UAV Toolbox

Reference

MATLAB®&SIMULINK®

R2020b

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UAV Toolbox Reference

Revision History

September 2020	Online only	New for Version 1.0 (R2020b)

Contents

1

Classes

extendedObjectMesh

Mesh representation of extended object

Description

The `extendedObjectMesh` represents the 3-D geometry of an object. The 3-D geometry is represented by faces and vertices. Use these object meshes to specify the geometry of an `uavPlatform` for simulating lidar sensor data using `uavLidarPointCloudGenerator`.

Creation

Syntax

```
mesh = extendedObjectMesh('cuboid')
mesh = extendedObjectMesh('cylinder')
mesh = extendedObjectMesh('cylinder',n)
mesh = extendedObjectMesh('sphere')
mesh = extendedObjectMesh('sphere',n)
mesh = extendedObjectMesh(vertices,faces)
```

Description

`mesh = extendedObjectMesh('cuboid')` returns an `extendedObjectMesh` object, that defines a cuboid with unit dimensions. The origin of the cuboid is located at its geometric center.

`mesh = extendedObjectMesh('cylinder')` returns a hollow cylinder mesh with unit dimensions. The cylinder mesh has 20 equally spaced vertices around its circumference. The origin of the cylinder is located at its geometric center. The height is aligned with the *z*-axis.

`mesh = extendedObjectMesh('cylinder',n)` returns a cylinder mesh with `n` equally spaced vertices around its circumference.

`mesh = extendedObjectMesh('sphere')` returns a sphere mesh with unit dimensions. The sphere mesh has 119 vertices and 180 faces. The origin of the sphere is located at its center.

`mesh = extendedObjectMesh('sphere',n)` additionally allows you to specify the resolution, `n`, of the spherical mesh. The sphere mesh has $(n + 1)^2 - 2$ vertices and $2n(n - 1)$ faces.

`mesh = extendedObjectMesh(vertices,faces)` returns a mesh from faces and vertices. `vertices` and `faces` set the `Vertices` and `Faces` properties respectively.

Properties

`Vertices` — Vertices of defined object
N-by-3 matrix of real scalar

Vertices of the defined object, specified as an *N*-by-3 matrix of real scalars. *N* is the number of vertices. The first, second, and third element of each row represents the x-, y-, and z-position of each vertex, respectively.

Faces — Faces of defined object

M-by-3 matrix of positive integer

Faces of the defined object, specified as a *M*-by-3 array of positive integers. *M* is the number of faces. The three elements in each row are the vertex IDs of the three vertices forming the triangle face. The ID of the vertex is its corresponding row number specified in the `Vertices` property.

Object Functions

Use the object functions to develop new meshes.

translate	Translate mesh along coordinate axes
rotate	Rotate mesh about coordinate axes
scale	Scale mesh in each dimension
applyTransform	Apply forward transformation to mesh vertices
join	Join two object meshes
scaleToFit	Auto-scale object mesh to match specified cuboid dimensions
show	Display the mesh as a patch on the current axes

Examples

Create and Translate Cuboid Mesh

This example shows how to create an `extendedObjectMesh` object and translate the object.

Construct a cuboid mesh.

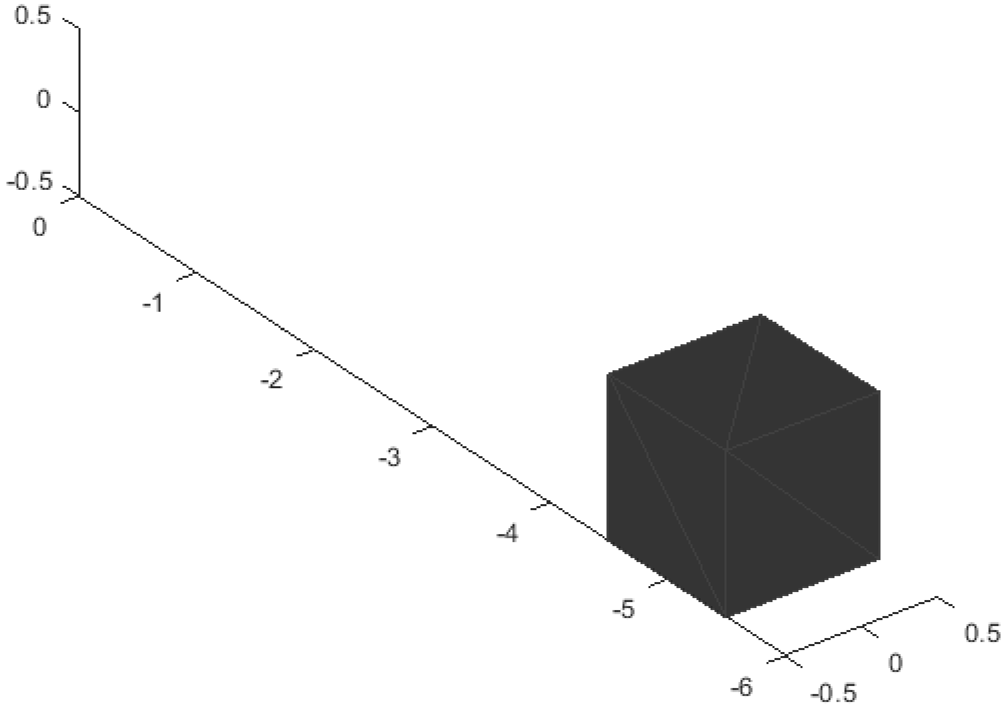
```
mesh = extendedObjectMesh('cuboid');
```

Translate the mesh by 5 units along the negative *y* axis.

```
mesh = translate(mesh,[0 -5 0]);
```

Visualize the mesh.

```
ax = show(mesh);
ax.YLim = [-6 0];
```



Create and Visualize Cylinder Mesh

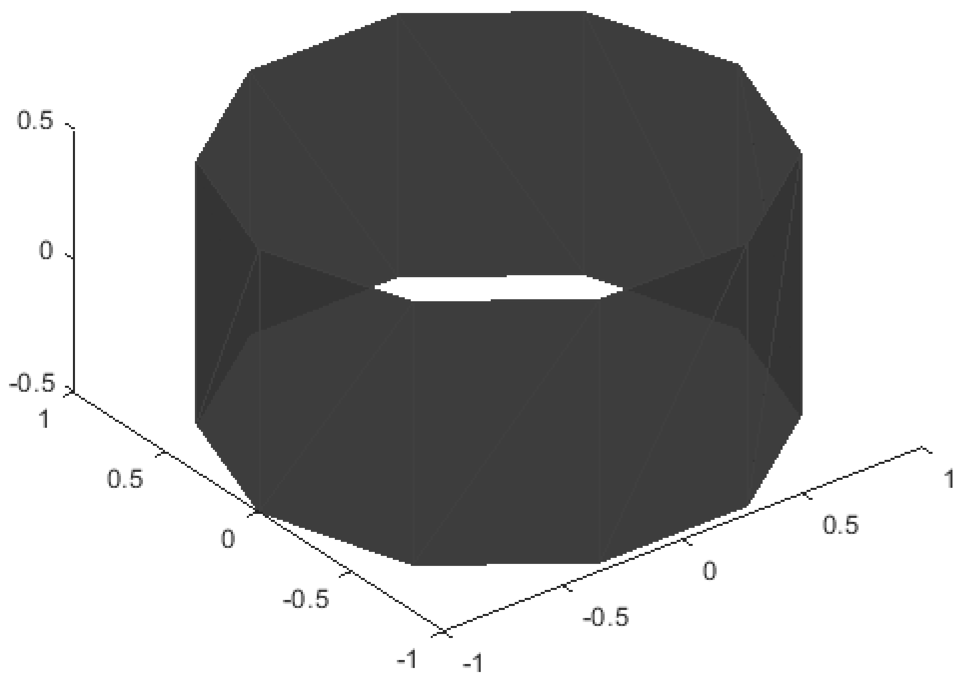
This example shows how to create an `extendedObjectMesh` object and visualize the object.

Construct a cylinder mesh.

```
mesh = extendedObjectMesh('cylinder');
```

Visualize the mesh.

```
ax = show(mesh);
```



Create and Auto-scale Sphere Mesh

This example shows how to create an `extendedObjectMesh` object and auto-scale the object to the required dimensions.

Construct a sphere mesh of unit dimensions.

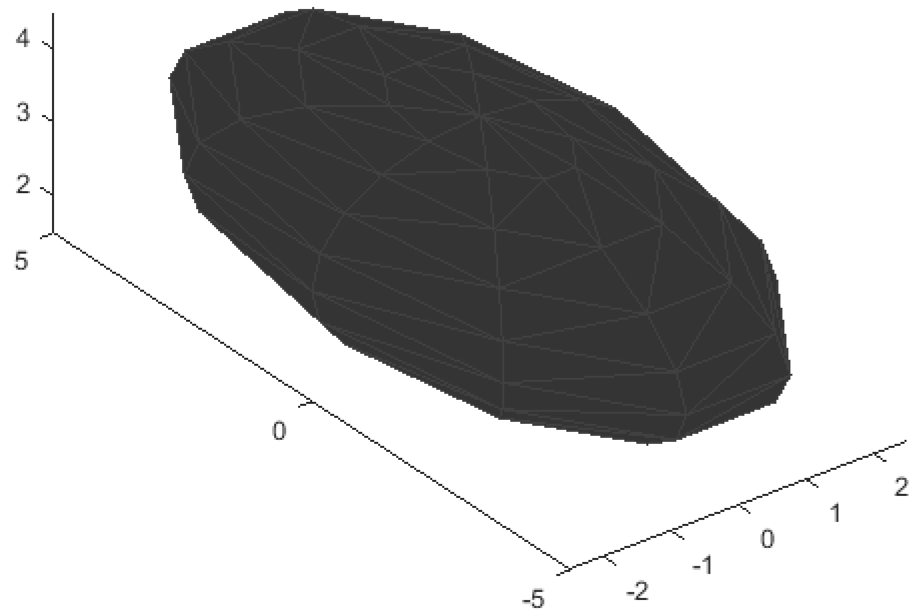
```
sph = extendedObjectMesh('sphere');
```

Auto-scale the mesh to the dimensions in `dims`.

```
dims = struct('Length',5,'Width',10,'Height',3,'OriginOffset',[0 0 -3]);
sph = scaleToFit(sph,dims);
```

Visualize the mesh.

```
show(sph);
```



See Also

Introduced in R2020b

fixedwing

Guidance model for fixed-wing UAVs

Description

A `fixedwing` object represents a reduced-order guidance model for an unmanned aerial vehicle (UAV). The model approximates the behavior of a closed-loop system consisting of an autopilot controller and a fixed-wing kinematic model for 3-D motion.

For multirotor UAVs, see `multirotor`.

Creation

`model = fixedwing` creates a fixed-wing motion model with `double` precision values for inputs, outputs, and configuration parameters of the guidance model.

`model = fixedwing(DataType)` specifies the data type precision (`DataType` property) for the inputs, outputs, and configurations parameters of the guidance model.

Properties

Name — Name of UAV
`"Unnamed"` (default) | string scalar

Name of the UAV, used to differentiate it from other models in the workspace, specified as a string scalar.

Example: `"myUAV1"`

Data Types: `string`

`Configuration` — UAV controller configuration
structure

UAV controller configuration, specified as a structure of parameters. Specify these parameters to tune the internal control behavior of the UAV. Specify the proportional (P) and derivative (D) gains for the dynamic model and other UAV parameters. The structure for fixed-wing UAVs contains these fields with defaults listed:

- `'PDRoll'` - `[3402.97 116.67]`
- `'PHeight'` - `3.9`
- `'PFlightPathAngle'` - `39`
- `'PAirspeed'` - `0.39`
- `'FlightPathAngleLimits'` - `[-pi/2 pi/2]` (`[min max]` angle in radians)

Example: `struct('PDRoll',[3402.97,116.67],'PHeight',3.9,'PFlightPathAngle',39,'PAirSpeed',0.39,'FlightPathAngleLimits',[-pi/2 pi/2])`

Data Types: `struct`

`ModelType` — UAV guidance model type
`'FixedWingGuidance'` (default)

This property is read-only.

UAV guidance model type, specified as `'FixedWingGuidance'`.

`DataType` — Input and output numeric data types
`'double'` (default) | `'single'`

Input and output numeric data types, specified as either `'double'` or `'single'`. Choose the data type based on possible software or hardware limitations.

Object Functions

control	Control commands for UAV
derivative	Time derivative of UAV states
environment	Environmental inputs for UAV
state	UAV state vector

Examples

Simulate A Fixed-Wing Control Command

This example shows how to use the `fixedwing` guidance model to simulate the change in state of a UAV due to a command input.

Create the fixed-wing guidance model.

```
model = fixedwing;
```

Set the air speed of the vehicle by modifying the structure from the `state` function.

```
s = state(model);
s(4) = 5; % 5 m/s
```

Specify a control command, `u`, that maintains the air speed and gives a roll angle of `pi/12`.

```
u = control(model);
u.RollAngle = pi/12;
u.AirSpeed = 5;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

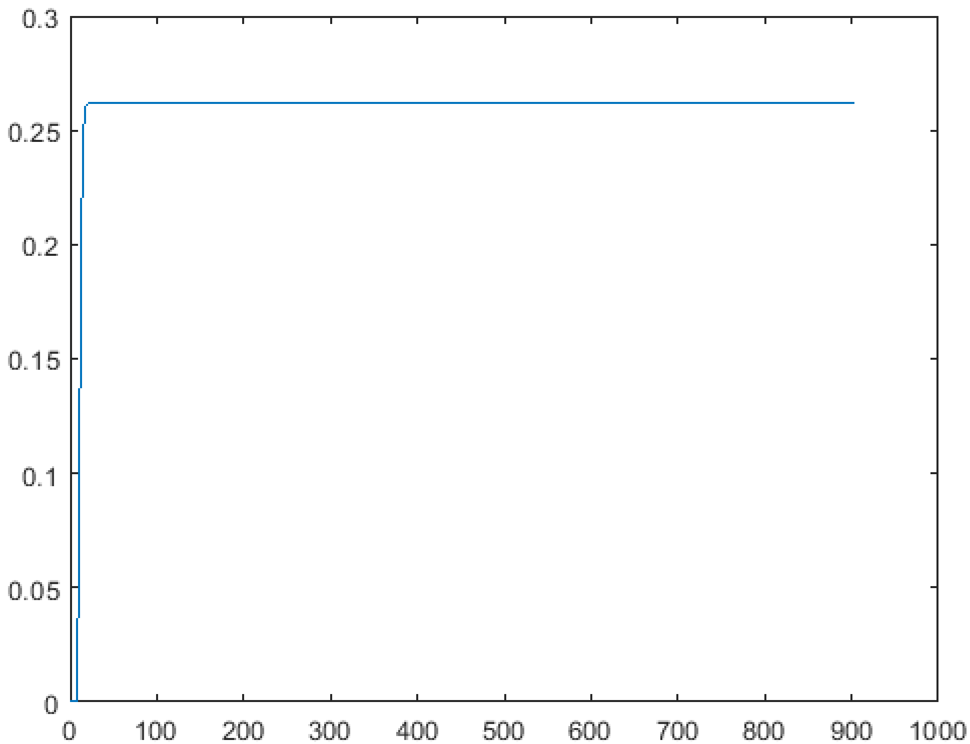
Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states based on this simulation.

```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 50], s);
size(simOut.y)
```

```
ans = 1×2

     8   904
```

Plot the change in roll angle based on the simulation output. The roll angle is the 7th row of the `simOut.y` output.

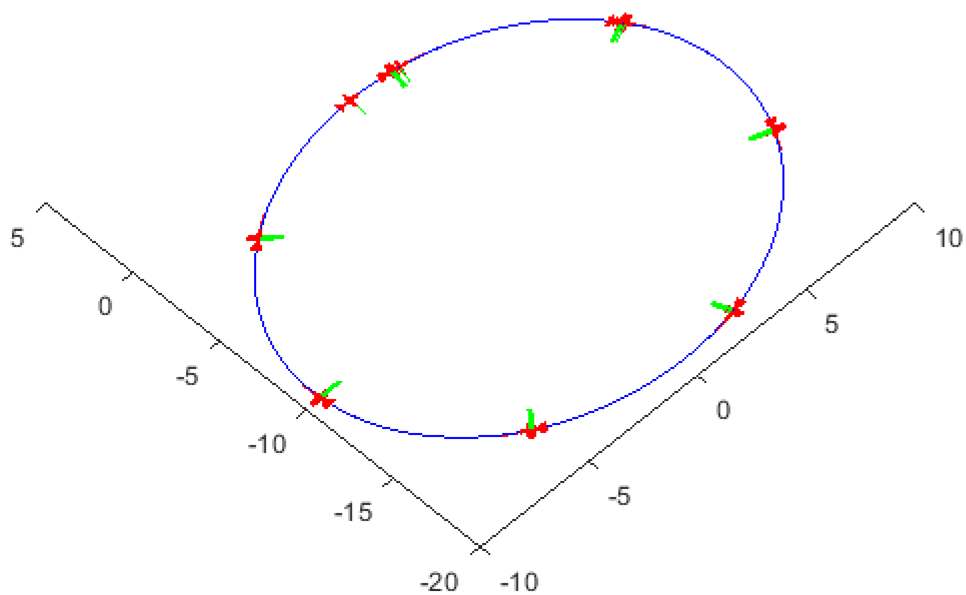
```
plot(simOut.y(7,:))
```



You can also plot the fixed-wing trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 30th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `fixedwing.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV making a constant turn based on the constant roll angle.

```
downsample = 1:30:size(simOut.y,2);
translations = simOut.y(1:3,downsample)'; % xyz-position
rotations = eul2quat([simOut.y(5,downsample)',simOut.y(6,downsample)',simOut.y(7,downsample)']);
plotTransforms(translations,rotations,...
    'MeshFilePath','fixedwing.stl','InertialZDirection',"down")
hold on
plot3(simOut.y(1,:),-simOut.y(2,:),simOut.y(3,:),'--b') % full path
xlim([-10.0 10.0])
```

