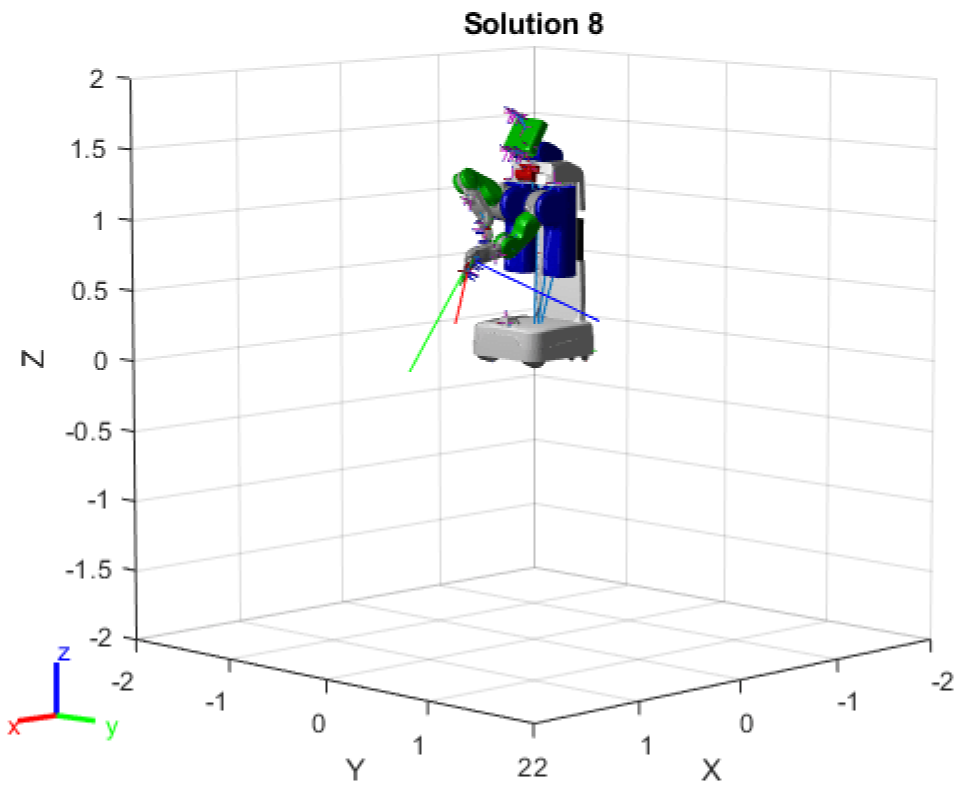

Solution 3
2
1.5
1
0.5
Z
0
-0.5
-1
-1.5
-2
-2
-1
0
1
Y
22
1
0
-1
-2
X
z
x
y


Solution 4
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
z
x
y


Solution 5
Z
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Y
-2
-1
0
1
2
X
2
1
0
-1
-2
z
x
y


Solution 6
Z
Y
X
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1
0
1
22
1
0
-1
-2
z
x
y


Solution 7
2
1.5
1
0.5
Z
0
-0.5
-1
-1.5
-2
-2
-1
0
1
Y
22
1
X
0
-1
-2
z
x
y



Input Arguments

`analyticalIK` — Analytical IK solver
`analyticalInverseKinematics` object

Analytical inverse kinematics solver, specified as an `analyticalInverseKinematics` object.

`functionName` — Name of generated function
string scalar | character vector

Name of the generated function, specified as a string scalar or character vector.

Example: `"jacoIKSolver"`

Data Types: `char` | `string`

Output Arguments

`ikFunction` — IK solver for selected kinematic group
function handle

IK solver for the selected kinematic group, returned as a function handle. The function generates closed-form solutions and has these syntax options:

```
robotConfig = ikFunction(eeTransform)
robotConfig = ikFunction(eeTransform,enforceJointLimits)
robotConfig = ikFunction(eeTransform,enforceJointLimits,sortByDistance)
robotConfig = ikFunction(eeTransform,enforceJointLimits,sortByDistance,referenceConfig)
```

`eeTransform` — Desired end-effector pose
4-by-4 homogeneous transformation matrix

Desired end-effector pose, specified as a 4-by-4 homogeneous transformation matrix. To generate a transformation matrix from an *xyz*-position and quaternion orientation, use the `trvec2tform` and `quat2tform` functions on the respective coordinates and multiply the resulting matrices.

```
tform1 = trvec2tform([x y z]);
tform2 = quat2tform([qw qx qy qz]);
eeTransform = tform1*tform2;
```

Data Types: `single` | `double`

`enforceJointLimits` — Enforce joint limits of rigid body tree model
`1` (`true`) | `0` (`false`)

Enforce joint limits of the rigid body tree model, specified as a logical, `1` (`true` or `0` (`false`). When set to `false`, the solver ignores the joint limits of the robot model in the RigidBodyTree property of the `analyticalInverseKinematics` object.

Data Types: `logical`

`sortByDistance` — Sort configurations based on distance from desired pose
`1` (`true`) | `0` (`false`)

Sort configurations based on distance from desired pose, specified as a logical, `1` (`true` or `0` (`false`).

Data Types: `logical`

`referenceConfig` — Reference configuration for IK solution
n-element vector

Reference configuration for the IK solution, specified as an *n*-element vector, where *n* is the number of nonfixed joints in the rigid body tree robot model. Each element corresponds to a joint position as either a rotation angle in radians for revolute joints or a linear distance in meters for prismatic joints.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

The `analyticalInverseKinematics` object only supports code generation for the function created by calling the `generateIKFunction`. Use the `analyticalInverseKinematics` object to modify parameters and setup the solver. Then, use `generateIKFunction` to create your custom IK function for your robot model. Call `codegen` on the output `ikFunction` that is generated.

See Also

Objects

`analyticalInverseKinematics` | `inverseKinematics` | `generalizedInverseKinematics` | `rigidBodyTree`

Functions
`loadrobot` | `importrobot` | `showdetails`

Introduced in R2020b

showdetails

Display overview of available kinematic groups

Syntax

`kinGroupDetails = showdetails(analyticalIK)`

Description

`kinGroupDetails = showdetails(analyticalIK)` displays an overview of all the kinematic group combinations available for the `rigidBodyTree` object associated with the analytical inverse kinematics (IK) solver. Each kinematic group contains body names for both a base and end effector that are valid for closed-form solutions to analytical IK.

To use a specific kinematic group for your object, click the corresponding **Use this kinematic group** link in the output table. This link updates the KinematicGroup and KinematicGroupType properties of the `analyticalInverseKinematics` object.

Examples

Solve Analytical IK for Large-DOF Robot

Some manipulator robot models have large degrees-of-freedom (DOFs). To reach certain end-effector poses, however, only six DOFs are required. Use the `analyticalInverseKinematics` object, which supports six-DOF robots, to determine various valid kinematic groups for this large-DOF robot model. Use the `showdetails` object function to get information about the model.

Load Robot Model and Generate IK Solver

Load the robot model into the workspace, and create an `analyicalInverseKinematics` object. Use the `showdetails` object function to see the supported kinematic groups.

```
robot = loadrobot('willowgaragePR2','DataFormat','row');
aik = analyticalInverseKinematics(robot);
opts = showdetails(aik);
```

```
--------------------
Robot: (94 bodies)

Index                                          Base Name                                       E
-----                                          ---------                                       --
    1                                l_shoulder_pan_link                                  l_wris
    2                                r_shoulder_pan_link                                  r_wris
    3                                l_shoulder_pan_link                                l_gripper
    4                                r_shoulder_pan_link                                r_gripper
    5                                l_shoulder_pan_link                                l_gripper
    6                                l_shoulder_pan_link                 l_gripper_motor_accelero
    7                                l_shoulder_pan_link                               l_gripper_
    8                                r_shoulder_pan_link                                r_gripper
    9                                r_shoulder_pan_link                 r_gripper_motor_accelero
   10                                r_shoulder_pan_link                               r_gripper_
```

Select a group programmically using the output of the `showdetails` object function, `opts`. The selected group uses the left shoulder as the base with the left wrist as the end effector.

```
aik.KinematicGroup = opts(1).KinematicGroup;
disp(aik.KinematicGroup)
```

```
               BaseName: 'l_shoulder_pan_link'
    EndEffectorBodyName: 'l_wrist_roll_link'
```

Generate the IK function for the selected group.

```
generateIKFunction(aik,'willowRobotIK');
```

Solve Analytical IK

Define a target end-effector pose using a randomly-generated configuration.

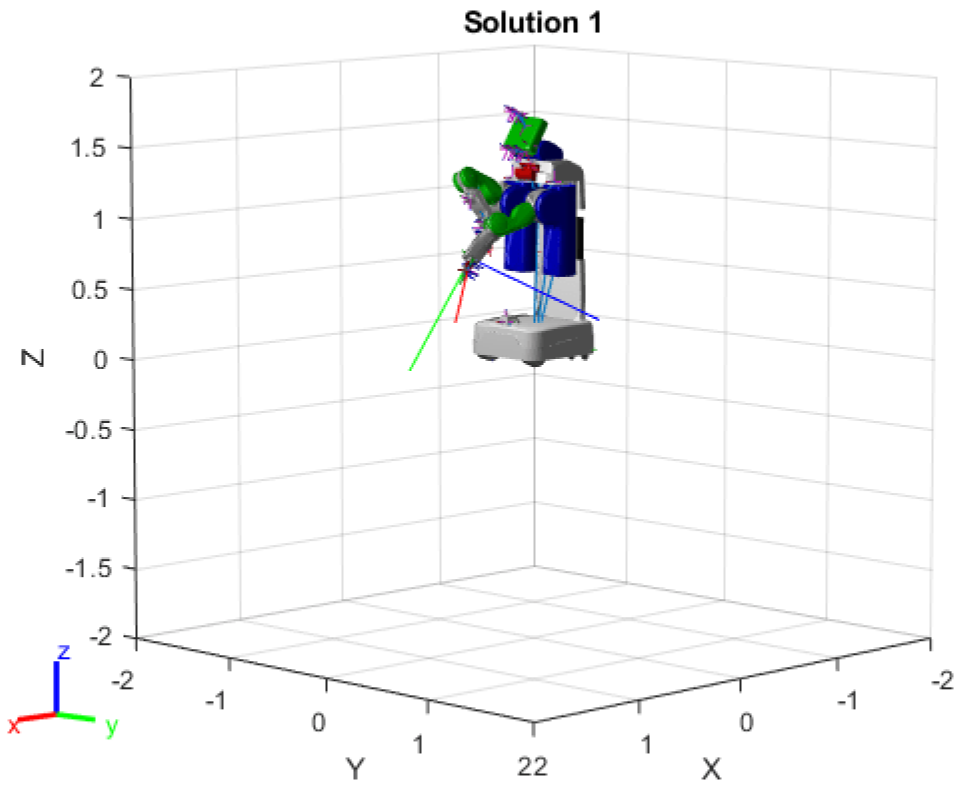
```
rng(0);
expConfig = randomConfiguration(robot);

eeBodyName = aik.KinematicGroup.EndEffectorBodyName;
baseName = aik.KinematicGroup.BaseName;
expEEPose = getTransform(robot,expConfig,eeBodyName,baseName);
```

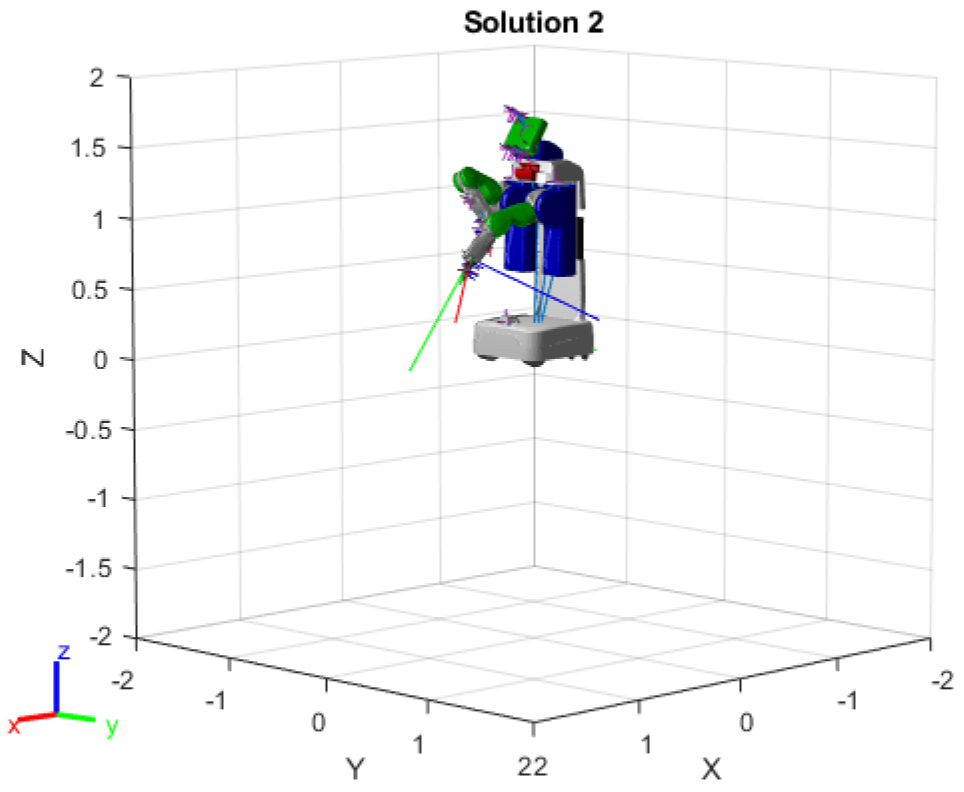
Solve for all robot configurations that achieve the defined end-effector pose using the generated IK function. To ignore joint limits, specify `false` as the second input argument.

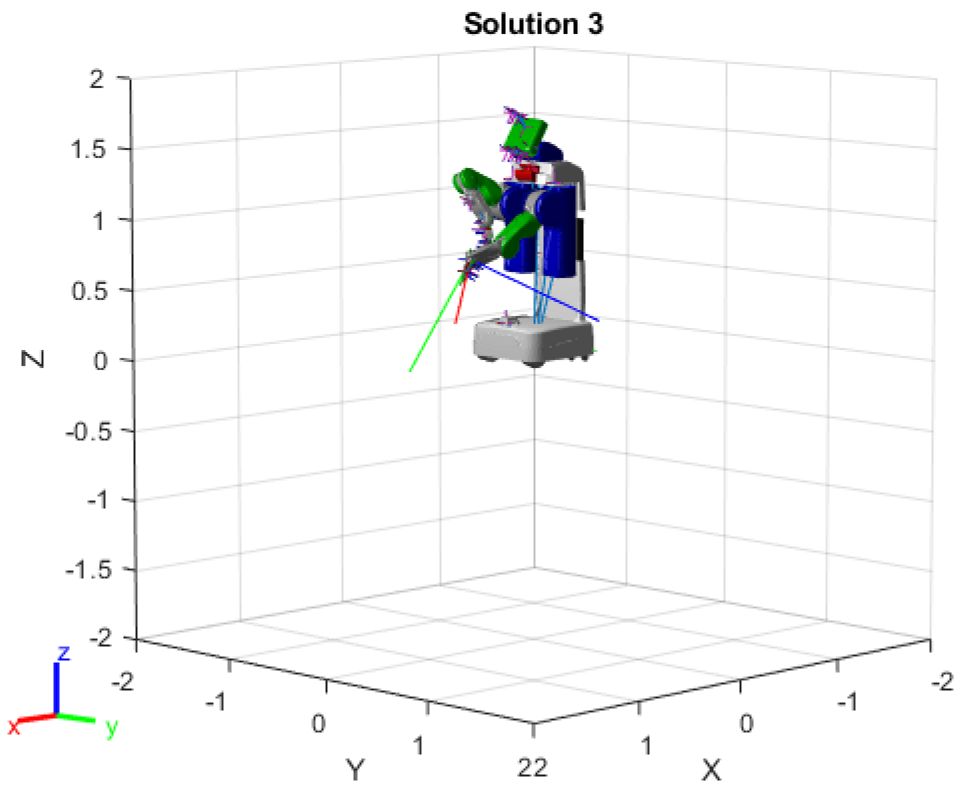
```
ikConfig = willowRobotIK(expEEPose,false);
```

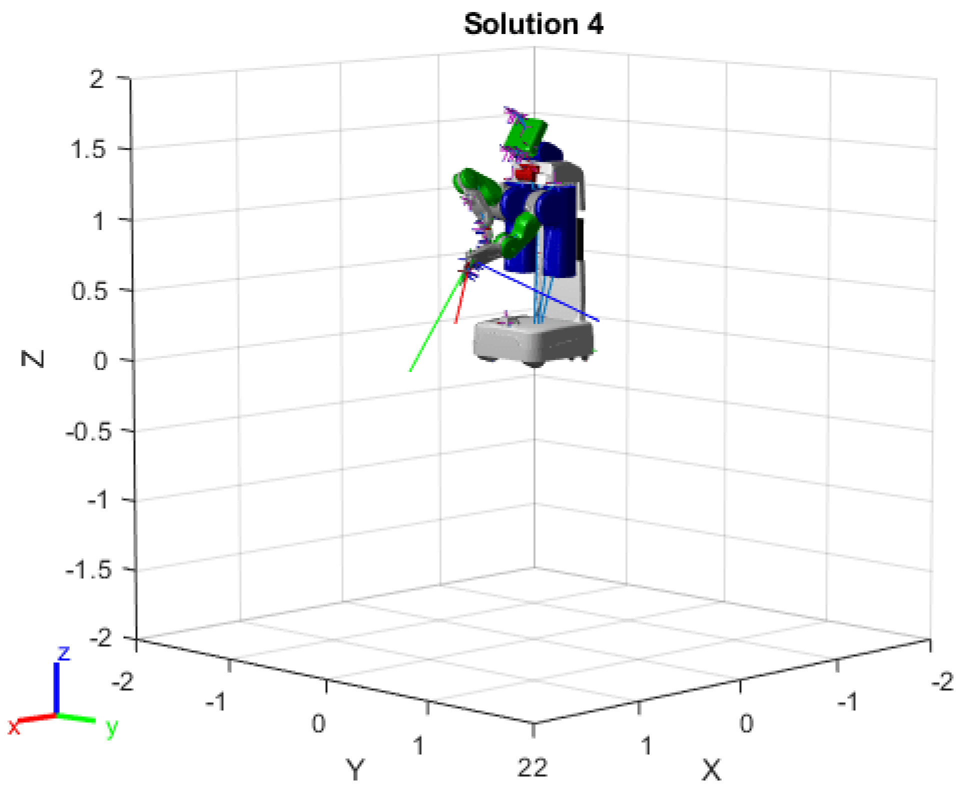
To display the target end-effector pose in the world frame, get the transformation from the base of the robot model, rather than the base of the kinematic group. Display all of the generated IK solutions by specifying the indices for your kinematic group IK solution in the configuration vector used with the `show` function.

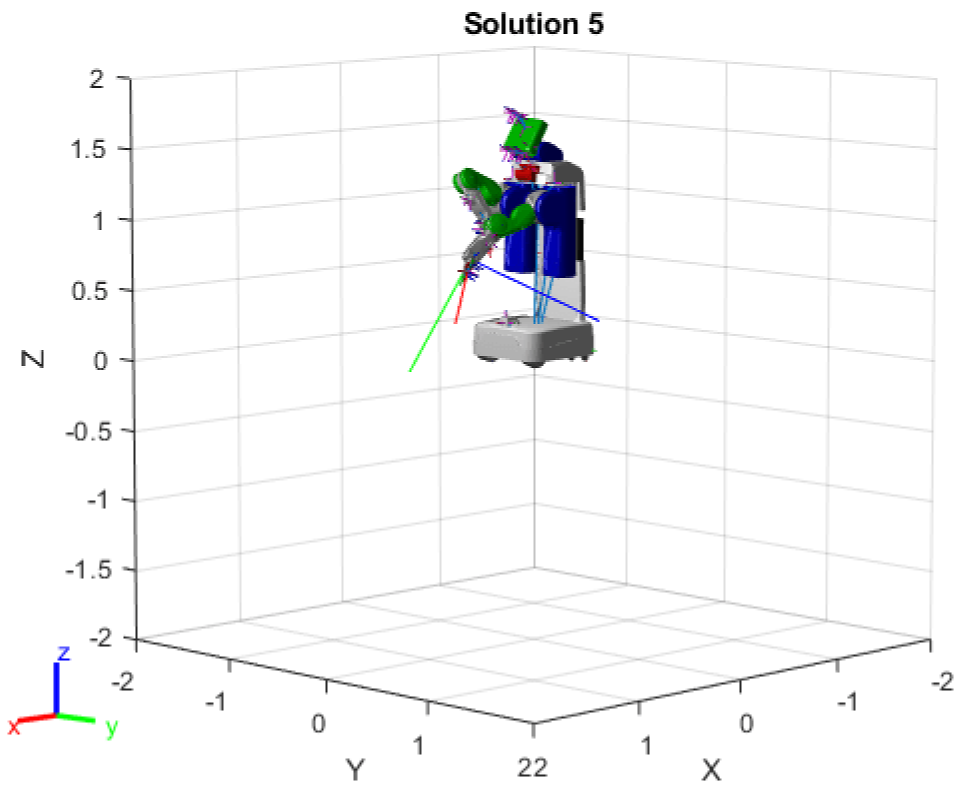
```
eeWorldPose = getTransform(robot,expConfig,eeBodyName);

generatedConfig = repmat(expConfig, size(ikConfig,1), 1);
generatedConfig(:,aik.KinematicGroupConfigIdx) = ikConfig;

for i = 1:size(ikConfig,1)
    figure;
    ax = show(robot,generatedConfig(i,:));
    hold all;
    plotTransforms(tform2trvec(eeWorldPose),tform2quat(eeWorldPose),'Parent',ax);
    title(['Solution ' num2str(i)]);
end
```

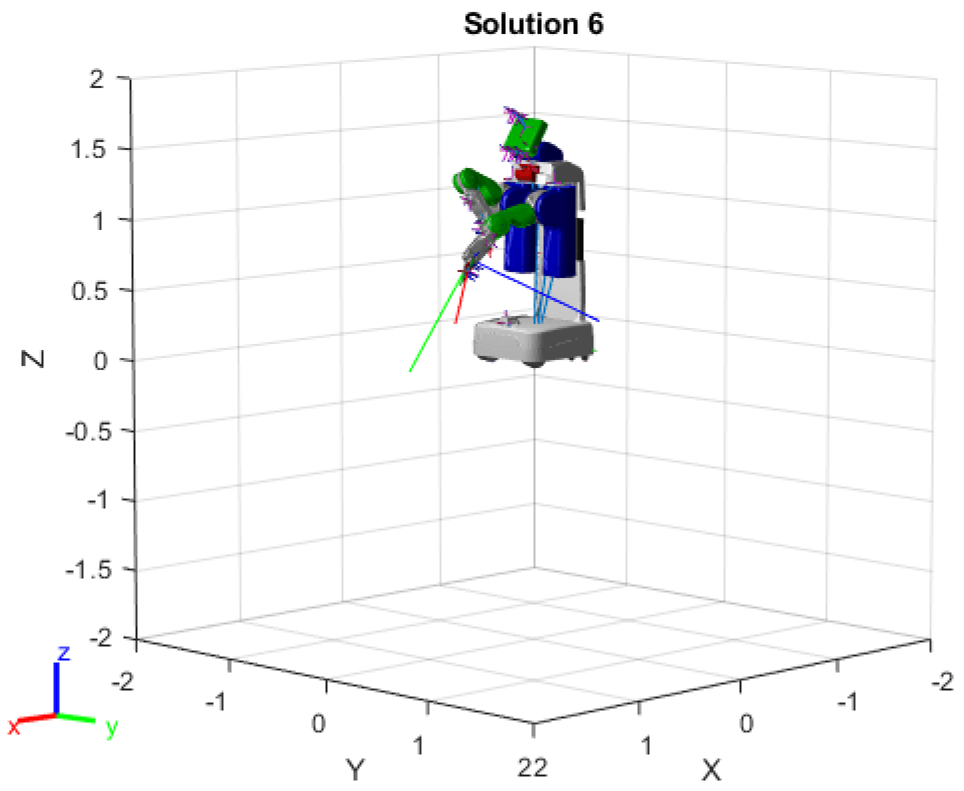

Solution 1
Z
Y
X
z
x
y

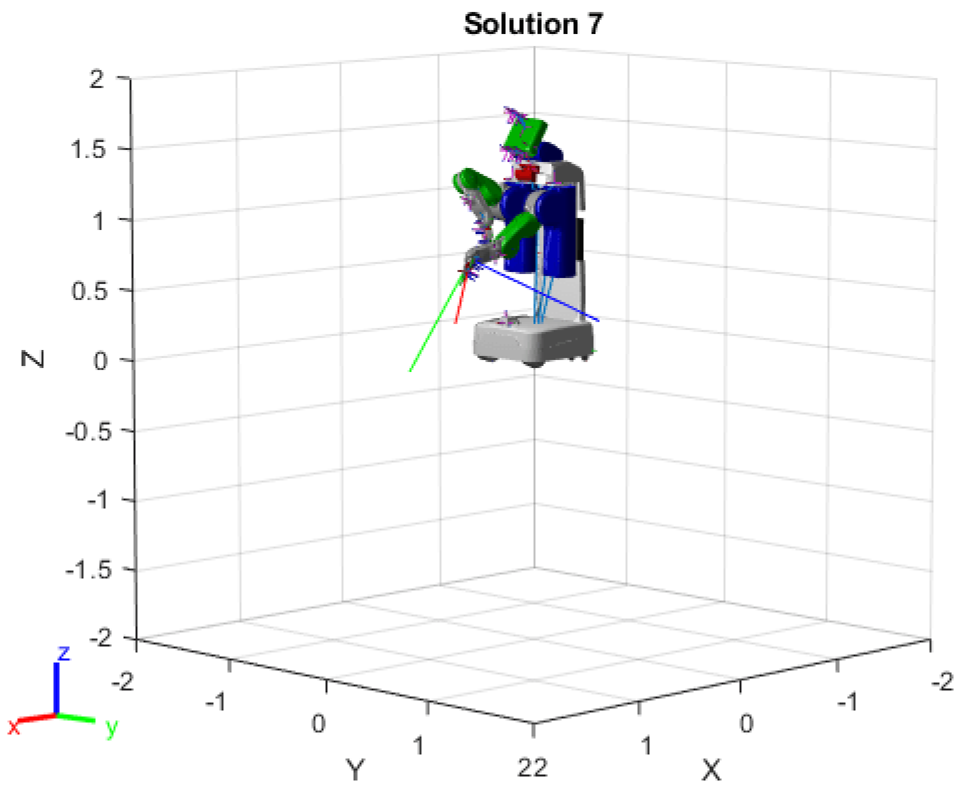

Solution 2
Z
Y
X
x
y
z

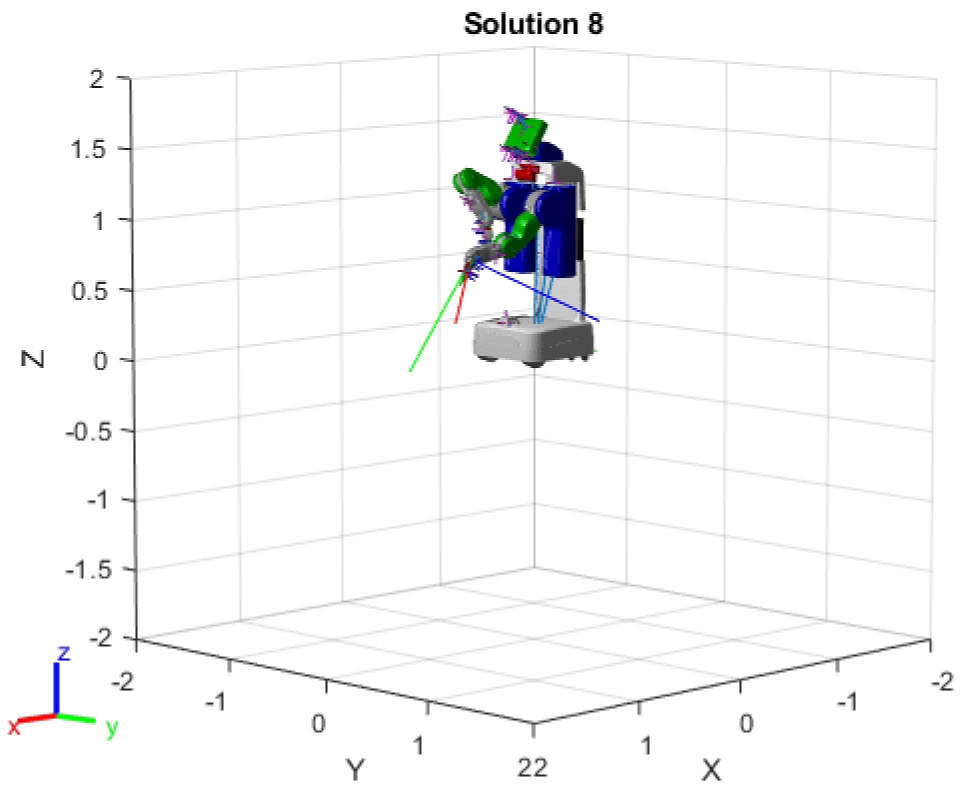

Solution 3
Z
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Y
-2
-1
0
1
22
X
1
0
-1
-2
z
x
y


Solution 4
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
z
x
y


Solution 5
Z
Y
X
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1
0
1
22
1
0
-1
-2
z
x
y


Solution 6
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Z
-2
-1
0
1
2
Y
2
1
0
-1
-2
X
z
x
y


Solution 7
Z
Y
X
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1
0
1
22
1
0
-1
-2
z
x
y



Input Arguments

`analyticalIK` — Analytical IK solver
`analyticalInverseKinematics` object

Analytical inverse kinematics solver, specified as an `analyticalInverseKinematics` object.

Output Arguments

`kinGroupDetails` — Kinematic group classification details
structure

Kinematic group classification details, returned as a structure with these fields:

- `KinematicGroup` — A structure that contains the base and end-effector body names of the kinematic group in the fields `BaseName` and `EndEffectorBodyName`, respectively.
- `Type` — A kinematic group classification type with the same format as that KinematicGroupType property of the `analyticalInverseKinematics` object.
- `IsIntersectionAxesMidpoint` — An *n*-element vector indicating whether each specific joint axis intersects with the preceding or following non-fixed joint. *n* is the number of non-fixed joints in the kinematic group.
- `MidpointAxisIntersections` — A 2-by-3-by-*n* array that stores the joint intersection points where each element of the third dimension corresponds to a single joint .For each channel of *n*,

the first row is the intersection point from the preceding joint to the joint represented by that channel. The second row is the intersection point from the joint to the following joint. The array gives intersection points as `[x y z]` coordinates relative to the base.

See Also

Objects
`analyticalInverseKinematics` | `inverseKinematics` | `generalizedInverseKinematics` | `rigidBodyTree`

Functions
`loadrobot` | `importrobot` | `generateIKFunction`

Introduced in R2020b

checkOccupancy

Check occupancy values for locations

Syntax

```
occVal = checkOccupancy(map,xy)
occVal = checkOccupancy(map,xy,"local")
occVal = checkOccupancy(map,ij,"grid")
[occVal,validPts] = checkOccupancy( ___ )

occMatrix = checkOccupancy(map)
occMatrix = checkOccupancy(map,bottomLeft,matSize)
occMatrix = checkOccupancy(map,bottomLeft,matSize,"local")
occMatrix = checkOccupancy(map,topLeft,matSize,"grid")
```

Description

`occVal = checkOccupancy(map,xy)` returns an array of occupancy values at the `xy` locations in the world frame. Obstacle-free cells return 0, occupied cells return 1. Unknown locations, including outside the map, return `-1`.

`occVal = checkOccupancy(map,xy,"local")` returns an array of occupancy values at the `xy` locations in the local frame. The local frame is based on the `LocalOriginInWorld` property of the `map`.

`occVal = checkOccupancy(map,ij,"grid")` specifies `ij` grid cell indices instead of `xy` locations. Grid indices start at (1,1) from the top left corner.

`[occVal,validPts] = checkOccupancy( ___ )` also outputs an `n`-element vector of logical values indicating whether input coordinates are within the map limits.

`occMatrix = checkOccupancy(map)` returns a matrix that contains the occupancy status of each location. Obstacle-free cells return 0, occupied cells return 1. Unknown locations, including outside the map, return `-1`.

`occMatrix = checkOccupancy(map,bottomLeft,matSize)` returns a matrix of occupancy values by specifying the bottom-left corner location in world coordinates and the matrix size in meters.

`occMatrix = checkOccupancy(map,bottomLeft,matSize,"local")` returns a matrix of occupancy values by specifying the bottom-left corner location in local coordinates and the matrix size in meters.

`occMatrix = checkOccupancy(map,topLeft,matSize,"grid")` returns a matrix of occupancy values by specifying the top-left cell index in grid coordinates and the matrix size.

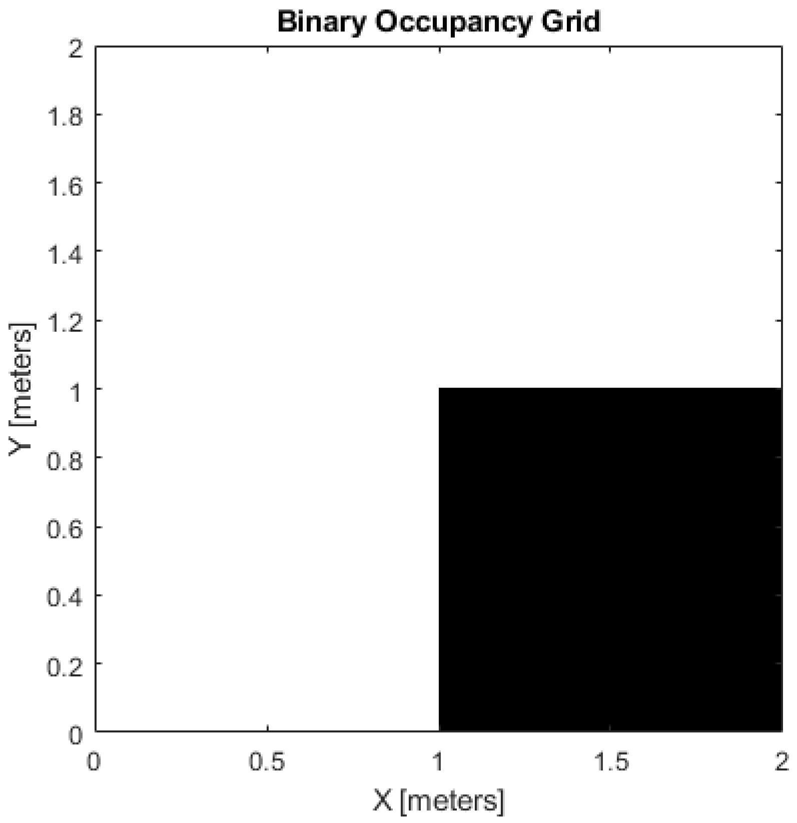
Examples

Get Occupancy Values and Check Occupancy Status

Access occupancy values and check their occupancy status based on the occupied and free thresholds of the `occupancyMap` object.

Create a matrix and populate it with values. Use this matrix to create an occupancy map.

```
p = zeros(20,20);
p(11:20,11:20) = ones(10,10);
map = binaryOccupancyMap(p,10);
show(map)
```



Get the occupancy of different locations and check their occupancy statuses. The occupancy status returns 0 for free space and 1 for occupied space. Unknown values return –1.

```
pocc = getOccupancy(map,[1.5 1]);
occupied = checkOccupancy(map,[1.5 1]);
pocc2 = getOccupancy(map,[5 5],'grid');
```

Input Arguments

map — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object.

`xy` — Coordinates in the map
n-by-2 matrix

Coordinates in the map, specified as an *n*-by-2 matrix of `[x y]` pairs, where *n* is the number of coordinates. Coordinates can be world or local coordinates depending on the syntax.

Data Types: `double`

`ij` — Grid locations in the map
n-by-2 matrix

Grid locations in the map, specified as an *n*-by-2 matrix of `[i j]` pairs, where *n* is the number of locations. Grid locations are given as `[row col]`.

Data Types: `double`

`bottomLeft` — Location of output matrix in world or local
two-element vector | `[xCoord yCoord]`

Location of bottom left corner of output matrix in world or local coordinates, specified as a two-element vector, `[xCoord yCoord]`. Location is in world or local coordinates based on syntax.

Data Types: `double`

`matSize` — Output matrix size
two-element vector | `[xLength yLength]` | `[gridRow gridCol]`

Output matrix size, specified as a two-element vector, `[xLength yLength]`, or `[gridRow gridCol]`. Size is in world, local, or grid coordinates based on syntax.

Data Types: `double`

`topLeft` — Location of grid
two-element vector | `[iCoord jCoord]`

Location of top left corner of grid, specified as a two-element vector, `[iCoord jCoord]`.

Data Types: `double`

Output Arguments

`occVal` — Occupancy values
n-by-1 column vector

Occupancy values, returned as an *n*-by-1 column vector equal in length to `xy` or `ij` input. Occupancy values can be obstacle free (0), occupied (1), or unknown (-1).

`validPts` — Valid map locations
n-by-1 column vector

Valid map locations, returned as an *n*-by-1 column vector equal in length to `xy` or `ij`. Locations inside the map return a value of 1. Locations outside the map limits return a value of 0.

`occMatrix` — Matrix of occupancy values
matrix

Matrix of occupancy values, returned as matrix with size equal to `matSize` or the size of your `map`. Occupancy values can be obstacle free (0), occupied (1), or unknown (-1).

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `getOccupancy` | `occupancyMap`

Introduced in R2019b

getOccupancy

Get occupancy value of locations

Syntax

```
occVal = getOccupancy(map,xy)
occVal = getOccupancy(map,xy,"local")
occVal = getOccupancy(map,ij,"grid")
[occVal,validPts] = getOccupancy( ___ )

occMatrix = getOccupancy(map)
occMatrix = getOccupancy(map,bottomLeft,matSize)
occMatrix = getOccupancy(map,bottomLeft,matSize,"local")
occMatrix = getOccupancy(map,topLeft,matSize,"grid")
```

Description

`occVal = getOccupancy(map,xy)` returns an array of occupancy values at the `xy` locations in the world frame. Unknown locations, including outside the map, return `map.DefaultValue`.

`occVal = getOccupancy(map,xy,"local")` returns an array of occupancy values at the `xy` locations in the local frame.

`occVal = getOccupancy(map,ij,"grid")` specifies `ij` grid cell indices instead of `xy` locations.

`[occVal,validPts] = getOccupancy( ___ )` additionally outputs an `n`-element vector of logical values indicating whether input coordinates are within the map limits.

`occMatrix = getOccupancy(map)` returns all occupancy values in the map as a matrix.

`occMatrix = getOccupancy(map,bottomLeft,matSize)` returns a matrix of occupancy values by specifying the bottom-left corner location in world coordinates and the matrix size in meters.

`occMatrix = getOccupancy(map,bottomLeft,matSize,"local")` returns a matrix of occupancy values by specifying the bottom-left corner location in local coordinates and the matrix size in meters.

`occMatrix = getOccupancy(map,topLeft,matSize,"grid")` returns a matrix of occupancy values by specifying the top-left cell index in grid indices and the matrix size.

Examples

Insert Laser Scans into Binary Occupancy Map

Create an empty binary occupancy grid map.

```
map = binaryOccupancyMap(10,10,20);
```

Input pose of the vehicle, ranges, angles, and the maximum range of the laser scan.

```
pose = [5,5,0];
ranges = 3*ones(100,1);
angles = linspace(-pi/2,pi/2,100);
maxrange = 20;
```

Create a `lidarScan` object with the specified ranges and angles.

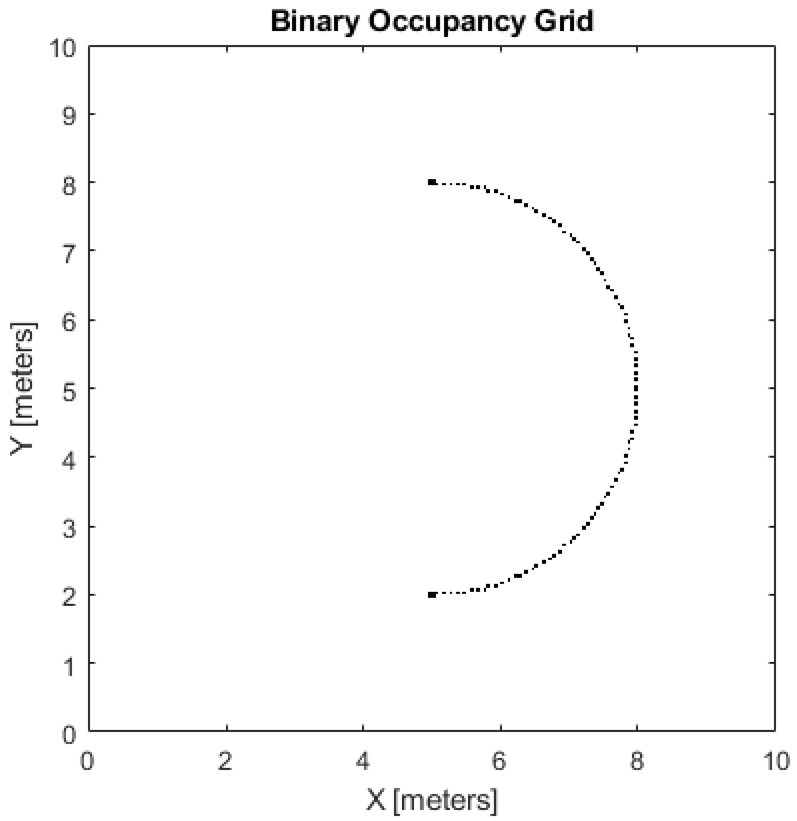
```
scan = lidarScan(ranges,angles);
```

Insert the laser scan data into the occupancy map.

```
insertRay(map,pose,scan,maxrange);
```

Show the map to see the results of inserting the laser scan.

```
show(map)
```



Check the occupancy of the spot directly in front of the vehicle.

```
getOccupancy(map,[8 5])
```

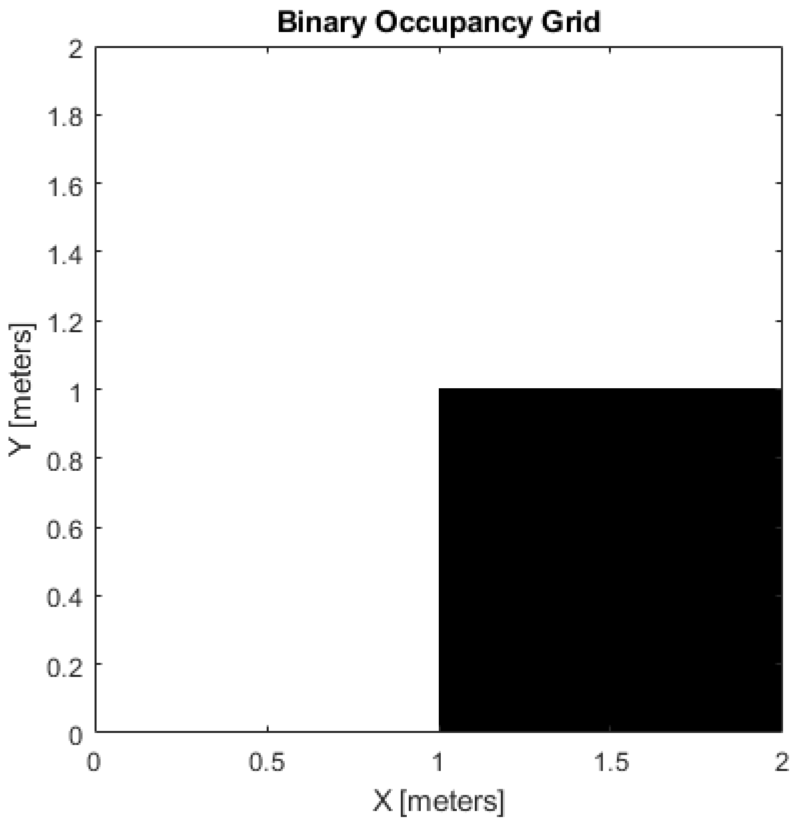
```
ans = logical
   1
```

Get Occupancy Values and Check Occupancy Status

Access occupancy values and check their occupancy status based on the occupied and free thresholds of the `occupancyMap` object.

Create a matrix and populate it with values. Use this matrix to create an occupancy map.

```
p = zeros(20,20);
p(11:20,11:20) = ones(10,10);
map = binaryOccupancyMap(p,10);
show(map)
```



Get the occupancy of different locations and check their occupancy statuses. The occupancy status returns 0 for free space and 1 for occupied space. Unknown values return –1.

```
pocc = getOccupancy(map,[1.5 1]);
occupied = checkOccupancy(map,[1.5 1]);
pocc2 = getOccupancy(map,[5 5],'grid');
```

Input Arguments

map — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the vehicle.

xy — Coordinates in the map
n-by-2 matrix

Coordinates in the map, specified as an *n*-by-2 matrix of `[x y]` pairs, where *n* is the number of coordinates. Coordinates can be world or local coordinates depending on the syntax.

Data Types: `double`

ij — Grid locations in the map
n-by-2 matrix

Grid locations in the map, specified as an *n*-by-2 matrix of `[i j]` pairs, where *n* is the number of locations. Grid locations are given as `[row col]`.

Data Types: `double`

bottomLeft — Location of output matrix in world or local
two-element vector | `[xCoord yCoord]`

Location of bottom left corner of output matrix in world or local coordinates, specified as a two-element vector, `[xCoord yCoord]`. Location is in world or local coordinates based on syntax.

Data Types: `double`

matSize — Output matrix size
two-element vector | `[xLength yLength]` | `[gridRow gridCol]`

Output matrix size, specified as a two-element vector, `[xLength yLength]` or `[gridRow gridCol]`. The size is in world coordinates, local coordinates, or grid indices based on syntax.

Data Types: `double`

topLeft — Location of grid
two-element vector | `[iCoord jCoord]`

Location of top left corner of grid, specified as a two-element vector, `[iCoord jCoord]`.

Data Types: `double`

Output Arguments

occVal — Occupancy values
n-by-1 column vector

Occupancy values, returned as an *n*-by-1 column vector equal in length to `xy` or `ij`. Occupancy values can be obstacle free (0) or occupied (1).

validPts — Valid map locations
n-by-1 column vector

Valid map locations, returned as an *n*-by-1 column vector equal in length to `xy` or `ij`. Locations inside the map return a value of 1. Locations outside the map limits return a value of 0.

occMatrix — Matrix of occupancy values
matrix

Matrix of occupancy values, returned as matrix with size equal to `matSize` or the size of `map`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `setOccupancy`

Topics
“Occupancy Grids”

Introduced in R2015a

grid2local

Convert grid indices to local coordinates

Syntax

```
xy = grid2local(map,ij)
```

Description

`xy = grid2local(map,ij)` converts a `[row col]` array of grid indices, `ij`, to an array of local coordinates, `xy`.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

`ij` — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 vertical array of `[i j]` pairs in `[rows cols]` format, where *n* is the number of grid positions.

Output Arguments

`xy` — Local coordinates
n-by-2 vertical array

Local coordinates, specified as an *n*-by-2 vertical array of `[x y]` pairs, where *n* is the number of local coordinates.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `world2grid`

Introduced in R2019b

grid2world

Convert grid indices to world coordinates

Syntax

```
xy = grid2world(map,ij)
```

Description

`xy = grid2world(map,ij)` converts a `[row col]` array of grid indices, `ij`, to an array of world coordinates, `xy`.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

`ij` — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 vertical array of `[i j]` pairs in `[rows cols]` format, where *n* is the number of grid positions.

Output Arguments

`xy` — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of `[x y]` pairs, where *n* is the number of world coordinates.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`binaryOccupancyMap` | `world2grid` | `grid2local`

Introduced in R2015a

inflate

Inflate each occupied grid location

Syntax

```
inflate(map,radius)
inflate(map,gridradius,'grid')
```

Description

`inflate(map,radius)` inflates each occupied position of the `map` by the radius given in meters. `radius` is rounded up to the nearest cell equivalent based on the resolution of the map. Every cell within the radius is set to `true` (`1`).

`inflate(map,gridradius,'grid')` inflates each occupied position by the radius given in number of cells.

Examples

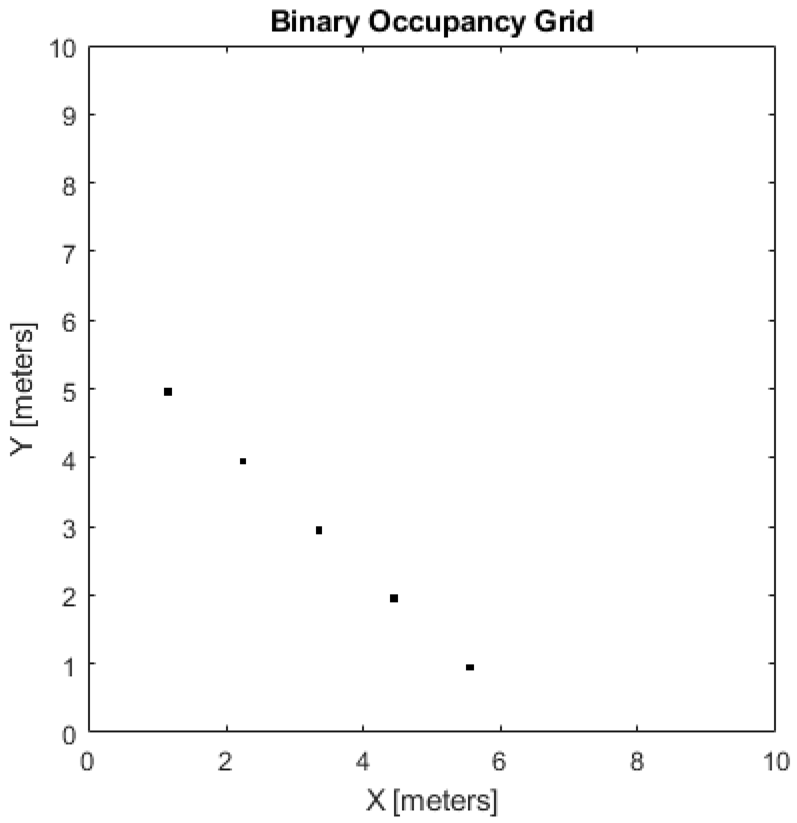
Create and Modify Binary Occupancy Grid

Create a 10m x 10m empty map.

```
map = binaryOccupancyMap(10,10,10);
```

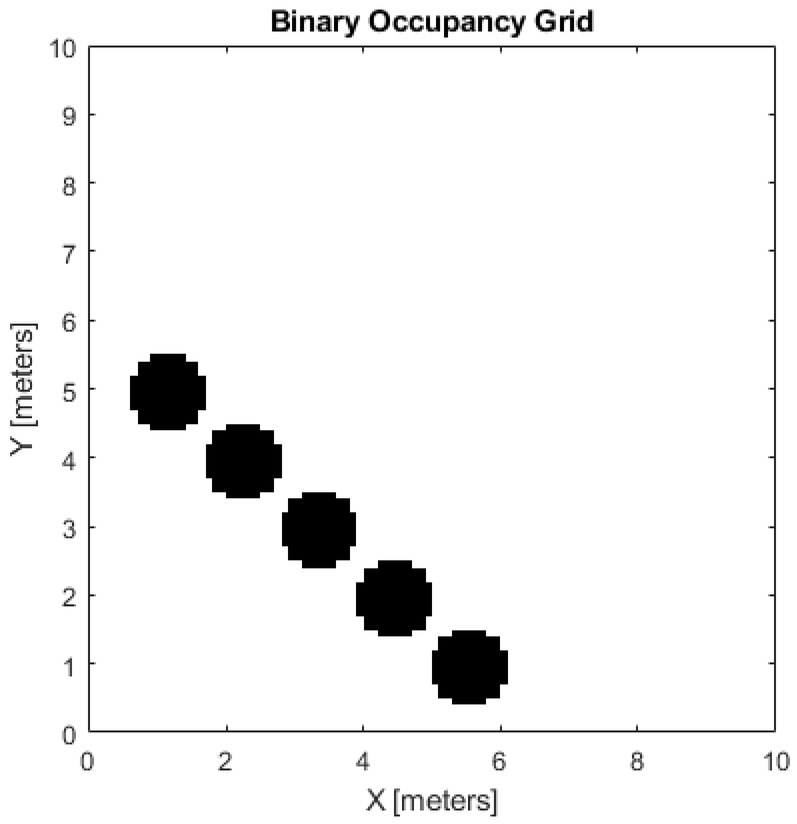
Set occupancy of world locations and show map.

```
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

setOccupancy(map, [x y], ones(5,1))
figure
show(map)
```



Inflate occupied locations by a given radius.

```
inflate(map, 0.5)
figure
show(map)
```

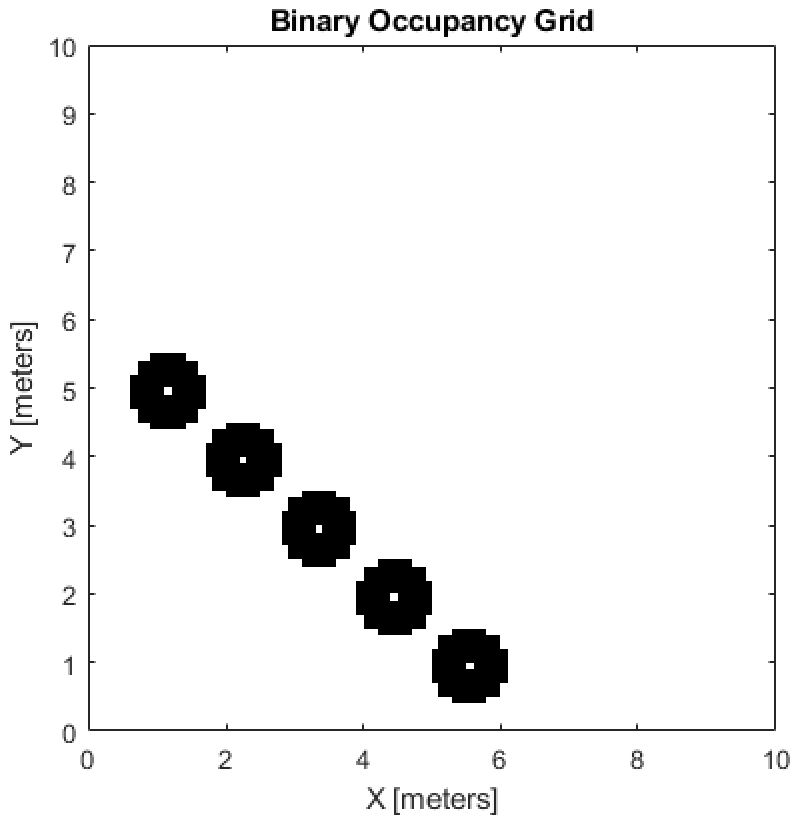


Get grid locations from world locations.

```
ij = world2grid(map, [x y]);
```

Set grid locations to free locations.

```
setOccupancy(map, ij, zeros(5,1), 'grid')
figure
show(map)
```



Input Arguments

map — Map representation
binaryOccupancyMap object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

radius — Dimension the defines how much to inflate occupied locations
scalar

Dimension that defines how much to inflate occupied locations, specified as a scalar. `radius` is rounded up to the nearest cell value.

Data Types: `double`

gridradius — Dimension the defines how much to inflate occupied locations
positive scalar

Dimension that defines how much to inflate occupied locations, specified as a positive scalar. `gridradius` is the number of cells to inflate the occupied locations.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `setOccupancy`

Topics
“Occupancy Grids”

Introduced in R2015a

insertRay

Insert ray from laser scan observation

Syntax

```
insertRay(map,pose,scan,maxrange)
insertRay(map,pose,ranges,angles,maxrange)
insertRay(map,startpt,endpoints)
```

Description

`insertRay(map,pose,scan,maxrange)` inserts one or more lidar scan sensor observations in the occupancy grid, `map`, using the input `lidarScan` object, `scan`, to get ray endpoints. End point locations are updated with an occupied value. If the ranges are above `maxrange`, the ray endpoints are considered free space. All other points along the ray are treated as obstacle-free.

`insertRay(map,pose,ranges,angles,maxrange)` specifies the range readings as vectors defined by the input `ranges` and `angles`.

`insertRay(map,startpt,endpoints)` inserts observations between the line segments from the start point to the end points. The endpoints are updated are occupied space and other points along the line segments are updated as free space.

Examples

Insert Laser Scans into Binary Occupancy Map

Create an empty binary occupancy grid map.

```
map = binaryOccupancyMap(10,10,20);
```

Input pose of the vehicle, ranges, angles, and the maximum range of the laser scan.

```
pose = [5,5,0];
ranges = 3*ones(100,1);
angles = linspace(-pi/2,pi/2,100);
maxrange = 20;
```

Create a `lidarScan` object with the specified ranges and angles.

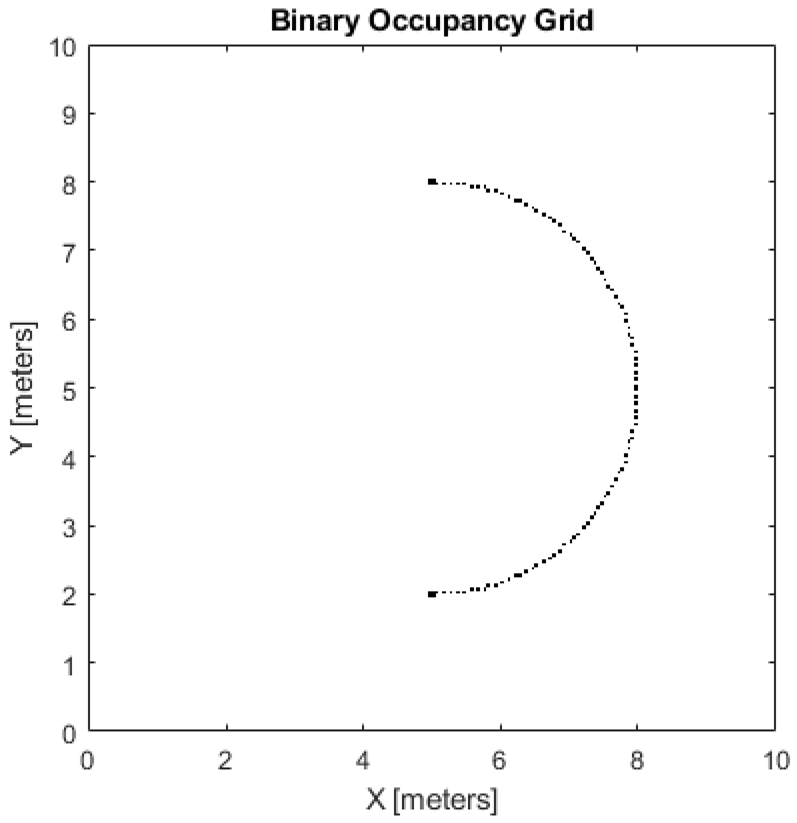
```
scan = lidarScan(ranges,angles);
```

Insert the laser scan data into the occupancy map.

```
insertRay(map,pose,scan,maxrange);
```

Show the map to see the results of inserting the laser scan.

```
show(map)
```



Check the occupancy of the spot directly in front of the vehicle.

```
getOccupancy(map,[8 5])
```

```
ans = logical
   1
```

Input Arguments

map — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (1) and free locations as `false` (0).

pose — Position and orientation of vehicle
three-element vector

Position and orientation of vehicle, specified as an `[x y theta]` vector. The vehicle pose is an *x* and *y* position with angular orientation *theta* (in radians) measured from the *x*-axis.

scan — Lidar scan readings
`lidarScan` object

Lidar scan readings, specified as a `lidarScan` object.

`ranges` — Range values from scan data
vector

Range values from scan data, specified as a vector of elements measured in meters. These range values are distances from a sensor at given `angles`. The vector must be the same length as the corresponding `angles` vector.

`angles` — Angle values from scan data
vector

Angle values from scan data, specified as a vector of elements measured in radians. These angle values correspond to the given `ranges`. The vector must be the same length as the corresponding `ranges` vector.

`maxrange` — Maximum range of sensor
scalar

Maximum range of laser range sensor, specified as a scalar in meters. Range values greater than or equal to `maxrange` are considered free along the whole length of the ray, up to `maxrange`.

`startpt` — Start point for rays
two-element vector

Start point for rays, specified as a two-element vector, `[x y]`, in the world coordinate frame. All rays are line segments that originate at this point.

`endpoints` — Endpoints for rays
n-by-2 matrix

Endpoints for rays, specified as an *n*-by-2 matrix of `[x y]` pairs in the world coordinate frame, where *n* is the length of `ranges` or `angles`. All rays are line segments that originate at `startpt`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`occupancyMap` | `binaryOccupancyMap` | `lidarScan` | `lidarScan`

Topics
"Occupancy Grids"

Introduced in R2019b

local2grid

Convert local coordinates to grid indices

Syntax

```
ij = local2grid(map,xy)
```

Description

`ij = local2grid(map,xy)` converts an array of local coordinates, `xy`, to an array of grid indices, `ij` in `[`*`row col`*`]` format.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the vehicle.

`xy` — Local coordinates
n-by-2 matrix

Local coordinates, specified as an *n*-by-2 matrix of `[`*`x y`*`]` pairs, where *n* is the number of local coordinates.

Data Types: `double`

Output Arguments

`ij` — Grid positions
n-by-2 matrix

Grid positions, returned as an *n*-by-2 matrix of `[`*`i j`*`]` pairs in `[`*`row col`*`]` format, where *n* is the number of grid positions. The grid cell locations are counted from the top left corner of the grid.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `occupancyMap` | `grid2local` | `grid2local`

Topics
"Occupancy Grids"

Introduced in R2019b

local2world

Convert local coordinates to world coordinates

Syntax

`xyWorld = local2world(map,xy)`

Description

`xyWorld = local2world(map,xy)` converts an array of local coordinates to world coordinates.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the vehicle.

xy — Local coordinates
n-by-2 matrix

Local coordinates, specified as an *n*-by-2 matrix of `[x y]` pairs, where *n* is the number of local coordinates.

Data Types: `double`

Output Arguments

`xyWorld` — World coordinates
n-by-2 matrix

World coordinates, specified as an *n*-by-2 matrix of `[x y]` pairs, where *n* is the number of world coordinates.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `grid2world` | `world2local` | `occupancyMap`

Topics
"Occupancy Grids"

Introduced in R2019b

move

Move map in world frame

Syntax

```
move(map,moveValue)
move(map,moveValue,Name,Value)
```

Description

`move(map,moveValue)` moves the local origin of the map to an absolute location, `moveValue`, in the world frame, and updates the map limits. Move values are truncated based on the resolution of the map. By default, newly revealed regions are set to `map.DefaultValue`.

`move(map,moveValue,Name,Value)` specifies additional options specified by one or more name-value pair arguments.

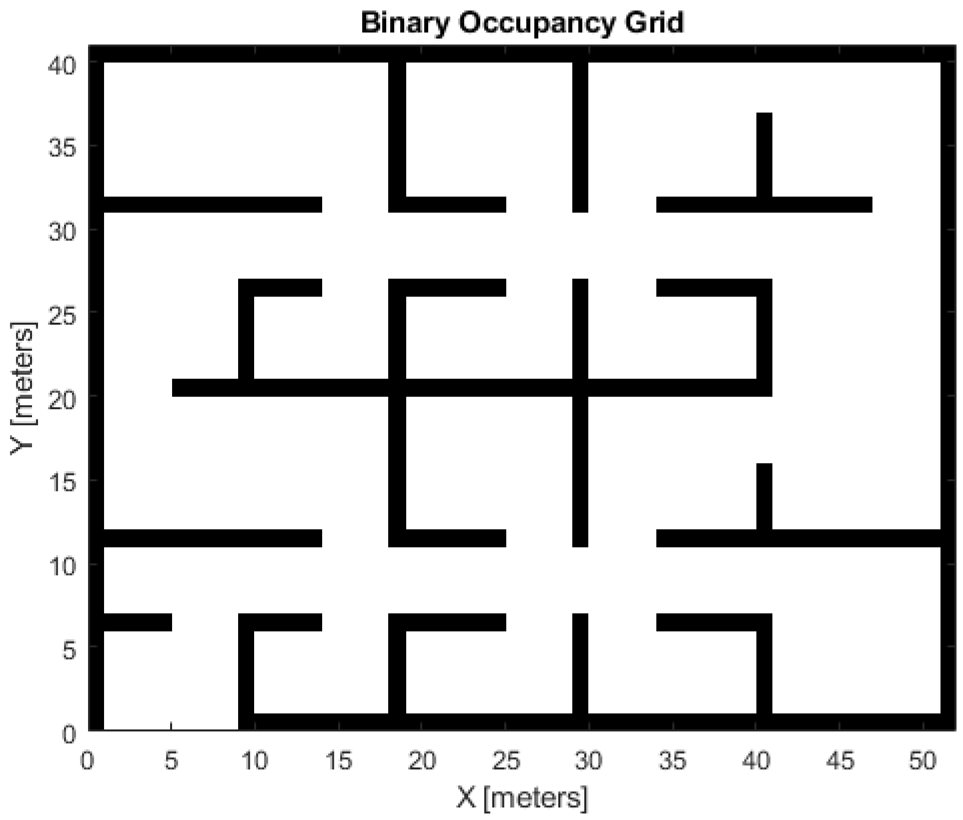
Examples

Move Local Map and Sync with World Map

This example shows how to move a local egocentric map and sync it with a larger world map. This process emulates a vehicle driving in an environment and getting updates on obstacles in the new areas.

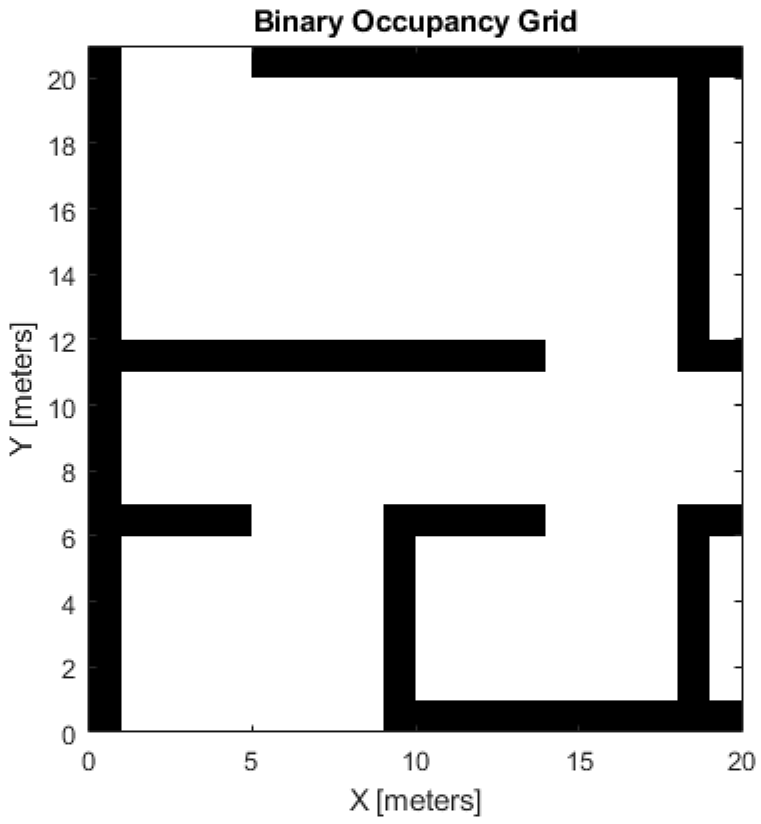
Load example maps. Create a binary occupancy map from the `complexMap`.

```
load exampleMaps.mat
map = binaryOccupancyMap(complexMap);
show(map)
```



Create a smaller local map.

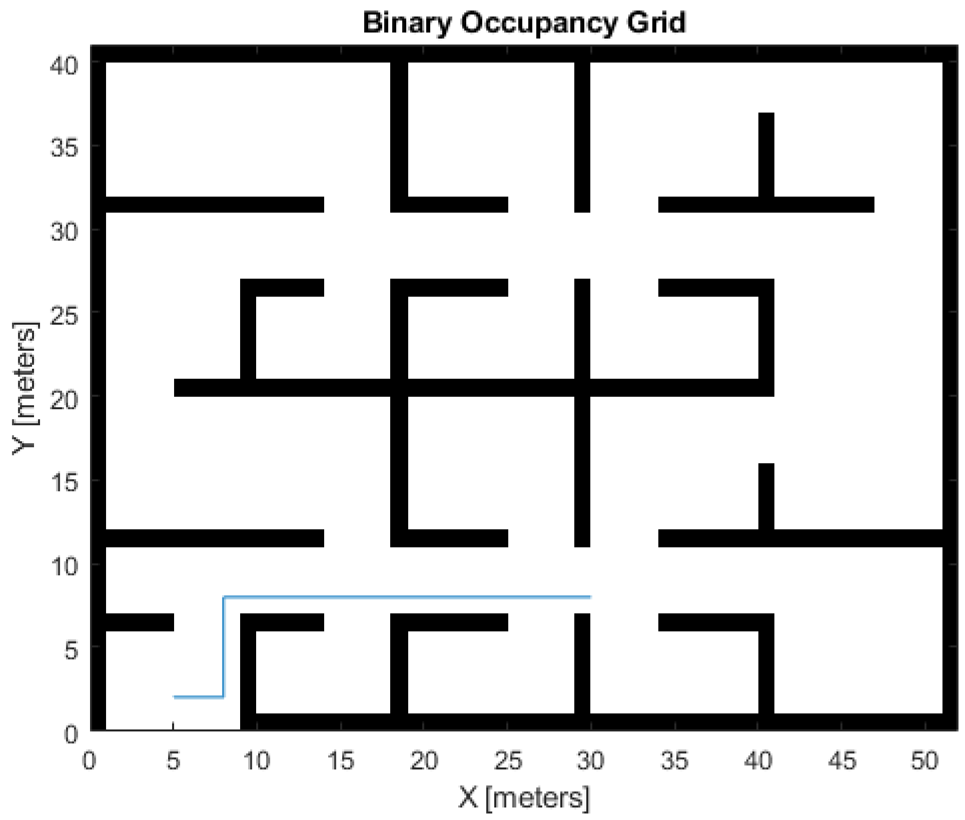
```
mapLocal = binaryOccupancyMap(complexMap(end-20:end,1:20));
show(mapLocal)
```



Follow a path planned in the world map and update the local map as you move your local frame.

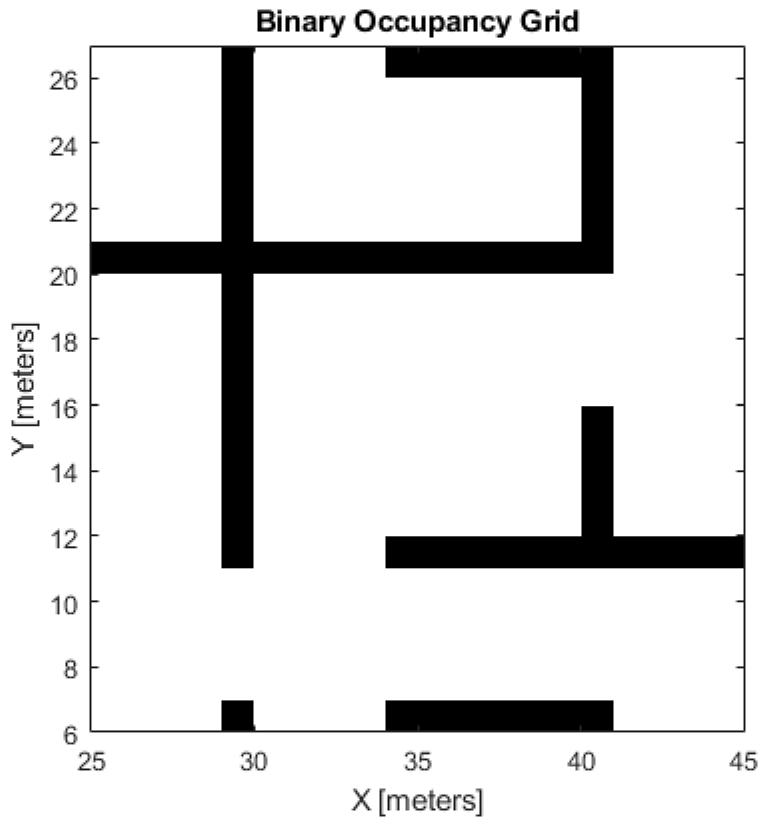
Specify path locations and plot on the map.

```
path = [5 2
        8 2
        8 8
        30 8];
show(map)
hold on
plot(path(:,1),path(:,2))
hold off
```



Create a loop for moving between points by the map resolution. Divide the difference between points by the map resolution to see how many incremental moves you can make.

```
for i = 1:length(path)-1
    moveAmount = (path(i+1,:)-path(i,:))/map.Resolution;
    for j = 1:abs(moveAmount(1)+moveAmount(2))
        moveValue = sign(moveAmount).*map.Resolution;
        move(mapLocal,moveValue, ...
            "MoveType","relative","SyncWith",map)

        show(mapLocal)
        drawnow limitrate
        pause(0.2)
    end
end
```



Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the vehicle.

`moveValue` — Local map origin move value
`[x y]` vector

Local map origin move value, specified as an `[x y]` vector. By default, the value is an absolute location to move the local origin to in the world frame. Use the `MoveType` name-value pair to specify a relative move.

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: `'MoveType','relative'`

`MoveType` — Type of move
`'absolute'` (default) | `'relative'`

Type of move, specified as `'absolute'` or `'relative'`. For relative moves, specify a relative `[x y]` vector for `moveValue` based on your current local frame.

`FillValue` — Fill value for revealed locations
`0` (default) | `1`

Fill value for revealed locations because of the shifted map limits, specified as `0` or `1`.

`SyncWith` — Secondary map to sync with
`binaryOccupancyMap` object

Secondary map to sync with, specified as a `binaryOccupancyMap` object. Any revealed locations based on the move are updated with values in this map using the world coordinates.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `occupancyMap` | `occupancyMatrix`

Introduced in R2019b

occupancyMatrix

Convert occupancy grid to matrix

Syntax

```
mat = occupancyMatrix(map)
```

Description

`mat = occupancyMatrix(map)` returns occupancy values stored in the occupancy grid object as a matrix.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

Output Arguments

`mat` — Occupancy values
matrix

Occupancy values, returned as an *h*-by-*w* matrix, where *h* and *w* are defined by the two elements of the `GridSize` property of the occupancy grid object.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `occupancyMap`

Topics
"Occupancy Grids"

Introduced in R2016b

raycast

Compute cell indices along a ray

Syntax

```
[endpoints,midpoints] = raycast(map,pose,range,angle)
[endpoints,midpoints] = raycast(map,p1,p2)
```

Description

`[endpoints,midpoints] = raycast(map,pose,range,angle)` returns cell indices of the specified `map` for all cells traversed by a ray originating from the specified `pose` at the specified `angle` and `range` values. `endpoints` contains all indices touched by the end of the ray, with all other points included in `midpoints`.

`[endpoints,midpoints] = raycast(map,p1,p2)` returns the cell indices of the line segment between the two specified points.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

`pose` — Position and orientation of sensor
three-element vector

Position and orientation of sensor, specified as an `[x y theta]` vector. The sensor pose is an *x* and *y* position with angular orientation *theta* (in radians) measured from the *x*-axis.

`range` — Range of ray
scalar

Range of ray, specified as a scalar in meters.

`angle` — Angle of ray
scalar

Angle of ray, specified as a scalar in radians. The angle value is for the corresponding `range`.

`p1` — Starting point of ray
two-element vector

Starting point of ray, specified as an `[x y]` two-element vector. Points are defined with respect to the world-frame.

`p2` — Endpoint of ray
two-element vector

Endpoint of ray, specified as an `[x y]` two-element vector. Points are defined with respect to the world-frame.

Output Arguments

`endpoints` — Endpoint grid indices
n-by-2 matrix

Endpoint indices, returned as an *n*-by-2 matrix of `[i j]` pairs, where *n* is the number of grid indices. The endpoints are where the `range` value hits at the specified `angle`. Multiple indices are returned when the endpoint lies on the boundary of multiple cells.

`midpoints` — Midpoint grid indices
n-by-2 matrix

Midpoint indices, returned as an *n*-by-2 matrix of `[i j]` pairs, where *n* is the number of grid indices. This argument includes all grid indices the ray intersects, excluding the endpoint.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `insertRay` | `occupancyMap`

Introduced in R2019b

rayIntersection

Find intersection points of rays and occupied map cells

Syntax

```
intersectionPts = rayIntersection(map,pose,angles,maxrange)
```

Description

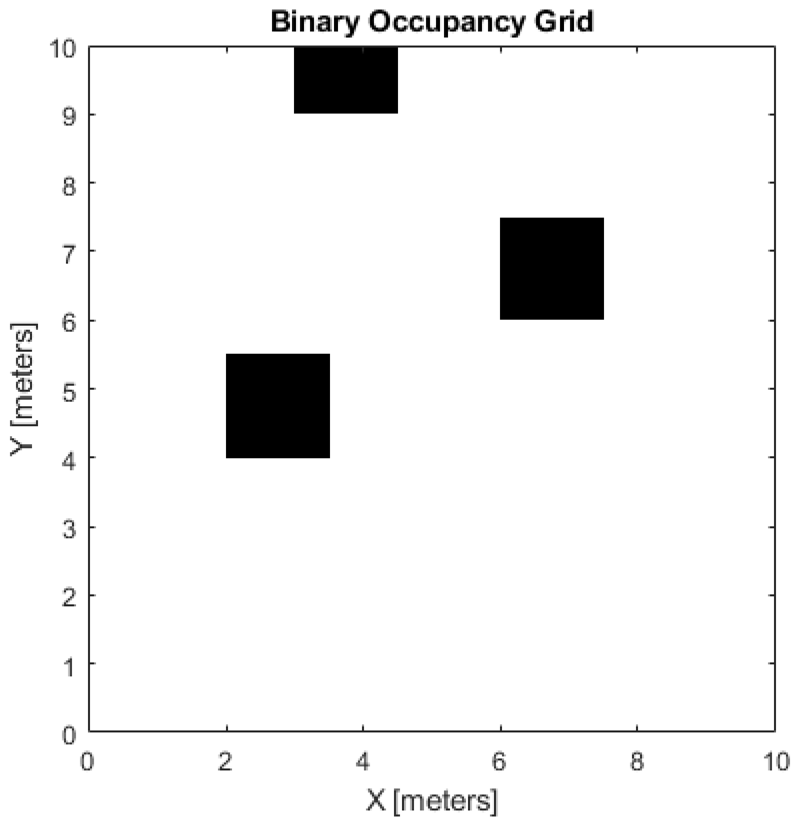
`intersectionPts = rayIntersection(map,pose,angles,maxrange)` returns intersection points of rays and occupied cells in the specified `map`. Rays emanate from the specified `pose` and `angles`. Intersection points are returned in the world coordinate frame. If there is no intersection up to the specified `maxrange`, `[NaN NaN]` is returned.

Examples

Get Ray Intersection Points on Occupancy Map

Create a binary occupancy grid map. Add obstacles and inflate them. A lower resolution map is used to illustrate the importance of the size of your grid cells. Show the map.

```
map = binaryOccupancyMap(10,10,2);
obstacles = [4 10; 3 5; 7 7];
setOccupancy(map,obstacles,ones(length(obstacles),1))
inflate(map,0.25)
show(map)
```



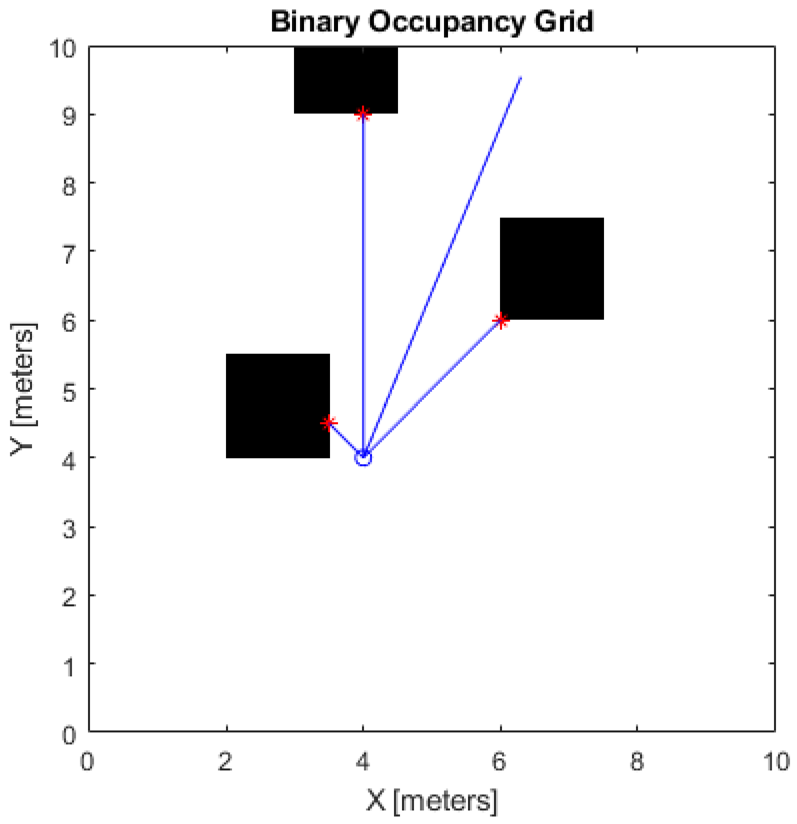
Find the intersection points of occupied cells and rays that emit from the given vehicle pose. Specify the max range and angles for these rays. The last ray does not intersect with an obstacle within the max range, so it has no collision point.

```
maxrange = 6;
angles = [pi/4,-pi/4,0,-pi/8];
vehiclePose = [4,4,pi/2];
intsectionPts = rayIntersection(map,vehiclePose,angles,maxrange)
```

```
intsectionPts = 4×2

    3.5000    4.5000
    6.0000    6.0000
    4.0000    9.0000
       NaN       NaN
```

Plot the intersection points and rays from the pose.

```
hold on
plot(intsectionPts(:,1),intsectionPts(:,2),'*r') % Intersection points
plot(vehiclePose(1),vehiclePose(2),'ob') % Vehicle pose
for i = 1:3
    plot([vehiclePose(1),intsectionPts(i,1)],...
        [vehiclePose(2),intsectionPts(i,2)],'-b') % Plot intersecting rays
end
plot([vehiclePose(1),vehiclePose(1)-6*sin(angles(4))],...
    [vehiclePose(2),vehiclePose(2)+6*cos(angles(4))],'-b') % No intersection ray
```



Input Arguments

map — Map representation
binaryOccupancyMap object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

pose — Position and orientation of sensor
three-element vector

Position and orientation of the sensor, specified as an `[x y theta]` vector. The sensor pose is an *x* and *y* position with angular orientation *theta* (in radians) measured from the *x*-axis.

angles — Ray angles emanating from sensor
vector

Ray angles emanating from the sensor, specified as a vector with elements in radians. These angles are relative to the specified sensor `pose`.

maxrange — Maximum range of sensor
scalar

Maximum range of laser range sensor, specified as a scalar in meters. Range values greater than or equal to `maxrange` are considered free along the whole length of the ray, up to `maxrange`.

Output Arguments

`intersectionPts` — Intersection points
n-by-2 matrix

Intersection points, returned as *n*-by-2 matrix of `[x y]` pairs in the world coordinate frame, where *n* is the length of `angles`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`binaryOccupancyMap` | `occupancyMap`

Topics
"Occupancy Grids"
"Occupancy Grids"

Introduced in R2019b

setOccupancy

Set occupancy value of locations

Syntax

```
setOccupancy(map,xy,occval)
setOccupancy(map,xy,occval,"local")
setOccupancy(map,ij,occval,"grid")
validPts = setOccupancy( ___ )
```

```
setOccupancy(map,bottomLeft,inputMatrix)
setOccupancy(map,bottomLeft,inputMatrix,"local")
setOccupancy(map,topLeft,inputMatrix,"grid")
```

Description

`setOccupancy(map,xy,occval)` assigns occupancy values, `occval`, to the input array of world coordinates, `xy` in the occupancy grid, `map`. Each row of the array, `xy`, is a point in the world and is represented as an `[x y]` coordinate pair. `occval` is either a scalar or a single column array of the same length as `xy` . An occupied location is represented as `true` (`1`), and a free location is represented as `false` (`0`).

`setOccupancy(map,xy,occval,"local")` assigns occupancy values, `occval`, to the input array of local coordinates, `xy`, as local coordinates.

`setOccupancy(map,ij,occval,"grid")` assigns occupancy values, `occval`, to the input array of grid indices, `ij`, as `[rows cols]`.

`validPts = setOccupancy( ___ )` outputs an `n`-element vector of logical values indicating whether input coordinates are within the map limits.

`setOccupancy(map,bottomLeft,inputMatrix)` assigns a matrix of occupancy values by specifying the bottom-left corner location in world coordinates.

`setOccupancy(map,bottomLeft,inputMatrix,"local")` assigns a matrix of occupancy values by specifying the bottom-left corner location in local coordinates.

`setOccupancy(map,topLeft,inputMatrix,"grid")` assigns a matrix of occupancy values by specifying the top-left cell index in grid indices and the matrix size.

Examples

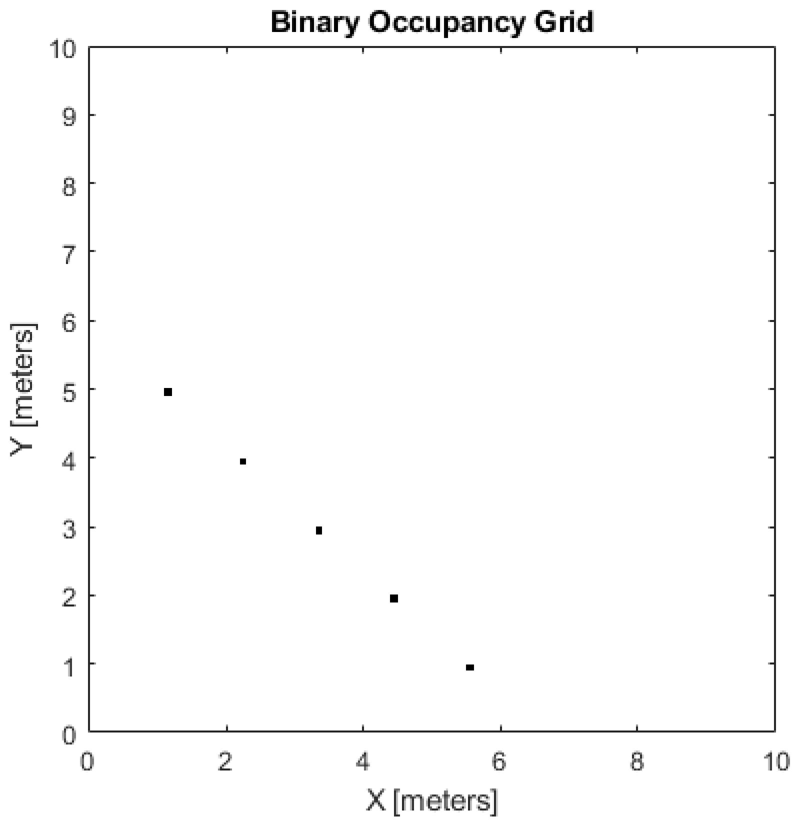
Create and Modify Binary Occupancy Grid

Create a 10m x 10m empty map.

```
map = binaryOccupancyMap(10,10,10);
```

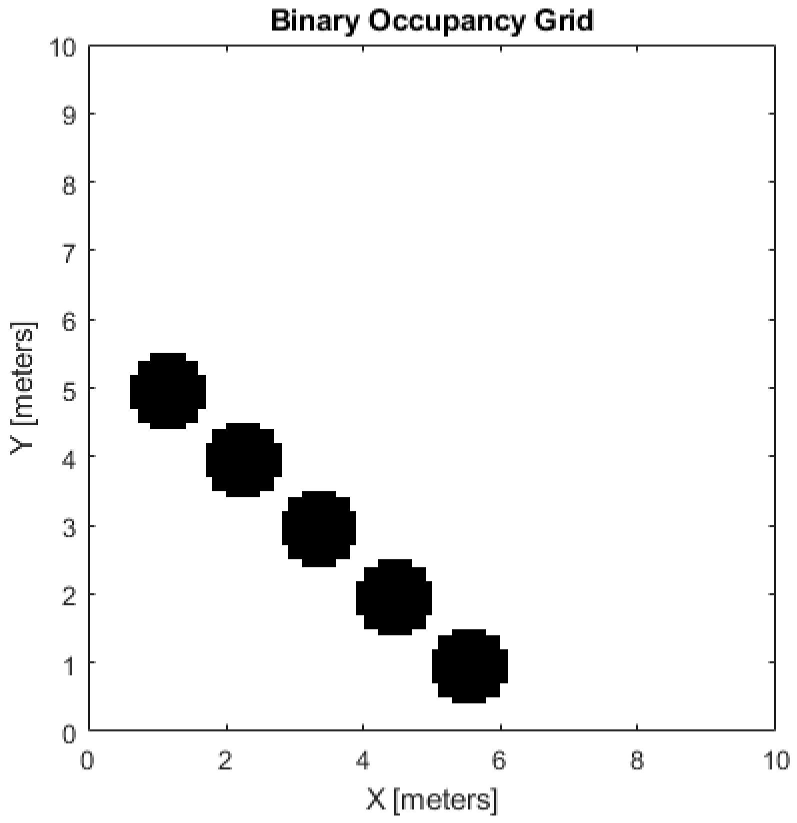
Set occupancy of world locations and show map.

```
x = [1.2; 2.3; 3.4; 4.5; 5.6];
y = [5.0; 4.0; 3.0; 2.0; 1.0];

setOccupancy(map, [x y], ones(5,1))
figure
show(map)
```



Inflate occupied locations by a given radius.

```
inflate(map, 0.5)
figure
show(map)
```

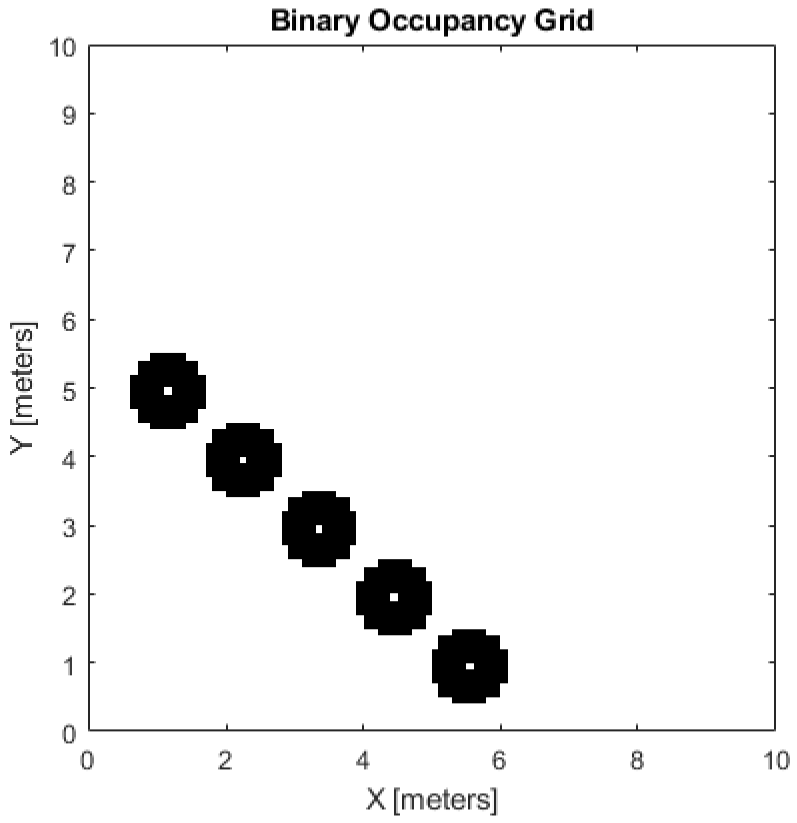


Get grid locations from world locations.

```
ij = world2grid(map, [x y]);
```

Set grid locations to free locations.

```
setOccupancy(map, ij, zeros(5,1), 'grid')
figure
show(map)
```



Input Arguments

map — Map representation
binaryOccupancyMap object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the robot. The object contains a matrix grid with binary values indicating obstacles as `true` (`1`) and free locations as `false` (`0`).

xy — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of `[x y]` pairs, where *n* is the number of world coordinates.

Data Types: `double`

ij — Grid positions
n-by-2 vertical array

Grid positions, specified as an *n*-by-2 vertical array of `[i j]` pairs in `[rows cols]` format, where *n* is the number of grid positions.

Data Types: `double`

`occval` — Occupancy values
n-by-1 vertical array

Occupancy values of the same length as either `xy` or `ij`, returned as an *n*-by-1 vertical array, where *n* is the same *n* in either `xy` or `ij`. Values are given between 0 and 1 inclusively.

`inputMatrix` — Occupancy values
matrix

Occupancy values, specified as a matrix. Values are given between 0 and 1 inclusively.

`bottomLeft` — Location of output matrix in world or local
two-element vector | `[xCoord yCoord]`

Location of bottom left corner of output matrix in world or local coordinates, specified as a two-element vector, `[xCoord yCoord]`. Location is in world or local coordinates based on syntax.

Data Types: `double`

`topLeft` — Location of grid
two-element vector | `[iCoord jCoord]`

Location of top left corner of grid, specified as a two-element vector, `[iCoord jCoord]`.

Data Types: `double`

Output Arguments

`validPts` — Valid map locations
n-by-1 column vector

Valid map locations, returned as an *n*-by-1 column vector equal in length to `xy` or `ij`. Locations inside the map return a value of 1. Locations outside the map limits return a value of 0.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `getOccupancy` | `occupancyMap`

Introduced in R2015a

show

Show occupancy grid values

Syntax

```
show(map)
show(map, "local")
show(map, "grid")
show( ___ ,Name,Value)
mapImage = show( ___ )
```

Description

`show(map)` displays the binary occupancy grid `map` in the current axes, with the axes labels representing the world coordinates.

`show(map, "local")` displays the binary occupancy grid `map` in the current axes, with the axes labels representing the local coordinates instead of world coordinates.

`show(map, "grid")` displays the binary occupancy grid `map` in the current axes, with the axes labels representing the grid coordinates.

`show( ___ ,Name,Value)` specifies additional options specified by one or more name-value pair arguments.

`mapImage = show( ___ )` returns the handle to the image object created by `show`.

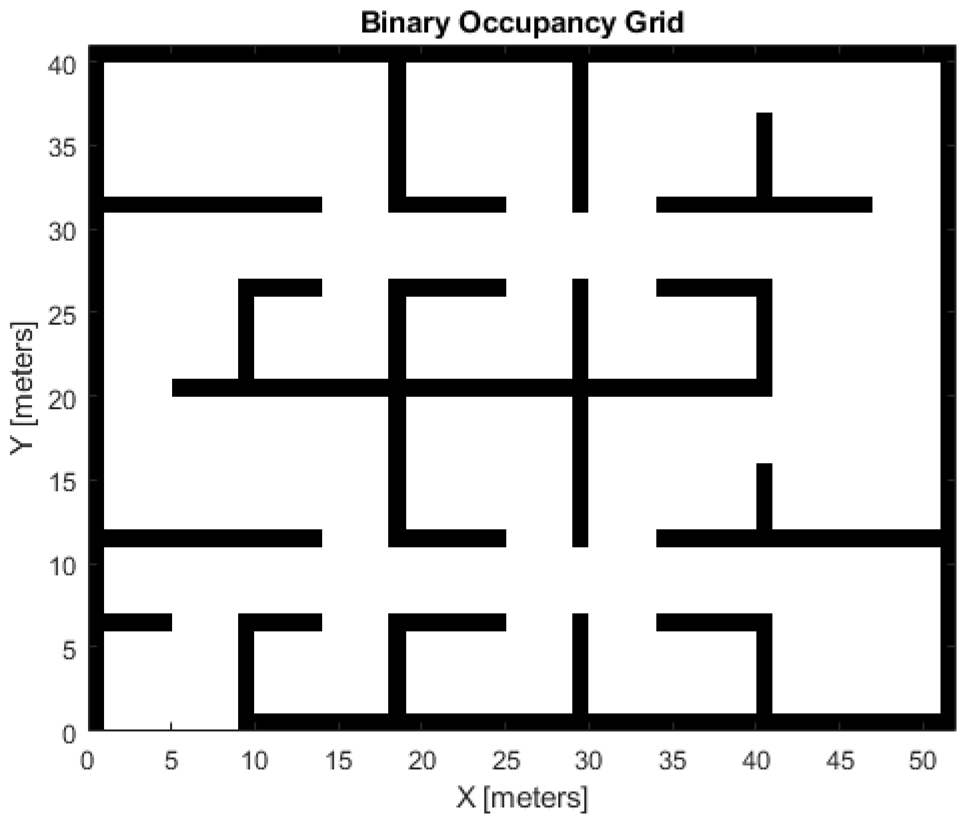
Examples

Move Local Map and Sync with World Map

This example shows how to move a local egocentric map and sync it with a larger world map. This process emulates a vehicle driving in an environment and getting updates on obstacles in the new areas.

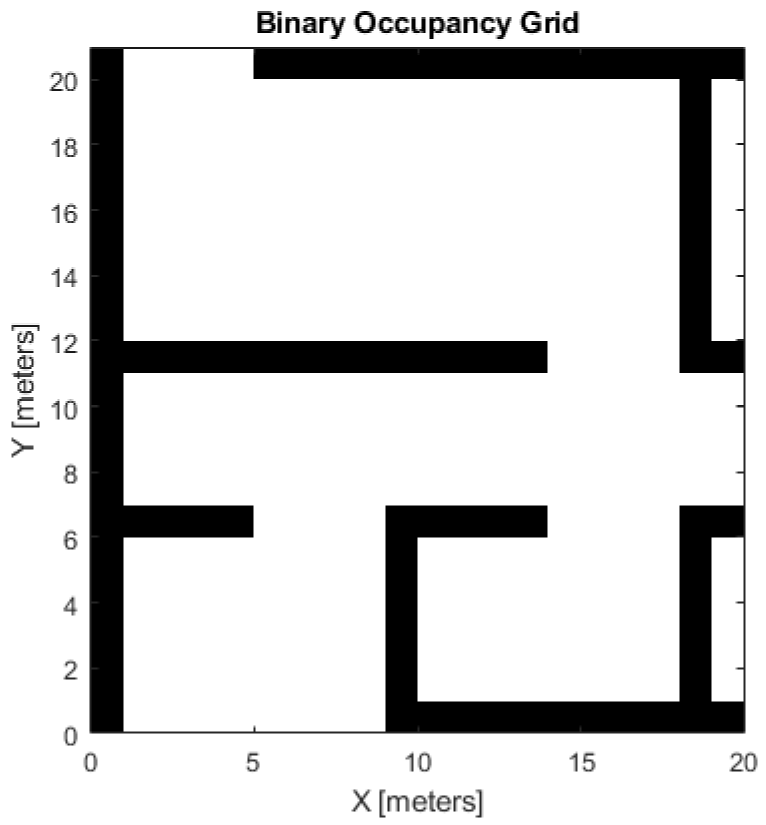
Load example maps. Create a binary occupancy map from the `complexMap`.

```
load exampleMaps.mat
map = binaryOccupancyMap(complexMap);
show(map)
```



Create a smaller local map.

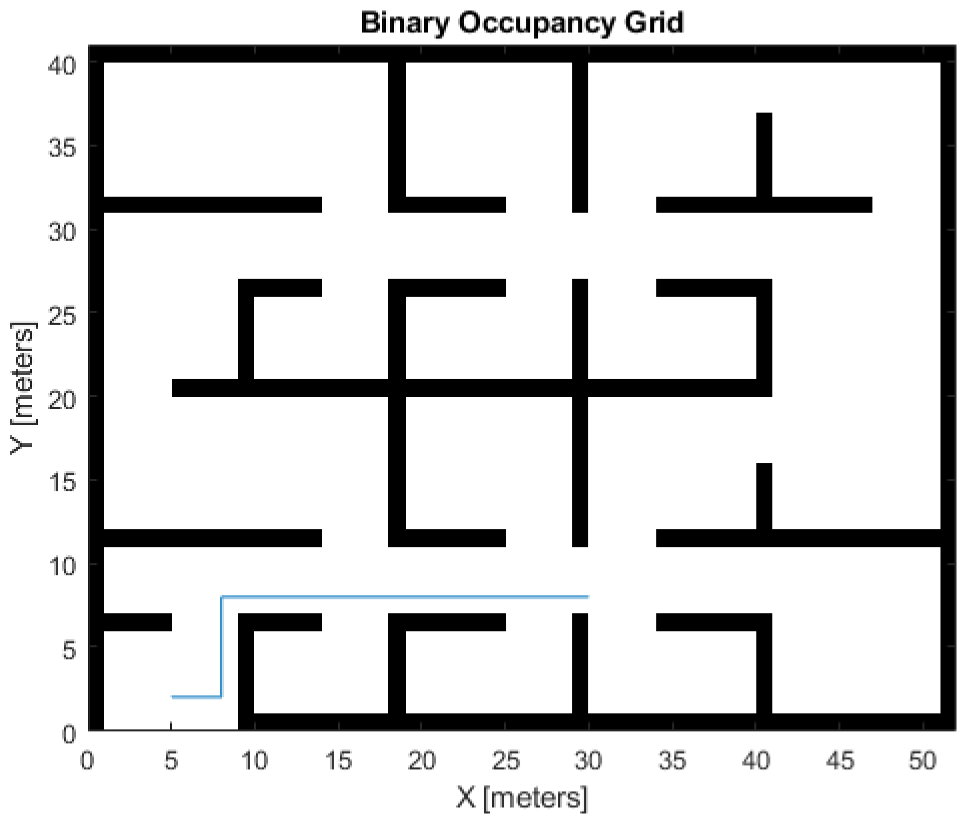
```
mapLocal = binaryOccupancyMap(complexMap(end-20:end,1:20));
show(mapLocal)
```



Follow a path planned in the world map and update the local map as you move your local frame.

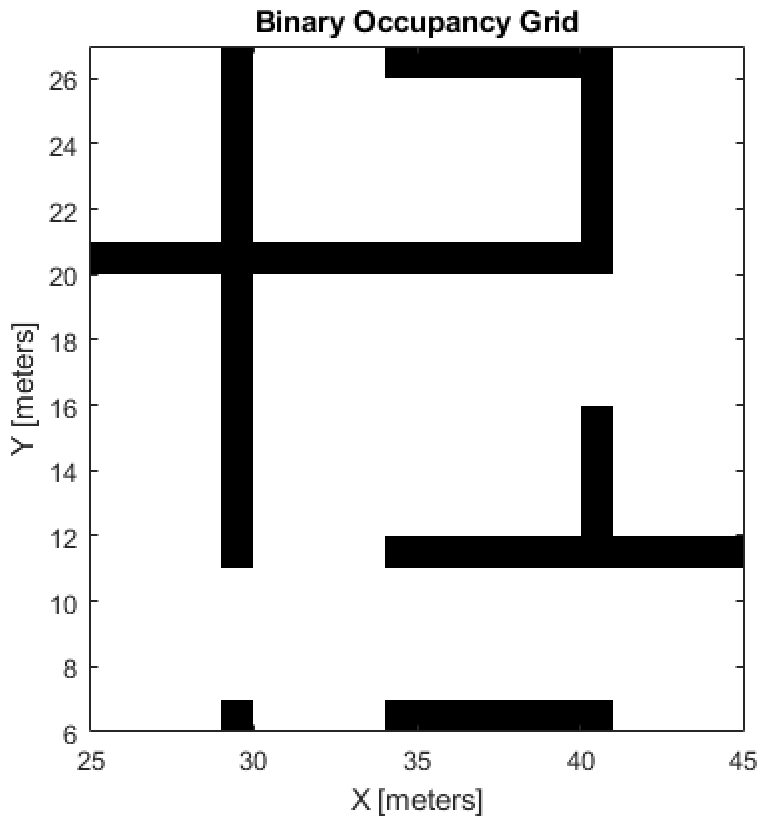
Specify path locations and plot on the map.

```
path = [5 2
        8 2
        8 8
        30 8];
show(map)
hold on
plot(path(:,1),path(:,2))
hold off
```



Create a loop for moving between points by the map resolution. Divide the difference between points by the map resolution to see how many incremental moves you can make.

```
for i = 1:length(path)-1
    moveAmount = (path(i+1,:)-path(i,:))/map.Resolution;
    for j = 1:abs(moveAmount(1)+moveAmount(2))
        moveValue = sign(moveAmount).*map.Resolution;
        move(mapLocal,moveValue, ...
            "MoveType","relative","SyncWith",map)

        show(mapLocal)
        drawnow limitrate
        pause(0.2)
    end
end
```



Input Arguments

map — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object. This object represents the environment of the vehicle.

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: `'Parent',axHandle`

`Parent` — Axes to plot the map
`Axes` object | `UIAxes` object

Axes to plot the map specified as either an `Axes` or `UIAxes`object. See `axes` or `uiaxes`.

`FastUpdate` — Update existing map plot
`0` (default) | `1`

Update existing map plot, specified as `0` or `1`. If you previously plotted your map on your figure, set to `1` for a faster update to the figure. This is useful for updating the figure in a loop for fast animations.

See Also

`binaryOccupancyMap` | `occupancyMap`

Introduced in R2015a

syncWith

Sync map with overlapping map

Syntax

```
mat = syncWith(map,sourcemap)
```

Description

`mat = syncWith(map,sourcemap)` updates `map` with data from another `binaryOccupancyMap` object, `sourcemap`. Locations in `map` that are also found in `sourcemap` are updated. All other cells in `map` are set to `map.DefaultValue`.

Examples

Sync Map With an Overlapping Map

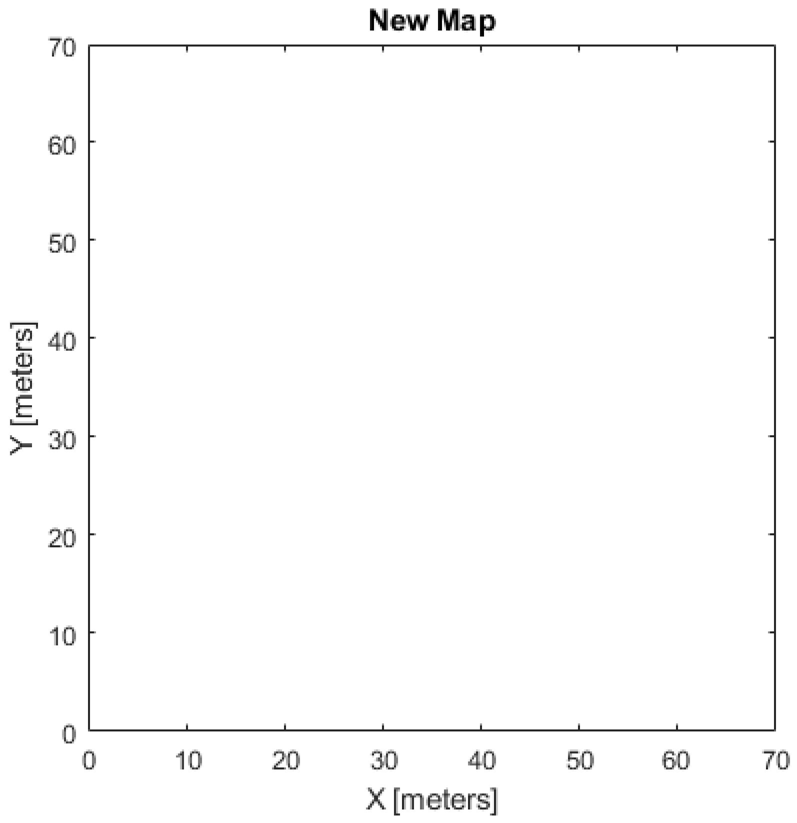
This example shows how to sync two overlapping maps using the `syncWith` function.

2-D occupancy maps are used to represent and visualize robot workspaces. In this example 2-D occupancy maps are created using existing map grid values stored inside `exampleMaps.mat`.

```
load('exampleMaps.mat');
```

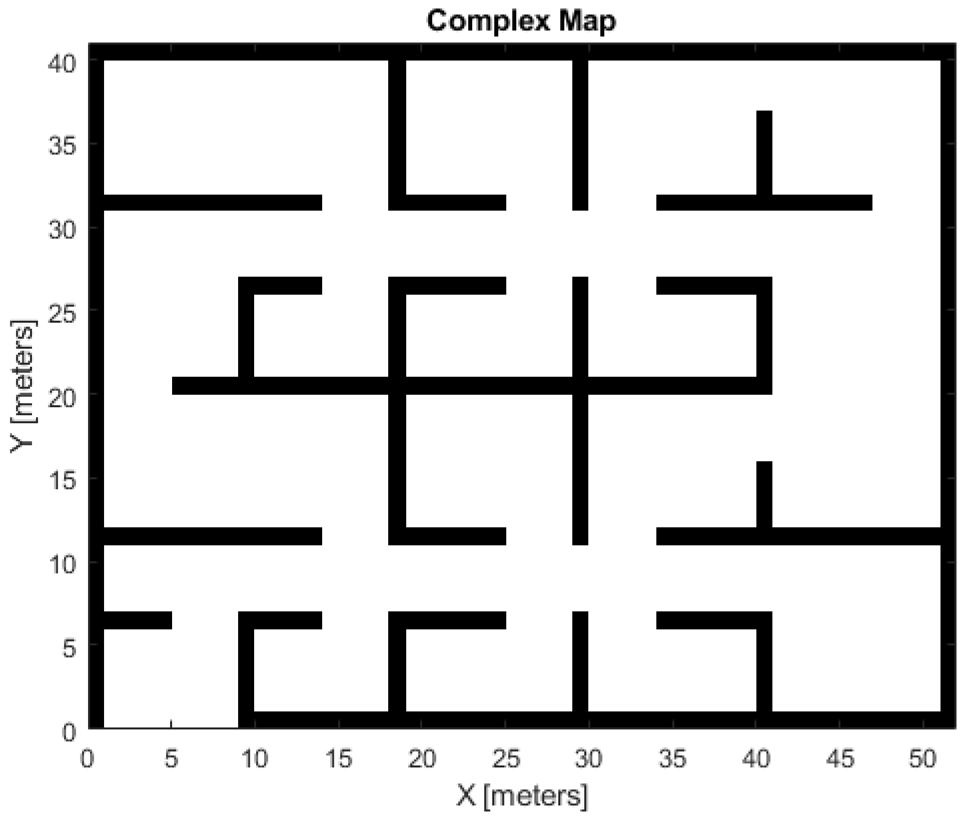
Create and display a new empty 2-D occupancy map object using `binaryOccupancyMap` function.

```
map1 = binaryOccupancyMap(70,70);
show(map1)
title('New Map')
```



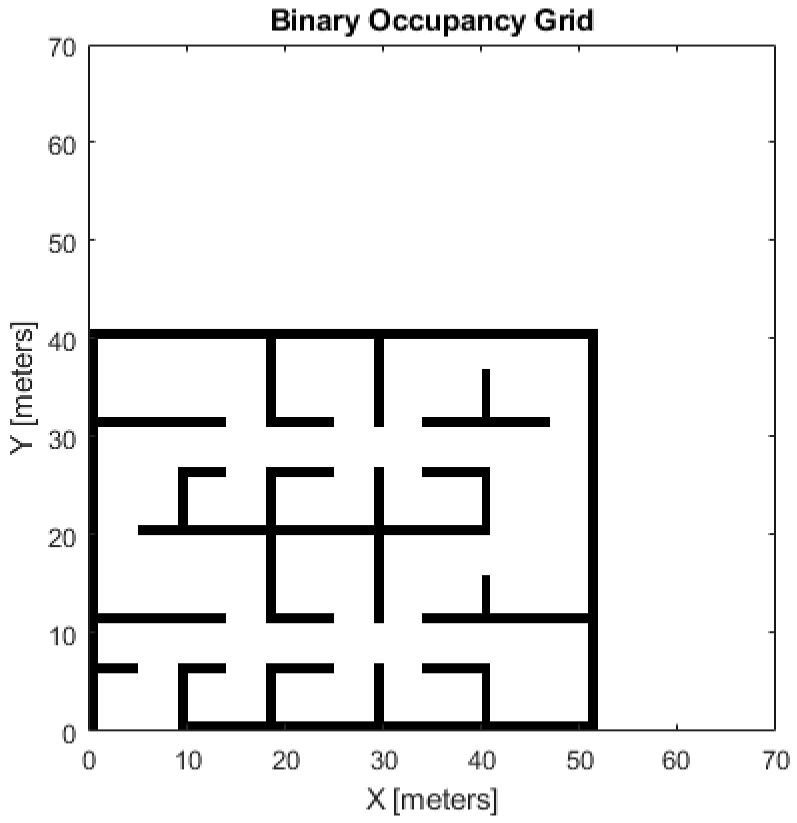
Create and display 2-D occupancy map using the map grid values stored in `complexMap`.

```
map2 = binaryOccupancyMap(complexMap);
show(map2)
title('Complex Map')
```



Now update `map1` with `map2` using the `syncWith` function.

```
syncWith(map1,map2);
show(map1)
```



Input Arguments

map — Map representation
binaryOccupancyMap object

Map representation, specified as a binaryOccupancyMap object.

sourcemap — Map representation
binaryOccupancyMap object

Map representation, specified as a binaryOccupancyMap object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

binaryOccupancyMap | occupancyMap

Topics
"Occupancy Grids"

Introduced in R2019b

world2grid

Convert world coordinates to grid indices

Syntax

`ij = world2grid(map,xy)`

Description

`ij = world2grid(map,xy)` converts an array of world coordinates, `xy`, to a `[rows cols]` array of grid indices, `ij`.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object.

`xy` — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of `[x y]` pairs, where *n* is the number of world coordinates.

Output Arguments

`ij` — Grid indices
n-by-2 vertical array

Grid indices, specified as an *n*-by-2 vertical array of `[i j]` pairs in `[rows cols]` format, where *n* is the number of grid positions.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `grid2world`

Introduced in R2015a

world2local

Convert world coordinates to local coordinates

Syntax

`xyLocal = world2local(map,xy)`

Description

`xyLocal = world2local(map,xy)` converts an array of world coordinates to local coordinates.

Input Arguments

`map` — Map representation
`binaryOccupancyMap` object

Map representation, specified as a `binaryOccupancyMap` object.

`xy` — World coordinates
n-by-2 vertical array

World coordinates, specified as an *n*-by-2 vertical array of `[x y]` pairs, where *n* is the number of world coordinates.

Output Arguments

`xyLocal` — Local coordinates
n-by-2 vertical array

Local coordinates, specified as an *n*-by-2 vertical array of `[x y]` pairs, where *n* is the number of local coordinates.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`binaryOccupancyMap` | `grid2world` | `local2world`

Introduced in R2019b

show

Show collision geometry

Syntax

```
ax = show(geom)
[ax,patchobj] = show(geom)
```

```
show(geom)
show(geom,'Parent',AX)
```

Description

`ax = show(geom)` returns the axes under which the collision geometry is plotted.

`[ax,patchobj] = show(geom)` returns the `patchobj` graphic object that represents the collision geometry in the plot.

`show(geom)` shows the collision geometry in the current figure at its current pose. The tessellation is generated automatically.

`show(geom,'Parent',AX)` specifies the axes `AX` in which to plot the collision geometry.

Examples

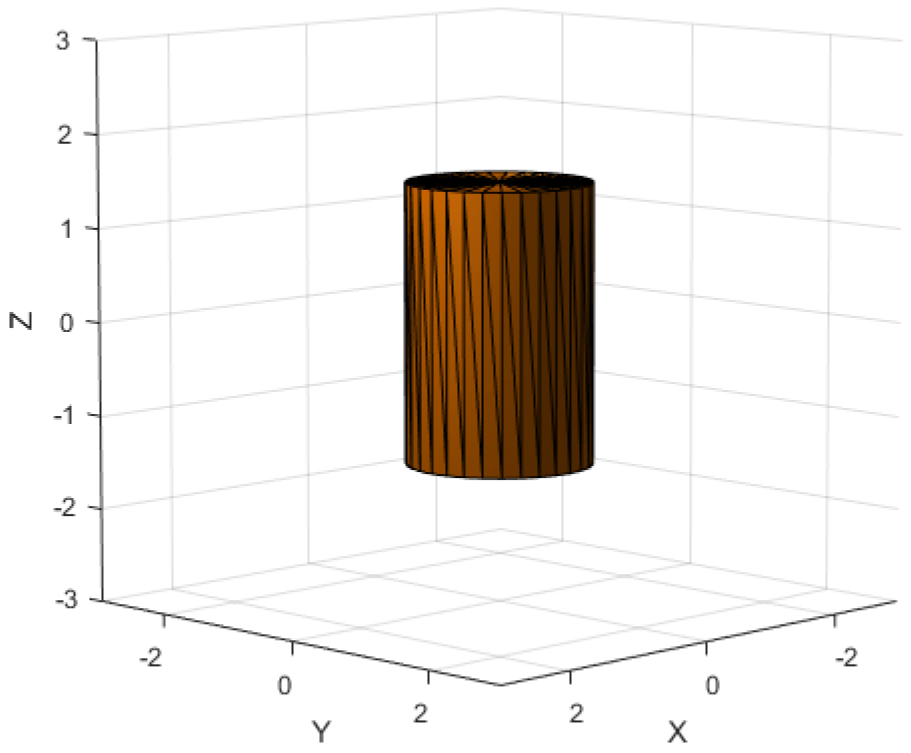
Show Collision Geometry

Create a cylinder collision geometry. The cylinder has a length of 3 meters and a radius of 1 meter.

```
cyl = collisionCylinder(1,3);
```

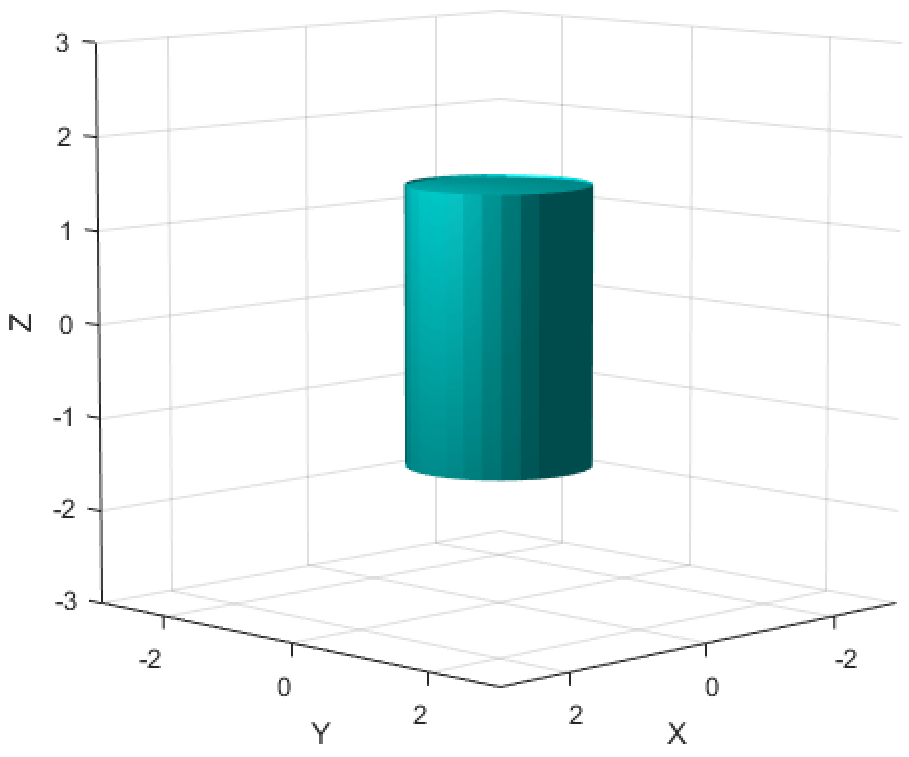
Show the cylinder.

```
show(cyl)
```



Show the cylinder in a new figure, and return the patch object that represents the cylinder. Change the cylinder color to cyan by changing the RGB value of the `FaceColor` field in the patch object. Hide the edges by setting `EdgeColor` to `'none'`.

```
figure
[~,patchObj] = show(cyl);
patchObj.FaceColor = [0 1 1];
patchObj.EdgeColor = 'none';
```



Input Arguments

geom — Collision geometry
`collisionBox` object | `collisionCylinder` object | `collisionMesh` object | `collisionSphere` object

Collision geometry to show.

AX — Axes on which to plot
`Axes` object

Axes in which to plot the collision geometry, specified as an `Axes` object.

Output Arguments

ax — Axes
`Axes` object

Axes under which the collision geometry `geom` is shown, returned as an `Axes` object. For more information, see Axes Properties.

`patchobj` — Graphic object
`Patch` object

Graphic object that represents the collision geometry, returned as a `Patch` object. For more information, see Patch Properties.

See Also

`collisionBox` | `collisionCylinder` | `collisionMesh` | `collisionSphere`

Introduced in R2019b

info

Characteristic information about `controllerPurePursuit` object

Syntax

```
controllerInfo = info(controller)
```

Description

`controllerInfo = info(controller)` returns a structure, `controllerInfo`, with additional information about the status of the `controllerPurePursuit` object, `controller`. The structure contains the fields, `RobotPose` and `LookaheadPoint`.

Examples

Get Additional Pure Pursuit Object Information

Use the `info` method to get more information about a `controllerPurePursuit` object. The `info` function returns two fields, `RobotPose` and `LookaheadPoint`, which correspond to the current position and orientation of the robot and the point on the path used to compute outputs from the last call of the object.

Create a `controllerPurePursuit` object.

```
pp = controllerPurePursuit;
```

Assign waypoints.

```
pp.Waypoints = [0 0;1 1];
```

Compute control commands using the `pp` object with the initial pose `[x y theta]` given as the input.

```
[v,w] = pp([0 0 0]);
```

Get additional information.

```
s = info(pp)
```

```
s = struct with fields:
         RobotPose: [0 0 0]
    LookaheadPoint: [0.7071 0.7071]
```

Input Arguments

`controller` — Pure pursuit controller
`controllerPurePursuit` object

Pure pursuit controller, specified as a `controllerPurePursuit` object.

Output Arguments

`controllerInfo` — Information on the `controllerPurePursuit` object
structure

Information on the `controllerPurePursuit` object, returned as a structure. The structure contains two fields:

- `RobotPose` – A three-element vector in the form `[x y theta]` that corresponds to the *x*-*y* position and orientation of the vehicle. The angle, `theta`, is measured in radians with positive angles measured counterclockwise from the *x*-axis.
- `LookaheadPoint`– A two-element vector in the form `[x y]`. The location is a point on the path that was used to compute outputs of the last call to the object.

See Also
`controllerPurePursuit`

Topics
"Pure Pursuit Controller"

Introduced in R2019b

addConfiguration

Store current configuration

Syntax

```
addConfiguration(viztree)
addConfiguration(viztree,index)
```

Description

`addConfiguration(viztree)` adds the current configuration to the `StoredConfigurations` property of the `interactiveRigidBodyTree` object, `viztree`.

`addConfiguration(viztree,index)` inserts the current configuration into the `StoredConfigurations` property at the specified index. The stored configurations after the specified index shift down by one.

Examples

Interactively Build and Play Back Series of Robot Configurations

Use the `interactiveRigidBodyTree` object to manually move around a robot in a figure. The object uses interactive markers in the figure to track the desired poses of different rigid bodies in the `rigidBodyTree` object.

Load Robot Model

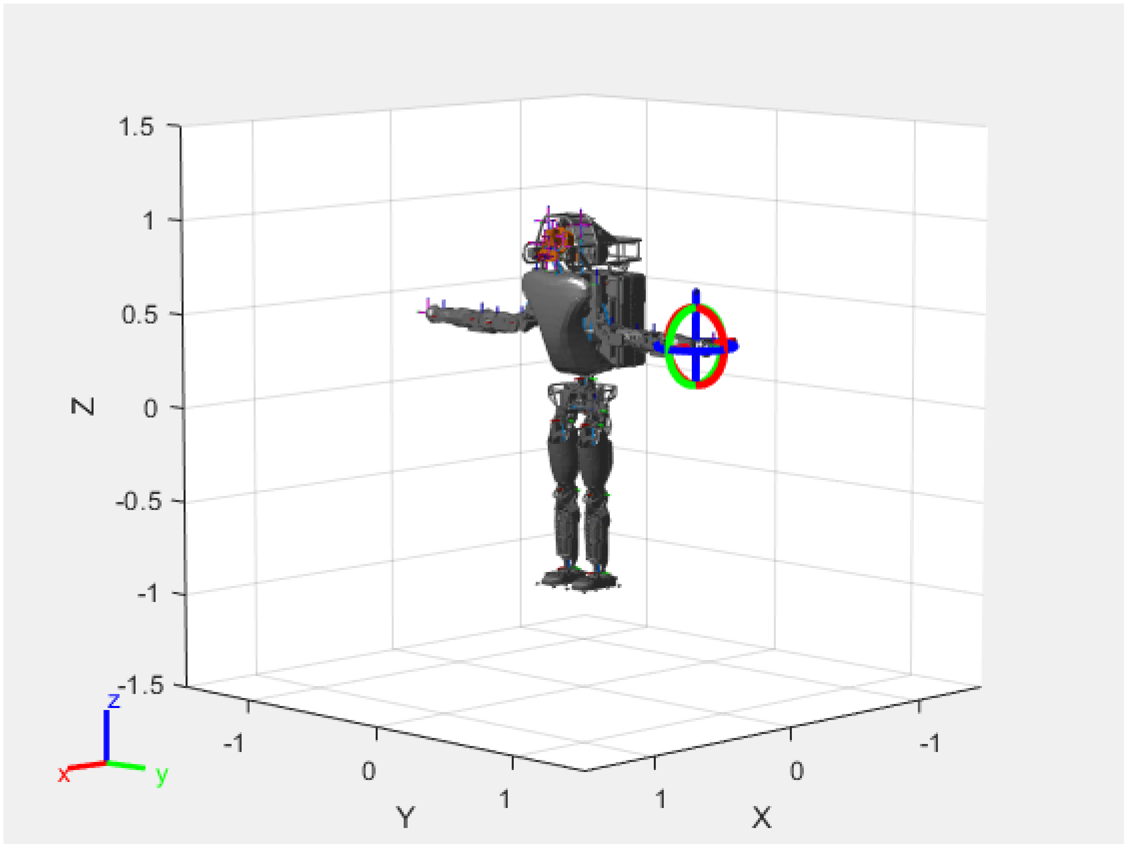
Use the `loadrobot` function to access provided robot models as `rigidBodyTree` objects.

```
robot = loadrobot("atlas");
```

Visualize Robot and Save Configurations

Create an interactive tree object and associated figure, specifying the loaded robot model and its left hand as the end effector.

```
viztree = interactiveRigidBodyTree(robot,"MarkerBodyName","l_hand");
```

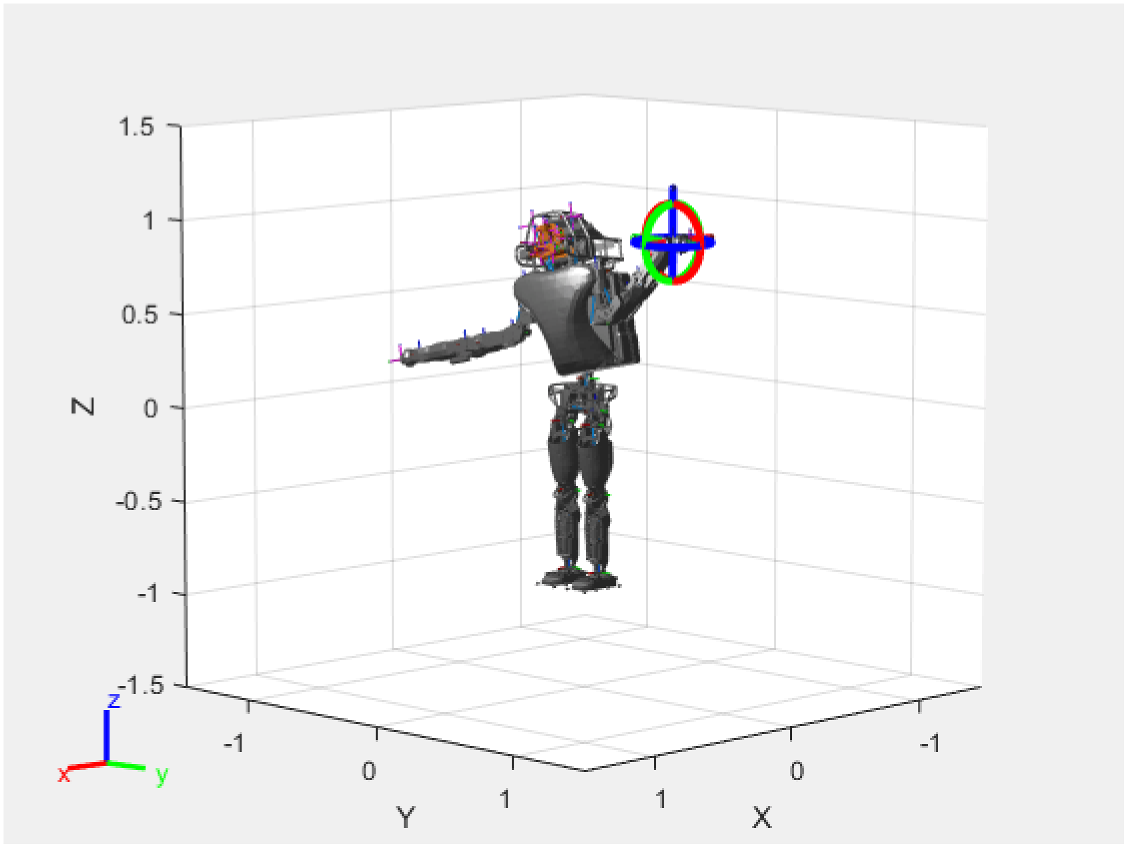


Click and drag the interactive marker to change the robot configuration. You can click and drag any of the axes for linear motion, rotate the body about an axis using the red, green, and blue circles, and drag the center of the interactive marker to position it in 3-D space.

The `interactiveRigidBodyTree` object uses inverse kinematics to determine a configuration that achieves the desired end-effector pose. If the associated rigid body cannot reach the marker, the figure renders the best configuration from the inverse kinematics solver.

Programmatically set the current configuration. Assign a vector of length equal to the number of nonfixed joints in the `RigidBodyTree` to the `Configuration` property.

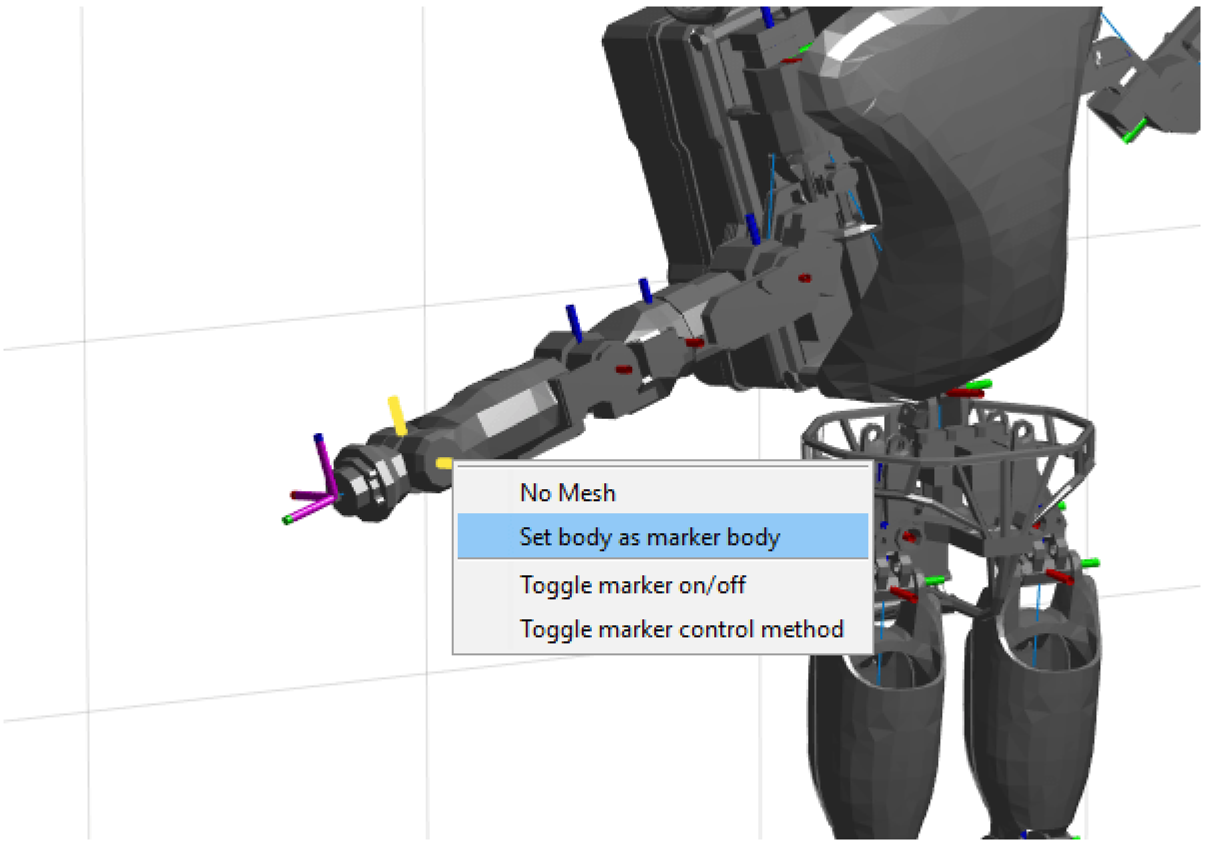
```
currConfig = homeConfiguration(viztree.RigidBodyTree);
currConfig(1:10) = [ 0.2201 -0.1319 0.2278 -0.3415 0.4996 ...
                     0.0747 0.0377 0.0718 -0.8117 -0.0427]';
viztree.Configuration = currConfig;
```



Save the current robot configuration in the `StoredConfigurations` property.

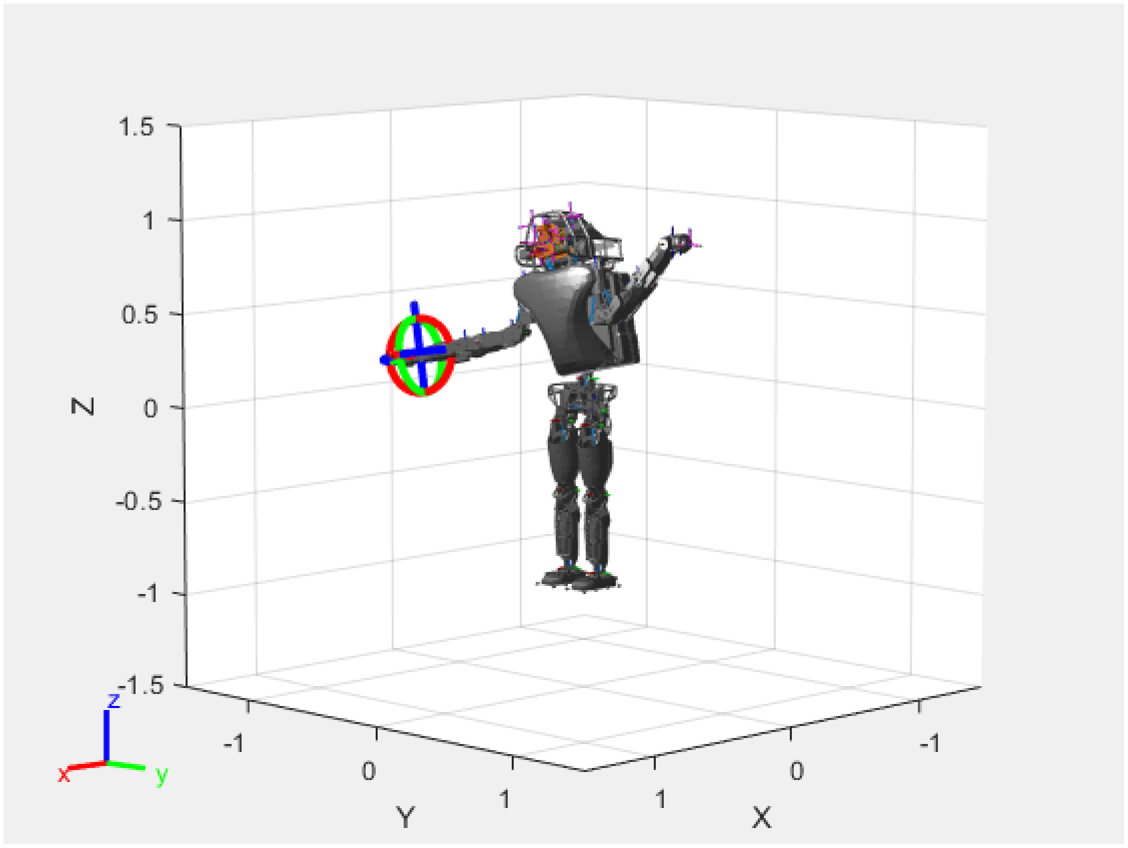
```
addConfiguration(viztree)
```

To switch the end effector to a different rigid body, right-click the desired body in the figure and select **Set body as marker body**. Use this process to select the right hand frame.



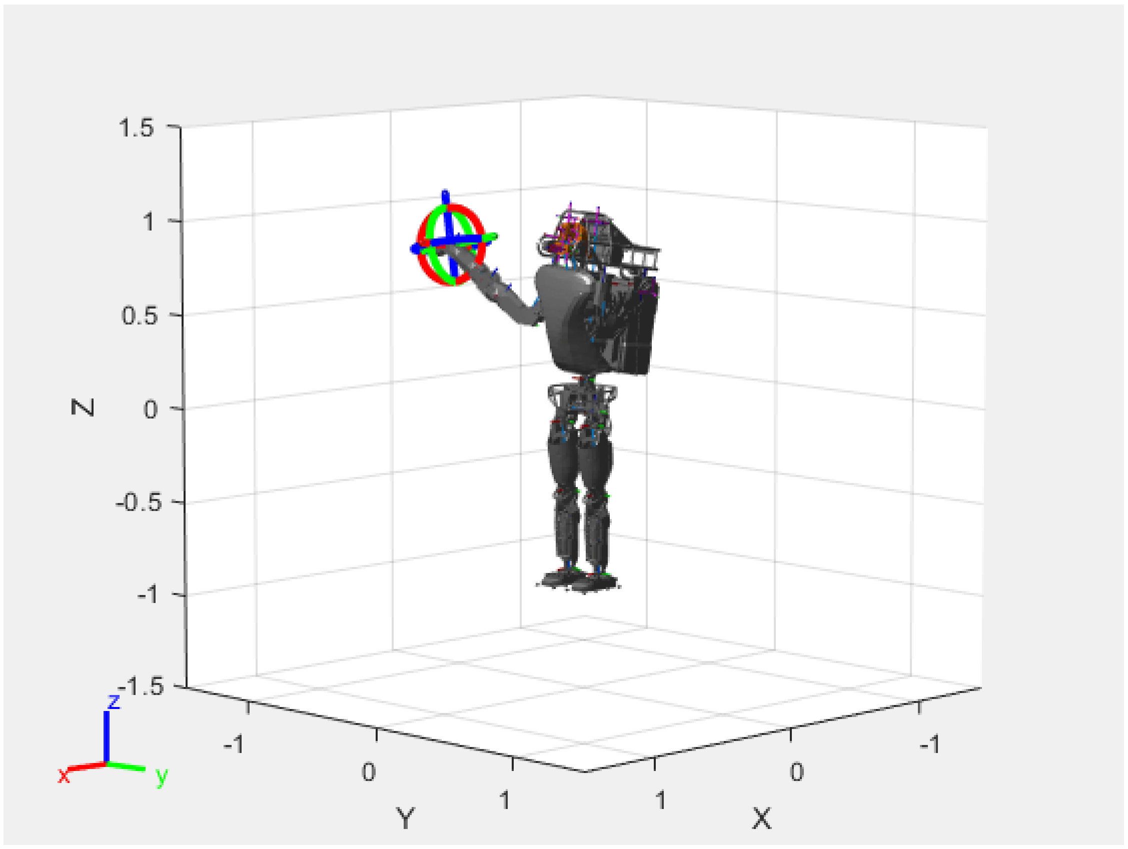
You can also set the `MarkerBodyName` property to the specific body name.

```
viztree.MarkerBodyName = "r_hand";
```



Move the right hand to a new position. Set the configuration programmatically. The marker moves to the new position of the end effector.

```
currConfig(1:18) = [-0.1350 -0.1498 -0.0167 -0.3415 0.4996 0.0747
                     0.0377 0.0718 -0.8117 -0.0427 0 0.4349
                    -0.5738 0.0563 -0.0095 0.0518 0.8762 -0.0895]';

viztree.Configuration = currConfig;
```



Save the current configuration.

```
addConfiguration(viztree)
```

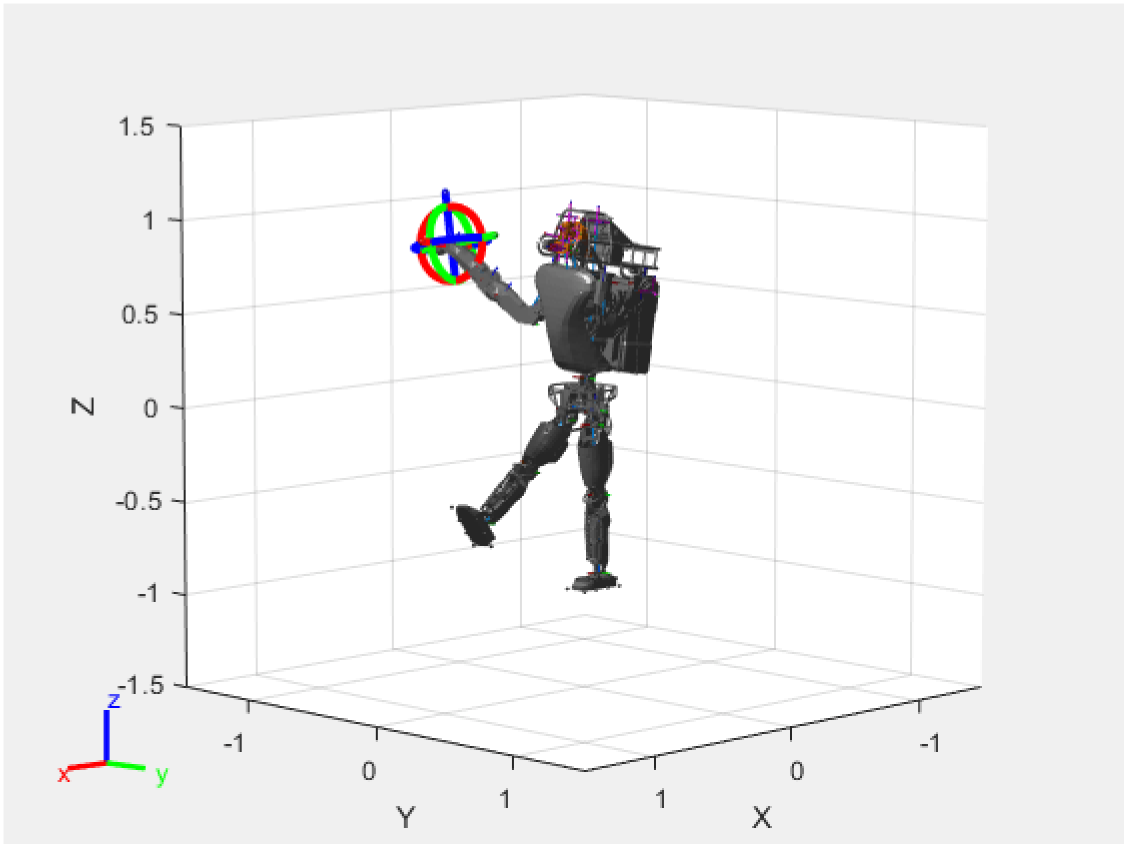
Add Constraints

By default, the robot model respects only the joint limits of the `rigidBodyJoint` objects associated with the `RigidBodyTree` property. To add constraints, generate **Robot Constraint** objects and specify them as a cell array in the `Constraints` property. To see a list of robotic constraints, see “Inverse Kinematics”. Specify a pose target for the pelvis to keep it fixed to the home position. Specify a position target for the right foot to be raised in front front and above its current position.

```
fixedWaist = constraintPoseTarget("pelvis");
raiseRightLeg = constraintPositionTarget("r_foot","TargetPosition",[1 0 0.5]);
```

Apply these constraints to the interactive rigid body tree object as a cell array. The right leg in the resulting figure changes position.

```
viztree.Constraints = {fixedWaist raiseRightLeg};
```



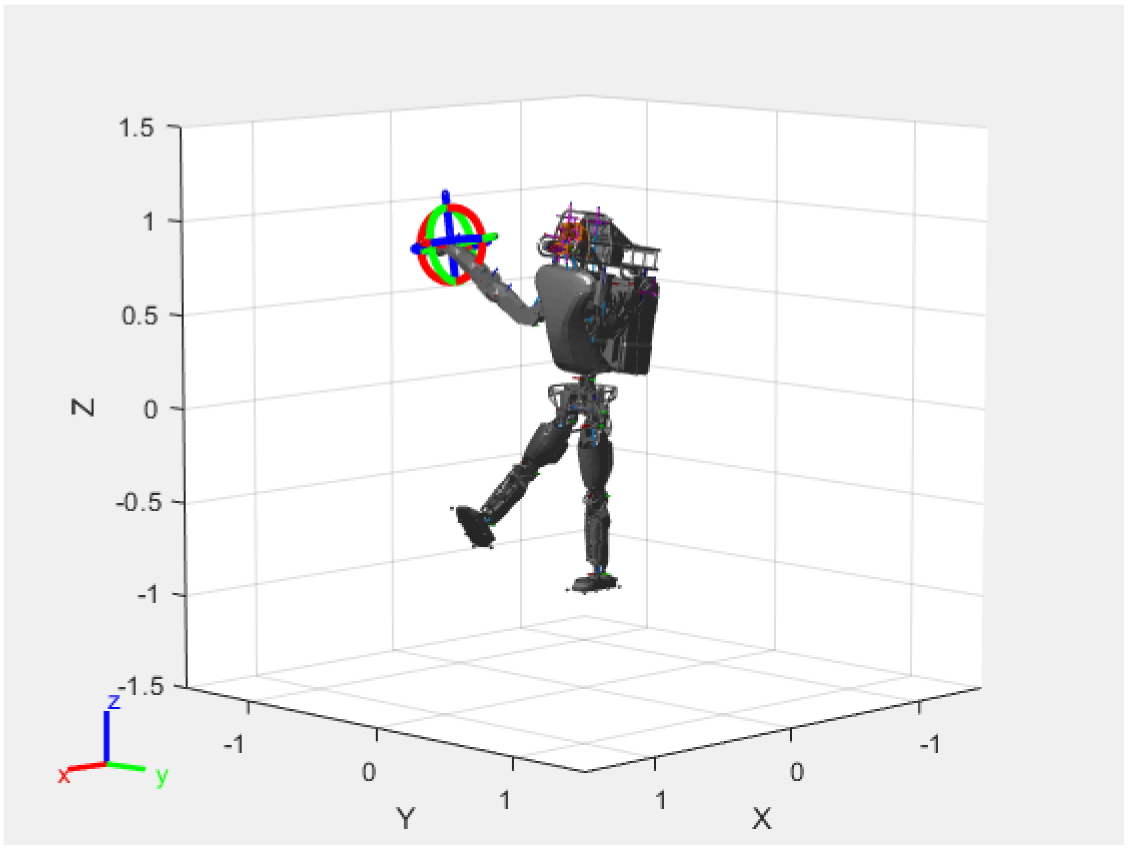
Notice the change in position of the right leg. Save this configuration as well.

```
addConfiguration(viztree)
```

Play Back Configurations

To play back configurations, iterate through the stored configurations index and set the current configuration equal to the stored configuration column vector at each iteration. Because configurations are stored as column vectors, use the second dimension of the matrix.

```
for i = 1:size(viztree.StoredConfigurations,2)
    viztree.Configuration = viztree.StoredConfigurations(:,i);
    pause(0.5)
end
```



Input Arguments

viztree — Interactive rigid body tree robot model visualization
`interactiveRigidBodyTree` object

Interactive rigid body tree robot model visualization, specified as an `interactiveRigidBodyTree` object.

index — Index location to store current configuration
positive integer

Index location to store current configuration, specified as a positive integer. The stored configurations after the specified index shift down by one.

Data Types: `double`

See Also

Functions
`removeConfigurations` | `loadrobot` | `importrobot` | `homeConfiguration`

Objects
`interactiveRigidBodyTree` | `rigidBodyTree` | `rigidBody` | `rigidBodyJoint` | `generalizedInverseKinematics`

Topics
"Rigid Body Tree Robot Model"
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"
"Trajectory Control Modeling with Inverse Kinematics"

Introduced in R2020a

addConstraint

Add inverse kinematics constraint

Syntax

```
addConstraint(viztree,gikConstraint)
```

Description

`addConstraint(viztree,gikConstraint)` adds an inverse kinematics constraint, `gikConstaint`, to the `Constraints` property of the `interactiveRigidBodyTree` object, `viztree`.

Examples

Interactively Build and Play Back Series of Robot Configurations

Use the `interactiveRigidBodyTree` object to manually move around a robot in a figure. The object uses interactive markers in the figure to track the desired poses of different rigid bodies in the `rigidBodyTree` object.

Load Robot Model

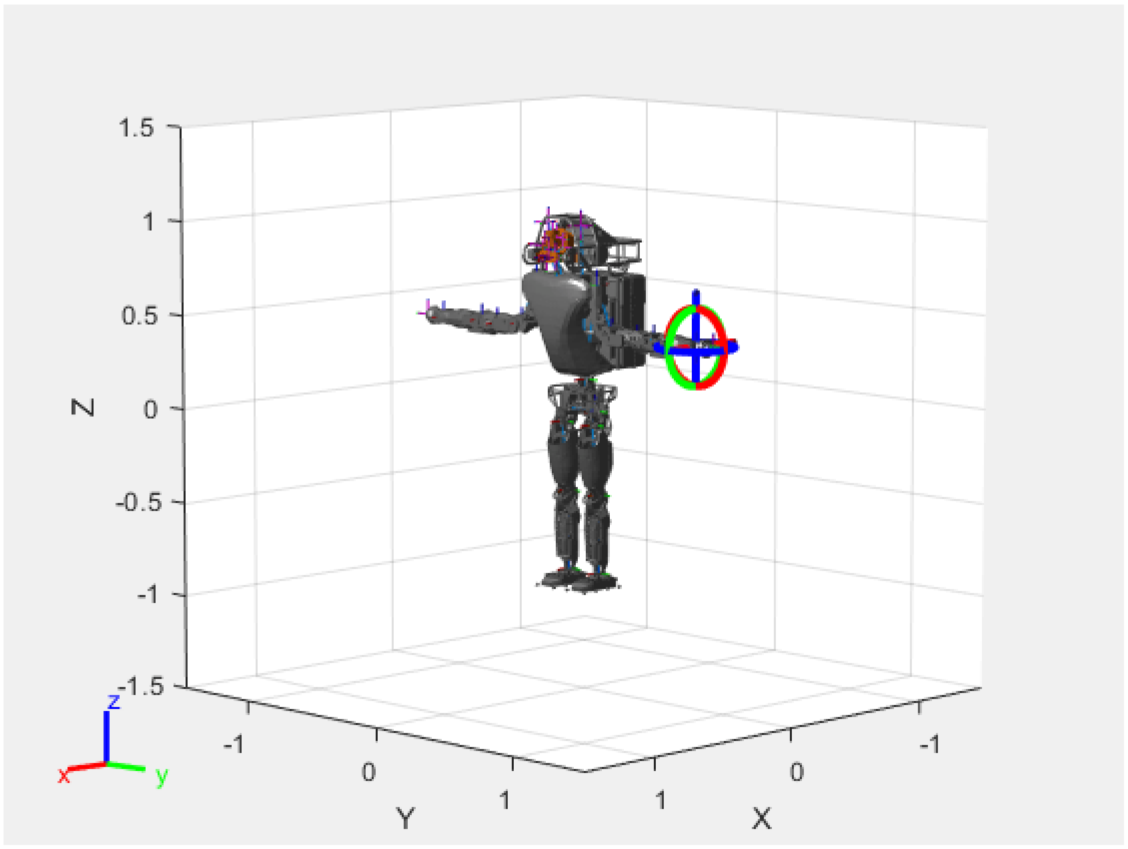
Use the `loadrobot` function to access provided robot models as `rigidBodyTree` objects.

```
robot = loadrobot("atlas");
```

Visualize Robot and Save Configurations

Create an interactive tree object and associated figure, specifying the loaded robot model and its left hand as the end effector.

```
viztree = interactiveRigidBodyTree(robot,"MarkerBodyName","l_hand");
```

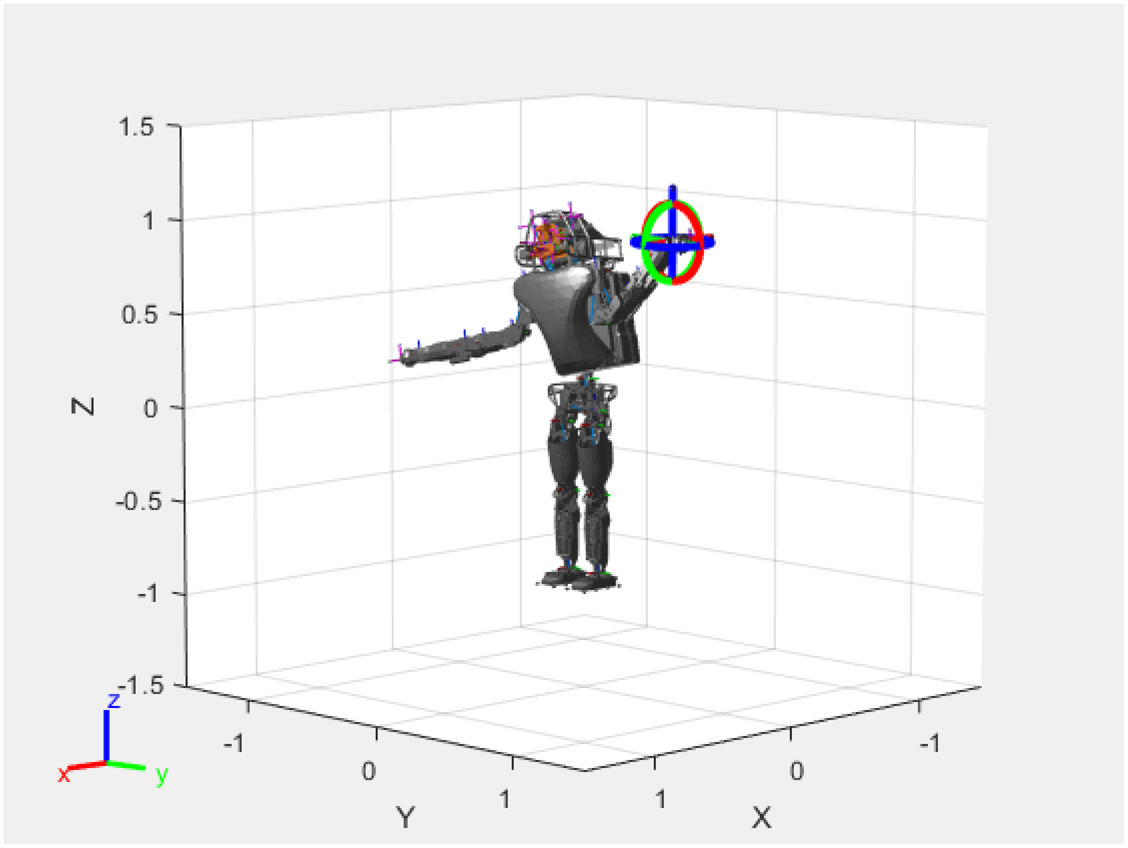


Click and drag the interactive marker to change the robot configuration. You can click and drag any of the axes for linear motion, rotate the body about an axis using the red, green, and blue circles, and drag the center of the interactive marker to position it in 3-D space.

The `interactiveRigidBodyTree` object uses inverse kinematics to determine a configuration that achieves the desired end-effector pose. If the associated rigid body cannot reach the marker, the figure renders the best configuration from the inverse kinematics solver.

Programmatically set the current configuration. Assign a vector of length equal to the number of nonfixed joints in the `RigidBodyTree` to the `Configuration` property.

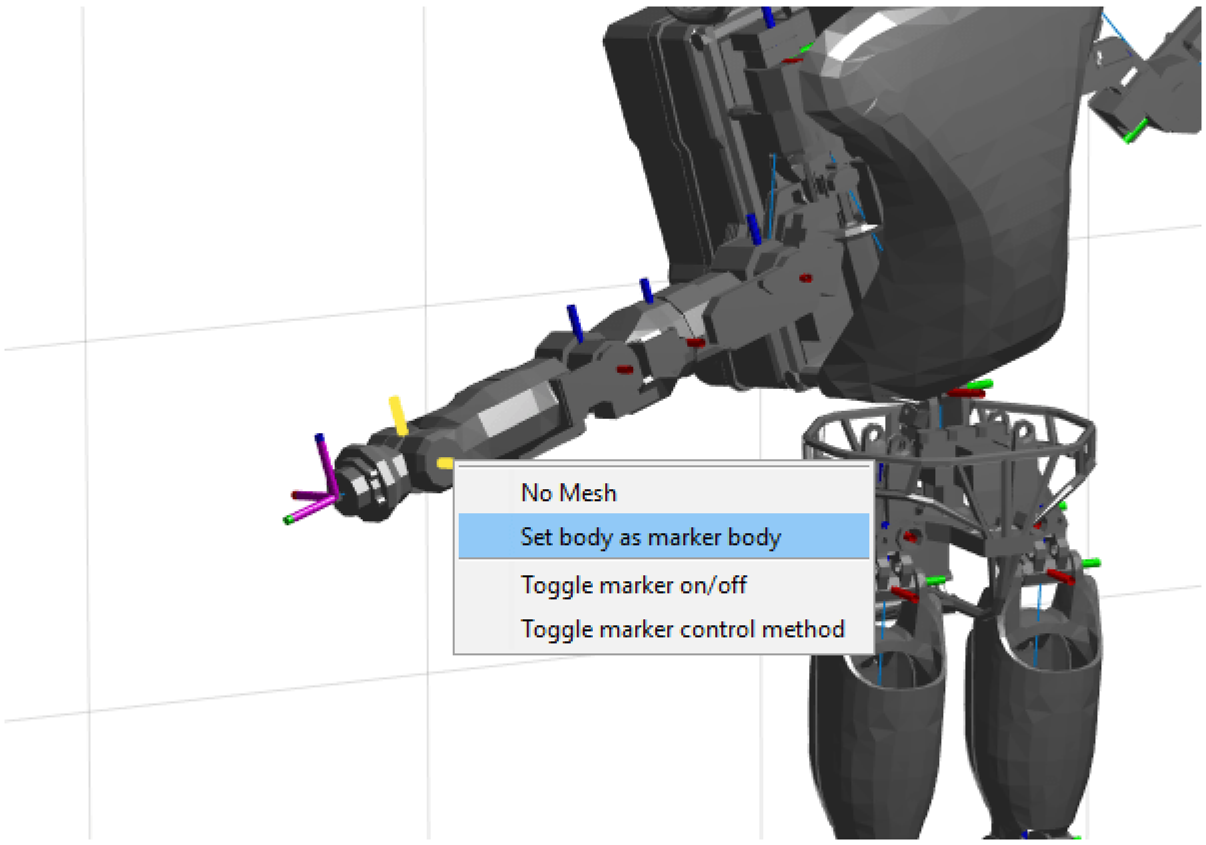
```
currConfig = homeConfiguration(viztree.RigidBodyTree);
currConfig(1:10) = [ 0.2201 -0.1319 0.2278 -0.3415 0.4996 ...
                     0.0747 0.0377 0.0718 -0.8117 -0.0427]';
viztree.Configuration = currConfig;
```



Save the current robot configuration in the `StoredConfigurations` property.

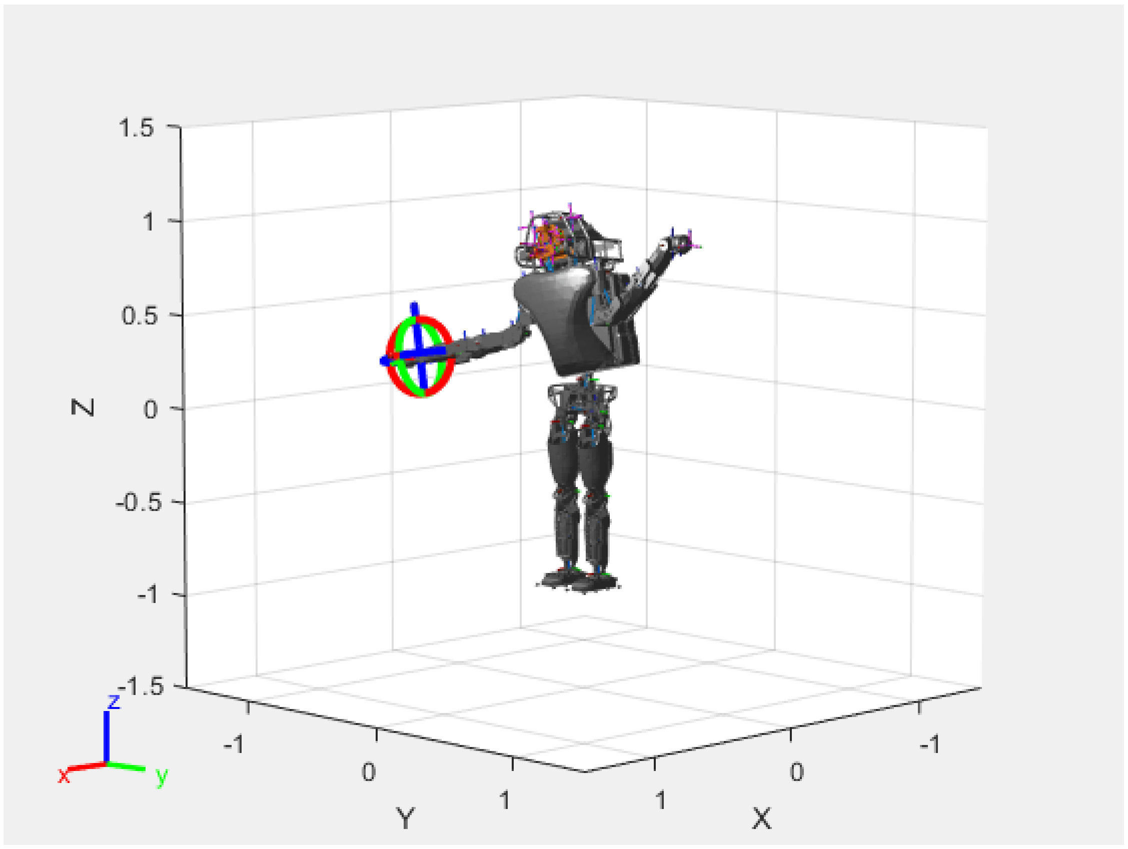
```
addConfiguration(viztree)
```

To switch the end effector to a different rigid body, right-click the desired body in the figure and select **Set body as marker body**. Use this process to select the right hand frame.



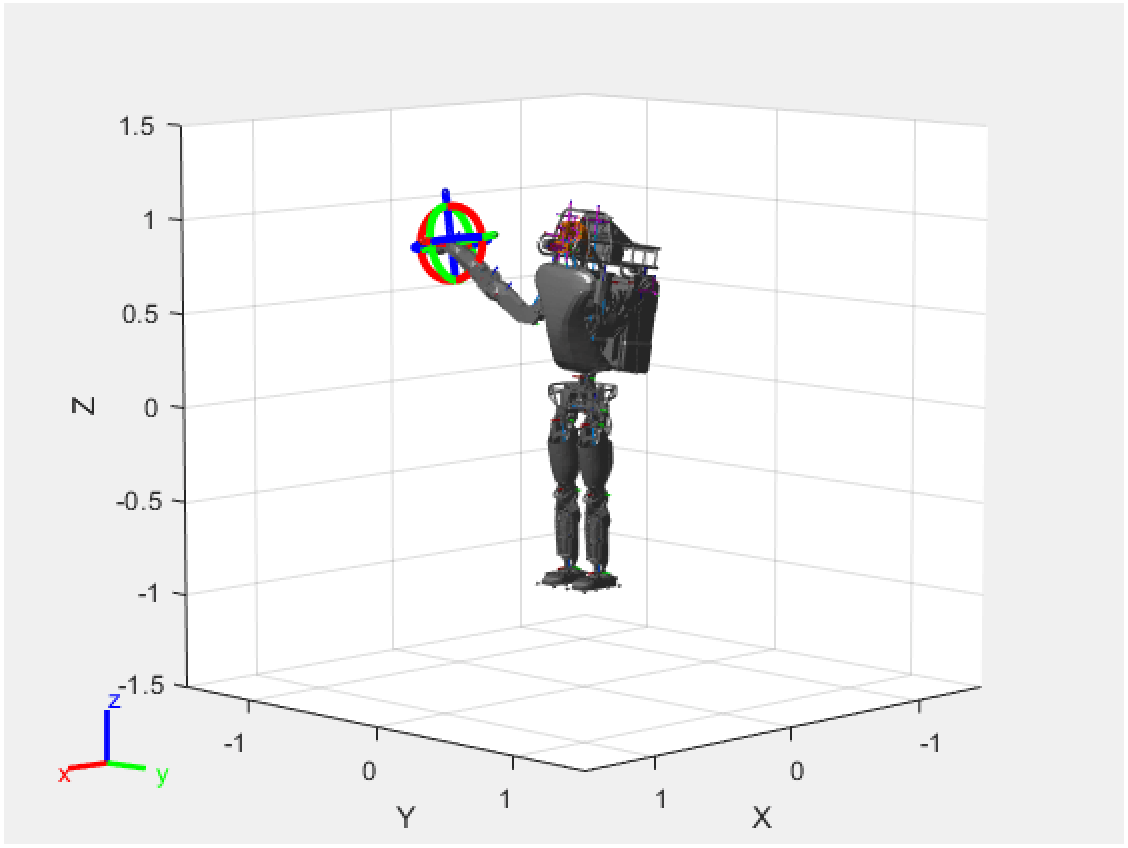
You can also set the `MarkerBodyName` property to the specific body name.

```
viztree.MarkerBodyName = "r_hand";
```



Move the right hand to a new position. Set the configuration programmatically. The marker moves to the new position of the end effector.

```
currConfig(1:18) = [-0.1350 -0.1498 -0.0167 -0.3415 0.4996 0.0747
                     0.0377 0.0718 -0.8117 -0.0427 0 0.4349
                    -0.5738 0.0563 -0.0095 0.0518 0.8762 -0.0895]';

viztree.Configuration = currConfig;
```



Save the current configuration.

```
addConfiguration(viztree)
```

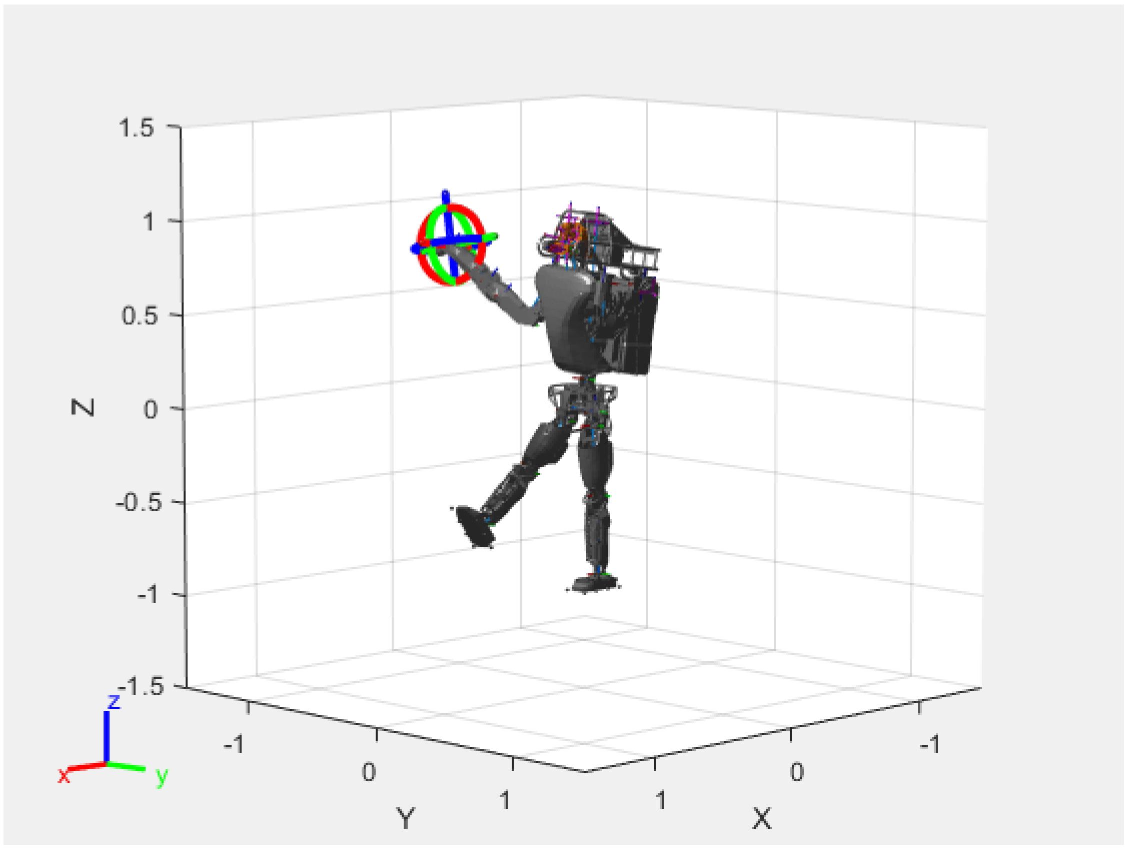
Add Constraints

By default, the robot model respects only the joint limits of the `rigidBodyJoint` objects associated with the `RigidBodyTree` property. To add constraints, generate **Robot Constraint** objects and specify them as a cell array in the `Constraints` property. To see a list of robotic constraints, see "Inverse Kinematics". Specify a pose target for the pelvis to keep it fixed to the home position. Specify a position target for the right foot to be raised in front front and above its current position.

```
fixedWaist = constraintPoseTarget("pelvis");
raiseRightLeg = constraintPositionTarget("r_foot","TargetPosition",[1 0 0.5]);
```

Apply these constraints to the interactive rigid body tree object as a cell array. The right leg in the resulting figure changes position.

```
viztree.Constraints = {fixedWaist raiseRightLeg};
```



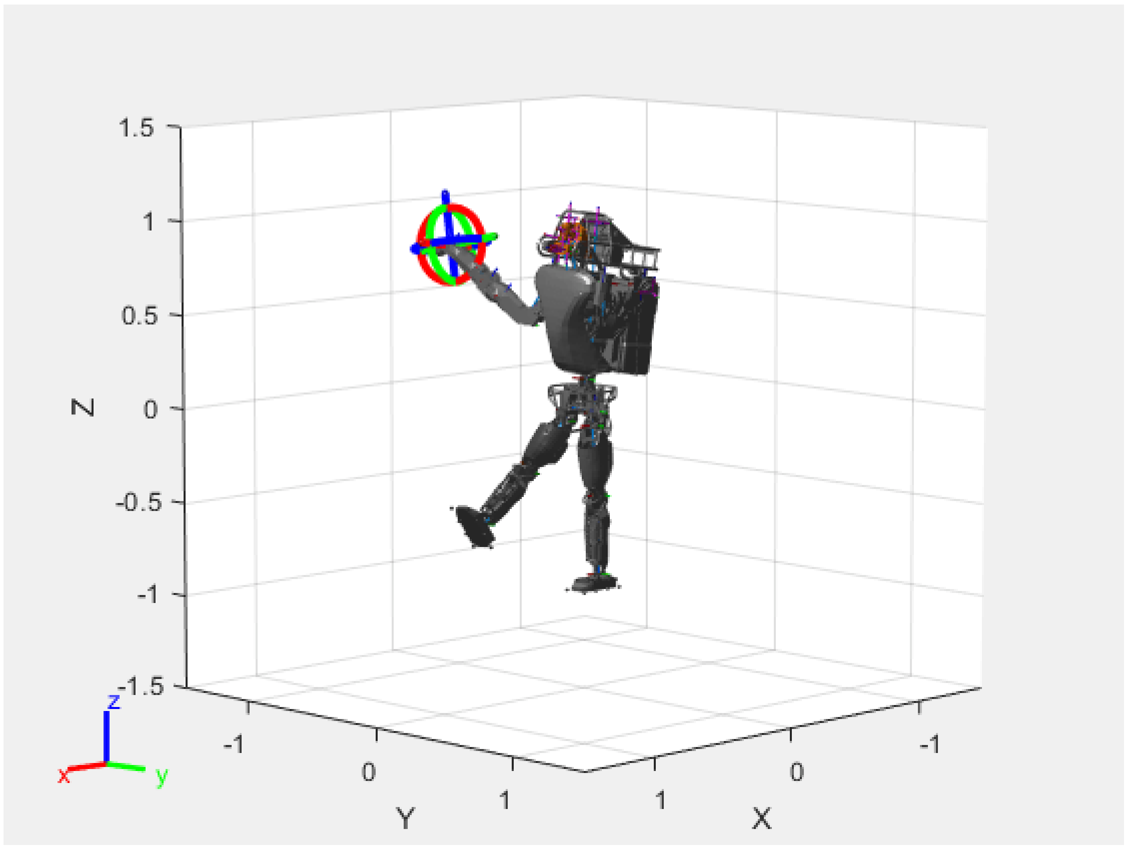
Notice the change in position of the right leg. Save this configuration as well.

```
addConfiguration(viztree)
```

Play Back Configurations

To play back configurations, iterate through the stored configurations index and set the current configuration equal to the stored configuration column vector at each iteration. Because configurations are stored as column vectors, use the second dimension of the matrix.

```
for i = 1:size(viztree.StoredConfigurations,2)
    viztree.Configuration = viztree.StoredConfigurations(:,i);
    pause(0.5)
end
```



Input Arguments

`viztree` — Interactive rigid body tree robot model visualization

`interactiveRigidBodyTree` object

Interactive rigid body tree robot model visualization, specified as an `interactiveRigidBodyTree` object.