```
ylim([-20.0 5.0])
zlim([-0.5 4.00])
view([-45 90])
hold off
```



More About

UAV Coordinate Systems

The UAV Toolbox uses the North-East-Down (NED) coordinate system convention, which is also sometimes called the local tangent plane (LTP). The UAV position vector consists of three numbers for position along the northern-axis, eastern-axis, and vertical position. The down element complies with the right-hand rule and results in negative values for altitude gain.

The ground plane, or earth frame (NE plane, D = 0), is assumed to be an inertial plane that is flat based on the operation region for small UAV control. The earth frame coordinates are $[x_e,y_e,z_e]$. The body frame of the UAV is attached to the center of mass with coordinates $[x_b,y_b,z_b]$. x_b is the preferred forward direction of the UAV, and z_b is perpendicular to the plane that points downwards when the UAV travels during perfect horizontal flight.

The orientation of the UAV (body frame) is specified in ZYX Euler angles. To convert from the earth frame to the body frame, we first rotate about the z_e-axis by the yaw angle, ψ. Then, rotate about the intermediate y-axis by the pitch angle, ϕ. Then, rotate about the intermediate x-axis by the roll angle, Θ.

The angular velocity of the UAV is represented by $[p,q,r]$ with respect to the body axes, $[x_b,y_b,z_b]$.

UAV Fixed-Wing Guidance Model Equations

For fixed-wing UAVs, the following equations are used to define the guidance model of the UAV. Use the `derivative` function to calculate the time-derivative of the UAV state using these governing equations. Specify the inputs using the `state`, `control`, and `environment` functions.

The UAV position in the earth frame is $[x_e, y_e, h]$ with orientation as heading angle, flight path angle, and roll angle, $[\chi, \gamma, \phi]$ in radians.

The model assumes that the UAV is flying under a coordinated-turn condition, with zero side-slip. The autopilot controls airspeed, altitude, and roll angle. The corresponding equations of motion are:

$$\dot{x}_e = V_g \cos\chi \cos\gamma$$

$$\dot{y}_e = V_g \sin\chi \cos\gamma$$

$$\dot{h} = V_g \sin\gamma$$

$$\dot{\chi} = \frac{g\cos(\chi - \psi)}{V_g}\tan\phi$$

$$V_g \sin(\gamma^c) = min\Big(max\big(k_h(h^c - h), -V_g\big), V_g\Big)$$

$$\dot{\gamma} = k_\gamma(\gamma^c - \gamma)$$

$$\dot{V}_a = k_{V_a}(V_a^c - V_a)$$

$$\frac{g\cos(\chi - \psi)}{V_g}\tan(\phi^c) = k_\chi(\chi^c - \chi)$$

$$\ddot{\phi} = k_{P\phi}(\phi^c - \phi) + k_{D\phi}(-\dot{\phi})$$

V_a and V_g denote the UAV air and ground speeds.

The wind speed is specified as $[V_{w_n},V_{w_e},V_{w_d}]$ for the north, east, and down directions. To generate the structure for these inputs, use the `environment` function.

k_* are controller gains. To specify these gains, use the `Configuration` property of the `fixedwing` object.

From these governing equations, the model gives the following variables:

$$[x_e \quad y_e \quad h \quad V_a \quad \chi \quad \gamma \quad \phi \quad \dot{\phi}]$$

These variables match the output of the `state` function.

References

[1] Randal W. Beard and Timothy W. McLain. "Chapter 9." *Small Unmanned Aircraft Theory and Practice*, NJ: Princeton University Press, 2012.

Extended Capabilities

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

See Also

Functions
`control` | `derivative` | `environment` | `ode45` | `plotTransforms` | `state`

Objects
`multirotor` | `uavWaypointFollower`

Blocks
UAV Guidance Model | Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

flightLogSignalMapping

Visualize UAV flight logs

Description

The `flightLogSignalMapping` provides visualization tools to analyze flight logs. To inspect UAV logs, first load your file using a file or log reader like `mavlinktlog` or `ulogreader`. Use preconfigured signal mapping and plots from ULOG or TLOG log files, or define your own signal mapping using `mapSignal`. Update or add new plots with `updatePlot`. Then, call `show` with a structure of data to display the list of configured plots defined in the AvailablePlots property.

For ease of use, specific Predefined Signals on page 1-14 and Predefined Plots on page 1-15 are provided. Details are listed below or can be viewed by calling `info` for your specific object.

Creation

Description

`mapper = flightLogSignalMapping` creates a flight log signal mapping object with no preset signal mapping. Before you can visualize signals, map signals using `mapSignal`.

`mapper = flightLogSignalMapping("tlog")` creates a flight log signal mapping object for the imported MAVLink TLOG message tables.

`mapper = flightLogSignalMapping("ulog")` creates a flight log signal mapping object for imported PX4 ULOG files.

Properties

`MappedSignals` — Names of all mapped signals

string array

Names of all mapped signals, specified as a string array.

Example: `["Accel" "Gyro" "Mag" "Barometer" "Gyro2"]`

Data Types: `string`

`AvailablePlots` — Names of plots that are available

string array

Names of plots that are available based on the mapped signals, specified as a string array. To add plots to this list, either map signals for the PreDefined Plots on page 1-15 or call `updatePlot`.

Example: `["Accel" "Gyro" "Mag" "Barometer" "Gyro2"]`

Data Types: `string`

Object Functions

extract	Extract UAV flight log signals as timetables
info	Signal mapping and plot information for UAV log signal mapping
mapSignal	Map UAV flight log signal
show	Display plots for inspection of UAV logs
updatePlot	Update UAV flight log plot functions

More About

Predefined Signals

A set of predefined signals and plots are configured in the `flightLogSignalMapping` object. Depending on your log file type, you can map specific signals to the provided signal names using `mapSignal`. You can also call `info` to view the table for your log type and see whether you have already mapped a signal to that plot type.

Specify the `SignalName` as the input to `mapSignal`. Signals with the format `SignalName#` support mapping multiple signals of the same type. Replace `#` with incremental integers for each signal name when calling `mapSignal`.

The predefined signals have specific names and required fields when mapping the signal.

Predefined Signals

Signal Name	Description	Fields	Uni
`Accel#`	Raw magnetometer reading from IMU sensor	`[ax ay az]`	m/s^2
`Airspeed#`	Airspeed reading of pressure differential, indicated air speed, and temperature	`[PressDiff, AirSpeed, Temp]`	Pa,
`AttitudeEuler`	Attitude of UAV in Euler (ZYX) form	`[Roll, Pitch, Yaw]`	radi
`AttitudeRate`	Angular velocity along each body axis	`[xRotRate, yRotRate, zRotRate]`	rad/
`AttitudeTargetEuler`	Target attitude of UAV in Euler (ZYX) form	`[TargetRoll, TargetPitch, TargetYaw]`	radi
`Barometer#`	Barometer readings for absolute pressure, relative pressure, and temperature	`[PressAbs, PressAltitude, Temp]`	Pa,
`Battery`	Voltage readings for battery and remaining battery capacity (%)	`[Volt1,Volt2, ... Volt16, RemainingCapacity`	V, %
`GPS#`	GPS readings for latitude, longitude, altitude, ground speed, course angle, and number of satellites visible	`[lat, long, alt, groundspeed, courseAngle, satellites]`	deg deg
`Gyro#`	Raw body angular velocity readings from IMU sensor	`[GyroX, GyroY, GyroZ]`	rad/
`LocalNED`	Local NED coordinates estimated by the UAV	`[xNED, yNED, zNED]`	met
`LocalNEDTarget`	Target location in local NED coordinates	`[xTarget, yTarget, zTarget]`	met
`LocalNEDVel`	Local NED velocity estimated by the UAV	`[vx vy vz]`	m/s
`LocalNEDVelTarget`	Target velocity in NED in local NED	`[vxTarget, vyTarget, vzTarget]`	m/s
`Mag#`	Raw magnetometer reading from IMU sensor	`[x y z]`	Gs

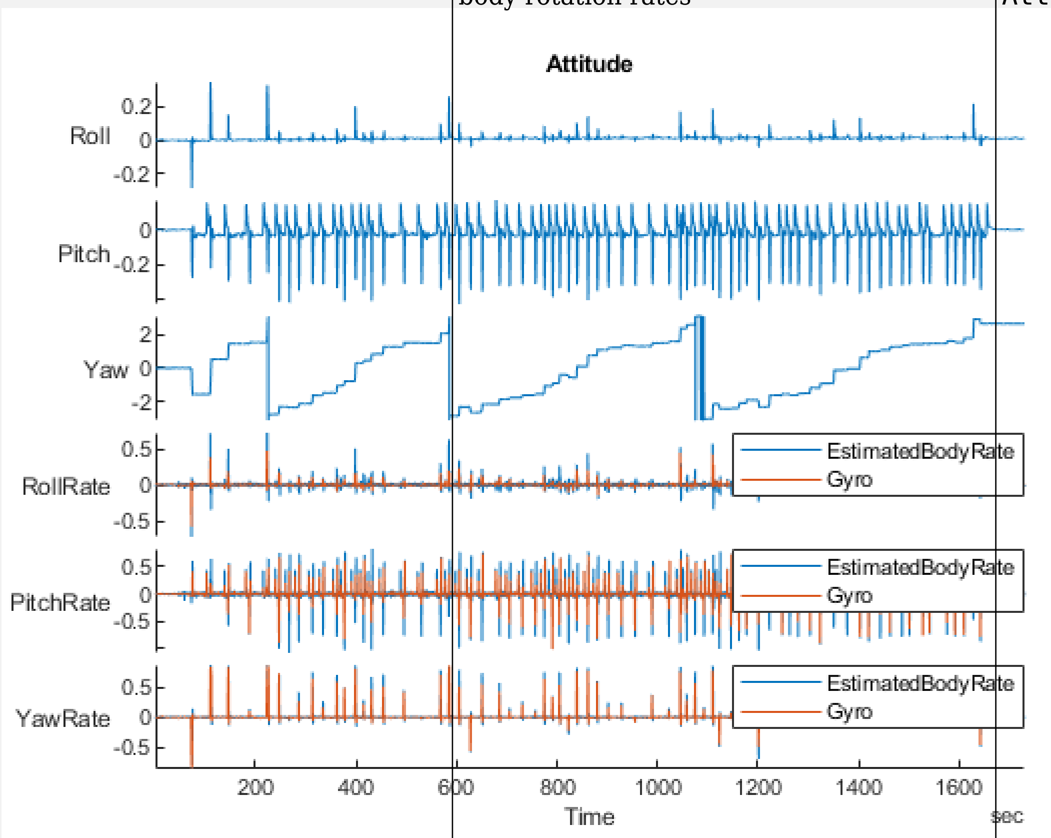
Predefined Plots

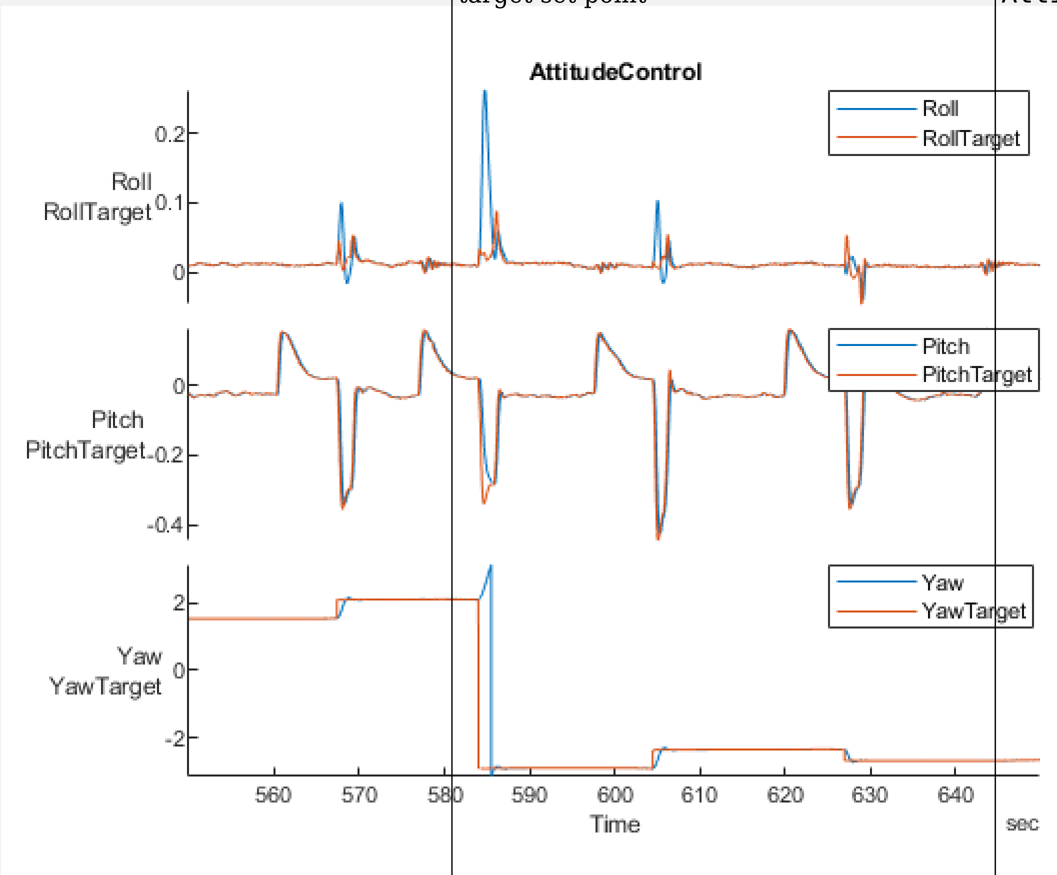
After mapping signals to the list of predefined signals using `mapSignal`, specific plots are made available when calling `show`. To view a list of available plots and their associated signals for your specific object, call `info(mapper,"Plot")`. If you want to define custom plots based on signals, use `updatePlot`.

Each predefined plot has a set of required signals that must be mapped.

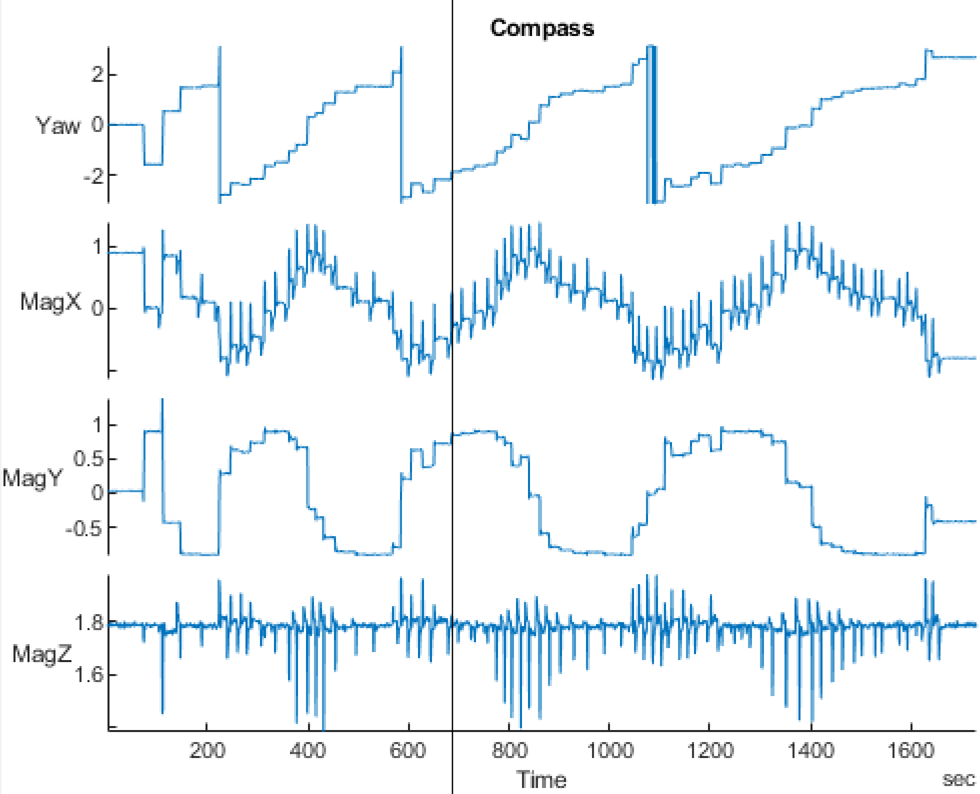
Predefined Plots

Plot	Description	Signals
Attitude	Stacked plot of roll, pitch, yaw angles and body rotation rates	AttitudeEuler, AttitudeRate, Gyro#

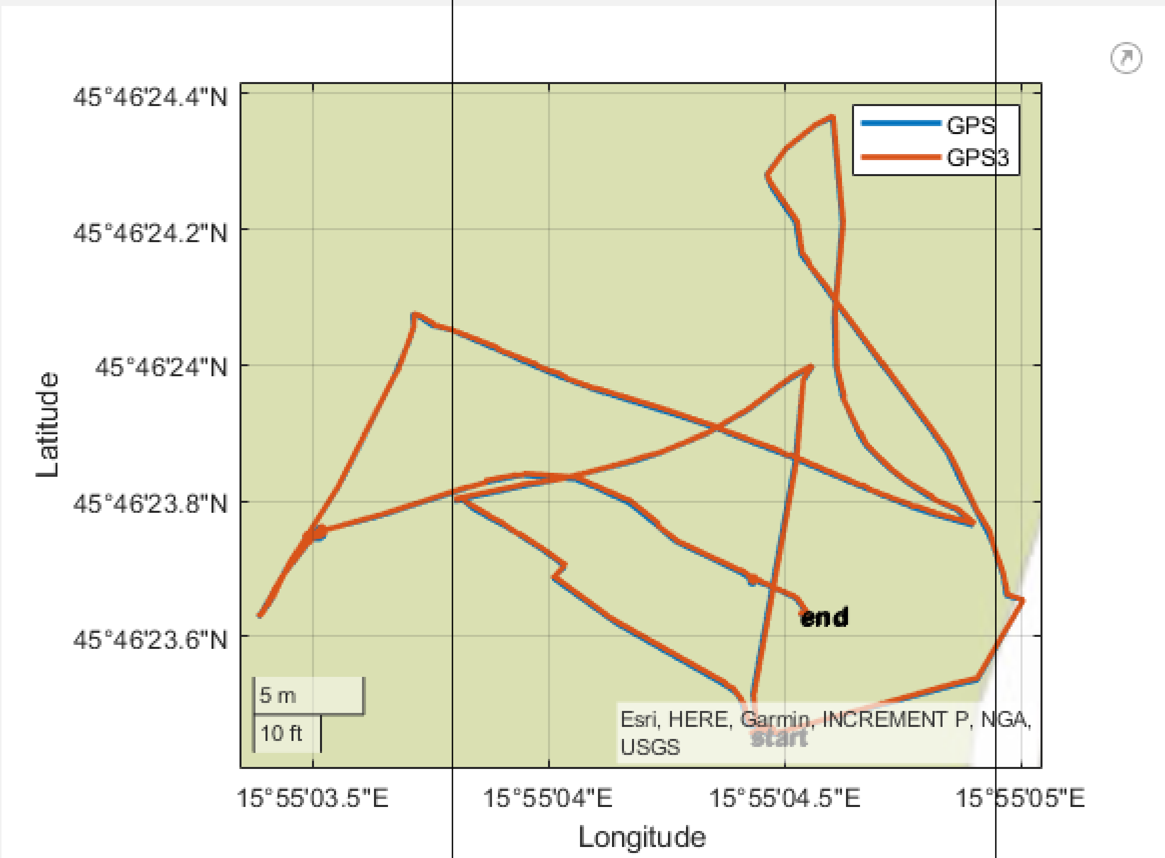


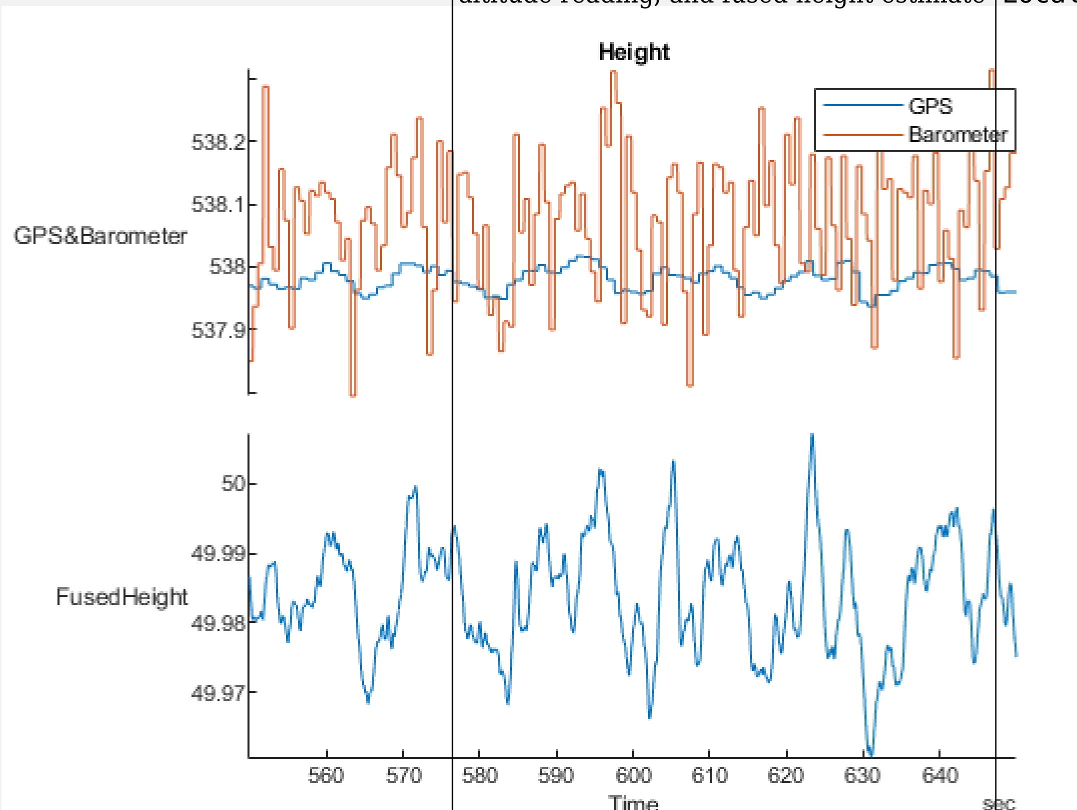
Plot	Description	Signals
AttitudeControl	Estimated attitude of UAV and the attitude target set point	AttitudeEuler, AttitudeTargetEuler
		
Battery	Battery consumption plot	Battery

Plot	Description	Signals
`Compass`	Estimated yaw and magnetometer readings	`AttitudeEuler, Mag#, GPS#`

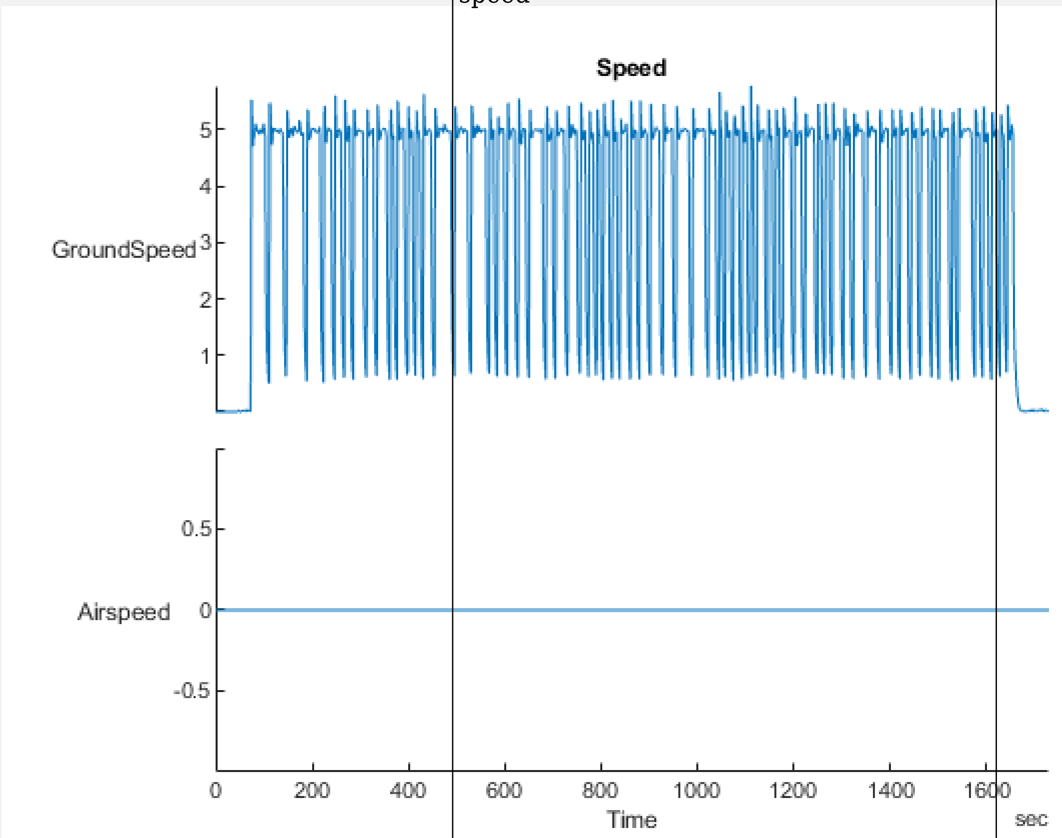


Plot	Description	Signals
GPS2D	Raw Lat-Lon plot for GPS sensor readings.	GPS#

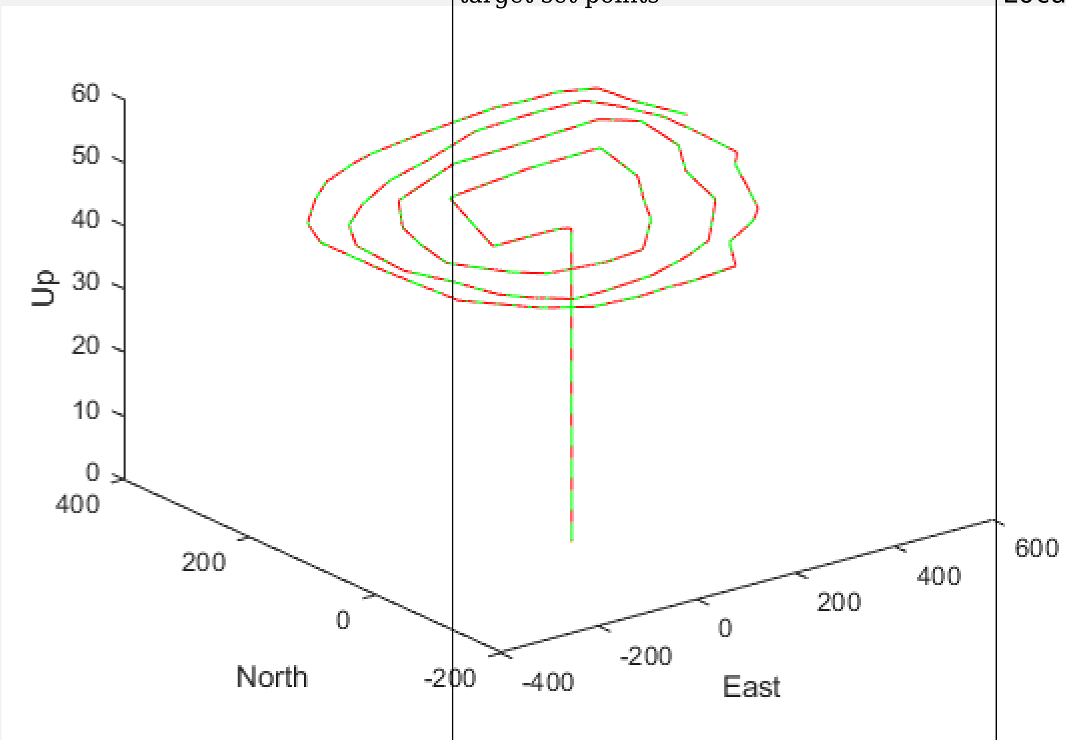


Plot	Description	Signals
`Height` 	Stacked plots of barometer reading, GPS altitude reading, and fused height estimate	`Barometer#, GPS#, LocalNED`

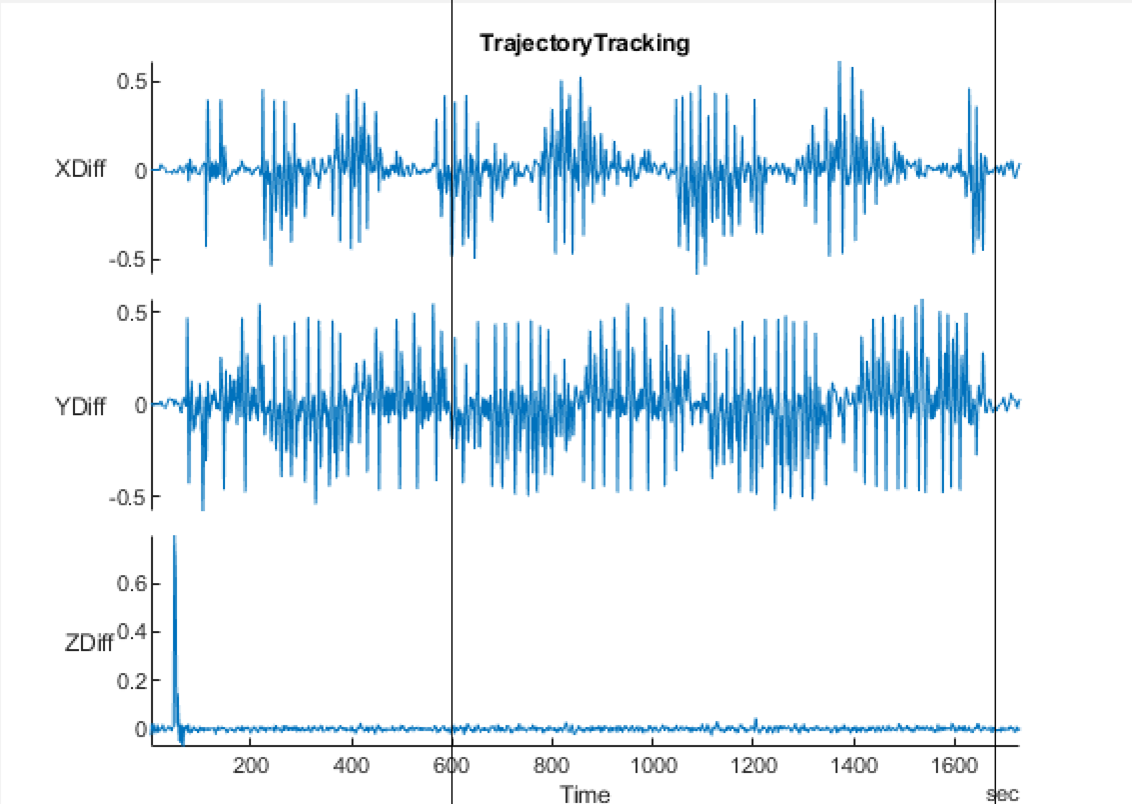
Plot	Description	Signals
`Speed`	Stacked plot of ground velocity and air speed	`GPS#, Airspeed#`



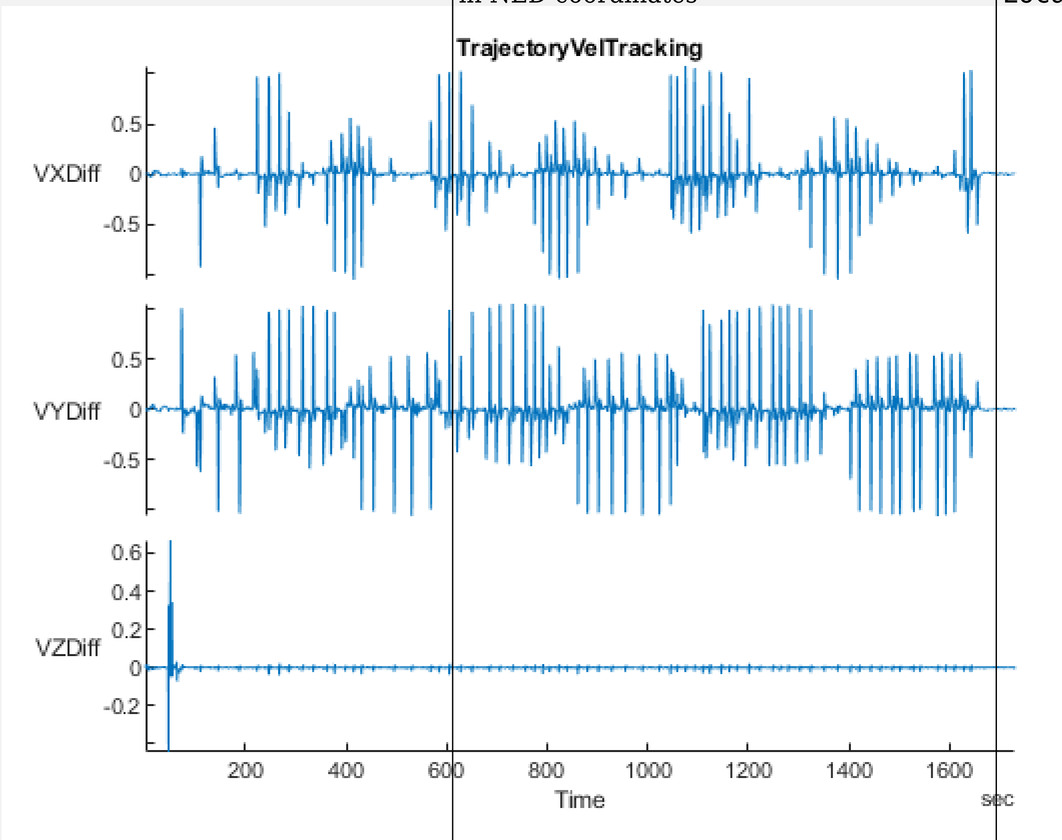
Plot	Description	Signals
`Trajectory`	Trajectory in local coordinates versus target set points	`LocalNED`, `LocalNEDTarget`



Plot	Description	Signals
`TrajectoryTracking`	Error between desired and actual position in NED coordinates	`LocalNED`, `LocalNEDTarget`



Plot	Description	Signals
`TrajectoryVelTracking`	Error between desired and actual velocity in NED coordinates	`LocalNEDVel`, `LocalNEDVelTarget`



See Also

`mavlinktlog`

Introduced in R2020b

gpsSensor

GPS receiver simulation model

Description

The `gpsSensor` System object™ models data output from a Global Positioning System (GPS) receiver.

To model a GPS receiver:

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

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

Creation

Syntax