`gikConstraint` — Generalized inverse kinematics constraint

constraint object

Generalized inverse kinematics constraint, specified as one of these constraint objects.

- `constraintAiming`
- `constraintCartesianBounds`
- `constraintJointBounds`
- `constraintOrientationTarget`
- `constraintPoseTarget`
- `constraintPositionTarget`

See Also

Functions
`removeConstraints` | `loadrobot` | `importrobot` | `homeConfiguration`

Objects
`interactiveRigidBodyTree` | `rigidBodyTree` | `rigidBody` | `rigidBodyJoint` | `generalizedInverseKinematics`

Topics
"Rigid Body Tree Robot Model"
"Plan a Reaching Trajectory With Multiple Kinematic Constraints"
"Trajectory Control Modeling with Inverse Kinematics"

Introduced in R2020a

removeConfigurations

Remove configurations from `StoredConfigurations` property

Syntax

```
removeConfigurations(viztree)
removeConfigurations(viztree,index)
```

Description

`removeConfigurations(viztree)` removes the configuration stored at the last index of the `StoredConfigurations` property of the `interactiveRigidBodyTree` object, `viztree`.

`removeConfigurations(viztree,index)` removes the configurations with the specified indices.

Examples

Interactively Build and Play Back Series of Robot Configurations

Use the `interactiveRigidBodyTree` object to manually move around a robot in a figure. The object uses interactive markers in the figure to track the desired poses of different rigid bodies in the `rigidBodyTree` object.

Load Robot Model

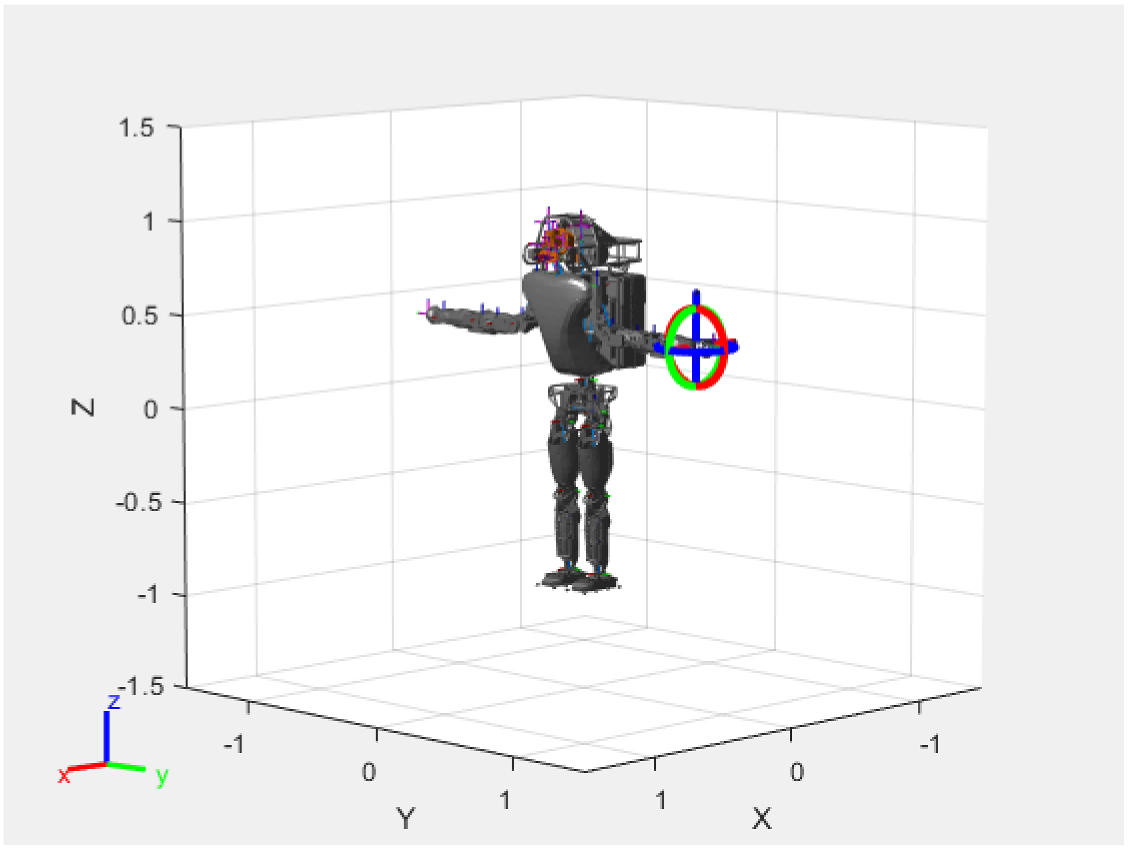
Use the `loadrobot` function to access provided robot models as `rigidBodyTree` objects.

```
robot = loadrobot("atlas");
```

Visualize Robot and Save Configurations

Create an interactive tree object and associated figure, specifying the loaded robot model and its left hand as the end effector.

```
viztree = interactiveRigidBodyTree(robot,"MarkerBodyName","l_hand");
```

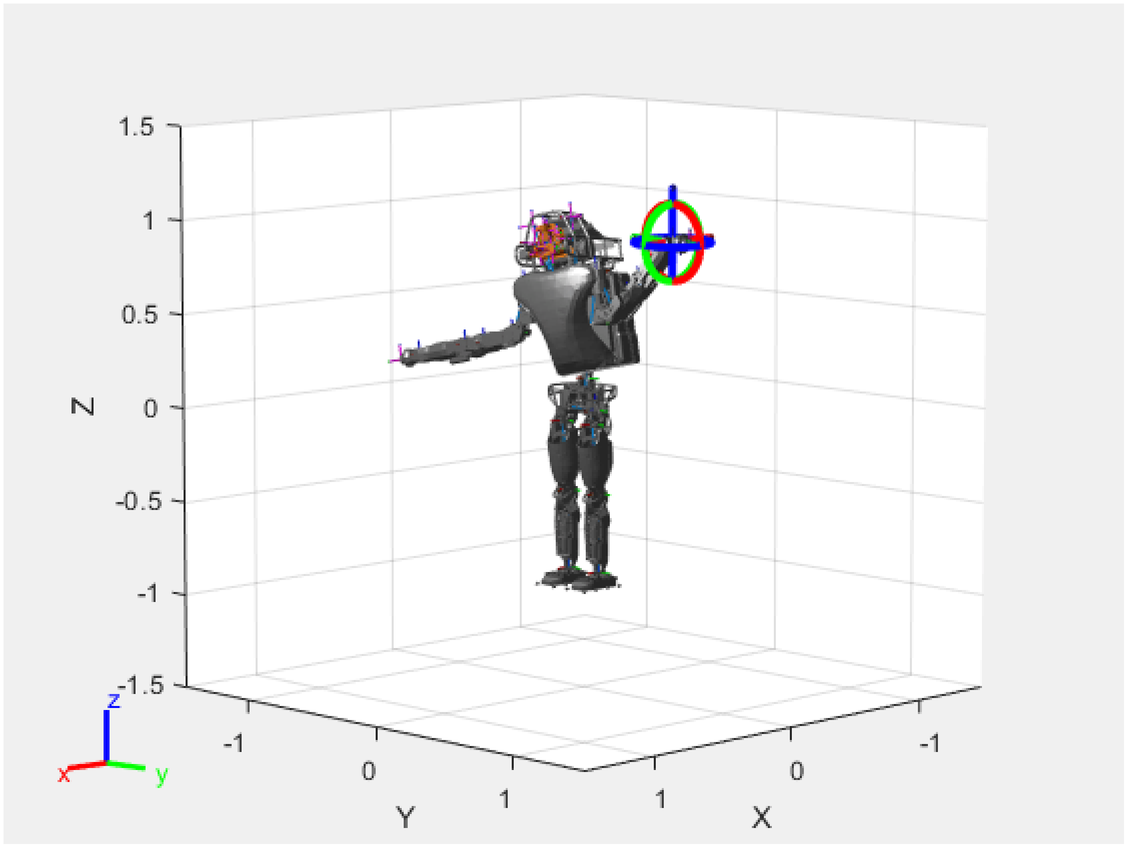


Click and drag the interactive marker to change the robot configuration. You can click and drag any of the axes for linear motion, rotate the body about an axis using the red, green, and blue circles, and drag the center of the interactive marker to position it in 3-D space.

The `interactiveRigidBodyTree` object uses inverse kinematics to determine a configuration that achieves the desired end-effector pose. If the associated rigid body cannot reach the marker, the figure renders the best configuration from the inverse kinematics solver.

Programmatically set the current configuration. Assign a vector of length equal to the number of nonfixed joints in the `RigidBodyTree` to the `Configuration` property.

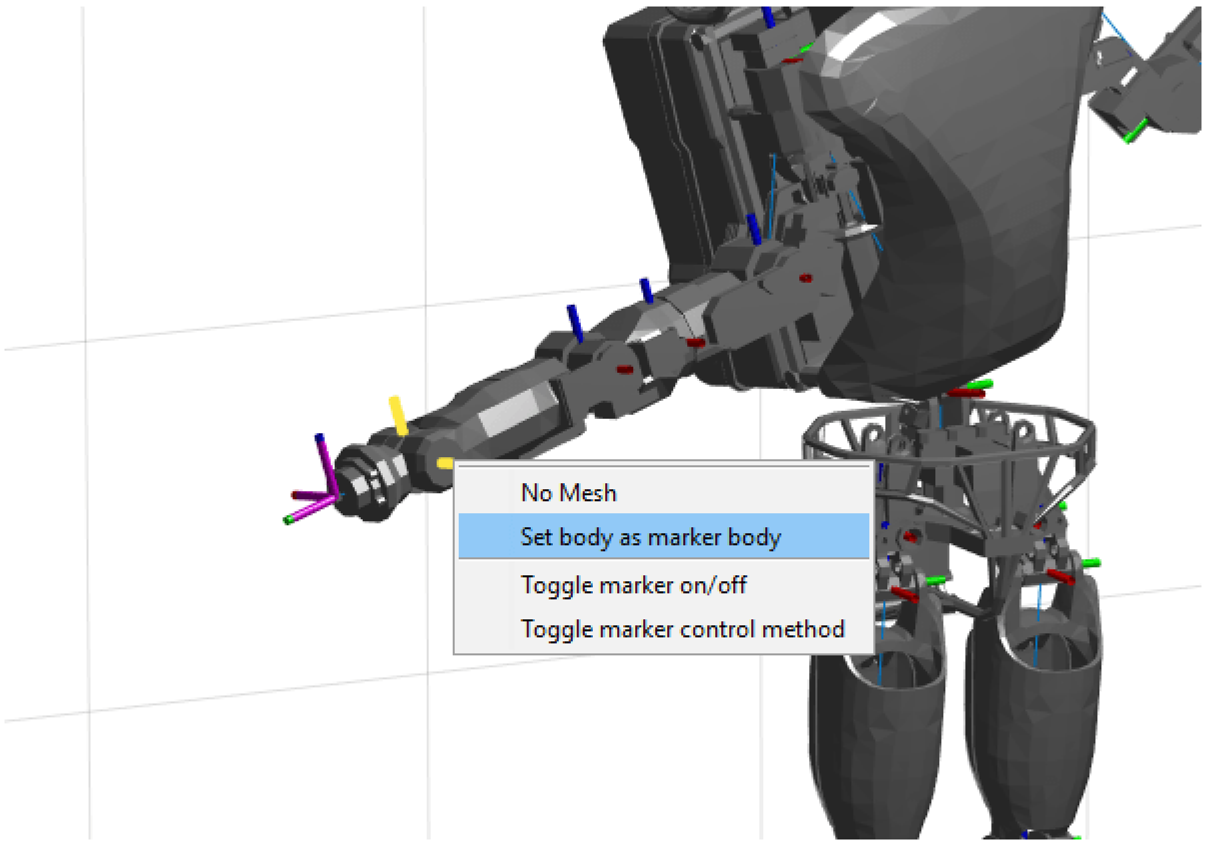
```
currConfig = homeConfiguration(viztree.RigidBodyTree);
currConfig(1:10) = [ 0.2201 -0.1319 0.2278 -0.3415 0.4996 ...
                     0.0747 0.0377 0.0718 -0.8117 -0.0427]';
viztree.Configuration = currConfig;
```



Save the current robot configuration in the `StoredConfigurations` property.

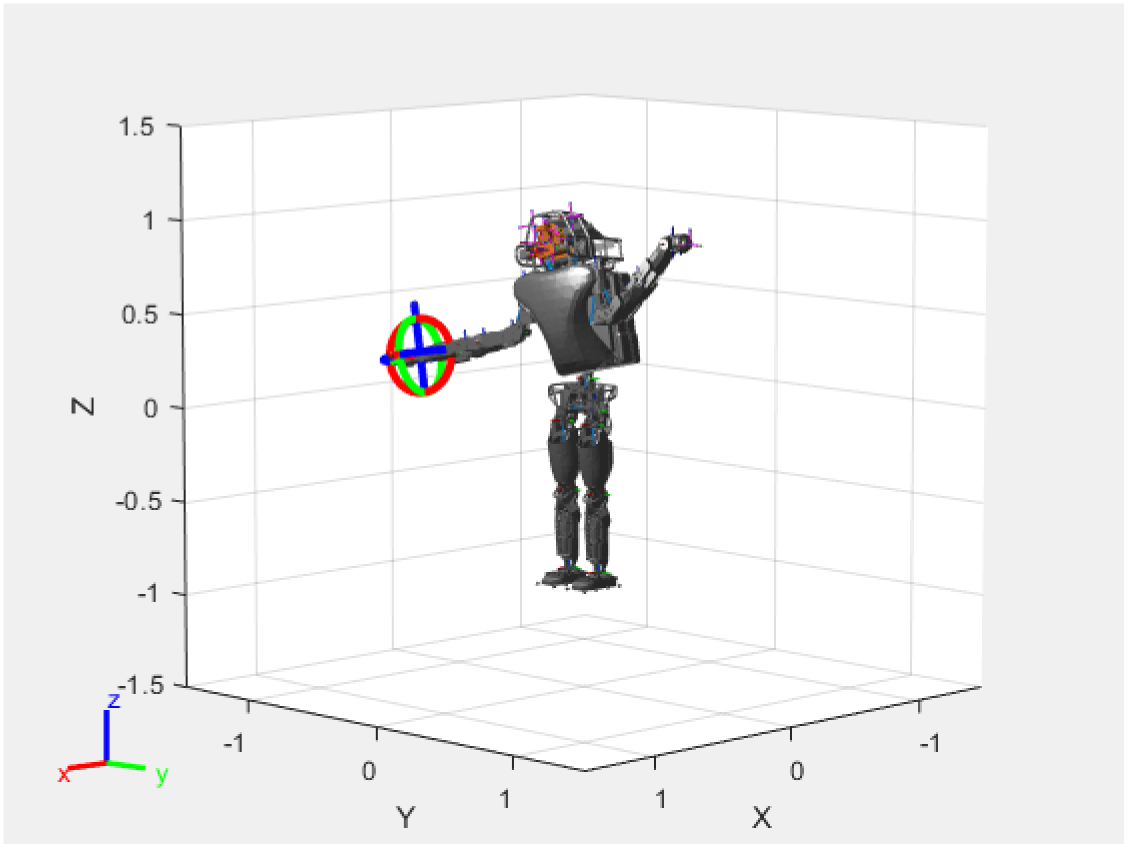
```
addConfiguration(viztree)
```

To switch the end effector to a different rigid body, right-click the desired body in the figure and select **Set body as marker body**. Use this process to select the right hand frame.



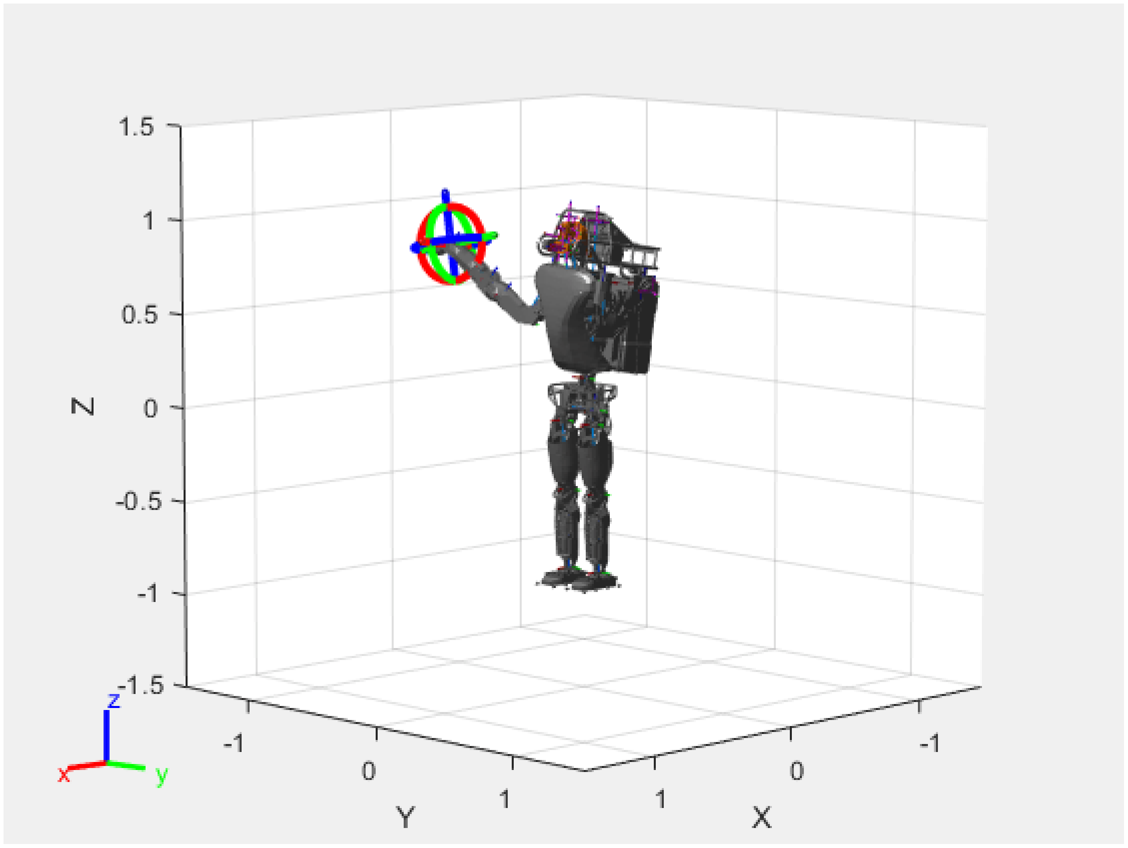
You can also set the `MarkerBodyName` property to the specific body name.

```
viztree.MarkerBodyName = "r_hand";
```



Move the right hand to a new position. Set the configuration programmatically. The marker moves to the new position of the end effector.

```
currConfig(1:18) = [-0.1350 -0.1498 -0.0167 -0.3415 0.4996 0.0747
                     0.0377 0.0718 -0.8117 -0.0427 0 0.4349
                    -0.5738 0.0563 -0.0095 0.0518 0.8762 -0.0895]';

viztree.Configuration = currConfig;
```



Save the current configuration.

```
addConfiguration(viztree)
```

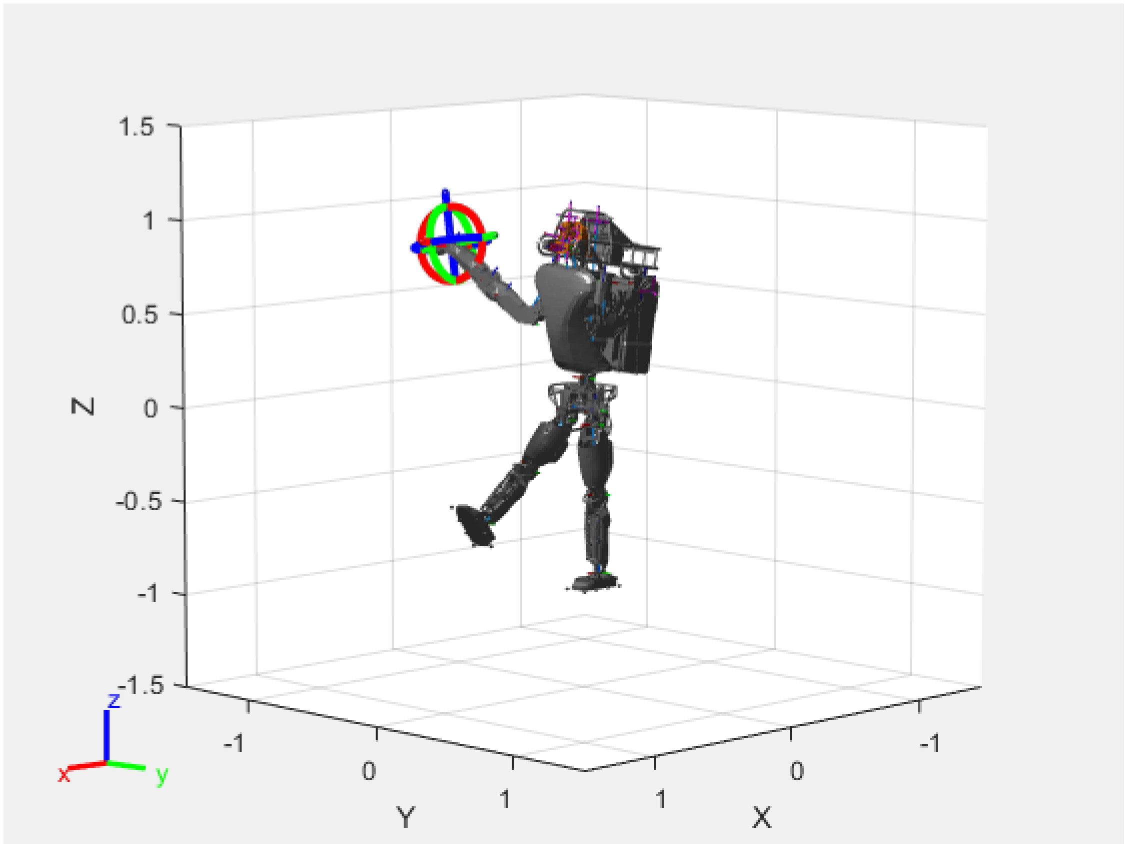
Add Constraints

By default, the robot model respects only the joint limits of the `rigidBodyJoint` objects associated with the `RigidBodyTree` property. To add constraints, generate **Robot Constraint** objects and specify them as a cell array in the `Constraints` property. To see a list of robotic constraints, see "Inverse Kinematics". Specify a pose target for the pelvis to keep it fixed to the home position. Specify a position target for the right foot to be raised in front front and above its current position.

```
fixedWaist = constraintPoseTarget("pelvis");
raiseRightLeg = constraintPositionTarget("r_foot","TargetPosition",[1 0 0.5]);
```

Apply these constraints to the interactive rigid body tree object as a cell array. The right leg in the resulting figure changes position.

```
viztree.Constraints = {fixedWaist raiseRightLeg};
```



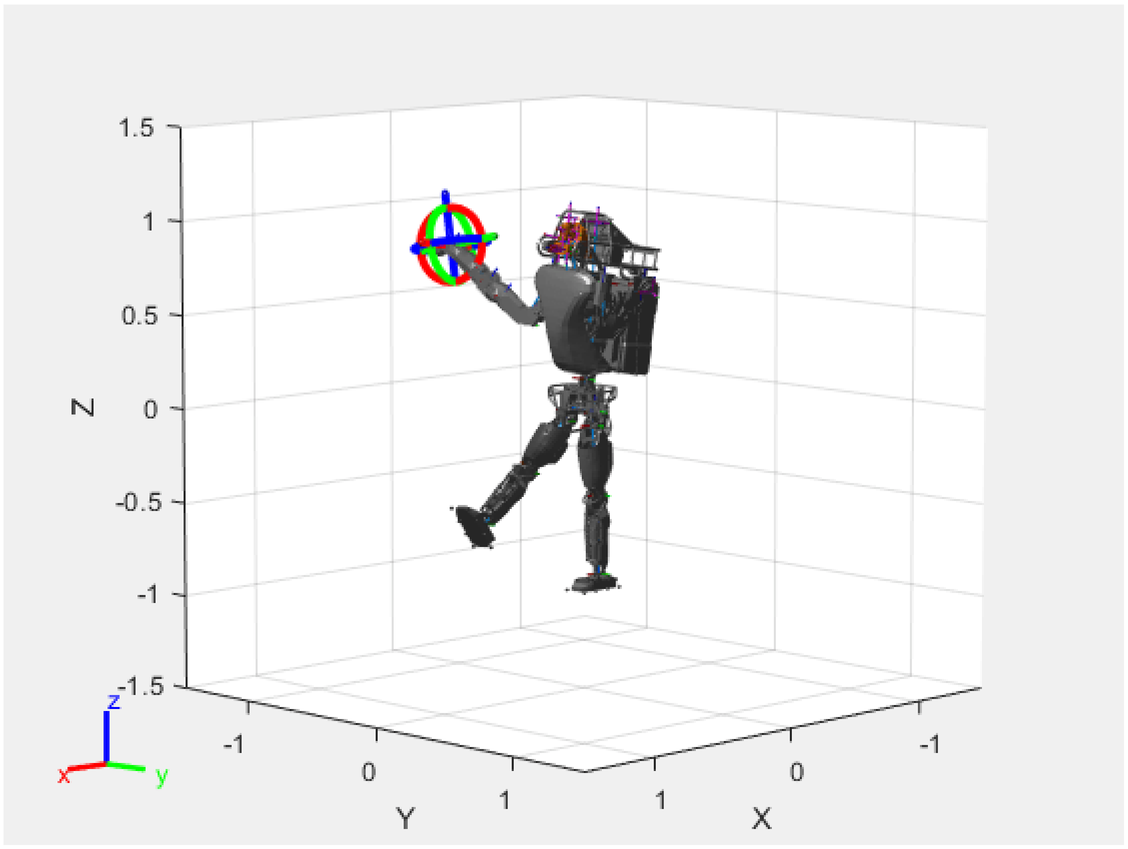
Notice the change in position of the right leg. Save this configuration as well.

```
addConfiguration(viztree)
```

Play Back Configurations

To play back configurations, iterate through the stored configurations index and set the current configuration equal to the stored configuration column vector at each iteration. Because configurations are stored as column vectors, use the second dimension of the matrix.

```
for i = 1:size(viztree.StoredConfigurations,2)
    viztree.Configuration = viztree.StoredConfigurations(:,i);
    pause(0.5)
end
```



Input Arguments

`viztree` — Interactive rigid body tree robot model visualization
`interactiveRigidBodyTree` object

Interactive rigid body tree robot model visualization, specified as an `interactiveRigidBodyTree` object.

`index` — Index locations to remove configurations
positive integer | vector of positive integers

Index locations to remove configurations, specified as a positive integer or vector of positive integers.

Data Types: `double`

See Also

Functions
`addConfiguration` | `loadrobot` | `importrobot` | `homeConfiguration`

Objects
`interactiveRigidBodyTree` | `rigidBodyTree` | `rigidBody` | `rigidBodyJoint` | `generalizedInverseKinematics`

Topics
"Rigid Body Tree Robot Model"

“Plan a Reaching Trajectory With Multiple Kinematic Constraints”
“Trajectory Control Modeling with Inverse Kinematics”

Introduced in R2020a

removeConstraints

Remove inverse kinematics constraints

Syntax

```
removeConstraints(viztree)
removeConstraints(viztree,index)
```

Description

`removeConstraints(viztree)`removes the constraint stored at the last index of the `Constraints` property of the `interactiveRigidBodyTree` object, `viztree`.

`removeConstraints(viztree,index)` removes the constraints with the specified indices.

Examples

Interactively Build and Play Back Series of Robot Configurations

Use the `interactiveRigidBodyTree` object to manually move around a robot in a figure. The object uses interactive markers in the figure to track the desired poses of different rigid bodies in the `rigidBodyTree` object.

Load Robot Model

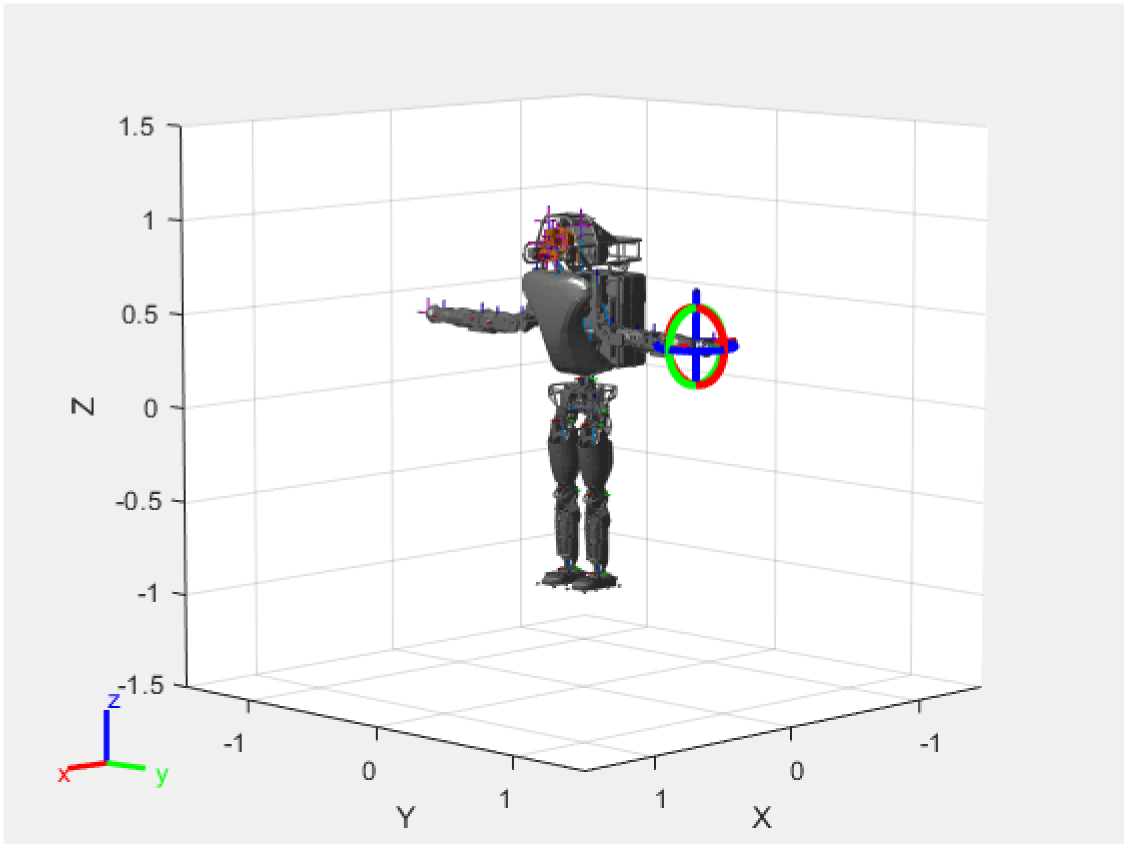
Use the `loadrobot` function to access provided robot models as `rigidBodyTree` objects.

```
robot = loadrobot("atlas");
```

Visualize Robot and Save Configurations

Create an interactive tree object and associated figure, specifying the loaded robot model and its left hand as the end effector.

```
viztree = interactiveRigidBodyTree(robot,"MarkerBodyName","l_hand");
```

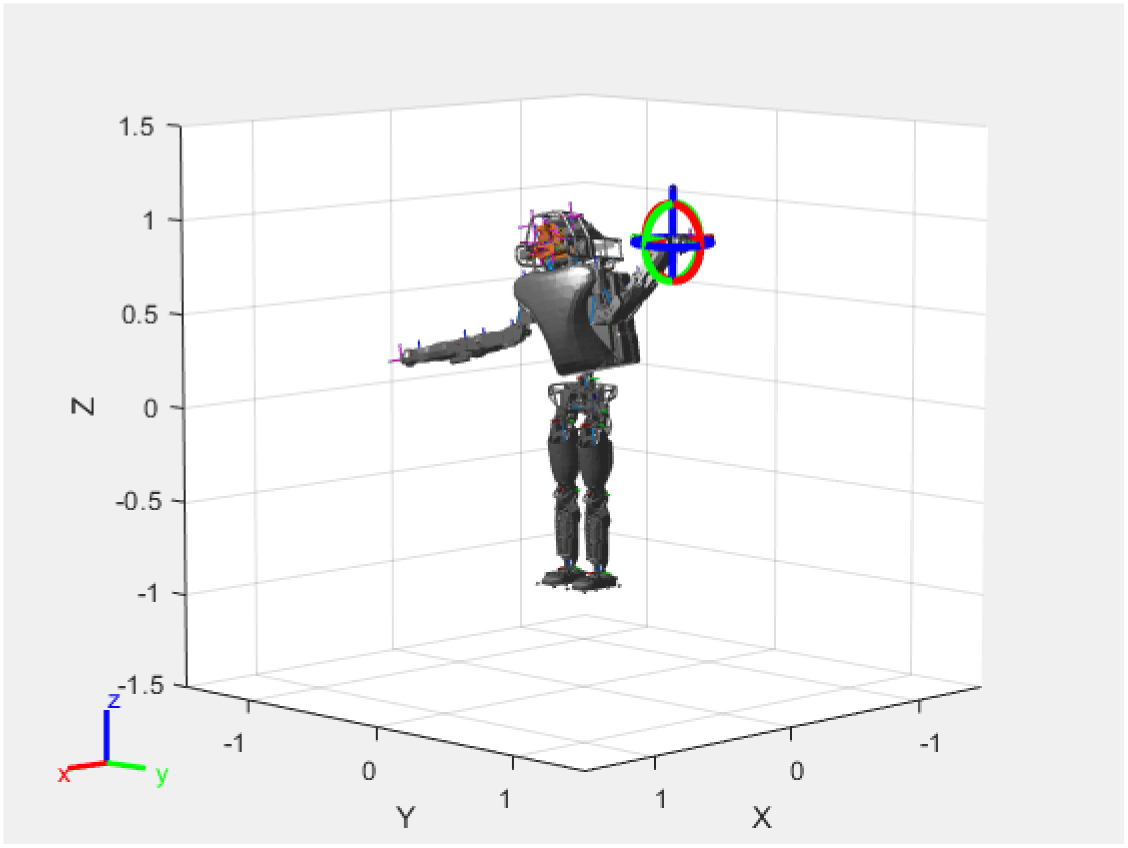


Click and drag the interactive marker to change the robot configuration. You can click and drag any of the axes for linear motion, rotate the body about an axis using the red, green, and blue circles, and drag the center of the interactive marker to position it in 3-D space.

The `interactiveRigidBodyTree` object uses inverse kinematics to determine a configuration that achieves the desired end-effector pose. If the associated rigid body cannot reach the marker, the figure renders the best configuration from the inverse kinematics solver.

Programmatically set the current configuration. Assign a vector of length equal to the number of nonfixed joints in the `RigidBodyTree` to the `Configuration` property.

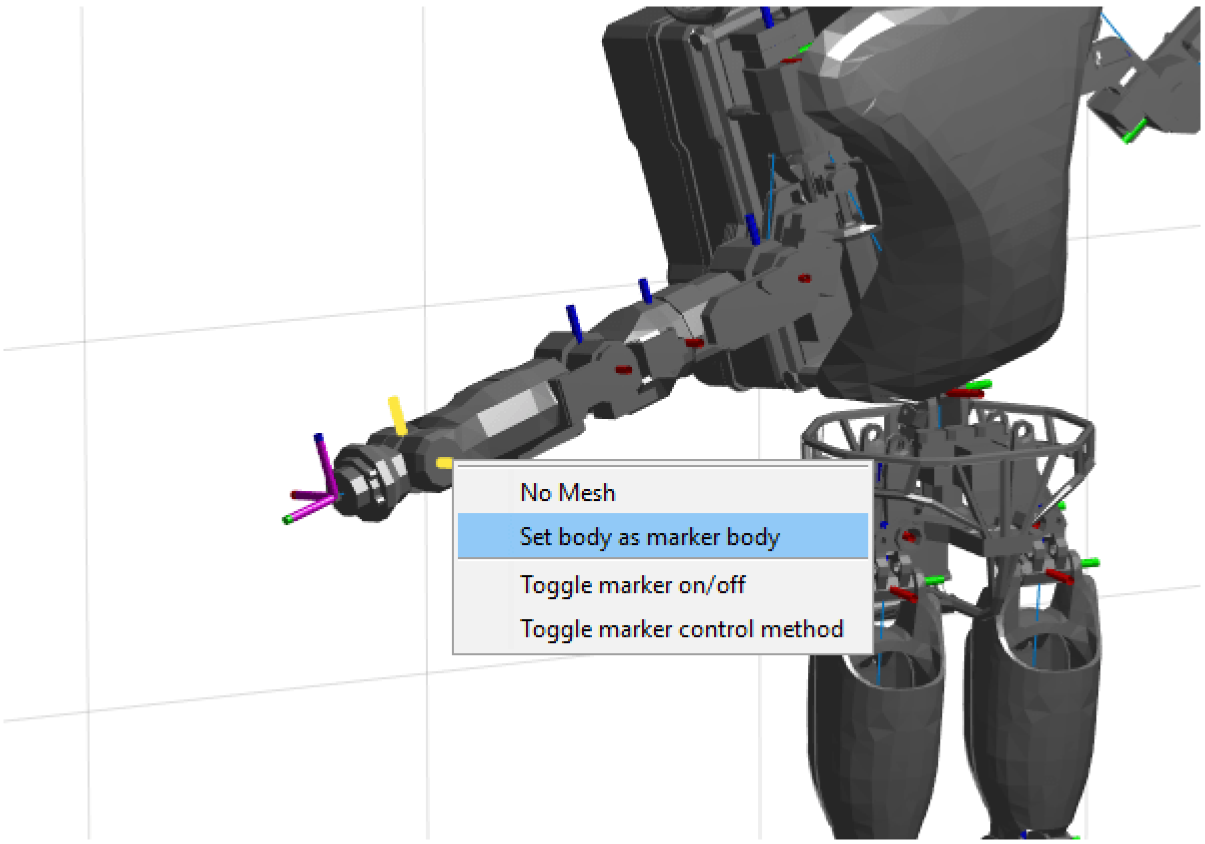
```
currConfig = homeConfiguration(viztree.RigidBodyTree);
currConfig(1:10) = [ 0.2201 -0.1319 0.2278 -0.3415 0.4996 ...
                     0.0747 0.0377 0.0718 -0.8117 -0.0427]';
viztree.Configuration = currConfig;
```



Save the current robot configuration in the `StoredConfigurations` property.

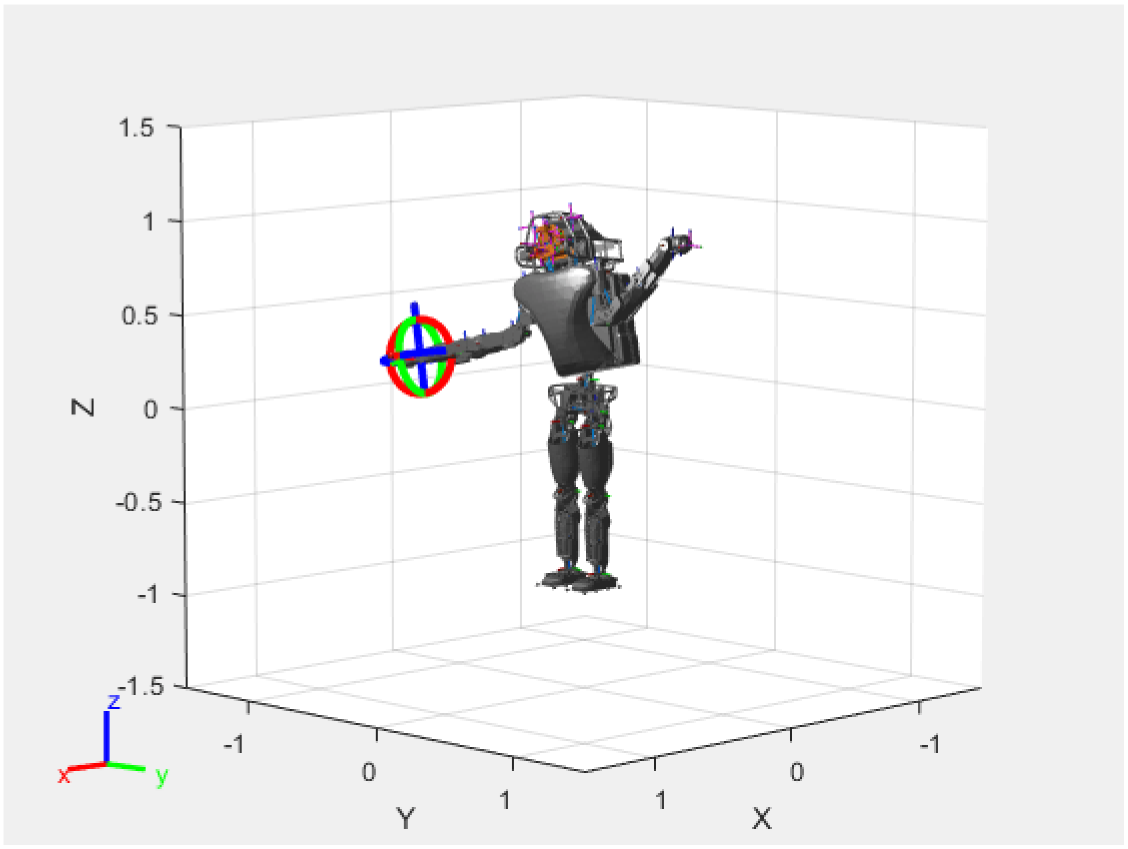
```
addConfiguration(viztree)
```

To switch the end effector to a different rigid body, right-click the desired body in the figure and select **Set body as marker body**. Use this process to select the right hand frame.



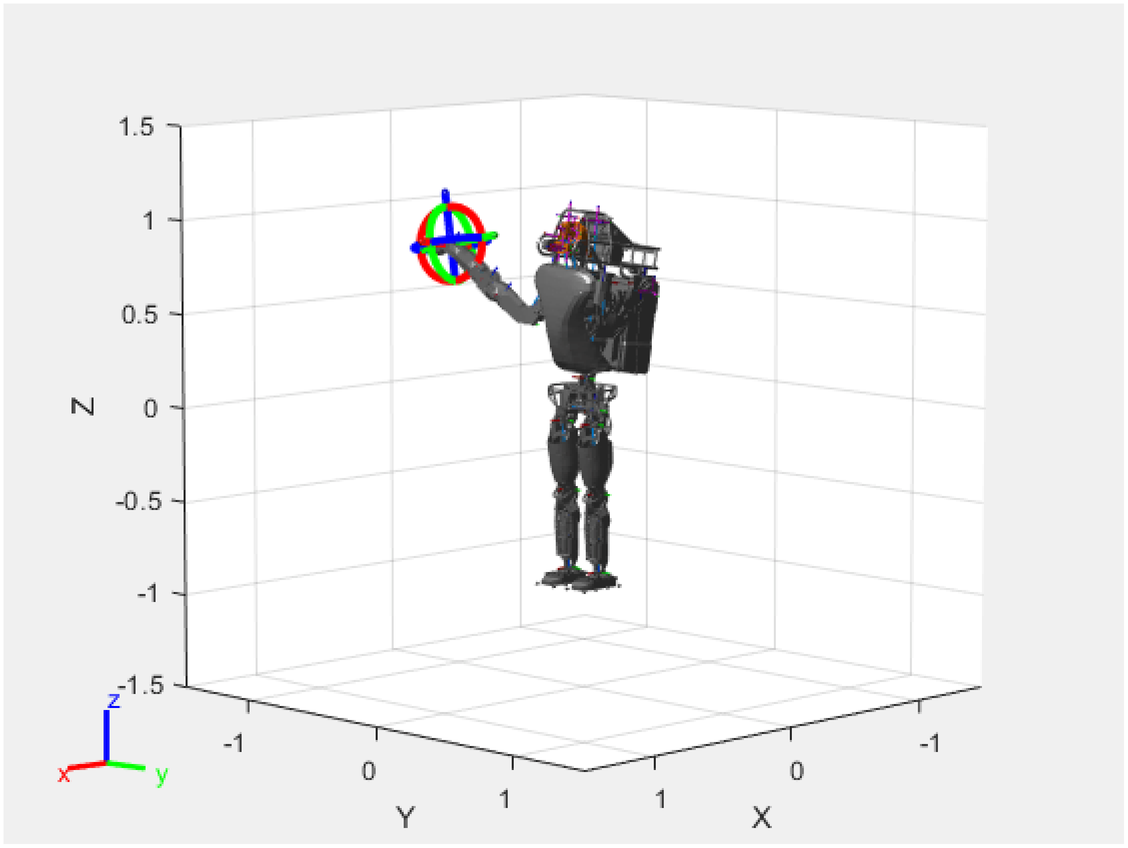
You can also set the `MarkerBodyName` property to the specific body name.

```
viztree.MarkerBodyName = "r_hand";
```



Move the right hand to a new position. Set the configuration programmatically. The marker moves to the new position of the end effector.

```
currConfig(1:18) = [-0.1350 -0.1498 -0.0167 -0.3415 0.4996 0.0747
                     0.0377 0.0718 -0.8117 -0.0427 0 0.4349
                    -0.5738 0.0563 -0.0095 0.0518 0.8762 -0.0895]';

viztree.Configuration = currConfig;
```



Save the current configuration.

```
addConfiguration(viztree)
```

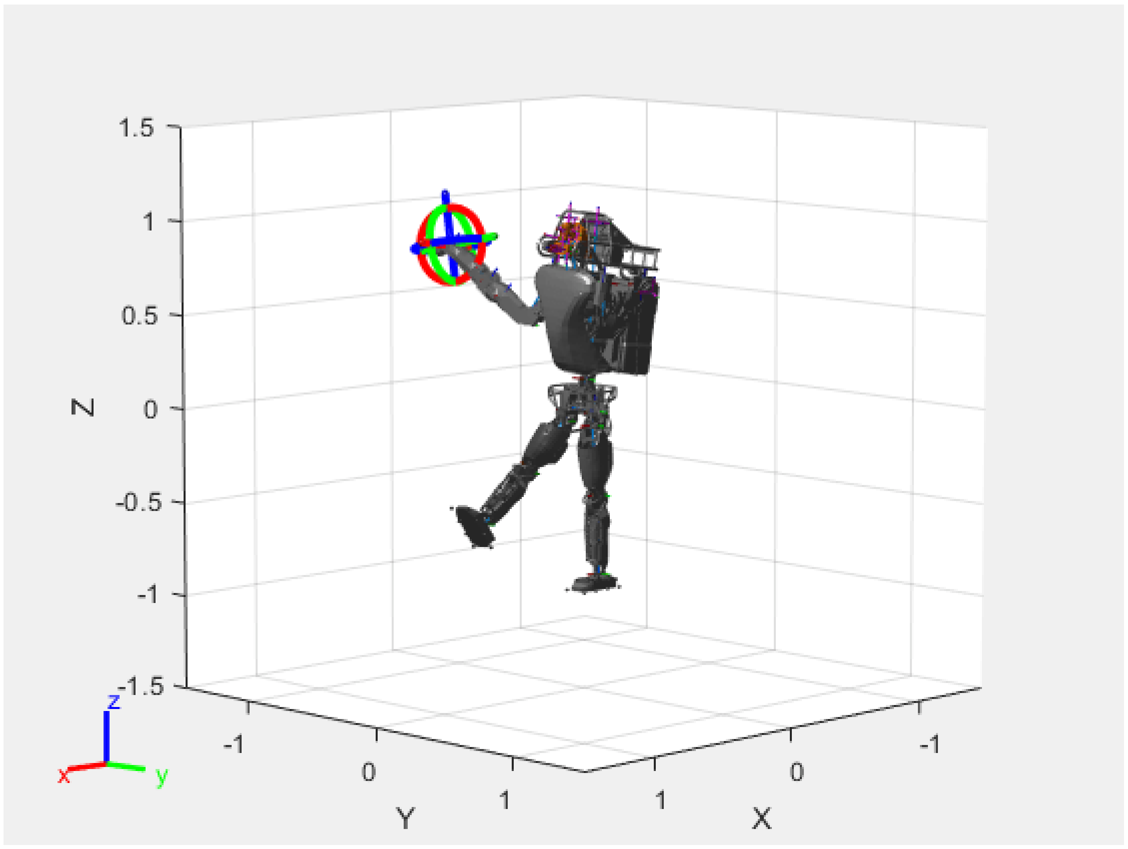
Add Constraints

By default, the robot model respects only the joint limits of the `rigidBodyJoint` objects associated with the `RigidBodyTree` property. To add constraints, generate **Robot Constraint** objects and specify them as a cell array in the `Constraints` property. To see a list of robotic constraints, see "Inverse Kinematics". Specify a pose target for the pelvis to keep it fixed to the home position. Specify a position target for the right foot to be raised in front front and above its current position.

```
fixedWaist = constraintPoseTarget("pelvis");
raiseRightLeg = constraintPositionTarget("r_foot","TargetPosition",[1 0 0.5]);
```

Apply these constraints to the interactive rigid body tree object as a cell array. The right leg in the resulting figure changes position.

```
viztree.Constraints = {fixedWaist raiseRightLeg};
```



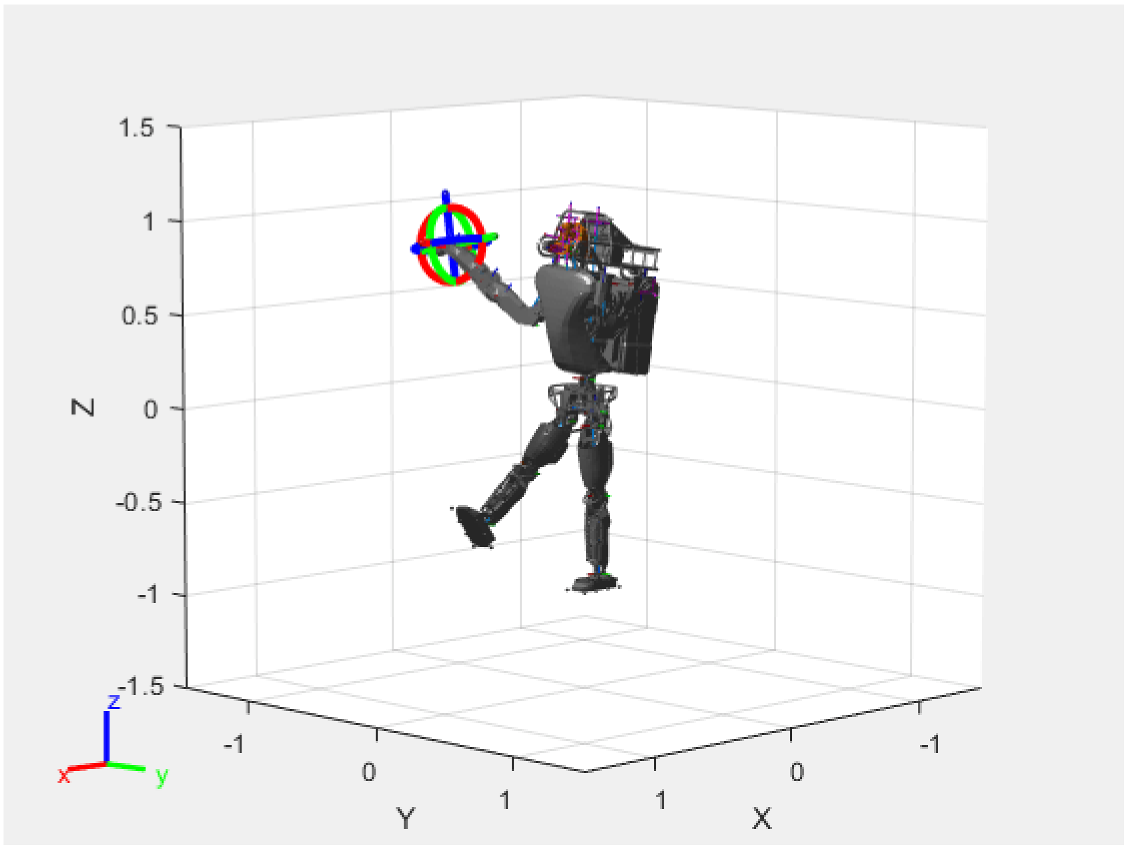
Notice the change in position of the right leg. Save this configuration as well.

```
addConfiguration(viztree)
```

Play Back Configurations

To play back configurations, iterate through the stored configurations index and set the current configuration equal to the stored configuration column vector at each iteration. Because configurations are stored as column vectors, use the second dimension of the matrix.

```
for i = 1:size(viztree.StoredConfigurations,2)
    viztree.Configuration = viztree.StoredConfigurations(:,i);
    pause(0.5)
end
```



Input Arguments

`viztree` — Interactive rigid body tree robot model visualization
`interactiveRigidBodyTree` object

Interactive rigid body tree robot model visualization, specified as an `interactiveRigidBodyTree` object.

`index` — Index locations to remove configurations
positive integer | vector of positive integers

Index locations to remove configurations, specified as a positive integer or vector of positive integers.

Data Types: `double`

See Also

Functions
`addConstraint` | `loadrobot` | `importrobot` | `homeConfiguration`

Objects
`interactiveRigidBodyTree` | `rigidBodyTree` | `rigidBody` | `rigidBodyJoint` | `generalizedInverseKinematics`

Topics
“Rigid Body Tree Robot Model”

“Plan a Reaching Trajectory With Multiple Kinematic Constraints”
“Trajectory Control Modeling with Inverse Kinematics”

Introduced in R2020a

showFigure

Show interactive rigid body tree figure

Syntax

```
showFigure(viztree)
```

Description

`showFigure(viztree)` shows the figure associated with the `interactiveRigidBodyTree` object, `viztree`. If the figure window is open, the function brings it into focus. If the figure window is not open, the function opens it and brings it into focus.

Examples

Interactively Build and Play Back Series of Robot Configurations

Use the `interactiveRigidBodyTree` object to manually move around a robot in a figure. The object uses interactive markers in the figure to track the desired poses of different rigid bodies in the `rigidBodyTree` object.

Load Robot Model

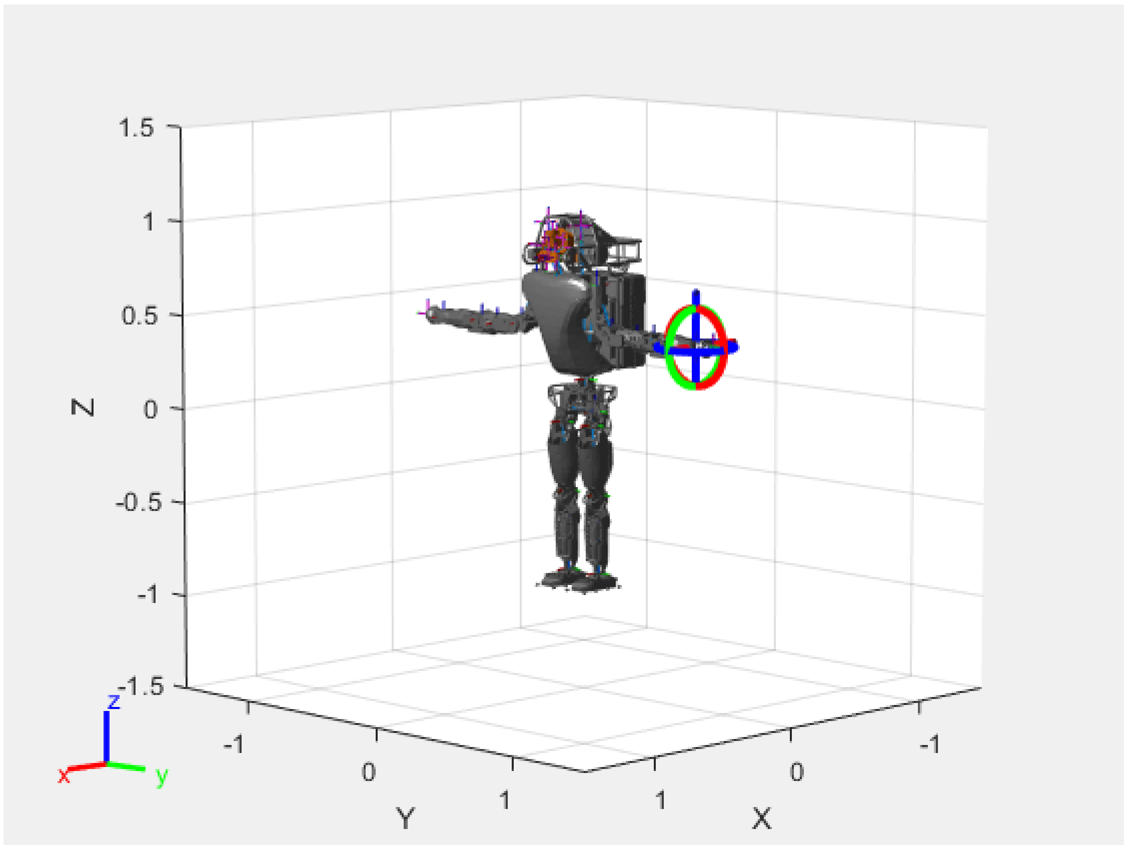
Use the `loadrobot` function to access provided robot models as `rigidBodyTree` objects.

```
robot = loadrobot("atlas");
```

Visualize Robot and Save Configurations

Create an interactive tree object and associated figure, specifying the loaded robot model and its left hand as the end effector.

```
viztree = interactiveRigidBodyTree(robot,"MarkerBodyName","l_hand");
```

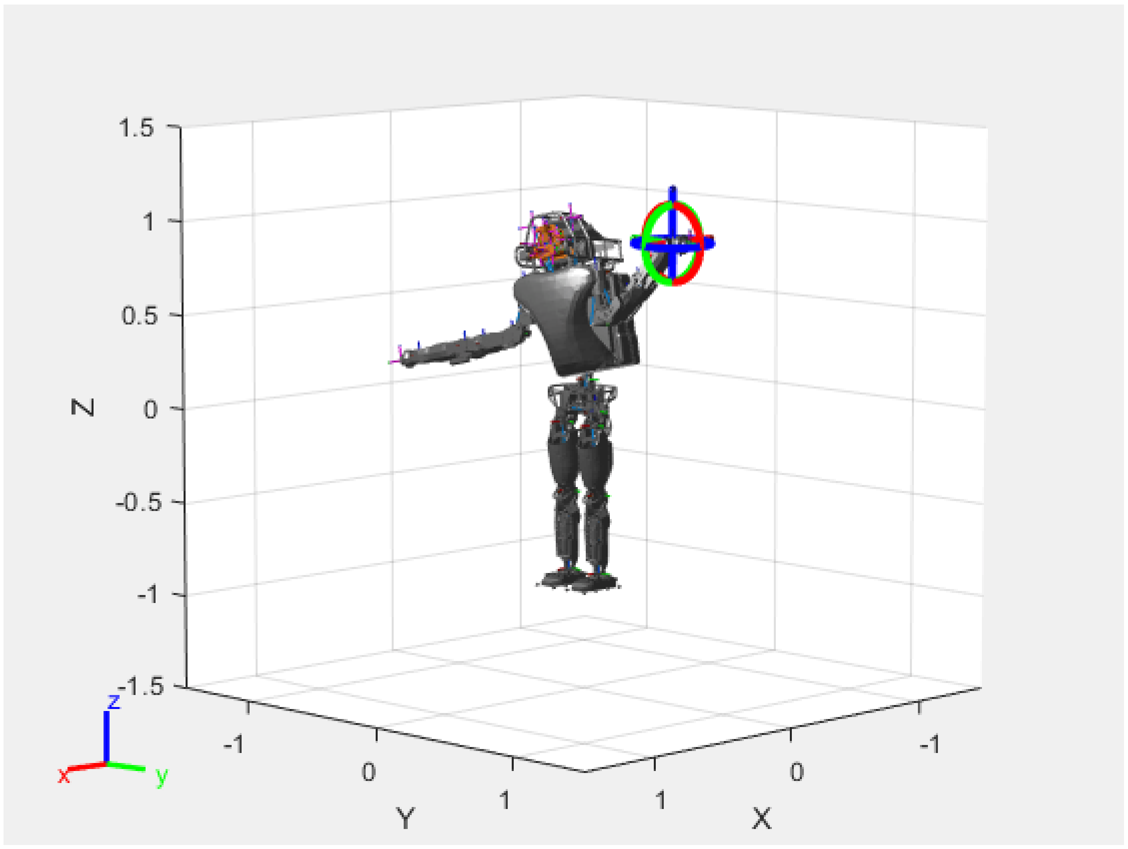


Click and drag the interactive marker to change the robot configuration. You can click and drag any of the axes for linear motion, rotate the body about an axis using the red, green, and blue circles, and drag the center of the interactive marker to position it in 3-D space.

The `interactiveRigidBodyTree` object uses inverse kinematics to determine a configuration that achieves the desired end-effector pose. If the associated rigid body cannot reach the marker, the figure renders the best configuration from the inverse kinematics solver.

Programmatically set the current configuration. Assign a vector of length equal to the number of nonfixed joints in the `RigidBodyTree` to the `Configuration` property.

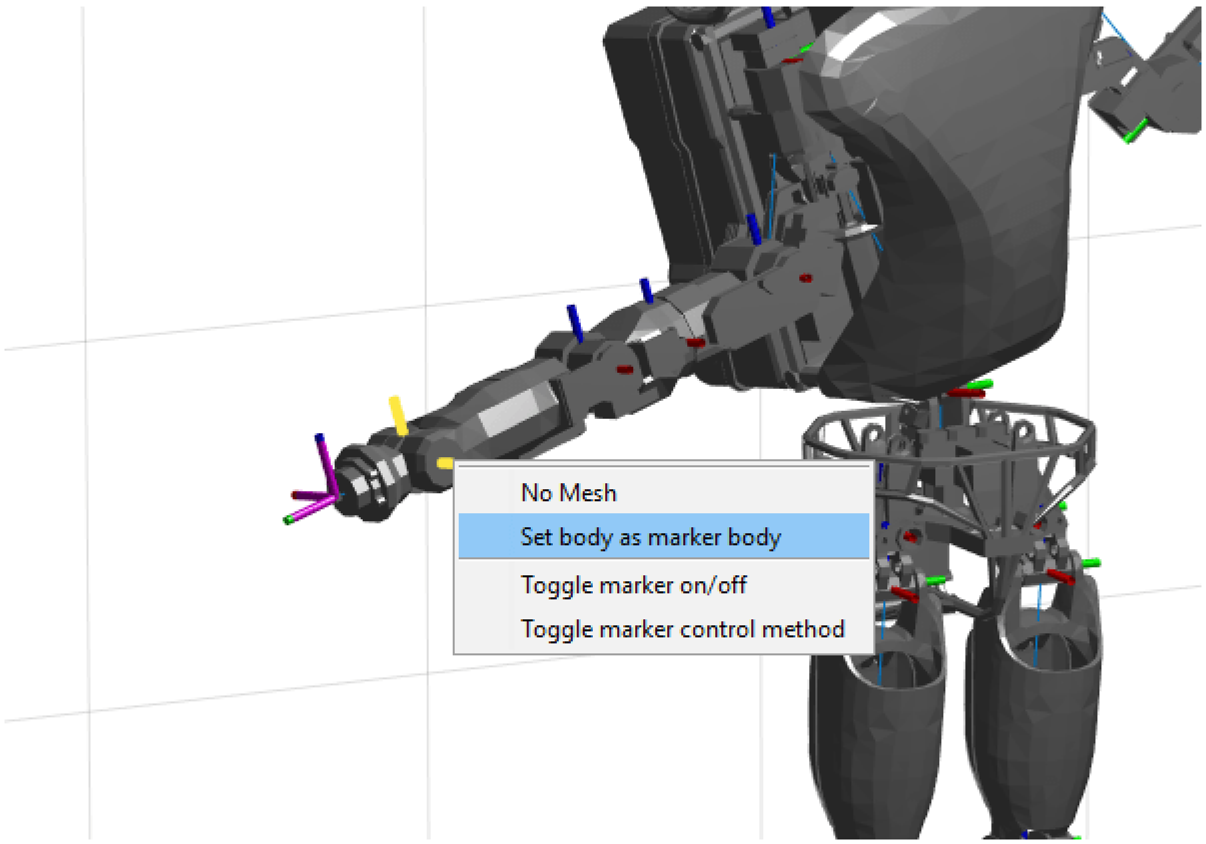
```
currConfig = homeConfiguration(viztree.RigidBodyTree);
currConfig(1:10) = [ 0.2201 -0.1319 0.2278 -0.3415 0.4996 ...
                     0.0747 0.0377 0.0718 -0.8117 -0.0427]';
viztree.Configuration = currConfig;
```



Save the current robot configuration in the `StoredConfigurations` property.

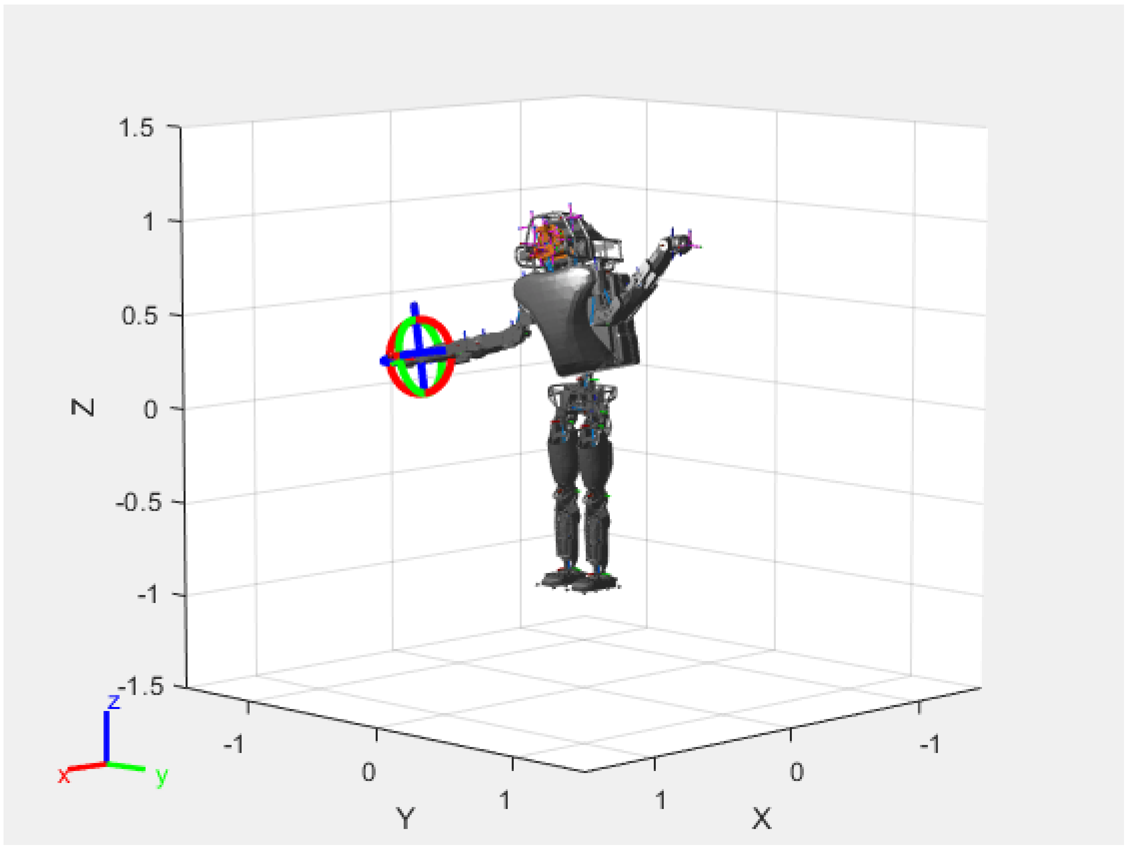
```
addConfiguration(viztree)
```

To switch the end effector to a different rigid body, right-click the desired body in the figure and select **Set body as marker body**. Use this process to select the right hand frame.



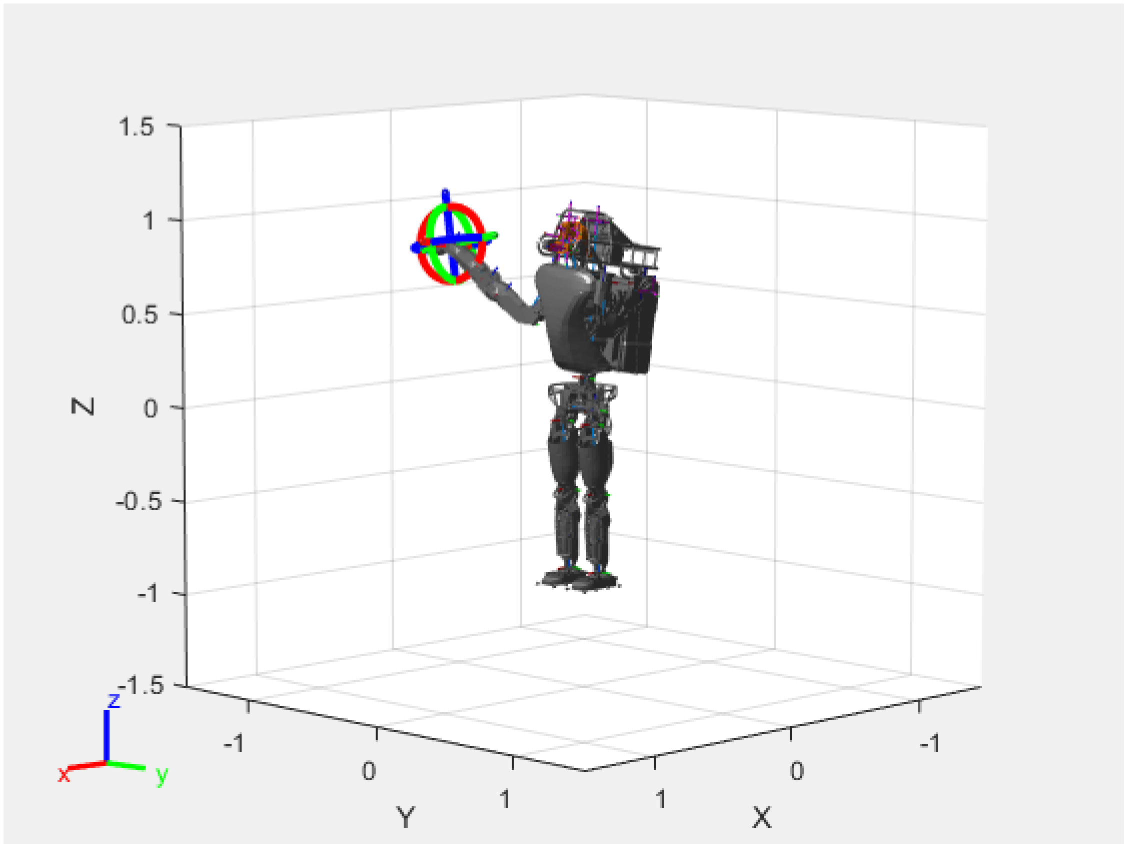
You can also set the `MarkerBodyName` property to the specific body name.

```
viztree.MarkerBodyName = "r_hand";
```



Move the right hand to a new position. Set the configuration programmatically. The marker moves to the new position of the end effector.

```
currConfig(1:18) = [-0.1350 -0.1498 -0.0167 -0.3415 0.4996 0.0747
                     0.0377 0.0718 -0.8117 -0.0427 0 0.4349
                    -0.5738 0.0563 -0.0095 0.0518 0.8762 -0.0895]';

viztree.Configuration = currConfig;
```



Save the current configuration.

```
addConfiguration(viztree)
```

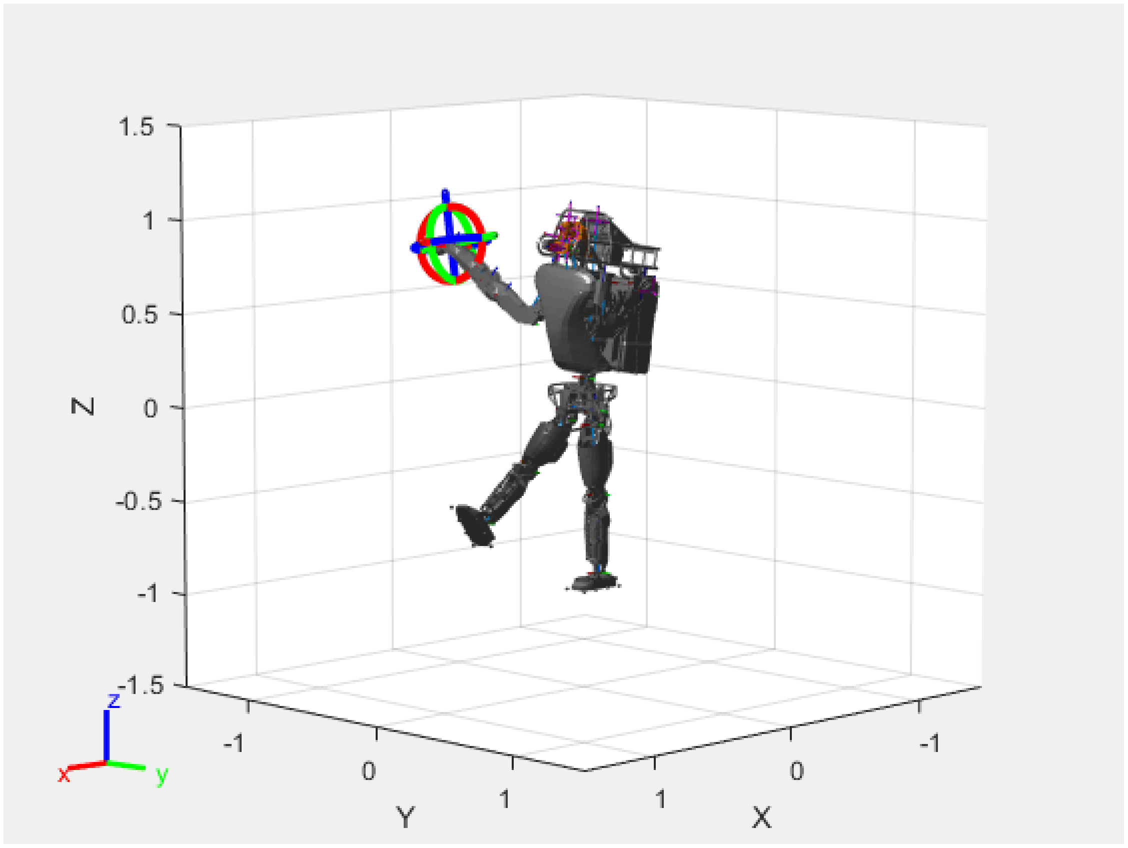
Add Constraints

By default, the robot model respects only the joint limits of the `rigidBodyJoint` objects associated with the `RigidBodyTree` property. To add constraints, generate **Robot Constraint** objects and specify them as a cell array in the `Constraints` property. To see a list of robotic constraints, see "Inverse Kinematics". Specify a pose target for the pelvis to keep it fixed to the home position. Specify a position target for the right foot to be raised in front front and above its current position.

```
fixedWaist = constraintPoseTarget("pelvis");
raiseRightLeg = constraintPositionTarget("r_foot","TargetPosition",[1 0 0.5]);
```

Apply these constraints to the interactive rigid body tree object as a cell array. The right leg in the resulting figure changes position.

```
viztree.Constraints = {fixedWaist raiseRightLeg};
```



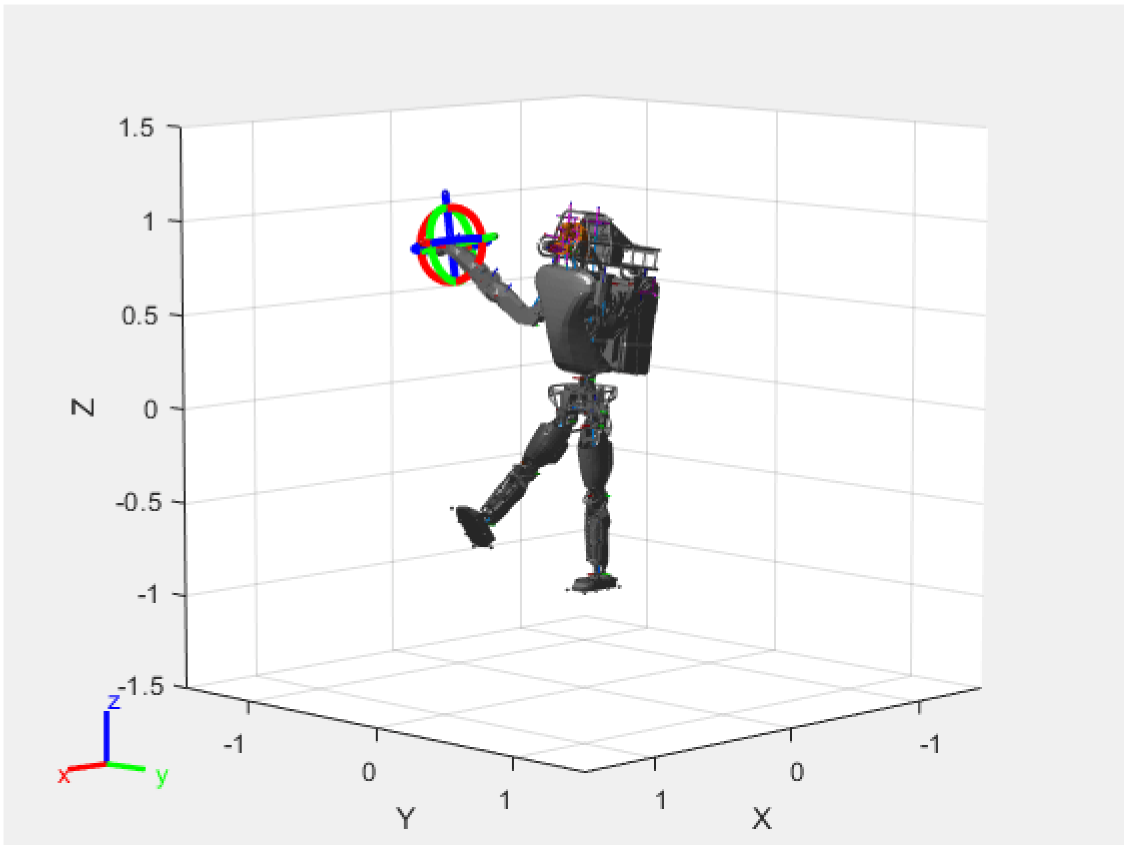
Notice the change in position of the right leg. Save this configuration as well.

```
addConfiguration(viztree)
```

Play Back Configurations

To play back configurations, iterate through the stored configurations index and set the current configuration equal to the stored configuration column vector at each iteration. Because configurations are stored as column vectors, use the second dimension of the matrix.

```
for i = 1:size(viztree.StoredConfigurations,2)
    viztree.Configuration = viztree.StoredConfigurations(:,i);
    pause(0.5)
end
```



Input Arguments

`viztree` — Interactive rigid body tree robot model visualization
`interactiveRigidBodyTree` object

Interactive rigid body tree robot model visualization, specified as an `interactiveRigidBodyTree` object.

See Also

Functions
`loadrobot` | `importrobot` | `homeConfiguration`

Objects
`interactiveRigidBodyTree` | `rigidBodyTree` | `rigidBody` | `rigidBodyJoint` | `generalizedInverseKinematics`

Topics
“Rigid Body Tree Robot Model”
“Plan a Reaching Trajectory With Multiple Kinematic Constraints”
“Trajectory Control Modeling with Inverse Kinematics”

Introduced in R2020a

removeInvalidData

Remove invalid range and angle data

Syntax

```
validScan = removeInvalidData(scan)
validScan = removeInvalidData(scan,Name,Value)
```

Description

`validScan = removeInvalidData(scan)` returns a new `lidarScan` object with all `Inf` and `NaN` values from the input `scan` removed. The corresponding angle readings are also removed.

`validScan = removeInvalidData(scan,Name,Value)` provides additional options specified by one or more `Name,Value` pairs.