```
GPS = gpsSensor
GPS = gpsSensor('ReferenceFrame',RF)
GPS = gpsSensor( ___ ,Name,Value)
```

Description

`GPS = gpsSensor` returns a `gpsSensor`System object that computes a Global Positioning System receiver reading based on a local position and velocity input signal. The default reference position in geodetic coordinates is

- latitude: 0º N
- longitude: 0º E
- altitude: 0 m

`GPS = gpsSensor('ReferenceFrame',RF)` returns a `gpsSensor`System object that computes a global positioning system receiver reading relative to the reference frame `RF`. Specify `RF` as `'NED'` (North-East-Down) or `'ENU'`(East-North-Up). The default value is `'NED'`.

`GPS = gpsSensor( ___ ,Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Properties

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

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

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

SampleRate — Update rate of receiver (Hz)
1 (default) | positive real scalar

Update rate of the receiver in Hz, specified as a positive real scalar.

Data Types: single | double

ReferenceLocation — Origin of local navigation reference frame
[0 0 0] (default) | [degrees degrees meters]

Reference location, specified as a 3-element row vector in geodetic coordinates (latitude, longitude, and altitude). Altitude is the height above the reference ellipsoid model, WGS84. The reference location is in [degrees degrees meters]. The degree format is decimal degrees (DD).

Data Types: single | double

HorizontalPositionAccuracy — Horizontal position accuracy (m)
1.6 (default) | nonnegative real scalar

Horizontal position accuracy in meters, specified as a nonnegative real scalar. The horizontal position accuracy specifies the standard deviation of the noise in the horizontal position measurement.

Tunable: Yes

Data Types: single | double

VerticalPositionAccuracy — Vertical position accuracy (m)
3 (default) | nonnegative real scalar

Vertical position accuracy in meters, specified as a nonnegative real scalar. The vertical position accuracy specifies the standard deviation of the noise in the vertical position measurement.

Tunable: Yes

Data Types: single | double

VelocityAccuracy — Velocity accuracy (m/s)
0.1 (default) | nonnegative real scalar

Velocity accuracy in meters per second, specified as a nonnegative real scalar. The velocity accuracy specifies the standard deviation of the noise in the velocity measurement.

Tunable: Yes

Data Types: single | double

DecayFactor — Global position noise decay factor
0.999 (default) | scalar in the range [0,1]

Global position noise decay factor, specified as a scalar in the range [0,1].

A decay factor of 0 models the global position noise as a white noise process. A decay factor of 1 models the global position noise as a random walk process.

Tunable: Yes

Data Types: `single` | `double`

`RandomStream` — Random number source
`'Global stream'` (default) | `'mt19937ar with seed'`

Random number source, specified as a character vector or string:

- `'Global stream'` –– Random numbers are generated using the current global random number stream.
- `'mt19937ar with seed'` –– Random numbers are generated using the mt19937ar algorithm with the seed specified by the `Seed` property.

Data Types: `char` | `string`

Seed — Initial seed
`67` (default) | nonnegative integer scalar

Initial seed of an mt19937ar random number generator algorithm, specified as a nonnegative integer scalar.

Dependencies

To enable this property, set `RandomStream` to `'mt19937ar with seed'`.

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

Usage

Syntax

`[position,velocity,groundspeed,course] = GPS(truePosition,trueVelocity)`

Description

`[position,velocity,groundspeed,course] = GPS(truePosition,trueVelocity)` computes global navigation satellite system receiver readings from the position and velocity inputs.

Input Arguments

`truePosition` — Position of GPS receiver in local navigation coordinate system (m)
N-by-3 matrix

Position of the GPS receiver in the local navigation coordinate system in meters, specified as a real finite *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: `single` | `double`

`trueVelocity` — Velocity of GPS receiver in local navigation coordinate system (m/s)
N-by-3 matrix

Velocity of GPS receiver in the local navigation coordinate system in meters per second, specified as a real finite *N*-by-3 matrix.

N is the number of samples in the current frame.

Data Types: `single` | `double`

Output Arguments

`position` — Position in LLA coordinate system
N-by-3 matrix

Position of the GPS receiver in the geodetic latitude, longitude, and altitude (LLA) coordinate system, returned as a real finite *N*-by-3 array. Latitude and longitude are in degrees with North and East being positive. Altitude is in meters.

N is the number of samples in the current frame.

Data Types: `single` | `double`

`velocity` — Velocity in local navigation coordinate system (m/s)
N-by-3 matrix

Velocity of the GPS receiver in the local navigation coordinate system in meters per second, returned as a real finite *N*-by-3 array.

N is the number of samples in the current frame.

Data Types: `single` | `double`

`groundspeed` — Magnitude of horizontal velocity in local navigation coordinate system (m/s)
N-by-1 column vector

Magnitude of the horizontal velocity of the GPS receiver in the local navigation coordinate system in meters per second, returned as a real finite *N*-by-1 column vector.

N is the number of samples in the current frame.

Data Types: `single` | `double`

`course` — Direction of horizontal velocity in local navigation coordinate system (°)
N-by-1 column vector

Direction of the horizontal velocity of the GPS receiver in the local navigation coordinate system in degrees, returned as a real finite *N*-by-1 column of values between 0 and 360. North corresponds to 360 degrees and East corresponds to 90 degrees.

N is the number of samples in the current frame.

Data Types: `single` | `double`

Object Functions

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

```
release(obj)
```

Common to All System Objects

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

Extended Capabilities

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

Usage notes and limitations:

See “System Objects in MATLAB Code Generation” (MATLAB Coder).

See Also

Objects

Introduced in R2018b

insSensor

Inertial navigation and GPS simulation model

Description

The `insSensor` System object models data output from an inertial navigation and GPS.

To model output from an inertial navigation and GPS:

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

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

Creation

Syntax

```
INS = insSensor
INS = insSensor(Name,Value)
```

Description

`INS = insSensor` returns a System object, `INS`, that models an inertial navigation and GPS reading based on an inertial input signal.

`INS = insSensor(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Properties

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

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

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

`RollAccuracy` — Accuracy of roll measurement (deg)
`0.2` (default) | nonnegative real scalar

Accuracy of the roll measurement of the sensor body in degrees, specified as a nonnegative real scalar.

Roll is defined as rotation around the *x*-axis of the sensor body. Roll noise is modeled as a white noise process. `RollAccuracy` sets the standard deviation, in degrees, of the roll measurement noise.

Tunable: Yes

Data Types: `single` | `double`

`PitchAccuracy` — Accuracy of pitch measurement (deg)
`0.2` (default) | nonnegative real scalar

Accuracy of the pitch measurement of the sensor body in degrees, specified as a nonnegative real scalar.

Pitch is defined as rotation around the *y*-axis of the sensor body. Pitch noise is modeled as a white noise process. `PitchAccuracy` defines the standard deviation, in degrees, of the pitch measurement noise.

Tunable: Yes

Data Types: `single` | `double`

`YawAccuracy` — Accuracy of yaw measurement (deg)
`1` (default) | nonnegative real scalar

Accuracy of the yaw measurement of the sensor body in degrees, specified as a nonnegative real scalar.

Yaw is defined as rotation around the *z*-axis of the sensor body. Yaw noise is modeled as a white noise process. `YawAccuracy` defines the standard deviation, in degrees, of the yaw measurement noise.

Tunable: Yes

Data Types: `single` | `double`

`PositionAccuracy` — Accuracy of position measurement (m)
`1` (default) | nonnegative real scalar

Accuracy of the position measurement of the sensor body in meters, specified as a nonnegative real scalar.

Position noise is modeled as a white noise process. `PositionAccuracy` defines the standard deviation, in meters, of the position measurement noise.

Tunable: Yes

Data Types: `single` | `double`

`VelocityAccuracy` — Accuracy of velocity measurement (m/s)
`0.05` (default) | nonnegative real scalar

Accuracy of the velocity measurement of the sensor body in meters per second, specified as a nonnegative real scalar.

Velocity noise is modeled as a white noise process. `VelocityAccuracy` defines the standard deviation, in meters per second, of the velocity measurement noise.

Tunable: Yes

Data Types: `single` | `double`

RandomStream — Random number source
'Global stream' (default) | 'mt19937ar with seed'

Random number source, specified as a character vector:

- 'Global stream' –– Random numbers are generated using the current global random number stream.
- 'mt19937ar with seed' –– Random numbers are generated using the mt19937ar algorithm with the seed specified by the Seed property.

Data Types: char | string

Seed — Initial seed
67 (default) | nonnegative integer scalar

Initial seed of an mt19937ar random number generator algorithm, specified as a real, nonnegative integer scalar.

Dependencies

To enable this property, set RandomStream to 'mt19937ar with seed'.

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

Usage

Syntax

```
measurement = INS(motion)
```

Description

measurement = INS(motion) models the data received from an inertial navigation and GPS reading. The measurement is based on the input signal, motion.

Input Arguments

motion — Ground-truth sensor body motion in local NED
struct

motion is a struct with the following fields:

- 'Position' –– Position of the sensor body in the local NED coordinate system specified as a real finite *N*-by-3 array in meters. *N* is the number of samples in the current frame.
- 'Velocity' –– Velocity of the sensor body in the local NED coordinate system specified as a real finite *N*-by-3 array in meters per second. *N* is the number of samples in the current frame.
- 'Orientation' –– Orientation of the sensor body with respect to the local NED coordinate system specified as a quaternion *N*-element column vector or a single or double 3-by-3-by-*N* rotation matrix. Each quaternion or rotation matrix is a frame rotation from the local NED coordinate system to the current sensor body coordinate system. *N* is the number of samples in the current frame.

Example: motion = struct('Position',[0,0,0],'Velocity',[0,0,0],'Orientation',quaternion([1,0,0,0]))

Output Arguments

`measurement` — Measurement of sensor body motion in local NED
struct

`measurement` is a struct with the following fields:

- `'Position'` –– Position measurement of the sensor body in the local NED coordinate system specified as a real finite *N*-by-3 array in meters. *N* is the number of samples in the current frame.
- `'Velocity'` –– Velocity measurement of the sensor body in the local NED coordinate system specified as a real finite *N*-by-3 array in meters per second. *N* is the number of samples in the current frame.
- `'Orientation'` –– Orientation measurement of the sensor body with respect to the local NED coordinate system specified as a quaternion *N*-element column vector or a single or double 3-by-3-by-*N* rotation matrix. Each quaternion or rotation matrix is a frame rotation from the local NED coordinate system to the current sensor body coordinate system. *N* is the number of samples in the current frame.

Object Functions

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

```
release(obj)
```

Common to All System Objects

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

Extended Capabilities

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

Usage notes and limitations:

See “System Objects in MATLAB Code Generation” (MATLAB Coder).

See Also

Objects

mavlinkdialect

Parse and store MAVLink dialect XML

Description

The `mavlinkdialect` object parses and stores message and enum definitions extracted from a MAVLink message definition file (`.xml`). The message definition files define the messages supported for this specific dialect. The structure of the message definitions is defined by the MAVLink message protocol.

Creation

Syntax

```
dialect = mavlinkdialect("common.xml")
dialect = mavlinkdialect(dialectXML)
dialect = mavlinkdialect(dialectXML,version)
```

Description

`dialect = mavlinkdialect("common.xml")` creates a MAVLink dialect using the `common.xml` file for standard MAVLink messages.

`dialect = mavlinkdialect(dialectXML)` specifies the XML file for parsing the message definitions. The input sets the `DialectXML` property.

`dialect = mavlinkdialect(dialectXML,version)` additionally specifies the MAVLink protocol version. The inputs set the `DialectXML` and `Version` properties, respectively.

Properties

`DialectXML` — MAVLink dialect name
string

MAVLink dialect name, specified as a string. This name is based on the XML file name.

Example: `"ardupilotmega"`

Data Types: `char` | `string`

`Version` — MAVLink protocol version
2 (default) | 1

MAVLink protocol version, specified as either 1 or 2.

Data Types: `double`

Object Functions

createcmd	Create MAVLink command message
createmsg	Create MAVLink message
deserializemsg	Deserialize MAVLink message from binary buffer
msginfo	Message definition for message ID
enuminfo	Enum definition for enum ID
enum2num	Enum value for given entry
num2enum	Enum entry for given value

Examples

Parse and Use MAVLink Dialect

This example shows how to parse a MAVLink XML file and create messages and commands from the definitions.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Parse and store the MAVLink dialect XML. Specify the XML path. The default `"common.xml"` dialect is provided. This XML file contains all the message and enum definitions.

```
dialect = mavlinkdialect("common.xml");
```

Create a MAVLink command from the `MAV_CMD` enum, which is an enum of MAVLink commands to send to the UAV. Specify the setting as `"int"` or `"long"`, and the type as an integer or string.

```
cmdMsg = createcmd(dialect,"long",22)
```

```
cmdMsg = struct with fields:
      MsgID: 76
    Payload: [1x1 struct]
```

Verify the command name using `num2enum`. Command 22 is a take-off command for the UAV. You can convert back to an ID using `enum2num`. Your dialect can contain many different enums with different names and IDs.

```
cmdName = num2enum(dialect,"MAV_CMD",22)
```

```
cmdName = 
"MAV_CMD_NAV_TAKEOFF"
```

```
cmdID = enum2num(dialect,"MAV_CMD",cmdName)
```

```
cmdID = 22
```

Use `enuminfo` to view the table of the `MAV_CMD` enum entries.

```
info = enuminfo(dialect,"MAV_CMD");
info.Entries{:}
```

```
ans=133×3 table
                Name                        Value
    ____________________________________    _____    __________________________________________
```

```
    "MAV_CMD_NAV_WAYPOINT"                    16       "Navigate to waypoint."
    "MAV_CMD_NAV_LOITER_UNLIM"                17       "Loiter around this waypoint an unlimited a
    "MAV_CMD_NAV_LOITER_TURNS"                18       "Loiter around this waypoint for X turns"
    "MAV_CMD_NAV_LOITER_TIME"                 19       "Loiter around this waypoint for X seconds'
    "MAV_CMD_NAV_RETURN_TO_LAUNCH"            20       "Return to launch location"
    "MAV_CMD_NAV_LAND"                        21       "Land at location"
    "MAV_CMD_NAV_TAKEOFF"                     22       "Takeoff from ground / hand"
    "MAV_CMD_NAV_LAND_LOCAL"                  23       "Land at local position (local frame only)'
    "MAV_CMD_NAV_TAKEOFF_LOCAL"               24       "Takeoff from local position (local frame c
    "MAV_CMD_NAV_FOLLOW"                      25       "Vehicle following, i.e. this waypoint repr
    "MAV_CMD_NAV_CONTINUE_AND_CHANGE_ALT"     30       "Continue on the current course and climb/c
    "MAV_CMD_NAV_LOITER_TO_ALT"               31       "Begin loiter at the specified Latitude anc
    "MAV_CMD_DO_FOLLOW"                       32       "Being following a target"
    "MAV_CMD_DO_FOLLOW_REPOSITION"            33       "Reposition the MAV after a follow target c
    "MAV_CMD_DO_ORBIT"                        34       "Start orbiting on the circumference of a c
    "MAV_CMD_NAV_ROI"                         80       "Sets the region of interest (ROI) for a se
      ⋮
```

Query the dialect for a specific message ID. Create a blank MAVLink message using the message ID.

```
info = msginfo(dialect,"HEARTBEAT")
```

```
info=1×4 table
    MessageID    MessageName
    _________    ___________    ____________________________________________________________

        0        "HEARTBEAT"    "The heartbeat message shows that a system is present and respond
```

```
msg = createmsg(dialect,info.MessageID);
```

See Also

`mavlinkclient` | `mavlinkio` | `mavlinksub`

Topics

"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites

MAVLink Developer Guide

Introduced in R2019a

mavlinkclient

MAVLink client information

Description

The `mavlinkclient` object stores MAVLink client information for connecting to UAVs (unmanned aerial vehicles) that utilize the MAVLink communication protocol. Connect with a MAVLink client using `mavlinkio` and use this object for saving the component and system information.

Creation

Syntax

`client = mavlinkclient(mavlink,sysID,compID)`

Description

`client = mavlinkclient(mavlink,sysID,compID)` creates a MAVLink client interface for a MAVLink component. Connect to a MAVLink client using `mavlinkio` and specify the object in `mavlink`. When a heartbeat is received by the client, the `ComponentType` and `AutoPilotType` properties are updated automatically. Specify the `SystemID` and `ComponentID` as integers.

Properties

`SystemID` — MAVLink system ID
positive integer between 1 and 255

MAVLink system ID, specified as a positive integer between 1 and 255. MAVLink protocol only supports up to 255 systems. Usually, each UAV has its own system ID, but multiple UAVs could be considered one system.

Example: `1`

Data Types: `uint8`

`ComponentID` — MAVLink component ID
positive integer between 1 and 255

MAVLink component ID, specified as a positive integer between 1 and 255.

Example: `2`

Data Types: `uint8`

`ComponentType` — MAVLink component type
`"Unknown"` (default) | string

MAVLink component type, specified as a string. This value is automatically updated to the correct type if a heartbeat message is received by the client with the matching system ID and component ID. You must be connected to a client using `mavlinkio`.

Example: "MAV_TYPE_GCS"

Data Types: string

AutoPilot — Autopilot type for UAV
"Unknown" (default) | string

Autopilot type for UAV, specified as a string. This value is automatically updated to the correct type if a heartbeat message is received by the client with the matching system ID and component ID. You must be connected to a client using `mavlinkio`.

Example: "MAV_AUTOPILOT_INVALID"

Data Types: string

Examples

Store MAVLink Client Information

Connect to a MAVLink client.

```
mavlink = mavlinkio("common.xml");
connect(mavlink,"UDP");
```

Create the object for storing the client information. Specify the system and component ID.

```
client = mavlinkclient(mavlink,1,1)
```

```
client =
  mavlinkclient with properties:

         SystemID: 1
      ComponentID: 1
    ComponentType: "Unknown"
    AutopilotType: "Unknown"
```

Disconnect from client.

```
disconnect(mavlink)
```

See Also

`mavlinkdialect` | `mavlinkio` | `mavlinksub`

Topics
"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites
MAVLink Developer Guide

Introduced in R2019a

mavlinkio

Connect with MAVLink clients to exchange messages

Description

The `mavlinkio` object connects with MAVLink clients through UDP ports to exchange messages with UAVs (unmanned aerial vehicles) using the MAVLink communication protocols.

Creation

Syntax

```
mavlink = mavlinkio(msgDefinitions)
mavlink = mavlinkio(dialectXML)
mavlink = mavlinkio(dialectXML,version)
mavlink = mavlinkio( ___ ,Name,Value)
```

Description

`mavlink = mavlinkio(msgDefinitions)` creates an interface to connect with MAVLink clients using the input `mavlinkdialect` object, which defines the message definitions. This dialect object is set directly to the `Dialect` property.

`mavlink = mavlinkio(dialectXML)` directly specifies the XML file for the message definitions as a file name. A `mavlinkdialect` is created using this XML file and set to the `Dialect` property

`mavlink = mavlinkio(dialectXML,version)` additionally specifies the MAVLink protocol version as either `1` or `2`.

`mavlink = mavlinkio( ___ ,Name,Value)` additionally specifies arguments using the following name-value pairs.

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`.

The name-value pairs directly set the MAVLink client information in the `LocalClient` property. See LocalClient for more info on what values can be set.

Properties

`Dialect` — MAVLink dialect
`mavlinkdialect` object

MAVLink dialect, specified as a `mavlinkdialect` object. The dialect specifies the message structure for the MAVLink protocol.

`LocalClient` — Local client information
structure

This property is read-only.

Local client information, specified as a structure. The local client is setup in MATLAB® to communicate with other MAVLink clients. The structure contains the following fields:

- `SystemID`
- `ComponentID`
- `ComponentType`
- `AutopilotType`

To set these values when creating the `mavlinkio` object, use name-value pairs. For example:

```
mavlink = mavlinkio("common.xml","SystemID",1,"ComponentID",1)
```

This property is nontunable when you are connected to a MAVLink client. For more information, see `mavlinkclient`.

Data Types: `struct`

Object Functions

connect	Connect to MAVLink clients through UDP port
disconnect	Disconnect from MAVLink clients
sendmsg	Send MAVLink message
sendudpmsg	Send MAVLink message to UDP port
serializemsg	Serialize MAVLink message to binary buffer
listConnections	List all active MAVLink connections
listClients	List all connected MAVLink clients
listTopics	List all topics received by MAVLink client

Examples

Store MAVLink Client Information

Connect to a MAVLink client.

```
mavlink = mavlinkio("common.xml");
connect(mavlink,"UDP");
```

Create the object for storing the client information. Specify the system and component ID.

```
client = mavlinkclient(mavlink,1,1)
```

```
client = 
  mavlinkclient with properties:

         SystemID: 1
      ComponentID: 1
    ComponentType: "Unknown"
    AutopilotType: "Unknown"
```

Disconnect from client.

```
disconnect(mavlink)
```

Work with MAVLink Connection

This example shows how to connect to MAVLink clients, inspect the list of topics, connections, and clients, and send messages through UDP ports using the MAVLink communication protocol.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Connect to a MAVLink client using the `"common.xml"` dialect. This local client communicates with any other clients through a UDP port.

```
dialect = mavlinkdialect("common.xml");
mavlink = mavlinkio(dialect);
connect(mavlink,"UDP")
```

```
ans =
"Connection1"
```

You can list all the active clients, connections, and topics for the MAVLink connection. Currently, there is only one client connection and no topics have received messages.

```
listClients(mavlink)
```

```
ans=1×4 table
    SystemID    ComponentID    ComponentType           AutopilotType
    ________    ___________    _____________    _______________________

      255            1         "MAV_TYPE_GCS"    "MAV_AUTOPILOT_INVALID"
```

```
listConnections(mavlink)
```

```
ans=1×2 table
    ConnectionName       ConnectionInfo
    ______________    ___________________

    "Connection1"     "UDP@0.0.0.0:56764"
```

```
listTopics(mavlink)
```

```
ans =

  0x5 empty table
```

Create a subscriber for receiving messages on the client. This subscriber listens for the `"HEARTBEAT"` message topic with ID equal to `0`.