Examples

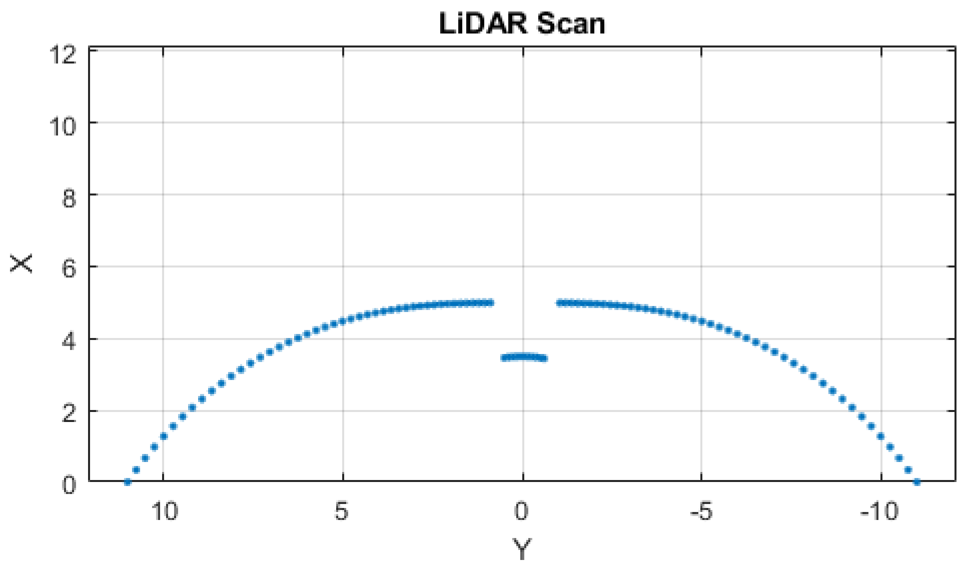
Plot Lidar Scan and Remove Invalid Points

Specify lidar data as vectors of ranges and angles. These values include readings outside of the sensors range.

```
x = linspace(-2,2);
ranges = abs((1.5).*x.^2 + 5);
ranges(45:55) = 3.5;
angles = linspace(-pi/2,pi/2,numel(ranges));
```

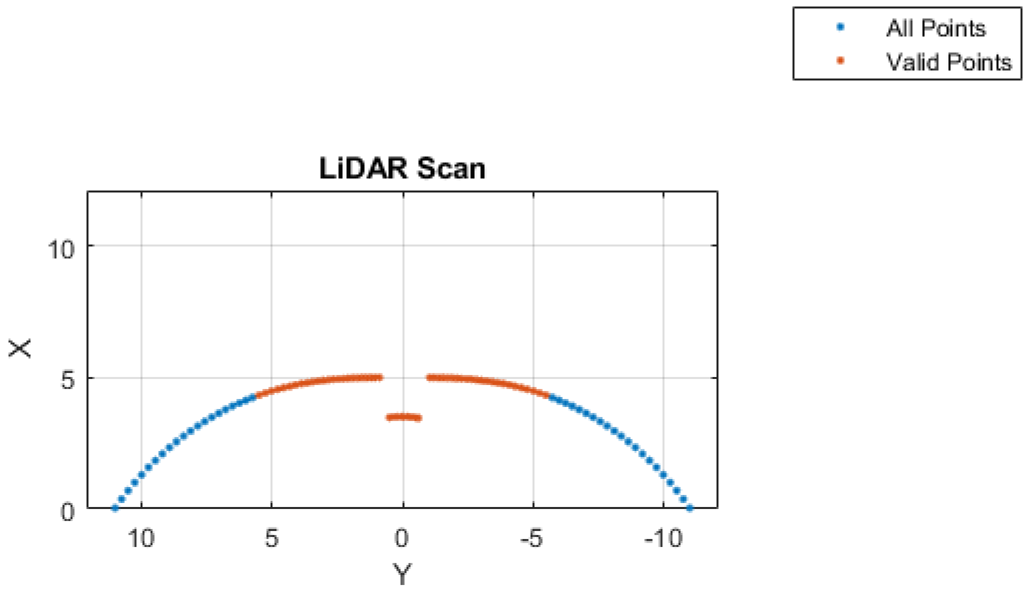
Create a lidar scan by specifying the ranges and angles. Plot all points of the lidar scan.

```
scan = lidarScan(ranges,angles);
plot(scan)
```



Remove invalid points based on a specified minimum and maximum range.

```
minRange = 0.1;
maxRange = 7;
scan2 = removeInvalidData(scan,'RangeLimits',[minRange maxRange]);
hold on
plot(scan2)
legend('All Points','Valid Points')
```



Input Arguments

`scan` — Lidar scan readings
`lidarScan` object

Lidar scan readings, specified as a `lidarScan` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `["RangeLimits",[0.05 2]`

`RangeLimits` — Range reading limits
two-element vector

Range reading limits, specified as a two-element vector, `[minRange maxRange]`, in meters. All range readings and corresponding angles outside these range limits are removed

Data Types: `single` | `double`

`AngleLimits` — Angle limits
two-element vector

Angle limits, specified as a two-element vector, `[minAngle maxAngle]` in radians. All angles and corresponding range readings outside these angle limits are removed.

Angles are measured counter-clockwise around the positive*z*-axis.

Data Types: `single` | `double`

Output Arguments

`validScan` — Lidar scan readings
`lidarScan` object

Lidar scan readings, specified as a `lidarScan` object. All invalid lidar scan readings are removed.

See Also

`transformScan`

Introduced in R2017b

plot

Display laser or lidar scan readings

Syntax

```
plot(scanObj)
plot( ___ ,Name,Value)
linehandle = plot( ___ )
```

Description

`plot(scanObj)` plots the lidar scan readings specified in `scanObj`.

`plot( ___ ,Name,Value)` provides additional options specified by one or more `Name,Value` pair arguments.

`linehandle = plot( ___ )` returns a column vector of line series handles, using any of the arguments from previous syntaxes. Use `linehandle` to modify properties of the line series after it is created.

Examples

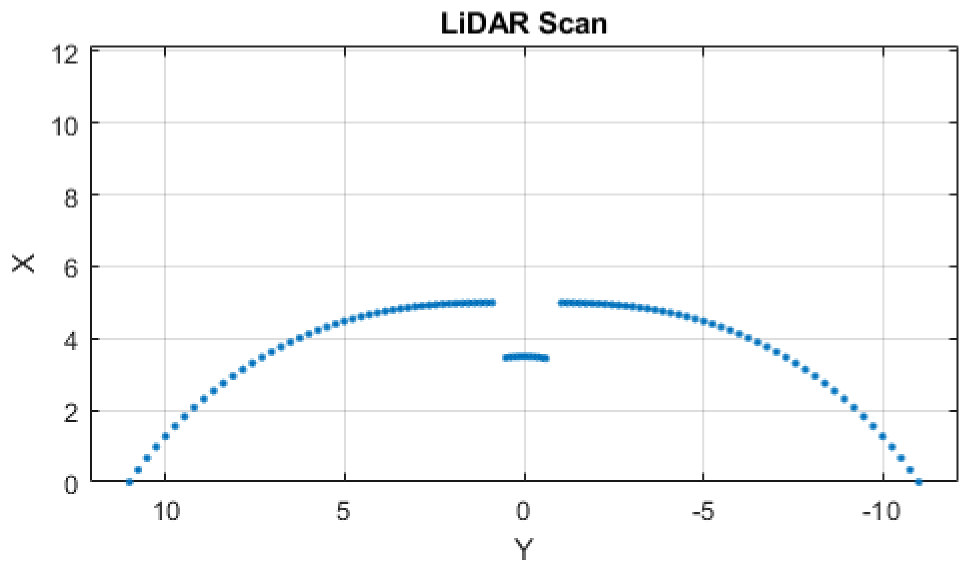
Plot Lidar Scan and Remove Invalid Points

Specify lidar data as vectors of ranges and angles. These values include readings outside of the sensors range.

```
x = linspace(-2,2);
ranges = abs((1.5).*x.^2 + 5);
ranges(45:55) = 3.5;
angles = linspace(-pi/2,pi/2,numel(ranges));
```

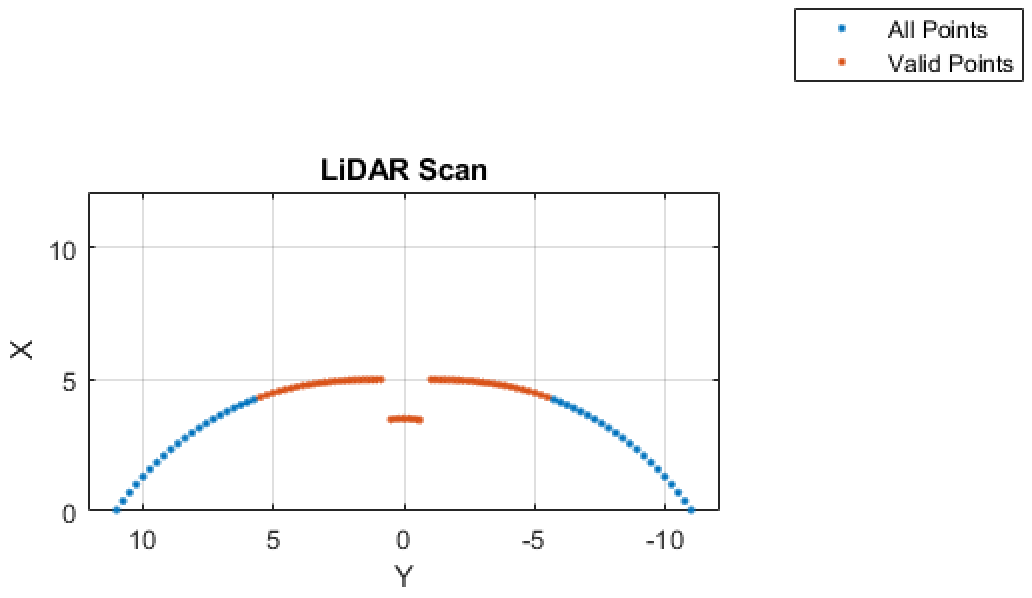
Create a lidar scan by specifying the ranges and angles. Plot all points of the lidar scan.

```
scan = lidarScan(ranges,angles);
plot(scan)
```



Remove invalid points based on a specified minimum and maximum range.

```
minRange = 0.1;
maxRange = 7;
scan2 = removeInvalidData(scan,'RangeLimits',[minRange maxRange]);
hold on
plot(scan2)
legend('All Points','Valid Points')
```



Input Arguments

`scanObj` — Lidar scan readings
`lidarScan` object

Lidar scan readings, specified as a `lidarScan` object.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `"MaximumRange",5`

`Parent` — Parent of axes
axes object

Parent of axes, specified as the comma-separated pair consisting of `"Parent"` and an axes object in which the laser scan is drawn. By default, the laser scan is plotted in the currently active axes.

`MaximumRange` — Range of laser scan
`scan.RangeMax` (default) | scalar

Range of laser scan, specified as the comma-separated pair consisting of `"MaximumRange"` and a scalar. When you specify this name-value pair argument, the minimum and maximum *x*-axis and the maximum *y*-axis limits are set based on specified value. The minimum *y*-axis limit is automatically determined by the opening angle of the laser scanner.

This name-value pair only works when you input `scanMsg` as the laser scan.

Outputs

`linehandle` — One or more chart line objects
scalar | vector

One or more chart line objects, returned as a scalar or a vector. These are unique identifiers, which you can use to query and modify properties of a specific chart line.

See Also

`transformScan`

Introduced in R2015a

isMotionValid

Check if path between states is valid

Syntax

```
[isValid,lastValid] = isMotionValid(manipSV,startConfig,goalConfig)
```

Description

`[isValid,lastValid] = isMotionValid(manipSV,startConfig,goalConfig)` checks if the path between two states is valid by interpolating between states using the state validator `manipSV`. The function also returns the last valid state along the path `lastValid`.

Examples

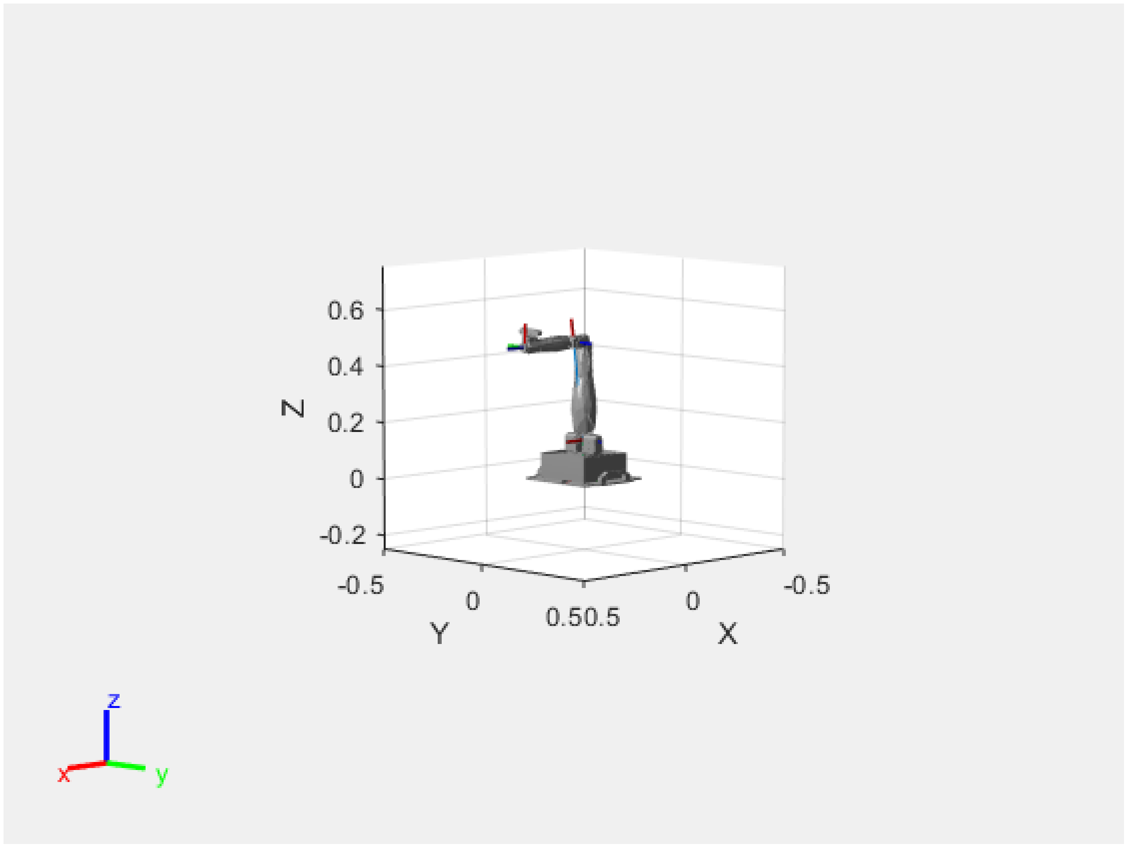
Validate State and Motion Manipulator State Space

Generate states to form a path, validate motion between states, and check for self-collisions and environmental collisions with objects in your world. The `manipulatorStateSpace` object represents the joint configuration space of your rigid body tree robot model, and can sample states, calculate distances, and enforce state bounds. The `manipulatorCollisionBodyValidator` object validates the state and motion based on the collision bodies in your robot model and any obstacles in your environment.

Load Robot Model

Use the `loadrobot` function to access predefined robot models. This example uses the Quanser QArm™ robot and joint configurations are specified as row vectors.

```
robot = loadrobot("quanserQArm",DataFormat="row");
figure(Visible="on")
show(robot);
xlim([-0.5 0.5])
ylim([-0.5 0.5])
zlim([-0.25 0.75])
hold on
```



Configure State Space and State Validation

Create the state space and state validator from the robot model.

```
ss = manipulatorStateSpace(robot);
sv = manipulatorCollisionBodyValidator(ss);
```

Set the validation distance to `0.05`, which is based on the distance normal between two states. You can configure the validator to ignore self collisions to improve the speed of validation, but must consider whether your robot model has the proper joint limit settings set to ensure it does not collide with itself.

```
sv.ValidationDistance = 0.05;
sv.IgnoreSelfCollision = true;
```

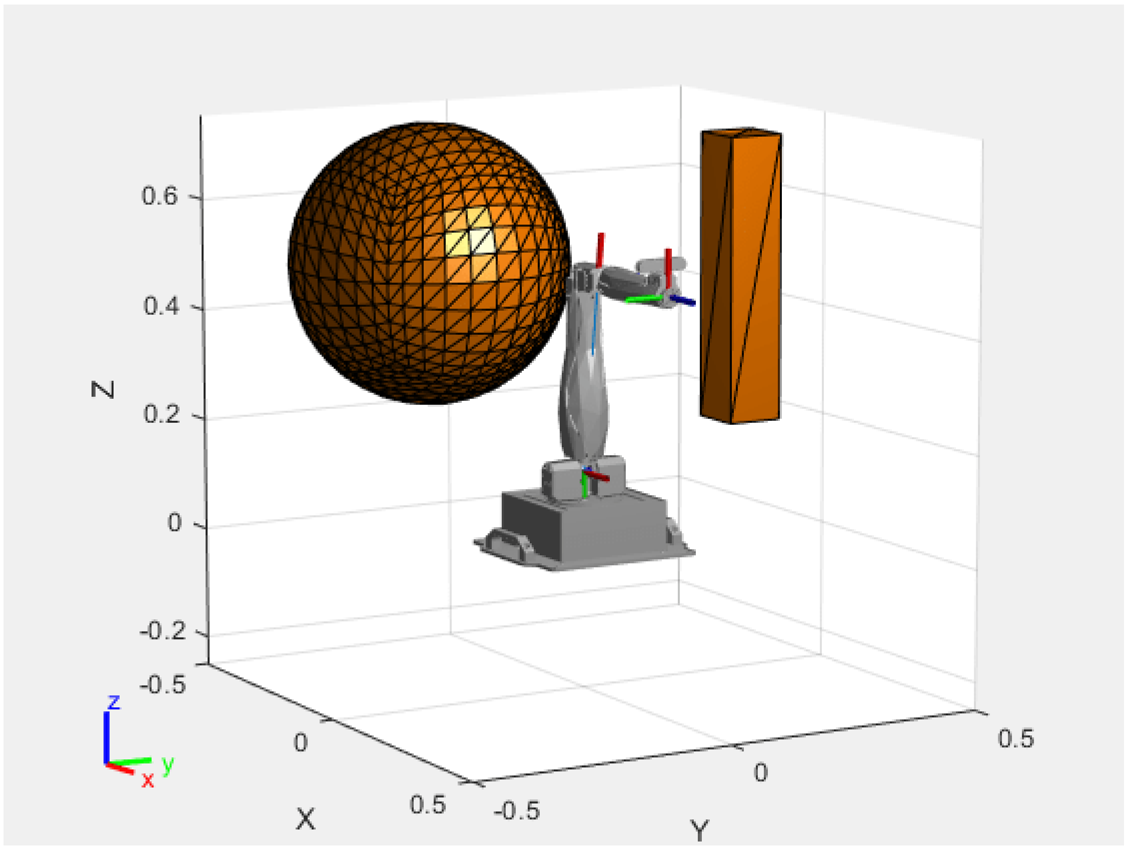
Place collision objects in the robot environment. Set the `Environment` property of the collision validator object using a cell array of objects.

```
box = collisionBox(0.1,0.1,0.5); % XYZ Lengths
box.Pose = trvec2tform([0.2 0.2 0.5]); % XYZ Position
sphere = collisionSphere(0.25); % Radius
sphere.Pose = trvec2tform([-0.2 -0.2 0.5]); % XYZ Position
env = {box sphere};
sv.Environment = env;
```

Visualize the environment.

```
for i = 1:length(env)
    show(env{i})
```

```
end
view(60,10)
```



Plan Path

Start with the home configuration as the first point on the path.

```
rng(0); % Repeatable results
start = homeConfiguration(robot);
path = start;
idx = 1;
```

Plan a path using these steps, in a loop:

- Sample a nearby goal configuration, using the Gaussian distribution, by specifying the standard deviation for each joint angle.
- Check if the sampled goal state is valid.
- If the sampled goal state is valid, check if the motion between states is valid and, if so, add it to the path.

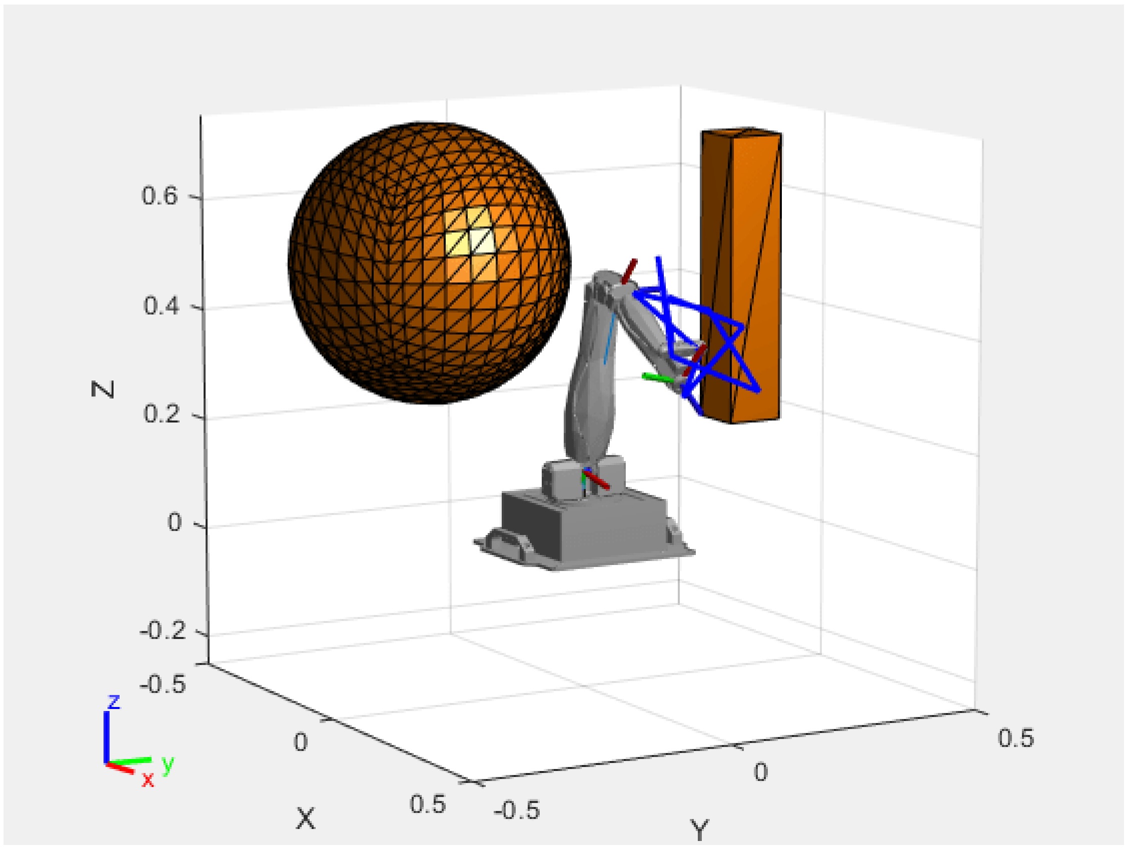
```
for i = 2:25
    goal = sampleGaussian(ss,start,0.25*ones(4,1));
    validState = isStateValid(sv,goal);

    if validState % If state is valid, check motion between states.
        [validMotion,~] = isMotionValid(sv,path(idx,:),goal);
        if validMotion % If motion is valid, add to path.
            path = [path; goal];
            idx = idx + 1;
        end
    end
end
```

Visualize Path

After generating the path of valid motions, visualize the robot motion. Because you sampled random states near the home configuration, you should see the arm move around that initial configuration.

To visualize the path of the end effector in 3-D, get the transformation, relative to the base world frame at each point. Store the points as an *xyz* translation vector. Plot the path of the end effector.

```
eePose = nan(3,size(path,1));

for i = 1:size(path,1)
    show(robot,path(i,:),PreservePlot=false);
    eePos(i,:) = tform2trvec(getTransform(robot,path(i,:),"END-EFFECTOR")); % XYZ translation vec
    plot3(eePos(:,1),eePos(:,2),eePos(:,3),"-b",LineWidth=2)
    drawnow
end
```



Input Arguments

`manipSV` — Manipulator state validator
`manipulatorCollisionBodyValidator` object

Manipulator state validator, specified as a `manipulatorCollisionBodyValidator` object, which is a subclass of `nav.StateValidator`. The state validator contains properties that determine the behavior of this function and `isStateValid`.

`startConfig` — Initial robot configuration
n-element row vector of joint positions

Initial robot configuration, specified as an *n*-element row vector of joint positions for the `rigidBodyTree` robot model. *n* is the number of nonfixed joints in the robot model.

Data Types: `double`

`goalConfig` — Desired robot configuration
n-element row vector of joint positions

Desired robot configuration, specified as an *n*-element row vector of joint positions for the `rigidBodyTree` robot model. *n* is the number of nonfixed joints in the robot model.

Data Types: `double`

Output Arguments

`isValid` — Valid states
m-element logical column vector

Valid states, returned as an *m*-element logical column vector.

Data Types: `logical`

`lastValid` — Final valid state along each path
n-element row vector | *m*-by-*n* matrix

Final valid state along each path, returned as an *n*-element row vector or *m*-by-*n* matrix. *n* is the number of nonfixed joints in the robot model.. *m* is the number of paths validated. Each row contains the final valid state along the associated path.

Data Types: `single` | `double`

See Also

Objects
`rigidBodyTree` | `manipulatorStateSpace` | `workspaceGoalRegion` | `manipulatorRRT` | `manipulatorCollisionBodyValidator`

Functions
`isStateValid` | `sampleUniform` | `sampleGaussian` | `interpolate` | `distance` | `enforceStateBounds`

Introduced in R2021b

isStateValid

Check if state is valid

Syntax

```
isValid = isStateValid(manipSV,state)
```

Description

`isValid = isStateValid(manipSV,state)` checks if a given state, or joint configuration, is valid for the rigid body tree robot model specified by the state validator `manipSV`. This object function checks for self-collisions and collisions with the environment based on the properties of the state validator.

Examples

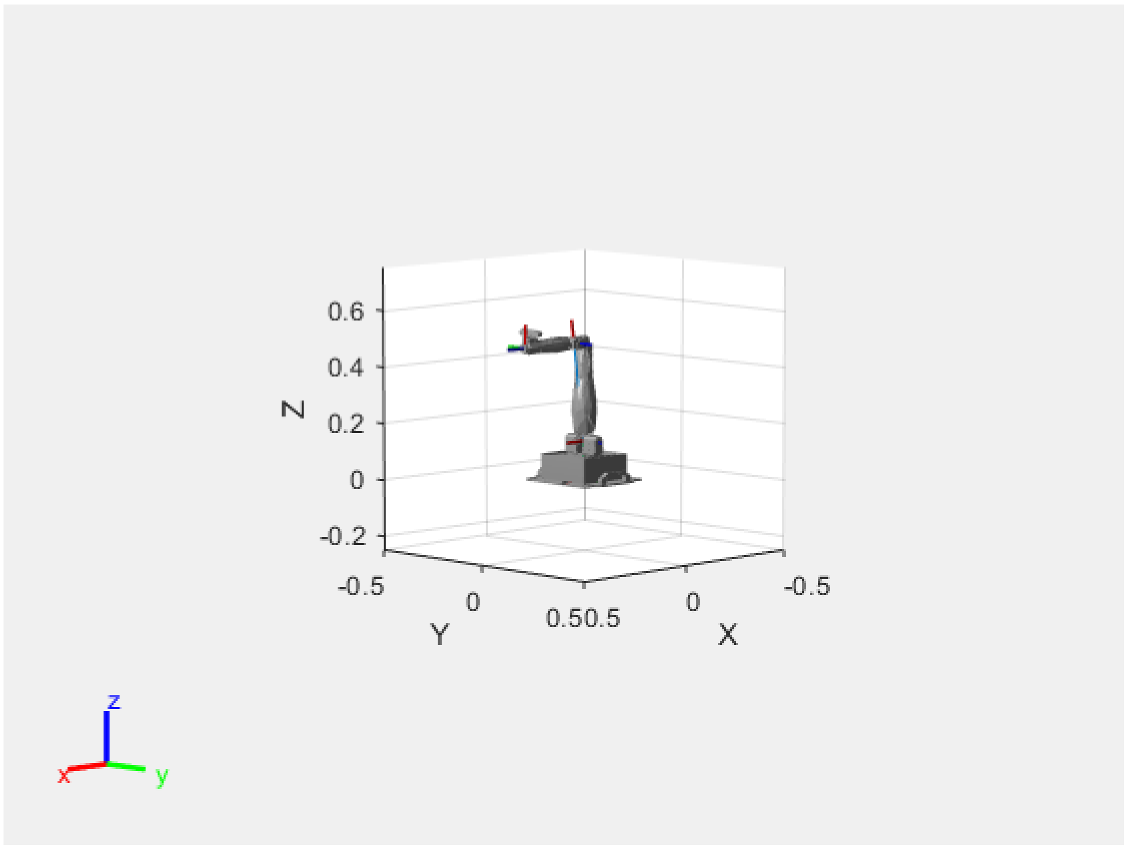
Validate State and Motion Manipulator State Space

Generate states to form a path, validate motion between states, and check for self-collisions and environmental collisions with objects in your world. The `manipulatorStateSpace` object represents the joint configuration space of your rigid body tree robot model, and can sample states, calculate distances, and enforce state bounds. The `manipulatorCollisionBodyValidator` object validates the state and motion based on the collision bodies in your robot model and any obstacles in your environment.

Load Robot Model

Use the `loadrobot` function to access predefined robot models. This example uses the Quanser QArm™ robot and joint configurations are specified as row vectors.

```
robot = loadrobot("quanserQArm",DataFormat="row");
figure(Visible="on")
show(robot);
xlim([-0.5 0.5])
ylim([-0.5 0.5])
zlim([-0.25 0.75])
hold on
```



Configure State Space and State Validation

Create the state space and state validator from the robot model.

```
ss = manipulatorStateSpace(robot);
sv = manipulatorCollisionBodyValidator(ss);
```

Set the validation distance to `0.05`, which is based on the distance normal between two states. You can configure the validator to ignore self collisions to improve the speed of validation, but must consider whether your robot model has the proper joint limit settings set to ensure it does not collide with itself.

```
sv.ValidationDistance = 0.05;
sv.IgnoreSelfCollision = true;
```

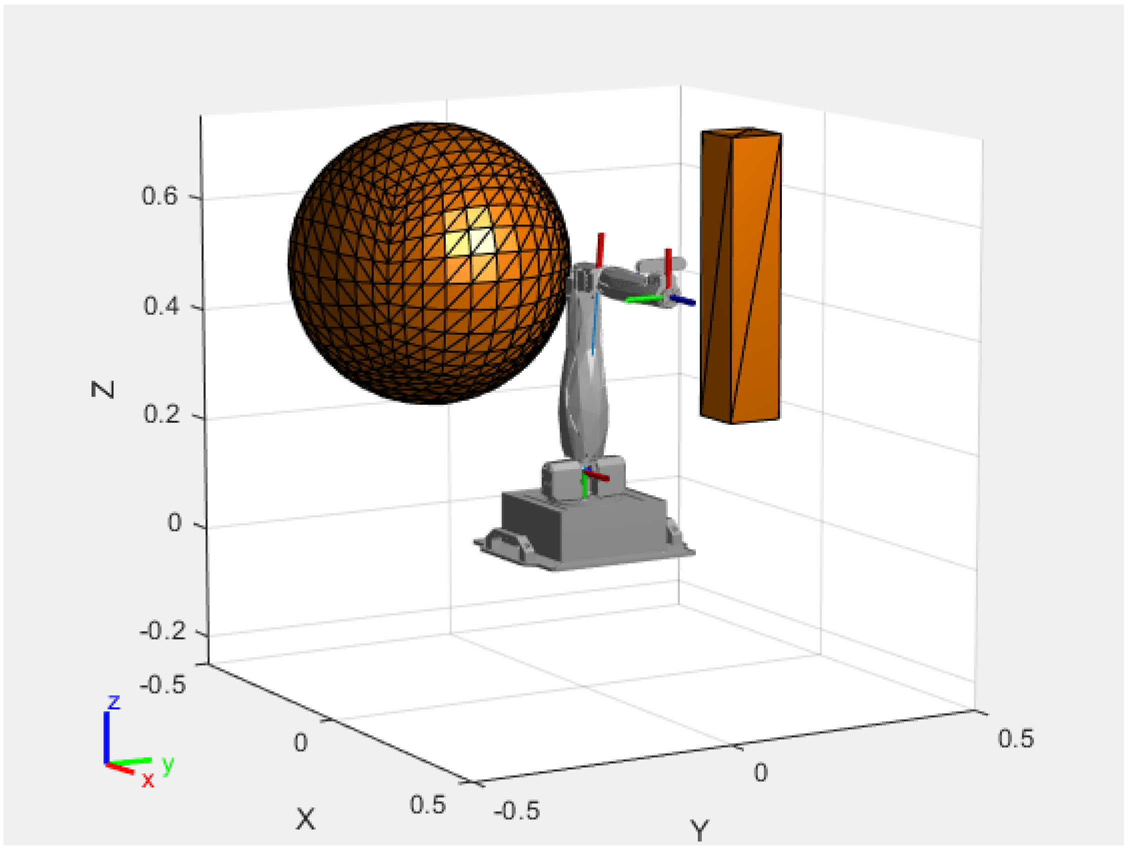
Place collision objects in the robot environment. Set the `Environment` property of the collision validator object using a cell array of objects.

```
box = collisionBox(0.1,0.1,0.5); % XYZ Lengths
box.Pose = trvec2tform([0.2 0.2 0.5]); % XYZ Position
sphere = collisionSphere(0.25); % Radius
sphere.Pose = trvec2tform([-0.2 -0.2 0.5]); % XYZ Position
env = {box sphere};
sv.Environment = env;
```

Visualize the environment.

```
for i = 1:length(env)
    show(env{i})
```

```
end
view(60,10)
```



Plan Path

Start with the home configuration as the first point on the path.

```
rng(0); % Repeatable results
start = homeConfiguration(robot);
path = start;
idx = 1;
```

Plan a path using these steps, in a loop:

- Sample a nearby goal configuration, using the Gaussian distribution, by specifying the standard deviation for each joint angle.
- Check if the sampled goal state is valid.
- If the sampled goal state is valid, check if the motion between states is valid and, if so, add it to the path.

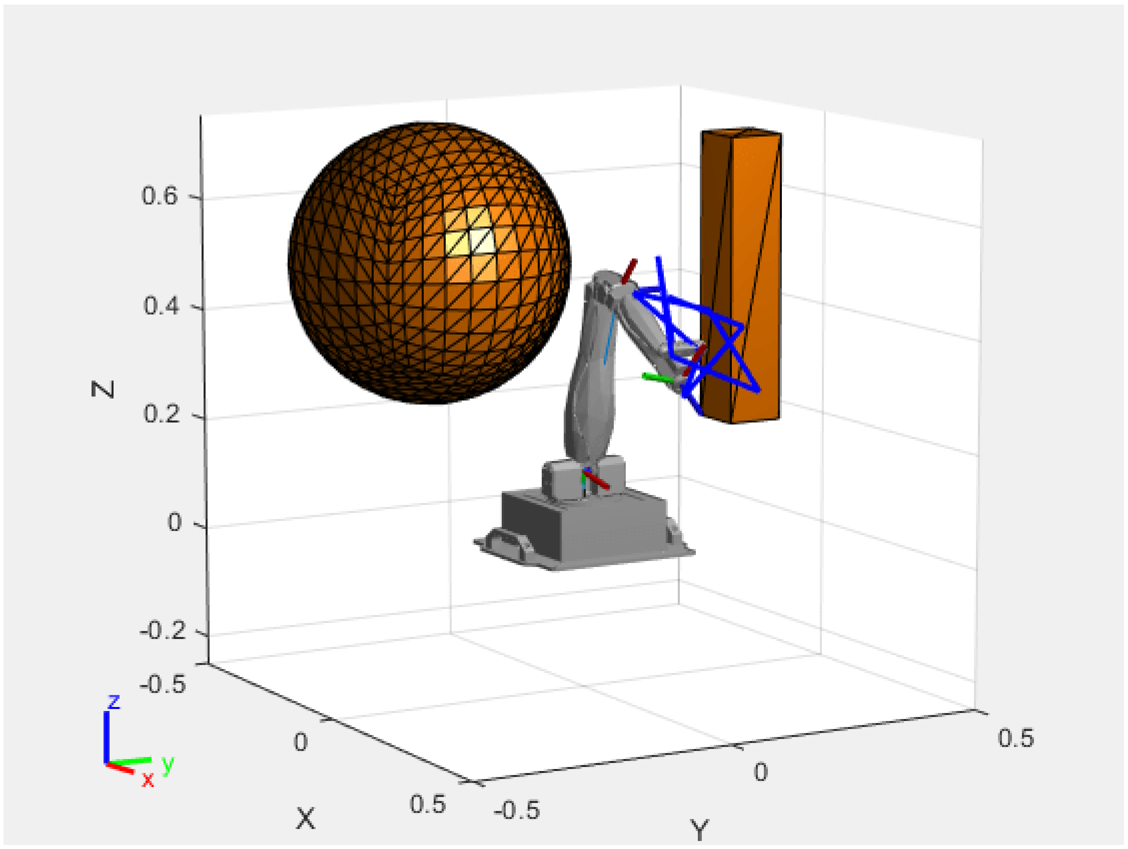
```
for i = 2:25
    goal = sampleGaussian(ss,start,0.25*ones(4,1));
    validState = isStateValid(sv,goal);

    if validState % If state is valid, check motion between states.
        [validMotion,~] = isMotionValid(sv,path(idx,:),goal);
        if validMotion % If motion is valid, add to path.
            path = [path; goal];
            idx = idx + 1;
        end
    end
end
```

Visualize Path

After generating the path of valid motions, visualize the robot motion. Because you sampled random states near the home configuration, you should see the arm move around that initial configuration.

To visualize the path of the end effector in 3-D, get the transformation, relative to the base world frame at each point. Store the points as an *xyz* translation vector. Plot the path of the end effector.

```
eePose = nan(3,size(path,1));

for i = 1:size(path,1)
    show(robot,path(i,:),PreservePlot=false);
    eePos(i,:) = tform2trvec(getTransform(robot,path(i,:),"END-EFFECTOR")); % XYZ translation vec
    plot3(eePos(:,1),eePos(:,2),eePos(:,3),"-b",LineWidth=2)
    drawnow
end
```



Input Arguments

`manipSV` — Manipulator state validator

`manipulatorCollisionBodyValidator` object

Manipulator state validator, specified as a `manipulatorCollisionBodyValidator` object, which is a subclass of `nav.StateValidator`. The state validator contains properties that determine the behavior of this function and `isMotionValid`.

`state` — Robot state in joint space

n-element row vector of joint positions

Robot state in the joint space, specified as an *n*-element row vector of joint positions. *n* is the number of nonfixed joints in the `rigidBodyTree` robot model.

Data Types: `double`

Output Arguments

`isValid` — Validity of state

logical scalar

Validity of input state returned as logical scalar. The state is valid if it does not result in self-collisions, collisions with the environment, and it is within state bounds.

Data Types: `logical`

See Also

Objects
`rigidBodyTree` | `manipulatorStateSpace` | `workspaceGoalRegion` | `manipulatorRRT`

Functions
`isMotionValid` | `sampleUniform` | `sampleGaussian` | `interpolate` | `distance`

Introduced in R2021b

derivative

Time derivative of manipulator model states

Syntax

```
stateDot = derivative(taskMotionModel,state,refPose,refVel)
stateDot = derivative(taskMotionModel,state,refPose, refVel,fExt)

stateDot = derivative(jointMotionModel,state,cmds)
stateDot = derivative(jointMotionModel,state,cmds,fExt)
```

Description

`stateDot = derivative(taskMotionModel,state,refPose,refVel)` computes the time derivative of the motion model based on the current state and motion commands using a task-space model.

`stateDot = derivative(taskMotionModel,state,refPose, refVel,fExt)` computes the time derivative based on the current state, motion commands, and any external forces on the manipulator using a task space model.

`stateDot = derivative(jointMotionModel,state,cmds)` computes the time derivative of the motion model based on the current state and motion commands using a joint-space model.

`stateDot = derivative(jointMotionModel,state,cmds,fExt)` computes the time derivative based on the current state, motion commands, and any external forces on the manipulator using a joint-space model.

Examples

Create Joint-Space Motion Model

This example shows how to create and use a `jointSpaceMotionModel` object for a manipulator robot in joint-space.

Create the Robot

```
robot = loadrobot("kinovaGen3","DataFormat","column","Gravity",[0 0 -9.81]);
```

Set Up the Simulation

Set the timespan to be 1 s with a timestep size of 0.01 s. Set the initial state to be the robots, home configuration with a velocity of zero.

```
tspan = 0:0.01:1;
initialState = [homeConfiguration(robot); zeros(7,1)];
```

Define the a reference state with a target position, zero velocity, and zero acceleration.

```
targetState = [pi/4; pi/3; pi/2; -pi/3; pi/4; -pi/4; 3*pi/4; zeros(7,1); zeros(7,1)];
```

Create the Motion Model

Model the system with computed torque control and error dynamics defined by a moderately fast step response with 5% overshoot.

```
motionModel = jointSpaceMotionModel("RigidBodyTree",robot);
updateErrorDynamicsFromStep(motionModel,.3,.05);
```

Simulate the Robot

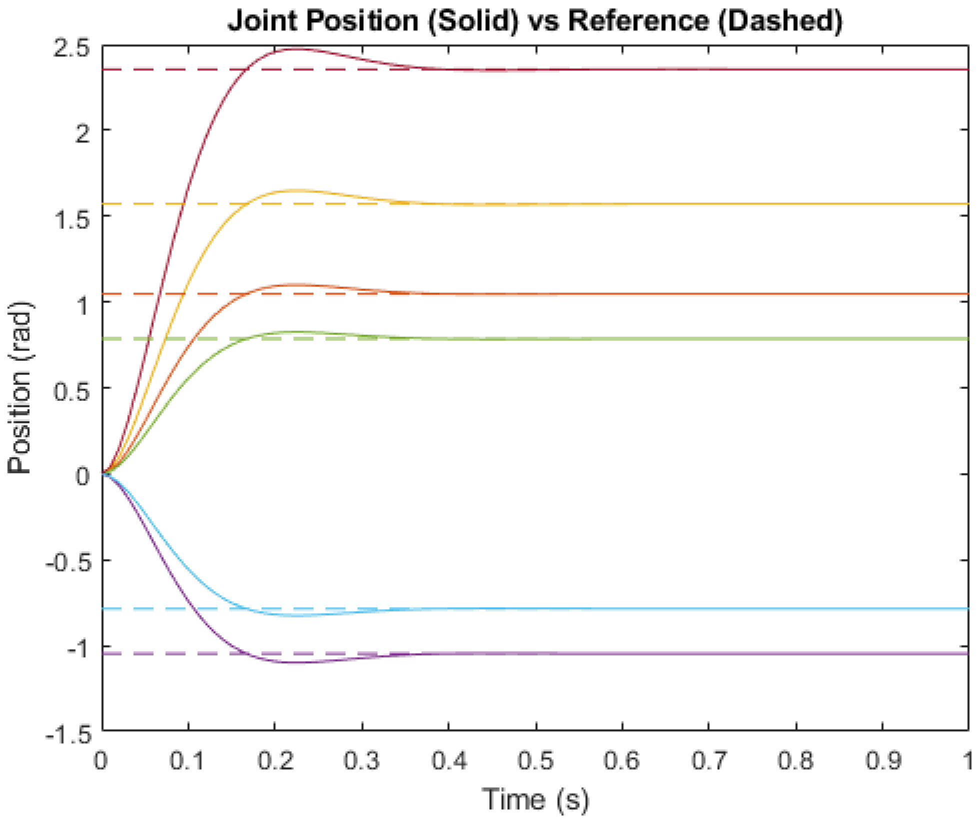
Use the derivative function of the model as the input to the `ode45` solver to simulate the behavior over 1 second.

```
[t,robotState] = ode45(@(t,state)derivative(motionModel,state,targetState),tspan,initialState);
```

Plot the Response

Plot the positions of all the joints actuating to their target state. Joints with a higher displacement between the starting position and the target position actuate to the target at a faster rate than those with a lower displacement. This leads to an overshoot, but all of the joints have the same settling time.

```
figure
plot(t,robotState(:,1:motionModel.NumJoints));
hold all;
plot(t,targetState(1:motionModel.NumJoints)*ones(1,length(t)),"--");
title("Joint Position (Solid) vs Reference (Dashed)");
xlabel("Time (s)")
ylabel("Position (rad)");
```



Create Task-Space Motion Model

This example shows how to create and use a `taskSpaceMotionModel` object for a manipulator robot arm in task-space.

Create the Robot

```
robot = loadrobot("kinovaGen3","DataFormat","column","Gravity",[0 0 -9.81]);
```

Set Up the Simulation

Set the time span to be 1 second with a timestep size of 0.02 seconds. Set the initial state to the home configuration of the robot, with a velocity of zero.

```
tspan = 0:0.02:1;
initialState = [homeConfiguration(robot);zeros(7,1)];
```

Define a reference state with a target position and zero velocity.

```
refPose = trvec2tform([0.6 -.1 0.5]);
refVel = zeros(6,1);
```

Create the Motion Model

Model the behavior as a system under proportional-derivative (PD) control.

```
motionModel = taskSpaceMotionModel("RigidBodyTree",robot,"EndEffectorName","EndEffector_Link");
```

Simulate the Robot

Simulate the behavior over 1 second using a stiff solver to more efficiently capture the robot dynamics. Using `ode15s` enables higher precision around the areas with a high rate of change.

```
[t,robotState] = ode15s(@(t,state)derivative(motionModel,state,refPose,refVel),tspan,initialState
```

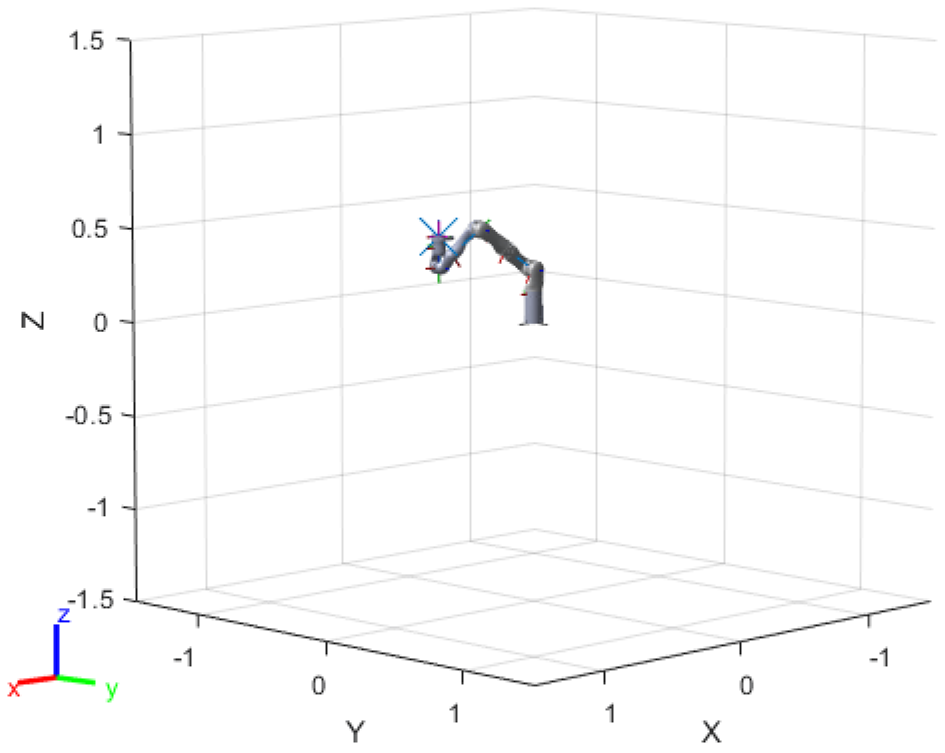
Plot the Response

Plot the robot's initial position and mark the target with an X.

```
figure
show(robot,initialState(1:7));
hold all
plot3(refPose(1,4),refPose(2,4),refPose(3,4),"x","MarkerSize",20)
```

Observe the response by plotting the robot in a 5 Hz loop.

```
r = rateControl(5);
for i = 1:size(robotState,1)
    show(robot,robotState(i,1:7)',"PreservePlot",false);
    waitfor(r);
end
```



Input Arguments

`taskMotionModel` — `taskSpaceMotionModel` object
`taskSpaceMotionModel` object

`taskSpaceMotionModel` object, which defines the properties of the motion model.

`jointMotionModel` — `jointSpaceMotionModel` object
`jointSpaceMotionModel` object

`jointSpaceMotionModel` object, which defines the properties of the motion model.

`state` — Joint positions and velocities
1-by-2*n*-element vector

Joint positions and velocities represented as a 2*n*-element vector, specified as [*q; qDot*]. *n* is the number of non-fixed joints in the associated `rigidBodyTree` of the `motionModel`. *q*, represents the position of each joint, specified in radians. *qDot* represents the velocity of each joint, specified in radians per second.

`refPose` — Robot pose
4-by-4 matrix

The reference pose of the end effector in the task-space in meters, specified as an 4-by-4 homogeneous transformation matrix.

`refVel` — Joint velocities
six-element row vector

The reference velocities of the end effector in the task space, specified as a six-element vector of real values, specified as [*omega v*]. *omega* represents a row vector of three angular velocities about the `x`, `y`, and `z` axes, specified in radians per second, and *v* represents a row vector of three linear velocities along the `x`, `y`, and `z` axes, specified in meters per second.

`cmds` — Control commands indicating desired motion
2-by-*n* matrix | 3-by-*n* matrix

Control commands indicating desired motion. The dimensions of `cmds` depend on the MotionType property of the motion model:

- `"PDControl"` — 2-by-*n* matrix, `[qRef; qRefDot]`. The first and second rows represent joint positions and joint velocities, respectively.
- `"ComputedTorqueControl"` — 3-by-*n* matrix, `[qRef; qRefDot; qRefDDot]`. The first, second, and third rows represent joint positions, joint velocities, and joint accelerations respectively.
- `"IndependentJointMotion"` — 3-by-*n* matrix, `[qRef; qRefDot; qRefDDot]`. The first, second, and third rows represent joint positions, joint velocities, and joint accelerations respectively.

Note that `jointSpaceMotionModel` supports all three MotionType listed above, but `taskSpaceMotionModel` only supports `"PDControl"` MotionType.

`fExt` — Joint positions and velocities
m-element vector

External forces, specified as an *m*-element vector, where *m* is the number of bodies in the associated `rigidBodyTree` object.

Output Arguments

`stateDot` — Time derivative of current state
2-by-*n* matrix

Time derivative based on current state and specified control commands, returned as a 2-by-*n* matrix of real values, [*qDot; qDDot*], where *qDot* is an *n*-element row vector of joint velocities, and *qDDot* is an *n*-element row vector of joint accelerations. *n* is the number of joints in the associated `rigidBodyTree` of the `motionModel`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Classes
`jointSpaceMotionModel` | `taskSpaceMotionModel`

Introduced in R2019b

interpolate

Interpolate states along path from RRT

Syntax

```
interpPath = interpolate(rrt,path)
interpPath = interpolate(rrt,path,numInterp)
```

Description

`interpPath = interpolate(rrt,path)` interpolates states between each adjacent configuration in the path based on the ValidationDistance property of the manipulator rapidly exploring random tree (RRT) planner `rrt`.

`interpPath = interpolate(rrt,path,numInterp)` specifies the number of interpolations between adjacent configurations.

Examples

Plan Path for Manipulator Robot Using RRT

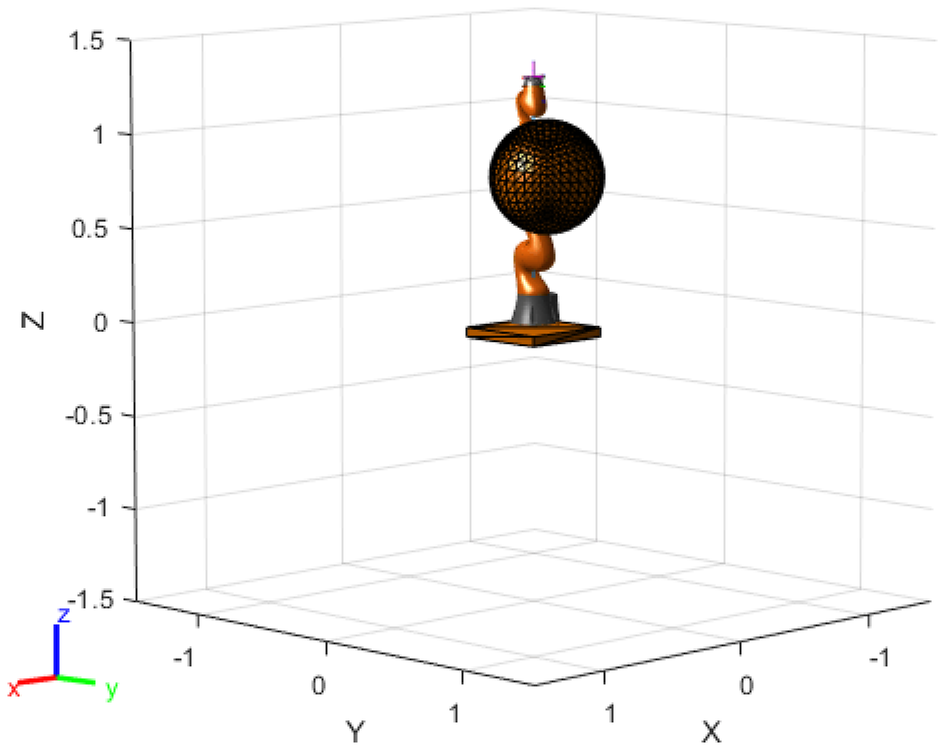
Use the `manipulatorRRT` object to plan a path for a rigid body tree robot model in an environment with obstacles. Visualize the planned path with interpolated states.

Load a robot model into the workspace. Use the KUKA LBR iiwa© manipulator arm.

```
robot = loadrobot("kukaIiwa14","DataFormat","row");
```

Generate the environment for the robot. Create collision objects and specify their poses relative to the robot base. Visualize the environment.

```
env = {collisionBox(0.5, 0.5, 0.05) collisionSphere(0.3)};
env{1}.Pose(3, end) = -0.05;
env{2}.Pose(1:3, end) = [0.1 0.2 0.8];

show(robot);
hold on
show(env{1})
show(env{2})
```



Create the RRT planner for the robot model.

```
rrt = manipulatorRRT(robot,env);
```

Specify a start and a goal configuration.

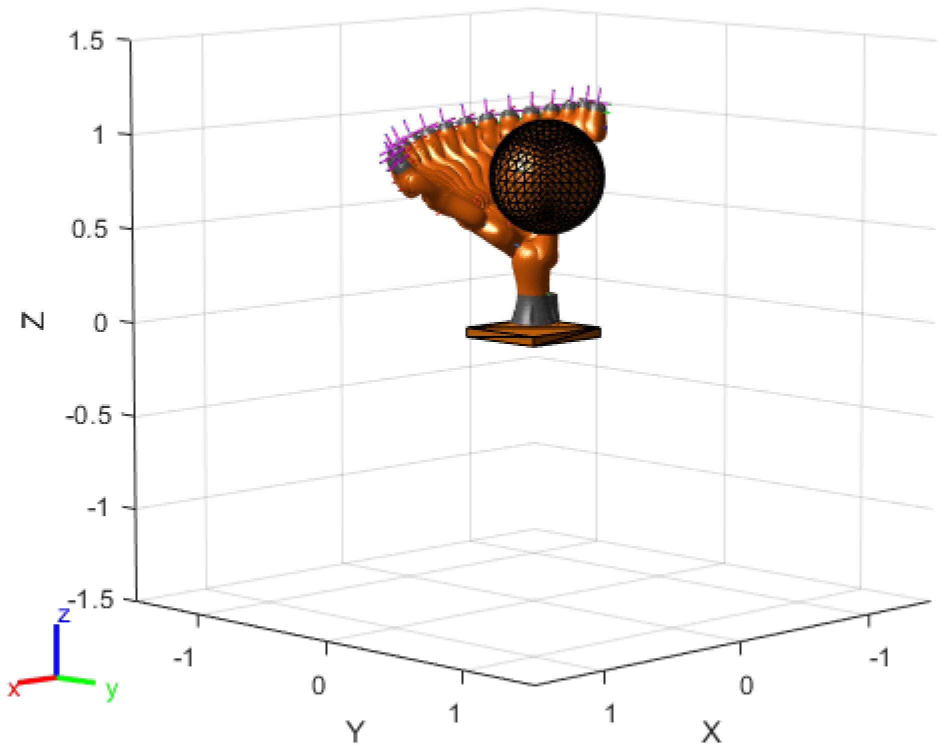
```
startConfig = [0.08 -0.65 0.05 0.02 0.04 0.49 0.04];
goalConfig =  [2.97 -1.05 0.05 0.02 0.04 0.49 0.04];
```

Plan the path. Due to the randomness of the RRT algorithm, set the `rng` seed for repeatability.

```
rng(0)
path = plan(rrt,startConfig,goalConfig);
```

Visualize the path. To add more intermediate states, interpolate the path. By default, the `interpolate` object function uses the value of `ValidationDistance` property to determine the number of intermediate states. The `for` loop shows every 20th element of the interpolated path.

```
interpPath = interpolate(rrt,path);
clf
for i = 1:20:size(interpPath,1)
    show(robot,interpPath(i,:));
    hold on
end
show(env{1})
show(env{2})
hold off
```



Input Arguments

`rrt` — Manipulator RRT planner
`manipulatorRRT` object

Manipulator RRT planner, specified as a `manipulatorRRT` object. This planner is for a specific rigid body tree robot model stored as a `rigidBodyTree` object.

`path` — Planned path in joint space
r-by-*n* matrix of joint configurations

Planned path in joint space, specified as an *r*-by-*n* matrix of joint configurations, where *r* is the number of configurations in the path, and *n* is the number of nonfixed joints in the `rigidBodyTree` robot model.

Data Types: `double`

`numInterp` — Number of interpolations between each configuration
positive integer

Number of interpolations between each configuration, specified as a positive integer.

Data Types: `double`

Output Arguments

`interpPath` — Interpolated path in joint space
r-by-*n* matrix of joint configurations

Planned path in joint space, specified as an *r*-by-*n* matrix of joint configurations, where *r* is the number of configurations in the path and *n* is the number of nonfixed joints in the `rigidBodyTree` robot model.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Objects
`manipulatorRRT` | `rigidBodyTree` | `interactiveRigidBodyTree` | `analyticalInverseKinematics`

Functions
`plan` | `shorten`

Topics
"Pick and Place Using RRT for Manipulators"
"Pick-and-Place Workflow Using RRT Planner and Stateflow for MATLAB"

Introduced in R2020b

plan

Plan path using RRT for manipulators

Syntax

```
path = plan(rrt,startConfig,goalConfig)
path = plan(rrt,startConfig,goalRegion)
[path,solnInfo] = plan( ___ )
```

Description

`path = plan(rrt,startConfig,goalConfig)` plans a path between the specified start and goal configurations using the manipulator rapidly exploring random trees (RRT) planner `rrt`.

`path = plan(rrt,startConfig,goalRegion)` plans a path between the specified start and a goal region as a `workspaceGoalRegion` object

`[path,solnInfo] = plan( ___ )` also returns solution info about the results from the RRT planner using the previous input arguments.

Examples

Plan Path for Manipulator Robot Using RRT

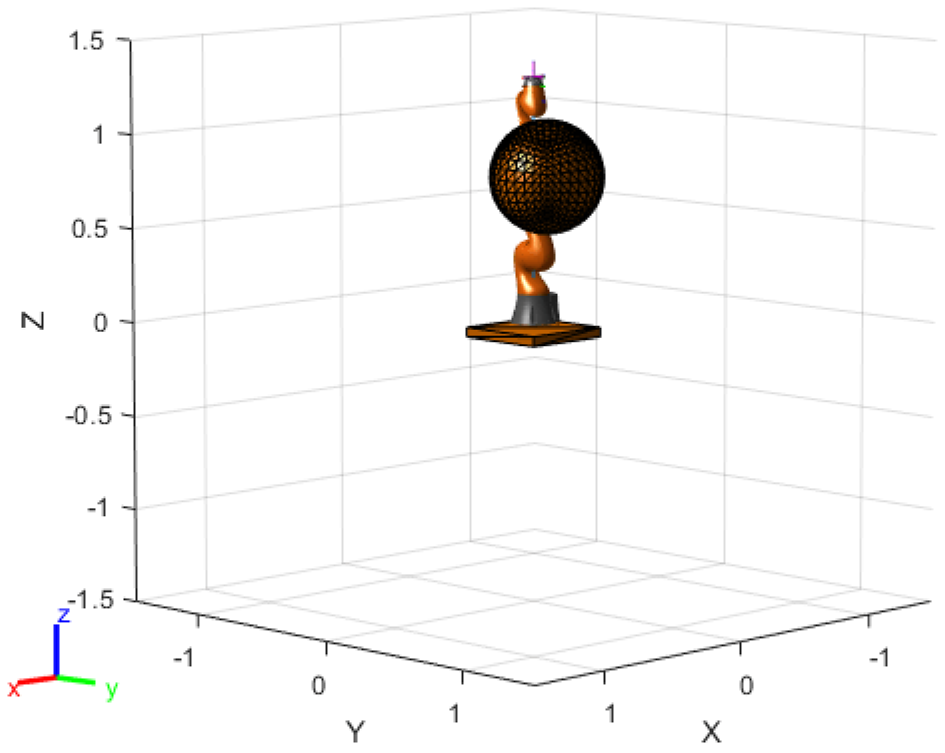
Use the `manipulatorRRT` object to plan a path for a rigid body tree robot model in an environment with obstacles. Visualize the planned path with interpolated states.

Load a robot model into the workspace. Use the KUKA LBR iiwa© manipulator arm.

```
robot = loadrobot("kukaIiwa14","DataFormat","row");
```

Generate the environment for the robot. Create collision objects and specify their poses relative to the robot base. Visualize the environment.

```
env = {collisionBox(0.5, 0.5, 0.05) collisionSphere(0.3)};
env{1}.Pose(3, end) = -0.05;
env{2}.Pose(1:3, end) = [0.1 0.2 0.8];

show(robot);
hold on
show(env{1})
show(env{2})
```



Create the RRT planner for the robot model.

```
rrt = manipulatorRRT(robot,env);
```

Specify a start and a goal configuration.

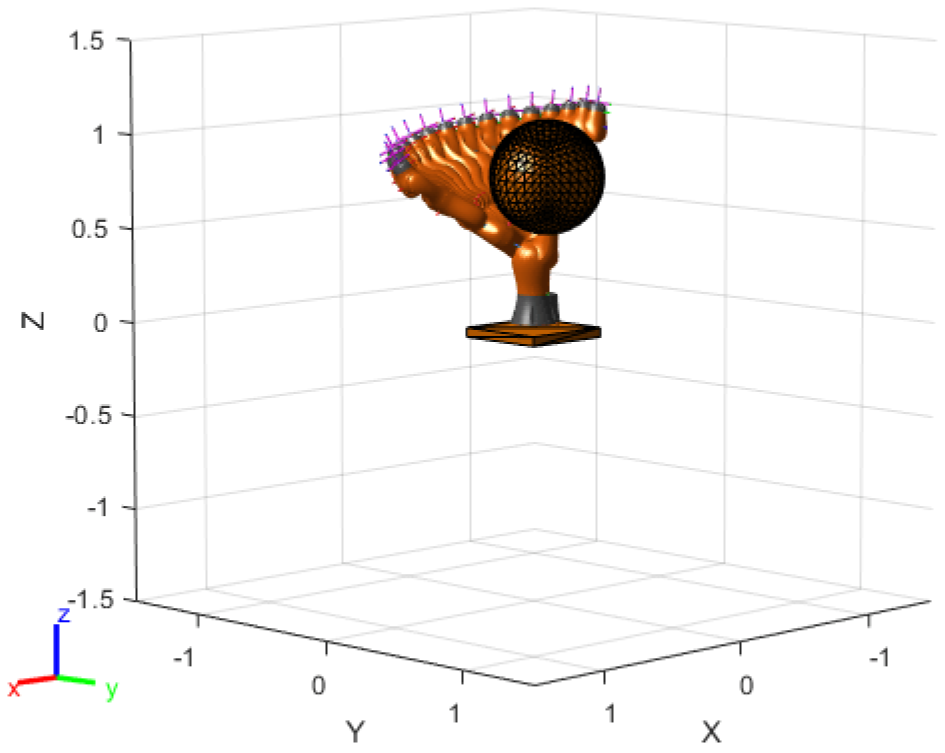
```
startConfig = [0.08 -0.65 0.05 0.02 0.04 0.49 0.04];
goalConfig =  [2.97 -1.05 0.05 0.02 0.04 0.49 0.04];
```

Plan the path. Due to the randomness of the RRT algorithm, set the `rng` seed for repeatability.

```
rng(0)
path = plan(rrt,startConfig,goalConfig);
```

Visualize the path. To add more intermediate states, interpolate the path. By default, the `interpolate` object function uses the value of `ValidationDistance` property to determine the number of intermediate states. The `for` loop shows every 20th element of the interpolated path.

```
interpPath = interpolate(rrt,path);
clf
for i = 1:20:size(interpPath,1)
    show(robot,interpPath(i,:));
    hold on
end
show(env{1})
show(env{2})
hold off
```

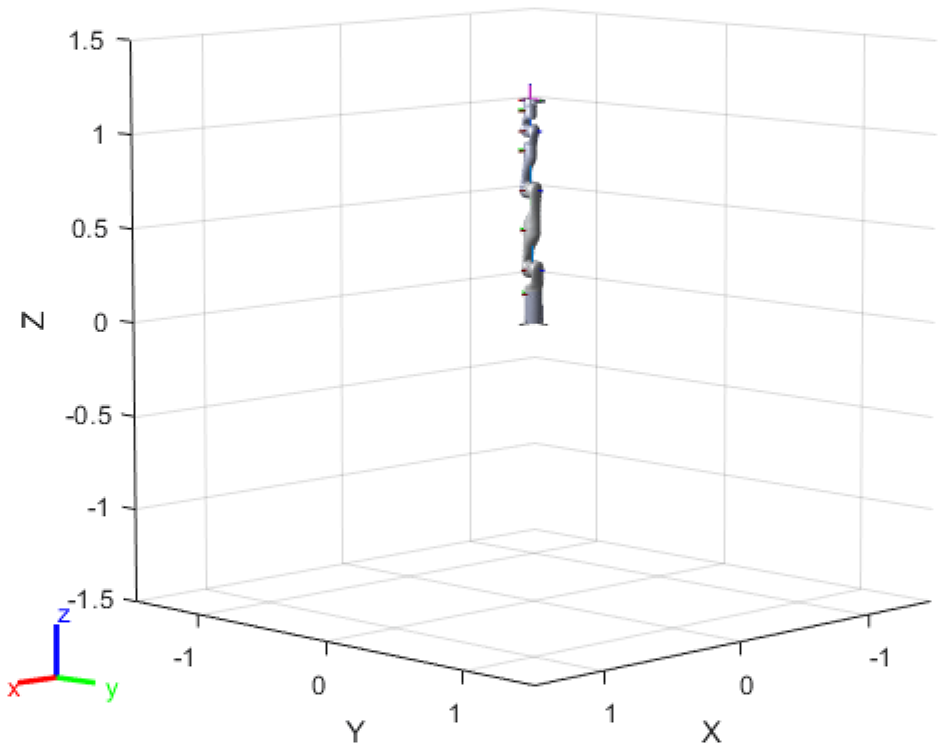


Plan Path To A Workspace Goal Region

Specify a goal region in your workspace and plan a path within those bounds. The `workspaceGoalRegion` object defines the bounds on the XYZ-position and ZYX Euler orientation of the robot end effector. The `manipulatorRRT` object plans a path based on that goal region and samples random poses within the bounds.

Load an existing robot model as a `rigidBodyTree` object.

```
robot = loadrobot("kinovaGen3", "DataFormat", "row");
ax = show(robot);
```



Create Path Planner

Create a rapidly-exploring random tree (RRT) path planner for the robot. This example uses an empty environment, but this workflow also works well with cluttered environments. You can add collision objects to the environment like the `collisionBox` or `collisionMesh` object.

```
planner = manipulatorRRT(robot,{});
```

Define Goal Region

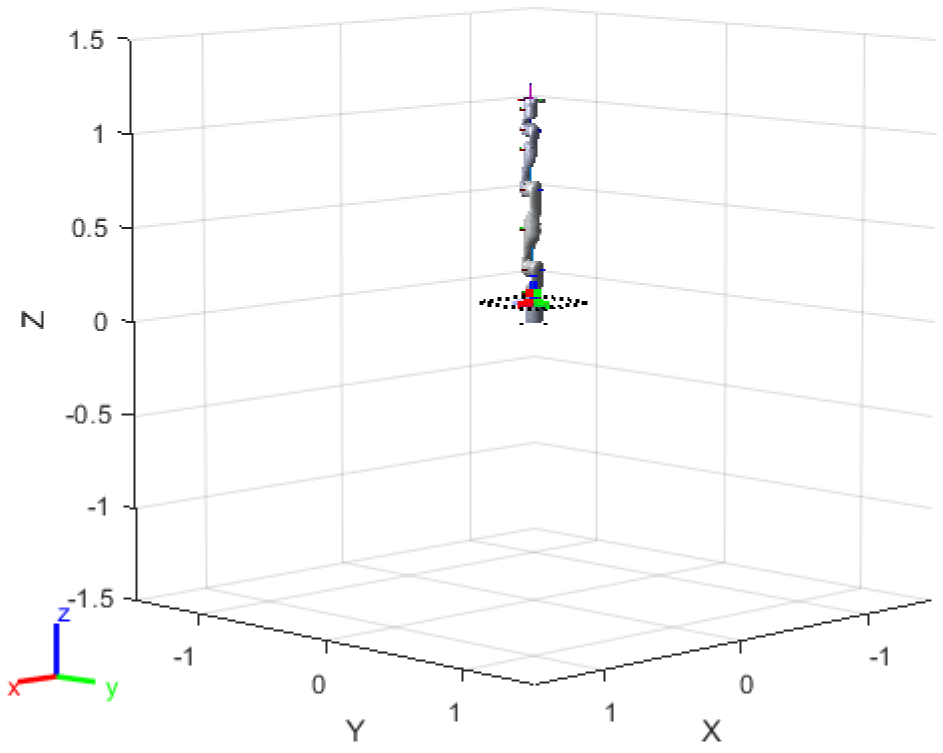
Create a workspace goal region using the end-effector body name of the robot.

Define the goal region parameters for your workspace. The goal region includes a reference pose, XYZ-position bounds, and orientation limits on the ZYX Euler angles. This example specifies bounds on the XY-plane in meters and allows rotation about the Z-axis in radians.

```
goalRegion = workspaceGoalRegion(robot.BodyNames{end});
goalRegion.ReferencePose = trvec2tform([0.5 0.5 0.2]);
goalRegion.Bounds(1, :) = [-0.2 0.2];    % X Bounds
goalRegion.Bounds(2, :) = [-0.2 0.2];    % Y Bounds
goalRegion.Bounds(4, :) = [-pi/2 pi/2];  % Rotation about the Z-axis
```

You can also apply a fixed offset to all poses sampled within the region. This offset can account for grasping tools or variations in dimensions within your workspace. For this example, apply a fixed transformation that places the end effector 5 cm above the workspace.

```
goalRegion.EndEffectorOffsetPose = trvec2tform([0 0 0.05]);
hold on
show(goalRegion);
```



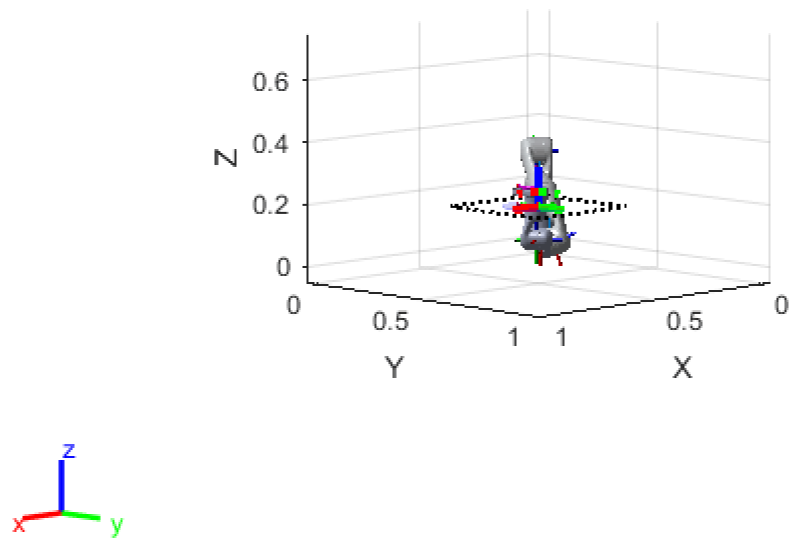
Plan Path To Goal Region

Plan a path to the goal region from the robot's home configuration. Due to the randomness in the RRT algorithm, this example sets the `rng` seed to ensure repeatable results.

```
rng(0)
path = plan(planner,homeConfiguration(robot),goalRegion);
```

Show the robot executing the path. To visualize a more realistic path, interpolate points between path configurations.

```
interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot,interpConfigurations(i,:),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1],...
        'CameraViewAngle',5)

    drawnow
end
hold off
```



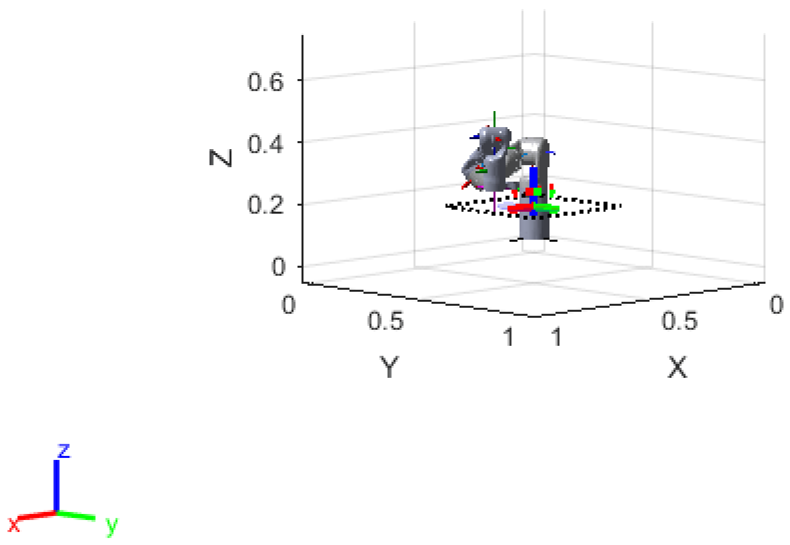
Adjust End-effector Pose

Notice that the robot arm approaches the workspace from the bottom. To flip the orientation of the final position, add a `pi` rotation to the Y-axis for the reference pose.

```
goalRegion.EndEffectorOffsetPose = ...
    goalRegion.EndEffectorOffsetPose*eul2tform([0 pi 0],"ZYX");
```

Replan the path and visualize the robot motion again. The robot now approaches from the top.

```
hold on
show(goalRegion);
path = plan(planner,homeConfiguration(robot),goalRegion);

interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot, interpConfigurations(i, :),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1])
    drawnow;
end
hold off
```



Input Arguments

`rrt` — Manipulator RRT planner
`manipulatorRRT` object

Manipulator RRT planner, specified as a `manipulatorRRT` object. This planner is for a specific rigid body tree robot model stored as a `rigidBodyTree` object.

`startConfig` — Initial robot configuration
n-element vector of joint positions

Initial robot configuration, specified as an *n*-element vector of joint positions for the `rigidBodyTree` object stored in the RRT planner `rrt`. *n* is the number of nonfixed joints in the robot model.

Data Types: `double`

`goalConfig` — Desired robot configuration
n-element vector of joint positions

Desired robot configuration, specified as an *n*-element vector of joint positions for the `rigidBodyTree` object stored in the RRT planner `rrt`. *n* is the number of nonfixed joints in the robot model.

Data Types: `double`

`goalRegion` — Workspace goal region
`workspaceGoalRegion` object

Workspace goal region, specified as a `workspaceGoalRegion` object.

The `workspaceGoalRegion` object defines the bounds on the end-effector pose and the `sample` object function returns random poses to add to the RRT tree. Set the WorkspaceGoalRegionBias property to change the probability of sampling a state within the goal region.

Output Arguments

`path` — Planned path in joint space
r-by-*n* matrix of joint configurations

Planned path in joint space, returned as an *r*-by-*n* matrix of joint configurations, where *r* is the number of configurations in the path, and *n* is the number of nonfixed joints in the `rigidBodyTree` robot model.

Data Types: `double`

`solnInfo` — Solution information from planner
structure

Solution information from planner, returned as a structure with these fields:

- `IsPathFound` — A logical indicating if a path was found
- `ExitFlag` — An integer indicating why the planner terminated:
  - `1` — Goal configuration reached
  - `2` — Maximum number of iterations reached

Data Types: `struct`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Objects
`manipulatorRRT` | `rigidBodyTree` | `interactiveRigidBodyTree` | `analyticalInverseKinematics`

Functions
`interpolate` | `shorten`

Topics
"Pick and Place Using RRT for Manipulators"
"Pick-and-Place Workflow Using RRT Planner and Stateflow for MATLAB"

Introduced in R2020b

shorten

Trim edges to shorten path from RRT

Syntax

```
shortPath = shorten(rrt,path,numIter)
```

Description

`shortPath = shorten(rrt,path,numIter)` trims edges to shorten the specified path `path` by running a randomized shortening strategy for a specified number of iterations `numIter`.

Input Arguments

`rrt` — Manipulator RRT planner
`manipulatorRRT` object

Manipulator RRT planner, specified as a `manipulatorRRT` object. This planner is for a specific rigid body tree robot model stored as a `rigidBodyTree` object.

`path` — Planned path in joint space
r-by-*n* matrix of joint configurations

Planned path in joint space, specified as an *r*-by-*n* matrix of joint configurations, where *r* is the number of configurations in the path, and *n* is the number of nonfixed joints in the `rigidBodyTree` robot model.

Data Types: `double`

`numIter` — Number of iterations to attempt shortening the path
positive integer

Number of iterations to attempt shortening path, specified as a positive integer.

Data Types: `double`

Output Arguments

`shortPath` — Planned path in joint space
r-by-*n* matrix of joint configurations

Planned path in joint space, returned as an *r*-by-*n* matrix of joint configurations, where *r* is the number of configurations in the path, and *n* is the number of nonfixed joints in the `rigidBodyTree` robot model.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

Objects
`manipulatorRRT` | `rigidBodyTree` | `interactiveRigidBodyTree` | `analyticalInverseKinematics`

Functions
`plan` | `interpolate` | `shorten`

Topics
“Pick and Place Using RRT for Manipulators”
“Pick-and-Place Workflow Using RRT Planner and Stateflow for MATLAB”

Introduced in R2020b

distance

Distance between states

Syntax

```
dist = distance(manipSS,state1,state2)
```

Description

`dist = distance(manipSS,state1,state2)` calculates the distance between one or more initial states and one more final states.

Input Arguments

`manipSS` — Manipulator state space
`manipulatorStateSpace` object

Manipulator state space, specified as a `manipulatorStateSpace` object, which is a subclass of `nav.StateSpace`.

`state1` — Initial state position
n-element row vector | *m*-by-*n* matrix

Initial state position, specified as an*n*-element row vector or *m*-by-*n* matrix. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`. *m* is the number of initial state positions.

The sizes of `state1` and `state2` determine the size of the `dist` output:

State Vectors and Distances

`state1` Size	`state2` Size	`dist` Size
n-element row vector	*n*-element row vector	scalar
n-element row vector	*m*-by-*n* matrix	*m*-element column vector
m-by-*n* matrix	*n*-element row vector	*m*-element column vector
m-by-*n* matrix	*m*-by-*n* matrix	*m*-element column vector

`state2` — Final state position
n-element vector | *m*-by-*n* matrix of row vectors

Final state position, specified as a *n*-element row vector or *m*-by-*n* matrix. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`. *m* is the number of initial state positions.

The sizes of `state1` and `state2` determine the size of the `dist` output:

State Vectors and Distances

`state1` Size	`state2` Size	`dist` Size
n-element row vector	*n*-element row vector	scalar
n-element row vector	*m*-by-*n* matrix	*m*-element column vector
m-by-*n* matrix	*n*-element row vector	*m*-element column vector
m-by-*n* matrix	*m*-by-*n* matrix	*m*-element column vector

Output Arguments

`dist` — Distance between two states

numeric scalar | *m*-element column vector

Distance between two states, returned as a numeric scalar or *m*-element column vector. This distance calculation is the main component in evaluating the costs of paths. For prismatic joints, the distance between two states is the Euclidean norm of the difference between the state vectors. For revolute joints with infinite bounds, the difference in joint values is calculated using `angdiff`.

For revolute joints, distances measure joint differences in radians. For prismatic joints, distances measure displacement in meters.

The sizes of `state1` and `state2` determine the size of output `dist`:

State Vectors and Distances

`state1` Size	`state2` Size	`dist` Size
n-element row vector	*n*-element row vector	scalar
n-element row vector	*m*-by-*n* matrix	*m*-element column vector
m-by-*n* matrix	*n*-element row vector	*m*-element column vector
m-by-*n* matrix	*m*-by-*n* matrix	*m*-element column vector

See Also

`nav.StateSpace` | `nav.StateValidator` | `stateSpaceSE2` | `stateSpaceDubins` | `stateSpaceReedsShepp`

Topics

“Create Custom State Space for Path Planning” (Navigation Toolbox)

Introduced in R2021b

enforceStateBounds

Limit state to state space bounds

Syntax

`boundedState = enforceStateBounds(manipSS,state)`

Description

`boundedState = enforceStateBounds(manipSS,state)` limits the specified `state` to the bounds specified by the `StateBounds` property of the state space object, `manipSS`, and returns the bounded state, `boundedState`.

Input Arguments

`manipSS` — Manipulator state space
`manipulatorStateSpace` object

Manipulator state space, specified as a `manipulatorStateSpace` object, which is a subclass of `nav.StateSpace`.

`state` — State position
n-element row vector | *m*-by-*n* matrix

State position, specified as an *n*-element row vector or an *m*-by-*n* matrix. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`. *m* is the number of initial state positions.

Output Arguments

`boundedState` — State position with enforced state bounds
n-element row vector | *m*-by-*n* matrix

State position with enforced state bounds, returned as an *n*-element vector or *m*-by-*n* matrix. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`. *m* is the number of initial state positions.

See Also

Objects
`manipulatorStateSpace` | `rigidBodyTree` | `manipulatorCollisionBodyValidator` | `manipulatorRRT` | `workspaceGoalRegion`

Functions
`isStateValid` | `isMotionValid` | `sampleUniform` | `sampleGaussian` | `interpolate` | `distance`

Introduced in R2021b

interpolate

Interpolate between states

Syntax

```
interpStates = interpolate(manipSS,state1,state2,ratios)
```

Description

`interpStates = interpolate(manipSS,state1,state2,ratios)` interpolates between two states in your state space using the specified ratio values `ratios`.

Input Arguments

`manipSS` — Manipulator state space
`manipulatorStateSpace` object

Manipulator state space, specified as a `manipulatorStateSpace` object, which is a subclass of `nav.StateSpace`.

`state1` — Initial state position
n-element row vector

Initial state position, specified as an *n*-element row vector. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`.

`state2` — Final state position
n-element row vector

Final state position, specified as an *n*-element row vector. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`.

`ratios` — Ratio values for interpolating along path
m-element vector values in range [0 1]

Ratio values for interpolating along the path, specified as an *m*-element vector of values in range [0 1]. These ratios determine the distance of the interpolated state from `state1`.

Output Arguments

`interpStates` — Interpolated states
m-by-*n* matrix

Interpolated states, returned as an *m*-by-*n* matrix. *m* is the length of `ratios` and *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`.

See Also

Objects
`manipulatorStateSpace` | `rigidBodyTree` | `manipulatorCollisionBodyValidator` | `manipulatorRRT` | `workspaceGoalRegion`

Functions
`isStateValid` | `isMotionValid` | `sampleUniform` | `sampleGaussian` | `enforceStateBounds` | `distance`

Introduced in R2021b

sampleGaussian

Sample state using Gaussian distribution

Syntax

```
states = sampleGaussian(manipSS,meanState,stdDev)
states = sampleGaussian(manipSS,meanState,stdDev,numSamples)
```

Description

`states = sampleGaussian(manipSS,meanState,stdDev)` samples a state in the state space `manipSS` from a Gaussian (normal) distribution centered on the mean `meanState` with the standard deviation, `stdDev`.

`states = sampleGaussian(manipSS,meanState,stdDev,numSamples)` samples the number of multiple states specified by `numSamples`.

Examples

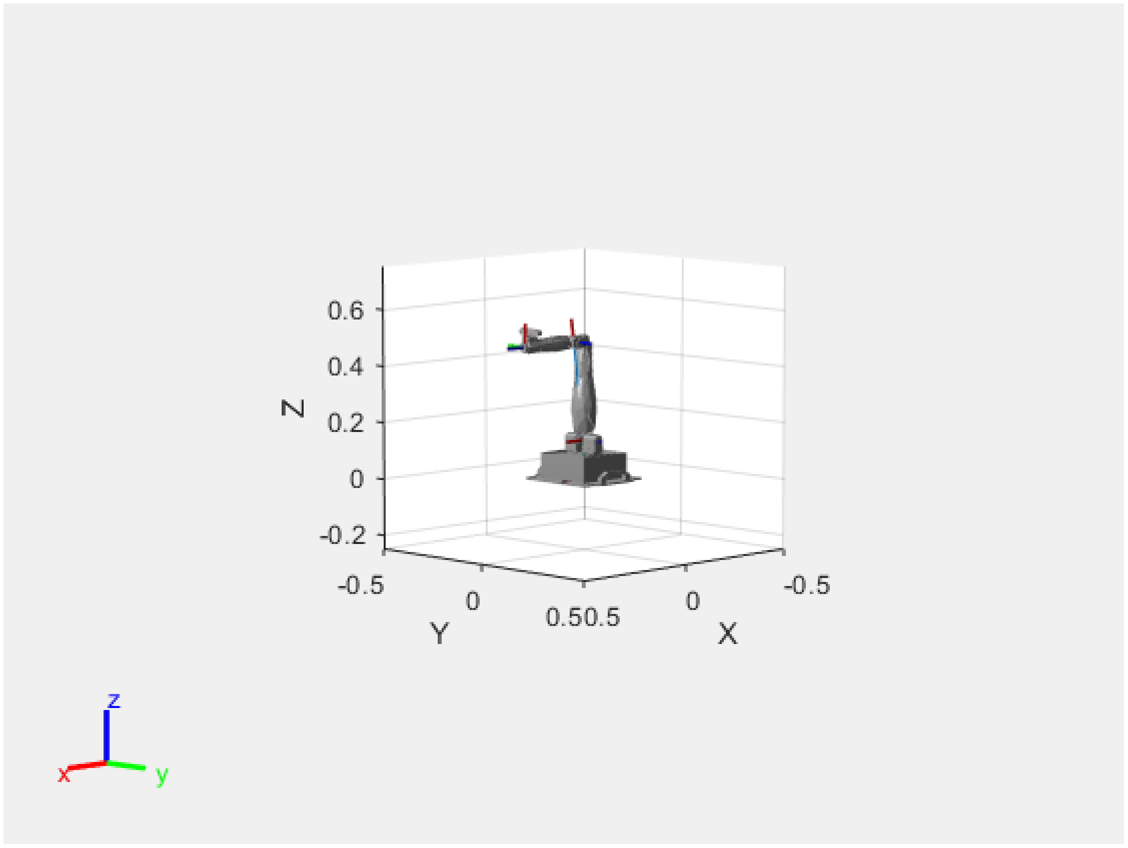
Validate State and Motion Manipulator State Space

Generate states to form a path, validate motion between states, and check for self-collisions and environmental collisions with objects in your world. The `manipulatorStateSpace` object represents the joint configuration space of your rigid body tree robot model, and can sample states, calculate distances, and enforce state bounds. The `manipulatorCollisionBodyValidator` object validates the state and motion based on the collision bodies in your robot model and any obstacles in your environment.