```
sub = mavlinksub(mavlink,0);
```

Create a `"HEARTBEAT"` message using the `mavlinkdialect` object. Specify payload information and send the message over the MAVLink client.

```
msg = createmsg(dialect,"HEARTBEAT");
msg.Payload.type(:) = enum2num(dialect,'MAV_TYPE','MAV_TYPE_QUADROTOR');
sendmsg(mavlink,msg)
```

Disconnect from the client.

```
disconnect(mavlink)
```

See Also

`connect` | `mavlinkclient` | `mavlinkdialect` | `mavlinksub`

Topics

"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites

MAVLink Developer Guide

Introduced in R2019a

mavlinksub

Receive MAVLink messages

Description

The `mavlinksub` object subscribes to topics from the connected MAVLink clients using a `mavlinkio` object. Use the `mavlinksub` object to obtain the most recently received messages and call functions to process newly received messages.

Creation

Syntax

```
sub = mavlinksub(mavlink)
sub = mavlinksub(mavlink,topic)
sub = mavlinksub(mavlink,client)
sub = mavlinksub(mavlink,client,topic)
sub = mavlinksub( ___ ,Name,Value)
```

Description

`sub = mavlinksub(mavlink)` subscribes to all topics from all clients connected via the `mavlinkio` object. This syntax sets the `Client` property to `"Any"`.

`sub = mavlinksub(mavlink,topic)` subscribes to a specific topic, specified as a string or integer, from all clients connected via the `mavlinkio` object. The function sets the `topic` input to the `Topic` property.

`sub = mavlinksub(mavlink,client)` subscribes to all topics from the client specified as a `mavlinkclient` object. The function sets the `Client` property to this input client.

`sub = mavlinksub(mavlink,client,topic)` subscribes to a specific topic on a specific client. The function sets the `Client` and `Topic` properties.

`sub = mavlinksub( ___ ,Name,Value)` additionally specifies the `BuffferSize` or `NewMessageFcn` properties using name-value pairs and the previous syntaxes. The `Name` input is one of the property names.

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`.

Properties

`Client` — Client information of received message
`"Any"` (default) | `mavlinkclient` object

Client information of the received message, specified as a `mavlinkclient` object. The default value of `"Any"` means the subscriber is listening to all clients connected via the `mavlinkio` object.

`Topic` — Topic name
`"Any"` (default) | string

Topic name the subscriber listens to, specified as a string. The default value of `"Any"` means the subscriber is listening to all topics on the client.

Example: `"HEARTBEAT"`

Data Types: `char` | `string`

`BufferSize` — Length of message buffer
`1` (default) | positive integer

Length of message buffer, specified as a positive integer. This value is the maximum number of messages that can be stored in this subscriber.

Data Types: `double`

`NewMessageFcn` — Callback function for new messages
`[]` (default) | function handle

Callback function for new messages, specified as a function handle. This function is called when a new message is received by the client. The function handle has the following syntax:

```
callback(sub,msg)
```

`sub` is a structure with fields for the `Client`, `Topic`, and `BufferSize` properties of the `mavlinksub` object. `msg` is the message received as a structure with the fields:

- `MsgID` –– Positive integer for message ID.
- `SystemID` –– System ID of MAVLink client that sent message.
- `ComponentID`–– Component ID of MAVLink client that sent message.
- `Payload` –– Structure containing fields based on the message definition.
- `Seq` –– Positive integer for sequence of message.

The `Payload` is a structure defined by the message definition for the MAVLink dialect.

Data Types: `function_handle`

Object Functions

latestmsgs   Received messages from MAVLink subscriber

Examples

Subscribe to MAVLink Topic

Connect to a MAVLink client.

```
mavlink = mavlinkio("common.xml")
```

```
mavlink = 
  mavlinkio with properties:
```

```
        Dialect: [1x1 mavlinkdialect]
    LocalClient: [1x1 struct]
```

```
connect(mavlink,"UDP")
```

```
ans = 
"Connection1"
```

Get the client information.

```
client = mavlinkclient(mavlink,1,1);
```

Subscribe to the "HEARTBEAT" topic.

```
heartbeat = mavlinksub(mavlink,client,'HEARTBEAT');
```

Get the latest message. You must wait for a message to be received. Currently, no heartbeat message has been received on the `mavlink` object.

```
latestmsgs(heartbeat,1)
```

```
ans = 

  1x0 empty struct array with fields:

    MsgID
    SystemID
    ComponentID
    Payload
    Seq
```

Disconnect from client.

```
disconnect(mavlink)
```

See Also

`latestmsgs` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio`

Topics

"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites

MAVLink Developer Guide

Introduced in R2019a

mavlinktlog

Read MAVLink message from TLOG file

Description

The `mavlinktlog` object reads all messages from a telemetry log or TLOG file (`.tlog`). The object gives you information about the file, including the start and end time, number of messages, available topics, and packet loss percentage. You can specify a MAVLink dialect for parsing the messages or use the `common.xml` dialect.

Creation

Syntax

```
tlogReader = mavlinktlog(filePath)
tlogReader = mavlinktlog(filePath,dialect)
```

Description

`tlogReader = mavlinktlog(filePath)` reads all messages from the tlog file at the given file path and returns an object summarizing the file. This syntax uses the `common.xml` dialect for the MAVLink protocol (Version 2.0) for parsing the messages. The information in `filePath` is used to set the `FileName` property.

`tlogReader = mavlinktlog(filePath,dialect)` reads the MAVLink messages based on the dialect specified as a `mavlinkdialect` object or string scalar specifying the XML file path. `dialect` sets the `Dialect` property.

Properties

`FileName` — Name of TLOG file
string scalar | character vector

This property is read-only.

Name of the TLOG file, specified as a string scalar or character vector. The name is the last part of the path given in the `filePath` input.

Example: `'flightlog.tlog'`

Data Types: `string` | `char`

`Dialect` — MAVLink dialect
`'common.xml'` (default) | `mavlinkdialect` object

This property is read-only.

MAVLink dialect used for parsing the message data, specified as a `mavlinkdialect` object.

`StartTime` — Time of first message recorded
`datetime` object

This property is read-only.

Time of the first message recorded in the TLOG file, specified as a `datetime` object.

Data Types: `datetime`

`EndTime` — Time of last message recorded
`datetime` object

This property is read-only.

Time of the last message recorded in the TLOG file, specified as a `datetime` object.

Data Types: `datetime`

`NumMessages` — Number of MAVLink messages in TLOG file
numeric scalar

This property is read-only.

Number of MAVLink messages in the TLOG file, specified as a numeric scalar.

Data Types: `double`

`AvailableTopics` — List of different message types
table

This property is read-only.

List of different messages, specified as a table that contains:

- `MessageID`
- `MessageName`
- `SystemID`
- `ComponentID`
- `NumMessages`

Data Types: `table`

`NumPacketsLost` — Percentage of packets lost
numeric scalar from 0 through 100

This property is read-only.

Percentage of packets lost, specified as a numeric scalar from 0 through 100.

Data Types: `double`

Object Functions

readmsg   Read specific messages from TLOG file

Examples

Read Messages from MAVLink TLOG File

Load the TLOG file. Specify the relative path of the file name.

```
tlogReader = mavlinktlog('flight.tlog');
```

Read the 'REQUEST_DATA_STREAM' messages from the file.

```
msgData = readmsg(result,'MessageName','REQUEST_DATA_STREAM');
```

See Also

mavlinkclient | mavlinkdialect | mavlinkio | readmsg

Topics

"Visualize and Playback MAVLink Flight Log"

Introduced in R2019a

multirotor

Guidance model for multirotor UAVs

Description

A `multirotor` object represents a reduced-order guidance model for an unmanned aerial vehicle (UAV). The model approximates the behavior of a closed-loop system consisting of an autopilot controller and a multirotor kinematic model for 3-D motion.

For fixed-wing UAVs, see `fixedwing`.

Creation

`model = multirotor` creates a multirotor motion model with `double` precision values for inputs, outputs, and configuration parameters of the guidance model.

`model = multirotor(DataType)` specifies the data type precision (`DataType` property) for the inputs, outputs, and configurations parameters of the guidance model.

Properties

Name — Name of UAV
`"Unnamed"` (default) | string scalar

Name of the UAV, used to differentiate it from other models in the workspace, specified as a string scalar.

Example: `"myUAV1"`

Data Types: `string`

`Configuration` — UAV controller configuration
structure

UAV controller configuration, specified as a structure of parameters. Specify these parameters to tune the internal control behaviour of the UAV. Specify the proportional (P) and derivative (D) gains for the dynamic model and other UAV parameters. For multirotor UAVs, the structure contains these fields with defaults listed:

- `'PDRoll'`- `[3402.97 116.67]`
- `'PDPitch'` - `[3402.97 116.67]`
- `'PYawRate'` - `1950`
- `'PThrust'` - `3900`
- `'Mass'` - `0.1` (measured in kg)

Example: `struct('PDRoll',[3402.97,116.67],'PDPitch',[3402.97,116.67],'PYawRate',1950,'PThrust',3900,'Mass',0.1)`

Data Types: `struct`

`ModelType` — UAV guidance model type
`'MultirotorGuidance'` (default)

This property is read-only.

UAV guidance model type, specified as `'MultirotorGuidance'`.

`DataType` — Input and output numeric data types
`'double'` (default) | `'single'`

Input and output numeric data types, specified as either `'double'` or `'single'`. Choose the data type based on possible software or hardware limitations. Specify `DataType` when first creating the object.

Object Functions

control	Control commands for UAV
derivative	Time derivative of UAV states
environment	Environmental inputs for UAV
state	UAV state vector

Examples

Simulate A Multirotor Control Command

This example shows how to use the `multirotor` guidance model to simulate the change in state of a UAV due to a command input.

Create the multirotor guidance model.

```
model = multirotor;
```

Create a state structure. Specify the location in world coordinates.

```
s = state(model);
s(1:3) = [3;2;1];
```

Specify a control command, `u`, that specified the roll and thrust of the multirotor.

```
u = control(model);
u.Roll = pi/12;
u.Thrust = 1;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

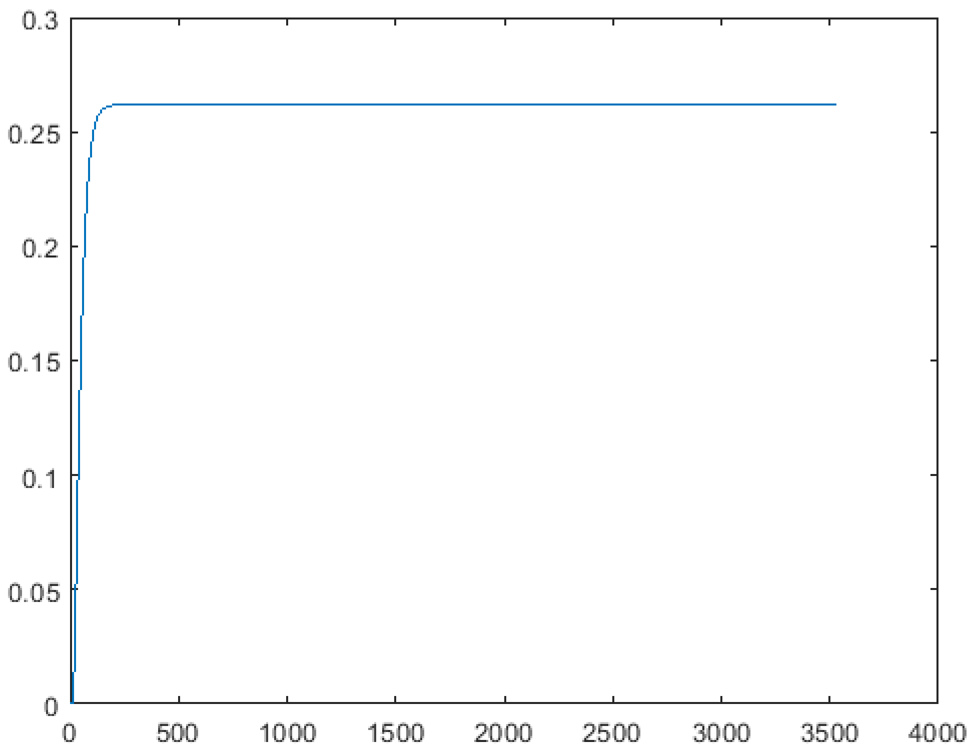
Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states as a 13-by-*n* matrix.

```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 3], s);
size(simOut.y)
```

```
ans = 1×2

          13        3536
```

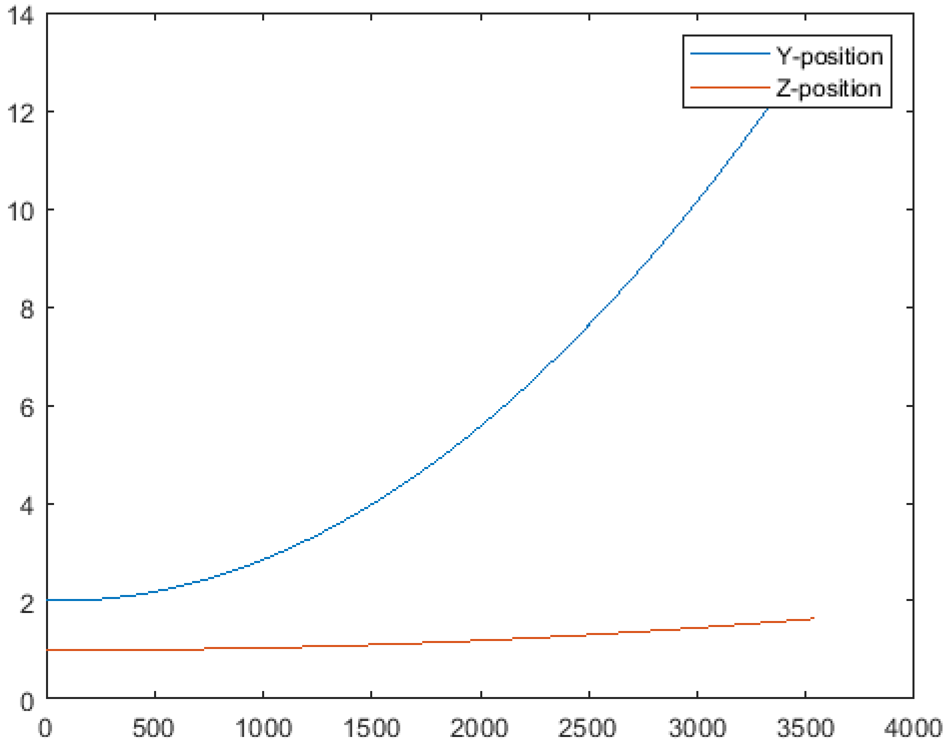
Plot the change in roll angle based on the simulation output. The roll angle (the X Euler angle) is the 9th row of the `simOut.y` output.

```
plot(simOut.y(9,:))
```



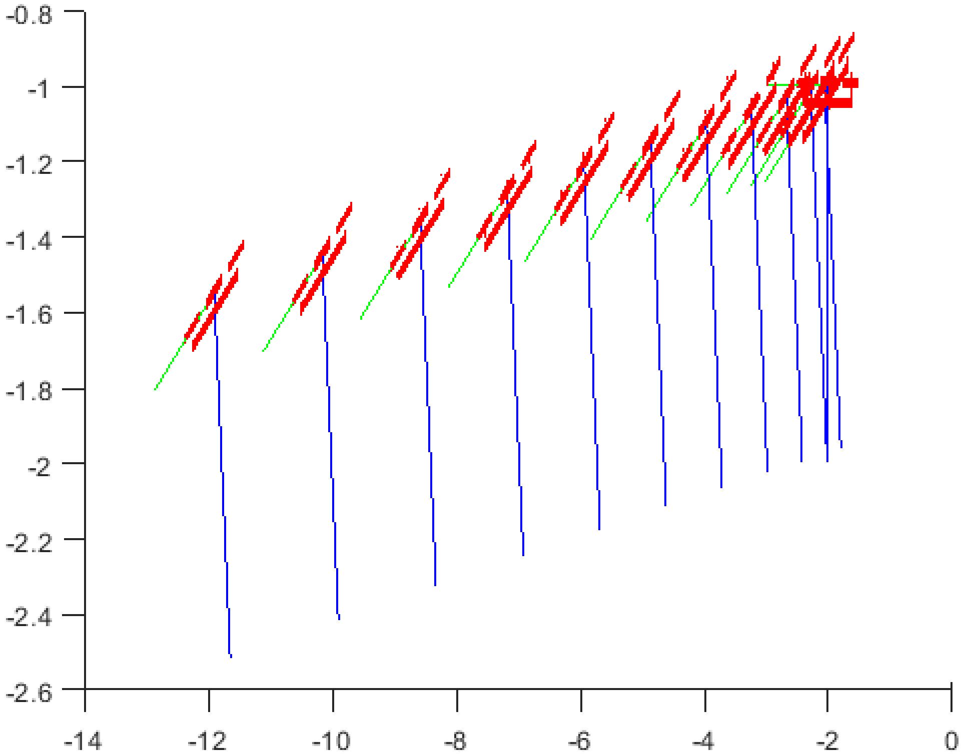
Plot the change in the Y and Z positions. With the specified thrust and roll angle, the multirotor should fly over and lose some altitude. A positive value for Z is expected as positive Z is down.

```
figure
plot(simOut.y(2,:));
hold on
plot(simOut.y(3,:));
legend('Y-position','Z-position')
hold off
```



You can also plot the multirotor trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 300th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `multirotor.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV translating in the Y-direction and losing altitude.

```
translations = simOut.y(1:3,1:300:end)'; % xyz position
rotations = eul2quat(simOut.y(7:9,1:300:end)'); % ZYX Euler
plotTransforms(translations,rotations,...
    'MeshFilePath','multirotor.stl','InertialZDirection',"down")
view([90.00 -0.60])
```



More About

UAV Coordinate Systems

The UAV Toolbox uses the North-East-Down (NED) coordinate system convention, which is also sometimes called the local tangent plane (LTP). The UAV position vector consists of three numbers for position along the northern-axis, eastern-axis, and vertical position. The down element complies with the right-hand rule and results in negative values for altitude gain.

The ground plane, or earth frame (NE plane, D = 0), is assumed to be an inertial plane that is flat based on the operation region for small UAV control. The earth frame coordinates are $[x_e,y_e,z_e]$. The body frame of the UAV is attached to the center of mass with coordinates $[x_b,y_b,z_b]$. x_b is the preferred forward direction of the UAV, and z_b is perpendicular to the plane that points downwards when the UAV travels during perfect horizontal flight.

The orientation of the UAV (body frame) is specified in ZYX Euler angles. To convert from the earth frame to the body frame, we first rotate about the z_e-axis by the yaw angle, ψ. Then, rotate about the intermediate y-axis by the pitch angle, ϕ. Then, rotate about the intermediate x-axis by the roll angle, Θ.

The angular velocity of the UAV is represented by $[p,q,r]$ with respect to the body axes, $[x_b,y_b,z_b]$.

UAV Multirotor Guidance Model Equations

For multirotors, the following equations are used to define the guidance model of the UAV. To calculate the time-derivative of the UAV state using these governing equations, use the `derivative` function. Specify the inputs using `state`, `control`, and `environment`.

The UAV position in the earth frame is $[x_e, y_e, z_e]$ with orientation as ZYX Euler angles, $[\psi, \Theta, \phi]$ in radians. Angular velocities are $[p, q, r]$ in radians per second.

The UAV body frame uses coordinates as $[x_b, y_b, z_b]$.

The rotation matrix that rotates from world to body frame is:

$$R_b^e = \begin{bmatrix} c_\theta c_\psi & c_\psi s_\phi s_\theta - c_\phi s_\psi & c_\phi c_\psi s_\theta + s_\phi s_\psi \\ c_\theta s_\psi & c_\phi c_\psi + s_\phi s_\theta s_\psi & -c_\psi s_\phi + c_\phi s_\theta s_\psi \\ -s_\theta & c_\theta s_\phi & c_\phi c_\theta \end{bmatrix}$$

The cos(x) and sin(x) are abbreviated as c_x and s_x.

The acceleration of the UAV center of mass in earth coordinates is governed by:

$$m \begin{bmatrix} \ddot{x}_e \\ \ddot{y}_e \\ \ddot{z}_e \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} + R_b^e \begin{bmatrix} 0 \\ 0 \\ -F_{thrust} \end{bmatrix}$$

m is the UAV mass, g is gravity, and F_{thrust} is the total force created by the propellers applied to the multirotor along the $-z_b$ axis (points upwards in a horizontal pose).

The closed-loop roll-pitch attitude controller is approximated by the behavior of 2 independent PD controllers for the two rotation angles, and 2 independent P controllers for the yaw rate and thrust. The angular velocity, angular acceleration, and thrust are governed by:

$$J = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta} \end{bmatrix}$$

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\sin\theta \\ 0 & \cos\phi & \sin\phi\cos\theta \\ 0 & -\sin\phi & \cos\phi\cos\theta \end{bmatrix} \begin{bmatrix} KP_{\phi}\left(\dot{\phi}^{c} - \dot{\phi}\right) + KD_{\phi}\left(-\dot{\phi}\right) \\ KP_{\theta}(\theta^{c} - \theta) + KD_{\theta}\left(-\dot{\theta}\right) \\ KP_{\psi}\left(\dot{\psi}^{c} - \dot{\psi}\right) \end{bmatrix}$$

$$\dot{F}_{thrust} = KP_{F}(F^{c}_{thrust} - F_{thrust})$$

This model assumes the autopilot takes in commanded roll, pitch, yaw rate, [ψ^c, Θ^c, $\dot{\phi}^c$] and a commanded total thrust force, $F^c{}_{thrust}$. The structure to specify these inputs is generated from `control`.

The P and D gains for the control inputs are specified as KP_α and KD_α, where α is either the rotation angle or thrust. These gains along with the UAV mass, m, are specified in the `Configuration` property of the `multirotor` object.

From these governing equations, the model gives the following variables:

$$[x_e \quad y_e \quad z_e \quad \dot{x}_e \quad \dot{y}_e \quad \dot{z}_e \quad \psi \quad \theta \quad \phi \quad p \quad q \quad r \quad F_{thrust}]$$

These variables match the output of the `state` function.

References

[1] Mellinger, Daniel, and Nathan Michael. "Trajectory Generation and Control for Precise Aggressive Maneuvers with Quadrotors." *The International Journal of Robotics Research*. 2012, pp. 664-74.

Extended Capabilities

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

See Also

Functions
control | derivative | environment | ode45 | plotTransforms | state

Objects
fixedwing | uavWaypointFollower

Blocks
UAV Guidance Model | Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

quaternion

Create a quaternion array

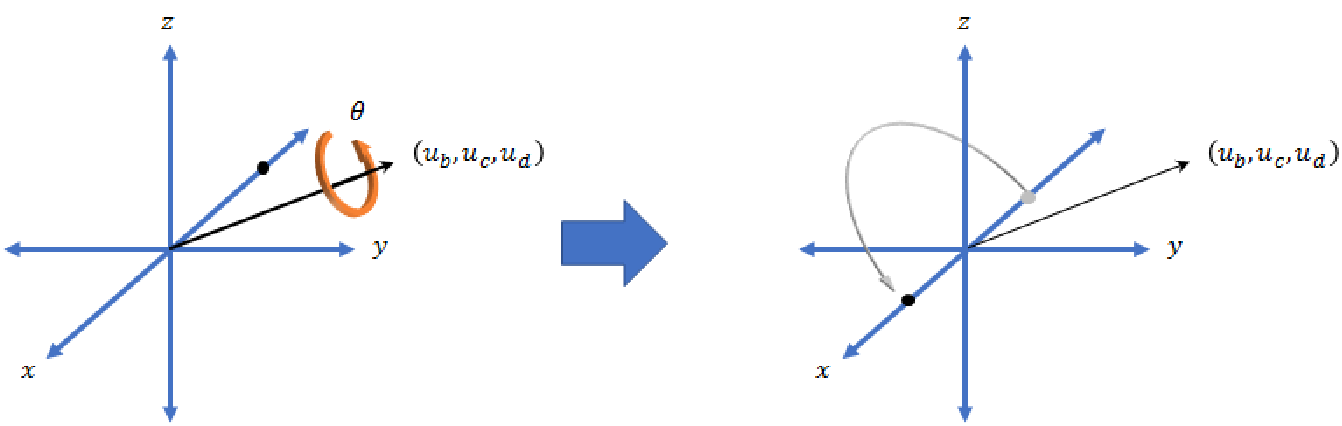
Description

A quaternion is a four-part hyper-complex number used in three-dimensional rotations and orientations.

A quaternion number is represented in the form $a + b\text{i} + c\text{j} + d\text{k}$, where a, b, c, and d parts are real numbers, and i, j, and k are the basis elements, satisfying the equation: $\text{i}^2 = \text{j}^2 = \text{k}^2 = \text{ijk} = -1$.

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 $q = \cos\left(\theta/2\right) + \sin\left(\theta/2\right)(u_b\text{i} + u_c\text{j} + u_d\text{k})$, 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];
```

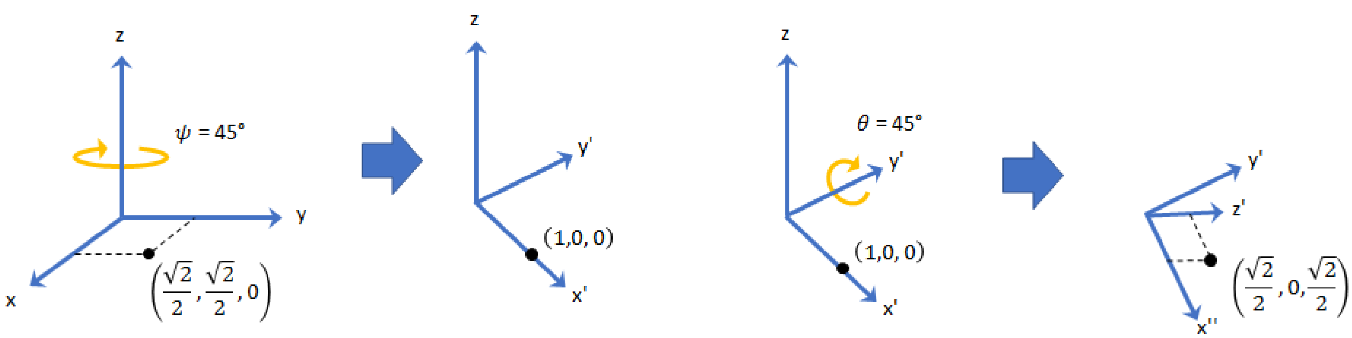
In this representation, the first column represents the *x*-axis, the second column represents the *y*-axis, and the third column represents the *z*-axis.

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)
  ```

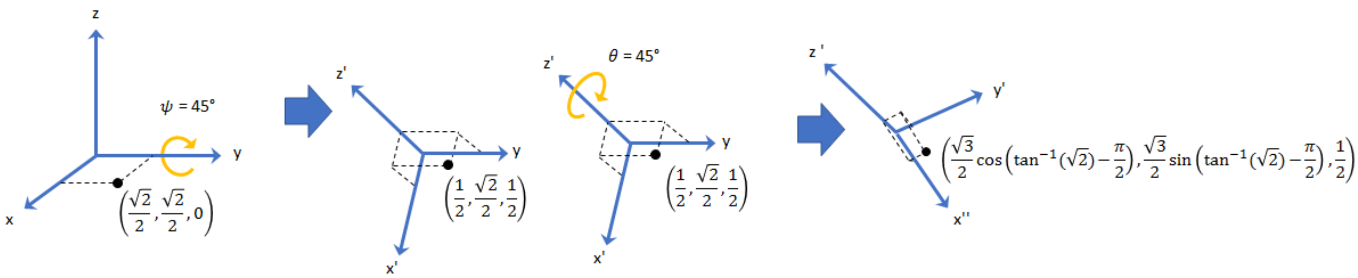
  ```
  newPointCoordinate =

      0.7071   -0.0000    0.7071
  ```



- If you create a quaternion rotator and specify the 'YZX' sequence, the frame is first rotated 45° around the *y*-axis, then 45° around the new *z*-axis.

  ```
  quatRotator = quaternion([45,45,0],'eulerd','YZX','frame');
  newPointCoordinate = rotateframe(quatRotator,point)
  ```

  ```
  newPointCoordinate =

      0.8536    0.1464    0.5000
  ```



Data Types: `char` | `string`

Object Functions

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
ctranspose, '	Complex conjugate transpose of quaternion array
dist	Angular distance in radians
euler	Convert quaternion to Euler angles (radians)
eulerd	Convert quaternion to Euler angles (degrees)
exp	Exponential of quaternion array
ldivide, .\	Element-wise quaternion left division
log	Natural logarithm of quaternion array
meanrot	Quaternion mean rotation
minus, -	Quaternion subtraction
mtimes, *	Quaternion multiplication
norm	Quaternion norm
normalize	Quaternion normalization
ones	Create quaternion array with real parts set to one and imaginary parts set to zero
parts	Extract quaternion parts
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, .'	Transpose a quaternion array
uminus, -	Quaternion unary minus
zeros	Create quaternion array with all parts set to zero

Examples

Create Empty Quaternion

```
quat = quaternion()
```

```
quat =

  0x0 empty quaternion array
```

By default, the underlying class of the quaternion is a double.

```
classUnderlying(quat)
```

```
ans =
'double'
```

Create Quaternion by Specifying Individual Quaternion Parts

You can create a quaternion array by specifying the four parts as comma-separated scalars, matrices, or multidimensional arrays of the same size.

Define quaternion parts as scalars.

```
A = 1.1;
B = 2.1;
C = 3.1;
D = 4.1;
quatScalar = quaternion(A,B,C,D)
```

```
quatScalar = quaternion
     1.1 + 2.1i + 3.1j + 4.1k
```

Define quaternion parts as column vectors.

```
A = [1.1;1.2];
B = [2.1;2.2];
C = [3.1;3.2];
D = [4.1;4.2];
quatVector = quaternion(A,B,C,D)
```

```
quatVector=2×1 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=2×2 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=3×1 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=1×2 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=2×2 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=4×1 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=2×2 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 R2020b

transformTree

Define coordinate frames and relative transformations

Description

The `transformTree` object contains an organized tree structure for coordinate frames and their relative transformations over time. The object stores the relative transformations between children frames and their parents. You can specify a timestamped transform for frames and query the relative transformations between different frames in the tree. The object interpolates intermediate timestamps using a constant velocity assumption for linear motion, and spherical linear interpolation (SLERP) for angular motion. Otherwise, the relative transformations are kept constant past the range of the timestamps specified. Times prior to the first timestamp return `NaN`.

Use the `updateTransform` function to add timestamps to the tree by defining the parent-to-child relationships. Query specific transformations at given timestamps using `getTransform` and display the frame relationships using `show`.

Creation

Syntax

```
frames = transformTree
frames = transformTree(baseName)
frames = transformTree(baseName,numFrames)
frames = transformTree(baseName,numFrames,numTransforms)
frames = transformTree(baseName,numFrames,numTransforms,rootTime)
```

Description

`frames = transformTree` creates a transformation tree data structure with a single frame, `"root"`, with the maximum number of frames and timestamped transforms per frame, set to 10.

`frames = transformTree(baseName)` specifies the name of the root frame as a string or character vector.

`frames = transformTree(baseName,numFrames)` additionally sets the MaxNumFrames property, which defines the max number of named frames in the object.

`frames = transformTree(baseName,numFrames,numTransforms)` additionally sets the `MaxNumTransforms` property, which defines the max number of timestamped transforms per frame name.

`frames = transformTree(baseName,numFrames,numTransforms,rootTime)` additionally specifies the timestamp of the initial `baseName` frame as a scalar time in seconds.

Properties

`MaxNumFrames` — Maximum number of frames in tree
10 (default) | positive integer

Maximum number of frames in the tree, specified as a positive integer. Each frame has associated timestamped transforms that define the state of the frame at those specific times.

Data Types: `double`

`MaxNumTransforms` — Maximum number of timestamped transforms per frame
10 (default) | positive integer

Maximum number of timestamped transforms per frame, specified as a positive integer. This property sets an upper limit on the number of timestamped transforms the object can store for each frame named in the structure. A `transformTree` object with `MaxNumFrames` and `MaxNumTransforms` set to 10 can store a maximum of 100 transformations with 10 for each frame.

Data Types: `double`

`NumFrames` — Current number of coordinate frames stored
1 (default) | positive integer

Current number of coordinate frames stored, specified as a positive integer. The object starts with a single root frame, and new frames and specific timestamps are added using `updateFrame`.

Data Types: `double`

Object Functions

getGraph	Graph object representing tree structure
getTransform	Get relative transform between frames
info	List all frame names and stored timestamps
removeTransform	Remove frame transform relative to its parent
show	Show transform tree
updateTransform	Update frame transform relative to its parent

See Also

Objects
`fixedwing` | `multirotor` | `uavDubinsPathSegment`

Functions
`getGraph` | `getTransform` | `info` | `removeTransform` | `show` | `updateTransform`

Introduced in R2020b

uavDubinsConnection

Dubins path connection for UAV

Description

The `uavDubinsConnection` object holds information for computing a `uavDubinsPathSegment` path segment to connect start and goal poses of a UAV.

A UAV Dubins path segment connects two poses as a sequence of motions in the north-east-down coordinate system.

The motion options are:

- Straight
- Left turn (counterclockwise)
- Right turn (clockwise)
- Helix left turn (counterclockwise)
- Helix right turn (clockwise)
- No motion

The turn direction is defined as viewed from the top of the UAV. Helical motions are used to ascend or descend.

Use this connection object to define parameters for a UAV motion model, including the minimum turning radius and options for path types. To generate a path segment between poses using this connection type, call the `connect` function.

Creation

Syntax

```
connectionObj = uavDubinsConnection
connectionObj = uavDubinsConnection(Name,Value)
```

Description

`connectionObj = uavDubinsConnection` creates an object using default property values.

`connectionObj = uavDubinsConnection(Name,Value)` specifies property values using name-value pairs. To set multiple properties, specify multiple name-value pairs.

Properties

`AirSpeed` — Airspeed of UAV
`10` (default) | positive numeric scalar

Airspeed of the UAV, specified as a positive numeric scalar in m/s.

Data Types: `double`

`MaxRollAngle` — Maximum roll angle

`0.5` (default) | positive numeric scalar

Maximum roll angle to make the UAV turn left or right, specified as a positive numeric scalar in radians.

Note The minimum and maximum values for `MaxRollAngle` are greater than `0` and less than `pi/2`, respectively.

Data Types: `double`

`FlightPathAngleLimit` — Minimum and maximum flight path angles

`[-0.5 0.5]` (default) | two-element numeric vector

Flight path angle limits, specified as a two-element numeric vector `[`*`min max`*`]` in radians.

min is the minimum flight path angle the UAV takes to lose altitude, and *max* is the maximum flight path angle to gain altitude.

Note The minimum and maximum values for `FlightPathAngleLimit` are greater than `-pi/2` and less than `pi/2`, respectively.

Data Types: `double`

`DisabledPathTypes` — Path types to disable

`{}` (default) | cell array of four-element character vectors | vector of four-element string scalars

UAV Dubins path types to disable, specified as a cell array of four-element character vectors or vector of string scalars. The cell array defines the four prohibited sequences of motions.

Motion Type	Description
`"S"`	Straight
`"L"`	Left turn (counterclockwise)
`"R"`	Right turn (clockwise)
`"Hl"`	Helix left turn (counterclockwise)
`"Hr"`	Helix right turn (clockwise)
`"N"`	No motion

Note The no motion segment `"N"` is used as a filler at the end when only three path segments are needed.

To see all available path types, see the AllPathTypes property.

Example: `{'RLRN'}`

Data Types: `string` | `cell`

`MinTurningRadius` — Minimum turning radius
positive numeric scalar

This property is read-only.

Minimum turning radius of the UAV, specified as a positive numeric scalar in meters. This value corresponds to the radius of the circle at the maximum roll angle and a constant airspeed of the UAV.

Data Types: `double`

`AllPathTypes` — All possible path types
cell array of character vectors

This property is read-only.

All possible path types, returned as a cell array of character vectors. This property lists all types. To disable certain types, specify types from this list in the DisabledPathTypes property.

For UAV Dubins connections, the available path types are: `{'LSLN'} {'LSRN'} {'RSLN'} {'RSRN'} {'RLRN'} {'LRLN'} {'HlLSL'} {'HlLSR'} {'HrRSL'} {'HrRSR'} {'HrRLR'} {'HlLRL'} {'LSLHl'} {'LSRHr'} {'RSLHl'} {'RSRHr'} {'RLRHr'} {'LRLHl'} {'LRSL'} {'LRSR'} {'LRLR'} {'RLSR'} {'RLRL'} {'RLSL'} {'LSRL'} {'RSRL'} {'LSLR'} {'RSLR'}`.

Data Types: `cell`

Object Functions

connect   Connect poses with UAV Dubins connection path

Examples

Connect Poses Using UAV Dubins Connection Path

This example shows how to calculate a UAV Dubins path segment and connect poses using the `uavDubinsConnection` object.

Create a `uavDubinsConnection` object.

```
connectionObj = uavDubinsConnection;
```

Define start and goal poses as [`x`, `y`, `z`, `headingAngle`] vectors.

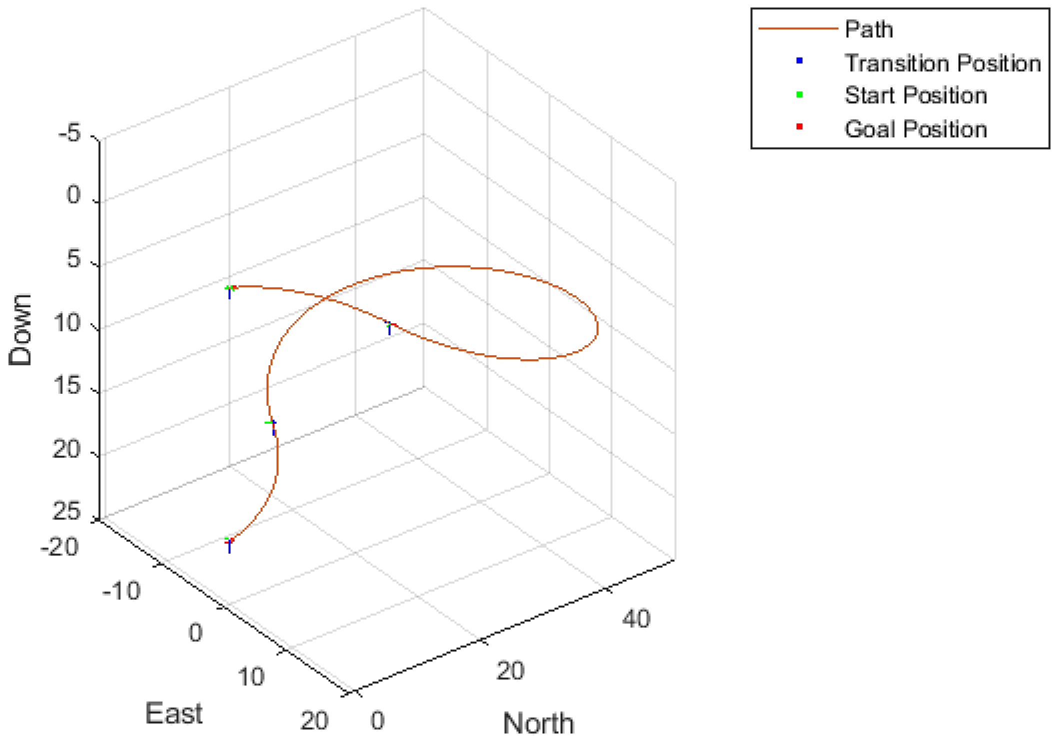
```
startPose = [0 0 0 0]; % [meters, meters, meters, radians]
goalPose = [0 0 20 pi];
```

Calculate a valid path segment and connect the poses. Returns a path segment object with the lowest path cost.

```
[pathSegObj,pathCosts] = connect(connectionObj,startPose,goalPose);
```

Show the generated path.

```
show(pathSegObj{1})
```



Display the motion type and the path cost of the generated path.

```
fprintf('Motion Type: %s\nPath Cost: %f\n',strjoin(pathSegObj{1}.MotionTypes),pathCosts);
```

```
Motion Type: R L R N
Path Cost: 138.373157
```

Modify Connection Types for UAV Dubins Connection Path

This example shows how to modify an existing `uavDubinsPathSegment`object.

Connect Poses Using UAV Dubins Connection Path

Create a `uavDubinsConnection` object.

```
connectionObj = uavDubinsConnection;
```

Define start and goal poses as [`x`, `y`, `z`, `headingAngle`] vectors.

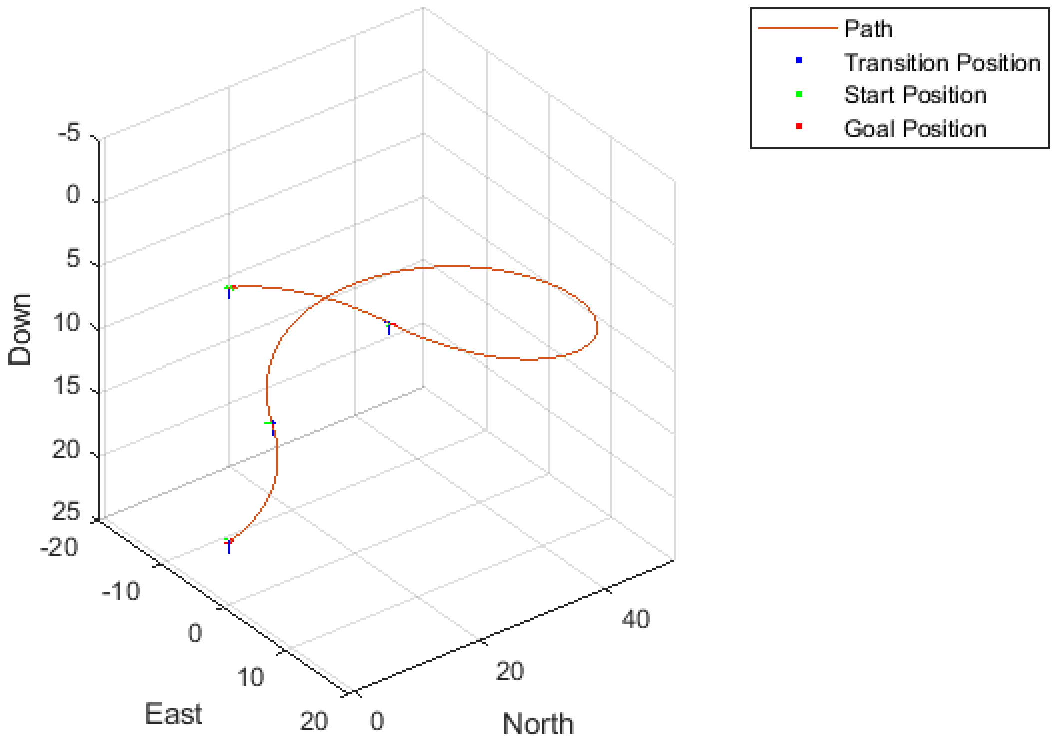
```
startPose = [0 0 0 0]; % [meters, meters, meters, radians]
goalPose = [0 0 20 pi];
```

Calculate a valid path segment and connect the poses. Returns a path segment object with the lowest path cost.

```
[pathSegObj,pathCosts] = connect(connectionObj,startPose,goalPose);
```

Show the generated path.

```
show(pathSegObj{1})
```



Verify the motion type and the path cost of the returned path segment.

```
fprintf('Motion Type: %s\nPath Cost: %f\n',strjoin(pathSegObj{1}.MotionTypes),pathCosts);
```

```
Motion Type: R L R N
Path Cost: 138.373157
```

Modify Connection Type and Properties

Disable this specific motion sequence in a new connection object. Specify the `AirSpeed`, `MaxRollAngle`, and `FlightPathAngleLimit` properties of the connection object.

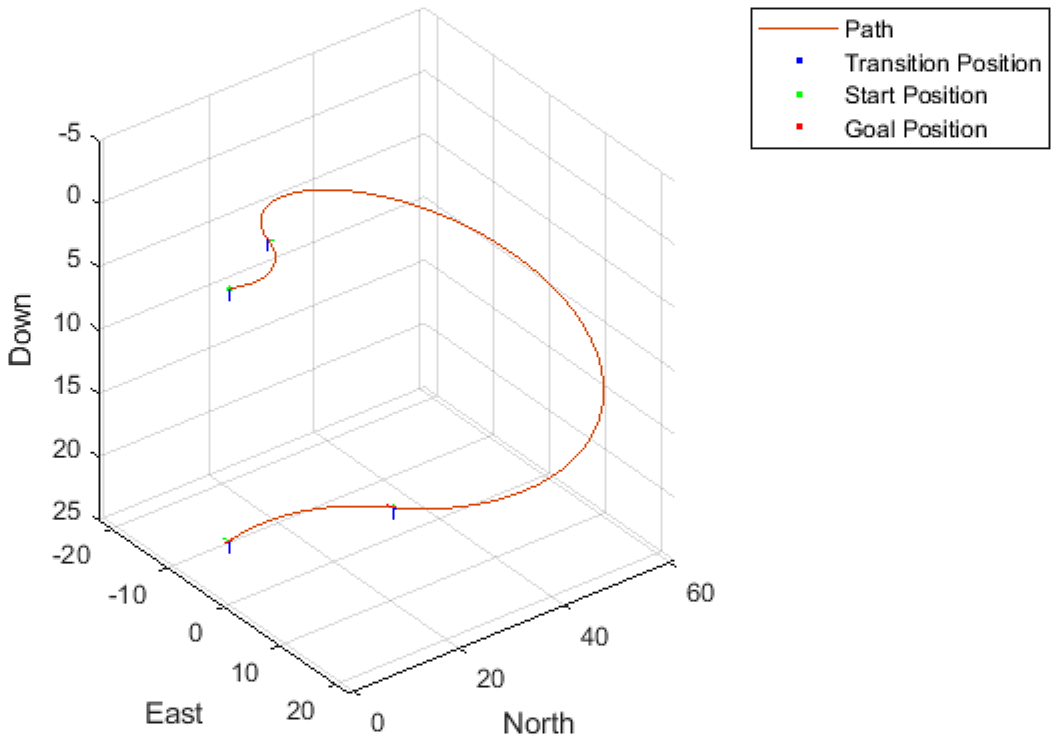
```
connectionObj = uavDubinsConnection('DisabledPathTypes',{'RLRN'});
connectionObj.AirSpeed = 15;
connectionObj.MaxRollAngle = 0.8;
connectionObj.FlightPathAngleLimit = [-1.47 1.47];
```

Connect the poses again to get a different path. Returns a path segment object with the next lowest path cost.

```
[pathSegObj,pathCosts] = connect(connectionObj,startPose,goalPose);
```

Show the modified path.

```
show(pathSegObj{1})
```



Verify the motion type and the path cost of the modified path segment.