Load Robot Model

Use the `loadrobot` function to access predefined robot models. This example uses the Quanser QArm™ robot and joint configurations are specified as row vectors.

```
robot = loadrobot("quanserQArm",DataFormat="row");
figure(Visible="on")
show(robot);
xlim([-0.5 0.5])
ylim([-0.5 0.5])
zlim([-0.25 0.75])
hold on
```



Configure State Space and State Validation

Create the state space and state validator from the robot model.

```
ss = manipulatorStateSpace(robot);
sv = manipulatorCollisionBodyValidator(ss);
```

Set the validation distance to `0.05`, which is based on the distance normal between two states. You can configure the validator to ignore self collisions to improve the speed of validation, but must consider whether your robot model has the proper joint limit settings set to ensure it does not collide with itself.

```
sv.ValidationDistance = 0.05;
sv.IgnoreSelfCollision = true;
```

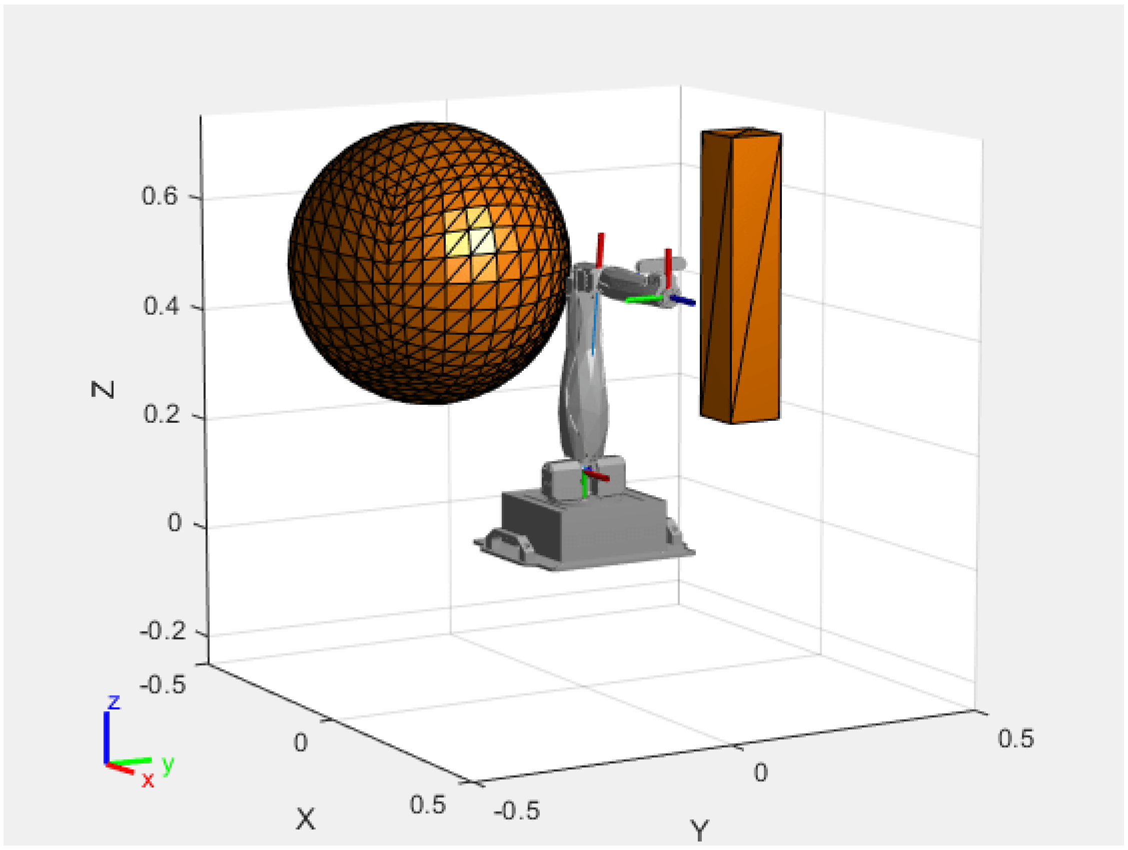
Place collision objects in the robot environment. Set the `Environment` property of the collision validator object using a cell array of objects.

```
box = collisionBox(0.1,0.1,0.5); % XYZ Lengths
box.Pose = trvec2tform([0.2 0.2 0.5]); % XYZ Position
sphere = collisionSphere(0.25); % Radius
sphere.Pose = trvec2tform([-0.2 -0.2 0.5]); % XYZ Position
env = {box sphere};
sv.Environment = env;
```

Visualize the environment.

```
for i = 1:length(env)
    show(env{i})
```

```
end
view(60,10)
```



Plan Path

Start with the home configuration as the first point on the path.

```
rng(0); % Repeatable results
start = homeConfiguration(robot);
path = start;
idx = 1;
```

Plan a path using these steps, in a loop:

- Sample a nearby goal configuration, using the Gaussian distribution, by specifying the standard deviation for each joint angle.
- Check if the sampled goal state is valid.
- If the sampled goal state is valid, check if the motion between states is valid and, if so, add it to the path.

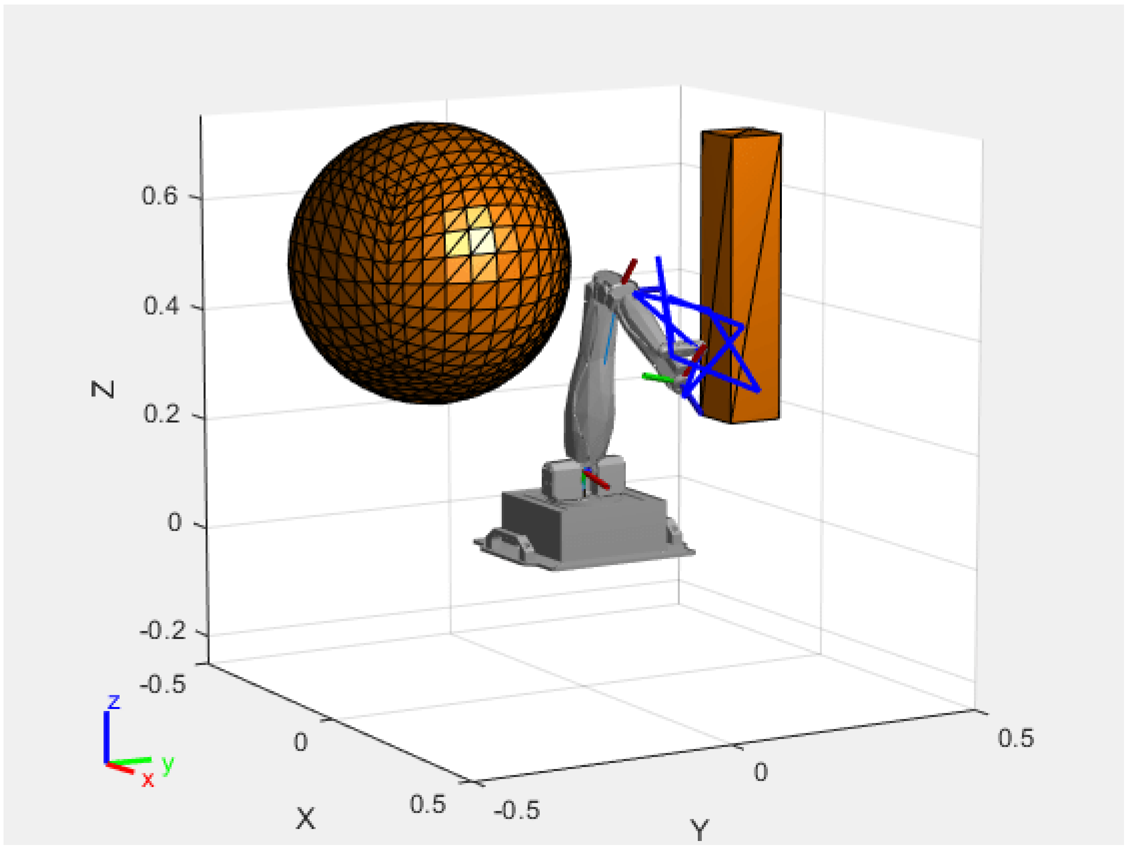
```
for i = 2:25
    goal = sampleGaussian(ss,start,0.25*ones(4,1));
    validState = isStateValid(sv,goal);

    if validState % If state is valid, check motion between states.
        [validMotion,~] = isMotionValid(sv,path(idx,:),goal);
        if validMotion % If motion is valid, add to path.
            path = [path; goal];
            idx = idx + 1;
        end
    end
end
```

Visualize Path

After generating the path of valid motions, visualize the robot motion. Because you sampled random states near the home configuration, you should see the arm move around that initial configuration.

To visualize the path of the end effector in 3-D, get the transformation, relative to the base world frame at each point. Store the points as an *xyz* translation vector. Plot the path of the end effector.

```
eePose = nan(3,size(path,1));

for i = 1:size(path,1)
    show(robot,path(i,:),PreservePlot=false);
    eePos(i,:) = tform2trvec(getTransform(robot,path(i,:),"END-EFFECTOR")); % XYZ translation vec
    plot3(eePos(:,1),eePos(:,2),eePos(:,3),"-b",LineWidth=2)
    drawnow
end
```



Input Arguments

manipSS — Manipulator state space

manipulatorStateSpace object

Manipulator state space, specified as a `manipulatorStateSpace` object, which is a subclass of `nav.StateSpace`.

meanState — Mean state position

n-element row vector

Mean state position, specified as an *n*-element row vector, where *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`.

stdDev — Standard deviation around mean state

n-element row vector

Standard deviation around the mean state, specified as an *n*-element row vector. Each element corresponds to an element in `meanState`.

numSamples — Number of samples

1 (default) | positive integer

Number of samples, specified as a positive integer.

Output Arguments

`states` — Sampled states from state space
n-element row vector | *m*-by-*n* matrix

Sampled states from the state space, returned as an *n*-element row vector or *m*-by-*n* matrix. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`. *m* is the number of samples specified in `numSamples`. All states are sampled within the bounds specified by the `StateBounds` property of `manipSS`.

See Also

Objects
`manipulatorStateSpace` | `rigidBodyTree` | `manipulatorCollisionBodyValidator` | `manipulatorRRT` | `workspaceGoalRegion`

Functions
`isStateValid` | `isMotionValid` | `sampleUniform` | `interpolate` | `distance` | `enforceStateBounds`

Introduced in R2021b

sampleUniform

Sample state using uniform distribution

Syntax

```
states = sampleUniform(manipSS)
states = sampleUniform(manipSS,numSamples)
```

Description

`states = sampleUniform(manipSS)` samples a single random state within the bounds of the state space `manipSS` using a uniform distribution.

`states = sampleUniform(manipSS,numSamples)` samples the number of states specified by `numSamples`.

Input Arguments

`manipSS` — Manipulator state space
`manipulatorStateSpace` object

Manipulator state space, specified as a `manipulatorStateSpace` object, which is a subclass of `nav.StateSpace`.

`numSamples` — Number of samples
positive integer

Number of samples, specified as a positive integer.

Output Arguments

`states` — Sampled states from state space
n-element row vector | *m*-by-*n* matrix

Sampled states from the state space, returned as an *n*-element row vector or *m*-by-*n* matrix. *n* is the dimension of the state space specified in the `NumStateVariables` property of `manipSS`. *m* is the number of samples specified in `numSamples`. All states are sampled within the bounds specified by the `StateBounds` property of `manipSS`.

See Also

Objects
`manipulatorStateSpace` | `rigidBodyTree` | `manipulatorCollisionBodyValidator` | `manipulatorRRT` | `workspaceGoalRegion`

Functions
`isStateValid` | `isMotionValid` | `sampleGaussian` | `interpolate` | `distance` | `enforceStateBounds`

Topics

"Create Custom State Space for Path Planning" (Navigation Toolbox)

Introduced in R2021b

derivative

Time derivative of vehicle state

Syntax

```
stateDot = derivative(motionModel,state,cmds)
```

Description

`stateDot = derivative(motionModel,state,cmds)` returns the current state derivative, `stateDot`, as a three-element vector [*xDot yDot thetaDot*] if the motion model is a `bicycleKinematics`, `differentialDriveKinematics`, or `unicycleKinematics` object. It returns `state` as a four-element vector, [*xDot yDot thetaDot psiDot*], if the motion model is a `ackermannKinematics` object. *xDot* and *yDot* refer to the vehicle velocity, specified in meters per second. *thetaDot* is the angular velocity of the vehicle heading and *psiDot* is the angular velocity of the vehicle steering, both specified in radians per second.

Examples

Simulate Different Kinematic Models for Mobile Robots

This example shows how to model different robot kinematics models in an environment and compare them.

Define Mobile Robots with Kinematic Constraints

There are a number of ways to model the kinematics of mobile robots. All dictate how the wheel velocities are related to the robot state: `[x y theta]`, as *xy*-coordinates and a robot heading, `theta`, in radians.

Unicycle Kinematic Model

The simplest way to represent mobile robot vehicle kinematics is with a unicycle model, which has a wheel speed set by a rotation about a central axle, and can pivot about its z-axis. Both the differential-drive and bicycle kinematic models reduce down to unicycle kinematics when inputs are provided as vehicle speed and vehicle heading rate and other constraints are not considered.

```
unicycle = unicycleKinematics("VehicleInputs","VehicleSpeedHeadingRate");
```

Differential-Drive Kinematic Model

The differential drive model uses a rear driving axle to control both vehicle speed and head rate. The wheels on the driving axle can spin in both directions. Since most mobile robots have some interface to the low-level wheel commands, this model will again use vehicle speed and heading rate as input to simplify the vehicle control.

```
diffDrive = differentialDriveKinematics("VehicleInputs","VehicleSpeedHeadingRate");
```

To differentiate the behavior from the unicycle model, add a wheel speed velocity constraint to the differential-drive kinematic model

```
diffDrive.WheelSpeedRange = [-10 10]*2*pi;
```

Bicycle Kinematic Model

The bicycle model treats the robot as a car-like model with two axles: a rear driving axle, and a front axle that turns about the z-axis. The bicycle model works under the assumption that wheels on each axle can be modeled as a single, centered wheel, and that the front wheel heading can be directly set, like a bicycle.

```
bicycle = bicycleKinematics("VehicleInputs","VehicleSpeedHeadingRate","MaxSteeringAngle",pi/8);
```

Other Models

The Ackermann kinematic model is a modified car-like model that assumes Ackermann steering. In most car-like vehicles, the front wheels do not turn about the same axis, but instead turn on slightly different axes to ensure that they ride on concentric circles about the center of the vehicle's turn. This difference in turning angle is called Ackermann steering, and is typically enforced by a mechanism in actual vehicles. From a vehicle and wheel kinematics standpoint, it can be enforced by treating the steering angle as a rate input.

```
carLike = ackermannKinematics;
```

Set up Simulation Parameters

These mobile robots will follow a set of waypoints that is designed to show some differences caused by differing kinematics.

```
waypoints = [0 0; 0 10; 10 10; 5 10; 11 9; 4 -5];
% Define the total time and the sample rate
sampleTime = 0.05;               % Sample time [s]
tVec = 0:sampleTime:20;          % Time array

initPose = [waypoints(1,:)'; 0]; % Initial pose (x y theta)
```

Create a Vehicle Controller

The vehicles follow a set of waypoints using a Pure Pursuit controller. Given a set of waypoints, the robot current state, and some other parameters, the controller outputs vehicle speed and heading rate.

```
% Define a controller. Each robot requires its own controller
controller1 = controllerPurePursuit("Waypoints",waypoints,"DesiredLinearVelocity",3,"MaxAngularVe
controller2 = controllerPurePursuit("Waypoints",waypoints,"DesiredLinearVelocity",3,"MaxAngularVe
controller3 = controllerPurePursuit("Waypoints",waypoints,"DesiredLinearVelocity",3,"MaxAngularVe
```

Simulate the Models Using an ODE Solver

The models are simulated using the `derivative` function to update the state. This example uses an ordinary differential equation (ODE) solver to generate a solution. Another way would be to update the state using a loop, as shown in “Path Following for a Differential Drive Robot”.

Since the ODE solver requires all outputs to be provided as a single output, the pure pursuit controller must be wrapped in a function that outputs the linear velocity and heading angular velocity as a single output. An example helper, `exampleHelperMobileRobotController`, is used for that purpose. The example helper also ensures that the robot stops when it is within a specified radius of the goal.

```
goalPoints = waypoints(end,:)';
goalRadius = 1;
```

`ode45` is called once for each type of model. The derivative function computes the state outputs with initial state set by `initPose`. Each derivative accepts the corresponding kinematic model object, the current robot pose, and the output of the controller at that pose.

```
% Compute trajectories for each kinematic model under motion control
[tUnicycle,unicyclePose] = ode45(@(t,y)derivative(unicycle,y,exampleHelperMobileRobotController(c
[tBicycle,bicyclePose] = ode45(@(t,y)derivative(bicycle,y,exampleHelperMobileRobotController(cont
[tDiffDrive,diffDrivePose] = ode45(@(t,y)derivative(diffDrive,y,exampleHelperMobileRobotControlle
```

Plot Results

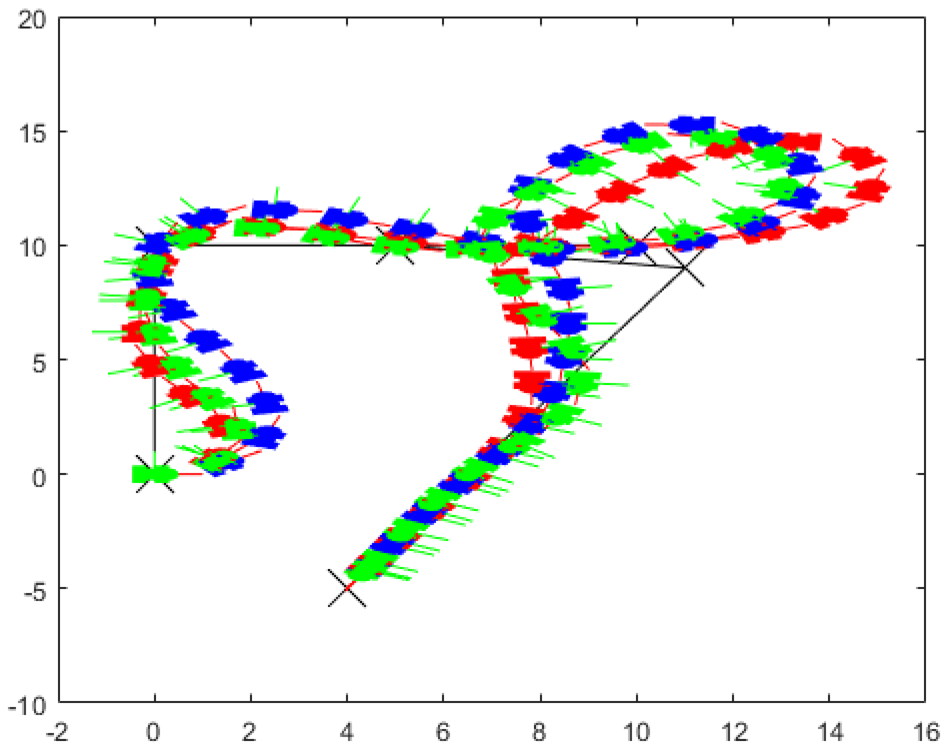
The results of the ODE solver can be easily viewed on a single plot using `plotTransforms` to visualize the results of all trajectories at once.

The pose outputs must first be converted to indexed matrices of translations and quaternions.

```
unicycleTranslations = [unicyclePose(:,1:2) zeros(length(unicyclePose),1)];
unicycleRot = axang2quat([repmat([0 0 1],length(unicyclePose),1) unicyclePose(:,3)]);

bicycleTranslations = [bicyclePose(:,1:2) zeros(length(bicyclePose),1)];
bicycleRot = axang2quat([repmat([0 0 1],length(bicyclePose),1) bicyclePose(:,3)]);

diffDriveTranslations = [diffDrivePose(:,1:2) zeros(length(diffDrivePose),1)];
diffDriveRot = axang2quat([repmat([0 0 1],length(diffDrivePose),1) diffDrivePose(:,3)]);
```

Next, the set of all transforms can be plotted and viewed from the top. The paths of the unicycle, bicycle, and differential-drive robots are red, blue, and green, respectively. To simplify the plot, only show every tenth output.

```
figure
plot(waypoints(:,1),waypoints(:,2),"kx-","MarkerSize",20);
hold all
plotTransforms(unicycleTranslations(1:10:end,:),unicycleRot(1:10:end,:),'MeshFilePath','groundveh
plotTransforms(bicycleTranslations(1:10:end,:),bicycleRot(1:10:end,:),'MeshFilePath','groundvehic
plotTransforms(diffDriveTranslations(1:10:end,:),diffDriveRot(1:10:end,:),'MeshFilePath','groundv
view(0,90)
```



Simulate Ackermann Kinematic Model with Steering Angle Constraints

Simulate a mobile robot model that uses Ackermann steering with constraints on its steering angle. During simulation, the model maintains maximum steering angle after it reaches the steering limit. To see the effect of steering saturation, you compare the trajectory of two robots, one with the constraints on the steering angle and the other without any steering constraints.

Define the Model

Define the Ackermann kinematic model. In this car-like model, the front wheels are a given distance apart. To ensure that they turn on concentric circles, the wheels have different steering angles. While turning, the front wheels receive the steering input as rate of change of steering angle.

```
carLike = ackermannKinematics;
```

Set Up Simulation Parameters

Set the mobile robot to follow a constant linear velocity and receive a constant steering rate as input. Simulate the constrained robot for a longer period to demonstrate steering saturation.

```
velo = 5;    % Constant linear velocity
psidot = 1;  % Constant left steering rate

% Define the total time and sample rate
sampleTime = 0.05;                 % Sample time [s]
```

```
timeEnd1 = 1.5;                     % Simulation end time for unconstrained robot
timeEnd2 = 10;                      % Simulation end time for constrained robot
tVec1 = 0:sampleTime:timeEnd1;      % Time array for unconstrained robot
tVec2 = 0:sampleTime:timeEnd2;      % Time array for constrained robot

initPose = [0;0;0;0];               % Initial pose (x y theta phi)
```

Create Options Structure for ODE Solver

In this example, you pass an `options` structure as argument to the ODE solver. The `options` structure contains the information about the steering angle limit. To create the `options` structure, use the `Events` option of `odeset` and the created event function, `detectSteeringSaturation`. `detectSteeringSaturation` sets the maximum steering angle to 45 degrees.

For a description of how to define `detectSteeringSaturation`, see **Define Event Function** at the end of this example.

```
options = odeset('Events',@detectSteeringSaturation);
```

Simulate Model Using ODE Solver

Next, you use the `derivative` function and an ODE solver, `ode45`, to solve the model and generate the solution.

```
% Simulate the unconstrained robot
[t1,pose1] = ode45(@(t,y)derivative(carLike,y,[velo psidot]),tVec1,initPose);

% Simulate the constrained robot
[t2,pose2,te,ye,ie] = ode45(@(t,y)derivative(carLike,y,[velo psidot]),tVec2,initPose,options);
```

Detect Steering Saturation

When the model reaches the steering limit, it registers a timestamp of the event. The time it took to reach the limit is stored in `te`.

```
if te < timeEnd2
    str1 = "Steering angle limit was reached at ";
    str2 = " seconds";
    comp = str1 + te + str2;
    disp(comp)
end
```

```
Steering angle limit was reached at 0.785 seconds
```

Simulate Constrained Robot with New Initial Conditions

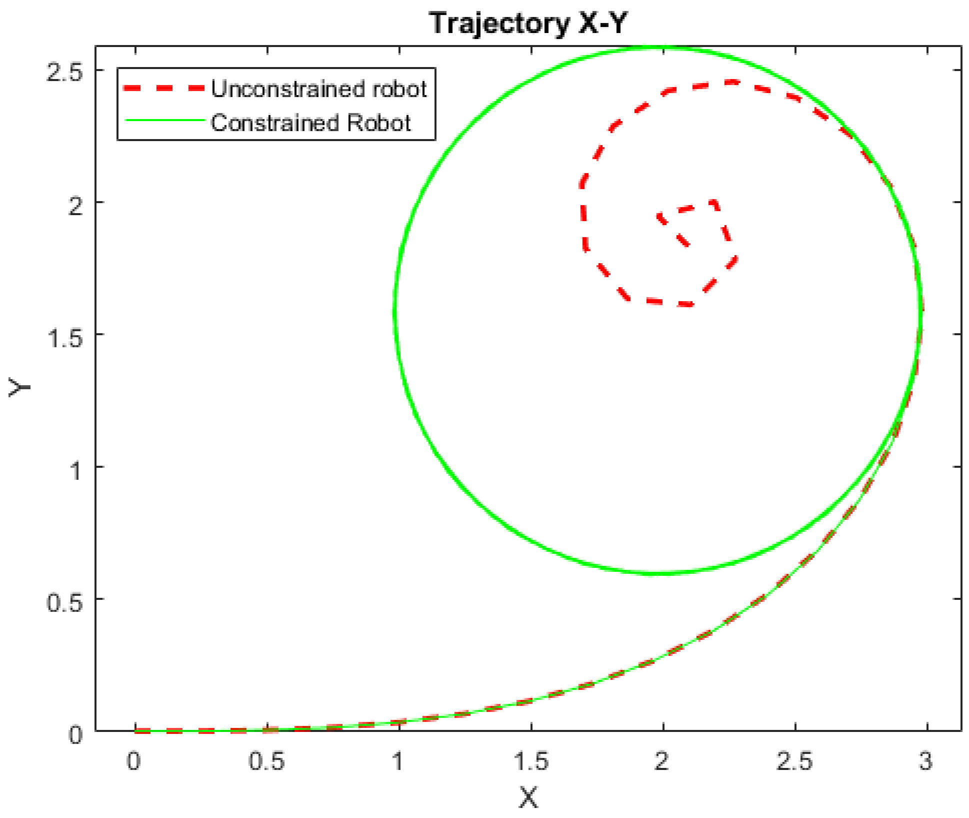
Now use the state of the constrained robot before termination of integration as initial condition for the second simulation. Modify the input vector to represent steering saturation, that is, set the steering rate to zero.

```
saturatedPsiDot = 0;              % Steering rate after saturation
cmds = [velo saturatedPsiDot];    % Command vector
tVec3 = te:sampleTime:timeEnd2;   % Time vector
pose3 = pose2(length(pose2),:);
[t3,pose3,te3,ye3,ie3] = ode45(@(t,y)derivative(carLike,y,cmds), tVec3,pose3, options);
```

Plot the Results

Plot the trajectory of the robot using `plot` and the data stored in `pose`.

```
figure(1)
plot(pose1(:,1),pose1(:,2),'--r','LineWidth',2);
hold on;
plot([pose2(:,1); pose3(:,1)],[pose2(:,2);pose3(:,2)],'g');
title('Trajectory X-Y')
xlabel('X')
ylabel('Y')
legend('Unconstrained robot','Constrained Robot','Location','northwest')
axis equal
```



The unconstrained robot follows a spiral trajectory with decreasing radius of curvature while the constrained robot follows a circular trajectory with constant radius of curvature after the steering limit is reached.

Define Event Function

Set the event function such that integration terminates when 4th state, theta, is equal to maximum steering angle.

```
function [state,isterminal,direction] = detectSteeringSaturation(t,y)
  maxSteerAngle = 0.785;               % Maximum steering angle (pi/4 radians)
  state(4) = (y(4) - maxSteerAngle);   % Saturation event occurs when the 4th state, theta, is e
  isterminal(4) = 1;                   % Integration is terminated when event occurs
  direction(4) = 0;                    % Bidirectional termination
```

```
end
```

Input Arguments

`motionModel` — Mobile kinematic model object
`ackermannKinematics` object | `bicycleKinematics` object | `differentialDriveKinematics` object | `unicycleKinematics` object

The mobile kinematics model object, which defines the properties of the motion model, specified as an `ackermannKinematics`, `bicycleKinematics`, `differentialDriveKinematics`, or a `unicycleKinematics` object.

`state` — Current vehicle state
three-element vector | four-element vector

Current vehicle state returned as a three-element or four-element vector, depending on the `motionModel` input:

- `unicycleKinematics` -- [*x y theta*]
- `bicycleKinematics` -- [*x y theta*]
- `differentialDriveKinematics` -- [*x y theta*]
- `ackermannKinematics` -- [*x y theta psi*]

x and *y* refer to the vehicle position, specified in meters per second. *theta* is the vehicle heading and *psi* is the vehicle steering angle, both specified in radians per second.

`cmds` — Input commands to motion model
two-element vector

Input commands to the motion model, specified as a two-element vector that depends on the motion model.

For `ackermannKinematics` objects, the commands are [*v psiDot*].

For other motion models, the `VehicleInputs` property of `motionModel` determines the command vector:

- `"VehicleSpeedSteeringAngle"` -- [*v psiDot*]
- `"VehicleSpeedHeadingRate"` -- [*v omegaDot*]
- `"WheelSpeedHeadingRate"` (`unicycleKinematics` only) -- [*wheelSpeed omegaDot*]
- `"WheelSpeeds"` (`differentialDriveKinematics` only) -- [*wheelL wheelR*]

v is the vehicle velocity in the direction of motion in meters per second. *psiDot* is the steering angle rate in radians per second. *omegaDot* is the angular velocity at the rear axle. *wwheelL* and *wheelR* are the left and right wheel speeds respectively.

Output Arguments

`stateDot` — State derivative of current state
three-element vector | four-element vector

The current state derivative returned as a three-element or four-element vector, depending on the `motionModel` input:

- `unicycleKinematics` -- `[`*`xDot yDot thetaDot`*`]`
- `bicycleKinematics` -- `[`*`xDot yDot thetaDot`*`]`
- `differentialDriveKinematics` -- `[`*`xDot yDot thetaDot`*`]`
- `ackermannKinematics` -- `[`*`xDot yDot thetaDot psiDot`*`]`

xDot and *yDot* refer to the vehicle velocity, specified in meters per second. *thetaDot* is the angular velocity of the vehicle heading and *psiDot* is the angular velocity of the vehicle steering, both specified in radians per second.

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control*. 1st ed. Cambridge, MA: Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`ackermannKinematics` | `bicycleKinematics` | `differentialDriveKinematics` | `unicycleKinematics`

Topics
"Mobile Robot Kinematics Equations"

Introduced in R2019b

findpath

Find path between start and goal points on roadmap

Syntax

```
xy = findpath(prm,start,goal)
```

Description

`xy = findpath(prm,start,goal)` finds an obstacle-free path between `start` and `goal` locations within `prm`, a roadmap object that contains a network of connected points.

If any properties of `prm` change, or if the roadmap is not created, `update` is called.

Input Arguments

`prm` — Roadmap path planner
`mobileRobotPRM` object

Roadmap path planner, specified as a `mobileRobotPRM` object.

`start` — Start location of path
1-by-2 vector

Start location of path, specified as a 1-by-2 vector representing an `[x y]` pair.

Example: [0 0]

`goal` — Final location of path
1-by-2 vector

Final location of path, specified as a 1-by-2 vector representing an `[x y]` pair.

Example: [10 10]

Output Arguments

`xy` — Waypoints for a path between `start` and `goal`
n-by-2 column vector

Waypoints for a path between start and goal, specified as a *n*-by-2 column vector of `[x y]` pairs, where *n* is the number of waypoints. These pairs represent the solved path from the `start` and `goal` locations, given the roadmap from the `prm` input object.

See Also

`mobileRobotPRM` | `show` | `update`

Introduced in R2019b

show

Show map, roadmap, and path

Syntax

```
show(prm)
show(prm,Name,Value)
```

Description

`show(prm)` shows the map and the roadmap, specified as `prm` in a figure window. If no roadmap exists, `update` is called. If a path is computed before calling `show`, the path is also plotted on the figure.

`show(prm,Name,Value)` sets the specified `Value` to the property `Name`.

Input Arguments

`prm` — Roadmap path planner
`mobileRobotPRM` object

Roadmap path planner, specified as a `mobileRobotPRM` 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: `'Path','off'`

`Parent` — Axes to plot the map
`Axes` object | `UIAxes` object

Axes to plot the map specified as a comma-separated pair consisting of `"Parent"` and either an `Axes` or `UIAxes`object. See `axes` or `uiaxes`.

`Map` — Map display option
`"on"` (default) | `"off"`

Map display option, specified as the comma-separated pair consisting of `"Map"` and either `"on"` or `"off"`.

`Roadmap` — Roadmap display option
`"on"` (default) | `"off"`

Roadmap display option, specified as the comma-separated pair consisting of `"Roadmap"` and either `"on"` or `"off"`.

`Path` — Path display option
`"on"` (default) | `"off"`

Path display option, specified as `"on"` or `"off"`. This controls whether the computed path is shown in the plot.

See Also
`mobileRobotPRM` | `findpath` | `update`

Topics
“Path Following for a Differential Drive Robot”

Introduced in R2019b

update

Create or update roadmap

Syntax

`update(prm)`

Description

`update(prm)` creates a roadmap if called for the first time after creating the `mobileRobotPRM` object, `prm`. Subsequent calls of `update` recreate the roadmap by resampling the map. `update` creates the new roadmap using the `Map`, `NumNodes`, and `ConnectionDistance` property values specified in `prm`.

Input Arguments

`prm` — Roadmap path planner
`mobileRobotPRM` object

Roadmap path planner, specified as a `mobileRobotPRM` object.

See Also

`mobileRobotPRM` | `findpath` | `show`

Introduced in R2019b

reset

Reset `Rate` object

Syntax

`reset(rate)`

Description

`reset(rate)` resets the state of the `Rate` object, including the elapsed time and all statistics about previous periods. `reset` is useful if you want to run multiple successive loops at the same rate, or if the object is created before the loop is executed.

Input Arguments

`rate` — Rate object
handle

`Rate` object, specified as a handle. This object contains the information for the desired rate and other information about the execution. See `rateControlrateControl` for more information.

Examples

Run Loop At Fixed Rate and Reset Rate Object

Create a `rateControl` object for running at 20 Hz.

```
r = rateControl(2);
```

Start a loop and control operation using the `Rate` object.

```
for i = 1:30
    % Your code goes here
    waitfor(r);
end
```

Display the `rateControl` object properties after loop operation.

```
disp(r)
```

```
  rateControl with properties:

         DesiredRate: 2
       DesiredPeriod: 0.5000
       OverrunAction: 'slip'
    TotalElapsedTime: 15.0135
          LastPeriod: 0.4916
```

Reset the object to restart the time statistics.

```
reset(r);
disp(r)

  rateControl with properties:

         DesiredRate: 2
       DesiredPeriod: 0.5000
       OverrunAction: 'slip'
    TotalElapsedTime: 0.0040
          LastPeriod: NaN
```

See Also
`rateControl` | `rateControl` | `waitfor`

Topics
“Execute Code at a Fixed-Rate”

Introduced in R2016a

statistics

Statistics of past execution periods

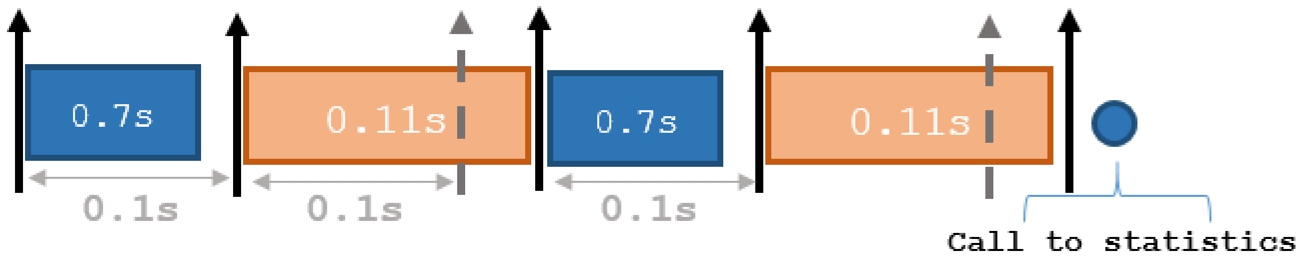
Syntax

```
stats = statistics(rate)
```

Description

`stats = statistics(rate)` returns statistics of previous periods of code execution. `stats` is a struct with these fields: `Periods`, `NumPeriods`, `AveragePeriod`, `StandardDeviation`, and `NumOverruns`.

Here is a sample execution graphic using the default setting, `'slip'`, for the `OverrunAction` property in the `Rate` object. See `OverrunAction` for more information on overrun code execution.



The output of `statistics` is:

```
stats = 

             Periods: [0.7 0.11 0.7 0.11]
          NumPeriods: 4
       AveragePeriod: 0.09
   StandardDeviation: 0.0231
         NumOverruns: 2
```

Input Arguments

rate — Rate object
handle

`Rate` object, specified as an object handle. This object contains the information for the `DesiredRate` and other info about the execution. See `rateControlrateControl` for more information.

Output Arguments

stats — Time execution statistics
structure

Time execution statistics, returned as a structure. This structure contains the following fields:

- `Period` — All time periods (returned in seconds) used to calculate statistics as an indexed array. `stats.Period(end)` is the most recent period.
- `NumPeriods` — Number of elements in `Periods`
- `AveragePeriod` — Average time in seconds
- `StandardDeviation` — Standard deviation of all periods in seconds, centered around the mean stored in `AveragePeriod`
- `NumOverruns` — Number of periods with overrun

Examples

Get Statistics From Rate Object Execution

Create a `rateControl` object for running at 20 Hz.

```
r = rateControl(20);
```

Start a loop and control operation using the `rateControl` object.

```
for i = 1:30
    % Your code goes here
    waitfor(r);
end
```

Get `Rate` object statistics after loop operation.

```
stats = statistics(r)
```

```
stats = struct with fields:
              Periods: [0.0558 0.0610 0.0355 0.0551 0.0611 0.0494 0.2308 ... ]
           NumPeriods: 30
        AveragePeriod: 0.0551
    StandardDeviation: 0.0352
          NumOverruns: 1
```

See Also
`rateControl` | `rateControl` | `waitfor`

Topics
“Execute Code at a Fixed-Rate”

Introduced in R2016a

waitfor

Package: `robotics`

Pause code execution to achieve desired execution rate

Syntax

```
waitfor(rate)
numMisses = waitfor(rate)
```

Description

`waitfor(rate)` pauses execution until the code reaches the desired execution rate. The function accounts for the time that is spent executing code between `waitfor` calls.

`numMisses = waitfor(rate)` returns the number of iterations missed while executing code between calls.

Examples

Run Loop at Fixed Rate

Create a rate object that runs at 1 Hz.

```
r = rateControl(1);
```

Start a loop using the `rateControl` object inside to control the loop execution. Reset the object prior to the loop execution to reset timer. Print the iteration and time elapsed.

```
reset(r)
for i = 1:10
    time = r.TotalElapsedTime;
    fprintf('Iteration: %d - Time Elapsed: %f\n',i,time)
    waitfor(r);
end
```

```
Iteration: 1 - Time Elapsed: 0.004098
Iteration: 2 - Time Elapsed: 1.004890
Iteration: 3 - Time Elapsed: 2.009797
Iteration: 4 - Time Elapsed: 3.024798
Iteration: 5 - Time Elapsed: 4.004382
Iteration: 6 - Time Elapsed: 5.009306
Iteration: 7 - Time Elapsed: 6.002341
Iteration: 8 - Time Elapsed: 7.013342
Iteration: 9 - Time Elapsed: 8.004305
Iteration: 10 - Time Elapsed: 9.000212
```

Each iteration executes at a 1-second interval.

Input Arguments

`rate` — Rate object
handle

`Rate` object, specified as a handle. This object contains the information for the desired rate and other information about the execution. See `rateControl` for more information.

Output Arguments

`numMisses` — Number of missed task executions
scalar

Number of missed task executions, returned as a scalar. `waitfor` returns the number of times the task was missed in the `Rate` object based on the `LastPeriod` time. For example, if the desired rate is 1 Hz and the last period was 3.2 seconds, `numMisses` returns 3.

See Also
`rateControl` | `rateControl`

Topics
"Execute Code at a Fixed-Rate"

Introduced in R2016a

addCollision

Add collision geometry to rigid body

Syntax

```
addCollision(body,type,parameters)
addCollision(body,collisionObj)
addCollision( ___ ,tform)
```

Description

`addCollision(body,type,parameters)` adds a collision geometry of the specified type `type` and geometric parameters `parameters` to the specified rigid body `body`.

`addCollision(body,collisionObj)` adds a collision geometry object to the rigid body `body`, specified as one of these collision objects:

- `collisionBox`
- `collisionCylinder`
- `collisionSphere`
- `collisionMesh`

This syntax uses the `Pose` property of the specified collision object to transform the collision vertices into the rigid body frame.

`addCollision( ___ ,tform)` specifies a transformation for the collision geometry relative to the body frame in addition to any combination of input arguments from previous syntaxes.

Examples

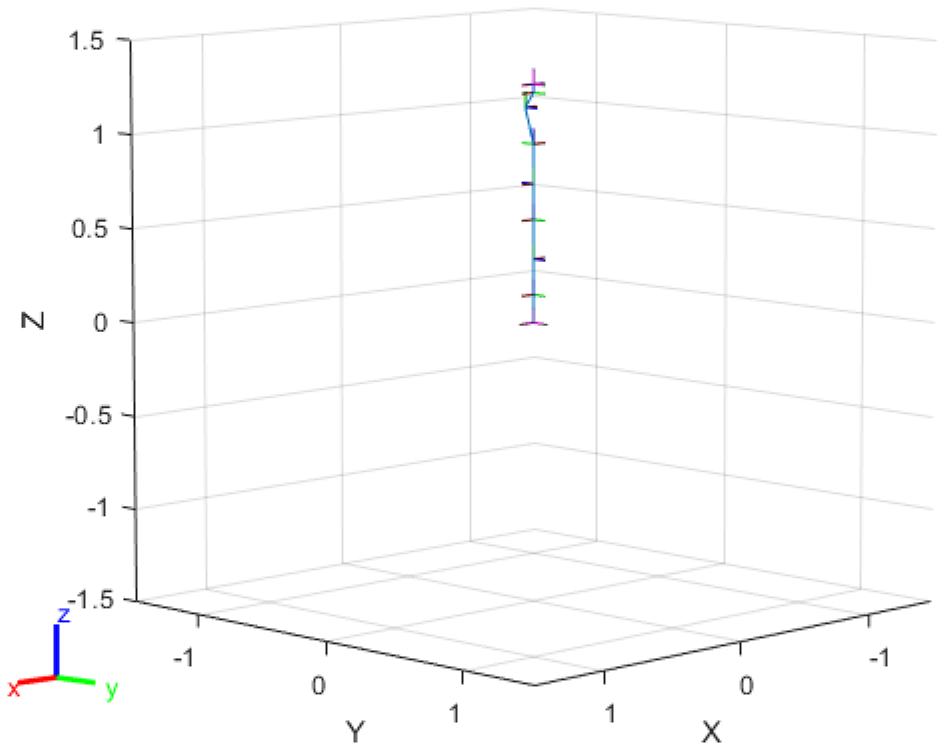
Add Collision Meshes and Check Collisions for Manipulator Robot Arm

Load a robot model and modify the collision meshes. Clear existing collision meshes, add simple collision object primitives, and check whether certain configurations are in collision.

Load Robot Model

Load a preconfigured robot model into the workspace using the `loadrobot` function. This model already has collision meshes specified for each body. Iterate through all the rigid body elements and clear the existing collision meshes. Confirm that the existing meshes are gone.

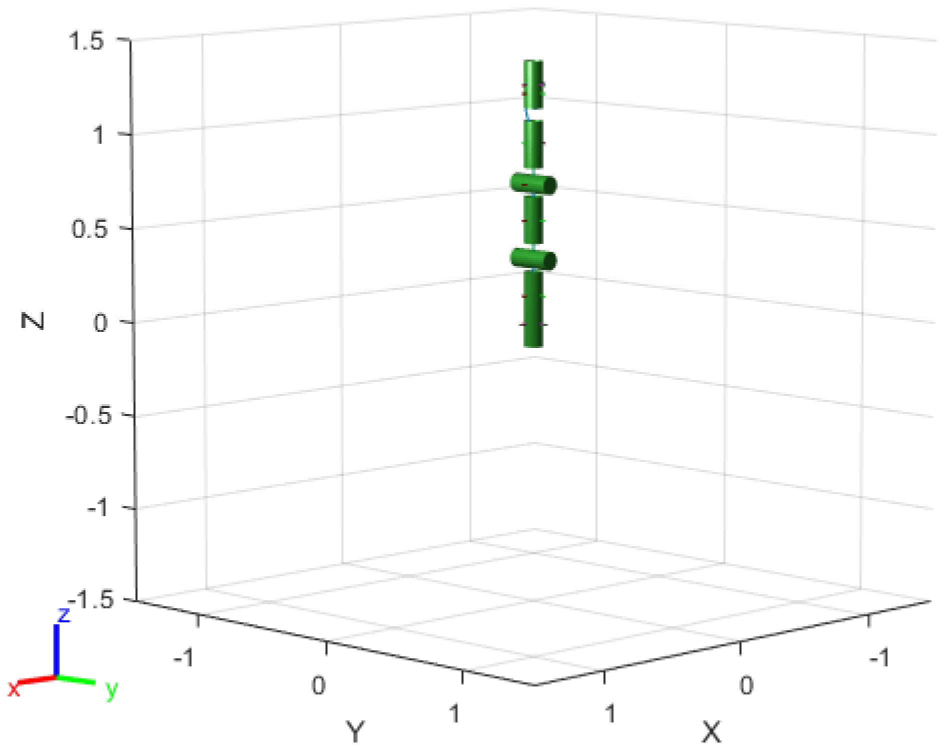
```
robot = loadrobot('kukaIiwa7','DataFormat','column');

for i = 1:robot.NumBodies
    clearCollision(robot.Bodies{i})
end

show(robot,'Collisions','on','Visuals','off');
```



Add Collision Cylinders

Iteratively add a collision cylinder to each body. Skip some bodies for this specific model, as they overlap and always collide with the end effector (body 10).

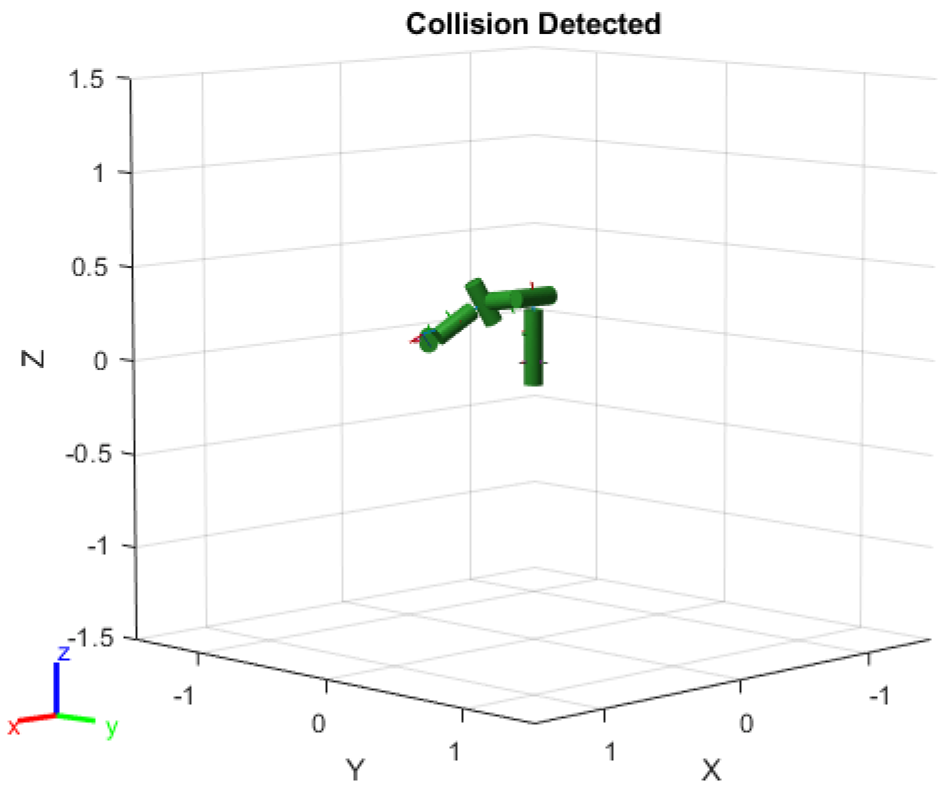
```
collisionObj = collisionCylinder(0.05,0.25);

for i = 1:robot.NumBodies
    if i > 6 && i < 10
        % Skip these bodies.
    else
        addCollision(robot.Bodies{i},collisionObj)
    end
end

show(robot,'Collisions','on','Visuals','off');
```



Check for Collisions

Generate a series of random configurations. Check whether the robot is in collision at each configuration. Visualize each configuration that has a collision.

```
figure
rng(0) % Set random seed for repeatability.
for i = 1:20
    config = randomConfiguration(robot);
    isColliding = checkCollision(robot,config);
    if isColliding
        show(robot,config,'Collisions','on','Visuals','off');
        title('Collision Detected')
    else
        % Skip non-collisions.
    end
end
```



Input Arguments

body — Rigid body
`rigidBody` object

Rigid body, specified as a `rigidBody` object.

type — Geometry type for collision geometry
`"box"` | `"cylinder"` | `"sphere"` | `"mesh"`

Geometry type for collision geometry, specified as a string scalar. The specified type determines the format of the `parameters` input.

- `"box"` — `[x y z]`
- `"cylinder"` — `[radius length]`
- `"sphere"` — `radius`
- `"mesh"` — *n*-by-3 matrix of vertices or an STL or DAE file name as a string

Data Types: `char` | `string`

`parameters` — Collision geometry parameters
numeric vector | numeric matrix | string scalar

Collision geometry parameters, specified as a numeric vector, numeric matrix, or string scalar. The `type` input determines the format of this value.

- `"box"` — `[x y z]`
- `"cylinder"` — `[radius length]`
- `"sphere"` — `radius`
- `"mesh"` — *n*-by-3 matrix of vertices or an STL or DAE file name as a string

Data Types: `single` | `double` | `char` | `string`

`collisionObj` — Collision geometry object
`collisionBox` object | `collisionCylinder` object | `collisionSphere` object | `collisionMesh` object

Collision geometry object, specified as a `collisionBox`, `collisionCylinder`, `collisionSphere`, or `collisionMesh` object.

`tform` — Transformation of collision geometry
`eye(4)` (default) | 4-by-4 homogeneous transformation

Transformation of collision geometry, specified as a 4-by-4 homogeneous transformation. If specifying a collision object for the `collisionObj` input, this function applies the specified transformation to the `Pose` property of the specified collision object to transform the collision vertices into the rigid body frame.

Data Types: `single` | `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`addVisual` | `checkCollision` | `clearCollision` | `clearVisual` | `show` | `rigidBodyTree`

Introduced in R2020b

addVisual

Add visual geometry data to rigid body

Syntax

```
addVisual(body,"Mesh",filename)
addVisual(body,"Mesh",filename,tform)
```

Description

`addVisual(body,"Mesh",filename)` adds a polygon mesh on top of any current visual geometry using the specified `.stl` or `.dae` file, `filename`. Multiple visual geometries can be added to a single body. The coordinate frame is assumed to coincide with the frame of `body`. You can view the meshes for an entire rigid body tree using `show`.

`addVisual(body,"Mesh",filename,tform)` specifies a homogeneous transformation for the polygon mesh relative to the body frame.

Input Arguments

body — RigidBody object
handle

`RigidBody` object, specified as a handle. Create a rigid body object using `rigidBody`.

`filename` — Name of mesh file
string scalar | character vector

Name of mesh file, specified as a string scalar or character vector. This file must be a valid `.stl` or `.dae` file.

Data Types: `char` | `string`

`tform` — Polygon mesh transformation
4-by-4 homogeneous transformation

Mesh transformation relative to the body coordinate frame, specified as a 4-by-4 homogeneous transformation.

See Also

`addCollision` | `clearCollision` | `clearVisual` | `show` | `rigidBodyTree`

Introduced in R2017b

clearCollision

Clear all attached collision geometries

Syntax

```
clearCollision(body)
```

Description

`clearCollision(body)` clears all collision geometries attached to the specified rigid body object.

Examples

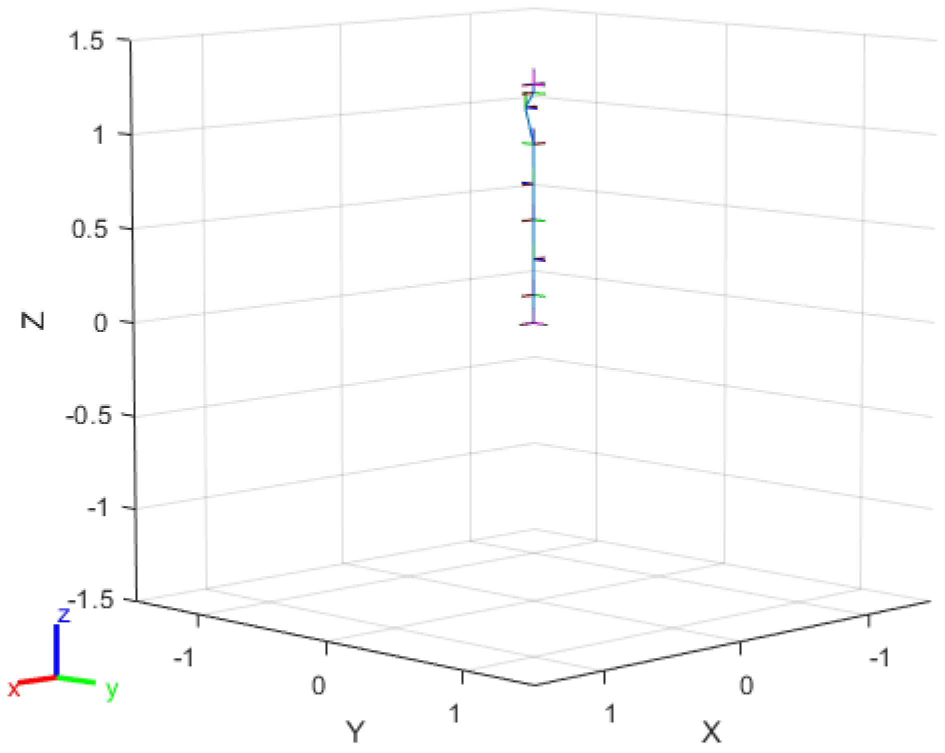
Add Collision Meshes and Check Collisions for Manipulator Robot Arm

Load a robot model and modify the collision meshes. Clear existing collision meshes, add simple collision object primitives, and check whether certain configurations are in collision.

Load Robot Model

Load a preconfigured robot model into the workspace using the `loadrobot` function. This model already has collision meshes specified for each body. Iterate through all the rigid body elements and clear the existing collision meshes. Confirm that the existing meshes are gone.

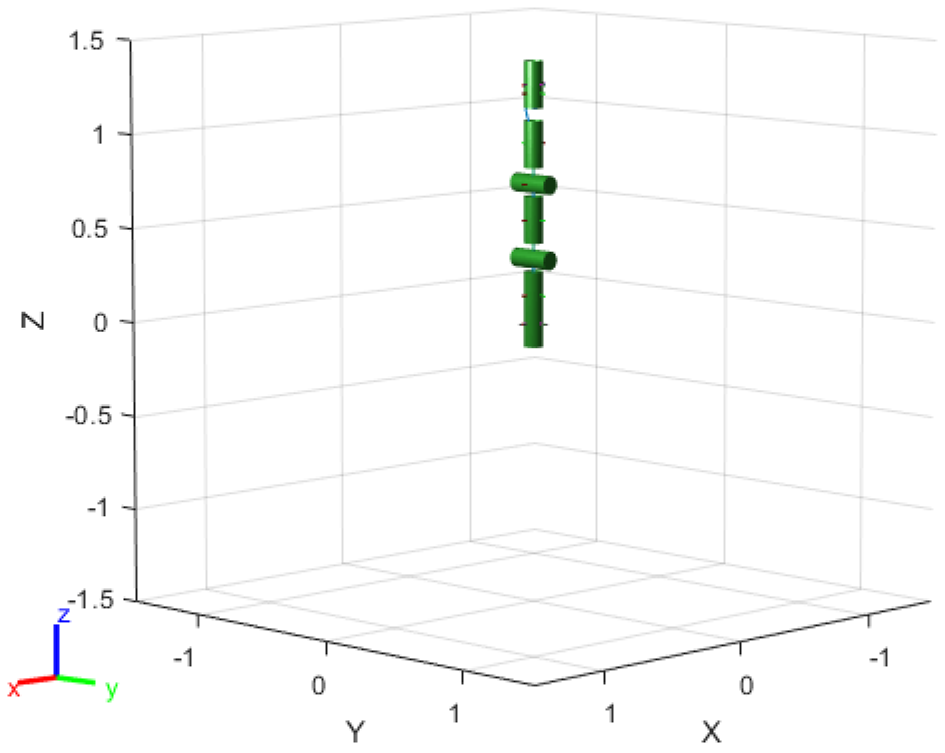
```
robot = loadrobot('kukaIiwa7','DataFormat','column');

for i = 1:robot.NumBodies
    clearCollision(robot.Bodies{i})
end

show(robot,'Collisions','on','Visuals','off');
```



Add Collision Cylinders

Iteratively add a collision cylinder to each body. Skip some bodies for this specific model, as they overlap and always collide with the end effector (body 10).

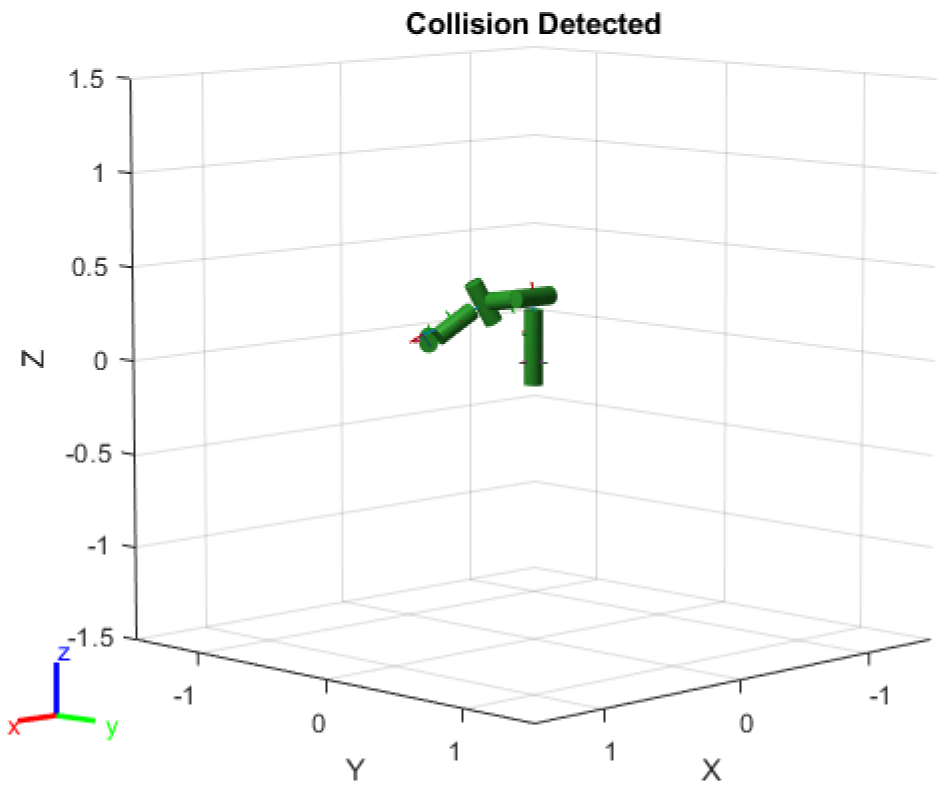
```
collisionObj = collisionCylinder(0.05,0.25);

for i = 1:robot.NumBodies
    if i > 6 && i < 10
        % Skip these bodies.
    else
        addCollision(robot.Bodies{i},collisionObj)
    end
end

show(robot,'Collisions','on','Visuals','off');
```



Check for Collisions

Generate a series of random configurations. Check whether the robot is in collision at each configuration. Visualize each configuration that has a collision.

```
figure
rng(0) % Set random seed for repeatability.
for i = 1:20
    config = randomConfiguration(robot);
    isColliding = checkCollision(robot,config);
    if isColliding
        show(robot,config,'Collisions','on','Visuals','off');
        title('Collision Detected')
    else
        % Skip non-collisions.
    end
end
```



Input Arguments

body — Rigid body
`rigidBody` object

Rigid body, specified as a `rigidBody` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`addVisual` | `addCollision` | `clearCollision` | `show` | `rigidBodyTree`

Introduced in R2020b

clearVisual

Clear all visual geometries

Syntax

`clearVisual(body)`

Description

`clearVisual(body)` clears all visual geometries attached to the given rigid body object.

Input Arguments

body — Rigid body
`rigidBody` object

Rigid body, specified as a `rigidBody` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`addVisual` | `addCollision` | `clearCollision` | `show` | `rigidBodyTree`

Introduced in R2017b

copy

Create a deep copy of rigid body

Syntax

```
copyObj = copy(bodyObj)
```

Description

`copyObj = copy(bodyObj)` creates a copy of the rigid body object with the same properties.

Input Arguments

`bodyObj` — RigidBody object
handle

`RigidBody` object, specified as a handle. Create a rigid body object using `rigidBody`.

Output Arguments

`copyObj` — RigidBody object
handle

`RigidBody` object, returned as a handle. Create a rigid body object using `rigidBody`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`rigidBodyJoint` | `rigidBodyTree`

Introduced in R2016b

copy

Create copy of joint

Syntax

```
jCopy = copy(jointObj)
```

Description

`jCopy = copy(jointObj)` creates a copy of the `rigidBodyJoint` object with the same properties.

Input Arguments

`jointObj` — `rigidBodyJoint` object
handle

`rigidBodyJoint` object, specified as a handle.

Output Arguments

`jCopy` — `rigidBodyJoint` object
handle

`rigidBodyJoint` object, returned as a handle. This copy has the same properties.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`rigidBodyJoint` | `rigidBody` | `rigidBodyTree`

Introduced in R2016b

setFixedTransform

Set fixed transform properties of joint

Syntax

```
setFixedTransform(jointObj,tform)
```

```
setFixedTransform(jointObj,dhparams,"dh")
setFixedTransform(jointObj,mdhparams,"mdh")
```

Description

`setFixedTransform(jointObj,tform)` sets the `JointToParentTransform` property of the `rigidBodyJoint` object directly with the specified homogenous transformation, `tform`.

`setFixedTransform(jointObj,dhparams,"dh")` sets the `ChildToJointTransform` property using Denavit-Hartenberg (DH) parameters. The `JointToParentTransform` property is set to an identity matrix. DH parameters are given in the order `[a alpha d theta]`.

For revolute joints, the `theta` input is ignored when specifying the fixed transformation between joints because that angle is dependent on the joint configuration. For prismatic joints, the `d` input is ignored. For more information, see “Rigid Body Tree Robot Model”.

`setFixedTransform(jointObj,mdhparams,"mdh")` sets the `JointToParentTransform` property using modified DH parameters. The `ChildToJointTransform` property is set to an identity matrix. Modified DH parameters are given in the order `[a alpha d theta]`.

Examples

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix[1] on page 3-0 . The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0       pi/2    0       0;
            0.4318    0       0       0
            0.0203    -pi/2    0.15005    0;
            0       pi/2    0.4318    0;
            0       -pi/2    0       0;
            0       0       0       0];
```

Create a rigid body tree object to build the robot.

```
robot = rigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1. Create a `rigidBody` object and give it a unique name.
2. Create a `rigidBodyJoint` object and give it a unique name.
3. Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4. Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = rigidBody('body1');
jnt1 = rigidBodyJoint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = rigidBody('body2');
jnt2 = rigidBodyJoint('jnt2','revolute');
body3 = rigidBody('body3');
jnt3 = rigidBodyJoint('jnt3','revolute');
body4 = rigidBody('body4');
jnt4 = rigidBodyJoint('jnt4','revolute');
body5 = rigidBody('body5');
jnt5 = rigidBodyJoint('jnt5','revolute');
body6 = rigidBody('body6');
jnt6 = rigidBodyJoint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

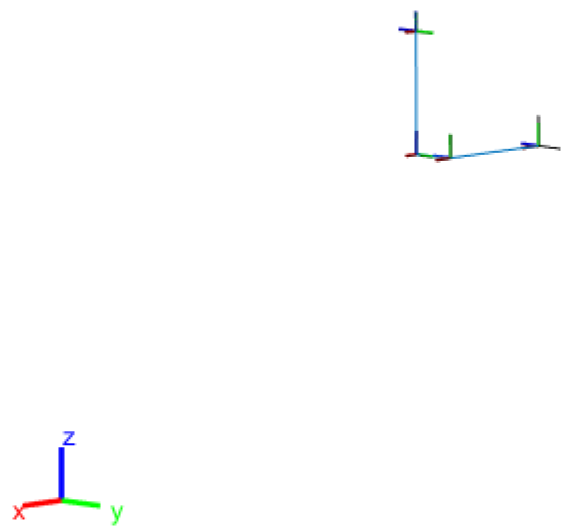
Verify that your robot was built properly by using the `showdetails` or `show` function. `showdetails` lists all the bodies in the MATLAB® command window. `show` displays the robot with a given configuration (home by default). Calls to `axis` modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)
```

```
 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1        body1         jnt1     revolute             base(0)   body2(2)
   2        body2         jnt2     revolute            body1(1)   body3(3)
   3        body3         jnt3     revolute            body2(2)   body4(4)
   4        body4         jnt4     revolute            body3(3)   body5(5)
   5        body5         jnt5     revolute            body4(4)   body6(6)
   6        body6         jnt6     revolute            body5(5)   
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```



References

[1] Corke, P. I., and B. Armstrong-Helouvry. “A Search for Consensus among Model Parameters Reported for the PUMA 560 Robot.” *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, IEEE Comput. Soc. Press, 1994, pp. 1608–13. *DOI.org (Crossref)*, doi:10.1109/ROBOT.1994.351360.

Input Arguments

jointObj — rigidBodyJoint object
handle

`rigidBodyJoint` object, specified as a handle.

`tform` — Homogeneous transform
4-by-4 matrix

Homogeneous transform, specified as a 4-by-4 matrix. The transform is set to the `ChildToJointTransform` property. The `JointToParentTransform` property is set to an identity matrix.

`dhparams` — Denavit-Hartenberg (DH) parameters
four-element vector

Denavit-Hartenberg (DH) parameters, specified as a four-element vector, `[a alpha d theta]`. These parameters are used to set the `ChildToJointTransform` property. The `JointToParentTransform` property is set to an identity matrix.

The `theta` input is ignored when specifying the fixed transformation between joints because that angle is dependent on the joint configuration. For more information, see “Rigid Body Tree Robot Model”.

`mdhparams` — Modified Denavit-Hartenberg (DH) parameters
four-element vector

Modified Denavit-Hartenberg (DH) parameters, specified as a four-element vector, `[a alpha d theta]`. These parameters are used to set the `JointToParentTransform` property. The `ChildToJointTransform` is set to an identity matrix.

The `theta` input is ignored when specifying the fixed transformation between joints because that angle is dependent on the joint configuration. For more information, see “Rigid Body Tree Robot Model”.

References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control*. Reading, MA: Addison-Wesley, 1989.

[2] Siciliano, Bruno. *Robotics: Modelling, Planning and Control.* London: Springer, 2009.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`rigidBodyJoint` | `rigidBody` | `rigidBodyTree`

Introduced in R2016b

addBody

Add body to robot

Syntax

`addBody(robot,body,parentname)`

Description

`addBody(robot,body,parentname)` adds a rigid body to the robot object and is attached to the rigid body parent specified by `parentname`. The `body` property defines how this body moves relative to the parent body.

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `rigidBody` object contains a `rigidBodyJoint` object and must be added to the `rigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = rigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = rigidBody('b1');
```

Create a revolute joint. By default, the `rigidBody` object comes with a fixed joint. Replace the joint by assigning a new `rigidBodyJoint` object to the `body1.Joint` property.

```
jnt1 = rigidBodyJoint('jnt1','revolute');
body1.Joint = jnt1;
```

Add the rigid body to the tree. Specify the body name that you are attaching the rigid body to. Because this is the first body, use the base name of the tree.

```
basename = rbtree.BaseName;
addBody(rbtree,body1,basename)
```

Use `showdetails` on the tree to confirm the rigid body and joint were added properly.

```
showdetails(rbtree)
```

```
--------------------
Robot: (1 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1           b1         jnt1     revolute             base(0)   
--------------------
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix[1] on page 3-0 . The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0       pi/2    0       0;
            0.4318    0       0       0
            0.0203    -pi/2    0.15005    0;
            0       pi/2    0.4318    0;
            0       -pi/2    0       0;
            0       0       0       0];
```

Create a rigid body tree object to build the robot.

```
robot = rigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1. Create a `rigidBody` object and give it a unique name.
2. Create a `rigidBodyJoint` object and give it a unique name.
3. Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4. Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = rigidBody('body1');
jnt1 = rigidBodyJoint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

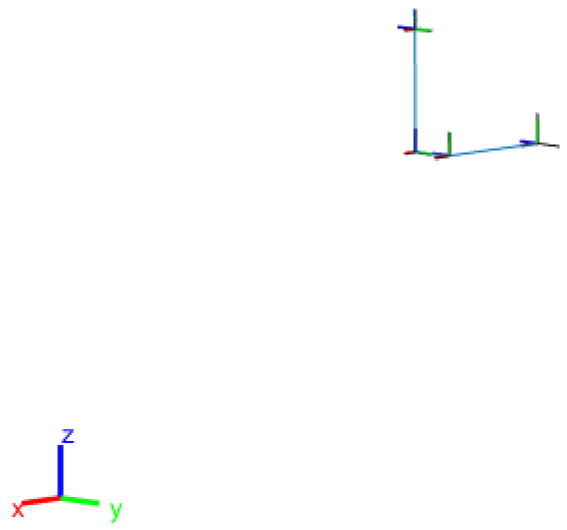
```
body2 = rigidBody('body2');
jnt2 = rigidBodyJoint('jnt2','revolute');
body3 = rigidBody('body3');
jnt3 = rigidBodyJoint('jnt3','revolute');
body4 = rigidBody('body4');
jnt4 = rigidBodyJoint('jnt4','revolute');
body5 = rigidBody('body5');
jnt5 = rigidBodyJoint('jnt5','revolute');
body6 = rigidBody('body6');
jnt6 = rigidBodyJoint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

Verify that your robot was built properly by using the `showdetails` or `show` function. `showdetails` lists all the bodies in the MATLAB® command window. `show` displays the robot with a given configuration (home by default). Calls to `axis` modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1        body1         jnt1     revolute             base(0)   body2(2)
   2        body2         jnt2     revolute            body1(1)   body3(3)
   3        body3         jnt3     revolute            body2(2)   body4(4)
   4        body4         jnt4     revolute            body3(3)   body5(5)
   5        body5         jnt5     revolute            body4(4)   body6(6)
   6        body6         jnt6     revolute            body5(5)
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```



References

[1] Corke, P. I., and B. Armstrong-Helouvry. “A Search for Consensus among Model Parameters Reported for the PUMA 560 Robot.” *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, IEEE Comput. Soc. Press, 1994, pp. 1608–13. *DOI.org (Crossref)*, doi:10.1109/ROBOT.1994.351360.

Modify a Robot Rigid Body Tree Model

Make changes to an existing `rigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name    Joint Name    Joint Type     Parent Name(Idx)    Children Name(s)
 ---     ---------    ----------    ----------     ----------------    ----------------
```

```
   1           L1         jnt1     revolute             base(0)   L2(2)
   2           L2         jnt2     revolute               L1(1)   L3(3)
   3           L3         jnt3     revolute               L2(2)   L4(4)
   4           L4         jnt4     revolute               L3(3)   L5(5)
   5           L5         jnt5     revolute               L4(4)   L6(6)
   6           L6         jnt6     revolute               L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}
```

```
childBody = 
  rigidBody with properties:

            Name: 'L4'
           Joint: [1x1 rigidBodyJoint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 rigidBody]
        Children: {[1x1 rigidBody]}
         Visuals: {}
      Collisions: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the `L3` body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name       Joint Name       Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------       ----------       ----------    ----------------   ----------------
   1            L1             jnt1         revolute             base(0)   L2(2)
   2            L2             jnt2         revolute               L1(1)   L3(3)
   3            L3        prismatic            fixed               L2(2)   L4(4)
   4            L4             jnt4         revolute               L3(3)   L5(5)
   5            L5             jnt5         revolute               L4(4)   L6(6)
   6            L6             jnt6         revolute               L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree = 
  rigidBodyTree with properties:
     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified `L3` body. Add the original copied `L3` body to the `L2` body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

`body` — Rigid body
`rigidBody` object

Rigid body, specified as a `rigidBody` object.

`parentname` — Parent body name
string scalar | character vector

Parent body name, specified as a string scalar or character vector. This parent body must already exist in the robot model. The new body is attached to this parent body.

Data Types: `char` | `string`

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyJoint` | `rigidBody` | `removeBody` | `replaceBody`

Introduced in R2016b

addSubtree

Add subtree to robot

Syntax

`addSubtree(robot,parentname,subtree)`

Description

`addSubtree(robot,parentname,subtree)` attaches the robot model, `newSubtree`, to an existing robot model, `robot`, at the body specified by `parentname`. The subtree base is not added as a body.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `rigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1           L1         jnt1     revolute             base(0)   L2(2)
   2           L2         jnt2     revolute               L1(1)   L3(3)
   3           L3         jnt3     revolute               L2(2)   L4(4)
   4           L4         jnt4     revolute               L3(3)   L5(5)
   5           L5         jnt5     revolute               L4(4)   L6(6)
   6           L6         jnt6     revolute               L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}
```

```
childBody =
  rigidBody with properties:

            Name: 'L4'
           Joint: [1x1 rigidBodyJoint]
```

```
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 rigidBody]
        Children: {[1x1 rigidBody]}
         Visuals: {}
      Collisions: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the `L3` body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name       Joint Name       Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------       ----------       ----------    ----------------   ----------------
   1           L1             jnt1         revolute             base(0)   L2(2)
   2           L2             jnt2         revolute               L1(1)   L3(3)
   3           L3        prismatic            fixed               L2(2)   L4(4)
   4           L4             jnt4         revolute               L3(3)   L5(5)
   5           L5             jnt5         revolute               L4(4)   L6(6)
   6           L6             jnt6         revolute               L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree = 
  rigidBodyTree with properties:

     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified `L3` body. Add the original copied `L3` body to the `L2` body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Input Arguments

robot — Robot model
RigidBodyTree object

Robot model, specified as a rigidBodyTree object.

parentname — Parent body name
string scalar | character vector

Parent body name, specified as a string scalar or character vector. This parent body must already exist in the robot model. The new body is attached to this parent body.

Data Types: char | string

subtree — Subtree robot model
rigidBodyTree object

Subtree robot model, specified as a rigidBodyTree object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the rigidBodyTree object, use the syntax that specifies the MaxNumBodies as an upper bound for adding bodies to the robot model. You must also specify the DataFormat property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to "row" or "column".

The show and showdetails functions do not support code generation.

See Also

rigidBodyJoint | rigidBody | addBody | removeBody | replaceBody

Introduced in R2016b

centerOfMass

Center of mass position and Jacobian

Syntax

```
com = centerOfMass(robot)
com = centerOfMass(robot,configuration)
[com,comJac] = centerOfMass(robot,configuration)
```

Description

`com = centerOfMass(robot)` computes the center of mass position of the robot model at its home configuration, relative to the base frame.

`com = centerOfMass(robot,configuration)` computes the center of mass position of the robot model at the specified joint configuration, relative to the base frame.

`[com,comJac] = centerOfMass(robot,configuration)` also returns the center of mass Jacobian, which relates the center of mass velocity to the joint velocities.

Examples

Calculate Center of Mass and Jacobian for Robot Configuration

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Compute the center of mass position and Jacobian at the home configuration of the robot.

```
[comLocation,comJac] = centerOfMass(lbr);
```

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. To use the `centerOfMass` function, set the `DataFormat` property to either `'row'` or `'column'`.

`configuration` — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Output Arguments

com — Center of mass location

`[x y z]` vector

Center of mass location, returned as an `[x y z]` vector. The vector describes the location of the center of mass for the specified `configuration` relative to the body frame, in meters.

comJac — Center of mass Jacobian

3-by-*n* matrix

Center of mass Jacobian, returned as a 3-by-*n* matrix, where *n* is the robot velocity degrees of freedom.

References

[1] Featherstone, Roy. *Rigid Body Dynamics Algorithms*. Springer US, 2008. DOI.org (Crossref), doi:10.1007/978-1-4899-7560-7.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyTree` | `massMatrix` | `velocityProduct` | `gravityTorque`

Topics

“Robot Dynamics”

Introduced in R2017a

checkCollision

Check if robot is in collision

Syntax

```
[isSelfColliding,selfSeparationDist,selfWitnessPts] = checkCollision(robot,
config)
```

```
[isColliding,separationDist,witnessPts] = checkCollision(robot,config,
worldObjects)
```

```
[ ___ ] = checkCollision( ___ ,Name,Value)
```

Description

`[isSelfColliding,selfSeparationDist,selfWitnessPts] = checkCollision(robot, config)` checks if the specified rigid body tree robot model `robot` is in self-collision at the specified configuration `config`. Add collision objects to the rigid body tree robot model using the `addCollision` function. The `checkCollision` function also returns the closest separation distance `selfSeparationDist` and the witness points `selfWitnessPts` as points on each body.

The function ignores adjacent bodies when checking for self-collisions.

`[isColliding,separationDist,witnessPts] = checkCollision(robot,config, worldObjects)` checks if the specified rigid body tree robot model is in collision with itself or a specified set of collision objects in the world `worldObjects`.

`[ ___ ] = checkCollision( ___ ,Name,Value)` specifies additional options using one or more name-value pair arguments in addition to any of argument combinations from previous syntaxes.

Examples

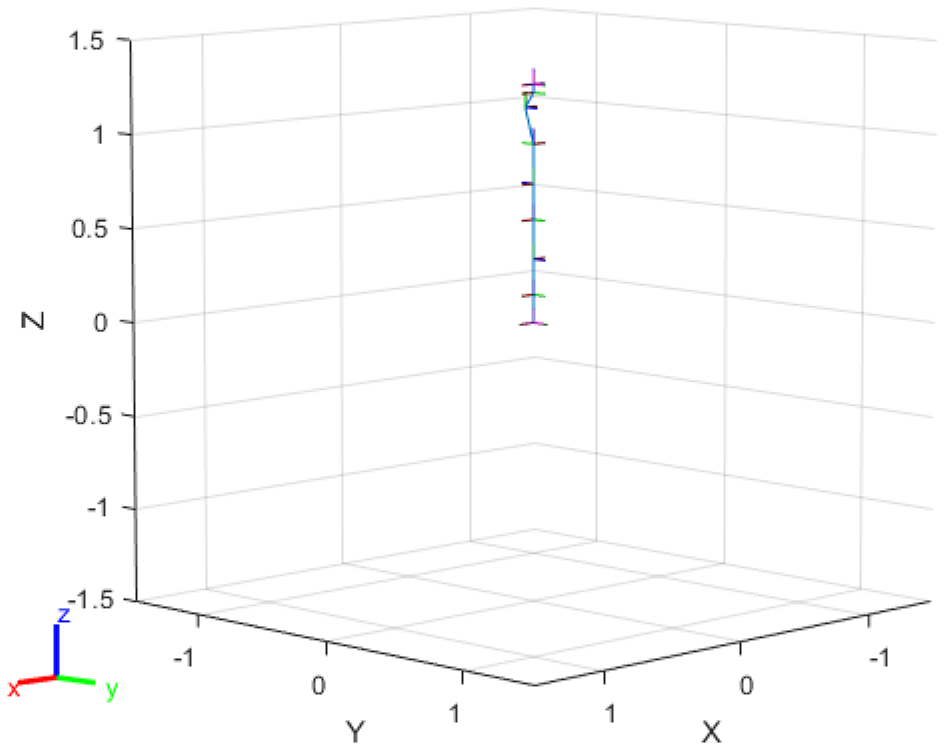
Add Collision Meshes and Check Collisions for Manipulator Robot Arm

Load a robot model and modify the collision meshes. Clear existing collision meshes, add simple collision object primitives, and check whether certain configurations are in collision.

Load Robot Model

Load a preconfigured robot model into the workspace using the `loadrobot` function. This model already has collision meshes specified for each body. Iterate through all the rigid body elements and clear the existing collision meshes. Confirm that the existing meshes are gone.

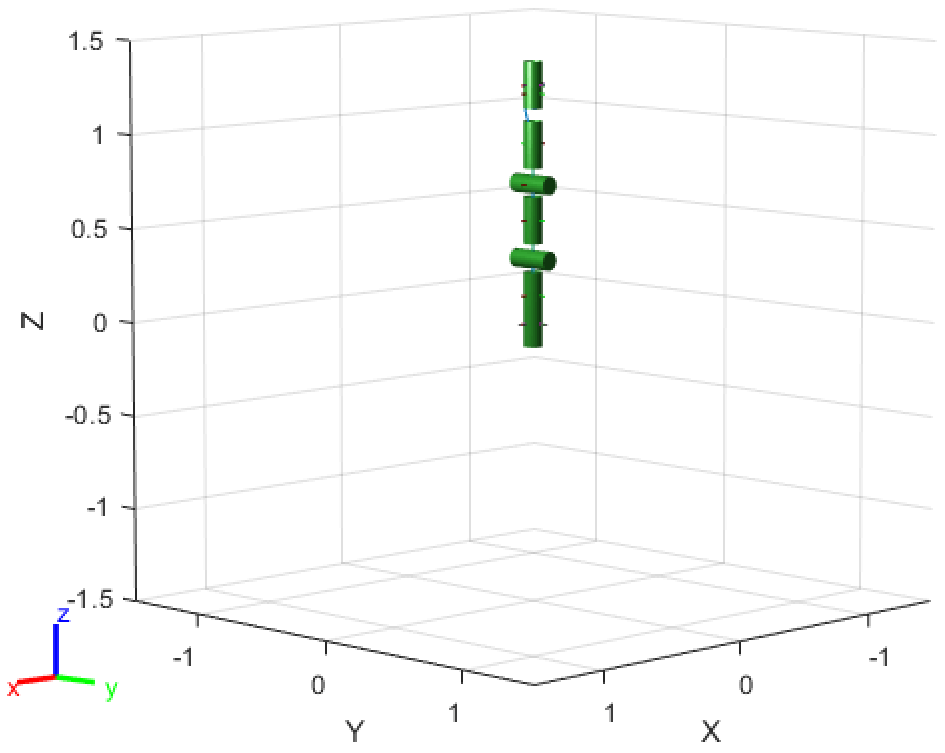
```
robot = loadrobot('kukaIiwa7','DataFormat','column');

for i = 1:robot.NumBodies
    clearCollision(robot.Bodies{i})
end

show(robot,'Collisions','on','Visuals','off');
```



Add Collision Cylinders

Iteratively add a collision cylinder to each body. Skip some bodies for this specific model, as they overlap and always collide with the end effector (body 10).

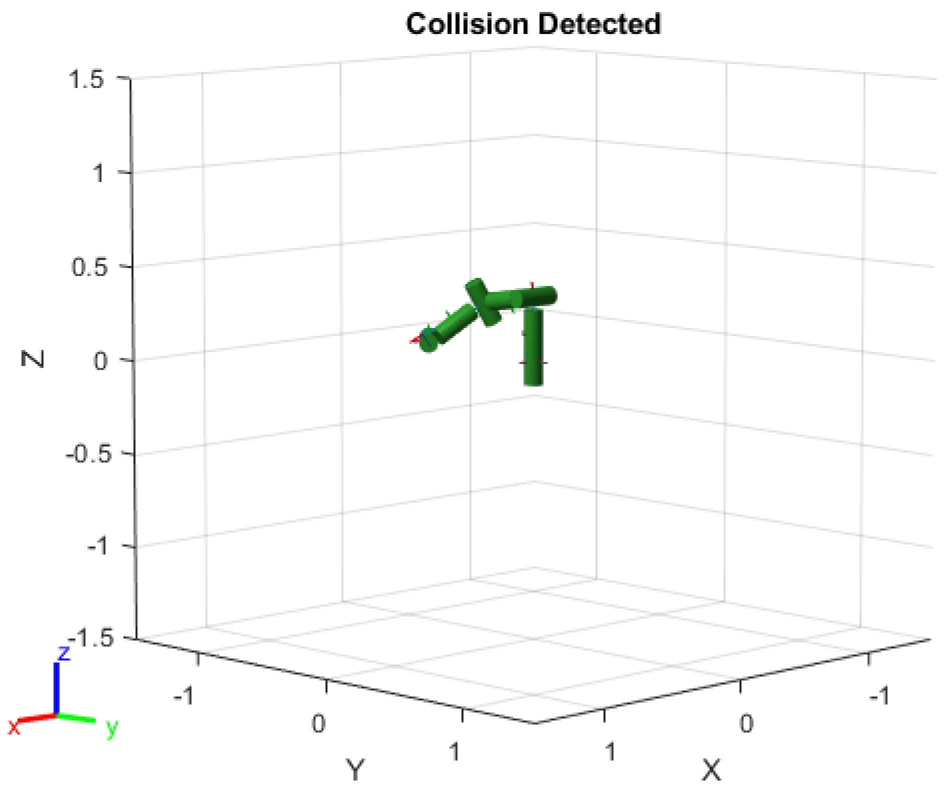
```
collisionObj = collisionCylinder(0.05,0.25);

for i = 1:robot.NumBodies
    if i > 6 && i < 10
        % Skip these bodies.
    else
        addCollision(robot.Bodies{i},collisionObj)
    end
end

show(robot,'Collisions','on','Visuals','off');
```



Check for Collisions

Generate a series of random configurations. Check whether the robot is in collision at each configuration. Visualize each configuration that has a collision.