```
fprintf('Motion Type: %s\nPath Cost: %f\n',strjoin(pathSegObj{1}.MotionTypes),pathCosts);
```

```
Motion Type: L R L N
Path Cost: 164.674067
```

References

[1] Owen, Mark, Randal W. Beard, and Timothy W. McLain. "Implementing Dubins Airplane Paths on Fixed-Wing UAVs." *Handbook of Unmanned Aerial Vehicles*, 2015, pp. 1677–1701.

Extended Capabilities

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

See Also

`uavDubinsPathSegment`

Introduced in R2019b

uavDubinsPathSegment

Dubins path segment connecting two poses of UAV

Description

The `uavDubinsPathSegment` object holds information for a Dubins path segment that connects start and goal poses of a UAV as a sequence of motions in the north-east-down coordinate system.

The motion options are:

- Straight
- Left turn (counterclockwise)
- Right turn (clockwise)
- Helix left turn (counterclockwise)
- Helix right turn (clockwise)
- No motion

The turn direction is defined as viewed from the top of the UAV. Helical motions are used to ascend or descend.

Creation

Syntax

```
pathSegObj = connect(connectionObj,start,goal)

pathSegObj = uavDubinsPathSegment(connectionObj,start,goal)
pathSegObj = uavDubinsPathSegment(connectionObj,start,goal,motionTypes)
pathSegObj = uavDubinsPathSegment(start,goal,flightPathAngle,airSpeed,
minTurningRadius,helixRadius,motionTypes,motionLengths)
```

Description

To generate a `uavDubinsPathSegment` object, use the `connect` function with a `uavDubinsConnection` object:

`pathSegObj = connect(connectionObj,start,goal)` connects the start and goal poses using the specified `uavDubinsConnection` object. The `start` and `goal` inputs set the value of the properties StartPose and GoalPose, respectively.

To specifically define a path segment:

`pathSegObj = uavDubinsPathSegment(connectionObj,start,goal)` creates a Dubins path segment to connect start and goal poses of a UAV. The `uavDubinsConnection` object provides the minimum turning radius and flight path angle. It internally computes the optimal path and assigns it to `pathSegObj`.

`pathSegObj = uavDubinsPathSegment(connectionObj,start,goal,motionTypes)` creates a Dubins path segment to connect start and goal poses of a UAV with the given `motionTypes`. The `motionTypes` input sets the value of the MotionTypes property.

`pathSegObj = uavDubinsPathSegment(start,goal,flightPathAngle,airSpeed, minTurningRadius,helixRadius,motionTypes,motionLengths)` creates a Dubins path segment to connect start and goal poses of a UAV by explicitly specifying all the parameters. The input values are set to their corresponding properties in the object.

Properties

`StartPose` — Initial pose of UAV
four-element numeric vector

This property is read-only.

Initial pose of the UAV at the start of the path segment, specified as a four-element numeric vector [*x*, *y*, *z*, *headingAngle*].

x, *y*, and *z* specify the position in meters. *headingAngle* specifies the heading angle in radians.

Data Types: `double`

`GoalPose` — Goal pose of UAV
four-element numeric vector

This property is read-only.

Goal pose of the UAV at the end of the path segment, specified as a four-element numeric vector [*x*, *y*, *z*, *headingAngle*].

x, *y*, and *z* specify the position in meters. *headingAngle* specifies the heading angle in radians.

Data Types: `double`

`MinTurningRadius` — Minimum turning radius
positive numeric scalar

This property is read-only.

Minimum turning radius of the UAV, specified as a positive numeric scalar in meters. This value corresponds to the radius of the circle at the maximum roll angle and a constant airspeed of the UAV.

Data Types: `double`

`HelixRadius` — Helical path radius
positive numeric scalar

This property is read-only.

Helical path radius of the UAV, specified as a positive numeric scalar in meters.

Data Types: `double`

`FlightPathAngle` — Flight path angle
positive numeric scalar

This property is read-only.

Flight path angle of the UAV to reach the goal altitude, specified as a positive numeric scalar in radians.

Data Types: `double`

`AirSpeed` — Airspeed of UAV
positive numeric scalar

This property is read-only.

Airspeed of the UAV, specified as a positive numeric scalar in m/s.

Data Types: `double`

`MotionLengths` — Length of each motion
four-element numeric vector

This property is read-only.

Length of each motion in the path segment, specified as a four-element numeric vector in meters. Each motion length corresponds to a motion type specified in the MotionTypes property.

Data Types: `double`

`MotionTypes` — Type of each motion
four-element string cell array

This property is read-only.

Type of each motion in the path segment, specified as a three-element string cell array.

Motion Type	Description
`"S"`	Straight
`"L"`	Left turn (counterclockwise)
`"R"`	Right turn (clockwise)
`"Hl"`	Helix left turn (counterclockwise)
`"Hr"`	Helix right turn (clockwise)
`"N"`	No motion

Note The no motion segment `"N"` is used as a filler at the end when only three path segments are needed.

Each motion type corresponds to a motion length specified in the MotionLengths property.

For UAV Dubins connections, the available path types are: `{'LSLN'} {'LSRN'} {'RSLN'} {'RSRN'} {'RLRN'} {'LRLN'} {'HlLSL'} {'HlLSR'} {'HrRSL'} {'HrRSR'} {'HrRLR'} {'HlLRL'} {'LSLHl'} {'LSRHr'} {'RSLHl'} {'RSRHr'} {'RLRHr'} {'LRLHl'} {'LRSL'} {'LRSR'} {'LRLR'} {'RLSR'} {'RLRL'} {'RLSL'} {'LSRL'} {'RSRL'} {'LSLR'} {'RSLR'}`.

Example: `{'L','R','L','N'}`

Data Types: `cell`

`Length` — Length of path segment
positive numeric scalar

This property is read-only.

Length of the path segment or the flight path, specified as a positive numeric scalar in meters. This length is the sum of the elements in the MotionLengths vector.

Data Types: `double`

Object Functions

interpolate	Interpolate poses along UAV Dubins path segment
show	Visualize UAV Dubins path segment

Examples

Specify Motion Type for UAV Dubins Path

This example shows how to calculate a UAV Dubins path segment and connect poses using the `uavDubinsConnection` object for a specified motion type.

Create a `uavDubinsConnection` object.

```
connectionObj = uavDubinsConnection;
```

Define start and goal poses as [`x`, `y`, `z`, `headingAngle`] vectors.

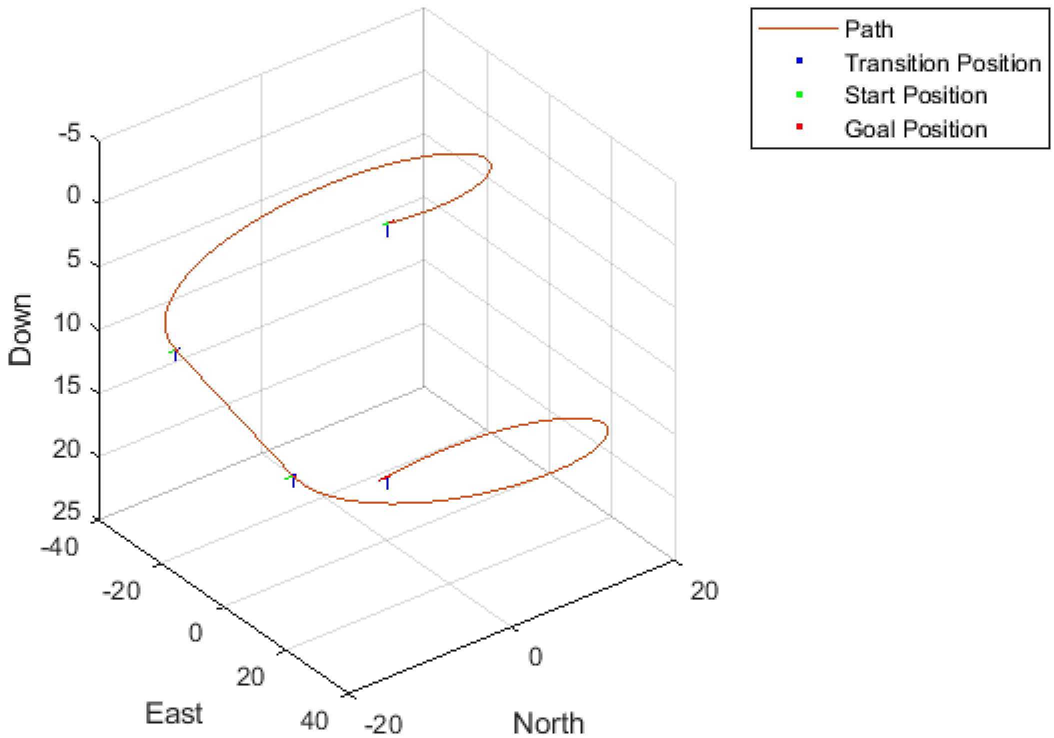
```
startPose = [0 0 0 0]; % [meters, meters, meters, radians]
goalPose = [0 0 20 pi];
```

Calculate a valid path segment and connect the poses for a specified motion type.

```
pathSegObj = uavDubinsPathSegment(connectionObj,startPose,goalPose,{'L','S','L','N'});
```

Show the generated path.

```
show(pathSegObj)
```



Verify the motion type of the returned path segment.

```
fprintf('Motion Type: %s\n',strjoin(pathSegObj.MotionTypes));
```

```
Motion Type: L S L N
```

Extended Capabilities

C/C++ Code Generation

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

See Also

`interpolate` | `show`

Introduced in R2019b

uavLidarPointCloudGenerator

Generate point clouds from meshes

Description

The `uavLidarPointCloudGenerator` System object generates detections from a lidar sensor. The system object uses a statistical sensor model to simulate real lidar detections with added random noise. All detections are with respect to the coordinate frame of the vehicle mounted sensor. You can use the `uavLidarPointCloudGenerator` object in a scenario containing static meshes, UAV platforms and sensors, which you can create using a `uavScenario` object.

To generate lidar point clouds:

1. Create the `uavLidarPointCloudGenerator` 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

```
lidar= uavLidarPointCloudGenerator
lidar= uavLidarPointCloudGenerator(Name,Value)
```

Description

`lidar= uavLidarPointCloudGenerator` returns a statistical sensor model to generate point cloud for a lidar. This sensor model will have default properties.

Generate Point Clouds from Mesh on page 1-87

`lidar= uavLidarPointCloudGenerator(Name,Value)` sets additional properties for the statistical sensor model using one or more name-value pairs. For example, `uavLidarPointCloudGenerator('UpdateRate',100,'HasNoise',0)` creates a lidar point cloud generator that reports detections at an update rate of 100 Hz without noise.

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.

UpdateRate — Update rate of the lidar sensor
10 (default) | positive real scalar

Update rate of the lidar sensor specifies the frequency at which the lidar point clouds are generated in Hz. This property sets the frequency at which new detections happen.

Example: 20

Data Types: `double`

MaxRange — Maximum detection range
120 (default) | positive real scalar

Maximum detection range of the sensor, specified as a positive scalar value. The sensor cannot detect objects beyond this range. The units are in meters.

Example: 120

Data Types: `double`

RangeAccuracy — Accuracy of the range measurements
0.002 (default) | positive real scalar

Accuracy of the range measurements, specified as a positive real scalar with units in meters. This property sets the one standard deviation accuracy of the sensor range measurements.

Example: 0.001

Data Types: `single` | `double`

AzimuthResolution — Azimuthal resolution of the lidar
0.16 (default) | positive real scalar

Azimuthal resolution of the lidar, specified as a positive real scalar with units in degrees. The azimuthal resolution defines the minimum separation in azimuth angle at which the lidar can distinguish two targets.

Example: 0.6

Data Types: `single` | `double`

ElevationResolution — Elevation resolution of the lidar
1.25 (default) | positive real scalar

Elevation resolution of the lidar, specified as a positive real scalar with units in degrees. The elevation resolution defines the minimum separation in elevation angle at which the lidar can distinguish two targets.

Example: 0.6

Data Types: `single` | `double`

AzimuthLimits — Azimuthal limits of the lidar
[-180 180] (default) | 1-by-2 real-valued vector

Azimuth limits of the lidar, specified as a 1-by-2 real-valued vector of the form [min max]. Units are in degrees.

Example: [-60 100]

Data Types: single | double

ElevationLimits — Elevation limits of the lidar
[-20 20] (default) | 1-by-2 real-valued vector

Elevation limits of the lidar, specified as a 1-by-2 real-valued vector of the form [min max]. Units are in degrees.

Example: [-15 20]

Data Types: single | double

HasNoise — Enable adding noise to lidar sensor measurements
true (default) | false

Enable adding noise to lidar sensor measurements, specified as true or false. Set this property to true to add noise to the sensor measurements. Otherwise, the measurements have no noise.

Example: false

Data Types: logical

HasOrganizedOutput — Output generated data as organized point cloud
true (default) | false

Output generated data as organized point cloud, specified as true or false. Set this property to true to output an organized point cloud. Otherwise, the output is unorganized.

Example: false

Data Types: logical

Usage

Syntax

```
ptCloud= lidar(tgts,simTime)
[ptCloud,isValidTime]= lidar(tgts,simTime)
```

Description

ptCloud= lidar(tgts,simTime) generates a lidar point cloud object ptCloud from the N-element array of structs, tgts, at the current simulation time simTime.

[ptCloud,isValidTime]= lidar(tgts,simTime) additionally returns isValidTime which specifies if the specified simTime is a multiple of the sensor's update interval (1/UpdateRate).

Input Arguments

tgts — Target object data
structure | structure array

Target object data, specified as a structure or structure array. Each structure corresponds to a mesh. The table shows the properties that the object uses to generate detections.

Target Object Data

Field	Description
Mesh	An extendedObjectMeshrepresenting the geometry of the target object in its own coordinate frame.
Position	A 3-element vector defining the coordinate position of the target with respect to the sensor frame
Orientation	A quaternion object or a 3-by-3 matrix defining the orientation of the target with respect to the sensor frame.

simTime — Current simulation time
positive real scalar

Current simulation time, specified as a positive real scalar. The lidar object calls the lidar point cloud generator at regular intervals to generate new point clouds at frequency defined by the updateRate property. The value of the updateRate property must be an integer multiple of the simulation time interval. Updates requested from the sensor between update intervals do not generate a point cloud. Units are in seconds.

Output Arguments

ptCloud — Point cloud data
pointCloud object

Point cloud data, returned as a pointCloud object.

isValidTime — Valid time to generate point cloud
0 | 1

Valid time to generate point cloud, returned as 0 or 1. isValidTime is 0 when updates are requested at times that are between update intervals specified by 1/updateRate.

Data Types: logical

Object Functions

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

```
release(obj)
```

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 Point Clouds from Mesh

This example shows how to use a statistical lidar sensor model to generate point clouds from meshes.

Create Sensor Model

Use `uavLidarPointCloudGenerator` to create a statistical sensor model, `lidar`.

```
lidar = uavLidarPointCloudGenerator('HasOrganizedOutput',false);
```

Create Floor

Use the `extendedObjectMesh` object to create mesh for the target object.

```
tgts.Mesh = scale(extendedObjectMesh('cuboid'),[100 100 2]);
```

Define the position of the target object with respect to the sensor frame.

```
tgts.Position = [0 0 -10];
```

Define orientation of the target with respect to the sensor frame.

```
tgts.Orientation = quaternion([1 0 0 0]);
```

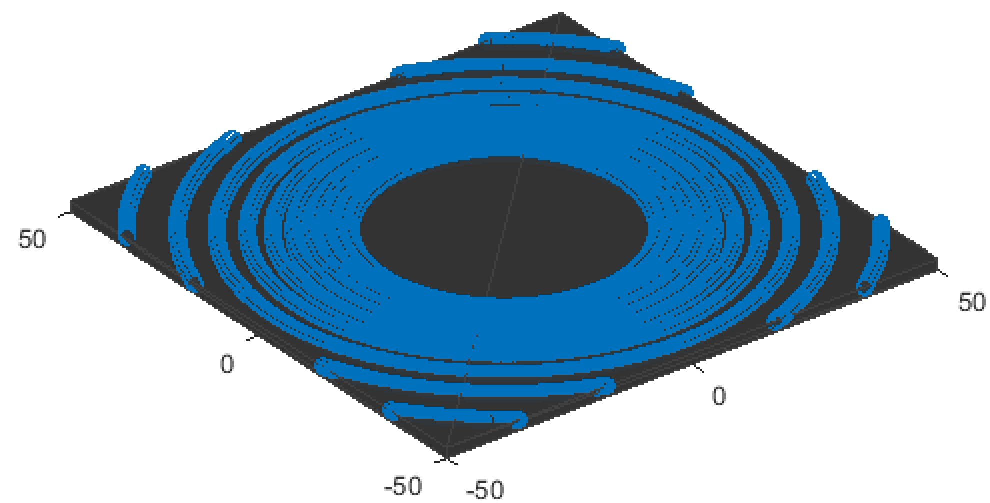
Generate Point Clouds from Floor

```
ptCloud = lidar(tgts,0);
```

Visulaize

Use the `translate` function to translate the object mesh to its location and use `show` function to visualize it. Use the `scatter3` function to plot the point clouds stored in `ptCloud`.

```
figure(1);
show(translate(tgts.Mesh,tgts.Position));
hold on
scatter3(ptCloud.Location(:,1), ptCloud.Location(:,2), ...
ptCloud.Location(:,3));
```



See Also
`uavScenario`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

uavOrbitFollower

Orbit location of interest using a UAV

Description

The `uavOrbitFollower` object is a 3-D path follower for unmanned aerial vehicles (UAVs) to follow circular paths that is based on a lookahead distance. Given the circle center, radius, and the pose, the orbit follower computes a desired yaw and course to follow a lookahead point on the path. The object also computes the cross-track error from the UAV pose to the path and tracks how many times the circular orbit has been completed.

Tune the `lookaheadDistance` input to help improve path tracking. Decreasing the distance can improve tracking, but may lead to oscillations in the path.

To orbit a location using a UAV:

1. Create the `uavOrbitFollower` 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

```
orbit = uavOrbitFollower
orbit = uavOrbitFollower(Name,Value)
```

Description

`orbit = uavOrbitFollower` returns an orbit follower object with default property values.

`orbit = uavOrbitFollower(Name,Value)` creates an orbit follower 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.

UAV type — Type of UAV
'fixed-wing' (default) | 'multirotor'

Type of UAV, specified as either 'fixed-wing' or 'multirotor'.

OrbitCenter — Center of orbit
[x y z] vector

Center of orbit, specified as an [x y z] vector. [x y z] is the orbit center position in NED-coordinates (north-east-down) specified in meters.

Example: [5,5,-10]

Data Types: single | double

OrbitRadius — Radius of orbit
positive scalar

Radius of orbit, specified as a positive scalar in meters.

Example: 5

Data Types: single | double

TurnDirection — Direction of orbit
scalar

Direction of orbit, specified as a scalar. Positive values indicate a clockwise turn as viewed from above. Negative values indicate a counter-clockwise turn. A value of 0 automatically determines the value based on the input Pose.

Example: -1

Data Types: single | double

MinOrbitRadius — Minimum orbit radius
1 (default) | positive numeric scalar

Minimum orbit radius, specified as a positive numeric scalar in meters.

Data Types: single | double

MinLookaheadDistance — Minimum lookahead distance
0.1 (default) | positive numeric scalar

Minimum lookahead distance, specified as a positive numeric scalar in meters.

Data Types: single | double

Usage

Syntax

```
[lookaheadPoint,desiredCourse,desiredYaw,orbitRadiusFlag,lookaheadDistFlag,
crossTrackError,numTurns] = orbit(currentPose,lookaheadDistance)
```

Description

`[lookaheadPoint,desiredCourse,desiredYaw,orbitRadiusFlag,lookaheadDistFlag, crossTrackError,numTurns] = orbit(currentPose,lookaheadDistance)` follows the set of waypoints specified in the waypoint follower object. The object takes the current position and lookahead distance to compute the lookahead point on the path. The desired course, yaw, and cross track error are also based on this lookahead point compared to the current position. `status` returns zero until the UAV has navigated all the waypoints.

Input Arguments

`currentPose` — Current UAV pose
`[x y z course]` vector

Current UAV pose, specified as a `[x y z course]` vector. This pose is used to calculate the lookahead point based on the input `LookaheadDistance`. `[x y z]` is the current position in meters. `course` is the current course in radians. The UAV course is the angle of direction of the velocity vector relative to north measured in radians.

Data Types: `single` | `double`

`lookaheadDistance` — Lookahead distance
positive numeric scalar

Lookahead distance along the path, specified as a positive numeric scalar in meters.

Data Types: `single` | `double`

Output Arguments

`lookaheadPoint` — Lookahead point on path
`[x y z]` position vector

Lookahead point on path, returned as an `[x y z]` position vector in meters.

Data Types: `double`

`desiredCourse` — Desired course
numeric scalar

Desired course, returned as numeric scalar in radians in the range of `[-pi, pi]`. The UAV course is the angle of direction of the velocity vector relative to north measured in radians. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: `double`

`desiredYaw` — Desired yaw
numeric scalar

Desired yaw, returned as numeric scalar in radians in the range of `[-pi, pi]`. The UAV yaw is the forward direction of the UAV regardless of the velocity vector relative to north measured in radians. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: `double`

`orbitRadiusFlag` — Orbit radius flag
`0` (default) | `1`

Orbit radius flag, returned as 0 or 1. 0 indicates orbit radius is not saturated, 1 indicates orbit radius is saturated to minimum orbit radius value specified.

Data Types: uint8

lookaheadDistFlag — Lookahead distance flag
0 (default) | 1

Lookahead distance flag, returned as 0 or 1. 0 indicates lookahead distance is not saturated, 1 indicates lookahead distance is saturated to minimum lookahead distance value specified.

Data Types: uint8

crossTrackError — Cross track error from UAV position to path
positive numeric scalar

Cross track error from UAV position to path, returned as a positive numeric scalar in meters. The error measures the perpendicular distance from the UAV position to the closest point on the path.

Data Types: double

numTurns — Number of times the UAV has completed the orbit
numeric scalar

Number of times the UAV has completed the orbit, specified as a numeric scalar. As the UAV circles the center point, this value increases or decreases based on the specified Turn Direction property. Decimal values indicate partial completion of a circle. If the UAV cross track error exceeds the lookahead distance, the number of turns is not updated.

NumTurns is reset whenever Center, Radius, or TurnDirection properties are changed.

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 Control Commands for Orbit Following

This example shows how to use the uavOrbitFollower to generate course and yaw commands for orbiting a location of interest with a UAV.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call roboticsAddons to open the Add-ons Explorer and install the library.

Create the orbit follower. Set the center of the location of interest and the radius of orbit. Set a `TurnDirection` of 1 for counter-clockwise rotation around the location.

```
orbFollower = uavOrbitFollower;

orbFollower.OrbitCenter = [1 1 5]';
orbFollower.OrbitRadius = 2.5;
orbFollower.TurnDirection = 1;
```

Specify the pose of the UAV and the lookahead distance for tracking the path.

```
pose = [0;0;5;0];
lookaheadDistance = 2;
```

Call the `orbFollower` object with the pose and lookahead distance. The object returns a lookahead point on the path, the desired course, and yaw. You can use the desired course and yaw to generate control commands for the UAV.

```
[lookaheadPoint,desiredCourse,desiredYaw,~,~] = orbFollower(pose,lookaheadDistance);
```

Extended Capabilities

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

See Also

Functions
`control` | `derivative` | `environment` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor` | `uavWaypointFollower`

Blocks
Orbit Follower | UAV Guidance Model | Waypoint Follower

Introduced in R2019a

uavPathManager

Compute and execute a UAV autonomous mission

Description

The `uavPathManager` System object computes mission parameters for an unmanned aerial vehicle (UAV) by sequentially switching between the mission points specified in the **MissionData** property. The **MissionCmd** property changes the execution order at runtime. The object supports both multirotor and fixed-wing UAV types.

To compute mission parameters:

1. Create the `uavPathManager` 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

```
pathManagerObj = uavPathManager
pathManagerObj = uavPathManager(Name,Value)
```

Description

`pathManagerObj = uavPathManager` creates a UAV path manager System object with default property values.

`pathManagerObj = uavPathManager(Name,Value)` creates a UAV path manager object with additional options specified by one or more `Name,Value` pair arguments.

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

Example: `uavPathManager('UAVType','fixed-wing')`

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.

UAVType — Type of UAV
'multirotor' (default) | 'fixed-wing'

Type of UAV, specified as either 'multirotor' or 'fixed-wing'.

Data Types: string

LoiterRadius — Loiter radius for fixed-wing UAV
25 (default) | positive numeric scalar

Loiter radius for the fixed-wing UAV, specified as a positive numeric scalar in meters.

Dependencies: To enable this parameter, set the **UAV type** property to 'fixed-wing'.

Data Types: single | double

MissionData — UAV mission data
n-by-1 array of structures

UAV mission data, specified as an *n*-by-1 array of structures. *n* is the number of mission points. The fields of each structure are:

- mode — Mode of the mission point, specified as an 8-bit unsigned integer between 1 and 6.
- position — Position of the mission point, specified as a three-element column vector of [*x*;*y*;*z*]. *x*, *y*, and *z* is the position in north-east-down (NED) coordinates specified in meters.
- params — Parameters of the mission point, specified as a four-element column vector.

This table describes types of mode and the corresponding values for the position and params fields in a mission point structure.

mode	position	params	Mode description
uint8(1)	[*x*;*y*;*z*]	[0;0;0;0]	**Takeoff** — Take off from the ground and travel towards the specified position
uint8(2)	[*x*;*y*;*z*]	[*yaw*;*radius*;0;0] *yaw* — Yaw angle in radians in the range [-pi, pi] *radius* — Transition radius in meters	**Waypoint** — Navigate to waypoint

mode	position	params	Mode description
`uint8(3)`	[*x*;*y*;*z*] *x*, *y*, and *z* is the center of the circular orbit in NED coordinates specified in meters	[*radius*;*turnDir*;*numTurns*;0] *radius* — Radius of the orbit in meters *turnDir* — Turn direction, specified as one of these: • `1` — Clockwise turn • `–1` — Counter-clockwise turn • `0` — Automatic selection of turn direction *numTurns* — Number of turns	**Orbit** — Orbit along the circumference of a circle defined by the parameters
`uint8(4)`	[*x*;*y*;*z*]	`[0;0;0;0]`	**Land** — Land at the specified position
`uint8(5)`	[*x*;*y*;*z*] The launch position is specified in the **Home** property	`[0;0;0;0]`	**RTL** — Return to launch position
`uint8(6)`	[*x*;*y*;*z*]	[*p1*;*p2*;*p3*;*p4*] *p1*, *p2*, *p3*, and *p4* are user-specified parameters corresponding to the custom mission point	**Custom** — Custom mission point

Example: `[struct('mode',uint8(1),'position',[0;0;100],'params',[0;0;0;0])]`

Tunable: Yes

`IsModeDone` — Determine if mission point was executed

false (default) | true

Determine if the mission point was executed, specified as `true` (`1`) or `false` (`0`).

Tunable: Yes

Data Types: `logical`

`MissionCmd` — Command to change mission

`uint8(0)` (default) | 8-bit unsigned integer between 0 and 3

Command to change mission at runtime, specified as an 8-bit unsigned integer between 0 and 3.

This table describes the possible mission commands.

Mission Command	Description
`uint8(0)`	**Default** — Execute the mission from first to the last mission point in the sequence
`uint8(1)`	**Hold** — Hold at the current mission point Loiter around the current position for fixed-wing, and hover at the current position for multirotor UAVs
`uint8(2)`	**Repeat** — Repeat the mission after reaching the last mission point
`uint8(3)`	**RTL** — Execute return to launch (RTL) mode After **RTL**, the mission resumes if the **MissionCmd** property is changed to **Default** or **Repeat**

Tunable: Yes

Data Types: `uint8`

Home — UAV home location
three-element column vector

UAV home location, specified as a three-element column vector of `[x;y;z]`. *x*, *y*, and *z* is the position in north-east-down (NED) coordinates specified in meters.

Tunable: Yes

Data Types: `single` | `double`

Usage

Syntax

`missionParams = pathManagerObj(pose)`

Description

`missionParams = pathManagerObj(pose)`

Input Arguments

pose — Current UAV pose
four-element column vector

Current UAV pose, specified as a four-element column vector of `[x;y;z;courseAngle]`. *x*, *y*, and *z* is the current position in north-east-down (NED) coordinates specified in meters. *courseAngle* specifies the course angle in radians in the range `[-pi, pi]`.

Data Types: `single` | `double`

Output Arguments

`missionParams` — UAV mission parameters
2-by-1 array of structures

UAV mission parameters, returned as a 2-by-1 array of structures. The first row of the array contains the structure of the current mission point, and the second row of the array contains the structure of the previous mission point. The fields of each structure are:

- `mode` — Mode of the mission point, returned as an 8-bit unsigned integer between 0 and 7.
- `position` — Position of the mission point based on the mode, returned as a three-element column vector of `[x;y;z]`. *x*, *y*, and *z* is the position in north-east-down (NED) coordinates specified in meters.
- `params` — Parameters of the mission point based on the mode, returned as a four-element column vector.

At start of simulation, the previous mission point is set to the **Armed** mode.