```
figure
rng(0) % Set random seed for repeatability.
for i = 1:20
    config = randomConfiguration(robot);
    isColliding = checkCollision(robot,config);
    if isColliding
        show(robot,config,'Collisions','on','Visuals','off');
        title('Collision Detected')
    else
        % Skip non-collisions.
    end
end
```



Input Arguments

robot — Rigid body tree robot model
rigidBodyTree object

Rigid body tree robot model, specified as a `rigidBodyTree` object. To use the `checkCollision` function, the DataFormat property of the `rigidBodyTree` object must be either `'row'` or `'column'`.

config — Joint configuration of rigid body tree
n-element numeric vector

Joint configuration of the rigid body tree, specified as an *n*-element numeric vector, where *n* is the number of nonfixed joints in the robot model. Each element of the vector is a specific joint position for a joint in the robot model.

Data Types: `single` | `double`

worldObjects — List of collision objects in world
`{}` (default) | cell array of collision objects

List of collision objects in the world, specified as a cell array of collision objects with any combination of `collisionBox`, `collisionCylinder`, `collisionSphere`, and `collisionMesh` objects. The function assumes that the `Pose` property of each object is relative to the base of the rigid body tree robot model.

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: `'Exhaustive','on'` enables exhaustive checking for collisions and causes the function to calculate all separation distances and witness points.

`Exhaustive` — Check for all collisions

`'off'` (default) | `'on'`

Exhaustively check for all collisions, specified as the comma-separated pair consisting of `'Exhaustive'` and `'on'` or `'off'`. By default, the function finds the first collision and stops, returning the separation distances and witness points for incomplete checks as `Inf`.

If this name-value pair argument is specified as `'on'`, the function instead continues checking for collisions until it has exhausted all possibilities.

Data Types: `char` | `string`

`IgnoreSelfCollision` — Skip checking for robot self-collisions

`'off'` (default) | `'on'`

Skip checking for robot self-collisions,, specified as the comma-separated pair consisting of `'IgnoreSelfCollision'` and `'on'` or `'off'`. When this argument is enabled, the function ignores collisions between the collision objects of the rigid body tree robot model bodies and other collision objects of the same model or its base.

This name-value pair argument affects the size of the `separationDist` and `witnessPts` output arguments.

Data Types: `char` | `string`

Output Arguments

Self Collisions

`isSelfColliding` — Robot configuration is in self-collision

`true`or `1` | `false`or `0`

Robot configuration is in self-collision returned as a logical `1` (`true`) or `0` (`false`). If the function returns a value of `true` for this argument, that means that one of the rigid body collision objects is touching another collision object in the robot model. Add collision objects to your rigid body tree robot model using the `addCollision` function.

Data Types: `logical`

`selfSeparationDist` — Minimum separation distance between bodies of robot

(m+1) -by-(m+1) matrix

Minimum separation distance between the bodies of the robot, returned as an (m+1) -by-(m+1) matrix, where m is the number of bodies. The final row and column correspond to the robot base. Units are in meters.

If a pair is in collision, the function returns the separation distance for the associated element as `NaN`.

Data Types: `double`

`selfWitnessPts` — Witness points between robot bodies
3(m+1) -by-2(m+1) matrix

Witness points between the robot bodies including the base, returned as an 3(m+1)-by-2(m+1) matrix, where m is the number of bodies. Witness points are the points on any two bodies that are closest to one another for a given configuration. The matrix takes the form:

The matrix is divided into 3-by-2 sections that represent the *xyz*-coordinates of witness point pairs in the form:

$$[x_1\ x_2\ y_1\ y_2\ z_1\ z_2] \tag{3-1}$$

Each section corresponds to a separation distance in the `selfSeparationDist` output matrix. Use these equations to determine where the section of the `selfWitnessPts` matrix that corresponds to a specific separation distance begins:

$$W_r = 3S_r - 2 \tag{3-2}$$

$$W_c = 2S_c - 1 \tag{3-3}$$

Where (S_r,S_c) is the index of a separation distance in the separation distance matrix and (W_r,W_c) is the index in the witness point matrix at which the corresponding witness points begin.

If a pair is in collision, the function returns each coordinate of the witness points for that element as `NaN`.

Data Types: `double`

World Collisions

`isColliding` — Robot configuration is in collision
two-element logical vector

Robot configuration is in collision, returned as a two-element logical vector. The first element indicates whether the robot is in self-collision. The second element indicates whether the robot model is in collision with any world objects.

Data Types: `logical`

`separationDist` — Minimum separation distance between collision objects
(m+w+1)-by-(m+w+1) matrix

Minimum separation distance between the collision objected, returned as an (m+w+1)-by-(m+w+1) matrix, where m is the number of bodies and w is the number of world objects. The final row and column correspond to the robot base.

The matrix is divided into 3-by-2 sections that represent the *xyz*-coordinates of witness point pairs in the form:

$$[x_1\ x_2\ y_1\ y_2\ z_1\ z_2] \tag{3-4}$$

Each section corresponds to a separation distance in the `separationDist` output matrix. Use these equations to determine where the section of the `witnessPts` matrix that corresponds to a specific separation distance begins:

$W_r = 3S_r - 2$ (3-5)

$W_c = 2S_c - 1$ (3-6)

Where (S_r,S_c) is the index of a separation distance in the separation distance matrix and (W_r,W_c) is the index in the witness point matrix at which the corresponding witness points begin.

If a pair is in collision, the function returns each coordinate of the witness points for that element as `NaN`.

If a pair is in collision, the function returns the separation distance as `NaN`.

Dependencies

If you specify the `'IgnoreSelfCollision'` name-value pair argument as `'on'`, then the matrix does not contain values for the distances between any given body and other bodies in the robot model.

Data Types: `double`

`witnessPts` — Witness points between collision objects
3(m+w+1)-by-2(m+w+1) matrix

Witness points between collision objects, specified as a 3(m+w+1)-by-2(m+w+1) matrix, where `m` is the number of bodies and `w` is the number of world objects. Witness points are the points on any two bodies that are closest to one another for a given configuration. The matrix takes the form:

```
[Wr1_1       Wr1_2     ...    Wr1_(N+1)     Wo1_1     Wo1_2      ... W1_M;
 Wr2_1       Wr2_2     ...    Wr2_(N+1)     Wo2_1     Wo2_2      ... W2_M;
  .           .         .      .             .         .          .   .
  .           .         .      .             .         .          .   .
  .           .         .      .             .         .          .   .
 Wr(N+1)_1   Wr(N+1)_2 ...    Wr(N+1)_(N+1) Wo(N+1)_1 Wo(N+1)_2  ... W(N+1)_M]
```

Each element in the above matrix is a 2-by-3 matrix that gives the nearest `[x y z]` points on the two corresponding bodies or world objects. The final row and column correspond to the robot base.

If a pair are in collision, witness points for that element are returned as `NaN(3,2)`.

Dependencies

If the `"IgnoreSelfCollision"` name-value pair is set to `"on"`, then the matrix contains no `Wr` elements.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyTree` | `addCollision` | `clearCollision`

Introduced in R2020b

copy

Copy robot model

Syntax

```
newrobot = copy(robot)
```

Description

`newrobot = copy(robot)` creates a deep copy of `robot` with the same properties. Any changes in `newrobot` are not reflected in `robot`.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `rigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}
```

```
childBody = 
  rigidBody with properties:

            Name: 'L4'
           Joint: [1x1 rigidBodyJoint]
```

```
             Mass: 1
     CenterOfMass: [0 0 0]
          Inertia: [1 1 1 0 0 0]
           Parent: [1x1 rigidBody]
         Children: {[1x1 rigidBody]}
          Visuals: {}
       Collisions: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the L3 body. You must create a new Joint object and use replaceJoint to ensure the downstream body geometry is unaffected. Call setFixedTransform if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name       Joint Name       Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------       ----------       ----------    ----------------   ----------------
   1           L1             jnt1         revolute             base(0)   L2(2)
   2           L2             jnt2         revolute               L1(1)   L3(3)
   3           L3        prismatic            fixed               L2(2)   L4(4)
   4           L4             jnt4         revolute               L3(3)   L5(5)
   5           L5             jnt5         revolute               L4(4)   L6(6)
   6           L6             jnt6         revolute               L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using removeBody. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree = 
  rigidBodyTree with properties:

     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified L3 body. Add the original copied L3 body to the L2 body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through showdetails.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Input Arguments

robot — Robot model
rigidBodyTree object

Robot model, specified as a rigidBodyTree object.

Output Arguments

newrobot — Robot model
rigidBodyTree object

Robot model, returned as a rigidBodyTree object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the rigidBodyTree object, use the syntax that specifies the MaxNumBodies as an upper bound for adding bodies to the robot model. You must also specify the DataFormat property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to "row" or "column".

The show and showdetails functions do not support code generation.

See Also

rigidBodyJoint | rigidBody | rigidBodyTree

Introduced in R2016b

externalForce

Compose external force matrix relative to base

Syntax

```
fext = externalForce(robot,bodyname,wrench)
fext = externalForce(robot,bodyname,wrench,configuration)
```

Description

`fext = externalForce(robot,bodyname,wrench)` composes the external force matrix, which you can use as inputs to `inverseDynamics` and `forwardDynamics` to apply an external force, `wrench`, to the body specified by `bodyname`. The `wrench` input is assumed to be in the base frame.

`fext = externalForce(robot,bodyname,wrench,configuration)` composes the external force matrix assuming that `wrench` is in the `bodyname` frame for the specified `configuration`. The force matrix `fext` is given in the base frame.

Examples

Compute Forward Dynamics Due to External Forces on Rigid Body Tree Model

Calculate the resultant joint accelerations for a given robot configuration with applied external forces and forces due to gravity. A wrench is applied to a specific body with the gravity being specified for the whole robot.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the gravity. By default, gravity is assumed to be zero.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for the `lbr` robot.

```
q = homeConfiguration(lbr);
```

Specify the wrench vector that represents the external forces experienced by the robot. Use the `externalForce` function to generate the external force matrix. Specify the robot model, the end effector that experiences the wrench, the wrench vector, and the current robot configuration. `wrench` is given relative to the `'tool0'` body frame, which requires you to specify the robot configuration, `q`.

```
wrench = [0 0 0.5 0 0 0.3];
fext = externalForce(lbr,'tool0',wrench,q);
```

Compute the resultant joint accelerations due to gravity, with the external force applied to the end-effector `'tool0'` when `lbr` is at its home configuration. The joint velocities and joint torques are assumed to be zero (input as an empty vector `[]`).

```
qddot = forwardDynamics(lbr,q,[],[],fext);
```

Compute Joint Torque to Counter External Forces

Use the `externalForce` function to generate force matrices to apply to a rigid body tree model. The force matrix is an *m*-by-6 vector that has a row for each joint on the robot to apply a six-element wrench. Use the `externalForce` function and specify the end effector to properly assign the wrench to the correct row of the matrix. You can add multiple force matrices together to apply multiple forces to one robot.

To calculate the joint torques that counter these external forces, use the `inverseDynamics` function.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for `lbr`.

```
q = homeConfiguration(lbr);
```

Set external force on `link1`. The input wrench vector is expressed in the base frame.

```
fext1 = externalForce(lbr,'link_1',[0 0 0.0 0.1 0 0]);
```

Set external force on the end effector, `tool0`. The input wrench vector is expressed in the `tool0` frame.

```
fext2 = externalForce(lbr,'tool0',[0 0 0.0 0.1 0 0],q);
```

Compute the joint torques required to balance the external forces. To combine the forces, add the force matrices together. Joint velocities and accelerations are assumed to be zero (input as `[]`).

```
tau = inverseDynamics(lbr,q,[],[],fext1+fext2);
```

Input Arguments

robot — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. To use the `externalForce` function, set the `DataFormat` property to either `"row"` or `"column"`.

`bodyname` — Name of body to which external force is applied
string scalar | character vector

Name of body to which the external force is applied, specified as a string scalar or character vector. This body name must match a body on the `robot` object.

Data Types: `char` | `string`

`wrench` — Torques and forces applied to body
`[Tx Ty Tz Fx Fy Fz]` vector

Torques and forces applied to the body, specified as a `[Tx Ty Tz Fx Fy Fz]` vector. The first three elements of the wrench correspond to the moments around *xyz*-axes. The last three elements are linear forces along the same axes. Unless you specify the robot `configuration`, the wrench is assumed to be relative to the base frame.

`configuration` — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `"row"` or `"column"` .

Output Arguments

`fext` — External force matrix
n-by-6 matrix | 6-by-*n* matrix

External force matrix, returned as either an *n*-by-6 or 6-by-*n* matrix, where *n* is the velocity number (degrees of freedom) of the robot. The shape depends on the `DataFormat` property of `robot`. The `"row"` data format uses an *n*-by-6 matrix. The `"column"` data format uses a 6-by-*n* .

The composed matrix lists only values other than zero at the locations relevant to the body specified. You can add force matrices together to specify multiple forces on multiple bodies. Use the external force matrix to specify external forces to dynamics functions `inverseDynamics` and `forwardDynamics`.

References

[1] Featherstone, Roy. *Rigid Body Dynamics Algorithms*. Springer US, 2008. DOI.org (Crossref), doi:10.1007/978-1-4899-7560-7.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also
`rigidBodyTree` | `inverseDynamics` | `forwardDynamics`

Topics
“Robot Dynamics”
“Compute Joint Torques To Balance An Endpoint Force and Moment”

Introduced in R2017a

forwardDynamics

Joint accelerations given joint torques and states

Syntax

```
jointAccel = forwardDynamics(robot)
jointAccel = forwardDynamics(robot,configuration)
jointAccel = forwardDynamics(robot,configuration,jointVel)
jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq)
jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq,fext)
```

Description

`jointAccel = forwardDynamics(robot)` computes joint accelerations due to gravity at the robot home configuration, with zero joint velocities and no external forces.

`jointAccel = forwardDynamics(robot,configuration)` also specifies the joint positions of the robot configuration.

To specify the home configuration, zero joint velocities, or zero torques, use `[]` for that input argument.

`jointAccel = forwardDynamics(robot,configuration,jointVel)` also specifies the joint velocities of the robot.

`jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq)` also specifies the joint torques applied to the robot.

`jointAccel = forwardDynamics(robot,configuration,jointVel,jointTorq,fext)` also specifies an external force matrix that contains forces applied to each joint.

Examples

Compute Forward Dynamics Due to External Forces on Rigid Body Tree Model

Calculate the resultant joint accelerations for a given robot configuration with applied external forces and forces due to gravity. A wrench is applied to a specific body with the gravity being specified for the whole robot.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the gravity. By default, gravity is assumed to be zero.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for the `lbr` robot.

```
q = homeConfiguration(lbr);
```

Specify the wrench vector that represents the external forces experienced by the robot. Use the `externalForce` function to generate the external force matrix. Specify the robot model, the end effector that experiences the wrench, the wrench vector, and the current robot configuration. `wrench` is given relative to the `'tool0'` body frame, which requires you to specify the robot configuration, `q`.

```
wrench = [0 0 0.5 0 0 0.3];
fext = externalForce(lbr,'tool0',wrench,q);
```

Compute the resultant joint accelerations due to gravity, with the external force applied to the end-effector `'tool0'` when `lbr` is at its home configuration. The joint velocities and joint torques are assumed to be zero (input as an empty vector `[]`).

```
qddot = forwardDynamics(lbr,q,[],[],fext);
```

Input Arguments

`robot` — Robot model
`RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. To use the `forwardDynamics` function, set the `DataFormat` property to either `'row'` or `'column'`.

`configuration` — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

`jointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom of the robot. To use the vector form of `jointVel`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

`jointTorq` — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. To use the vector form of `jointTorq`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'`.

`fext` — External force matrix
n-by-6 matrix | 6-by-*n* matrix

External force matrix, specified as either an *n*-by-6 or 6-by-*n* matrix, where *n* is the number of bodies of the robot. The shape depends on the `DataFormat` property of `robot`. The `'row'` data format uses an *n*-by-6 matrix. The `'column'` data format uses a 6-by-*n* .

The matrix lists only values other than zero at the locations relevant to the body specified. You can add force matrices together to specify multiple forces on multiple bodies.

To create the matrix for a specified force or torque, see `externalForce`.

Output Arguments

`jointAccel` — Joint accelerations

vector

Joint accelerations, returned as a vector. The dimension of the joint accelerations vector is equal to the degrees of freedom of the robot. Each element corresponds to a specific joint on the `robot`.

References

[1] Featherstone, Roy. *Rigid Body Dynamics Algorithms*. Springer US, 2008. DOI.org (Crossref), doi:10.1007/978-1-4899-7560-7.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyTree` | `inverseDynamics` | `externalForce`

Topics

"Robot Dynamics"
"Compute Joint Torques To Balance An Endpoint Force and Moment"

Introduced in R2017a

geometricJacobian

Geometric Jacobian for robot configuration

Syntax

```
jacobian = geometricJacobian(robot,configuration,endeffectorname)
```

Description

`jacobian = geometricJacobian(robot,configuration,endeffectorname)` computes the geometric Jacobian relative to the base for the specified end-effector name and configuration for the robot model.

Examples

Geometric Jacobian for Robot Configuration

Calculate the geometric Jacobian for a specific end effector and configuration of a robot.

Load a Puma robot, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat puma1
```

Calculate the geometric Jacobian of body `'L6'` on the Puma robot for a random configuration.

```
geoJacob = geometricJacobian(puma1,randomConfiguration(puma1),'L6')
```

```
geoJacob = 6×6

         0   -0.7795   -0.7795   -0.4592    0.5643   -0.6612
    0.0000    0.6264    0.6264   -0.5714   -0.7789   -0.2282
    1.0000    0.0000    0.0000    0.6801   -0.2734   -0.7146
    0.4544    0.3107    0.1746   -0.0000         0         0
   -0.5577    0.3866    0.2173   -0.0000         0         0
         0    0.7036    0.3304    0.0000         0         0
```

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

`configuration` — Robot configuration
vector | structure

Robot configuration, specified as a vector of joint positions or a structure with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions in a structure. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `"row"` or `"column"` .

`endeffectorname` — End-effector name
string scalar | character vector

End-effector name, specified as a string scalar or character vector. An end effector can be any body in the robot model.

Data Types: `char` | `string`

Output Arguments

`jacobian` — Geometric Jacobian
6-by-*n* matrix

Geometric Jacobian of the end effector with the specified `configuration`, returned as a 6-by-*n* matrix, where *n* is the number of degrees of freedom for the end effector. The Jacobian maps the joint-space velocity to the end-effector velocity, relative to the base coordinate frame. The end-effector velocity equals:

$$V_{EE} = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \\ v_x \\ v_y \\ v_z \end{bmatrix} = J\dot{q} = J \begin{bmatrix} \dot{q}_1 \\ \vdots \\ \dot{q}_n \end{bmatrix}$$

ω is the angular velocity, υ is the linear velocity, and $\dot{q}$ is the joint-space velocity.

References

[1] Featherstone, Roy. *Rigid Body Dynamics Algorithms*. Springer US, 2008. DOI.org (Crossref), doi:10.1007/978-1-4899-7560-7.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`getTransform` | `homeConfiguration` | `randomConfiguration` | `rigidBodyJoint` | `rigidBody`

Topics

"Robot Dynamics"

Introduced in R2016b

gravityTorque

Joint torques that compensate gravity

Syntax

```
gravTorq = gravityTorque(robot)
gravTorq = gravityTorque(robot,configuration)
```

Description

`gravTorq = gravityTorque(robot)` computes the joint torques required to hold the robot at its home configuration.

`gravTorq = gravityTorque(robot,configuration)` specifies a joint configuration for calculating the gravity torque.

Examples

Compute Gravity Torque for Robot Configuration

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`. Set the `Gravity` property.

```
lbr.DataFormat = 'row';
lbr.Gravity = [0 0 -9.81];
```

Get a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Compute the gravity-compensating torques for each joint.

```
gtau = gravityTorque(lbr,q);
```

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. To use the `gravityTorque` function, set the `DataFormat` property to either `'row'` or `'column'`.

`configuration` — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Output Arguments

`gravTorq` — Gravity-compensating torque for each joint
vector

Gravity-compensating torque for each joint, returned as a vector.

References

[1] Featherstone, Roy. *Rigid Body Dynamics Algorithms*. Springer US, 2008. DOI.org (Crossref), doi:10.1007/978-1-4899-7560-7.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyTree` | `inverseDynamics` | `velocityProduct`

Topics
"Robot Dynamics"

Introduced in R2017a

getBody

Get robot body handle by name

Syntax

```
body = getBody(robot,bodyname)
```

Description

`body = getBody(robot,bodyname)` gets a body handle by name from the robot model.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `rigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}
```

```
childBody = 
  rigidBody with properties:

            Name: 'L4'
           Joint: [1x1 rigidBodyJoint]
            Mass: 1
```

```
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 rigidBody]
        Children: {[1x1 rigidBody]}
         Visuals: {}
      Collisions: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the `L3` body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name       Joint Name       Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------       ----------       ----------    ----------------   ----------------
   1            L1             jnt1         revolute             base(0)   L2(2)
   2            L2             jnt2         revolute               L1(1)   L3(3)
   3            L3        prismatic            fixed               L2(2)   L4(4)
   4            L4             jnt4         revolute               L3(3)   L5(5)
   5            L5             jnt5         revolute               L4(4)   L6(6)
   6            L6             jnt6         revolute               L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree =
  rigidBodyTree with properties:

     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified `L3` body. Add the original copied `L3` body to the `L2` body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1           L1         jnt1     revolute             base(0)   L2(2)
   2           L2         jnt2     revolute               L1(1)   L3(3)
   3           L3         jnt3     revolute               L2(2)   L4(4)
   4           L4         jnt4     revolute               L3(3)   L5(5)
   5           L5         jnt5     revolute               L4(4)   L6(6)
   6           L6         jnt6     revolute               L5(5)
--------------------
```

Input Arguments

robot — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

bodyname — Body name
string scalar | character vector

Body name, specified as a string scalar or character vector. A body with this name must be on the robot model specified by `robot`.

Data Types: `char` | `string`

Output Arguments

body — Rigid body
`rigidBody` object

Rigid body, returned as a `rigidBody` object. The returned `rigidBodyTree` object is still a part of the `rigidBodyTree` robot model. Use `replaceBody` with a new body to modify the body in the robot model.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also
`rigidBodyJoint` | `rigidBody` | `addBody` | `replaceBody`

Introduced in R2016b

getTransform

Get transform between body frames

Syntax

```
transform = getTransform(robot,configuration,bodyname)
transform = getTransform(robot,configuration,sourcebody,targetbody)
```

Description

`transform = getTransform(robot,configuration,bodyname)` computes the transform that converts points in the `bodyname` frame to the robot base frame, using the specified robot configuration.

`transform = getTransform(robot,configuration,sourcebody,targetbody)` computes the transform that converts points from the source body frame to the target body frame, using the specified robot configuration.

Examples

Get Transform Between Frames for Robot Configuration

Get the transform between two frames for a specific robot configuration.

Load a sample robots that include the `puma1` robot.

```
load exampleRobots.mat
```

Get the transform between the `'L2'` and `'L6'` bodies of the `puma1` robot given a specific configuration. The transform converts points in 'L6' frame to the 'L2' frame.

```
transform = getTransform(puma1,randomConfiguration(puma1),'L2','L6')
```

```
transform = 4×4

    0.2295   -0.4122    0.8817    0.0485
    0.8621   -0.3344   -0.3807    0.2118
    0.4517    0.8475    0.2786   -0.4027
         0         0         0    1.0000
```

Input Arguments

robot — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

`configuration` — Robot configuration
structure array

Robot configuration, specified as a structure array with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint names and positions in a structure array.

`bodyname` — Body name
string scalar | character vector

Body name, specified as a string scalar or character vector. This body must be on the robot model specified in `robot`.

Data Types: `char` | `string`

`targetbody` — Target body name
string scalar | character vector

Target body name, specified as a character vector. This body must be on the robot model specified in `robot`. The target frame is the coordinate system you want to transform points into.

Data Types: `char` | `string`

`sourcebody` — Body name
string scalar | character vector

Body name, specified as a string scalar or character vector. This body must be on the robot model specified in `robot`. The source frame is the coordinate system you want points transformed from.

Data Types: `char` | `string`

Output Arguments

`transform` — Homogeneous transform
4-by-4 matrix

Homogeneous transform, returned as a 4-by-4 matrix.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyJoint` | `rigidBody` | `geometricJacobian` | `homeConfiguration` | `randomConfiguration`

Introduced in R2016b

homeConfiguration

Get home configuration of robot

Syntax

```
configuration = homeConfiguration(robot)
```

Description

`configuration = homeConfiguration(robot)` returns the home configuration of the robot model. The home configuration is the ordered list of `HomePosition` properties of each nonfixed joint.

Examples

Visualize Robot Configurations

Show different configurations of a robot created using a `RigidBodyTree` model. Use the `homeConfiguration` or `randomConfiguation` functions to generate the structure that defines all the joint positions.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

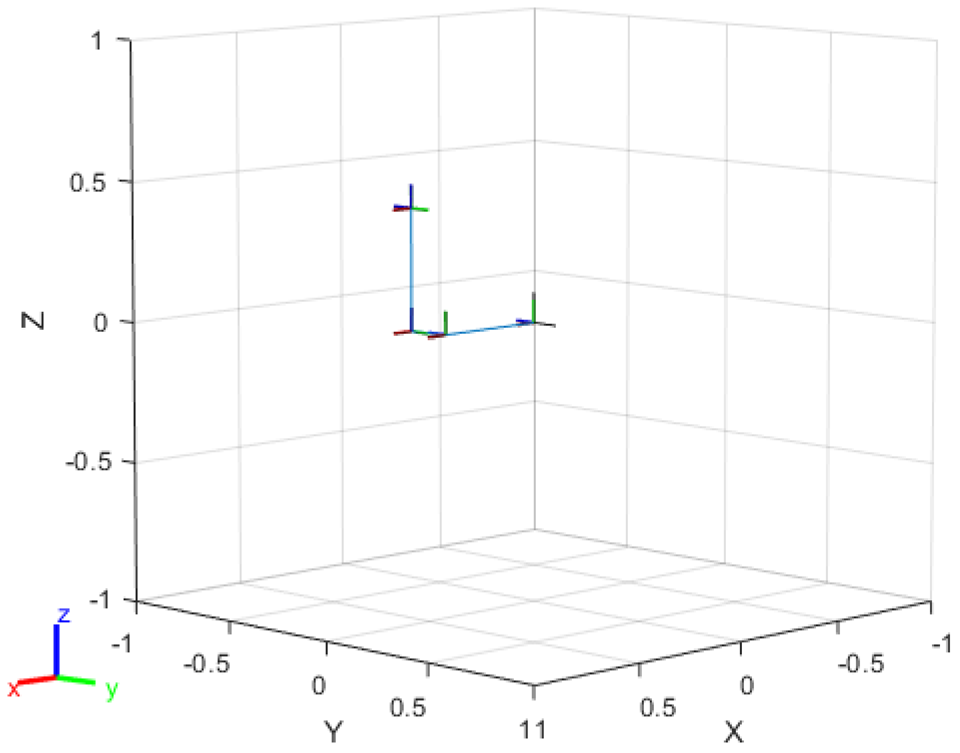
Create a structure for the home configuration of a Puma robot. The structure has joint names and positions for each body on the robot model.

```
config = homeConfiguration(puma1)
```

```
config=1×6 struct array with fields:
    JointName
    JointPosition
```

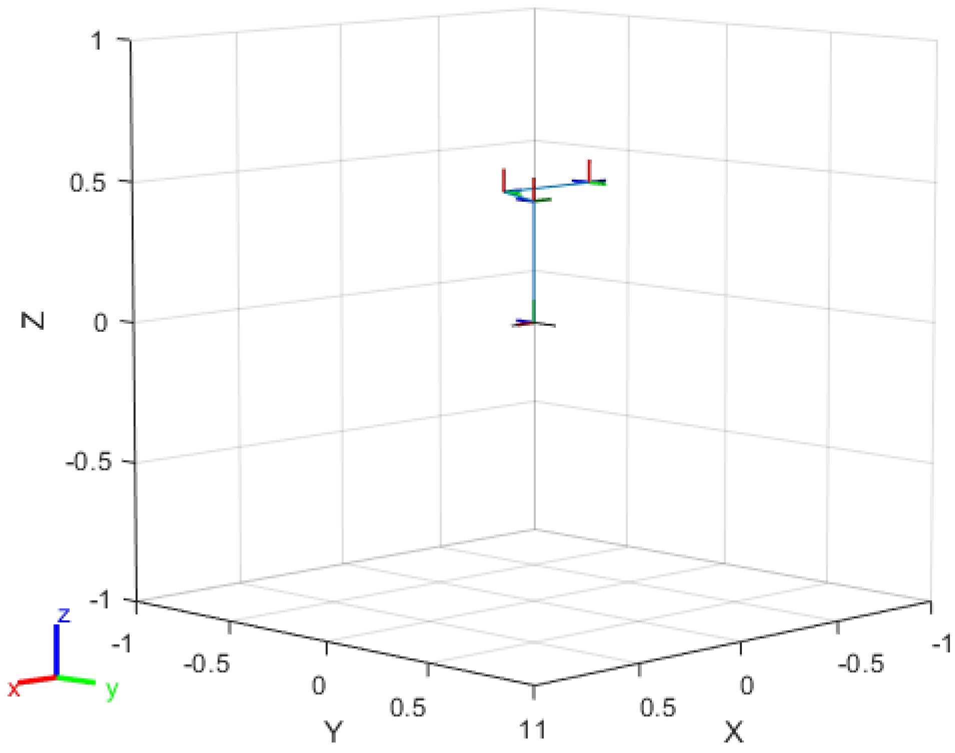
Show the home configuration using `show`. You do not need to specify a configuration input.

```
show(puma1);
```



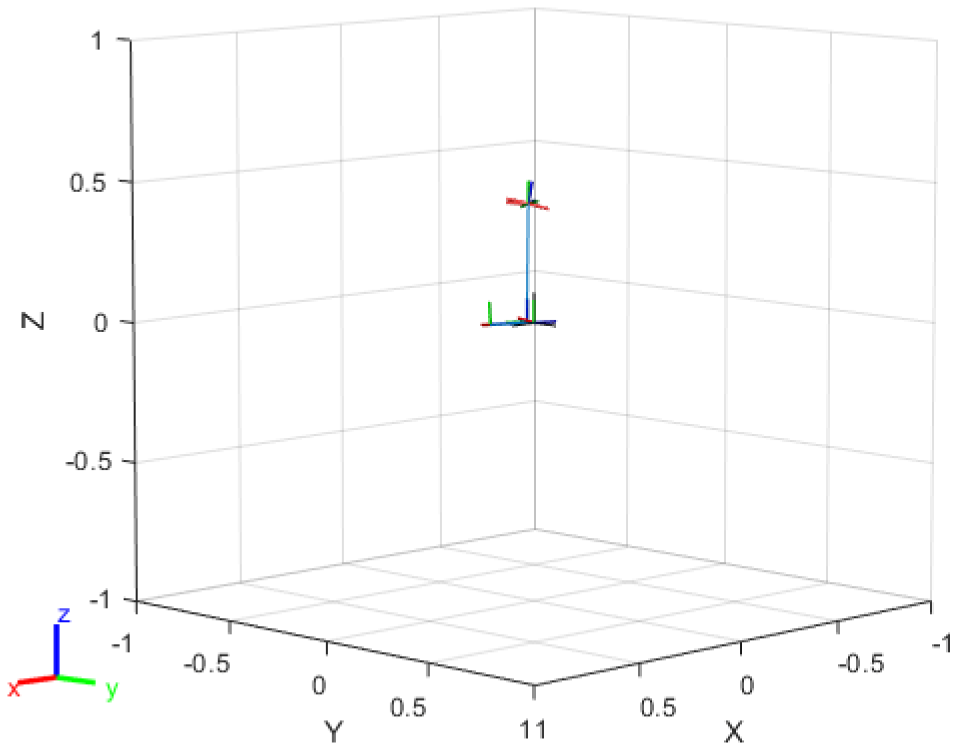
Modify the configuration and set the second joint position to `pi/2`. Show the resulting change in the robot configuration.

```
config(2).JointPosition = pi/2;
show(puma1,config);
```



Create random configurations and show them.

```
show(puma1,randomConfiguration(puma1));
```



Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

Output Arguments

`configuration` — Robot configuration
vector | structure

Robot configuration, returned as a vector of joint positions or a structure with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions in a structure. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also
`randomConfiguration` | `getTransform` | `geometricJacobian`

Introduced in R2016b

inverseDynamics

Required joint torques for given motion

Syntax

```
jointTorq = inverseDynamics(robot)
jointTorq = inverseDynamics(robot,configuration)
jointTorq = inverseDynamics(robot,configuration,jointVel)
jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel)
jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel,fext)
```

Description

`jointTorq = inverseDynamics(robot)` computes joint torques required for the robot to statically hold its home configuration with no external forces applied.

`jointTorq = inverseDynamics(robot,configuration)` computes joint torques to hold the specified robot configuration.

`jointTorq = inverseDynamics(robot,configuration,jointVel)` computes joint torques for the specified joint configuration and velocities with zero acceleration and no external forces.

`jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel)` computes joint torques for the specified joint configuration, velocities, and accelerations with no external forces. To specify the home configuration, zero joint velocities, or zero accelerations, use `[]` for that input argument.

`jointTorq = inverseDynamics(robot,configuration,jointVel,jointAccel,fext)` computes joint torques for the specified joint configuration, velocities, accelerations, and external forces. Use the `externalForce` function to generate `fext`.

Examples

Compute Inverse Dynamics from Static Joint Configuration

Use the `inverseDynamics` function to calculate the required joint torques to statically hold a specific robot configuration. You can also specify the joint velocities, joint accelerations, and external forces using other syntaxes.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Generate a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Compute the required joint torques for `lbr` to statically hold that configuration.

```
tau = inverseDynamics(lbr,q);
```

Compute Joint Torque to Counter External Forces

Use the `externalForce` function to generate force matrices to apply to a rigid body tree model. The force matrix is an *m*-by-6 vector that has a row for each joint on the robot to apply a six-element wrench. Use the `externalForce` function and specify the end effector to properly assign the wrench to the correct row of the matrix. You can add multiple force matrices together to apply multiple forces to one robot.

To calculate the joint torques that counter these external forces, use the `inverseDynamics` function.

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the `Gravity` property to give a specific gravitational acceleration.

```
lbr.Gravity = [0 0 -9.81];
```

Get the home configuration for `lbr`.

```
q = homeConfiguration(lbr);
```

Set external force on `link1`. The input wrench vector is expressed in the base frame.

```
fext1 = externalForce(lbr,'link_1',[0 0 0.0 0.1 0 0]);
```

Set external force on the end effector, `tool0`. The input wrench vector is expressed in the `tool0` frame.

```
fext2 = externalForce(lbr,'tool0',[0 0 0.0 0.1 0 0],q);
```

Compute the joint torques required to balance the external forces. To combine the forces, add the force matrices together. Joint velocities and accelerations are assumed to be zero (input as `[]`).

```
tau = inverseDynamics(lbr,q,[],[],fext1+fext2);
```

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. To use the `inverseDynamics` function, set the `DataFormat` property to either `'row'` or `'column'`.

`configuration` — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

`jointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the velocity degrees of freedom of the robot. To use the vector form of `jointVel`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

`jointAccel` — Joint accelerations
vector

Joint accelerations, returned as a vector. The dimension of the joint accelerations vector is equal to the velocity degrees of freedom of the robot. Each element corresponds to a specific joint on the `robot`. To use the vector form of `jointAccel`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

`fext` — External force matrix
n-by-6 matrix | 6-by-*n* matrix

External force matrix, specified as either an *n*-by-6 or 6-by-*n* matrix, where *n* is the velocity degrees of freedom of the robot. The shape depends on the `DataFormat` property of `robot`. The `'row'` data format uses an *n*-by-6 matrix. The `'column'` data format uses a 6-by-*n* .

The matrix lists only values other than zero at the locations relevant to the body specified. You can add force matrices together to specify multiple forces on multiple bodies.

To create the matrix for a specified force or torque, see `externalForce`.

Output Arguments

`jointTorq` — Joint torques
vector

Joint torques, returned as a vector. Each element corresponds to a torque applied to a specific joint.

References

[1] Featherstone, Roy. *Rigid Body Dynamics Algorithms*. Springer US, 2008. DOI.org (Crossref), doi:10.1007/978-1-4899-7560-7.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyTree` | `forwardDynamics` | `externalForce`

Topics
“Robot Dynamics”
“Compute Joint Torques To Balance An Endpoint Force and Moment”

Introduced in R2017a

massMatrix

Joint-space mass matrix

Syntax

```
H = massMatrix(robot)
H = massMatrix(robot,configuration)
```

Description

`H = massMatrix(robot)` returns the joint-space mass matrix of the home configuration of a robot.

`H = massMatrix(robot,configuration)` returns the mass matrix for a specified robot configuration.

Examples

Calculate The Mass Matrix For A Robot Configuration

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Generate a random configuration for `lbr`.

```
q = randomConfiguration(lbr);
```

Get the mass matrix at configuration `q`.

```
H = massMatrix(lbr,q);
```

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. To use the `massMatrix` function, set the `DataFormat` property to either `'row'` or `'column'`.

`configuration` — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Output Arguments

`H` — Mass matrix
positive-definite symmetric matrix

Mass matrix of the robot, returned as a positive-definite symmetric matrix with size *n*-by-*n*, where *n* is the velocity degrees of freedom of the robot.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also
`rigidBodyTree` | `gravityTorque` | `homeConfiguration` | `velocityProduct`

Topics
“Robot Dynamics”

Introduced in R2017a

randomConfiguration

Generate random configuration of robot

Syntax

```
configuration = randomConfiguration(robot)
```

Description

`configuration = randomConfiguration(robot)` returns a random configuration of the specified robot. Each joint position in this configuration respects the joint limits set by the `PositionLimits` property of the corresponding `rigidBodyJoint` object in the robot model.

Examples

Visualize Robot Configurations

Show different configurations of a robot created using a `RigidBodyTree` model. Use the `homeConfiguration` or `randomConfiguation` functions to generate the structure that defines all the joint positions.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

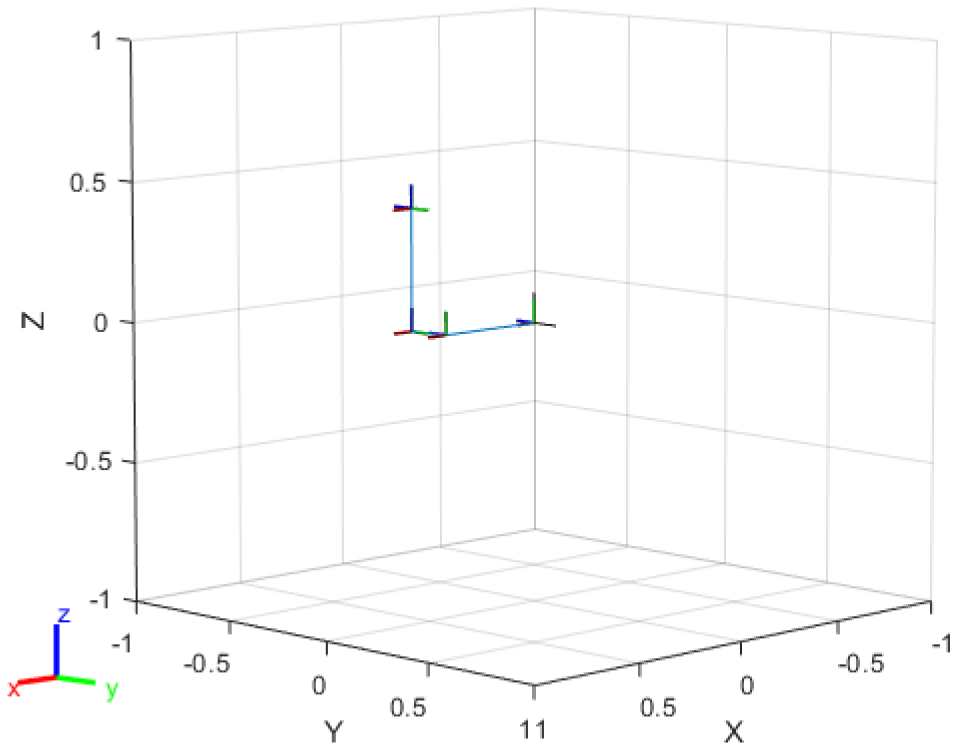
Create a structure for the home configuration of a Puma robot. The structure has joint names and positions for each body on the robot model.

```
config = homeConfiguration(puma1)
```

```
config=1×6 struct array with fields:
    JointName
    JointPosition
```

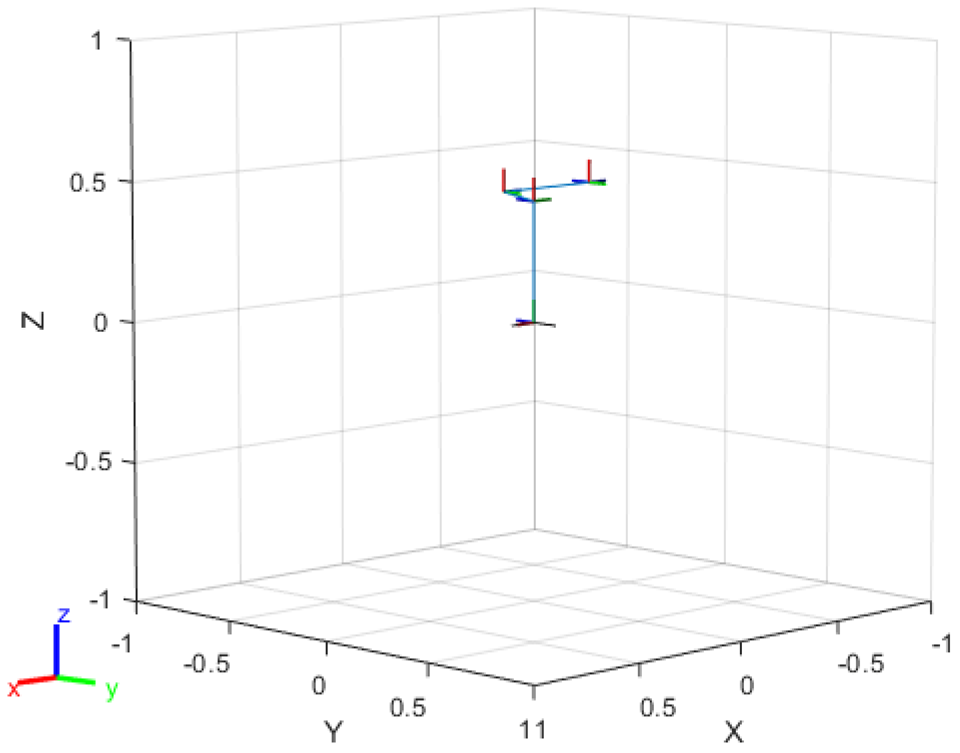
Show the home configuration using `show`. You do not need to specify a configuration input.

```
show(puma1);
```



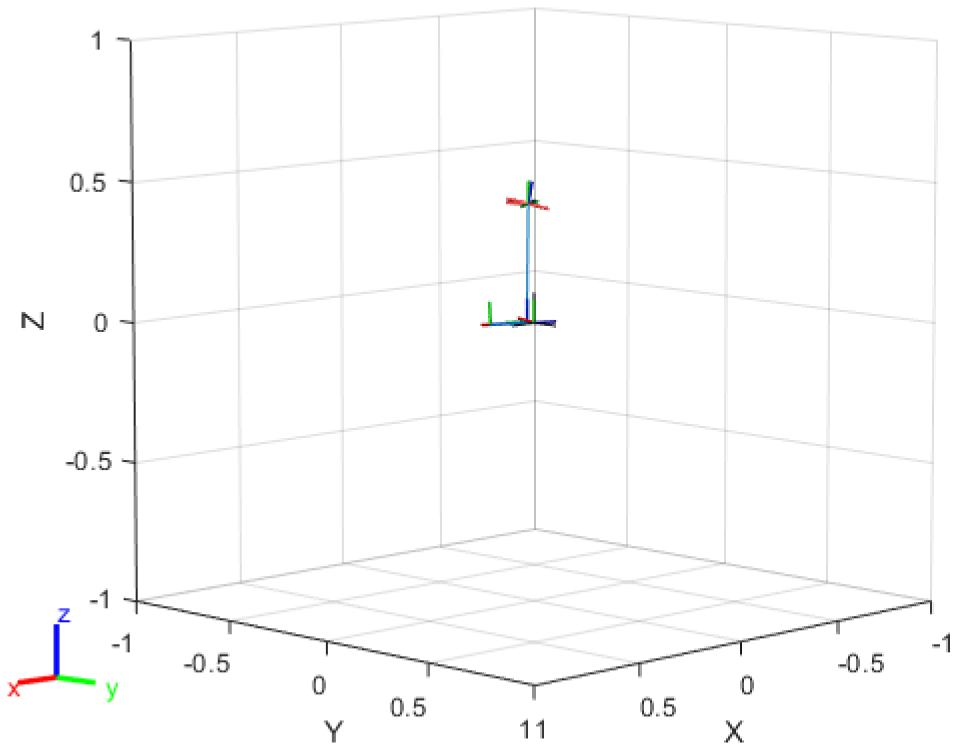
Modify the configuration and set the second joint position to `pi/2`. Show the resulting change in the robot configuration.

```
config(2).JointPosition = pi/2;
show(puma1,config);
```



Create random configurations and show them.

```
show(puma1,randomConfiguration(puma1));
```



Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

Output Arguments

`configuration` — Robot configuration
vector | structure

Robot configuration, returned as a vector of joint positions or a structure with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions in a structure. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`homeConfiguration` | `getTransform` | `geometricJacobian`

Introduced in R2016b

removeBody

Remove body from robot

Syntax

```
removeBody(robot,bodyname)
newSubtree = removeBody(robot,bodyname)
```

Description

`removeBody(robot,bodyname)` removes the body and all subsequently attached bodies from the robot model.

`newSubtree = removeBody(robot,bodyname)` returns the subtree created by removing the body and all subsequently attached bodies from the robot model.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `rigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1           L1         jnt1     revolute             base(0)   L2(2)
   2           L2         jnt2     revolute               L1(1)   L3(3)
   3           L3         jnt3     revolute               L2(2)   L4(4)
   4           L4         jnt4     revolute               L3(3)   L5(5)
   5           L5         jnt5     revolute               L4(4)   L6(6)
   6           L6         jnt6     revolute               L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}
```

```
childBody =
  rigidBody with properties:
```

```
           Name: 'L4'
          Joint: [1x1 rigidBodyJoint]
           Mass: 1
   CenterOfMass: [0 0 0]
        Inertia: [1 1 1 0 0 0]
         Parent: [1x1 rigidBody]
       Children: {[1x1 rigidBody]}
        Visuals: {}
     Collisions: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the `L3` body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name       Joint Name       Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------       ----------       ----------    ----------------   ----------------
   1           L1             jnt1         revolute             base(0)   L2(2)
   2           L2             jnt2         revolute               L1(1)   L3(3)
   3           L3        prismatic            fixed               L2(2)   L4(4)
   4           L4             jnt4         revolute               L3(3)   L5(5)
   5           L5             jnt5         revolute               L4(4)   L6(6)
   6           L6             jnt6         revolute               L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree = 
  rigidBodyTree with properties:

     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified `L3` body. Add the original copied `L3` body to the `L2` body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
```

```
addSubtree(puma1,'L3',subtree)

showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Input Arguments

robot — Robot model
rigidBodyTree object

Robot model, specified as a `rigidBodyTree` object.

bodyname — Body name
string scalar | character vector

Body name, specified as a string scalar character vector. This body must be on the robot model specified in `robot`.

Data Types: `char` | `string`

Output Arguments

newSubtree — Robot subtree
rigidBodyTree object

Robot subtree, returned as a `rigidBodyTree` object. This new subtree uses the parent name of the body specified by `bodyname` as the base name. All bodies that are attached in the previous robot model (including the body with `bodyname` specified) are added to the subtree.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyJoint` | `rigidBody` | `addBody` | `replaceBody`

Introduced in R2016b

replaceBody

Replace body on robot

Syntax

```
replaceBody(robot,bodyname,newbody)
```

Description

`replaceBody(robot,bodyname,newbody)` replaces the body in the robot model with the new body. All properties of the body are updated accordingly, except the `Parent` and `Children` properties. The rest of the robot model is unaffected.

Examples

Specify Dynamics Properties to Rigid Body Tree

To use dynamics functions to calculate joint torques and accelerations, specify the dynamics properties for the `rigidBodyTree` object and `rigidBody`.

Create a rigid body tree model. Create two rigid bodies to attach to it.

```
robot = rigidBodyTree('DataFormat','row');
body1 = rigidBody('body1');
body2 = rigidBody('body2');
```

Specify joints to attach to the bodies. Set the fixed transformation of `body2` to `body1`. This transform is 1m in the *x*-direction.

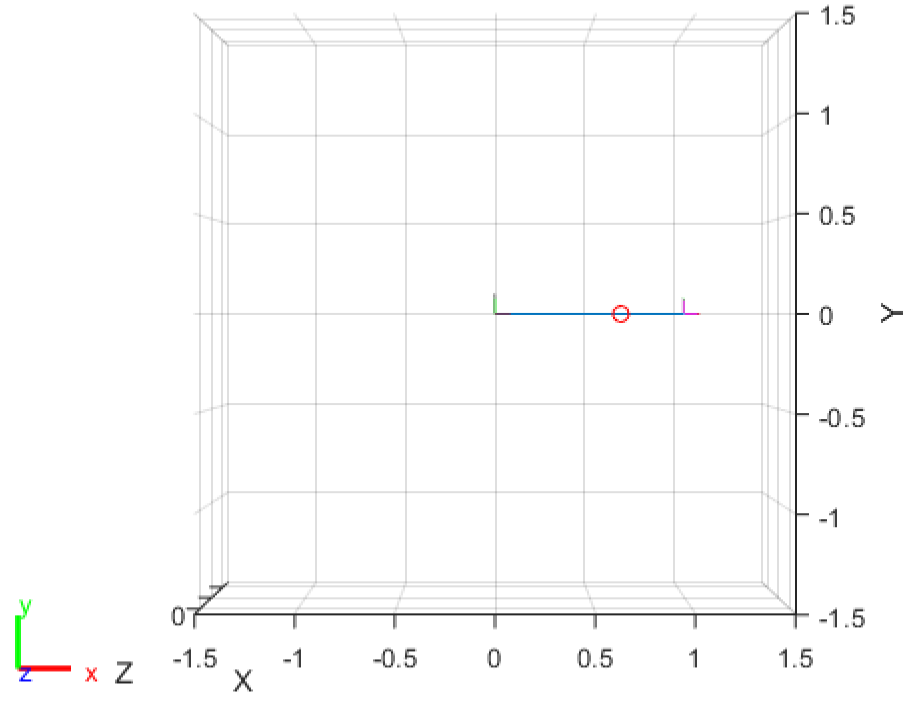
```
joint1 = rigidBodyJoint('joint1','revolute');
joint2 = rigidBodyJoint('joint2');
setFixedTransform(joint2,trvec2tform([1 0 0]))
body1.Joint = joint1;
body2.Joint = joint2;
```

Specify dynamics properties for the two bodies. Add the bodies to the robot model. For this example, basic values for a rod (`body1`) with an attached spherical mass (`body2`) are given.

```
body1.Mass = 2;
body1.CenterOfMass = [0.5 0 0];
body1.Inertia = [0.001 0.67 0.67 0 0 0];

body2.Mass = 1;
body2.CenterOfMass = [0 0 0];
body2.Inertia = 0.0001*[4 4 4 0 0 0];

addBody(robot,body1,'base');
addBody(robot,body2,'body1');
```

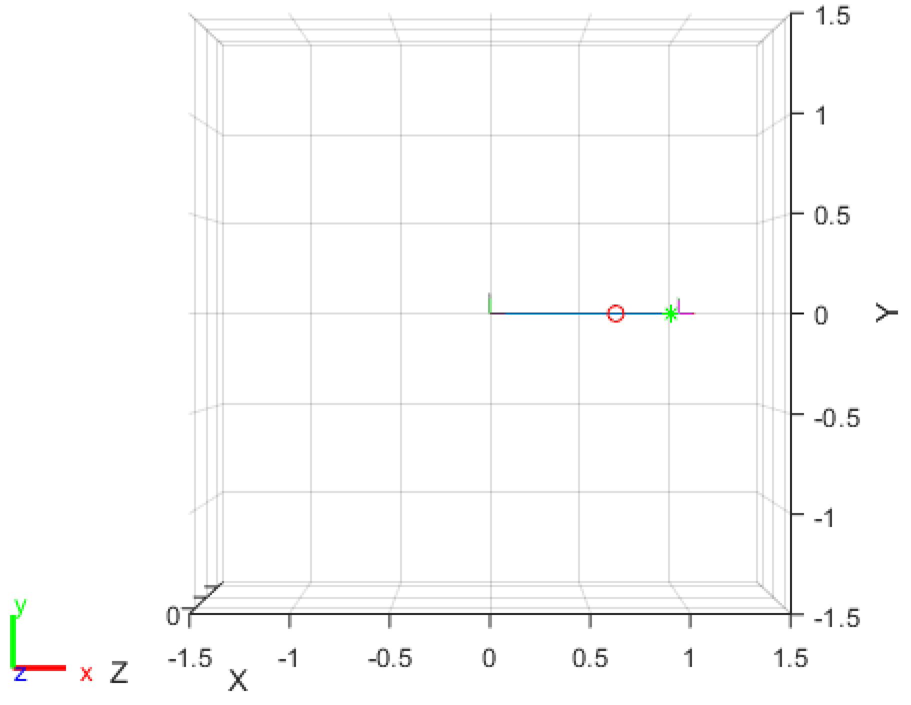
Compute the center of mass position of the whole robot. Plot the position on the robot. Move the view to the *xy* plane.

```
comPos = centerOfMass(robot);

show(robot);
hold on
plot(comPos(1),comPos(2),'or')
view(2)
```



Change the mass of the second body. Notice the change in center of mass.

```
body2.Mass = 20;
replaceBody(robot,'body2',body2)

comPos2 = centerOfMass(robot);
plot(comPos2(1),comPos2(2),'*g')
hold off
```



Input Arguments

robot — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. The rigid body is added to this object and attached at the rigid body specified by `bodyname`.

bodyname — Body name
string scalar | character vector

Body name, specified as a string scalar or character vector. This body must be on the robot model specified in `robot`.

Data Types: `char` | `string`

newbody — Rigid body
`rigidBody` object

Rigid body, specified as a `rigidBody` object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also
`rigidBodyJoint` | `rigidBody` | `replaceJoint` | `addBody` | `removeBody`

Introduced in R2016b

replaceJoint

Replace joint on body

Syntax

```
replaceJoint(robot,bodyname,joint)
```

Description

`replaceJoint(robot,bodyname,joint)` replaces the joint on the specified body in the robot model if the body is a part of the robot model. This method is the only way to change joints in a robot model. You cannot directly assign the `Joint` property of a rigid body.

Examples

Modify a Robot Rigid Body Tree Model

Make changes to an existing `rigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1           L1         jnt1     revolute             base(0)   L2(2)
   2           L2         jnt2     revolute               L1(1)   L3(3)
   3           L3         jnt3     revolute               L2(2)   L4(4)
   4           L4         jnt4     revolute               L3(3)   L5(5)
   5           L5         jnt5     revolute               L4(4)   L6(6)
   6           L6         jnt6     revolute               L5(5)   
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}
```

```
childBody = 
  rigidBody with properties:

            Name: 'L4'
```

```
           Joint: [1x1 rigidBodyJoint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 rigidBody]
        Children: {[1x1 rigidBody]}
         Visuals: {}
      Collisions: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the `L3` body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name       Joint Name       Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------       ----------       ----------    ----------------   ----------------
   1            L1             jnt1         revolute             base(0)   L2(2)
   2            L2             jnt2         revolute               L1(1)   L3(3)
   3            L3        prismatic            fixed               L2(2)   L4(4)
   4            L4             jnt4         revolute               L3(3)   L5(5)
   5            L5             jnt5         revolute               L4(4)   L6(6)
   6            L6             jnt6         revolute               L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree =
  rigidBodyTree with properties:

     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified `L3` body. Add the original copied `L3` body to the `L2` body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)
```

```
showdetails(puma1)

--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Input Arguments

robot — Robot model
rigidBodyTree object

Robot model, specified as a rigidBodyTree object.

bodyname — Body name
string scalar | character vector

Body name, specified as a string scalar or character vector. This body must be on the robot model specified in robot.

Data Types: char | string

joint — Replacement joint
rigidBodyJoint object

Replacement joint, specified as a rigidBodyJoint object.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the rigidBodyTree object, use the syntax that specifies the MaxNumBodies as an upper bound for adding bodies to the robot model. You must also specify the DataFormat property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to "row" or "column".

The show and showdetails functions do not support code generation.

See Also
`rigidBodyJoint` | `rigidBody` | `addBody` | `replaceBody`

Introduced in R2016b

show

Show robot model in figure

Syntax

```
show(robot)
show(robot,configuration)
show( ___ ,Name,Value)
ax = show( ___ )
```

Description

`show(robot)` plots the body frames of the robot model in a figure with the predefined home configuration. Both `Frames` and `Visuals` are displayed automatically.

`show(robot,configuration)` uses the joint positions specified in `configuration` to show the robot body frames.

`show( ___ ,Name,Value)` specifies options using one or more name-value pair arguments in addition to any combination of input arguments from previous syntaxes. For example, `'Frames','off'` hides the rigid body frames in the figure.

`ax = show( ___ )` returns the axes handle the robot is plotted on.

Examples

Display Robot Model with Visual Geometries

You can import robots that have `.stl` files associated with the Unified Robot Description format (URDF) file to describe the visual geometries of the robot. Each rigid body has an individual visual geometry specified. The `importrobot` function parses the URDF file to get the robot model and visual geometries. The function assumes that visual geometry and collision geometry of the robot are the same and assigns the visual geometries as collision geometries of corresponsing bodies.

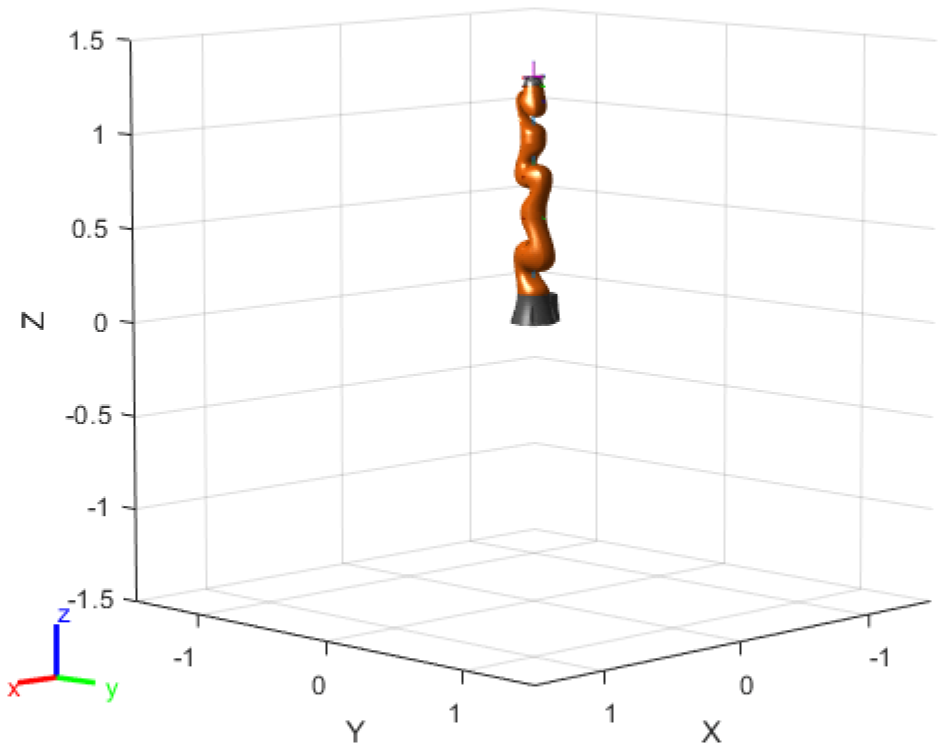
Use the `show` function to display the visual and collosion geometries of the robot model in a figure. You can then interact with the model by clicking components to inspect them and right-clicking to toggle visibility.

Import a robot model as a URDF file. The `.stl` file locations must be properly specified in this URDF. To add other `.stl` files to individual rigid bodies, see `addVisual`.

```
robot = importrobot('iiwa14.urdf');
```

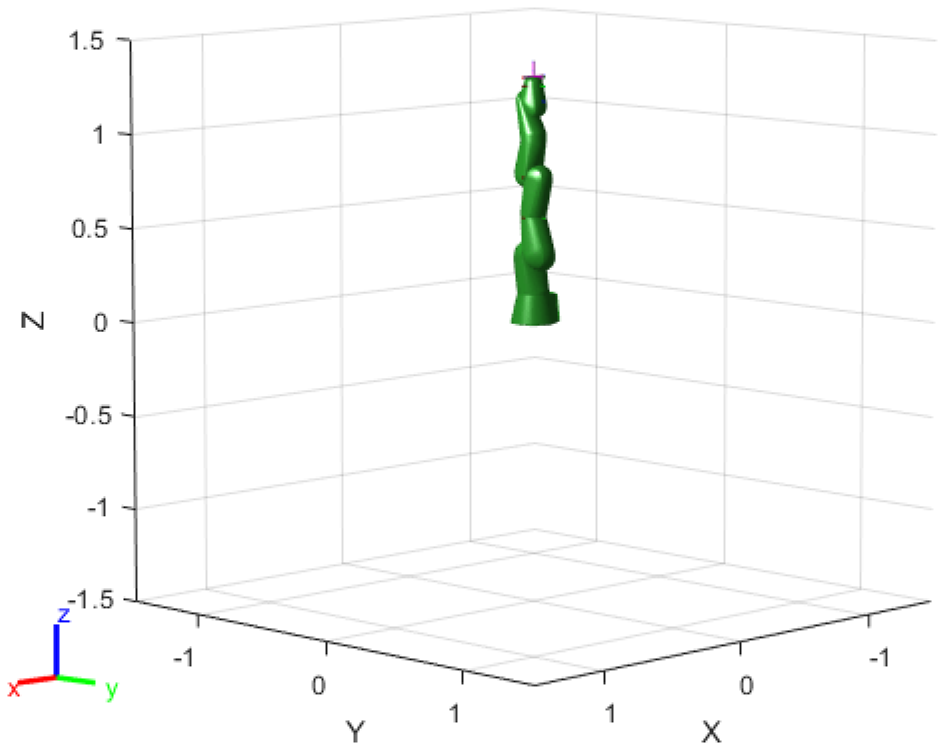
Visualize the robot with the associated visual model. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each visual geometry.

```
show(robot,'visuals','on','collision','off');
```



Visualize the robot with the associated collision geometries. Click bodies or frames to inspect them. Right-click bodies to toggle visibility for each collision geometry.

```
show(robot,'visuals','off','collision','on');
```



Visualize Robot Configurations

Show different configurations of a robot created using a `RigidBodyTree` model. Use the `homeConfiguration` or `randomConfiguation` functions to generate the structure that defines all the joint positions.

Load example robots as `RigidBodyTree` objects.

```
load exampleRobots.mat
```

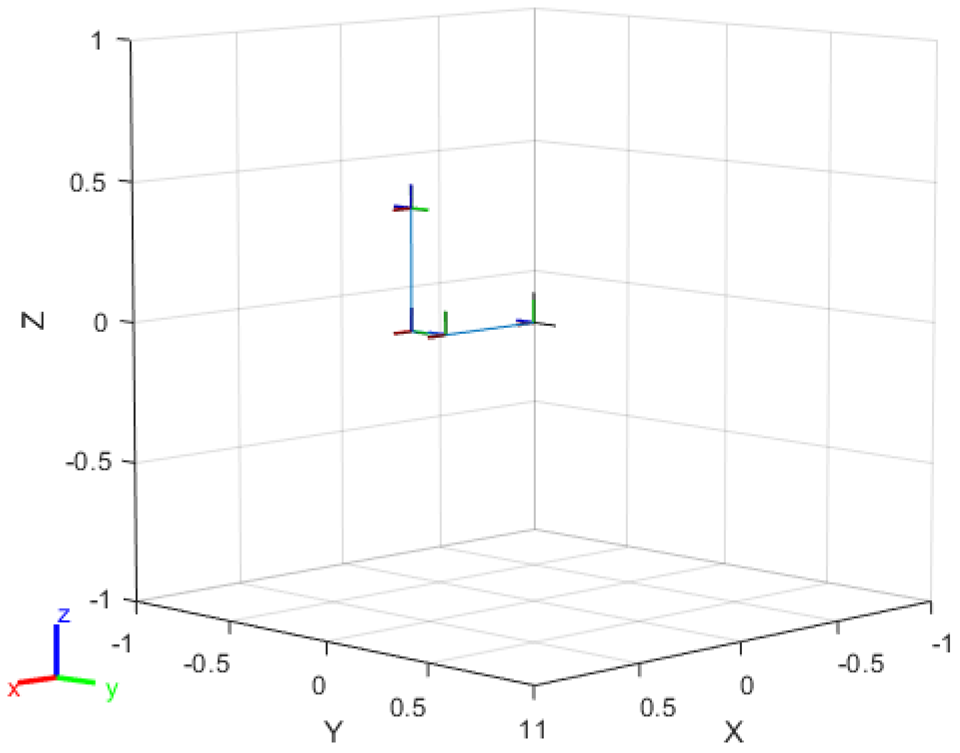
Create a structure for the home configuration of a Puma robot. The structure has joint names and positions for each body on the robot model.

```
config = homeConfiguration(puma1)
```

```
config=1×6 struct array with fields:
    JointName
    JointPosition
```

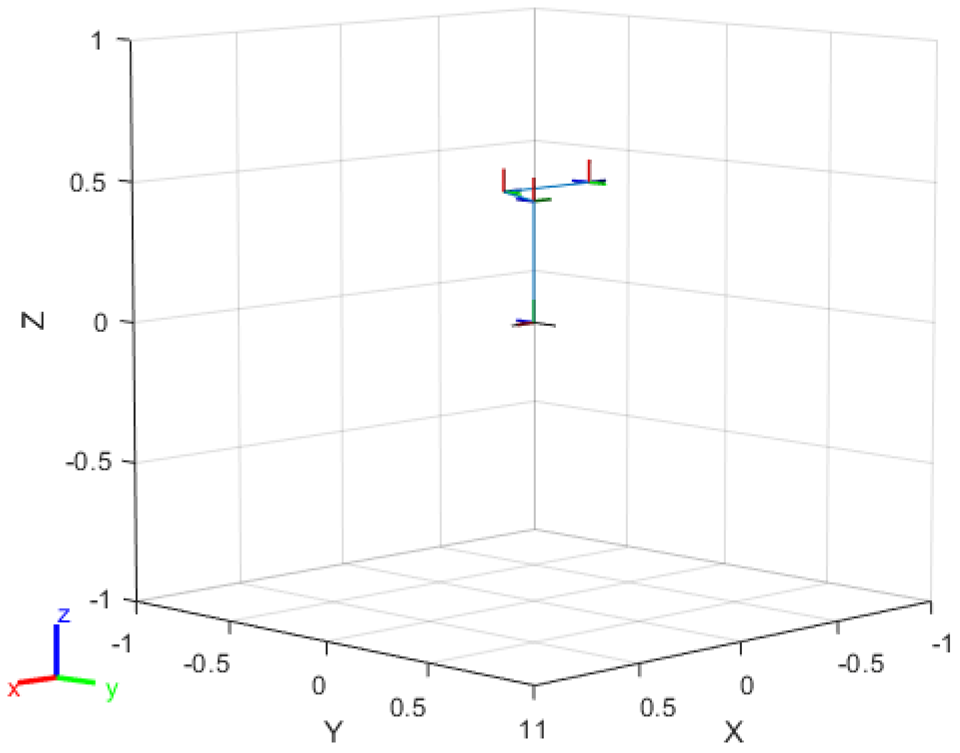
Show the home configuration using `show`. You do not need to specify a configuration input.

```
show(puma1);
```



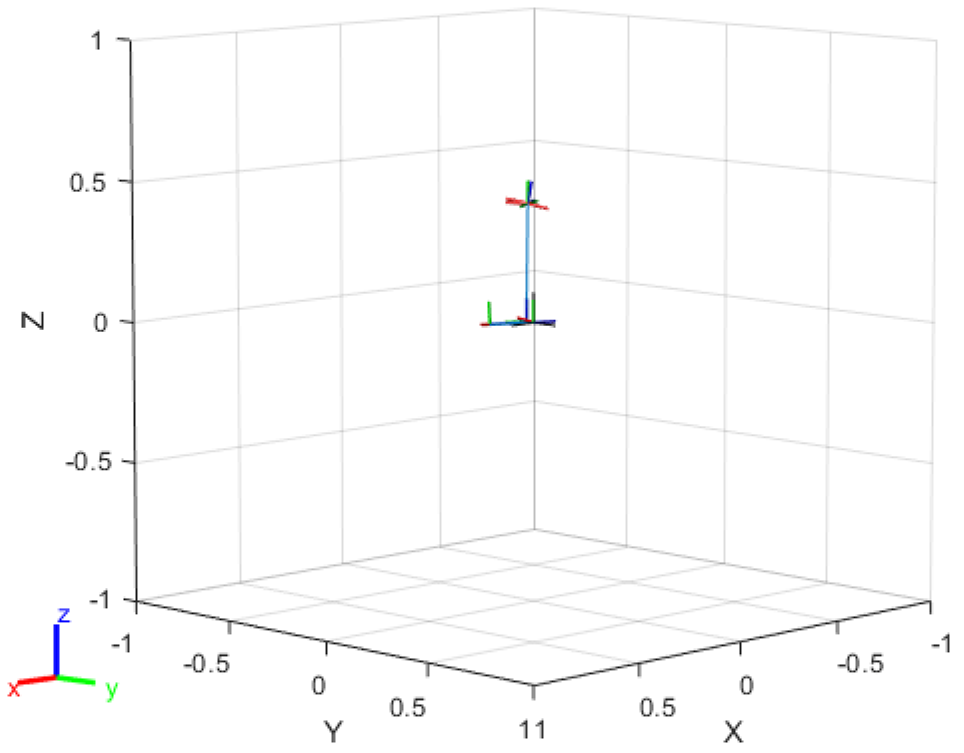
Modify the configuration and set the second joint position to `pi/2`. Show the resulting change in the robot configuration.

```
config(2).JointPosition = pi/2;
show(puma1,config);
```



Create random configurations and show them.

```
show(puma1,randomConfiguration(puma1));
```



Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix[1] on page 3-0 . The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0       pi/2    0       0;
            0.4318    0       0       0
            0.0203    -pi/2    0.15005    0;
            0       pi/2    0.4318    0;
            0       -pi/2    0       0;
            0       0       0       0];
```

Create a rigid body tree object to build the robot.

```
robot = rigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1 Create a `rigidBody` object and give it a unique name.

2. Create a `rigidBodyJoint` object and give it a unique name.
3. Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4. Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = rigidBody('body1');
jnt1 = rigidBodyJoint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

```
body2 = rigidBody('body2');
jnt2 = rigidBodyJoint('jnt2','revolute');
body3 = rigidBody('body3');
jnt3 = rigidBodyJoint('jnt3','revolute');
body4 = rigidBody('body4');
jnt4 = rigidBodyJoint('jnt4','revolute');
body5 = rigidBody('body5');
jnt5 = rigidBodyJoint('jnt5','revolute');
body6 = rigidBody('body6');
jnt6 = rigidBodyJoint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

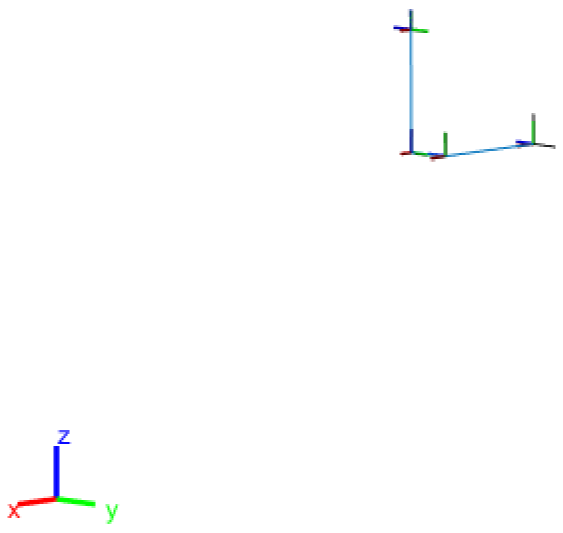
Verify that your robot was built properly by using the `showdetails` or `show` function. `showdetails` lists all the bodies in the MATLAB® command window. `show` displays the robot with a given configuration (home by default). Calls to `axis` modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
```

```
   1        body1         jnt1     revolute             base(0)   body2(2)
   2        body2         jnt2     revolute            body1(1)   body3(3)
   3        body3         jnt3     revolute            body2(2)   body4(4)
   4        body4         jnt4     revolute            body3(3)   body5(5)
   5        body5         jnt5     revolute            body4(4)   body6(6)
   6        body6         jnt6     revolute            body5(5)
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```



References

[1] Corke, P. I., and B. Armstrong-Helouvry. “A Search for Consensus among Model Parameters Reported for the PUMA 560 Robot.” *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, IEEE Comput. Soc. Press, 1994, pp. 1608–13. *DOI.org (Crossref)*, doi:10.1109/ROBOT.1994.351360.

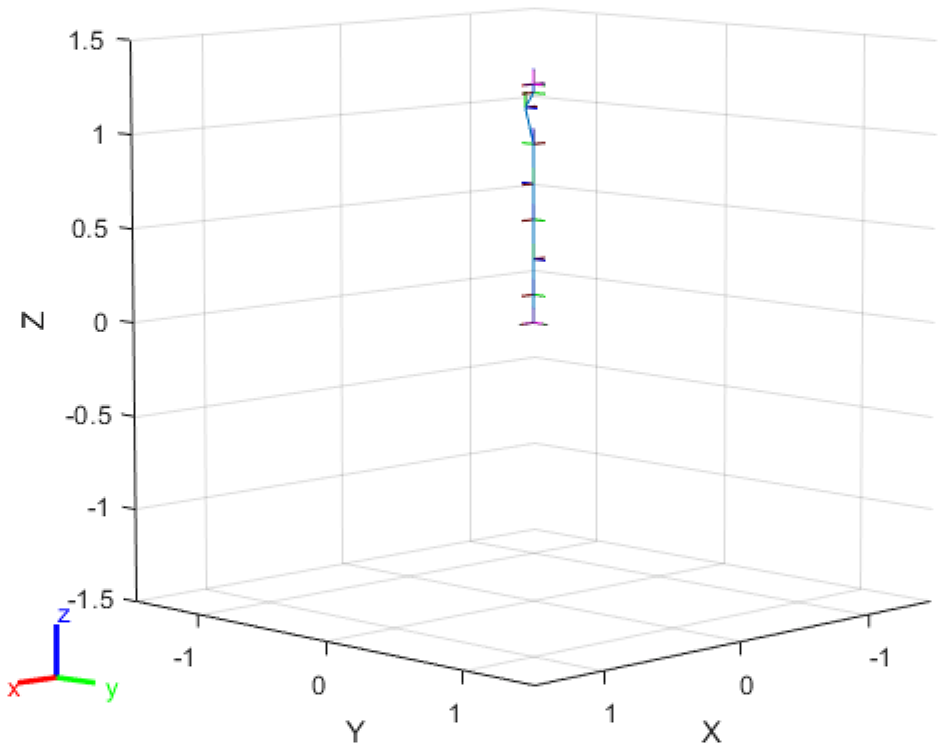
Add Collision Meshes and Check Collisions for Manipulator Robot Arm

Load a robot model and modify the collision meshes. Clear existing collision meshes, add simple collision object primitives, and check whether certain configurations are in collision.

Load Robot Model

Load a preconfigured robot model into the workspace using the `loadrobot` function. This model already has collision meshes specified for each body. Iterate through all the rigid body elements and clear the existing collision meshes. Confirm that the existing meshes are gone.

```
robot = loadrobot('kukaIiwa7','DataFormat','column');

for i = 1:robot.NumBodies
    clearCollision(robot.Bodies{i})
end

show(robot,'Collisions','on','Visuals','off');
```

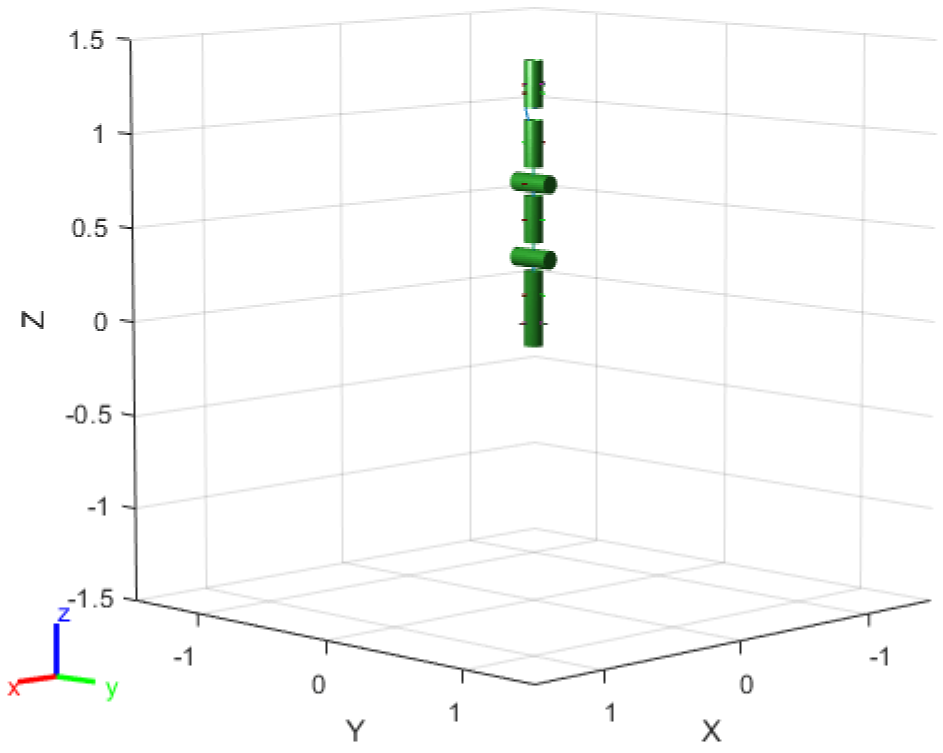


Add Collision Cylinders

Iteratively add a collision cylinder to each body. Skip some bodies for this specific model, as they overlap and always collide with the end effector (body 10).

```
collisionObj = collisionCylinder(0.05,0.25);

for i = 1:robot.NumBodies
    if i > 6 && i < 10
        % Skip these bodies.
    else
        addCollision(robot.Bodies{i},collisionObj)
    end
```

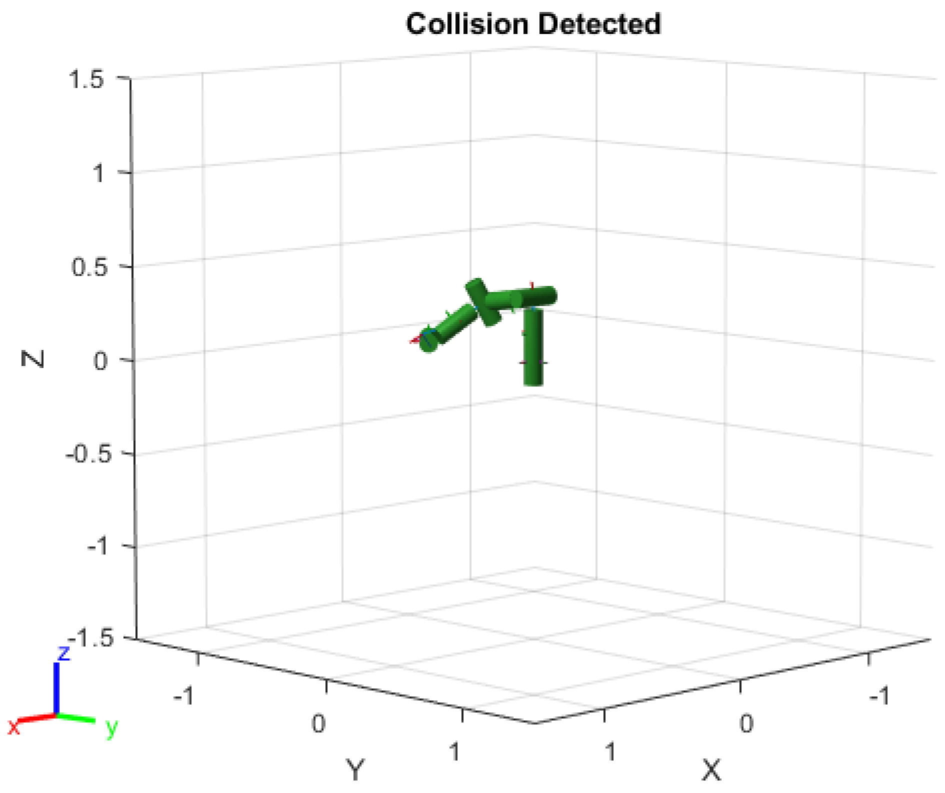
```
end

show(robot,'Collisions','on','Visuals','off');
```



Check for Collisions

Generate a series of random configurations. Check whether the robot is in collision at each configuration. Visualize each configuration that has a collision.

```
figure
rng(0) % Set random seed for repeatability.
for i = 1:20
    config = randomConfiguration(robot);
    isColliding = checkCollision(robot,config);
    if isColliding
        show(robot,config,'Collisions','on','Visuals','off');
        title('Collision Detected')
    else
        % Skip non-collisions.
    end
end
```



Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

`configuration` — Robot configuration
vector | structure

Robot configuration, specified as a vector of joint positions or a structure with joint names and positions for all the bodies in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions in a structure. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `"row"` or `"column"` .

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Frames','off'` hides the rigid body frames in the figure.

`Parent` — Parent of axes
`Axes` object

Parent of axes, specified as the comma-separated pair consisting of `'Parent'` and an `Axes` object in which to draw the robot. By default, the robot is plotted in the active axes.

`PreservePlot` — Option to preserve robot plot
`true` or `1` (default) | `false` or `0`

Option to preserve robot plot, specified as the comma-separated pair consisting of `'PreservePlot'` and a logical `1 (true)` or `0 (false)`. When you specify this argument as `true`, the function does not overwrite previous plots displayed by calling `show`. This setting functions similarly to `hold on` for a standard MATLAB figure, but is limited to robot body frames. When you specify this argument as `false`, the function overwrites previous plots of the robot.

Note When the `'PreservePlot'` value is `true`, the `'FastUpdate'` value must be `false`.

Data Types: `logical`

`Frames` — Display body frames
`'on'` (default) | `'off'`

Display body frames, specified as the comma-separated pair consisting of `'Frames'` and `'on'` or `'off'`. These frames are the coordinate frames of individual bodies on the rigid body tree.

Data Types: `char` | `string`

`Visuals` — Display visual geometries
`'on'` (default) | `'off'`

Display visual geometries, specified as the comma-separated pair consisting of `'Visuals'` and `'on'` or `'off'`. Individual visual geometries can also be turned off by right-clicking them in the figure.

Specify individual visual geometries using `addVisual`. To import a URDF robot model with `.stl` files for meshes, see the `importrobot` function.

Data Types: `char` | `string`

`Collisions` — Display collision geometries
`'off'` (default) | `'on'`

Display collision geometries, specified as the comma-separated pair consisting of `'Collisions'` and `'on'` or `'off'`.

Add collision geometries to the individual rigid bodies in the robot model using the `addCollision` function. To import a URDF robot model with `.stl` files for meshes, see the `importrobot` function.

Data Types: `char` | `string`

`Position` — Position of robot
`[0 0 0 0]` (default) | four-element vector

Position of the robot, specified as the comma-separated pair consisting of `'Position'` and a four-element vector of the form [*x y z yaw*]. The *x*, *y*, and *z* elements specify the position in meters, and *yaw* specifies the yaw angle in radians.

Data Types: `single` | `double`

`FastUpdate` — Fast updates to existing plot
`false` or `0` (default) | `true` or `1`

Fast updates to existing plot, specified as the comma-separated pair consisting of `'FastUpdate'` and a logical `0 (false)` or `1 (true)`. You must use the `show` object function to initially display the robot model before you can specify it with this argument.

Note When the `'FastUpdate'` value is `true`, the `'PreservePlot'` value must be `false`.