```
struct('mode',uint8(0),'position',[x;y;z],'params',[-1;-1;-1;-1])
```

Note The **Armed** mode cannot be configured by the user.

Set the end mission point to **RTL** or **Land** mode, else the end mission point is automatically set to **Hold** mode.

- Multirotor UAVs hover at the current position.

  ```
  struct('mode',uint8(7),'position',[x;y;z],'params',[-1;-1;-1;-1])
  ```
- Fixed-wing UAVs loiter around the current position.

  ```
  struct('mode',uint8(7),'position',[x;y;z],'params',[radius;turnDir;-1;-1])
  ```

Note The **Hold** mode cannot be configured by the user.

This table describes the output mission parameters depending on the mission mode.

Current Mission Mode	Output Mission Parameters			
	Mission Points	**mode**	**position**	**params**
Takeoff	Row 1: Current	`uint8(1)`	`[x;y;z]`	`[0;0;0;0]`
	Row 2: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point

<table>
<tr><th rowspan="2">Current Mission Mode</th><th colspan="4">Output Mission Parameters</th></tr>
<tr><th>Mission Points</th><th>mode</th><th>position</th><th>params</th></tr>
<tr><td rowspan="2">Waypoint</td><td>Row 1: Current</td><td><code>uint8(2)</code></td><td><code>[x;y;z]</code></td><td><code>[yaw;radius;0;0]</code>

yaw — Yaw angle in radians in the range <code>[-pi, pi]</code>

radius — Transition radius in meters</td></tr>
<tr><td>Row 2: Previous</td><td><code>mode</code> of the previous mission point</td><td><code>position</code> of the previous mission point</td><td>• <code>[yaw;radius;0;0]</code> if the previous mission point was Takeoff
• <code>[courseAngle;radius;0;0]</code> otherwise

courseAngle — Angle of the line segment between the previous and the current position, specified in radians in the range <code>[-pi, pi]</code></td></tr>
<tr><td>Orbit</td><td>Row 1: Current</td><td><code>uint8(3)</code></td><td><code>[x;y;z]</code>

x, y, and z is the center of the circular orbit in NED coordinates specified in meters</td><td><code>[radius;turnDir;numTurns;0]</code>

radius — Radius of the orbit in meters

turnDir — Turn direction, specified as one of these:
• <code>1</code> — Clockwise turn
• <code>–1</code> — Counter-clockwise turn
• <code>0</code> — Automatic selection of turn direction

numTurns — Number of turns</td></tr>
</table>

Current Mission Mode	Output Mission Parameters			
	Mission Points	**mode**	**position**	**params**
	Row 2: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point
Land	Row 1: Current	`uint8(4)`	[*x*;*y*;*z*]	`[0;0;0;0]`
	Row 2: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point
RTL	Row 1: Current	`uint8(5)`	[*x*;*y*;*z*] The launch position is specified in the **Home** property	`[0;0;0;0]`
	Row 2: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point
Custom	Row 1: Current	`uint8(6)`	[*x*;*y*;*z*]	[*p1*;*p2*;*p3*;*p4*] *p1*, *p2*, *p3*, and *p4* are user-specified parameters corresponding to the custom mission point
	Row 2: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point

This table describes the output mission parameters when the input to the **MissionCmd** property is set to **Hold** mode.

UAV Type	Output Mission Parameters			
	Mission Points	**mode**	**position**	**params**
Multirotor	Row 1: Current	`uint8(7)`	[*x*;*y*;*z*]	`[-1;-1;-1;-1]`
	Row 2: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point

UAV Type	Output Mission Parameters			
	Mission Points	**mode**	**position**	**params**
Fixed-Wing	Row 1: Current	`uint8(7)`	`[`*x*`;`*y*`;`*z*`]` *x*, *y*, and *z* is the center of the circular orbit in NED coordinates specified in meters	`[`*radius*`;`*turnDir*`;-1;-1]` *radius* — Loiter radius is specified in the **LoiterRadius** property *turnDir* — Turn direction is specified as `0` for automatic selection of turn direction
	Row 2: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point

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

See Also

`fixedwing` | `multirotor` | `uavOrbitFollower` | `uavWaypointFollower`

Introduced in R2020b

uavPlatform

UAV platform for sensors in scenario

Description

The uavPlatform object represents an unmanned aerial vehicle (UAV) platform in a given UAV scenario. Use the platform to define and track the trajectory of an object in the scenario. To simulate sensor readings for the platform, mount sensors like the gpsSensor, insSensor , or uavLidarPointCloudGenerator objects with a set of uavSensor objects. Add a body mesh for visualization using updateMesh. Set geofencing limitations using addGeoFence and check those limits using checkPermission.

Creation

Syntax

Description

`platform = uavPlatform(name,scenario)` create a platform with a specified name and adds it to the given scenario as a uavScenario.

`platform = uavPlatform(name,scenario,Name,Value)` specifies options using one or more name-value pair arguments in addition to the input arguments in the previous syntax. You can specify properties as name-value pairs as well. For example, 'StartTime',10 sets the initial time for the platform trajectory to 10 seconds.

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: 'StartTime',10 sets the initial time of the platform trajectory to 10 seconds.

StartTime — Initial time of platform trajectory
0 (default) | scalar in seconds

Initial time of the platform trajectory, specified as the comma-separated pair consisting of 'StartTime' and a scalar in seconds.

Data Types: double

InitialPosition — Initial platform position for UAV
[0 0 0] (default) | vector of the form [x y z]

Initial platform position for UAV, specified as the comma-separated pair consisting of 'InitialPosition' and a vector of the form [x y z]. Only specify this name-value pair if not specifying the Trajectory property.

Data Types: double

`InitialOrientation` — Initial platform orientation for UAV
`[1 0 0 0]` (default) | vector of the form `[w x y z]`

Initial platform orientation for UAV, specified as the comma-separated pair consisting of `'InitialOrientation'` and a vector of the form `[w x y z]`, representing a quaternion. Only specify this name-value pair if not specifying the Trajectory property.

Data Types: `double`

`InitialVelocity` — Initial platform velocity for UAV
`[0 0 0]` (default) | vector of the form `[vx vy vz]`

Initial platform velocity for UAV, specified as the comma-separated pair consisting of `'InitialVelocity'` and a vector of the form `[vx vy vz]`. Only specify this name-value pair if not specifying the Trajectory property.

Data Types: `double`

`InitialAcceleration` — Initial platform acceleration for UAV
`[0 0 0]` (default) | vector of the form `[ax ay az]`

Initial platform acceleration for UAV, specified as the comma-separated pair consisting of `'InitialAcceleration'` and a vector of the form `[ax ay az]`. Only specify this name-value pair if not specifying the Trajectory property.

Data Types: `double`

`InitialAngularVelocity` — Initial platform angular velocity for UAV
`[0 0 0]` (default) | three-element vector of the form `[x y z]` | vector

Initial platform angular velocity for UAV, specified as the comma-separated pair consisting of `'InitialAngularVelocity'` and a three-element vector of the form `[x y z]`. The magnitude of the vector defines the angular speed in radians per second. The *xyz*-coordinates define the axis of clockwise rotation. Only specify this name-value pair if not specifying the Trajectory property.

Data Types: `double`

`Trajectory` — Trajectory for UAV platform motion
`[]` (default) | `waypointTrajectory` object

Trajectory for UAV platform motion, specified as a `waypointTrajectory` object. By default, the platform is assumed to be stationary and at the origin. To move the platform at each simulation step of the scenario, use the `move` object function .

Note The `uavPlatform` object must specify the same `ReferenceFrame` property as the specified `waypointTrajectory` object.

`ReferenceFrame` — Reference frame for computing UAV platform motion
string scalar

Reference frame for computing UAV platform motion, specified as string scalar, which matches any reference frame in the `uavScenario`. All platform motion is computed relative to this inertial frame.

Data Types: `string`

Properties

`Name` — Identifier for UAV platform
string scalar | character vector

Identifier for the UAV platform, specified as a string scalar or character vector.

Example: `"uav1"`

Data Types: `string` | `char`

`Trajectory` — Trajectory for UAV platform motion
`[]` (default) | `waypointTrajectory` object

Trajectory for UAV platform motion, specified as a `waypointTrajectory` object. By default, the object assumes the platform is stationary and at the scenario origin. To move the platform at each simulation step of the scenario, use the `move` object function .

Note The `uavPlatform` object must specify the same `ReferenceFrame` property as the specified `waypointTrajectory` object.

`ReferenceFrame` — Reference frame for computing UAV platform motion
string scalar | character vector

Reference frame for computing UAV platform motion, specified as string scalar or character vector, which matches any reference frame in the `uavScenario`. The object computes all platform motion relative to this inertial frame.

Data Types: `string` | `char`

`Mesh` — UAV platform body mesh
`extendedObjectMesh` object

UAV platform body mesh, specified as an `extendedObjectMesh` object. The body mesh describes the 3-D model of the platform for visualization purposes.

`MeshColor` — UAV platform body mesh color
RGB triplet

UAV platform body mesh color when displayed in the scenario, specified as an RGB triplet.

Data Types: `double`

`MeshTransform` — Transform between UAV platform body and mesh frame
4-by-4 homogeneous transformation matrix

Transform between UAV platform body and mesh frame, specified as a 4-by-4 homogeneous transformation matrix that maps points in the platform mesh frame to points in the body frame.

Data Types: `double`

`Sensors` — Sensors mounted on UAV platform
array of `uavSensor` objects

Sensors mount on UAV platform, specified as an array of `uavSensor` objects.

GeoFences — Geofence restrictions for UAV platform
structure array

Geofence restrictions for UAV platform, specified as a structure array with these fields:

- `Geometry` — An `extendedObjectMesh` object representing the 3-D space for the geofence in the scenario frame.
- `Permission` — A logical scalar that indicates if the platform is permitted inside the geofence (`true`) or not permitted (`false`).

Data Types: `double`

Object Functions

move	Move UAV platform in scenario
read	Read UAV motion vector
updateMesh	Update body mesh for UAV platform
addGeoFence	Add geographical fencing to UAV platform
checkPermission	Check UAV platform permission based on geofencing

Examples

UAV Scenario Tutorial

Create a scenario to simulate unmanned aerial vechicle (UAV) flights between a set of buildings. The example demonstates updating the UAV pose in open-loop simulations. Use the UAV scenario to visualize the UAV flight and generate simulated point cloud sensor readings.

Introduction

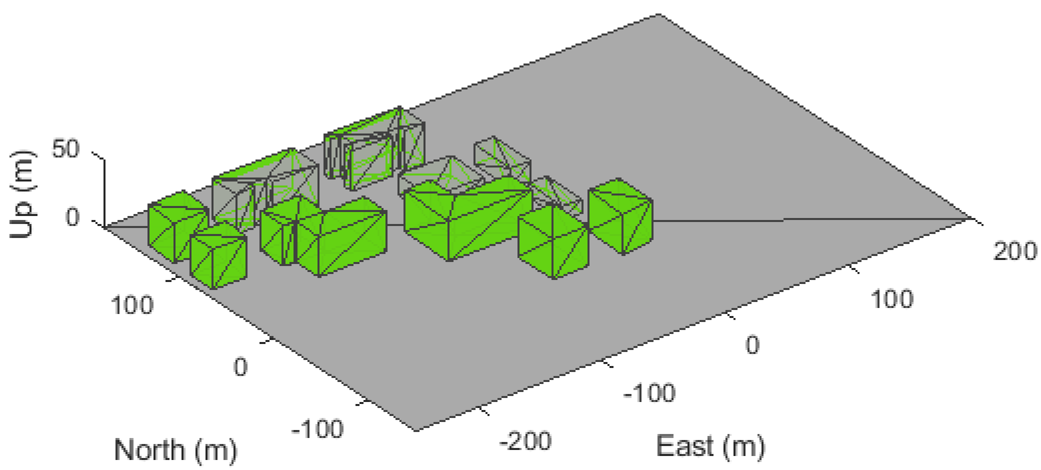
To test autonomous algorithms, a UAV scenario enables you to generate test cases and generate sensor data from the environment. You can specify obstacles in the workspace, provide trajectories of UAVs in global coordinates, and convert data between coordinate frames. The UAV scenario enables you to visualize this information in the reference frame of the environment.

Create Scenario with Polygon Building Meshes

A `uavScenario` object is model consisting of a set of static obstacles and movable objects called platforms. Use `uavPlatform` objects to model fixed-wing UAVs, multirotors, and other objects within the scenario. This example builds a scenario consisting of a ground plane and 11 buildings as by extruded polygons. The polygon data for the buildings is loaded and used to add polygon meshes.

```
% Create the UAV scenario.
scene = uavScenario("UpdateRate",2,"ReferenceLocation",[75 -46 0]);

% Add a ground plane.
color.Gray = 0.651*ones(1,3);
color.Green = [0.3922 0.8314 0.0745];
color.Red = [1 0 0];
addMesh(scene,"polygon",{[-250 -150; 200 -150; 200 180; -250 180],[-4 0]},color.Gray)

% Load building polygons.
load("buildingData.mat");
```

```
% Add sets of polygons as extruded meshes with varying heights from 10-30.
addMesh(scene,"polygon",{buildingData{1}(1:4,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{2}(2:5,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{3}(2:10,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{4}(2:9,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{5}(1:end-1,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{6}(1:end-1,:),[0 15]},color.Green)
addMesh(scene,"polygon",{buildingData{7}(1:end-1,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{8}(2:end-1,:),[0 10]},color.Green)
addMesh(scene,"polygon",{buildingData{9}(1:end-1,:),[0 15]},color.Green)
addMesh(scene,"polygon",{buildingData{10}(1:end-1,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{11}(1:end-2,:),[0 30]},color.Green)

% Show the scenario.
show3D(scene);
xlim([-250 200])
ylim([-150 180])
zlim([0 50])
```



Define UAV Platform and Mount Sensor

You can define a `uavPlatform` in the scenario as a carrier of your sensor models and drive them through the scenario to collect simulated sensor data. You can associate the platform with various meshes, such as `fixedwing`, `quadrotor`, and `cuboid` meshes. You can define a custom mesh defined ones represented by vertices and faces. Specify the reference frame for describing the motion of your platform.

Load flight data into the workspace and create a quadrotor platform using an NED reference frame. Specify the initial position and orientation based on loaded flight log data. The configuration of the UAV body frame orients the *x*-axis as forward-positive, the *y*-axis as right-positive, and the *z*-axis downward-positive.

```
load("flightData.mat")

% Set up platform
plat = uavPlatform("UAV",scene,"ReferenceFrame","NED", ...
    "InitialPosition",position(:,:,1),"InitialOrientation",eul2quat(orientation(:,:,1)));

% Set up platform mesh. Add a rotation to orient the mesh to the UAV body frame.
updateMesh(plat,"quadrotor",{10},color.Red,[0 0 0],eul2quat([0 0 pi]))
```

You can choose to mount different sensors, such as the `insSensor`, `gpsSensor`, or `uavLidarPointCloudGenerator` System objects to your UAV. Mount a lidar point cloud generator and a `uavSensor` object that contains the lidar sensor model. Specify a mounting location of the sensor that is relative to the UAV body frame.

```
lidarmodel = uavLidarPointCloudGenerator("AzimuthResolution",0.3324099,...
    "ElevationLimits",[-20 20],"ElevationResolution",1.25,...
    "MaxRange",90,"UpdateRate",2,"HasOrganizedOutput",true);

lidar = uavSensor("Lidar",plat,lidarmodel,"MountingLocation",[0,0,-1]);
```

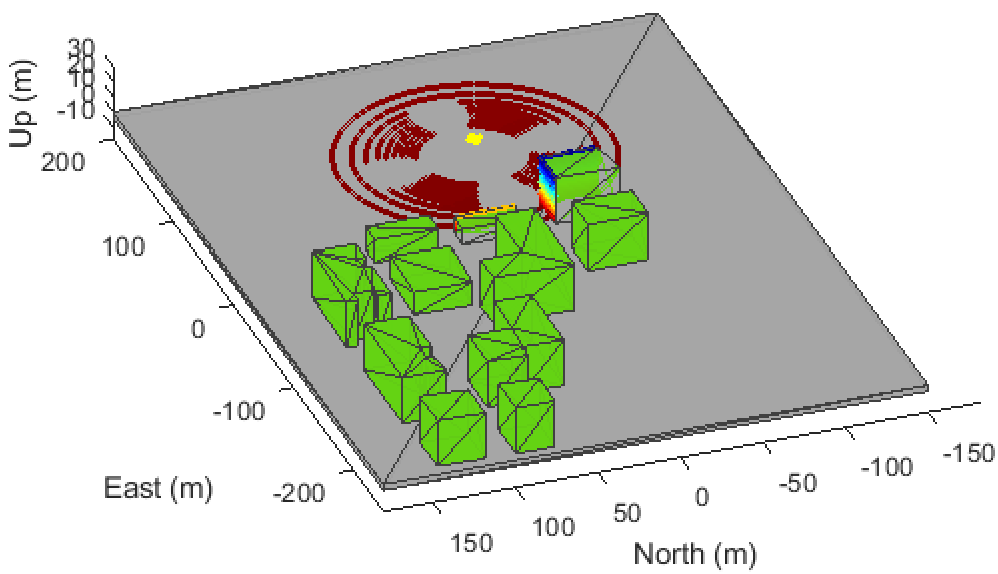
Fly the UAV Platform Along Pre-defined Trajectory and Collect Point Cloud Sensor Readings

Move the UAV along a pre-defined trajectory, and collect the lidar sensor readings along the way. This data could be used to test lidar-based mapping and localization algorithms.

Preallocate the `traj` and `scatterPlot` line plots and then specify the plot-specific data sources. During the simulation of the `uavScenario`, use the provided `plotFrames` output from the scene as the parent axes to visualize your sensor data in the correct coordinate frames.

```
% Visualize the scene
[ax,plotFrames] = show3D(scene);

% Update plot view for better visibility.
xlim([-250 200])
ylim([-150 180])
zlim([0 50])
view([-110 30])
axis equal
hold on

% Create a line plot for the trajectory.
traj = plot3(nan,nan,nan,"Color",[1 1 1],"LineWidth",2);
traj.XDataSource = "position(:,1,1:idx+1)";
traj.YDataSource = "position(:,2,1:idx+1)";
traj.ZDataSource = "position(:,3,1:idx+1)";

% Create a scatter plot for the  point cloud.
colormap("jet")
pt = pointCloud(nan(1,1,3));
scatterplot = scatter3(nan,nan,nan,1,[0.3020 0.7451 0.9333],...
    "Parent",plotFrames.UAV.Lidar);
scatterplot.XDataSource = "reshape(pt.Location(:,:,1),[],1)";
```

```
scatterplot.YDataSource = "reshape(pt.Location(:,:,2),[],1)";
scatterplot.ZDataSource = "reshape(pt.Location(:,:,3),[],1)";
scatterplot.CDataSource = "reshape(pt.Location(:,:,3),[],1) - min(reshape(pt.Location(:,:,3),[],1

% Start Simulation
setup(scene)
for idx = 0:size(position, 3)-1
    [isupdated,lidarSampleTime, pt] = read(lidar);
    if isupdated
        % Use fast update to move platform visualization frames.
        show3D(scene,"Time",lidarSampleTime,"FastUpdate",true,"Parent",ax);
        % Refresh all plot data and visualize.
        refreshdata
        drawnow limitrate
    end
    % Advance scene simulation time and move platform.
    advance(scene);
    move(plat,[position(:,:,idx+1),zeros(1,6),eul2quat(orientation(:,:,idx+1)),zeros(1,3)])
    % Update all sensors in the scene.
    updateSensors(scene)
end
hold off
```



See Also

Functions
addGeoFence | checkPermission | move | read | updateMesh

Objects
`uavScenario` | `uavSensor`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

uavScenario

Generate UAV simulation scenario

Description

The `uavScenario` object generates a simulation scenario consisting of static meshes, UAV platforms, and sensors in a 3-D environment.

Creation

`scene = uavScenario` creates an empty UAV scenario with default property values. The default inertial frames are the north-east-down (NED) and the east-north-up (ENU) frames.

`scene = uavScenario(Name,Value)` configures a `uavScenario` object with properties using one or more `Name,Value` pair arguments. `Name` is a property name and `Value` is the corresponding value. `Name` must appear inside quotes. You can specify several name-value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`. Any unspecified properties take default values.

Using this syntax, you can specify the `UpdateRate`, `StopTime`, `HistoryBufferSize`, `ReferenceLocation`, and `MaxNumFrames` properties. You cannot specify other properties of the `uavScenario` object, which are read-only.

Properties

`UpdateRate` — Simulation update rate
`10` (default) | positive scalar

Simulation update rate, specified as a positive scalar in Hz. The step size of the scenario when using an `advance` object function is equal to the inverse of the update rate.

Example: `2`

Data Types: `double`

`StopTime` — Stop time of simulation
`Inf` (default) | nonnegative scalar

Stop time of the simulation, specified as a nonnegative scalar. A scenario stops advancing when it reaches the stop time.

Example: `60.0`

Data Types: `double`

`HistoryBufferSize` — Maximum number of steps stored in scenario
`100` (default) | positive integer greater than 1

Maximum number of steps stored in scenario, specified as a positive integer greater than 1. This property determines the maximum number of frames of platform poses stored in the scenario. If the number of simulated steps exceeds the value of this property, then the scenario stores only latest steps.

Example: `60`

Data Types: `double`

`ReferenceLocation` — Scenario origin in geodetic coordinates
`[0 0 0]` (default) | 3-element vector of scalars

Scenario origin in geodetic coordinates, specified as a 3-element vector of scalars in the form [`latitude` `longitude` `altitude`]. `latitude` and `longitude` are geodetic coordinates in degrees. `altitude` is the height above the WGS84 rereference ellipsoid in meters.

Data Types: `double`

`MaxNumFrames` — Maximum number of frames in the scenario
`10` (default) | positive integer

Maximum number of frames in the scenario, specified as a positive integer. The combined number of inertial frames, platforms, and sensors added to the scenario must be less than or equal to the value of this property.

Example: `15`

Data Types: `double`

`CurrentTime` — Current simulation time
nonnegative scalar

This property is read-only.

Current simulation time, specified as a nonnegative scalar.

Data Types: `double`

`IsRunning` — Indicate whether scenario is running
`true` | `false`

This property is read-only.

Indicate whether the scenario is running, specified as `true` or `false`. After a scenario simulation starts, it runs until it reaches the stop time.

Data Types: `logical`

`TransformTree` — Transformation information between frames
`tranformTree` object

This property is read-only.

Transformation information between all the frames in the scenario, specified as a `transformTree` object. This property contains the transformation information between the inertial, platform, and sensor frames associated with the scenario.

Data Types: `object`

`InertialFrames` — Names of inertial frames in scenario
vector of string

This property is read-only.

Names of the inertial frames in the scenario, specified as a vector of strings.

Data Types: `string`

`Platforms` — UAV platforms in scenario
array of `uavPlatform` objects

This property is read-only.

UAV platforms in the scenario, specified as an array of `uavPlatform` objects.

Object Functions

setup	Prepare UAV scenario for simulation
advance	Advance UAV scenario simulation by one time step
updateSensors	Update sensor readings in UAV scenario
restart	Reset simulation of UAV scenario
addInertialFrame	Define new inertial frame in UAV scenario
addMesh	Add new static mesh to UAV scenario
show	Visualize UAV scenario in 2-D
show3D	Visualize UAV scenario in 3-D

Examples

Create and Simulate UAV Scenario

Create a UAV scenario and set its local origin.