Data Types: `logical`

Output Arguments

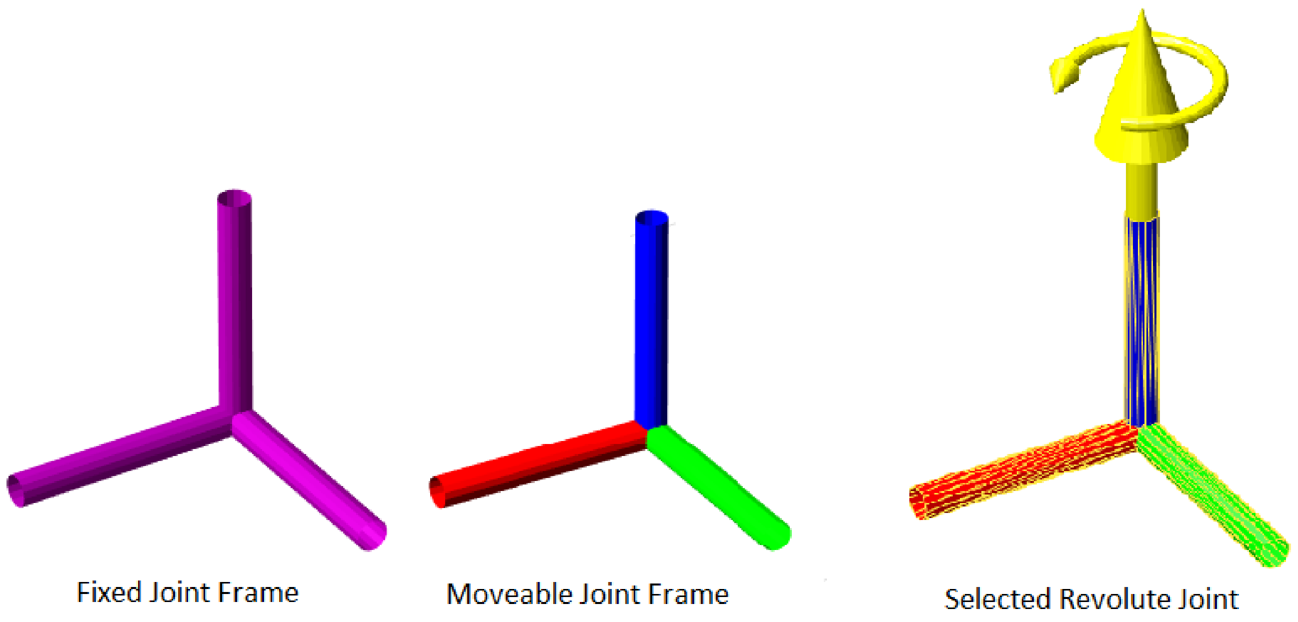
ax — Axes graphic handle
`Axes` object

Axes graphic handle, returned as an `Axes` object. This object contains the properties of the figure that the robot is plotted onto.

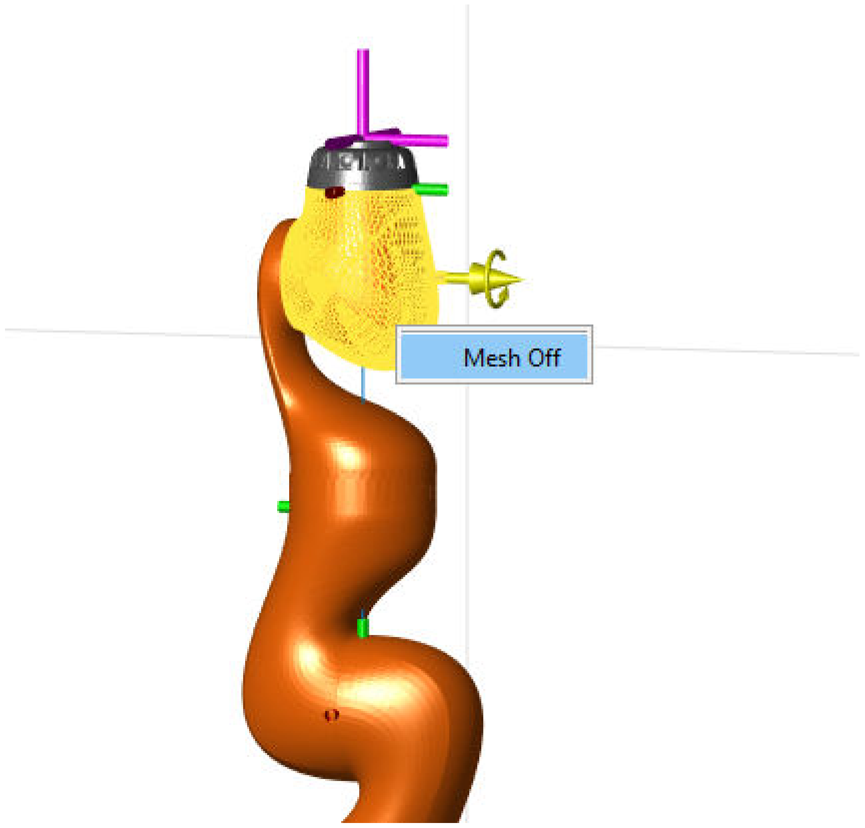
Tips

Your robot model has visual components associated with it. Each `rigidBody` object contains a coordinate frame that is displayed as the body frame. Each body also can have visual meshes associated with them. By default, both of these components are displayed automatically. You can inspect or modify the visual components of the rigid body tree display. Click body frames or visual meshes to highlight them in yellow and see the associated body name, index, and joint type. Right-click to toggle visibility of individual components.

- **Body Frames**: Individual body frames are displayed as a 3-axis coordinate frame. Fixed frames are pink frames. Movable joint types are displayed as RGB axes. You can click a body frame to see the axis of motion. Prismatic joints show a yellow arrow in the direction of the axis of motion and, revolute joints show a circular arrow around the rotation axis.



- **Visual Meshes**: Individual visual geometries are specified using `addVisual` or by using the `importrobot` to import a robot model with `.stl` files specified. By right-clicking individual bodies in a figure, you can turn off their meshes or specify the `Visuals` name-value pair to hide all visual geometries.



See Also

`showdetails` | `randomConfiguration` | `importrobot`

Introduced in R2016b

showdetails

Show details of robot model

Syntax

```
showdetails(robot)
```

Description

`showdetails(robot)` displays in the MATLAB command window the details of each body in the robot model. These details include the body name, associated joint name, joint type, parent name, and children names.

Examples

Attach Rigid Body and Joint to Rigid Body Tree

Add a rigid body and corresponding joint to a rigid body tree. Each `rigidBody` object contains a `rigidBodyJoint` object and must be added to the `rigidBodyTree` using `addBody`.

Create a rigid body tree.

```
rbtree = rigidBodyTree;
```

Create a rigid body with a unique name.

```
body1 = rigidBody('b1');
```

Create a revolute joint. By default, the `rigidBody` object comes with a fixed joint. Replace the joint by assigning a new `rigidBodyJoint` object to the `body1.Joint` property.

```
jnt1 = rigidBodyJoint('jnt1','revolute');
body1.Joint = jnt1;
```

Add the rigid body to the tree. Specify the body name that you are attaching the rigid body to. Because this is the first body, use the base name of the tree.

```
basename = rbtree.BaseName;
addBody(rbtree,body1,basename)
```

Use `showdetails` on the tree to confirm the rigid body and joint were added properly.

```
showdetails(rbtree)
```

```
--------------------
Robot: (1 bodies)

 Idx    Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---    ---------   ----------   ----------    ----------------   ----------------
   1           b1         jnt1     revolute             base(0)   
--------------------
```

Modify a Robot Rigid Body Tree Model

Make changes to an existing `rigidBodyTree` object. You can get replace joints, bodies and subtrees in the rigid body tree.

Load example robots as `rigidBodyTree` objects.

```
load exampleRobots.mat
```

View the details of the Puma robot using `showdetails`.

```
showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Get a specific body to inspect the properties. The only child of the `L3` body is the `L4` body. You can copy a specific body as well.

```
body3 = getBody(puma1,'L3');
childBody = body3.Children{1}
```

```
childBody = 
  rigidBody with properties:

            Name: 'L4'
           Joint: [1x1 rigidBodyJoint]
            Mass: 1
    CenterOfMass: [0 0 0]
         Inertia: [1 1 1 0 0 0]
          Parent: [1x1 rigidBody]
        Children: {[1x1 rigidBody]}
         Visuals: {}
      Collisions: {}
```

```
body3Copy = copy(body3);
```

Replace the joint on the `L3` body. You must create a new `Joint` object and use `replaceJoint` to ensure the downstream body geometry is unaffected. Call `setFixedTransform` if necessary to define a transform between the bodies instead of with the default identity matrices.

```
newJoint = rigidBodyJoint('prismatic');
replaceJoint(puma1,'L3',newJoint);

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name       Joint Name       Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------       ----------       ----------    ----------------   ----------------
   1            L1             jnt1         revolute             base(0)   L2(2)
   2            L2             jnt2         revolute               L1(1)   L3(3)
   3            L3        prismatic            fixed               L2(2)   L4(4)
   4            L4             jnt4         revolute               L3(3)   L5(5)
   5            L5             jnt5         revolute               L4(4)   L6(6)
   6            L6             jnt6         revolute               L5(5)
--------------------
```

Remove an entire body and get the resulting subtree using `removeBody`. The removed body is included in the subtree.

```
subtree = removeBody(puma1,'L4')
```

```
subtree =
  rigidBodyTree with properties:

     NumBodies: 3
        Bodies: {[1x1 rigidBody]  [1x1 rigidBody]  [1x1 rigidBody]}
          Base: [1x1 rigidBody]
     BodyNames: {'L4'  'L5'  'L6'}
      BaseName: 'L3'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Remove the modified `L3` body. Add the original copied `L3` body to the `L2` body, followed by the returned subtree. The robot model remains the same. See a detailed comparison through `showdetails`.

```
removeBody(puma1,'L3');
addBody(puma1,body3Copy,'L2')
addSubtree(puma1,'L3',subtree)

showdetails(puma1)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1            L1         jnt1     revolute             base(0)   L2(2)
   2            L2         jnt2     revolute               L1(1)   L3(3)
   3            L3         jnt3     revolute               L2(2)   L4(4)
   4            L4         jnt4     revolute               L3(3)   L5(5)
   5            L5         jnt5     revolute               L4(4)   L6(6)
   6            L6         jnt6     revolute               L5(5)
--------------------
```

Build Manipulator Robot Using Denavit-Hartenberg Parameters

Use the Denavit-Hartenberg (DH) parameters of the Puma560® robot to build a robot. Each rigid body is added one at a time, with the child-to-parent transform specified by the joint object.

The DH parameters define the geometry of the robot with relation to how each rigid body is attached to its parent. For convenience, setup the parameters for the Puma560 robot in a matrix[1] on page 3-0 . The Puma robot is a serial chain manipulator. The DH parameters are relative to the previous line in the matrix, corresponding to the previous joint attachment.

```
dhparams = [0       pi/2    0       0;
            0.4318    0       0       0
            0.0203    -pi/2    0.15005    0;
            0       pi/2    0.4318    0;
            0       -pi/2    0       0;
            0       0       0       0];
```

Create a rigid body tree object to build the robot.

```
robot = rigidBodyTree;
```

Create the first rigid body and add it to the robot. To add a rigid body:

1. Create a `rigidBody` object and give it a unique name.
2. Create a `rigidBodyJoint` object and give it a unique name.
3. Use `setFixedTransform` to specify the body-to-body transformation using DH parameters. The last element of the DH parameters, `theta`, is ignored because the angle is dependent on the joint position.
4. Call `addBody` to attach the first body joint to the base frame of the robot.

```
body1 = rigidBody('body1');
jnt1 = rigidBodyJoint('jnt1','revolute');

setFixedTransform(jnt1,dhparams(1,:),'dh');
body1.Joint = jnt1;

addBody(robot,body1,'base')
```

Create and add other rigid bodies to the robot. Specify the previous body name when calling `addBody` to attach it. Each fixed transform is relative to the previous joint coordinate frame.

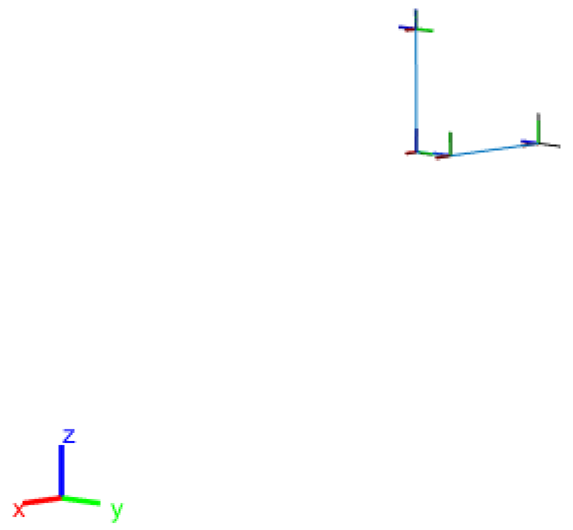
```
body2 = rigidBody('body2');
jnt2 = rigidBodyJoint('jnt2','revolute');
body3 = rigidBody('body3');
jnt3 = rigidBodyJoint('jnt3','revolute');
body4 = rigidBody('body4');
jnt4 = rigidBodyJoint('jnt4','revolute');
body5 = rigidBody('body5');
jnt5 = rigidBodyJoint('jnt5','revolute');
body6 = rigidBody('body6');
jnt6 = rigidBodyJoint('jnt6','revolute');

setFixedTransform(jnt2,dhparams(2,:),'dh');
setFixedTransform(jnt3,dhparams(3,:),'dh');
setFixedTransform(jnt4,dhparams(4,:),'dh');
setFixedTransform(jnt5,dhparams(5,:),'dh');
setFixedTransform(jnt6,dhparams(6,:),'dh');

body2.Joint = jnt2;
body3.Joint = jnt3;
body4.Joint = jnt4;
body5.Joint = jnt5;
body6.Joint = jnt6;

addBody(robot,body2,'body1')
addBody(robot,body3,'body2')
addBody(robot,body4,'body3')
addBody(robot,body5,'body4')
addBody(robot,body6,'body5')
```

Verify that your robot was built properly by using the `showdetails` or `show` function. `showdetails` lists all the bodies in the MATLAB® command window. `show` displays the robot with a given configuration (home by default). Calls to `axis` modify the axis limits and hide the axis labels.

```
showdetails(robot)
```

```
--------------------
Robot: (6 bodies)

 Idx     Body Name   Joint Name   Joint Type    Parent Name(Idx)   Children Name(s)
 ---     ---------   ----------   ----------    ----------------   ----------------
   1         body1         jnt1     revolute             base(0)   body2(2)
   2         body2         jnt2     revolute            body1(1)   body3(3)
   3         body3         jnt3     revolute            body2(2)   body4(4)
   4         body4         jnt4     revolute            body3(3)   body5(5)
   5         body5         jnt5     revolute            body4(4)   body6(6)
   6         body6         jnt6     revolute            body5(5)
--------------------
```

```
show(robot);
axis([-0.5,0.5,-0.5,0.5,-0.5,0.5])
axis off
```



References

[1] Corke, P. I., and B. Armstrong-Helouvry. “A Search for Consensus among Model Parameters Reported for the PUMA 560 Robot.” *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, IEEE Comput. Soc. Press, 1994, pp. 1608–13. *DOI.org (Crossref)*, doi:10.1109/ROBOT.1994.351360.

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

See Also

`show` | `replaceBody` | `replaceJoint`

Introduced in R2016b

subtree

Create subtree from robot model

Syntax

```
newSubtree = subtree(robot,bodyname)
```

Description

`newSubtree = subtree(robot,bodyname)` creates a new robot model using the parent name of the body specified by `bodyname` as the base name. All subsequently attached bodies (including the body with `bodyname` specified) are added to the subtree. The original `robot` model is unaffected.

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

`bodyname` — Body name
string scalar | character vector

Body name, specified as a string scalar or character vector. This body must be on the robot model specified in `robot`.

Data Types: `char` | `string`

Output Arguments

`newSubtree` — Robot subtree
`rigidBodyTree` object

Robot subtree, returned as a `rigidBodyTree` object. This new subtree uses the parent name of the body specified by `bodyname` as the base name. All bodies that are attached in the previous robot model (including the body with `bodyname` specified) are added to the subtree.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also

`rigidBodyJoint` | `rigidBody` | `addBody` | `replaceBody`

Introduced in R2016b

velocityProduct

Joint torques that cancel velocity-induced forces

Syntax

```
jointTorq = velocityProduct(robot,configuration,jointVel)
```

Description

`jointTorq = velocityProduct(robot,configuration,jointVel)` computes the joint torques required to cancel the forces induced by the specified joint velocities under a certain joint configuration. Gravity torque is not included in this calculation.

Examples

Compute Velocity-Induced Joint Torques

Load a predefined KUKA LBR robot model, which is specified as a `RigidBodyTree` object.

```
load exampleRobots.mat lbr
```

Set the data format to `'row'`. For all dynamics calculations, the data format must be either `'row'` or `'column'`.

```
lbr.DataFormat = 'row';
```

Set the joint velocity vector.

```
qdot = [0 0 0.2 0.3 0 0.1 0];
```

Compute the joint torques required to cancel the velocity-induced joint torques at the robot home configuration (`[]` input). The velocity-induced joint torques equal the negative of the `velocityProduct` output.

```
tau = -velocityProduct(lbr,[],qdot);
```

Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. To use the `velocityProduct` function, set the `DataFormat` property to either `'row'` or `'column'`.

`configuration` — Robot configuration
vector

Robot configuration, specified as a vector with positions for all nonfixed joints in the robot model. You can generate a configuration using `homeConfiguration(robot)`, `randomConfiguration(robot)`, or by specifying your own joint positions. To use the vector form of `configuration`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

`jointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the velocity degrees of freedom of the robot. To use the vector form of `jointVel`, set the `DataFormat` property for the `robot` to either `'row'` or `'column'` .

Output Arguments

`jointTorq` — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

When creating the `rigidBodyTree` object, use the syntax that specifies the `MaxNumBodies` as an upper bound for adding bodies to the robot model. You must also specify the `DataFormat` property as a name-value pair. For example:

```
robot = rigidBodyTree("MaxNumBodies",15,"DataFormat","row")
```

To minimize data usage, limit the upper bound to a number close to the expected number of bodies in the model. All data formats are supported for code generation. To use the dynamics functions, the data format must be set to `"row"` or `"column"`.

The `show` and `showdetails` functions do not support code generation.

See Also
`rigidBodyTree` | `inverseDynamics` | `gravityTorque` | `massMatrix`

Topics
“Robot Dynamics”

Introduced in R2017a

writeAsFunction

Create `rigidBodyTree` code generating function

Syntax

`writeAsFunction(robot,filename)`

Description

`writeAsFunction(robot,filename)` creates a function file that constructs the `rigidBodyTree` object. The created function supports code generation.

Examples

Create Rigid Body Tree Code Generating Function

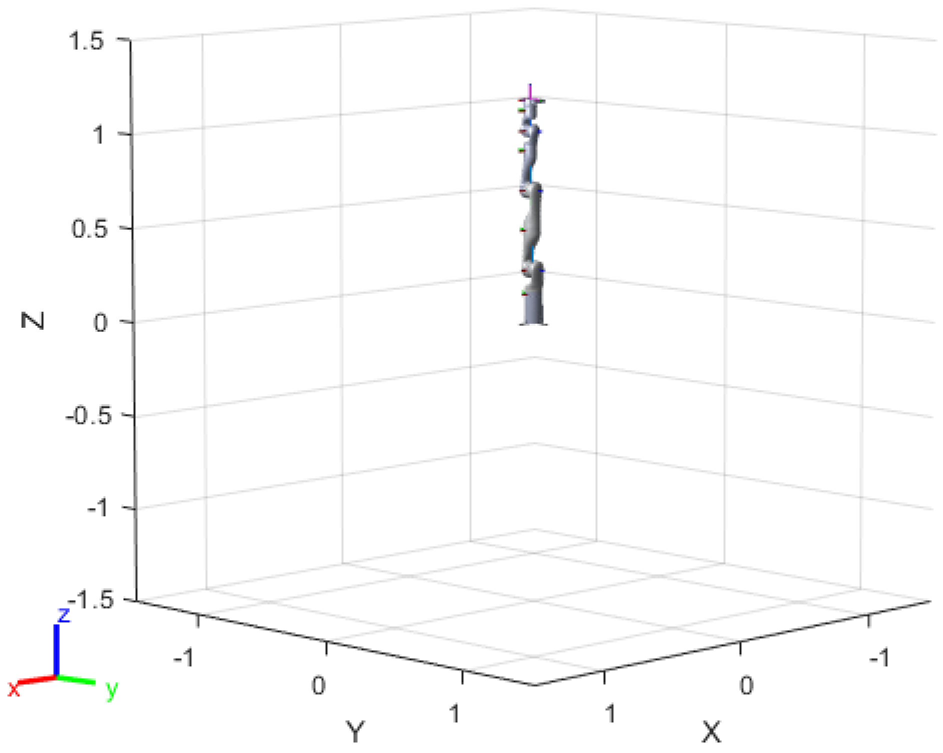
Load a robot model as a `rigidBodyTree` object.

```
robot = loadrobot("kinovaGen3")
```

```
robot = 
  rigidBodyTree with properties:

     NumBodies: 8
        Bodies: {1x8 cell}
          Base: [1x1 rigidBody]
     BodyNames: {1x8 cell}
      BaseName: 'base_link'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Show the robot model in a figure.

```
show(robot);
```



Create a code generating function that constructs the `rigidBodyTree` object.

```
writeAsFunction(robot,'KG3Codegen')
```

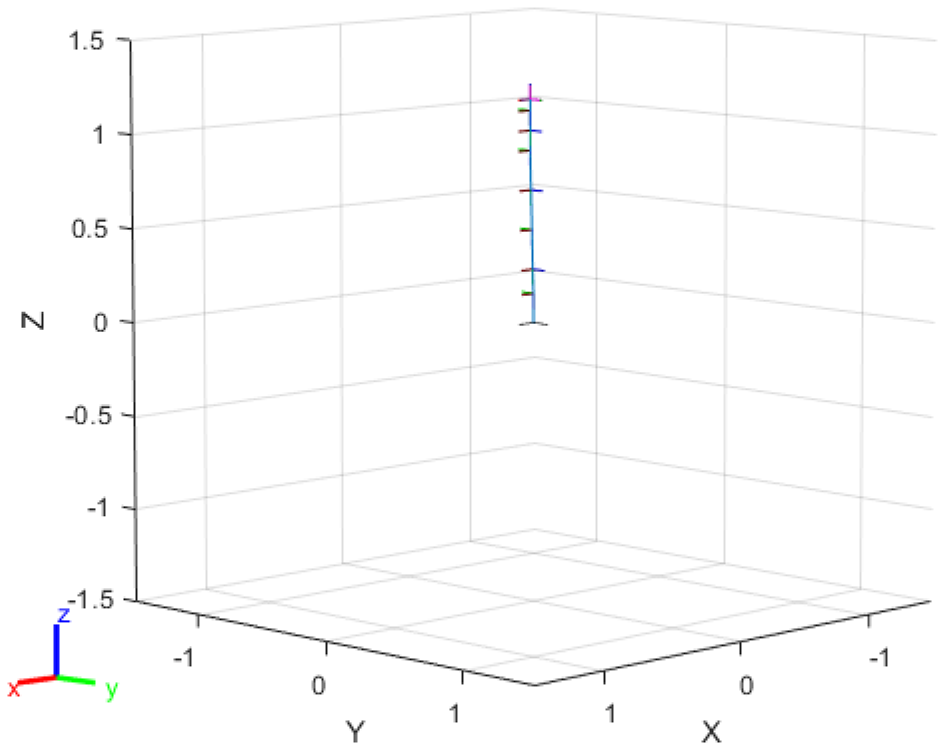
Construct the robot model using the generated function.

```
rbt = KG3Codegen
```

```
rbt = 
  rigidBodyTree with properties:

     NumBodies: 8
        Bodies: {1x8 cell}
          Base: [1x1 rigidBody]
     BodyNames: {1x8 cell}
      BaseName: 'base_link'
       Gravity: [0 0 0]
    DataFormat: 'struct'
```

Show the robot model in a figure.

```
show(rbt);
```



Input Arguments

`robot` — Robot model
`rigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object.

`filename` — Name of function file
string scalar | character vector

Name of the function file, specified as a string scalar or character vector. The name must be a valid MATLAB name (must start with a letter and contain only letters, numbers and underscores).

Example: `"iiwa14Codegen"`

Data Types: `char` | `string`

See Also

Functions
`importrobot` | `loadrobot`

Objects
`rigidBodyTree`

Introduced in R2021a

bodyInfo

Import information for body

Syntax

`info = bodyInfo(importInfo,bodyName)`

Description

`info = bodyInfo(importInfo,bodyName)` returns the import information for a body in a `rigidBodyTree` object that is created from calling `importrobot`. Specify the `rigidBodyTreeImportInfo` object from the import process.

Input Arguments

`importInfo` — Robot import information
`rigidBodyTreeImportInfo` object

Robot import information, specified as a `rigidBodyTreeImportInfo` object. This object is returned when you use `importrobot`.

bodyName — Name of body
character vector | string scalar

Name of a body in the `rigidBodyTree` object that was created using `importrobot`, specified as a character vector or string scalar. Partial string matching is accepted and returns a cell array of structures that match the partial string.

Example: `'Body01'`

Data Types: `char` | `string`

Output Arguments

`info` — Import information for specific component
structure | cell array of structures

Import information for specific component, returned as a structure or cell array of structures. This structure contains the information about the imported blocks from Simscape Multibody and the associated components in the `rigidBodyTree` object. The fields of each structure are:

- `BodyName` — Name of the body in the `rigidBodyTree` object.
- `JointName` — Name of the joint associated with `BodyName`.
- `BodyBlocks` — Blocks used from the Simscape Multibody model.
- `JointBlocks` — Joint blocks used from the Simscape Multibody model.

See Also

`importrobot` | `rigidBodyTreeImportInfo` | `rigidBodyTree` | `showdetails`

Introduced in R2018b

bodyInfoFromBlock

Import information for block name

Syntax

```
info = bodyInfo(importInfo,blockName)
```

Description

`info = bodyInfo(importInfo,blockName)` returns the import information for a block in a Simscape Multibody model that is imported from calling `importrobot`. Specify the `rigidBodyTreeImportInfo` object from the import process.

Input Arguments

`importInfo` — Robot import information
`rigidBodyTreeImportInfo` object

Robot import information, specified as a `rigidBodyTreeImportInfo` object. This object is returned when you use `importrobot`.

`blockName` — Name of block
character vector | string scalar

Name of a block in the Simscape Multibody model that was imported using `importrobot`, specified as a character vector or string scalar. Partial string matching is accepted and returns a cell array of structures that match the partial string.

Example: `'Prismatic Joint 2'`

Data Types: `char` | `string`

Output Arguments

`info` — Import information for specific component
structure | cell array of structures

Import information for specific component, returned as a structure or cell array of structures. This structure contains the information about the imported blocks from Simscape Multibody and the associated components in the `rigidBodyTree` object. The fields of each structure are:

- `BodyName` — Name of the body in the `rigidBodyTree` object.
- `JointName` — Name of the joint associated with `BodyName`.
- `BodyBlocks` — Blocks used from the Simscape Multibody model.
- `JointBlocks` — Joint blocks used from the Simscape Multibody model.

See Also
`importrobot` | `rigidBodyTreeImportInfo` | `rigidBodyTree` | `showdetails`

Introduced in R2018b

bodyInfoFromJoint

Import information for given joint name

Syntax

```
info = bodyInfo(importInfo,jointName)
```

Description

`info = bodyInfo(importInfo,jointName)` returns the import information for a joint in a `rigidBodyTree` object that is created from calling `importrobot`. Specify the `rigidBodyTreeImportInfo` object from the import process.

Input Arguments

`importInfo` — Robot import information
`rigidBodyTreeImportInfo` object

Robot import information, specified as a `rigidBodyTreeImportInfo` object. This object is returned when you use `importrobot`.

`jointName` — Name of joint
character vector | string scalar

Name of a joint in the `rigidBodyTree` object that was created using `importrobot`, specified as a character vector or string scalar. Partial string matching is accepted and returns a cell array of structures that match the partial string.

Example: `'Joint01'`

Data Types: `char` | `string`

Output Arguments

`info` — Import information for specific component
structure | cell array of structures

Import information for specific component, specified as a structure or cell array of structures. This structure contains the information about the imported blocks from Simscape Multibody and the associated components in the `rigidBodyTree` object. The fields of each structure are:

- `BodyName` — Name of the body in the `rigidBodyTree` object.
- `JointName` — Name of the joint associated with `BodyName`.
- `BodyBlocks` — Blocks used from the Simscape Multibody model.
- `JointBlocks` — Joint blocks used from the Simscape Multibody model.

See Also
`importrobot` | `rigidBodyTreeImportInfo` | `rigidBodyTree`

Introduced in R2018b

showdetails

Display details of imported robot

Syntax

```
showdetails(importInfo)
```

Description

`showdetails(importInfo)` displays the details of each body in the `rigidBodyTree` object that is created from calling `importrobot`. Specify the `rigidBodyTreeImportInfo` object from the import process.

The list shows the bodies with their associated joint name, joint type, source blocks, parent body name, and children body names. The list also provides highlight links to the associated blocks used in the Simscape Multibody model.

Note The `Highlight` links assume the block names are unchanged.

Input Arguments

`importInfo` — Robot import information
`rigidBodyTreeImportInfo` object

Robot import information, specified as a `rigidBodyTreeImportInfo` object. This object is returned when you use `importrobot`.

See Also

`importrobot` | `rigidBodyTreeImportInfo` | `rigidBodyTree`

Introduced in R2018b

copy

Create copy of particle filter

Syntax

`b = copy(a)`

Description

`b = copy(a)` copies each element in the array of handles, `a`, to the new array of handles, `b`.

The `copy` method does not copy dependent properties. MATLAB does not call `copy` recursively on any handles contained in property values. MATLAB also does not call the class constructor or property-set methods during the copy operation.

Input Arguments

a — Object array
handle

Object array, specified as a handle.

Output Arguments

b — Object array containing copies of the objects in a
handle

Object array containing copies of the object in `a`, specified as a handle.

`b` has the same number of elements and is the same size and class of `a`. `b` is the same class as `a`. If `a` is empty, `b` is also empty. If `a` is heterogeneous, `b` is also heterogeneous. If `a` contains deleted handles, then `copy` creates deleted handles of the same class in `b`. Dynamic properties and listeners associated with objects in `a` are not copied to objects in `b`.

See Also

`stateEstimatorPF` | `resamplingPolicyPF` | `initialize` | `getStateEstimate` | `predict` | `correct`

Topics
“Track a Car-Like Robot Using Particle Filter”
“Particle Filter Parameters”
“Particle Filter Workflow”

Introduced in R2016a

correct

Adjust state estimate based on sensor measurement

Syntax

```
[stateCorr,stateCov] = correct(pf,measurement)
[stateCorr,stateCov] = correct(pf,measurement,varargin)
```

Description

`[stateCorr,stateCov] = correct(pf,measurement)` calculates the corrected system state and its associated uncertainty covariance based on a sensor `measurement` at the current time step. `correct` uses the `MeasurementLikelihoodFcn` property from the particle filter object, `pf`, as a function to calculate the likelihood of the sensor measurement for each particle. The two inputs to the `MeasurementLikelihoodFcn` function are:

1. `pf` – The `stateEstimatorPF` object, which contains the particles of the current iteration
2. `measurement` – The sensor measurements used to correct the state estimate

The `MeasurementLikelihoodFcn` function then extracts the best state estimate and covariance based on the setting in the `StateEstimationMethod` property.

`[stateCorr,stateCov] = correct(pf,measurement,varargin)` passes all additional arguments in `varargin` to the underlying `MeasurementLikelihoodFcn` after the first three required inputs.

Examples

Particle Filter Prediction and Correction

Create a `stateEstimatorPF` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = stateEstimatorPF
```

```
pf = 
  stateEstimatorPF with properties:

           NumStateVariables: 3
                NumParticles: 1000
          StateTransitionFcn: @nav.algs.gaussianMotion
    MeasurementLikelihoodFcn: @nav.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
            ResamplingPolicy: [1x1 resamplingPolicyPF]
            ResamplingMethod: 'multinomial'
       StateEstimationMethod: 'mean'
```

```
            StateOrientation: 'row'
                   Particles: [1000x3 double]
                     Weights: [1000x1 double]
                       State: 'Use the getStateEstimate function to see the value.'
             StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

```
stateEst = getStateEstimate(pf)
```

```
stateEst = 1×3

    4.1562    0.9185    9.0202
```

Input Arguments

pf — stateEstimatorPF object
handle

`stateEstimatorPF` object, specified as a handle. See `stateEstimatorPF` for more information.

measurement — Sensor measurements
array

Sensor measurements, specified as an array. This input is passed directly into the `MeasurementLikelihoodFcn` property of `pf`. It is used to calculate the likelihood of the sensor measurement for each particle.

varargin — Variable-length input argument list
comma-separated list

Variable-length input argument list, specified as a comma-separated list. This input is passed directly into the `MeasurementLikelihoodFcn` property of `pf`. It is used to calculate the likelihood of the sensor measurement for each particle. When you call:

```
correct(pf,measurement,arg1,arg2)
```

MATLAB essentially calls `measurementLikelihoodFcn` as:

```
measurementLikelihoodFcn(pf,measurement,arg1,arg2)
```

Output Arguments

`stateCorr` — Corrected system state
vector with length `NumStateVariables`

Corrected system state, returned as a row vector with length `NumStateVariables`. The corrected state is calculated based on the `StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`.

`stateCov` — Corrected system covariance
N-by-*N* matrix | `[]`

Corrected system variance, returned as an *N*-by-*N* matrix, where *N* is the value of `NumStateVariables` property from `pf`. The corrected state is calculated based on the `StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the function returns `stateCov` as `[]`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`stateEstimatorPF` | `resamplingPolicyPF` | `initialize` | `getStateEstimate` | `predict` | `correct`

Topics
"Track a Car-Like Robot Using Particle Filter"
"Particle Filter Parameters"
"Particle Filter Workflow"

Introduced in R2016a

getStateEstimate

Extract best state estimate and covariance from particles

Syntax

```
stateEst = getStateEstimate(pf)
[stateEst,stateCov] = getStateEstimate(pf)
```

Description

`stateEst = getStateEstimate(pf)` returns the best state estimate based on the current set of particles. The estimate is extracted based on the `StateEstimationMethod` property from the `stateEstimatorPF` object, `pf`.

`[stateEst,stateCov] = getStateEstimate(pf)` also returns the covariance around the state estimate. The covariance is a measure of the uncertainty of the state estimate. Not all state estimate methods support covariance output. In this case, `getStateEstimate` returns `stateCov` as `[]`.

Examples

Particle Filter Prediction and Correction

Create a `stateEstimatorPF` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = stateEstimatorPF
```

```
pf = 
  stateEstimatorPF with properties:

           NumStateVariables: 3
                NumParticles: 1000
          StateTransitionFcn: @nav.algs.gaussianMotion
    MeasurementLikelihoodFcn: @nav.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
            ResamplingPolicy: [1x1 resamplingPolicyPF]
            ResamplingMethod: 'multinomial'
       StateEstimationMethod: 'mean'
            StateOrientation: 'row'
                   Particles: [1000x3 double]
                     Weights: [1000x1 double]
                       State: 'Use the getStateEstimate function to see the value.'
             StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

```
stateEst = getStateEstimate(pf)
```

```
stateEst = 1×3

    4.1562    0.9185    9.0202
```

Input Arguments

pf — stateEstimatorPF object

handle

`stateEstimatorPF` object, specified as a handle. See `stateEstimatorPF` for more information.

Output Arguments

stateEst — Best state estimate

vector

Best state estimate, returned as a row vector with length `NumStateVariables`. The estimate is extracted based on the `StateEstimationMethod` algorithm specified in `pf`.

stateCov — Corrected system covariance

N-by-*N* matrix | `[]`

Corrected system variance, returned as an *N*-by-*N* matrix, where *N* is the value of `NumStateVariables` property from `pf`. The corrected state is calculated based on the `StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the function returns `stateCov` as `[]`.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`stateEstimatorPF` | `resamplingPolicyPF` | `initialize` | `getStateEstimate` | `predict` | `correct`

Topics
“Track a Car-Like Robot Using Particle Filter”
“Particle Filter Parameters”
“Particle Filter Workflow”

Introduced in R2016a

initialize

Initialize the state of the particle filter

Syntax

```
initialize(pf,numParticles,mean,covariance)
initialize(pf,numParticles,stateBounds)
initialize( ___ ,Name,Value)
```

Description

`initialize(pf,numParticles,mean,covariance)` initializes the particle filter object, `pf`, with a specified number of particles, `numParticles`. The initial states of the particles in the state space are determined by sampling from the multivariate normal distribution with the specified `mean` and `covariance`.

`initialize(pf,numParticles,stateBounds)` determines the initial location of the particles by sample from the multivariate uniform distribution within the specified `stateBounds`.

`initialize( ___ ,Name,Value)` initializes the particles with additional options specified by one or more `Name,Value` pair arguments.

Examples

Particle Filter Prediction and Correction

Create a `stateEstimatorPF` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = stateEstimatorPF
```

```
pf = 
  stateEstimatorPF with properties:

           NumStateVariables: 3
                NumParticles: 1000
          StateTransitionFcn: @nav.algs.gaussianMotion
    MeasurementLikelihoodFcn: @nav.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
            ResamplingPolicy: [1x1 resamplingPolicyPF]
            ResamplingMethod: 'multinomial'
       StateEstimationMethod: 'mean'
            StateOrientation: 'row'
                   Particles: [1000x3 double]
                     Weights: [1000x1 double]
                       State: 'Use the getStateEstimate function to see the value.'
```

```
                  StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

```
stateEst = getStateEstimate(pf)
```

```
stateEst = 1×3

    4.1562    0.9185    9.0202
```

Input Arguments

`pf` — `stateEstimatorPF` object
handle

`stateEstimatorPF` object, specified as a handle. See `stateEstimatorPF` for more information.

`numParticles` — Number of particles used in the filter
scalar

Number of particles used in the filter, specified as a scalar.

`mean` — Mean of particle distribution
vector

Mean of particle distribution, specified as a vector. The `NumStateVariables` property of `pf` is set based on the length of this vector.

`covariance` — Covariance of particle distribution
N-by-*N* matrix

Covariance of particle distribution, specified as an *N*-by-*N* matrix, where *N* is the value of `NumStateVariables` property from `pf`.

`stateBounds` — Bounds of state variables
n-by-2 matrix

Bounds of state variables, specified as an *n*-by-2 matrix. The `NumStateVariables` property of `pf` is set based on the value of *n*. Each row corresponds to the lower and upper limit of the corresponding state variable.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `"CircularVariables",[0 0 1]`

`CircularVariables` — Circular variables
logical vector

Circular variables, specified as a logical vector. Each state variable that uses circular or angular coordinates is indicated with a 1. The length of the vector is equal to the `NumStateVariables` property of `pf`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`stateEstimatorPF` | `resamplingPolicyPF` | `initialize` | `getStateEstimate` | `predict` | `correct`

Topics
“Track a Car-Like Robot Using Particle Filter”
“Particle Filter Parameters”
“Particle Filter Workflow”

Introduced in R2016a

predict

Predict state of robot in next time step

Syntax

```
[statePred,stateCov] = predict(pf)
[statePred,stateCov] = predict(pf,varargin)
```

Description

`[statePred,stateCov] = predict(pf)` calculates the predicted system state and its associated uncertainty covariance. `predict` uses the `StateTransitionFcn` property of `stateEstimatorPF` object, `pf`, to evolve the state of all particles. It then extracts the best state estimate and covariance based on the setting in the `StateEstimationMethod` property.

`[statePred,stateCov] = predict(pf,varargin)` passes all additional arguments specified in `varargin` to the underlying `StateTransitionFcn` property of `pf`. The first input to `StateTransitionFcn` is the set of particles from the previous time step, followed by all arguments in `varargin`.

Examples

Particle Filter Prediction and Correction

Create a `stateEstimatorPF` object, and execute a prediction and correction step for state estimation. The particle filter gives a predicted state estimate based on the return value of `StateTransitionFcn`. It then corrects the state based on a given measurement and the return value of `MeasurementLikelihoodFcn`.

Create a particle filter with the default three states.

```
pf = stateEstimatorPF
```

```
pf = 
  stateEstimatorPF with properties:

           NumStateVariables: 3
                NumParticles: 1000
          StateTransitionFcn: @nav.algs.gaussianMotion
    MeasurementLikelihoodFcn: @nav.algs.fullStateMeasurement
     IsStateVariableCircular: [0 0 0]
            ResamplingPolicy: [1x1 resamplingPolicyPF]
            ResamplingMethod: 'multinomial'
       StateEstimationMethod: 'mean'
            StateOrientation: 'row'
                   Particles: [1000x3 double]
                     Weights: [1000x1 double]
                       State: 'Use the getStateEstimate function to see the value.'
             StateCovariance: 'Use the getStateEstimate function to see the value.'
```

Specify the mean state estimation method and systematic resampling method.

```
pf.StateEstimationMethod = 'mean';
pf.ResamplingMethod = 'systematic';
```

Initialize the particle filter at state [4 1 9] with unit covariance (`eye(3)`). Use 5000 particles.

```
initialize(pf,5000,[4 1 9],eye(3));
```

Assuming a measurement [4.2 0.9 9], run one predict and one correct step.

```
[statePredicted,stateCov] = predict(pf);
[stateCorrected,stateCov] = correct(pf,[4.2 0.9 9]);
```

Get the best state estimate based on the `StateEstimationMethod` algorithm.

```
stateEst = getStateEstimate(pf)
```

```
stateEst = 1×3

    4.1562    0.9185    9.0202
```

Input Arguments

`pf` — `stateEstimatorPF` object
handle

`stateEstimatorPF` object, specified as a handle. See `stateEstimatorPF` for more information.

`varargin` — Variable-length input argument list
comma-separated list

Variable-length input argument list, specified as a comma-separated list. This input is passed directly into the `StateTransitionFcn` property of `pf` to evolve the system state for each particle. When you call:

```
predict(pf,arg1,arg2)
```

MATLAB essentially calls the `stateTranstionFcn` as:

```
stateTransitionFcn(pf,prevParticles,arg1,arg2)
```

Output Arguments

`statePred` — Predicted system state
vector

Predicted system state, returned as a vector with length `NumStateVariables`. The predicted state is calculated based on the `StateEstimationMethod` algorithm.

`stateCov` — Corrected system covariance
N-by-*N* matrix | [ ]

Corrected system variance, returned as an *N*-by-*N* matrix, where *N* is the value of `NumStateVariables` property from `pf`. The corrected state is calculated based on the

`StateEstimationMethod` algorithm and the `MeasurementLikelihoodFcn`. If you specify a state estimate method that does not support covariance, then the function returns `stateCov` as `[]`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also

`stateEstimatorPF` | `resamplingPolicyPF` | `initialize` | `getStateEstimate` | `predict` | `correct`

Topics
“Track a Car-Like Robot Using Particle Filter”
“Particle Filter Parameters”
“Particle Filter Workflow”

Introduced in R2016a

sample

Sample end-effector poses in world frame

Syntax

```
eePose = sample(goalRegion)
eePose = sample(goalRegion,numSamples)
```

Description

`eePose = sample(goalRegion)` samples an end-effector pose in the world frame as a homogeneous transformation matrix.

The function returns a pose uniformly sampled within the Bounds property relative to the reference frame and applies the following transformations based on the ReferencePose and EndEffectorOffsetPose properties:

```
tSample; % Pose sampled within Bounds
Tw0 = goalRegion.ReferencePose;
TeW = goalRegion.EndEffectorOffsetPose;
eePose = Tw0 * tSample * TeW; % tSample is a pose within the bounds.
```

`eePose = sample(goalRegion,numSamples)` samples multiple poses based on the input `numSamples`. The function returns the end-effector poses as a 3-D array of homogeneous transforms.

Examples

Sample Multiple Poses In A Workspace Goal Region

Sample various poses within the bounds of a workspace goal region for a manipulator arm. Some end-effector poses may not be desirable due to the positioning of the arm bodies and obstacles in the scene. The `workspaceGoalRegion` object defines the bounds on the XYZ-position and ZYX Euler orientation of the robot end effector. The `sample` object function uniformly samples random poses within the bounds. Find configurations that achieve these end-effector poses and determine the best by visualization.

Load an existing robot model as a `rigidBodyTree` object.

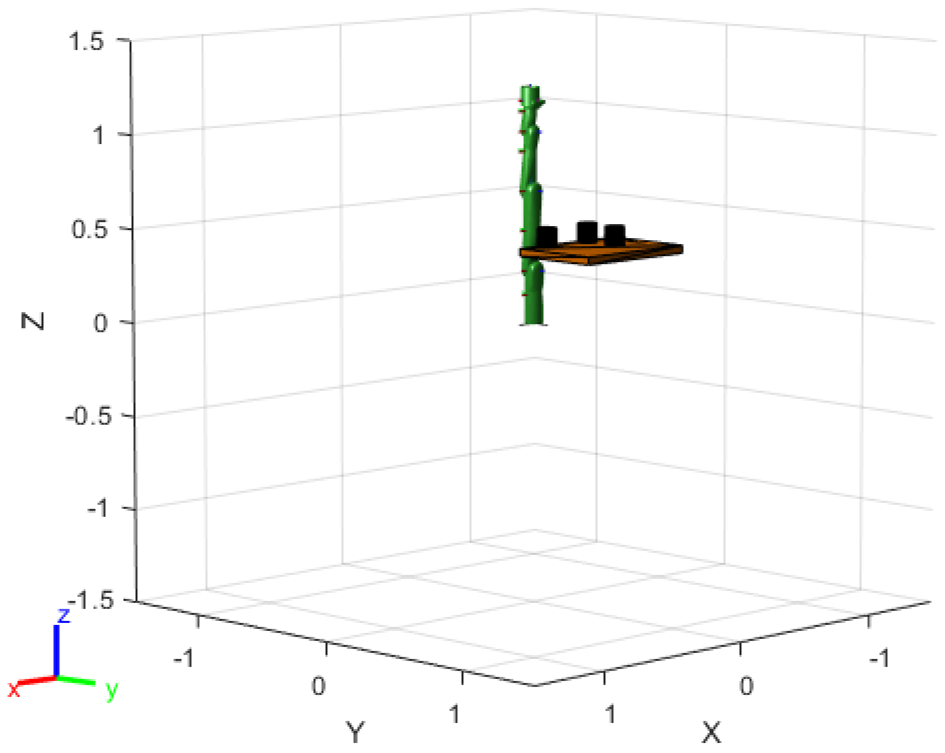
```
robot = loadrobot("kinovaGen3","DataFormat","row");
show(robot,"Collisions","on","Visuals","off");
```

Add a can as a `collisionCylinder` object to the robot arm.

```
can = collisionCylinder(0.05, 0.1);
can.Pose = trvec2tform([0.2, 0.3, 0.5]);

addCollision(robot.Bodies{end},"cylinder", [0.05, 0.1], trvec2tform([0, 0, 0.02]));
```

The goal of this example is to place this can on a table with other cans. Add the table and other cans to the environment by creating a cell array of collision objects. Show the entire `env` cell array.

```
table = collisionBox(0.7, 0.5, 0.04);
table.Pose = trvec2tform([0, 0.5, 0.43]);
env = {can, copy(can), copy(can), table};
env{2}.Pose = trvec2tform([-0.1, 0.3, 0.5]);
env{3}.Pose = trvec2tform([-0.1, 0.5, 0.5]);

hold on
for i = 1: length(env)
    show(env{i})
end
show(robot,homeConfiguration(robot),"Collisions","on","Visuals","off");
```

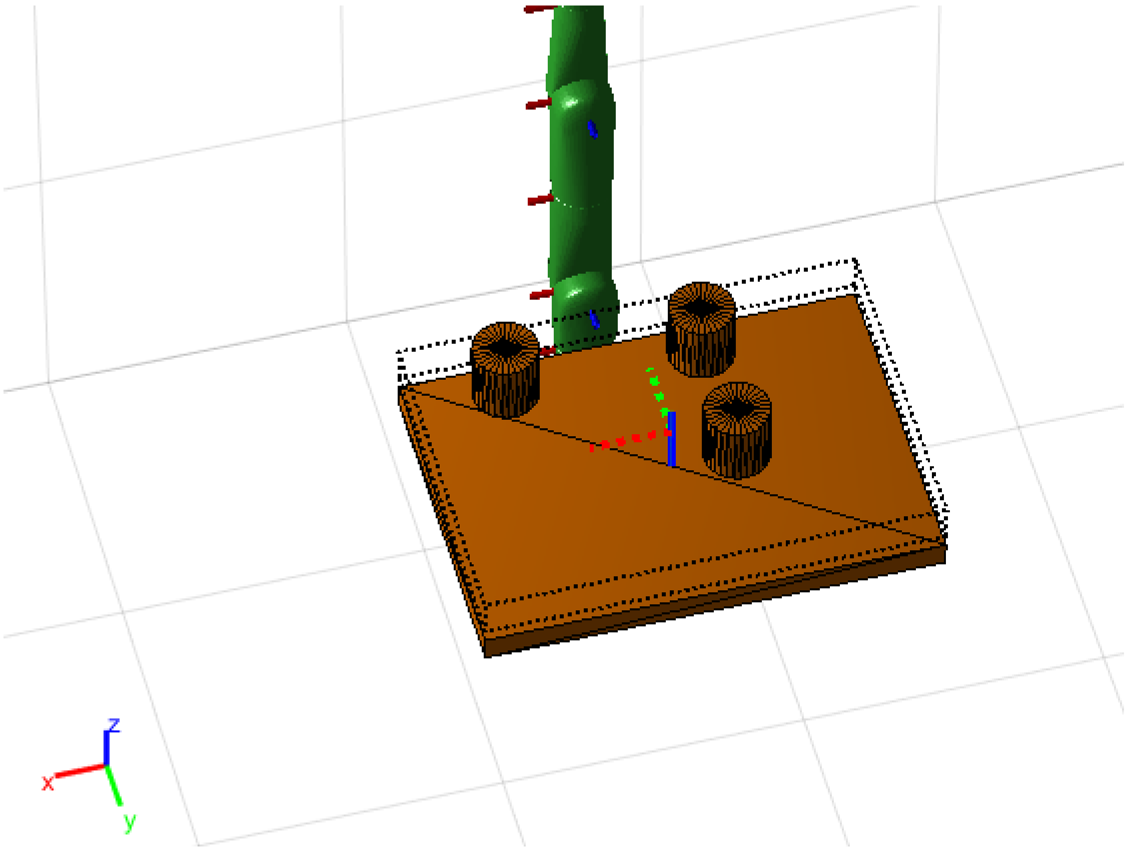


Define Goal Region

Create a workspace goal region using the end-effector body name of the robot.

Define the goal region parameters for your workspace. The goal region includes a reference pose, XYZ-position bounds, and orientation limits on the ZYX Euler angles. This example specifiies XYZ bounds within the table dimensions and fixes rotation to a small range in the Y and X axis.

```
tableRegion = workspaceGoalRegion("EndEffector_Link",...
    "ReferencePose",table.Pose);
tableRegion.EndEffectorOffsetPose(1:3,1:3) = eul2rotm([0, 0, pi]);
tableRegion.EndEffectorOffsetPose(3, end) = 0.1;

tableRegion.Bounds = ...
    [-table.X/2, table.X/2; % X Bounds
    -table.Y/2, table.Y/2;  % Y Bounds
    0.04, 0.10;               % Z Bounds
    -pi, pi;                  % Rotation about Z-axis
    -0.01, 0.01;              % Y-Axis
    -0.01, 0.01;];            % X-Axis

show(tableRegion);
view(165,50)
camzoom(3.5)
```



Sample Poses

Uniformly sample poses within the table region using the `sample` object function. In this example, set the `rng` seed to get repeatable results. Create vectors for storing valid and invalid poses.

```
rng(0)
poses = sample(tableRegion,10);
validPoses = [];
invalidPoses = [];
```

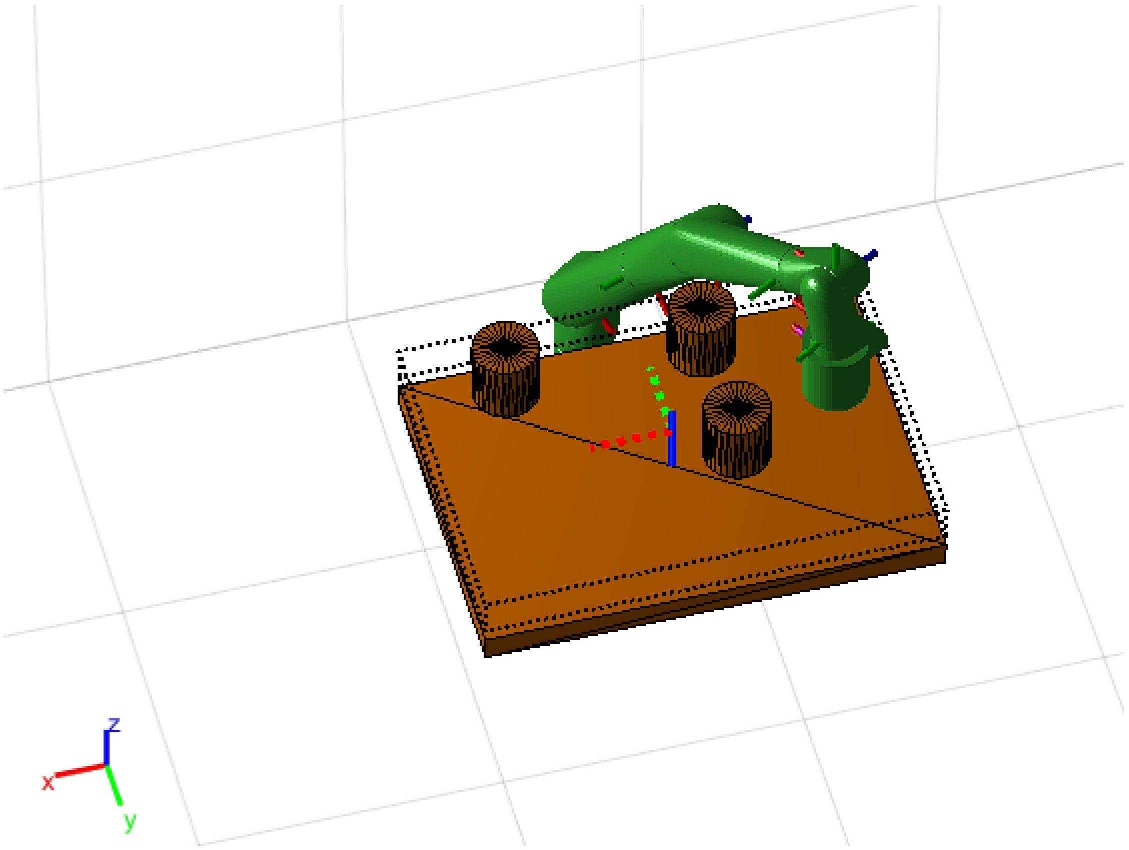
Check for Collisions

To find configurations for those poses, create an inverse kinematics (IK) solver.

```
ik = inverseKinematics('RigidBodyTree',robot);
config = cell(10);
```

Test the sampled poses by iterating through the sampled poses, solving for configurations using IK, and checking for collisions. Show the valid configurations.

```
for i = 1:length(poses)
    % Solve for robot configuraiton using IK.
    config{i} = ik("EndEffector_Link",poses(:,:,i),ones(6,1),homeConfiguration(robot));
    % Check for collisions.
    isColliding = checkCollision(robot,config{i},env);

    if ~isColliding % If not in collision, show robot configuration and save valid pose.
        show(robot,config{i},"PreservePlot",false,"Collisions","on","Visuals","off");
        drawnow
        validPoses = [validPoses; i];
    else
        invalidPoses = [invalidPoses; i];
    end

end
```



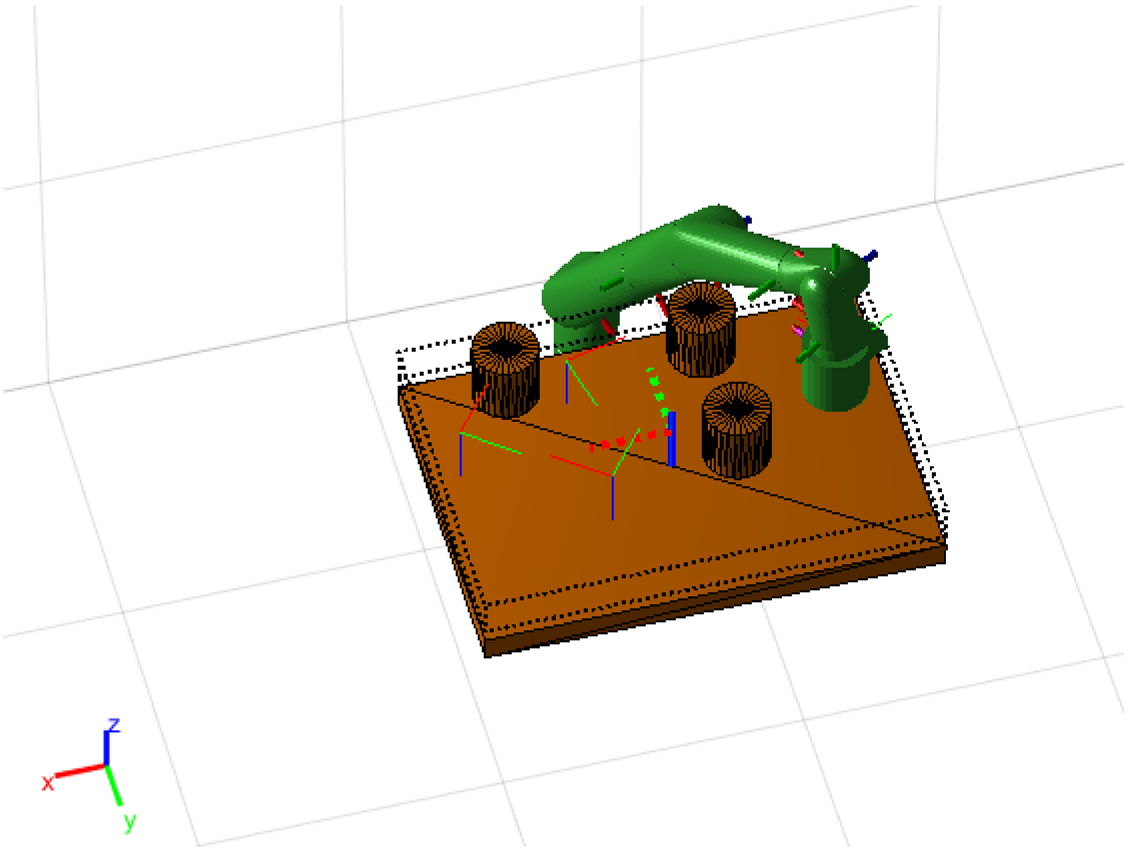
```
disp(string(validPoses'))
```

```
    "3"    "5"    "7"    "10"
```

Visualize A Singe Valid Pose

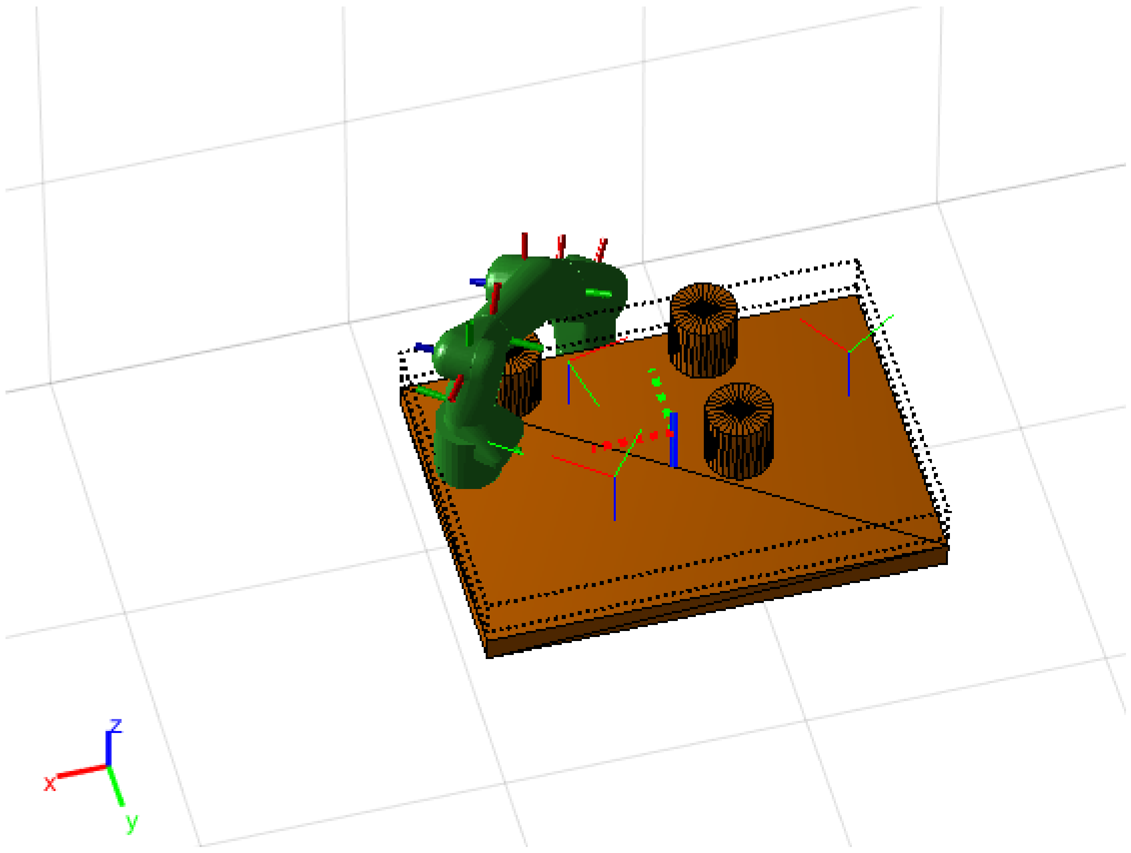
Plot all valid poses as transforms. The final valid configuration from checking collisions is still visible in the figure.

```
translations = tform2trvec(poses(:,:,validPoses));
rotations = tform2quat(poses(:,:,validPoses));

plotTransforms(translations,rotations,"FrameSize",0.1)
```



Show a valid configuration from the list. Change the index in `validPoses` to look at different poses. Call `hold off` to stop preserving figure elements. To manually inspect poses and configurations, comment out the final line when running.

```
poseIndex = validPoses(1);
show(robot,config{poseIndex},"PreservePlot",false,"Collisions","on","Visuals","off");
hold off
```



Input Arguments

goalRegion — Workspace goal region
workspaceGoalRegion object

Workspace goal region, specified as a `workspaceGoalRegion` object.

numSamples — Number of samples
positive integer

Number of samples, specified as a positive integer

Output Arguments

eePose — Poses sampled within workspace bounds
4-by-4 homogeneous transform matrix | four-by-four-by-*n* array

Poses sampled within the workspace bounds in the world frame, returned as a four-by-four homogeneous transformation matrix or 4-by-4-by-*n* array, where *n* is the number of samples `numSamples`.

The function returns a pose uniformly sampled within the Bounds property relative to the reference frame and applies the following transformations based on the ReferencePose and EndEffectorOffsetPose properties:

```
tSample = rand(6,2);
Tw0 = goalRegion.ReferencePose;
TeW = goalRegion.EndEffectorOffsetPose;
eePose = Tw0 * tSample * TeW;
```

Data Types: `double`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using MATLAB® Coder™.

See Also
`workspaceGoalRegion` | `manipulatorRRT` | `show`

Introduced in R2021a

show

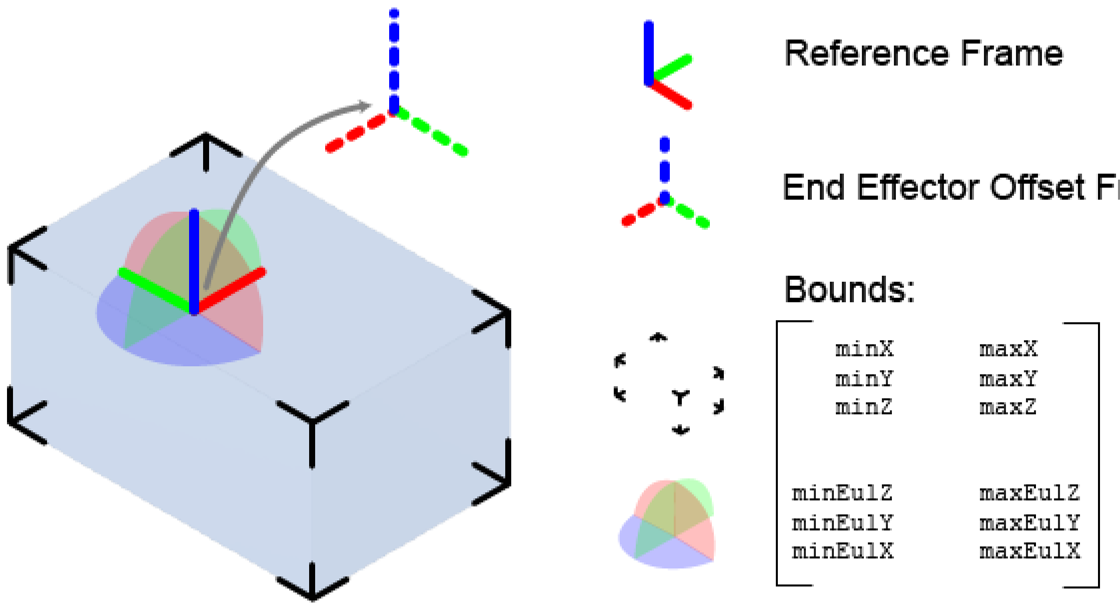
Visualize workspace bounds, reference frame, and offset frame

Syntax

```
show(goalRegion)
show(goalRegion,"Parent",axesHandle)
ax = show( ___ )
```

Description

`show(goalRegion)` plots the position and orientation bounds of the workspace goal region. The function also displays the reference frame and end-effector offset frame.



`show(goalRegion,"Parent",axesHandle)` specifies the parent axes on which to plot the workspace goal region.

`ax = show( ___ )` returns the axes handle that contains the workspace goal region plot using the input arguments from previous syntaxes.

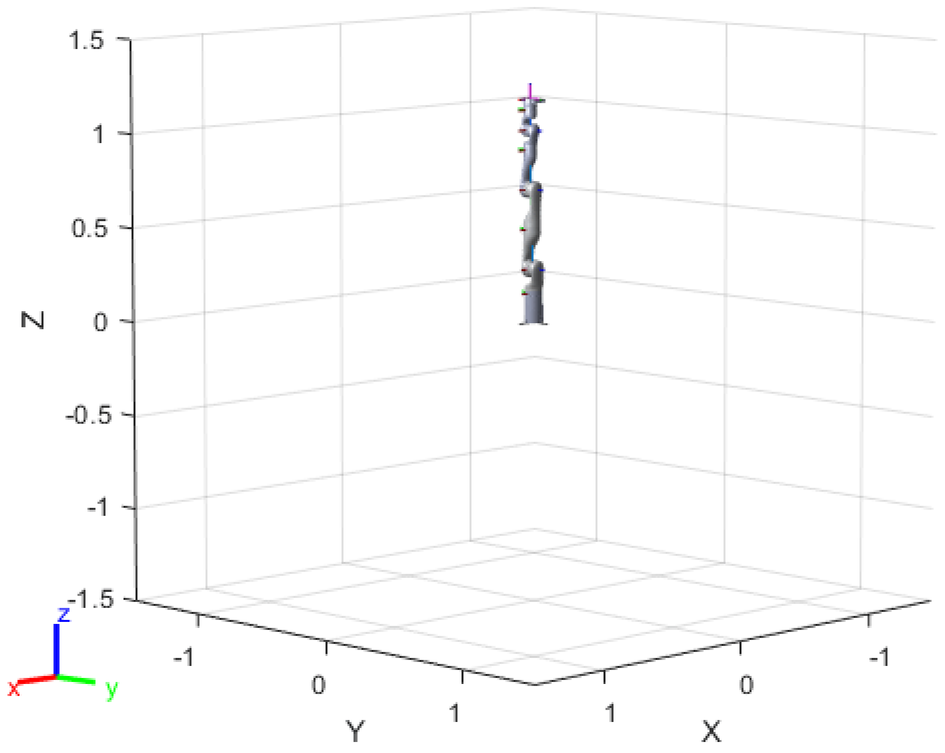
Examples

Plan Path To A Workspace Goal Region

Specify a goal region in your workspace and plan a path within those bounds. The `workspaceGoalRegion` object defines the bounds on the XYZ-position and ZYX Euler orientation of the robot end effector. The `manipulatorRRT` object plans a path based on that goal region and samples random poses within the bounds.

Load an existing robot model as a `rigidBodyTree` object.

```
robot = loadrobot("kinovaGen3", "DataFormat", "row");
ax = show(robot);
```



Create Path Planner

Create a rapidly-exploring random tree (RRT) path planner for the robot. This example uses an empty environment, but this workflow also works well with cluttered environments. You can add collision objects to the environment like the `collisionBox` or `collisionMesh` object.

```
planner = manipulatorRRT(robot,{});
```

Define Goal Region

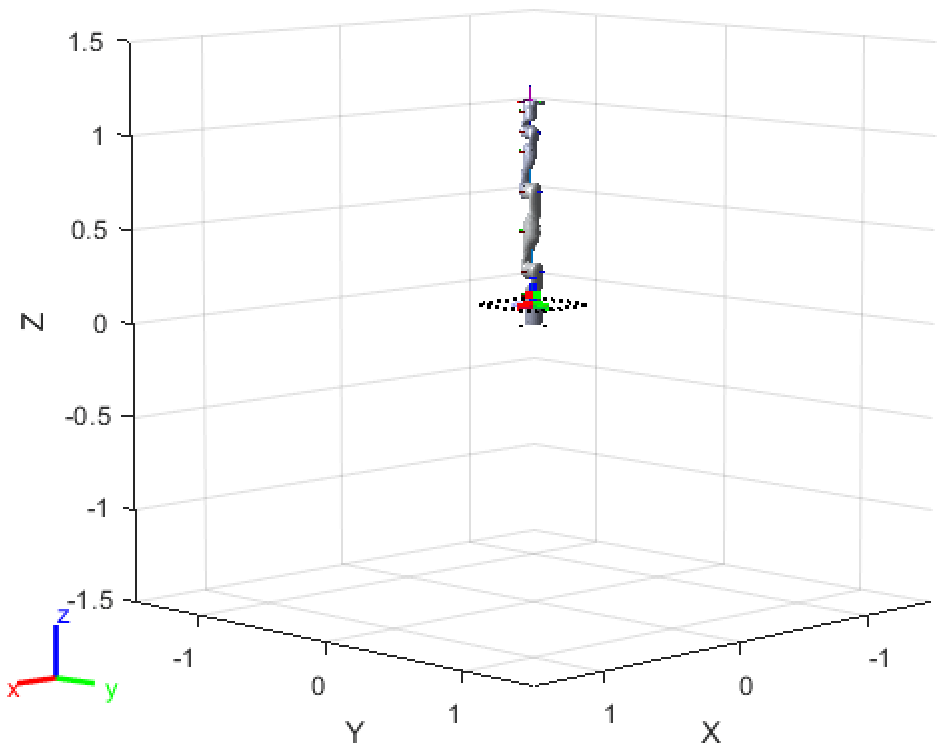
Create a workspace goal region using the end-effector body name of the robot.

Define the goal region parameters for your workspace. The goal region includes a reference pose, XYZ-position bounds, and orientation limits on the ZYX Euler angles. This example specifies bounds on the XY-plane in meters and allows rotation about the Z-axis in radians.

```
goalRegion = workspaceGoalRegion(robot.BodyNames{end});
goalRegion.ReferencePose = trvec2tform([0.5 0.5 0.2]);
goalRegion.Bounds(1, :) = [-0.2 0.2];    % X Bounds
goalRegion.Bounds(2, :) = [-0.2 0.2];     % Y Bounds
goalRegion.Bounds(4, :) = [-pi/2 pi/2];  % Rotation about the Z-axis
```

You can also apply a fixed offset to all poses sampled within the region. This offset can account for grasping tools or variations in dimensions within your workspace. For this example, apply a fixed transformation that places the end effector 5 cm above the workspace.

```
goalRegion.EndEffectorOffsetPose = trvec2tform([0 0 0.05]);
hold on
show(goalRegion);
```



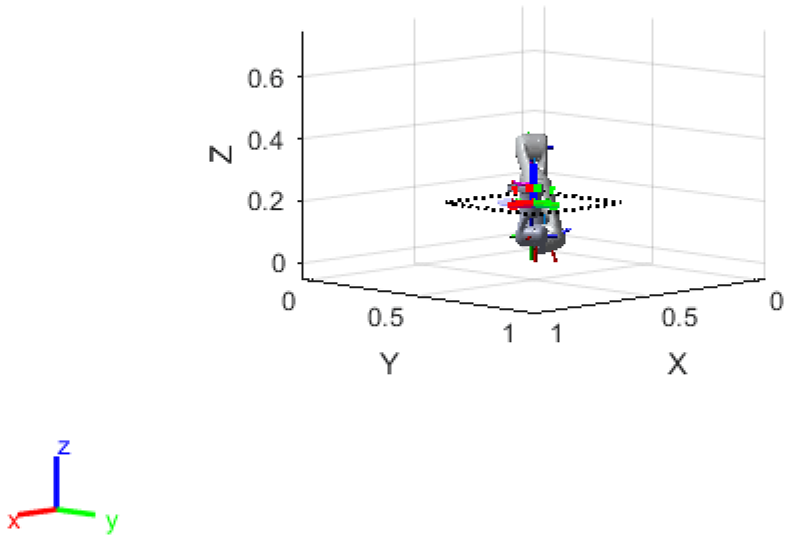
Plan Path To Goal Region

Plan a path to the goal region from the robot's home configuration. Due to the randomness in the RRT algorithm, this example sets the `rng` seed to ensure repeatable results.

```
rng(0)
path = plan(planner,homeConfiguration(robot),goalRegion);
```

Show the robot executing the path. To visualize a more realistic path, interpolate points between path configurations.

```
interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot,interpConfigurations(i,:),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1],...
        'CameraViewAngle',5)
    drawnow
end
hold off
```



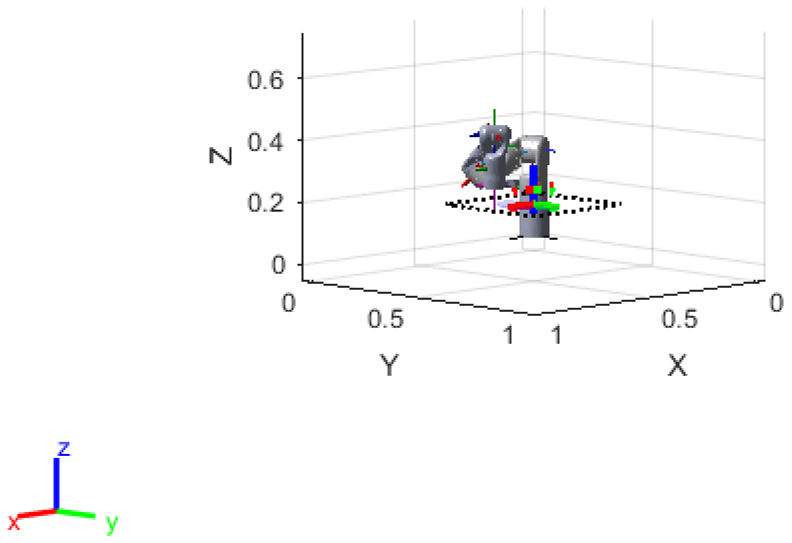
Adjust End-effector Pose

Notice that the robot arm approaches the workspace from the bottom. To flip the orientation of the final position, add a `pi` rotation to the Y-axis for the reference pose.

```
goalRegion.EndEffectorOffsetPose = ...
    goalRegion.EndEffectorOffsetPose*eul2tform([0 pi 0],"ZYX");
```

Replan the path and visualize the robot motion again. The robot now approaches from the top.

```
hold on
show(goalRegion);
path = plan(planner,homeConfiguration(robot),goalRegion);

interpConfigurations = interpolate(planner,path,5);

for i = 1 : size(interpConfigurations)
    show(robot, interpConfigurations(i, :),"PreservePlot",false);
    set(ax,'ZLim',[-0.05 0.75],'YLim',[-0.05 1],'XLim',[-0.05 1])
    drawnow;
end
hold off
```



Input Arguments

goalRegion — Workspace goal region
`workspaceGoalRegion` object

Workspace goal region, specified as a `workspaceGoalRegion` object.

Output Arguments

ax — Axes that contains the workspace goal region
`Axes` object

Axes that contains the workspace goal region, returned as an `axes` object.

See Also

`workspaceGoalRegion` | `manipulatorRRT` | `sample`

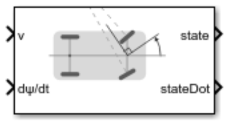
Introduced in R2021a

Blocks

Ackermann Kinematic Model

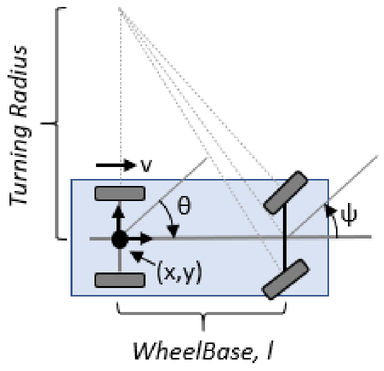
Car-like vehicle motion using Ackermann kinematic model

Library: Robotics System Toolbox / Mobile Robot Algorithms



Description

The Ackermann Kinematic Model block creates a car-like vehicle model that uses Ackermann steering. This model represents a vehicle with two axles separated by the distance, `Wheel base`. The state of the vehicle is defined as a four-element vector, [*x y θ ψ*], with an global *xy*-position, vehicle heading, *θ*, and steering angle, *ψ*. The vehicle heading and *xy*-position are defined at the center of the rear axle. Angles are specified in radians and the global positions are specified in meters. The steering input for the vehicle is given as `dψ/dt`, in radians per second.



Ports

Input

v — Vehicle speed
numeric scalar

Vehicle speed, specified in meters per second.

`dψ/dt` — Steering angular velocity
numeric scalar

Steering angular velocity of the vehicle, specified in radians per second.

Output

`state` — State of vehicle
four-element vector

Current *xy*-position, orientation, and steering angle, specified as [*x y θ ψ*], in meters and radians.

`stateDot` — Derivatives of `state` output
four-element vector

The linear and angular velocities of the vehicle, specified as a [*xDot yDot thetaDot psiDot*] vector in meters per second and radians per second. The linear and angular velocities are calculated by taking the time derivatives of the `state` output.

Parameters

`Wheel base` — Distance between front and rear axles
`1` (default) | positive numeric scalar

The wheel base refers to the distance between the front and rear vehicle axles, specified in meters.

`Vehicle speed range` — Minimum and maximum vehicle speeds
`[-Inf Inf]` (default) | two-element vector

The wheel speed range is a two-element vector that provides the minimum and maximum vehicle wheel speeds, [*MinSpeed MaxSpeed*], specified in radians per second.

`Maximum steering angle` — Distance between front and rear axles
`pi/4` (default) | positive numeric scalar

The maximum steering angle, refers to the maximum amount the vehicle can be steered to the right or left, specified in radians. The default value is `pi/4`.

`Initial state` — Initial state of vehicle
`[0;0;0;0]` (default) | four-element vector

The initial *x*-, *y*-position, heading angle, *theta*, and steering angle, *psi*, of the vehicle.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. For more information, see “Simulation Modes” (Simulink).
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change.

Tunable: No

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control*. 1st ed. Cambridge, MA: Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Bicycle Kinematic Model | Differential Drive Kinematic Model | Unicycle Kinematic Model

Classes
`ackermannKinematics`

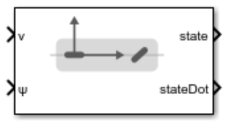
Topics
“Mobile Robot Kinematics Equations”

Introduced in R2019b

Bicycle Kinematic Model

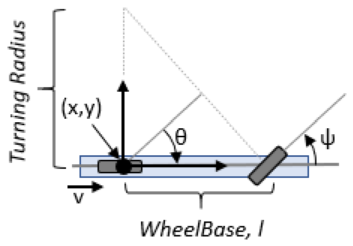
Compute car-like vehicle motion using bicycle kinematic model

Library: Robotics System Toolbox / Mobile Robot Algorithms



Description

The Bicycle Kinematic Model block creates a bicycle vehicle model to simulate simplified car-like vehicle dynamics. This model represents a vehicle with two axles defined by the length between the axles, `Wheel base`. The front wheel can be turned with steering angle `psi`. The vehicle heading `theta` is defined at the center of the rear axle.



Ports

Input

v — Vehicle speed
numeric scalar

Vehicle speed, specified in meters per second.

`psi` — Steering angle
numeric scalar

Steering angle of the vehicle, specified in radians.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Vehicle Speed & Steering Angle`.

omega — Steering angular velocity
numeric scalar

Angular velocity of the vehicle, specified in radians per second. A positive value steers the vehicle left and negative values steer the vehicle right.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Vehicle Speed & Heading Angular Velocity`.

Output

`state` — Pose of vehicle
three-element vector

Current *xy*-position and orientation of the vehicle, specified as a *[x y theta]* vector in meters and radians.

`stateDot` — Derivatives of `state` output
three-element vector

The linear and angular velocities of the vehicle, specified as a *[xDot yDot thetaDot]* vector in meters per second and radians per second. The linear and angular velocities are calculated by taking the derivative of the `state` output.

Parameters

`Vehicle inputs` — Type of speed and directional inputs for vehicle
`Vehicle Speed & Steering Angle` (default) | `Vehicle Speed & Heading Angular Velocity`

placeholder.

- `Vehicle Speed & Steering Angle` — Vehicle speed in meters per second with a steering angle in radians.
- `Vehicle Speed & Heading Angular Velocity` — Vehicle speed in meters per second with a heading angular velocity in radians per second.

`Wheel base` — Distance between front and rear axles
`1` (default) | positive numeric scalar

The wheel base refers to the distance between the front and rear vehicle axles, specified in meters.

`Vehicle speed range` — Minimum and maximum vehicle speeds
`[-Inf Inf]` (default) | two-element vector

The wheel speed range is a two-element vector that provides the minimum and maximum vehicle wheel speeds, [*MinSpeed MaxSpeed*], specified in radians per second.

`Maximum steering angle` — Max turning radius
`pi/4` (default) | numeric scaler

The maximum steering angle, refers to the maximum amount the vehicle can be steered to the right or left, specified in radians. The default value, `pi/4` provides the vehicle with minimum turning radius, `0`. This property is used to validate the user-provided state input.

`Initial state` — Initial pose of vehicle
`[0;0;0]` (default) | three-element vector

The initial *x*-, *y*-position and orientation, *theta*, of the vehicle.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. For more information, see “Simulation Modes” (Simulink).
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change.

Tunable: No

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control* 1st ed. Cambridge, MA: Cambridge University Press, 2017.

[2] Corke, Peter I. *Robotics, Vision and Control: Fundamental Algorithms in MATLAB*. Springer, 2011.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Ackermann Kinematic Model | Differential Drive Kinematic Model | Unicycle Kinematic Model

Classes
`bicycleKinematics`

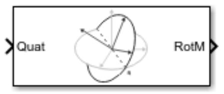
Topics
“Simulate Different Kinematic Models for Mobile Robots”
“Mobile Robot Kinematics Equations”

Introduced in R2019b

Coordinate Transformation Conversion

Convert to a specified coordinate transformation representation

Library: Robotics System Toolbox / Utilities
Navigation Toolbox / Utilities
ROS Toolbox / Utilities
UAV Toolbox / Utilities



Description

The Coordinate Transformation Conversion block converts a coordinate transformation from the input representation to a specified output representation. The input and output representations use the following forms:

- Axis-Angle (`AxAng`) – `[x y z theta]`
- Euler Angles (`Eul`) – `[z y x]`, `[z y z]`, or `[x y z]`
- Homogeneous Transformation (`TForm`) – 4-by-4 matrix
- Quaternion (`Quat`) – `[w x y z]`
- Rotation Matrix (`RotM`) – 3-by-3 matrix
- Translation Vector (`TrVec`) – `[x y z]`

All vectors must be **column vectors**.

To accommodate representations that only contain position or orientation information (`TrVec` or `Eul`, for example), you can specify two inputs or outputs to handle all transformation information. When you select the Homogeneous Transformation as an input or output, an optional `Show TrVec input/output port` parameter can be selected on the block mask to toggle the multiple ports.

Ports

Input

`Input transformation` — Coordinate transformation

column vector | 3-by-3 matrix | 4-by-4 matrix

Input transformation, specified as a coordinate transformation. The following representations are supported:

- Axis-Angle (`AxAng`) – `[x y z theta]`
- Euler Angles (`Eul`) – `[z y x]`, `[z y z]`, or `[x y z]`
- Homogeneous Transformation (`TForm`) – 4-by-4 matrix
- Quaternion (`Quat`) – `[w x y z]`
- Rotation Matrix (`RotM`) – 3-by-3 matrix

- Translation Vector (`TrVec`) – `[x y z]`

All vectors must be **column vectors**.

To accommodate representations that only contain position or orientation information (`TrVec` or `Eul`, for example), you can specify two inputs or outputs to handle all transformation information. When you select the Homogeneous Transformation as an input or output, an optional `Show TrVec input/output port` parameter can be selected on the block mask to toggle the multiple ports.

`TrVec` — Translation vector

3-element column vector

Translation vector, specified as a 3-element column vector, `[x y z]`, which corresponds to a translation in the *x*, *y*, and *z* axes respectively. This port can be used to input or output the translation information separately from the rotation vector.

Dependencies

You must select Homogeneous Transformation (`TForm`) for the opposite transformation port to get the option to show the additional `TrVec` port. Enable the port by clicking `Show TrVec input/output port`.

Output Arguments

`Output transformation` — Coordinate transformation

column vector | 3-by-3 matrix | 4-by-4 matrix

Output transformation, specified as a coordinate transformation with the specified representation. The following representations are supported:

- Axis-Angle (`AxAng`) – `[x y z theta]`
- Euler Angles (`Eul`) – `[z y x]`, `[z y z]`, or `[x y z]`
- Homogeneous Transformation (`TForm`) – 4-by-4 matrix
- Quaternion (`Quat`) – `[w x y z]`
- Rotation Matrix (`RotM`) – 3-by-3 matrix
- Translation Vector (`TrVec`) – `[x y z]`

To accommodate representations that only contain position or orientation information (`TrVec` or `Eul`, for example), you can specify two inputs or outputs to handle all transformation information. When you select the Homogeneous Transformation as an input or output, an optional `Show TrVec input/output port` parameter can be selected on the block mask to toggle the multiple ports.

`TrVec` — Translation vector

three-element column vector

Translation vector, specified as a three-element column vector, `[x y z]`, which corresponds to a translation in the *x*, *y*, and *z* axes respectively. This port can be used to input or output the translation information separately from the rotation vector.

Dependencies

You must select Homogeneous Transformation (`TForm`) for the opposite transformation port to get the option to show the additional `TrVec` port. Enable the port by clicking `Show TrVec input/output port`.

Parameters

`Representation` — Input or output representation
`Axis-Angle` | `Euler Angles` | `Homogeneous Transformation` | `Rotation Matrix` | `Translation Vector` | `Quaternion`

Select the representation for both the input and output port for the block. If you are using a transformation with only orientation information, you can also select the `Show TrVec input/output port` when converting to or from a homogeneous transformation.

`Axis rotation sequence` — Order of Euler angle axis rotations
`ZYX` (default) | `ZYZ` | `XYZ`

Order of the Euler angle axis rotations, specified as `ZYX`, `ZYZ`, or `XYZ`. The order of the angles in the input or output port `Eul` must match this rotation sequence. The default order `ZYX` specifies an orientation by:

- Rotating about the initial *z*-axis
- Rotating about the intermediate *y*-axis
- Rotating about the second intermediate *x*-axis

Dependencies

You must select `Euler Angles` for the `Representation` input or output parameter. The axis rotation sequence only applies to Euler angle rotations.

`Show TrVec input/output port` — Toggle `TrVec` port
off (default) | on

Toggle the `TrVec` input or output port when you want to specify or receive a separate translation vector for position information along with an orientation representation.

Dependencies

You must select Homogeneous Transformation (`TForm`) for the opposite transformation port to get the option to show the additional `TrVec` port.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

`axang2quat` | `eul2tform` | `trvec2tform`

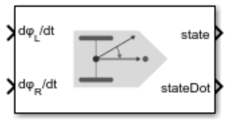
Topics
“Coordinate Transformations in Robotics”

Introduced in R2017b

Differential Drive Kinematic Model

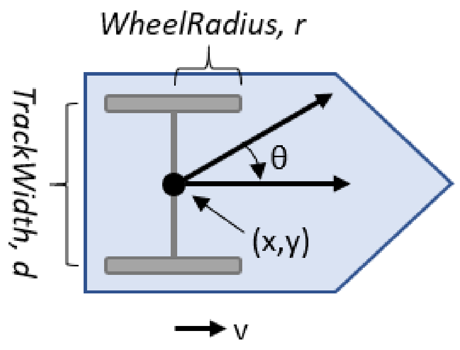
Compute vehicle motion using differential drive kinematic model

Library: Robotics System Toolbox / Mobile Robot Algorithms



Description

The Differential Drive Kinematic Model block creates a differential-drive vehicle model to simulate simplified vehicle dynamics. This model approximates a vehicle with a single fixed axle and wheels separated by a specified track width `Track width`. Each of the wheels can be driven independently using speed inputs, $d\phi_L/dt$ and $d\phi_R/dt$, for the left and right wheels respectively. Vehicle speed and heading is defined from the axle center.



Ports

Input

$d\phi_L/dt$ — Left wheel speed
numeric scalar

Left wheel speed of the vehicle, specified in radians per second.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Wheel Speeds`.

$d\phi_R/dt$ — Right wheel speed
numeric scalar

Right wheel speed of the vehicle, specified in radians per second.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Wheel Speeds`.

`v` — Vehicle speed
numeric scalar

Vehicle speed, specified in meters per second.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Vehicle Speed & Heading Angular Velocity`.

`ω` — Angular velocity of vehicle
numeric scalar

Angular velocity of the vehicle, specified in radians per second. A positive value steers the vehicle left and negative values steer the vehicle right.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Vehicle Speed & Heading Angular Velocity`.

Output

`state` — Pose of vehicle
three-element vector

Current position and orientation of the vehicle, specified as a [*x y theta*] vector in meters and radians.

`stateDot` — Derivatives of `state` output
three-element vector

The current linear and angular velocities of the vehicle specified as a [*xDot yDot thetaDot*] vector in meters per second and radians per second. The linear and angular velocities are calculated by taking the derivative of the `state` output.

Parameters

`Vehicle inputs` — Type of speed and directional inputs for vehicle
`Wheel Speeds` (default) | `Vehicle Speed & Heading Angular Velocity`

The format of the model input commands

- `Wheel Speeds` — Angular speeds of the two wheels in radians per second.
- `Vehicle Speed & Heading Angular Velocity` — Vehicle speed in meters per second with a heading angular velocity in radians per second.

`Wheel radius` — Wheel radius of vehicle
`0.05` (default) | positive numeric scalar

The radius of the wheels on the vehicle, specified in meters.

`Wheel speed range` — Minimum and maximum vehicle speeds
`[-Inf Inf]` (default) | two-element vector

The wheel speed range is a two-element vector that provides the minimum and maximum vehicle wheel speeds, [*MinSpeed MaxSpeed*], specified in radians per second.

`Track width` — Track length of vehicle from wheel to wheel
`0.2` (default) | numeric scalar

Length of the track from the left wheel to right wheel, specified in meters.

`Initial state` — Initial pose of the vehicle
`[0;0;0]` (default) | three-element vector

The initial *xy*-position and orientation, θ, of the vehicle.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. For more information, see “Simulation Modes” (Simulink).
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change.

Tunable: No

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control* 1st ed. Cambridge, MA: Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Ackermann Kinematic Model | Bicycle Kinematic Model | Unicycle Kinematic Model

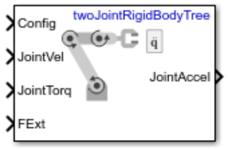
Classes
`differentialDriveKinematics`

Topics
“Control a Differential Drive Robot in Gazebo with Simulink”

Introduced in R2019b

Forward Dynamics

Joint accelerations given joint torques and states
Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Forward Dynamics block computes joint accelerations for a robot model given a robot state that is made up of joint torques, joint states, and external forces. To get the joint accelerations, specify the robot configuration (joint positions), joint velocities, applied torques, and external forces.

Specify the robot model in the **Rigid body tree** parameter as a `rigidBodyTree` object, and set the Gravity property on the object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

`JointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom (number of nonfixed joints) of the robot.

`JointTorq` — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

`FExt` — External force matrix
6-by-*n* matrix

External force matrix, specified as a 6-by-*n* matrix, where *n* is the number of bodies in the robot model. The matrix contains nonzero values in the rows corresponding to specific bodies. Each row is a vector of applied forces and torques that act as a wrench for that specific body. Generate this matrix using `externalForce` with a MATLAB Function block

Output

`JointAccel` — Joint accelerations
vector

Joint accelerations, returned as a vector. The number of joint accelerations is equal to the degrees of freedom of the robot.

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Inverse Dynamics | Get Jacobian | Gravity Torque | Joint Space Mass Matrix | Velocity Product Torque | Get Transform

Classes
`rigidBodyTree`

Functions
`forwardDynamics` | `importrobot` | `externalForce` | `homeConfiguration` | `randomConfiguration`

Topics
"Perform Safe Trajectory Tracking Control Using Robotics Manipulator Blocks"

Introduced in R2018a

Gazebo Apply Command

Send command to Gazebo simulator
Library: Robotics System Toolbox / Gazebo Co-Simulation

Cmd
cmd
Gazebo
Apply Link Wrench

Description

The Apply Command block sends commands to a Gazebo simulation. The block accepts a command message, input as a bus signal, and sends the command to the Gazebo server.

To send command messages, connect to a Gazebo simulation. Open the block mask and click **Configure Gazebo network and simulation settings**.

This block is part of a co-simulation interface between MATLAB and Gazebo for exchanging data and sending commands. To see a basic example, check “Perform Co-Simulation between Simulink and Gazebo”.

Limitations

- Models that use this block do not support Code Generation or Rapid Accelerator mode.

Ports

Input

`Cmd` — Gazebo Command
bus

Gazebo command message, specified as a bus. The command is an instruction for a specified model link or joint. Specify the model name as part of the bus signal using the Gazebo Select Entity block.

There are seven different command types with specific fields:

- `ApplyLinkWrench`:
  - `model_name` -- Variable-size `uint8` array representing the name of the model in the Gazebo simulator. You can specify this field using the Gazebo Select Entity block.
  - `link_name` -- Variable-size `uint8` array representing the name of the link in the model in the Gazebo simulator. You can specify this field using the Gazebo Select Entity block.
  - `force_type` -- Variable-size `uint8` array specified as `'SET'` or `'ADD'`. `'SET'` overwrites any existing force command for the specified duration. `'ADD'` adds the value with existing commands.
  - `Fx, fy, fz` -- `double` values specifying the amount of force applied to the Gazebo model link in world coordinates and Newtons.

  - `torque_type` –– Variable-size `uint8` array specified as `'SET'` or `'ADD'`. `'SET'` overwrites any existing torque command for the specified duration. `'ADD'` adds the value with existing commands.
  - `Tx, ty, tz` –– `double` values specifying the amount of torque applied to the Gazebo model link in world coordinates and Newton-meters.
  - `duration` –– Bus containing seconds and nanoseconds as `double` integers, which specify how long to apply the torque in simulation time.

- `ApplyJointTorque`:

  - `model_name` –– Variable-size `uint8` array representing the name of the model in the Gazebo simulator. You can specify this field using the Gazebo Select Entity block.
  - `joint_name` –– Variable-size `uint8` array representing the name of the joint in the model in the Gazebo simulator. You can specify this field using the Gazebo Select Entity block.
  - `index` –– `uint32` integer that identifies which joint axis the torque should be applied to.
  - `effort` –– `double` scalar value specifying the amount of torque or force to apply to the joint.
  - `duration` –– Bus containing seconds and nanoseconds as `double` integers, which specify how long to apply the torque in simulation time.

- `SetLinkWorldPose` — Set world pose in Gazebo world for selected link of Gazebo model
- `SetLinkLinearVelocity` — Set linear velocity of selected link of Gazebo model
- `SetLinkAngularVelocity` — Set angular velocity of selected link of Gazebo model
- `SetJointPosition` — Set position (angle) of selected joint of Gazebo model
- `SetJointVelocity` — Set velocity of selected joint of Gazebo model

Data Types: `bus`

Parameters

`Command type` — Type of command
`ApplyLinkWrench` (default) | `ApplyJointTorque` | `SetLinkWorldPose` | `SetLinkLinearVelocity` | `SetLinkAngularVelocity` | `SetJointPosition` | `SetJointVelocity`

Click **Select** to get a list of command types available in Gazebo. The input `Cmd` must contain the correct command message structure that matches this type.

`Sample time` — Sampling time of input
`0.001` (default) | positive

Sample time indicates the interval which commands are sent to the Gazebo simulator.

See Also

Blocks
Gazebo Blank Message | Gazebo Pacer | Gazebo Read | Gazebo Select Entity

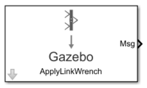
Topics
“Perform Co-Simulation between Simulink and Gazebo”
“Control a Differential Drive Robot in Gazebo with Simulink”

Introduced in R2019b

Gazebo Blank Message

Create blank Gazebo command

Library: Robotics System Toolbox / Gazebo Co-Simulation



Description

The Gazebo Blank Message block creates a blank Gazebo message or a command based on the specified type. The block output is a bus signal that contains the required elements for the type of command. Use a Bus Assignment block to modify specific fields in the bus signal. The bus signal initializes with zero value (ground).

This block is part of a co-simulation interface between MATLAB and Gazebo for exchanging data and sending commands. To see a basic example, check “Perform Co-Simulation between Simulink and Gazebo”.

Limitations

- Models that use this block do not support Code Generation or Rapid Accelerator mode.

Ports

Output

`Msg` — Blank message
bus

Blank message, output as a bus signal. with elements relevant to the specific `Message type`.

The `Msg` output always outputs the most recent message received.

Data Types: `bus`

Parameters

`Message type` — Type of message
`ApplyLinkWrench` (default) | `ApplyJointTorque` | `SetLinkWorldPose` | `SetLinkLinearVelocity` | `SetLinkAngularVelocity` | `SetJointPosition` | `SetJointVelocity`

Click **Select** to get a list of message types available in Gazebo.

`Sample time` — Sampling time of input
`0.001` (default) | positive

Sample time indicates when, during simulation, the block produces outputs and if appropriate, updates its internal state.

See Also

Blocks
Gazebo Apply Command | Gazebo Pacer | Gazebo Read | Gazebo Select Entity

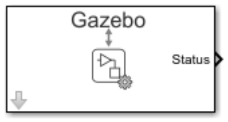
Topics
“Control a Differential Drive Robot in Gazebo with Simulink”

Introduced in R2019b

Gazebo Pacer

Settings for synchronized stepping between Gazebo and Simulink

Library: Robotics System Toolbox / Gazebo Co-Simulation



Description

The Gazebo Pacer block synchronizes the simulation times between Gazebo and Simulink. Synchronization is important for ensuring your Simulink model and the Gazebo simulation behave correctly. The block outputs a Boolean indicating successful synchronization. Synchronized stepping is only supported for one Gazebo simulation. Your entire model, including referenced models, can only contain one Gazebo Pacer block.

To ensure successful synchronization, connect to a Gazebo simulation. Open the block mask and click **Configure Gazebo network and simulation settings**.

Select the `Reset behavior` to reset the Gazebo simulation on model restart or only reset simulation time.

This block is part of a co-simulation interface between MATLAB and Gazebo for exchanging data and sending commands. To see a basic example, check "Perform Co-Simulation between Simulink and Gazebo".

Limitations

- Models that use this block do not support Code Generation or Rapid Accelerator mode.

Ports

Output

`Status` — Status of synchronization

0 | 1

Status of synchronization, output as either `0` or `1`. A value of `0` indicates successful time syncing. A value of `1` means the simulations are out of sync.

Data Types: `uint8`

Parameters

`Reset behavior` — Reset simulation time or scene

`Reset Gazebo simulation time` (default) | `Reset Gazebo simulation time and scene`

Select from the Reset behavior drop-down. Choose to reset the Gazebo simulator time only, or both the simulator time and scene.

`Sample time` — Sampling time of input
`0.001` (default) | positive

Set the Sample time parameter to step the Gazebo simulation at the given rate. This parameter must be a multiple of the maximum step size of the Gazebo solver.

See Also

Blocks
Gazebo Apply Command | Gazebo Blank Message | Gazebo Read | Gazebo Select Entity

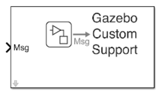
Topics
“Control a Differential Drive Robot in Gazebo with Simulink”

Introduced in R2019b

Gazebo Publish

Send custom messages to Gazebo server

Library: Robotics System Toolbox / Gazebo Co-Simulation



Description

The Gazebo Publish block sends custom messages to Gazebo server based on the topic and message type that the block specifies.

To send custom messages, connect to a Gazebo simulation. Open the block mask and click **Configure Gazebo network and simulation settings**.

This block is part of a co-simulation interface between MATLAB and Gazebo for exchanging data and sending commands.

Limitations

- Models that use this block do not support Code Generation or Rapid Accelerator mode.

Ports

Input

`Msg` — Gazebo custom message
bus

Gazebo custom message, specified as a bus signal, with elements relevant to the specific `Topic` and `Message type`.

Data Types: `bus`

Parameters

`Topic source` — Source for specifying topic
`From Gazebo` (default) | `Specify your own`

To get a topic from an existing Gazebo simulation, select `From Gazebo`. Click the **Select** button to see a list of available topics. To connect to a Gazebo simulation, click **Configure Gazebo network and simulation settings** in the block mask.

To enter a custom topic without an active Gazebo connection, select `Specify your own`. Use the `Topic` parameter to type the name of the message.

`Topic` — Topic name of custom message
`/my_topic` (default) | string

Topic name of custom message, specified as a string.

To get a topic from an existing Gazebo simulation, select `From Gazebo`. Click the **Select** button to see a list of available topics. To connect to a Gazebo simulation, click **Configure Gazebo network and simulation settings** in the block mask.

To specify a topic without connecting, select `Specify your own`.

`Message type` — Gazebo custom message type
`gazebo_msgs/TestPose` (default) | string

Click **Select** to get a list of message types available in Gazebo. If you choose your `Topic` from a connected Gazebo simulation, this parameter is set automatically.

`Sample time` — Sampling time of input
`0.001` (default) | positive

Sample time indicates the interval at which messages are sent to the Gazebo simulator.

See Also

`gazebogenmsg` | Gazebo Blank Message | Gazebo Subscribe

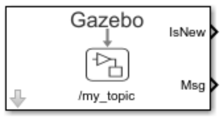
Topics
"Perform Co-Simulation between Simulink and Gazebo"

Introduced in R2020b

Gazebo Read

Receive messages from Gazebo server

Library: Robotics System Toolbox / Gazebo Co-Simulation



Description

The Gazebo Read block receives messages from the Gazebo server based on the topic and message type that the block specifies. The block outputs the latest message received as a bus signal, `Msg`, and a Boolean, `IsNew`, which indicates whether a message was received during the previous time step.

This block is part of a co-simulation interface between MATLAB and Gazebo for exchanging data and sending commands. To see a basic example, check “Perform Co-Simulation between Simulink and Gazebo”

Limitations

- Models that use this block do not support Code Generation or Rapid Accelerator mode.

Ports

Output

`IsNew` — Status of messages in the previous time step
`0` (default) | `1`

Status of the message received, output as a Boolean, which indicates whether the block output `Msg` was received in the previous time step.

Data Types: `Boolean`

`Msg` — Gazebo message
bus

Gazebo message, output as a bus signal, with elements relevant to the specific `Topic` and `Message type`.

The `Msg` output always outputs the most recent message received.

Data Types: `bus`

Parameters

`Topic source` — Source for specifying topic
`From Gazebo` (default) | `Specify your own`

To get a topic from an existing Gazebo simulation, select `From Gazebo`. Click the **Select** button to see a list of available topics. To connect to a Gazebo simulation, click **Configure Gazebo network and simulation settings** in the block mask.

To enter a custom topic without an active Gazebo connection, select `Specify your own`. Use the `Topic` parameter to type the name of the message.

`Topic` — Topic name of message
`/my_topic` (default) | string

Topic name of message, specified as a string.

To get a topic from an existing Gazebo simulation, select `From Gazebo`. Click the **Select** button to see a list of available topics. To connect to a Gazebo simulation, click **Configure Gazebo network and simulation settings** in the block mask.

To specify a topic without connecting, select `Specify your own`.

`Message type` — Gazebo message type
`gazebo_msgs/Pose` (default) | `gazebo_msgs/Image` | `gazebo_msgs/IMU` | `gazebo_msgs/LaserScan` | `gazebo_msgs/JointState` | `gazebo_msgs/LinkState`

Click **Select** to get a list of message types available in Gazebo. If you choose your `Topic` from a connected Gazebo simulation, this parameter is set automatically.

`Sample time` — Sampling time of input
`0.001` (default) | positive

Sample time indicates when, during simulation, the block produces outputs and if appropriate, updates its internal state.

See Also

Blocks
Gazebo Apply Command | Gazebo Blank Message | Gazebo Pacer | Gazebo Select Entity

Topics
“Control a Differential Drive Robot in Gazebo with Simulink”

Introduced in R2019b

Gazebo Select Entity

Select a Gazebo entity

Library: Robotics System Toolbox / Gazebo Co-Simulation

Gazebo
model
Joint
'model1/joint1'

Description

The Gazebo Select Entity block retrieves the model name of a Gazebo entity, such as a link or joint, from a simulated environment. The block outputs a string for both the model and associated joint or link name. Use both these names when specifying commands using the Gazebo Apply Command block.

Before selecting an entity, connect to a Gazebo simulation. Open the block mask and click **Configure Gazebo network and simulation settings**.

This block is part of a co-simulation interface between MATLAB and Gazebo for exchanging data and sending commands. To see a basic example, check “Perform Co-Simulation between Simulink and Gazebo”

Limitations

- Models that use this block do not support Code Generation or Rapid Accelerator mode.

Ports

Output

`model` — Model name of entity

`model1` (default) | string (`uint8[]`)

Model name of entity, output as string scalar. Strings are output as a variable-size `uint8` array for Gazebo.

Data Types: `uint8`

`Joint/Link` — Associated joint or link name of entity

joint1 (default) | string (`uint8[]`)

Associated joint or link, output as a string scalar. Strings are output as a `uint8` array for Gazebo.

Data Types: `uint8`

Parameters

`Model Name` — Choose model name

`'model1/joint1'` (default) | string scalar

Choose a model by clicking **Select**, which brings up a list of available names available on the Gazebo server. The block assumes you are already connected to a Gazebo simulation. If not, click **Configure Gazebo network and simulation settings** in the block mask.

`Output vector size upper bound` — Upper limit of output array
`128` (default)

Upper limit of the size of the output `uint8` arrays, `Model Name` and `Joint/Link`. Increase the upper bound when the names are longer than the default value `128`.

See Also

Blocks
Gazebo Apply Command | Gazebo Blank Message | Gazebo Pacer | Gazebo Read | Gazebo Select Entity

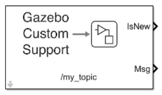
Topics
“Control a Differential Drive Robot in Gazebo with Simulink”

Introduced in R2019b

Gazebo Subscribe

Receive custom messages from Gazebo server

Library: Robotics System Toolbox / Gazebo Co-Simulation



Description

The Gazebo Subscribe block receives custom messages from Gazebo server based on the topic and message type that the block specifies. The block outputs the latest message received as a bus signal, `Msg`, and a Boolean, `IsNew`, which indicates whether a message was received during the previous time step.

To receive custom messages, connect to a Gazebo simulation. Open the block mask and click **Configure Gazebo network and simulation settings**.

This block is part of a co-simulation interface between MATLAB and Gazebo for exchanging data and sending commands.

Limitations

- Models that use this block do not support Code Generation or Rapid Accelerator mode.

Ports

Output

`IsNew` — Status of custom messages in the previous time step
`0` (default) | `1`

Status of the custom message received, output as a Boolean, which indicates whether the block output `Msg` was received in the previous time step.

Data Types: `Boolean`

`Msg` — Gazebo custom message
bus

Gazebo custom message, output as a bus signal, with elements relevant to the specific `Topic` and `Message type`.

The `Msg` output always outputs the most recent message received.

Data Types: `bus`

Parameters

`Topic source` — Source for specifying topic
`From Gazebo` (default) | `Specify your own`

To get a topic from an existing Gazebo simulation, select `From Gazebo`. Click the **Select** button to see a list of available topics. To connect to a Gazebo simulation, click **Configure Gazebo network and simulation settings** in the block mask.

To enter a custom topic without an active Gazebo connection, select `Specify your own`. Use the `Topic` parameter to type the name of the message.

`Topic` — Topic name of custom message
`/my_topic` (default) | string

Topic name of custom message, specified as a string.

To get a topic from an existing Gazebo simulation, select `From Gazebo`. Click the **Select** button to see a list of available topics. To connect to a Gazebo simulation, click **Configure Gazebo network and simulation settings** in the block mask.

To specify a topic without connecting, select `Specify your own`.

`Message type` — Gazebo custom message type
`gazebo_msgs/TestPose` (default) | string

Click **Select** to get a list of message types available in Gazebo. If you choose your `Topic` from a connected Gazebo simulation, this parameter is set automatically.

`Sample time` — Sampling time of input
`0.001` (default) | positive

Sample time indicates the interval at which messages are received from the Gazebo simulator.

See Also

`gazebogenmsg` | Gazebo Blank Message | Gazebo Publish

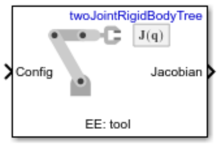
Topics
"Perform Co-Simulation between Simulink and Gazebo"

Introduced in R2020b

Get Jacobian

Geometric Jacobian for robot configuration

Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Get Jacobian block returns the geometric Jacobian relative to the base for the specified end effector at the given configuration of a `rigidBodyTree` robot model.

The Jacobian maps the joint-space velocity to the end-effector velocity relative to the base coordinate frame. The end-effector velocity equals:

$$V_{EE} = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \\ v_x \\ v_y \\ v_z \end{bmatrix} = J\dot{q} = J\begin{bmatrix} \dot{q}_1 \\ \vdots \\ \dot{q}_n \end{bmatrix}$$

ω is the angular velocity, υ is the linear velocity, and $\dot{q}$ is the joint-space velocity.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

`Jacobian` — Geometric Jacobian of end effector
6-by-*n* matrix

Geometric Jacobian of the end effector with the specified configuration, **Config**, returned as a 6-by-*n* matrix, where *n* is the number of degrees of freedom of the end effector. The Jacobian maps the joint-space velocity to the end-effector velocity relative to the base coordinate frame. The end-effector velocity equals:

$$V_{EE} = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \\ v_x \\ v_y \\ v_z \end{bmatrix} = J\dot{q} = J\begin{bmatrix} \dot{q}_1 \\ \vdots \\ \dot{q}_n \end{bmatrix}$$

ω is the angular velocity, υ is the linear velocity, and $\dot{q}$ is the joint-space velocity.

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`End effector` — End effector for Jacobian
body name

End effector for `Jacobian`, specified as a body name from the **Rigid body tree** robot model. To access body names from the robot model, click **Select body**.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Get Transform | Forward Dynamics | Inverse Dynamics | Gravity Torque | Joint Space Mass Matrix | Velocity Product Torque

Classes
`rigidBodyTree`

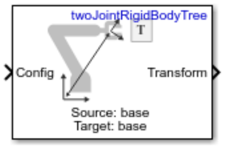
Functions
`geometricJacobian` | `importrobot` | `homeConfiguration` | `randomConfiguration`

Introduced in R2018a

Get Transform

Get transform between body frames

Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Get Transform block returns the homogeneous transformation between body frames on the **Rigid body tree** robot model. Specify a `rigidBodyTree` object for the robot model, and select a source and target body in the block.

The block uses **Config**, the robot configuration (joint positions) input, to calculate the transformation from the source body to the target body. This transformation is used to convert coordinates from the source to the target body. To convert to base coordinates, use the base body name as the **Target body** parameter.

Ports

Input

`Config` — Robot configuration

vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

`Transform` — Homogeneous transform

4-by-4 matrix

Homogeneous transform, returned as a 4-by-4 matrix.

Parameters

`Rigid body tree` — Robot model

`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`Target body` — Target body name
body name

Target body name, specified as a body name from the robot model specified in **Rigid body tree**. To access body names from the robot model, click **Select body**. The target frame is the coordinate system you want to transform points into.

`Source body` — Source body name
body name

Source body name, specified as a body name from the robot model specified in **Rigid body tree**.To access body names from the robot model, click **Select body**. The source frame is the coordinate system you want points transformed from.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Inverse Dynamics | Get Jacobian | Gravity Torque | Joint Space Mass Matrix | Velocity Product Torque

Classes
`rigidBodyTree`

Functions
`getTransform` | `importrobot` | `homeConfiguration` | `randomConfiguration`

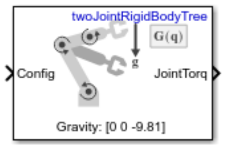
Topics
"Perform Safe Trajectory Tracking Control Using Robotics Manipulator Blocks"

Introduced in R2018a

Gravity Torque

Joint torques that compensate gravity

Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Gravity Torque block returns the joint torques required to hold the robot at a given configuration with the current Gravity setting on the **Rigid body tree** robot model.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

`JointTorq` — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Forward Dynamics | Inverse Dynamics | Get Jacobian | Joint Space Mass Matrix | Velocity Product Torque

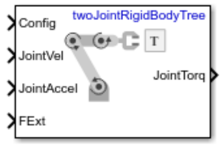
Classes
`rigidBodyTree`

Functions
`gravityTorque` | `importrobot` | `homeConfiguration` | `randomConfiguration`

Introduced in R2018a

Inverse Dynamics

Required joint torques for given motion
Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Inverse Dynamics block returns the joint torques required for the robot to maintain the specified robot state. To get the required joint torques, specify the robot configuration (joint positions), joint velocities, joint accelerations, and external forces.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

`JointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom (number of nonfixed joints) of the robot.

`JointAccel` — Joint accelerations
vector

Joint accelerations, specified as a vector. The number of joint accelerations is equal to the degrees of freedom of the robot.

`FExt` — External force matrix
6-by-*n* matrix

External force matrix, specified as a 6-by-*n* matrix, where *n* is the number of bodies in the robot model. The matrix contains nonzero values in the rows corresponding to specific bodies. Each row is a vector of applied forces and torques that act as a wrench for that specific body. Generate this matrix using `externalForce` with a MATLAB Function block

Output

`JointTorq` — Joint torques
vector

Joint torques, returned as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Parameters

`Rigid body tree` — Robot model

`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`Simulate using` — Type of simulation to run

`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Forward Dynamics | Get Jacobian | Gravity Torque | Joint Space Mass Matrix | Velocity Product Torque

Classes

`rigidBodyTree`

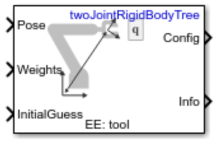
Functions

`inverseDynamics` | `externalForce` | `importrobot` | `homeConfiguration` | `randomConfiguration`

Introduced in R2018a

Inverse Kinematics

Compute joint configurations to achieve an end-effector pose
Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Inverse Kinematics block uses an inverse kinematic (IK) solver to calculate joint configurations for a desired end-effector pose based on a specified rigid body tree model. Create a rigid body tree model for your robot using the `rigidBodyTree` class. The rigid body tree model defines all the joint constraints that the solver enforces.

Specify the `RigidBodyTree` parameter and the desired end effector inside the block mask. You can also tune the algorithm parameters in the **Solver Parameters** tab.

Input the desired end-effector **Pose**, the **Weights** on pose tolerance, and an **InitialGuess** for the joint configuration. The solver outputs a robot configuration, **Config**, that satisfies the end-effector pose within the tolerances specified in the **Solver Parameters** tab.

Ports

Input

`Pose` — End-effector pose
4-by-4 homogeneous transform

End-effector pose, specified as a 4-by-4 homogeneous transform. This transform defines the desired position and orientation of the rigid body specified in the **End effector** parameter.

Data Types: `single` | `double`

`Weights` — Weights for pose tolerances
six-element vector

Weights for pose tolerances, specified as a six-element vector. The first three elements of the vector correspond to the weights on the error in orientation for the desired pose. The last three elements of the vector correspond to the weights on the error in the *xyz* position for the desired pose.

Data Types: `single` | `double`

`InitialGuess` — Initial guess of robot configuration
vector

Initial guess of robot configuration, specified as a vector of joint positions. The number of positions is equal to the number of nonfixed joints in the **Rigid body tree** parameter. Use this initial guess to help guide the solver to a desired robot configuration. However, the solution is not guaranteed to be close to this initial guess.

Data Types: `single` | `double`

Output

`Config` — Robot configuration solution
vector

Robot configuration that solves the desired end-effector pose, specified as a vector. A robot configuration is a vector of joint positions for the rigid body tree model. The number of positions is equal to the number of nonfixed joints in the **Rigid body tree** parameter.

Data Types: `single` | `double`

`Info` — Solution information
bus

Solution information, returned as a bus. The solution information bus contains these elements:

- `Iterations` — Number of iterations run by the algorithm.
- `PoseErrorNorm` — The magnitude of the error between the pose of the end effector in the solution and the desired end-effector pose.
- `ExitFlag` — Code that gives more details on the algorithm execution and what caused it to return. For the exit flags of each algorithm type, see “Exit Flags”.
- `Status` — Character vector describing whether the solution is within the tolerance (1) or is the best possible solution the algorithm could find (2).

Parameters

Block Parameters

`Rigid body tree` — Rigid body tree model
`twoJointRigidBodyTree` (default) | `rigidBodyTree` object

Rigid body tree model, specified as a `rigidBodyTree` object. Create the robot model in the MATLAB workspace before specifying in the block mask.

`End effector` — End-effector name
`'tool'` | `Select body`

End-effector name for desired pose. To see a list of bodies on the `rigidBodyTree` object, specify the **Rigid body tree** parameter, then click **Select body**.

`Show solution diagnostic outputs` — Enable info port
`on` (default) | `off`

Select to enable the **Info** port and get diagnostic info for the solver solution.

Solver Parameters

`Solver` — Algorithm for solving inverse kinematics
`'BFGSGradientProjection'` (default) | `'LevenbergMarquardt'`

Algorithm for solving inverse kinematics, specified as either `'BFGSGradientProjection'` or `'LevenbergMarquardt'`. For details of each algorithm, see “Inverse Kinematics Algorithms”.

`Enforce joint limits` — Enforce rigid body tree joint limits
`on` (default) | `off`

Select to enforce the joint limits specified in the **Rigid body tree** model.

`Maximum iterations` — Maximum number of iterations
`1500` (default) | positive integer

Maximum number of iterations to optimize the solution, specified as a positive integer. Increasing the number of iterations can improve the solution at the cost of execution time.

`Maximum time` — Maximum time
`10` (default) | positive scalar

Maximum number of seconds that the algorithm runs before timing out, specified as a positive scalar. Increasing the maximum time can improve the solution at the cost of execution time.

`Gradient tolerance` — Threshold on gradient of cost function
`1e-7` (default) | positive scalar

Threshold on the gradient of the cost function, specified as a positive scalar. The algorithm stops if the magnitude of the gradient falls below this threshold. A low gradient magnitude usually indicates that the solver has converged to a solution.

`Solution tolerance` — Threshold on pose error
`1e-6` (default) | positive scalar

Threshold on the magnitude of the error between the end-effector pose generated from the solution and the desired pose, specified as a positive scalar. The `Weights` specified for each component of the pose are included in this calculation.

`Step tolerance` — Minimum step size
`1e-14` (default) | positive scalar

Minimum step size allowed by the solver, specified as a positive scalar. Smaller step sizes usually mean that the solution is close to convergence.

`Error change tolerance` — Threshold on change in pose error
`1e-12` (default) | positive scalar

Threshold on the change in end-effector pose error between iterations, specified as a positive scalar. The algorithm returns if the changes in all elements of the pose error are smaller than this threshold.

Dependencies

This parameter is enabled when the **Solver** is `Levenberg-Marquadt`.

`Use error damping` — Enable error damping
`on` (default) | `off`

Select the check box to enable error damping, then specify the `Damping bias` parameter.

Dependencies

This parameter is enabled when the **Solver** is `Levenberg-Marquadt`.

`Damping bias` — Damping on cost function

0.0025 (default) | positive scalar

Damping on cost function, specified as a positive scalar. The Levenberg-Marquadt algorithm has a damping feature controlled by this scalar that works with the cost function to control the rate of convergence.

Dependencies

This parameter is enabled when the **Solver** is `Levenberg-Marquadt` and **Use error damping** is `on`.

`Simulate using` — Type of simulation to run

`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

References

[1] Badreddine, Hassan, Stefan Vandewalle, and Johan Meyers. "Sequential Quadratic Programming (SQP) for Optimal Control in Direct Numerical Simulation of Turbulent Flow." *Journal of Computational Physics*. 256 (2014): 1–16. doi:10.1016/j.jcp.2013.08.044.

[2] Bertsekas, Dimitri P. *Nonlinear Programming*. Belmont, MA: Athena Scientific, 1999.

[3] Goldfarb, Donald. "Extension of Davidon’s Variable Metric Method to Maximization Under Linear Inequality and Equality Constraints." *SIAM Journal on Applied Mathematics*. Vol. 17, No. 4 (1969): 739–64. doi:10.1137/0117067.

[4] Nocedal, Jorge, and Stephen Wright. *Numerical Optimization*. New York, NY: Springer, 2006.

[5] Sugihara, Tomomichi. "Solvability-Unconcerned Inverse Kinematics by the Levenberg–Marquardt Method." *IEEE Transactions on Robotics*. Vol. 27, No. 5 (2011): 984–91. doi:10.1109/tro.2011.2148230.

[6] Zhao, Jianmin, and Norman I. Badler. "Inverse Kinematics Positioning Using Nonlinear Programming for Highly Articulated Figures." *ACM Transactions on Graphics*. Vol. 13, No. 4 (1994): 313–36. doi:10.1145/195826.195827.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Objects
`rigidBodyTree` | `generalizedInverseKinematics` | `inverseKinematics`

Blocks
Get Transform | Inverse Dynamics

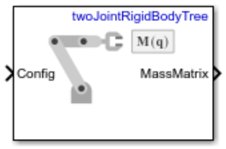
Topics
“Trajectory Control Modeling with Inverse Kinematics”
“Control PR2 Arm Movements Using ROS Actions and Inverse Kinematics”
“Inverse Kinematics Algorithms”

Introduced in R2018b

Joint Space Mass Matrix

Joint-space mass matrix for robot configuration

Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Joint Space Mass Matrix block returns the joint-space mass matrix for the given robot configuration (joint positions) for the **Rigid body tree** robot model.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

Output

`MassMatrix` — Joint-space mass matrix for configuration
positive-definite symmetric matrix

Joint-space mass matrix for the given robot configuration, returned as a positive-definite symmetric matrix.

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Forward Dynamics | Inverse Dynamics | Get Jacobian | Gravity Torque | Velocity Product Torque

Classes
`rigidBodyTree`

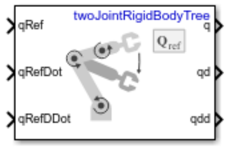
Functions
`massMatrix` | `importrobot` | `homeConfiguration` | `randomConfiguration`

Introduced in R2018a

Joint Space Motion Model

Model rigid body tree motion given joint-space inputs

Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Joint Space Motion Model block models the closed-loop joint-space motion of a manipulator robot, specified as a `rigidBodyTree` object. The motion model behavior is defined by the `Motion Type` parameter.

For more details about the equations of motion, see “Joint-Space Motion Model”.

Ports

Input

`qRef` — Joint positions

n-element vector

n-element vector representing the desired joint positions of radians, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter.

Dependencies

To enable this port, set the `Motion Type` parameter to `Computed Torque Control`, `PD Control`, or `Independent Joint Motion`.

`qRefDot` — Joint velocities

n-element vector

n-element vector representing the desired joint velocities of radians per second, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter.

Dependencies

To enable this port, set the `Motion Type` parameter to `Computed Torque Control`, or `Independent Joint Motion`.

`qRefDDot` — Joint accelerations

n-element vector

n-element vector representing the desired joint velocities of radians per second squared, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter.

Dependencies

To enable this port, set the `Motion Type` parameter to `Computed Torque Control`, `PD Control`, or `Independent Joint Motion`.

FExt — External forces acting on system
6-by-*m* matrix

A 6-by-*m* matrix of external forces for the *m* bodies in the `rigidBodyTree` object of the `Rigid body tree` parameter.

Dependencies

To enable this port, set the `Show external force input` parameter to `on`.

Output

q — Joint positions
n-element vector

Joint positions output as an *n*-element vector in radians or meters, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter.

qd — Joint velocities
n-element vector

Joint velocities output as an *n*-element vector in radians per second or meters per second, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter

qdd — Joint accelerations
n-element vector

Joint accelerations output as an *n*-element vector in radians per second squared or meters per second squared, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a manipulator with revolute joints and two degrees of freedom.

`Motion Type` — Type of motion computed by motion model
`Computed Torque Control` (default) | `Independent Joint Motion` | `PD Control` | `Open Loop Dynamics`

Type of motion, specified as a string scalar or character vector that defines the closed-loop joint-space behavior that the object models. Options are:

- `Computed Torque Control` — Compensates for full-body dynamics and assigns the error dynamics specified in the `Natural frequency` and `Damping ratio` parameters.
- `Independent Joint Motion` — Models each joint as an independent second order system using the error dynamics specified by the `Natural frequency` and `Damping ratio` parameters.
- `PD Control` — Uses proportional-derivative (PD) control on the joints based on the specified `Proportional gain` and `Derivative gain` parameters.

- `Open Loop Dynamics` — Disables inputs except for `FExt` if `Show external force input` is enabled. This is an open-loop configuration.

`Specification format` — Inputs to control robot
`Damping Ratio / Natural Frequency` (default) | `Step Response`

Inputs to control the robot system. Options are:

- `Damping Ratio / Natural Frequency` — Setting the natural frequency using the `Natural frequency` parameter of the system in Hz, and the damping ratio using the `Damping ratio` parameter.
- `Step Response` — Model at discrete time-steps with a fixed settling time and overshoot using the `Settling time` and the `Overshoot` parameters.

Dependencies

To enable this parameter, set the `Motion Type` parameter to `Computed Torque Control` or `Independent Joint Motion`.

`Damping ratio` — Damping ratio of system
`1` (default) | numeric scalar

Damping ratio use to decay system oscillations. A value of `1` results in no damping, whereas `0` fully dampens the system.

Dependencies

To enable this parameter, set the `Specification format` parameter to `Damping Ratio / Natural Frequency`.

`Natural frequency` — Natural frequency of system
`10` (default) | numeric scalar

Frequency of the system oscillations if unimpeded, specified in Hz.

Dependencies

To enable this parameter, set the `Specification format` parameter to `Damping Ratio / Natural Frequency`.

`Settling time` — Settling time of system
`0.59` (default) | numeric scalar

The time taken for each joint to reach steady state, measured in seconds.

Dependencies

To enable this parameter, set the `Specification format` parameter to `Step Response`.

`Overshoot` — System overshoot
`0.0` (default) | numeric scalar

The maximum value that the system exceeds the target position.

Dependencies

To enable this parameter, set the `Specification format` parameter to `Step Response`.

`Proportional gain` — Proportional gain for PD Control
`100` (default) | *n*-by-*n* matrix | scalar

Proportional gain for proportional-derivative (PD) control, specified as a scalar or *n*-by-*n* matrix, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter.

Dependencies

To enable this parameter, set the `Specification format` parameter to `PD Control`.

`Derivative gain` — Derivative gain for PD control
`10` (default) | *n*-by-*n* matrix | scalar

Derivative gain for proportional-derivative (PD) control, specified as a scalar or *n*-by-*n* matrix, where *n* is the number of nonfixed joints in the `rigidBodyTree` object of the `Rigid body tree` parameter

Dependencies

To enable this parameter, set the `Specification format` parameter to `PD Control`.

`Show external force input` — Display FExt port
`off` (default) | `on`

Enable this parameter to input external forces using the `FExt` port.

Dependencies

To enable this parameter, set the `Motion Type` parameter to `Computed Torque Control`, `PD Control`, or `Open Loop Dynamics`.

`Initial joint configuration` — Initial joint positions
`0` (default) | *n*-element vector | scalar

Initial joint positions, specified as a *n*-element vector or scalar in radians. *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

`Initial joint velocities` — Initial joint velocities
`0` (default) | *n*-element vector | scalar

Initial joint velocities, specified as a *n*-element vector or scalar in radians per second. *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. For more information, see “Simulation Modes” (Simulink).
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change.

Tunable: No

References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control*. Upper Saddle River, NJ: Pearson Education, 2005.

[2] Spong, Mark W., Seth Hutchinson, and Mathukumalli Vidyasagar. *Robot Modeling and Control*. Hoboken, NJ: Wiley, 2006.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

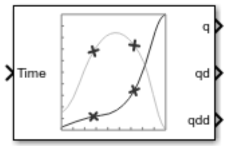
Blocks
Task Space Motion Model

Classes
`jointSpaceMotionModel` | `taskSpaceMotionModel`

Introduced in R2019b

Polynomial Trajectory

Generate polynomial trajectories through waypoints
Library: Robotics System Toolbox / Utilities



Description

The Polynomial Trajectory block generates trajectories to travel through waypoints at the given time points using either cubic, quintic, or B-spline polynomials. The block outputs positions, velocities, and accelerations for achieving this trajectory based on the **Time** input. For B-spline polynomials, the waypoints actually define the control points for the convex hull of the B-spline instead of the actual waypoints, but the first and last waypoint are still met.

The initial and final values are held constant outside the time period defined in **Time points**.

Ports

Input

`Time` — Time point along trajectory
scalar | vector

Time point along the trajectory, specified as a scalar or vector. In general, when specified as a scalar, this value is synced with simulation time and is used to specify the time point for sampling the trajectory. The block outputs a vector of the trajectory variables at that instant in time. If the time is specified as a vector, the block outputs a matrix with each column corresponding to each element of the vector.

Data Types: `single` | `double`

`Waypoints` — Waypoint positions along trajectory
n-by-*p* matrix

Positions of waypoints of the trajectory at given time points, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of waypoints. If you specify the **Method** as `B-spline`, these waypoints actually define the control points for the convex hull of the B-spline, but the first and last waypoint are still met.

Dependencies

To enable this input, set **Waypoint Source** to `External`.

`TimePoints` — Time points for waypoints of trajectory
p-element vector

Time points for waypoints of trajectory, specified as a *p*-element vector.

Dependencies

To enable this input, set **Waypoint Source** to `External`.

`VelBC` — Velocity boundary conditions for waypoints

n-by-*p* matrix

Velocity boundary conditions for waypoints, specified as an *n*-by-*p* matrix. Each row corresponds to the velocity at each of the *p* waypoints for the respective variable in the trajectory.

Dependencies

To enable this input, set **Method** to `Cubic Polynomial` or `Quintic Polynomial` and **Parameter Source** to `External`.

`AccelBC` — Acceleration boundary conditions for trajectory

n-by-*p* matrix

Acceleration boundary conditions for waypoints, specified as an *n*-by-*p* matrix. Each row corresponds to the acceleration at each of the *p* waypoints for the respective variable in the trajectory.

Dependencies

To enable this parameter, set **Method** to `Quintic Polynomial` and **Parameter Source** to `External`.

Output

q — Position of trajectory

scalar | vector | matrix

Position of the trajectory, specified as a scalar, vector, or matrix. If you specify a scalar for the **Time** input with an *n*-dimensional trajectory, the output is a vector with *n* elements. If you specify a vector of *m* elements for the **Time** input, the output is an *n*-by-*m* matrix.

Data Types: `single` | `double`

qd — Velocity of trajectory

scalar | vector | matrix

Velocity of the trajectory, specified as a scalar, vector, or matrix. If you specify a scalar for the **Time** input with an *n*-dimensional trajectory, the output is a vector with *n* elements. If you specify a vector of *m* elements for the **Time** input, the output is an *n*-by-*m* matrix.

Data Types: `single` | `double`

qdd — Acceleration of trajectory

scalar | vector | matrix

Acceleration of the trajectory, specified as a scalar, vector, or matrix. If you specify a scalar for the **Time** input with an *n*-dimensional trajectory, the output is a vector with *n* elements. If you specify a vector of *m* elements for the **Time** input, the output is an *n*-by-*m* matrix.

Data Types: `single` | `double`

Parameters

`Waypoint source` — Source for waypoints
`Internal` (default) | `External`

Specify `External` to specify the **Waypoints** and **Time points** parameters as block inputs instead of block parameters.

`Waypoints` — Waypoint positions along trajectory
n-by-*p* matrix

Positions of waypoints of the trajectory at given time points, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of waypoints. If you specify the **Method** as `B-spline`, these waypoints actually define the control points for the convex hull of the B-spline, but the first and last waypoint are still met.

Dependencies

To specify this parameter in the block mask, set **Waypoint Source** to `Internal`.

`Time points` — Time points for waypoints of trajectory
p-element vector

Time points for waypoints of trajectory, specified as a *p*-element vector, where *p* is the number of waypoints.

Dependencies

To specify this parameter in the block mask, set **Waypoint Source** to `Internal`.

`Method` — Method for trajectory generation
`Cubic Polynomial` (default) | `Quintic Polynomial` | `B-Spline`

Method for trajectory generation, specified as either `Cubic Polynomial`, `Quintic Polynomial`, or `B-Spline`.

`Parameter source` — Source for waypoints
`Internal` (default) | `External`

Specify `External` to specify the **Velocity boundary conditions** and **Acceleration boundary conditions** parameters as block inputs instead of block parameters.

`Velocity boundary conditions` — Velocity boundary conditions for waypoints
`zeroes(2,5)` (default) | *n*-by-*p* matrix

Velocity boundary conditions for waypoints, specified as an *n*-by-*p* matrix. Each row corresponds to the velocity at each of the *p* waypoints for the respective variable in the trajectory.

Dependencies

To enable this input, set **Method** to `Cubic Polynomial` or `Quintic Polynomial`.

`Acceleration boundary conditions` — Acceleration boundary conditions for trajectory
n-by-*p* matrix

Acceleration boundary conditions for waypoints, specified as an *n*-by-*p* matrix. Each row corresponds to the acceleration at each of the *p* waypoints for the respective variable in the trajectory.

Dependencies

To enable this parameter, set **Method** to `Quintic Polynomial`.

`Simulate using` — Type of simulation to run

`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

References

[1] Farin, Gerald E. *Curves and Surfaces for Computer Aided Geometric Design: A Practical Guide*. San Diego, CA: Academic Press, 1993.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Rotation Trajectory | Transform Trajectory | Trapezoidal Velocity Profile Trajectory

Functions

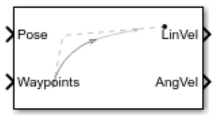
`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

Pure Pursuit

Linear and angular velocity control commands

Library:	Robotics System Toolbox / Mobile Robot Algorithms Navigation Toolbox / Control Algorithms



Description

The Pure Pursuit block computes linear and angular velocity commands for following a path using a set of waypoints and the current pose of a differential drive vehicle. The block takes updated poses to update velocity commands for the vehicle to follow a path along a desired set of waypoints. Use the **Max angular velocity** and **Desired linear velocity** parameters to update the velocities based on the performance of the vehicle.

The **Lookahead distance** parameter computes a look-ahead point on the path, which is an instantaneous local goal for the vehicle. The angular velocity command is computed based on this point. Changing **Lookahead distance** has a significant impact on the performance of the algorithm. A higher look-ahead distance results in a smoother trajectory for the vehicle, but can cause the vehicle to cut corners along the path. Too low of a look-ahead distance can result in oscillations in tracking the path, causing unstable behavior. For more information on the pure pursuit algorithm, see "Pure Pursuit Controller".

Input/Output Ports

Input

Pose — Current vehicle pose

`[x y theta]` vector

Current vehicle pose, specified as an `[x y theta]` vector, which corresponds to the *x*-*y* position and orientation angle, *theta*. Positive angles are measured counterclockwise from the positive *x*-axis.

`Waypoints` — Waypoints

[ ] (default) | *n*-by-2 array

Waypoints, specified as an *n*-by-2 array of `[x y]` pairs, where *n* is the number of waypoints. You can generate the waypoints using path planners like `mobileRobotPRM` or specify them as an array in Simulink.

Output

`LinVel` — Linear velocity

scalar in meters per second

Linear velocity, specified as a scalar in meters per second.

Data Types: `double`

`AngVel` — Angular velocity
scalar in radians per second

Angular velocity, specified as a scalar in radians per second.

Data Types: `double`

`TargetDir` — Target direction for vehicle
scalar in radians

Target direction for the vehicle, specified as a scalar in radians. The forward direction of the vehicle is considered zero radians, with positive angles measured counterclockwise. This output can be used as the input to the **TargetDir** port for the Vector Field Histogram block.

Dependencies

To enable this port, select the **Show TargetDir output port** parameter.

Parameters

`Desired linear velocity (m/s)` — Linear velocity
`0.1` (default) | scalar

Desired linear velocity, specified as a scalar in meters per second. The controller assumes that the vehicle drives at a constant linear velocity and that the computed angular velocity is independent of the linear velocity.

`Maximum angular velocity (rad/s)` — Angular velocity
`1.0` (default) | scalar

Maximum angular velocity, specified as a scalar in radians per second. The controller saturates the absolute angular velocity output at the given value.

`Lookahead distance (m)` — Look-ahead distance
`1.0` (default) | scalar

Look-ahead distance, specified as a scalar in meters. The look-ahead distance changes the response of the controller. A vehicle with a higher look-ahead distance produces smooth paths but takes larger turns at corners. A vehicle with a smaller look-ahead distance follows the path closely and takes sharp turns, but oscillate along the path. For more information on the effects of look-ahead distance, see “Pure Pursuit Controller”.

`Show TargetDir output port` — Target direction indicator
off (default) | on

Select this parameter to enable the **TargetDir** out port. This port gives the target direction as an angle in radians from the forward position, with positive angles measured counterclockwise.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Classes
`binaryOccupancyMap` | `occupancyMap` | `mobileRobotPRM`

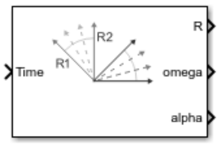
Topics
“Path Following for a Differential Drive Robot”
“Plan Path for a Differential Drive Robot in Simulink”
“Path Following with Obstacle Avoidance in Simulink®” (Navigation Toolbox)
“Pure Pursuit Controller”

Introduced in R2019b

Rotation Trajectory

Generate trajectory between two orientations

Library: Robotics System Toolbox / Utilities



Description

The Rotation Trajectory block generates an interpolated trajectory between two rotation matrices. The block outputs the rotation at the times given by the **Time** input, which can be a scalar or vector.

The trajectory is computed using quaternion spherical linear interpolation (SLERP) and finds the shortest path between points. Select the **Use custom time scaling** check box to compute using a custom time scaling. The block uses linear time scaling by default.

The initial and final values are held constant outside the time period defined in the **Time interval** parameter.

Ports

Input

`Time` — Time point along trajectory

scalar | vector

Time point along the trajectory, specified as a scalar or vector. In general, when specified as a scalar, this value is synced with simulation time and is used to specify the time point for sampling the trajectory. The block outputs a vector of the trajectory variables at that instant in time. If the time is specified as a vector, the block outputs a matrix with each column corresponding to each element of the vector.

Data Types: `single` | `double`

`R0` — Initial orientation

four-element quaternion vector | 3-by-3 rotation matrix

Initial orientation, specified as a four-element quaternion vector or 3-by-3 rotation matrix. The function generates a trajectory that starts at the initial orientation, **R0**, and goes to the final orientation, **RF**.

Example: `[1 0 0 0]'`

Dependencies

To enable this input, set the **Waypoint source** to `External`.

To specify quaternions, set **Rotation Format** parameter to `Quaternion`.

To specify rotation matrices, set **Rotation Format** parameter to `Rotation`.

Data Types: `single` | `double`

RF — Final orientation
four-element vector | 3-by-3 rotation matrix

Initial orientation, specified as a four-element vector or 3-by-3 rotation matrix. The function generates a trajectory that starts at the initial orientation, **R0**, and goes to the final orientation, **RF**.

Example: `[0 0 1 0]'`

Dependencies

To enable this input, set the **Waypoint source** to `External`.

To specify quaternions, set **Rotation Format** parameter to `Quaternion`.

To specify rotation matrices, set **Rotation Format** parameter to `Rotation`.

Data Types: `single` | `double`

`TimeInterval` — Start and end times for trajectory
two-element vector

Start and end times for the trajectory, specified as a two-element vector.

Example: `[0 10]`

Dependencies

To enable this input, set the **Waypoint source** to `External`.

Data Types: `single` | `double`

`TSTime` — Time scaling time points
scalar | *p*-element vector

Time scaling time points, specified as a scalar or n *p*-element vector, where *p* is the number of points for time scaling. By default, the time scaling is a linear time scaling spanning the **TimeInterval**. Specify the actual time scaling values in **TimeScaling**.

If the **Time** input is specified at a time not specified by these points, interpolation is used to find the right scaling time.

Dependencies

To enable this parameter, select the **Use custom time scaling** check box and set **Parameter source** to `External`.

To specify a scalar, the **Time** input must be a scalar.

Data Types: `single` | `double`

`TimeScaling` — Time scaling vector and first two derivatives
three-element vector | 3-by-*p* matrix

Time scaling vector and its first two derivatives, specified as a three element vector or a 3-by-*p* matrix, where *m* is the length of **TSTime**. By default, the time scaling is a linear time scaling spanning the **TimeInterval**.

For a nonlinear time scaling, specify the values of the time points in the first row. The second and third rows are the velocity and acceleration of the time points, respectively. For example, to follow the path with a linear velocity to the halfway point, and then jump to the end, the time-scaling would be:

```
s(1,:) = [0 0.25 0.5 1 1 1] % Position
s(2,:) = [1    1   1 0 0 0] % Velocity
s(3,:) = [0    0   0 0 0 0] % Acceleration
```

Dependencies

To enable this parameter, select the **Use custom time scaling** check box and set **Parameter source** to `External`.

To specify a three-element vector, the **Time** and **TSTime** inputs must be a scalar.

Data Types: `single` | `double`

Output

R — Orientation vectors
4-by-*m* quaternion array | 3-by-3-by-*m* rotation matrix array

Orientation vectors, returned as a 4-by-*m* quaternion array or 3-by-3-by-*m* rotation matrix array, where *m* is the number of points in the input to **Time**.

Dependencies

To get a quaternion array, set **Rotation Format** parameter to `Quaternion`.

To get a rotation matrix array, set **Rotation Format** parameter to `Rotation`.

`omega` — Orientation angular velocity
3-by-*m* matrix

Orientation angular velocity, returned as a 3-by-*m* matrix, where *m* is the number of points in the input to **Time**.

`alpha` — Orientation angular acceleration
3-by-*m* matrix

Orientation angular acceleration, returned as a 3-by-*m* matrix, where *m* is the number of points in the input to **Time**.

Parameters

`Rotation format` — Format for orientations
`Quaternion` (default) | `Rotation Matrix`

Select `Rotation Matrix` to specify the **Initial rotation** and **Final rotation** as 3-by-3 rotation matrices and get the orientation output (port **R**) as a rotation matrix array. By default, the initial and final rotations are specified as four-element quaternion vectors.

`Waypoint source` — Source for waypoints
`Internal` (default) | `External`

Specify `External` to specify the **Initial rotation**, **Final rotation**, and **Time interval** parameters as block inputs instead of block parameters.

`Initial rotation` — Initial orientation
`[1 0 0 0]'` (default) | four-element quaternion vector | 3-by-3 rotation matrix

Initial orientation, specified as a four-element quaternion vector or 3-by-3 rotation matrix. The function generates a trajectory that starts at the **Initial rotation** and goes to the **Final rotation**.

Dependencies

To specify quaternions, set **Rotation Format** parameter to `Quaternion`.

To specify rotation matrices, set **Rotation Format** parameter to `Rotation`.

Data Types: `single` | `double`

`Final rotation` — Final orientation
`[0 0 1 0]'` (default) | four-element vector | 3-by-3 rotation matrix

Final orientation, specified as a four-element vector or 3-by-3 rotation matrix. The function generates a trajectory that starts at the **Initial rotation** and goes to the **Final rotation**.

Dependencies

To specify quaternions, set **Rotation Format** parameter to `Quaternion`.

To specify rotation matrices, set **Rotation Format** parameter to `Rotation`.

Data Types: `single` | `double`

`Time interval` — Start and end times for trajectory
`[0 10]` (default) | two-element vector

Start and end times for the trajectory, specified as a two-element vector.

Data Types: `single` | `double`

`Use custom time scaling` — Enable custom time scaling
`off` (default) | `on`

Enable to specify custom time scaling for the trajectory using the **Parameter Source**, **Time scaling time**, and **Time scaling values** parameters.

`Parameter source` — Source for waypoints
`Internal` (default) | `External`

Specify `External` to specify the **Time scaling time** and **Time scaling values** parameters as block inputs instead of block parameters.

Dependencies

To enable this parameter, select the **Use custom time scaling** check box.

`Time scaling time` — Time scaling time points
`2:0.1:3` (default) | scalar | *p*-element vector

Time scaling time points, specified as a scalar or *p*-element vector, where *p* is the number of points for time scaling. By default, the time scaling is a linear time scaling spanning the **Time interval**. Specify the actual time scaling values in **Time scaling values**.

If the **Time** input is specified at a time not specified by these points, interpolation is used to find the right scaling time.

Dependencies

To enable this parameter, select the **Use custom time scaling** check box.

To specify a scalar, the **Time** input must be a scalar.

Data Types: `single` | `double`

`Time scaling values` — Time scaling vector and first two derivatives
`[0:0.1:1; ones(1,11); zeros(1,11)]` (default) | three-element vector | 3-by-*m* matrix

Time scaling vector and its first two derivatives, specified as a three-element vector or 3-by-*p* matrix, where *p* is the length of **Time scaling time**. By default, the time scaling is a linear time scaling spanning the **Time interval**.

For a nonlinear time scaling, specify the values of the time points in the first row. The second and third rows are the velocity and acceleration of the time points, respectively. For example, to follow the path with a linear velocity to the halfway point, and then jump to the end, the time-scaling would be:

```
s(1,:) = [0 0.25 0.5 1 1 1] % Position
s(2,:) = [1    1   1 0 0 0] % Velocity
s(3,:) = [0    0   0 0 0 0] % Acceleration
```

Dependencies

To enable this parameter, select the **Use custom time scaling** checkbox.

To specify a three-element vector, the **Time** and **TSTime** inputs must be a scalar.

Data Types: `single` | `double`

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control*. Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Polynomial Trajectory | Transform Trajectory | Trapezoidal Velocity Profile Trajectory

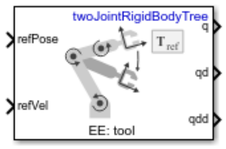
Functions
`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

Task Space Motion Model

Model rigid body tree motion given task-space inputs

Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Task Space Motion Model block models the closed-loop task-space motion of a manipulator, specified as a `rigidBodyTree` object. The motion model behavior is defined using proportional-derivative (PD) control.

For more details about the equations of motion, see “Task-Space Motion Model”.

Ports

Input

`refPose` — End-effector pose

4-by-4 matrix

Homogenous transformation matrix representing the desired end effector pose, specified in meters.

`refVel` — Joint velocities

6-element vector

6-element vector representing the desired linear and angular velocities of the end effector, specified in meters per second and radians per second.

`FExt` — External forces

6-by-*m* matrix

6-by-*m* matrix representing external forces, specified in meters per second. *m* is the number of bodies in the `rigidBodyTree` object in the `Rigid body tree` parameter.

Dependencies

To enable this port, set the `Show external force input` parameter to `on`.

Output

q — Joint positions

n-element vector

Joint positions output as an *n*-element vector in radians or meters, where *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

qd — Joint velocities

n-element

Joint velocities output as an *n*-element vector in radians per second or meters per second, where *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

qdd — Joint accelerations
n-element

Joint accelerations output as an *n*-element in radians per second squared or meters per second squared, where *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

Parameters

`Rigid body tree` — Rigid body tree
`twoJointRigidBodyTree` object (default) | `RigidBodyTree` object

Robot model, specified as a `RigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`End effector` — End effector body
`tool` (default)

This parameter defines the body that will be used as the end effector, and for which the task space motion is defined. The property must correspond to a body name in the `rigidBodyTree` object of the property. Click **Select body** to select a body from the `rigidBodyTree`. If the `rigidBodyTree` is updated without also updating the end effector, the body with the highest index is assigned by default.

`Proportional gain` — Proportional gain for PD Control
`500*eye(6)` (default) | 6-by-6 matrix

Proportional gain for proportional-derivative (PD) control, specified as a 6-by-6 matrix.

`Derivative gain` — Derivative gain for PD Control
`100*eye(6)` (default) | 6-by-6 matrix

Derivative gain for proportional-derivative (PD) control, specified as a 6-by-6 matrix.

`Joint damping` — Damping ratios
`[1 1]` (default) | *n*-element vector | scalar

Damping ratios on each joint, specified as a scalar or *n*-element vector, where *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

`Show external force input` — Display FExt port
`off` (default) | `on`

Click the check-box to enable this parameter to input external forces using the `FExt` port.

`Initial joint configuration` — Initial joint positions
`0` (default) | *n*-element vector | scalar

Initial joint positions, specified as a *n*-element vector or scalar in radians. *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

`Initial joint velocities` — Initial joint velocities
`0` (default) | *n*-element vector | scalar

Initial joint velocities, specified as a *n*-element vector or scalar in radians per second. *n* is the number of nonfixed joints in the `rigidBodyTree` object in the `Rigid body tree` parameter.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. For more information, see "Simulation Modes" (Simulink).
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change.

Tunable: No

References

[1] Craig, John J. *Introduction to Robotics: Mechanics and Control*. Upper Saddle River, NJ: Pearson Education, 2005.

[2] Spong, Mark W., Seth Hutchinson, and Mathukumalli Vidyasagar. *Robot Modeling and Control*. Hoboken, NJ: Wiley, 2006.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

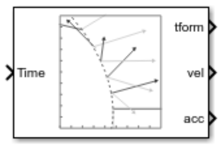
Blocks
Joint Space Motion Model

Classes
`taskSpaceMotionModel` | `jointSpaceMotionModel`

Introduced in R2019b

Transform Trajectory

Generate trajectory between two homogeneous transforms
Library: Robotics System Toolbox / Utilities



Description

The Transform Trajectory block generates an interpolated trajectory between two homogenous transformation matrices. The block outputs the transform at the times given by the **Time** input, which can be a scalar or vector.

The trajectory is computed using quaternion spherical linear interpolation (SLERP) for the rotation and linear interpolation for the translation. This method finds the shortest path between positions and rotations of the transformation. Select the **Use custom time scaling** check box to compute the trajectory using a custom time scaling. The block uses linear time scaling by default.

The initial and final values are held constant outside the time period defined in **Time interval**.

Ports

Input

`Time` — Time point along trajectory
scalar | vector

Time point along trajectory, specified as a scalar or vector. In general, when specified as a scalar, this value is synced with simulation time and is used to specify the time point for sampling the trajectory. The block outputs a vector of the trajectory variables at that instant in time. If the time is specified as a vector, the block outputs a matrix with each column corresponding to each element of the vector.

Data Types: `single` | `double`

`T0` — Initial transformation matrix
4-by-4 homogeneous transformation

Initial transformation matrix, specified as a 4-by-4 homogeneous transformation. The function generates a trajectory that starts at the initial orientation, **T0**, and goes to the final orientation, **TF**.

Example: `trvec2tform([1 10 -1])`

Dependencies

To enable this parameter, set the **Waypoint source** to `External`.

Data Types: `single` | `double`

`TF` — Final transformation matrix
4-by-4 homogeneous transformation

Final transformation matrix, specified as a 4-by-4 homogeneous transformation. The function generates a trajectory that starts at the initial orientation, **T0**, and goes to the final orientation, **TF**.

Example: `trvec2tform([1 10 -1])`

Dependencies

To enable this parameter, set the **Waypoint source** to `External`.

Data Types: `single` | `double`

`TimeInterval` — Start and end times for trajectory
two-element vector

Start and end times for the trajectory, specified as a two-element vector.

Example: `[0 10]`

Dependencies

To enable this parameter, set the **Waypoint source** to `External`.

Data Types: `single` | `double`

`TSTime` — Time scaling time points
scalar | *p*-element vector

Time scaling time points, specified as a scalar or n *p*-element vector, where *p* is the number of points for time scaling. By default, the time scaling is a linear time scaling spanning the **TimeInterval**. Specify the actual time scaling values in **TimeScaling**.

If the **Time** input is specified at a time not specified by these points, interpolation is used to find the right scaling time.

Dependencies

To enable this parameter, select the **Use custom time scaling** check box and set **Parameter source** to `External`.

To specify a scalar, the **Time** input must be a scalar.

Data Types: `single` | `double`

`TimeScaling` — Time scaling vector and first two derivatives
three-element vector | 3-by-*p* matrix

Time scaling vector and its first two derivatives, specified as a three element vector or a 3-by-*p* matrix, where *m* is the length of **TSTime**. By default, the time scaling is a linear time scaling spanning the **TimeInterval**.

For a nonlinear time scaling, specify the values of the time points in the first row. The second and third rows are the velocity and acceleration of the time points, respectively. For example, to follow the path with a linear velocity to the halfway point, and then jump to the end, the time-scaling would be:

```
s(1,:) = [0 0.25 0.5 1 1 1] % Position
s(2,:) = [1    1   1 0 0 0] % Velocity
s(3,:) = [0    0   0 0 0 0] % Acceleration
```

Dependencies

To enable this parameter, select the **Use custom time scaling** check box and set **Parameter source** to `External`.

To specify a three-element vector, the **Time** and **TSTime** inputs must be a scalar.

Data Types: `single` | `double`

Output

`tform` — Homogeneous transformation matrices
4-by-4-by-*m* homogenous matrix array

Homogeneous transformation matrices, returned as a 4-by-4-by-*m* homogenous matrix array, where *m* is the number of points input to **Time**.

`vel` — Transform velocities
6-by-*m* matrix

Transform velocities, returned as a 6-by-*m* matrix, where *m* is the number of points input to **Time**. Each row of the vector is the angular and linear velocity of the transform as `[wx wy wz vx vy vz]`. *w* represents an angular velocity and *v* represents a linear velocity.

`alpha` — Transform accelerations
6-by-*m* matrix

Transform velocities, returned as a 6-by-*m* matrix, where *m* is the number of points input to **Time**. Each row of the vector is the angular and linear acceleration of the transform as `[alphax alphay alphaz ax ay az]`. *alpha* represents an angular acceleration and *a* represents a linear acceleration.

Parameters

`Waypoint source` — Source for waypoints
`Internal` (default) | `External`

Specify `External` to specify the **Waypoints** and **Time points** parameters as block inputs instead of block parameters.

`Initial transform` — Initial transformation matrix
`trvec2tform([1 10 -1])` (default) | 4-by-4 homogeneous transformation

Initial transformation matrix, specified as a 4-by-4 homogeneous transformation. The function generates a trajectory that starts at the **Initial transform** and goes to the **Final transform**.

Data Types: `single` | `double`

`Final transform` — Final transformation matrix
`eul2tform([0 pi pi/2])` (default) | 4-by-4 homogeneous transformation

Final transformation matrix, specified as a 4-by-4 homogeneous transformation. The function generates a trajectory that starts at the **Initial transform** and goes to the **Final transform**.

Data Types: `single` | `double`

`Time interval` — Start and end times for trajectory
`[2 3]` | two-element vector

Start and end times for the trajectory, specified as a two-element vector in seconds.

Data Types: `single` | `double`

`Use custom time scaling` — Enable custom time scaling
`off` (default) | `on`

Enable to specify custom time scaling for the trajectory using the **Parameter Source**, **Time scaling time**, and **Time scaling values** parameters.

`Parameter source` — Source for waypoints
`Internal` (default) | `External`

Specify `External` to specify the **Time scaling time** and **Time scaling values** parameters as block inputs instead of block parameters.

Dependencies

To enable this parameter, select the **Use custom time scaling** check box.

`Time scaling time` — Time scaling time points
`2:0.1:3` (default) | scalar | *p*-element vector

Time scaling time points, specified as a scalar or *p*-element vector, where *p* is the number of points for time scaling. By default, the time scaling is a linear time scaling spanning the **Time interval**. Specify the actual time scaling values in **Time scaling values**.

If the **Time** input is specified at a time not specified by these points, interpolation is used to find the right scaling time.

Dependencies

To enable this parameter, select the **Use custom time scaling** check box.

To specify a scalar, the **Time** input must be a scalar.

Data Types: `single` | `double`

`Time scaling values` — Time scaling vector and first two derivatives
`[0:0.1:1; ones(1,11); zeros(1,11)]` (default) | three-element vector | 3-by-*m* matrix

Time scaling vector and its first two derivatives, specified as a three-element vector or 3-by-*p* matrix, where *p* is the length of **Time scaling time**. By default, the time scaling is a linear time scaling spanning the **Time interval**.

For a nonlinear time scaling, specify the values of the time points in the first row. The second and third rows are the velocity and acceleration of the time points, respectively. For example, to follow the path with a linear velocity to the halfway point, and then jump to the end, the time-scaling would be:

```
s(1,:) = [0 0.25 0.5 1 1 1] % Position
s(2,:) = [1    1   1 0 0 0] % Velocity
s(3,:) = [0    0   0 0 0 0] % Acceleration
```

Dependencies

To enable this parameter, select the **Use custom time scaling** checkbox.

To specify a three-element vector, the **Time** and **TSTime** inputs must be a scalar.

Data Types: `single` | `double`

`Simulate using` — Type of simulation to run

`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control*. Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Polynomial Trajectory | Rotation Trajectory | Trapezoidal Velocity Profile Trajectory

Functions

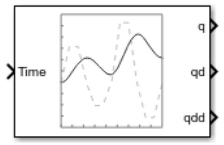
`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

Trapezoidal Velocity Profile Trajectory

Generate trajectories though multiple waypoints using trapezoidal velocity profiles

Library: Robotics System Toolbox / Utilities



Description

The Trapezoidal Velocity Profile Trajectory block generates a trajectory through a given set of waypoints that follow a trapezoidal velocity profile. The block outputs positions, velocities, and accelerations for a trajectory based on the given waypoints and velocity profile parameters.

Ports

Input

`Time` — Time point along trajectory

scalar | vector

Time point along trajectory, specified as a scalar or vector. In general, when specified as a scalar, this value is synced with simulation time and is used to specify the time point for sampling the trajectory. The block outputs a vector of the trajectory variables at that instant in time. If the time is specified as a vector, the block outputs a matrix with each column corresponding to each element of the vector.

Data Types: `single` | `double`

`Waypoints` — Waypoint positions along trajectory

n-by-*p* matrix

Positions of waypoints of the trajectory at given time points, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of waypoints.

Dependencies

To enable this input, set **Waypoint source** to `External`.

`PeakVelocity` — Peak velocity of the velocity profile

`[1;2]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Peak velocity of the profile segment, specified as a scalar, vector, or matrix. This peak velocity is the highest velocity achieved during the trapezoidal velocity profile.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. Set **Parameter 1** or **Parameter 2** to `Peak Velocity`. Then, set **Parameter source** to `External`.

Data Types: `single` | `double`

`Acceleration` — Acceleration of the velocity profile

`[2;2]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Acceleration of the velocity profile, specified as a scalar, vector, or matrix. This acceleration defines the constant acceleration from zero velocity to the **PeakVelocity** value.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. Set **Parameter 1** or **Parameter 2** to `Acceleration`. Then, set **Parameter source** to `External`.

Data Types: `single` | `double`

`EndTime` — Duration of trajectory segment

`[1;2]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Duration of trajectory segment, specified as a scalar, vector, or matrix.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. set **Parameter 1** or **Parameter 2** to `End Time`. Then, set **Parameter source** to `External`.

Data Types: `single` | `double`

`Acceleration Time` — Duration of acceleration phase of velocity profile

`[1;1]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Duration of acceleration phase of velocity profile, specified as a scalar, vector, or matrix.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. set **Parameter 1** or **Parameter 2** to `Acceleration Time`. Then, set **Parameter source** to `External`.

Data Types: `single` | `double`

Output

q — Position of trajectory
scalar | vector | matrix

Position of the trajectory, specified as a scalar, vector, or matrix. If you specify a scalar for the `Time` input with an *n*-dimensional trajectory, the output is a vector with *n* elements. If you specify a vector of *m* elements for the `Time` input, the output is an *n*-by-*m* matrix.

Data Types: `single` | `double`

qd — Velocity of trajectory
scalar | vector | matrix

Velocity of the trajectory, specified as a scalar, vector, or matrix. If you specify a scalar for the `Time` input with an *n*-dimensional trajectory, the output is a vector with *n* elements. If you specify a vector of *m* elements for the `Time` input, the output is an *n*-by-*m* matrix.

Data Types: `single` | `double`

qdd — Acceleration of trajectory
scalar | vector | matrix

Acceleration of the trajectory, specified as a scalar, vector, or matrix. If you specify a scalar for the `Time` input with an *n*-dimensional trajectory, the output is a vector with *n* elements. If you specify a vector of *m* elements for the `Time` input, the output is an *n*-by-*m* matrix.

Data Types: `single` | `double`

Parameters

`Waypoint source` — Source for waypoints
`Internal` (default) | `External`

Specify `External` to specify the **Waypoints** and **Time points** parameters as block inputs instead of block parameters.

`Waypoints` — Waypoint positions along trajectory
n-by-*p* matrix

Positions of waypoints of the trajectory at given time points, specified as an *n*-by-*p* matrix, where *n* is the dimension of the trajectory and *p* is the number of waypoints.

`Number of parameters` — Number of velocity profile parameters
`0` (default) | `1` | `2`

Number of velocity profile parameters, specified as `0`, `1`, or `2`. Increasing this value adds **Parameter 1** and **Parameter 2** for specifying parameters for the velocity profile.

`Parameter 1` — Velocity profile parameter
`Peak Velocity` | `Acceleration` | `End Time` | `Acceleration Time`

Velocity profile parameter, specified as `Peak Velocity`, `Acceleration`, `End Time`, or `Acceleration Time`. Setting this parameter creates a parameter in the mask with this value as its name.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`.

If **Parameter Source** is set to `Internal`, this parameter creates a parameter in the mask with this value as its name.

If **Parameter Source** is set to `External`, this parameter creates an input port based on this value.

`Parameter 2` — Velocity profile parameter

`Peak Velocity` | `Acceleration` | `End Time` | `Acceleration Time`

Velocity profile parameter, specified as `Peak Velocity`, `Acceleration`, `End Time`, or `Acceleration Time`. Setting this parameter creates a parameter in the mask with this value as its name.

Dependencies

To enable this parameter, set **Number of parameters** to `2`.

If **Parameter Source** is set to `Internal`, this parameter creates a parameter in the mask with this value as its name.

If **Parameter Source** is set to `External`, this parameter creates an input port based on this value.

`Parameter source` — Source for waypoints

`Internal` (default) | `External`

Specify `External` to specify the velocity profile parameters as block inputs instead of block parameters.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`.

`PeakVelocity` — Peak velocity of the velocity profile

`[1;2]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Peak velocity of the profile segment, specified as a scalar, vector, or matrix. This peak velocity is the highest velocity achieved during the trapezoidal velocity profile.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. Then, set **Parameter 1** or **Parameter 2** to `Peak Velocity`.

Data Types: `single` | `double`

`Acceleration` — Acceleration of the velocity profile

`[2;2]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Acceleration of the velocity profile, specified as a scalar, vector, or matrix. This acceleration defines the constant acceleration from zero velocity to the **PeakVelocity** value.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. Then, set **Parameter 1** or **Parameter 2** to `Acceleration`.

Data Types: `single` | `double`

`EndTime` — Duration of trajectory segment
`[1;2]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Duration of trajectory segment, specified as a scalar, vector, or matrix.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. Then, set **Parameter 1** or **Parameter 2** to `End Time`.

Data Types: `single` | `double`

`Acceleration Time` — Duration of acceleration phase of velocity profile
`[1;1]` (default) | scalar | *n*-element vector | *n*-by-(*p* – 1) matrix

Duration of acceleration phase of velocity profile, specified as a scalar, vector, or matrix.

A scalar value is applied to all elements of the trajectory and between all waypoints. An *n*-element vector is applied to each element of the trajectory between all waypoints. An *n*-by-(*p* – 1) matrix is applied to each element of the trajectory for each waypoint.

Dependencies

To enable this parameter, set **Number of parameters** to `1` or `2`. Then, set **Parameter 1** or **Parameter 2** to `Acceleration Time`.

Data Types: `single` | `double`

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning and Control*. Cambridge: Cambridge University Press, 2017.

[2] Spong, Mark W., Seth Hutchinson, and M. Vidyasagar. *Robot Modeling and Control*. John Wiley & Sons, 2006.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Polynomial Trajectory | Rotation Trajectory | Transform Trajectory

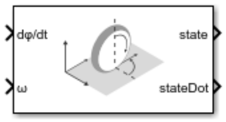
Functions
`bsplinepolytraj` | `cubicpolytraj` | `quinticpolytraj` | `rottraj` | `transformtraj` | `trapveltraj`

Introduced in R2019a

Unicycle Kinematic Model

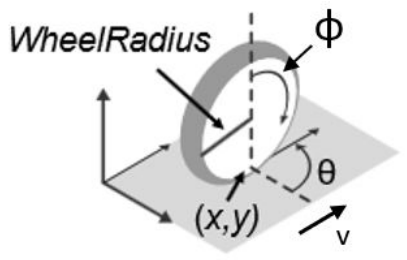
Compute vehicle motion using unicycle kinematic model

Library: Robotics System Toolbox / Mobile Robot Algorithms



Description

The Unicycle Kinematic Model block creates a unicycle vehicle model to simulate simplified car-like vehicle dynamics. This model approximates a vehicle as a unicycle with a given wheel radius, `Wheel radius`, that can spin in place according to a steering angular velocity, **ω**.



Ports

Input

`dϕ/dt` — Angular velocity of wheel

numeric scalar

Angular velocity of the wheel in radians per second.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Wheel Speed & Heading Angular Velocity`.

v — Vehicle speed

numeric scalar

Vehicle speed, specified in meters per second.

Dependencies

To enable this port, set the `Vehicle inputs` parameter to `Vehicle Speed & Heading Angular Velocity`.

ω — Steering angular velocity

numeric scalar

Angular velocity of the vehicle, specified in radians per second. A positive value steers the vehicle left and negative values steer the vehicle right.

Output

`state` — Pose of vehicle
three-element vector

Current *xy*-position and orientation of the vehicle, specified as a *[x y theta]* vector in meters and radians.

`stateDot` — Derivatives of `state` output
three-element vector

The linear and angular velocities of the vehicle, specified as a *[xDot yDot thetaDot]* vector in meters per second and radians per second. The linear and angular velocities are calculated by taking the derivative of the `state` output.

Parameters

`Vehicle inputs` — Type of speed and directional inputs for vehicle
`Vehicle Speed & Heading Angular Velocity` (default) | `Wheel Speed & Heading Angular Velocity`

Type of speed and directional inputs to control the vehicle. Options are:

- `Vehicle Speed & Heading Angular Velocity` — Vehicle speed in meters per second with a heading angular velocity in radians per second..
- `Wheel Speed & Heading Angular Velocity` — Wheel speed in radians per second with a heading angular velocity in radians per second.

`Wheel radius` — Wheel radius of vehicle
`0.1` (default) | positive numeric scalar

The wheel radius of the vehicle, specified in meters.

`Wheel speed range` — Minimum and Maximum vehicle speeds
`[-Inf Inf]` (default) | two-element vector

The minimum and maximum wheel speeds, specified in radians per second.

`Initial state` — Distance between front and rear axles
`[0;0;0]` (default) | three-element vector

The initial *x*-, *y*-position and orientation, *theta*, of the vehicle.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. For more information, see “Simulation Modes” (Simulink).
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change.

Tunable: No

References

[1] Lynch, Kevin M., and Frank C. Park. *Modern Robotics: Mechanics, Planning, and Control* 1st ed. Cambridge, MA: Cambridge University Press, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Differential Drive Kinematic Model | Ackermann Kinematic Model | Bicycle Kinematic Model

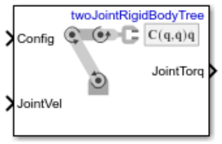
Classes
`unicycleKinematics`

Topics
“Simulate Different Kinematic Models for Mobile Robots”
“Mobile Robot Kinematics Equations”

Introduced in R2019b

Velocity Product Torque

Joint torques that cancel velocity-induced forces
Library: Robotics System Toolbox / Manipulator Algorithms



Description

The Velocity Product Torque block returns the torques that cancel the velocity-induced forces for the given robot configuration (joint positions) and joint velocities for the **Rigid body tree** robot model.

Ports

Input

`Config` — Robot configuration
vector

Robot configuration, specified as a vector of positions for all nonfixed joints in the robot model, as set by the **Rigid body tree** parameter. You can also generate this vector for a complex robot using the `homeConfiguration` or `randomConfiguration` functions inside a Constant or MATLAB Function block.

`JointVel` — Joint velocities
vector

Joint velocities, specified as a vector. The number of joint velocities is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Output

`JointTorq` — Joint torques
vector

Joint torques, specified as a vector. Each element corresponds to a torque applied to a specific joint. The number of joint torques is equal to the degrees of freedom (number of nonfixed joints) of the robot.

Parameters

`Rigid body tree` — Robot model
`twoJointRigidBodyTree` (default) | `RigidBodyTree` object

Robot model, specified as a `rigidBodyTree` object. You can also import a robot model from an URDF (Unified Robot Description Formation) file using `importrobot`.

The default robot model, `twoJointRigidBodyTree`, is a robot with revolute joints and two degrees of freedom.

`Simulate using` — Type of simulation to run
`Interpreted execution` (default) | `Code generation`

- `Interpreted execution` — Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` — Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to `Interpreted execution`.

Tunable: No

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks
Forward Dynamics | Inverse Dynamics | Get Jacobian | Gravity Torque | Joint Space Mass Matrix

Classes
`rigidBodyTree`

Functions
`velocityProduct` | `importrobot` | `homeConfiguration` | `randomConfiguration`

Introduced in R2018a