```
scene = uavScenario("UpdateRate",200,"StopTime",2,"ReferenceLocation",[46, 42, 0]);
```

Add an inertial frame called `MAP` to the scneario.

```
scene.addInertialFrame("ENU","MAP",trvec2tform([1 0 0]));
```

Add one ground mesh and two cylindrical obstacle meshes to the scenario.

```
scene.addMesh("Polygon", {[-100 0; 100 0; 100 100; -100 100],[-5 0]},[0.3 0.3 0.3]);
scene.addMesh("Cylinder", {[20 10 10],[0 30]}, [0 1 0]);
scene.addMesh("Cylinder", {[46 42 5],[0 20]}, [0 1 0], "UseLatLon", true);
```

Create a UAV platform with a specified waypoint trajectory in the scenario. Define the mesh for the UAV platform.

```
traj = waypointTrajectory("Waypoints", [0 -20 -5; 20 -20 -5; 20 0 -5],"TimeOfArrival",[0 1 2]);
uavPlat = uavPlatform("UAV",scene,"Trajectory",traj);
updateMesh(uavPlat,"quadrotor", {4}, [1 0 0],eul2tform([0 0 pi]));
addGeoFence(uavPlat,"Polygon", {[-50 0; 50 0; 50 50; -50 50],[0 100]},true,"ReferenceFrame","ENU
```

Attach an INS sensor to the front of the UAV platform.

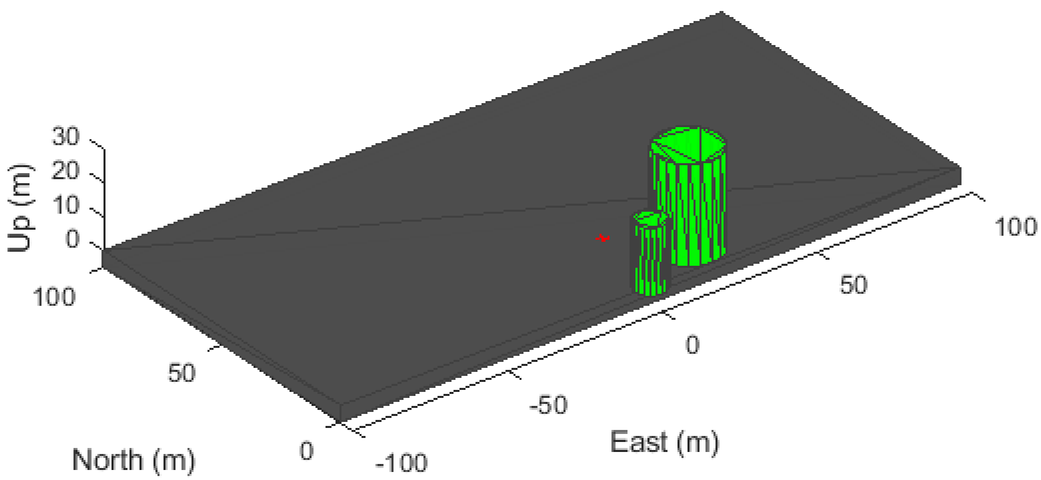
```
insModel = insSensor();
ins = uavSensor("INS",uavPlat,insModel,"MountingLocation",[4 0 0]);
```

Visualize the scenario in 3-D.

```
ax = show3D(scene);
axis(ax,"equal");
```

Simulate the scenario.

```
setup(scene);
while advance(scene)
    % Update sensor readings
    updateSensors(scene);

    % Visualize the scenario
    show3D(scene,"Parent",ax,"FastUpdate",true);
    drawnow limitrate
end
```



See Also

uavPlatform | uavSensor

Topics

"UAV Scenario Tutorial"

Introduced in R2020b

uavSensor

Sensor for UAV scenario

Description

The `uavSensor` object creates a sensor that is rigidly attached to a UAV platform, specified as a `uavPlatform` object. You can specify different mounting positions and orientations. Configure this object to automatically generate readings from a sensor specified as an `insSensor`, `gpsSensor`, or `uavLidarPointCloudGenerator` System object.

Creation

Syntax

```
sensor = uavSensor(name,platform,sensormodel)
sensor = uavSensor( ___ ,Name,Value)
```

Description

`sensor = uavSensor(name,platform,sensormodel)` creates a sensor with the specified name `name` and sensor model `sensormodel`, which set the `Name` and `SensorModel` properties respectively. The sensor is added to the platform `platform` specified as a `uavPlatform` object.

`sensor = uavSensor( ___ ,Name,Value)` sets properties on page 1-115 using one or more name-value pair arguments in addition to the input arguments in the previous syntax. You can specify the `MountingLocation`, `MountingAngles`, or `UpdateRate` properties as name-value pairs. For example, `uavSensor("uavLidar",plat,lidarmodel,'MountingLocation',[1 0 0])"` places the sensor one meter forward in the *x*-direction relative to the platform body frame. Enclose each property name in quotes.

Properties

Name — Sensor name
string scalar

Sensor name, specified as a string scalar. Choose a name to identify this specific sensor.

Example: `"uavLidar"`

Data Types: `string` | `char`

`MountingLocation` — Sensor position on platform
vector of the form `[x y z]`

Sensor position on platform, specified as a vector of the form `[x y z]` in the platform frame. Units are in meters.

Example: `[1 0 0]` is 1 m in the *x*-direction.

Data Types: `double`

`MountingAngles` — Sensor orientation rotation angles
vector of the form `[z y x]`

Sensor orientation rotation angles, specified as a vector of the form `[z y x]` where `z`, `y`, `x` are rotations about the *z*-axis, *y*-axis, and *x*-axis, sequentially, in degrees. The orientation is relative to the platform body frame.

Example: `[30 90 0]`

Data Types: `double`

`UpdateRate` — Update rate of sensor
positive scalar

Update rate of the sensor, specified as a positive scalar in hertz . By default, the object uses the `UpdateRate` property of the specified sensor model object.

Data Types: `double`

`SensorModel` — Sensor model for generating readings
`insSensor` System object | `gpsSensor` System object | `uavLidarPointCloudGenerator` System object

Sensor model for generating readings, specified as an `insSensor`, `gpsSensor`, or `uavLidarPointCloudGenerator` System object.

Object Functions

read   Gather latest reading from UAV sensor

Examples

UAV Scenario Tutorial

Create a scenario to simulate unmanned aerial vechicle (UAV) flights between a set of buildings. The example demonstates updating the UAV pose in open-loop simulations. Use the UAV scenario to visualize the UAV flight and generate simulated point cloud sensor readings.

Introduction

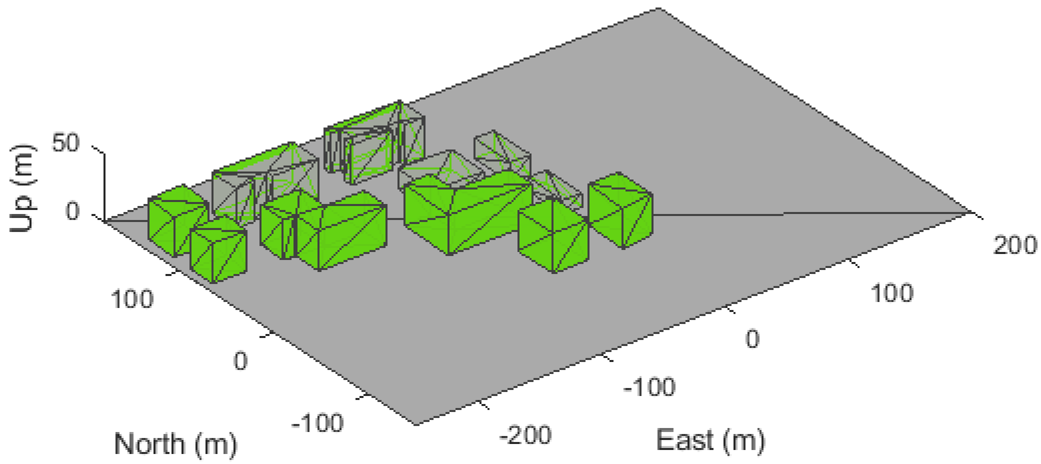
To test autonomous algorithms, a UAV scenario enables you to generate test cases and generate sensor data from the environment. You can specify obstacles in the workspace, provide trajectories of UAVs in global coordinates, and convert data between coordinate frames. The UAV scenario enables you to visualize this information in the reference frame of the environment.

Create Scenario with Polygon Building Meshes

A `uavScenario` object is model consisting of a set of static obstacles and movable objects called platforms. Use `uavPlatform` objects to model fixed-wing UAVs, multirotors, and other objects within the scenario. This example builds a scenario consisting of a ground plane and 11 buildings as by extruded polygons. The polygon data for the buildings is loaded and used to add polygon meshes.

```
% Create the UAV scenario.
scene = uavScenario("UpdateRate",2,"ReferenceLocation",[75 -46 0]);
```

```
% Add a ground plane.
color.Gray = 0.651*ones(1,3);
color.Green = [0.3922 0.8314 0.0745];
color.Red = [1 0 0];
addMesh(scene,"polygon",{[-250 -150; 200 -150; 200 180; -250 180],[-4 0]},color.Gray)

% Load building polygons.
load("buildingData.mat");

% Add sets of polygons as extruded meshes with varying heights from 10-30.
addMesh(scene,"polygon",{buildingData{1}(1:4,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{2}(2:5,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{3}(2:10,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{4}(2:9,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{5}(1:end-1,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{6}(1:end-1,:),[0 15]},color.Green)
addMesh(scene,"polygon",{buildingData{7}(1:end-1,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{8}(2:end-1,:),[0 10]},color.Green)
addMesh(scene,"polygon",{buildingData{9}(1:end-1,:),[0 15]},color.Green)
addMesh(scene,"polygon",{buildingData{10}(1:end-1,:),[0 30]},color.Green)
addMesh(scene,"polygon",{buildingData{11}(1:end-2,:),[0 30]},color.Green)

% Show the scenario.
show3D(scene);
xlim([-250 200])
ylim([-150 180])
zlim([0 50])
```



Define UAV Platform and Mount Sensor

You can define a `uavPlatform` in the scenario as a carrier of your sensor models and drive them through the scenario to collect simulated sensor data. You can associate the platform with various meshes, such as `fixedwing`, `quadrotor`, and `cuboid` meshes. You can define a custom mesh defined ones represented by vertices and faces. Specify the reference frame for describing the motion of your platform.

Load flight data into the workspace and create a quadrotor platform using an NED reference frame. Specify the initial position and orientation based on loaded flight log data. The configuration of the UAV body frame orients the *x*-axis as forward-positive, the *y*-axis as right-positive, and the *z*-axis downward-positive.

```
load("flightData.mat")

% Set up platform
plat = uavPlatform("UAV",scene,"ReferenceFrame","NED", ...
    "InitialPosition",position(:,:,1),"InitialOrientation",eul2quat(orientation(:,:,1)));

% Set up platform mesh. Add a rotation to orient the mesh to the UAV body frame.
updateMesh(plat,"quadrotor",{10},color.Red,[0 0 0],eul2quat([0 0 pi]))
```

You can choose to mount different sensors, such as the `insSensor`, `gpsSensor`, or `uavLidarPointCloudGenerator` System objects to your UAV. Mount a lidar point cloud generator and a `uavSensor` object that contains the lidar sensor model. Specify a mounting location of the sensor that is relative to the UAV body frame.

```
lidarmodel = uavLidarPointCloudGenerator("AzimuthResolution",0.3324099,...
    "ElevationLimits",[-20 20],"ElevationResolution",1.25,...
    "MaxRange",90,"UpdateRate",2,"HasOrganizedOutput",true);

lidar = uavSensor("Lidar",plat,lidarmodel,"MountingLocation",[0,0,-1]);
```

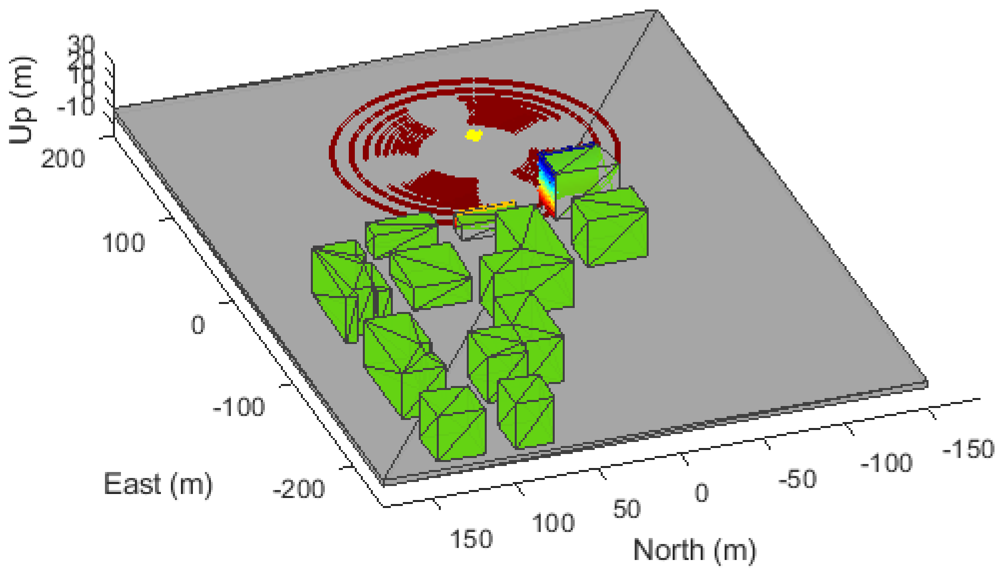
Fly the UAV Platform Along Pre-defined Trajectory and Collect Point Cloud Sensor Readings

Move the UAV along a pre-defined trajectory, and collect the lidar sensor readings along the way. This data could be used to test lidar-based mapping and localization algorithms.

Preallocate the `traj` and `scatterPlot` line plots and then specify the plot-specific data sources. During the simulation of the `uavScenario`, use the provided `plotFrames` output from the scene as the parent axes to visualize your sensor data in the correct coordinate frames.

```
% Visualize the scene
[ax,plotFrames] = show3D(scene);

% Update plot view for better visibility.
xlim([-250 200])
ylim([-150 180])
zlim([0 50])
view([-110 30])
axis equal
hold on

% Create a line plot for the trajectory.
traj = plot3(nan,nan,nan,"Color",[1 1 1],"LineWidth",2);
traj.XDataSource = "position(:,1,1:idx+1)";
traj.YDataSource = "position(:,2,1:idx+1)";
traj.ZDataSource = "position(:,3,1:idx+1)";

% Create a scatter plot for the  point cloud.
colormap("jet")
pt = pointCloud(nan(1,1,3));
scatterplot = scatter3(nan,nan,nan,1,[0.3020 0.7451 0.9333],...
    "Parent",plotFrames.UAV.Lidar);
scatterplot.XDataSource = "reshape(pt.Location(:,:,1),[],1)";
scatterplot.YDataSource = "reshape(pt.Location(:,:,2),[],1)";
scatterplot.ZDataSource = "reshape(pt.Location(:,:,3),[],1)";
scatterplot.CDataSource = "reshape(pt.Location(:,:,3),[],1) - min(reshape(pt.Location(:,:,3),[],

% Start Simulation
setup(scene)
for idx = 0:size(position, 3)-1
    [isupdated,lidarSampleTime, pt] = read(lidar);
    if isupdated
        % Use fast update to move platform visualization frames.
        show3D(scene,"Time",lidarSampleTime,"FastUpdate",true,"Parent",ax);
        % Refresh all plot data and visualize.
        refreshdata
        drawnow limitrate
    end
    % Advance scene simulation time and move platform.
    advance(scene);
    move(plat,[position(:,:,idx+1),zeros(1,6),eul2quat(orientation(:,:,idx+1)),zeros(1,3)])
    % Update all sensors in the scene.
    updateSensors(scene)
```

```
end
hold off
```



See Also

Functions
read

Objects
uavPlatform | uavScenario | uavSensor

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

uavWaypointFollower

Follow waypoints for UAV

Description

The `uavWaypointFollower` System object follows a set of waypoints for an unmanned aerial vehicle (UAV) using a lookahead point. The object calculates the lookahead point, desired course, and desired yaw given a UAV position, a set of waypoints, and a lookahead distance. Specify a set of waypoints and tune the`lookAheadDistance` input argument and `TransitionRadius` property for navigating the waypoints. The object supports both multirotor and fixed-wing UAV types.

To follow a set of waypoints:

1. Create the `uavWaypointFollower` 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

```
wpFollowerObj = uavWaypointFollower
wpFollowerObj = uavWaypointFollower(Name,Value)
```

Description

`wpFollowerObj = uavWaypointFollower` creates a UAV waypoint follower with default properties.

`wpFollowerObj = uavWaypointFollower(Name,Value)` creates a UAV waypoint follower 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.

UAV type — Type of UAV
'fixed-wing' (default) | 'multirotor'

Type of UAV, specified as either 'fixed-wing' or 'multirotor'.

StartFrom — Waypoint start behavior
'first' (default) | 'closest'

Waypoint start behavior, specified as either 'first' or 'closest'.

When set to 'first', the UAV flies to the first path segment between waypoints listed in Waypoints. When set to 'closest', the UAV flies to the closest path segment between waypoints listed in Waypoints. When the waypoints input changes, the UAV recalculates the closest path segment.

Waypoints — Set of waypoints
n-by-3 matrix of [x y z] vectors

Set of waypoints for UAV to follow, specified as a *n*-by-3 matrix of [x y z] vectors in meters.

Data Types: single | double

YawAngles — Yaw angle for each waypoint
scalar | *n*-element column vector | []

Yaw angle for each waypoint, specified as a scalar or *n*-element column vector in radians. A scalar is applied to each waypoint in Waypoints. An input of [] keeps the yaw aligned with the desired course based on the lookahead point.

Data Types: single | double

TransitionRadius — Transition radius for each waypoint
numeric scalar | *n*-element column vector

Transition radius for each waypoint, specified as a scalar or *n*-element vector in meter. When specified as a scalar, this parameter is applied to each waypoint in Waypoints. When the UAV is within the transition radius, the object transitions to following the next path segment between waypoints.

Data Types: single | double

MinLookaheadDistance — Minimum lookahead distance
0.1 (default) | positive numeric scalar

Minimum lookahead distance, specified as a positive numeric scalar in meters.

Data Types: single | double

Usage

Syntax

```
[lookaheadPoint,desiredCourse,desiredYaw,lookaheadDistFlag,crossTrackError,
status] = wpFollowerObj(currentPose,lookaheadDistance)
```

Description

`[lookaheadPoint,desiredCourse,desiredYaw,lookaheadDistFlag,crossTrackError,status] = wpFollowerObj(currentPose,lookaheadDistance)` follows the set of waypoints specified in the waypoint follower object. The object takes the current position and lookahead distance to compute the lookahead point on the path. The desired course, yaw, and cross track error are also based on this lookahead point compared to the current position. `status` returns zero until the UAV has navigated all the waypoints.

Input Arguments

`currentPose` — Current UAV pose
`[x y z chi]` vector

Current UAV pose, specified as a `[x y z chi]` vector. This pose is used to calculate the lookahead point based on the input `lookaheadDistance`. `[x y z]` is the current position in meters. `chi` is the current course in radians.

Data Types: `single` | `double`

`lookaheadDistance` — Lookahead distance along the path
positive numeric scalar

Lookahead distance along the path, specified as a positive numeric scalar in meters.

Data Types: `single` | `double`

Output Arguments

`lookaheadPoint` — Lookahead point on path
`[x y z]` position vector

Lookahead point on path, returned as an `[x y z]` position vector in meters.

Data Types: `single` | `double`

`desiredCourse` — Desired course
numeric scalar

Desired course, returned as a numeric scalar in radians in the range of `[-pi, pi]`. The UAV course is the direction of the velocity vector. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: `single` | `double`

`desiredYaw` — Desired yaw
numeric scalar

Desired yaw, returned as a numeric scalar in radians in the range of `[-pi, pi]`. The UAV yaw is the angle of the forward direction of the UAV regardless of the velocity vector. The desired yaw is computed using linear interpolation between the yaw angle for each waypoint. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: `single` | `double`

`lookaheadDistFlag` — Lookahead distance flag
`0` (default) | `1`

Lookahead distance flag, returned as `0` or `1`. `0` indicates lookahead distance is not saturated, `1` indicates lookahead distance is saturated to minimum lookahead distance value specified.

Data Types: `uint8`

`crossTrackError` — Cross track error from UAV position to path
positive numeric scalar

Cross track error from UAV position to path, returned as a positive numeric scalar in meters. The error measures the perpendicular distance from the UAV position to the closest point on the path.

Data Types: `single` | `double`

`status` — Status of waypoint navigation
`0` | `1`

Status of waypoint navigation, returned as `0` or `1`. When the follower has navigated all waypoints, the object outputs `1`. Otherwise, the object outputs `0`.

Data Types: `uint8`

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)
```

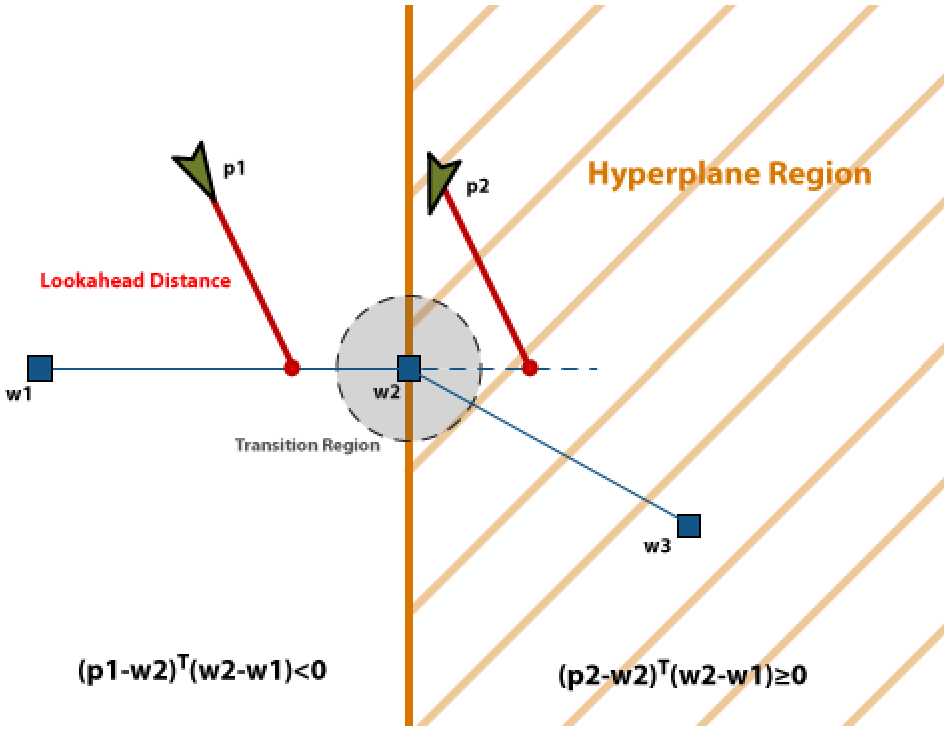
Common to All System Objects

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

More About

Waypoint Hyperplane Condition

When following a set of waypoints, the first waypoint may be ignored based on the pose of the UAV. Due to the nature of the lookahead distance used to track the path, the waypoint follower checks if the UAV is near the next waypoint to transition to the next path segment using a transition region. However, there is also a condition where the UAV transitions when outside of this region. A 3-D hyperplane is drawn at the next waypoint. If the UAV pose is inside this hyperplane, the waypoint follower transitions to the next waypoint. This behavior helps to ensure the UAV follows an achievable path.



The hyperplane condition is satisfied if:

$(p\text{-}w1)^{T}\ (w2\text{-}w1) \geq 0$

p is the UAV position, and *w1* and *w2* are sequential waypoint positions.

If you find this behavior limiting, consider adding more waypoints based on your initial pose to force the follower to navigate towards your initial waypoint.

References

[1] Park, Sanghyuk, John Deyst, and Jonathan How. "A New Nonlinear Guidance Logic for Trajectory Tracking." *AIAA Guidance, Navigation, and Control Conference and Exhibit*, 2004.

Extended Capabilities

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

See Also

Functions
`control` | `derivative` | `environment` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor` | `uavOrbitFollower`

Blocks
UAV Guidance Model

Topics
“Approximate High-Fidelity UAV model with UAV Guidance Model block”
“Tuning Waypoint Follower for Fixed-Wing UAV”

Introduced in R2018b

ulogreader

Read messages from ULOG file

Description

The `ulogreader` object reads a ULOG file (`.ulg`). The object stores information about the file, including start and end logging times, summary of available topics, and dropout intervals.

Creation

Syntax

`ulogOBJ = ulogreader(filePath)`

Description

`ulogOBJ = ulogreader(filePath)` reads the ULOG file from the specified path and returns an object containing information about the file. The information in `filePath` is used to set the FileName property.

Properties

`FileName` — Name of ULOG file
string scalar | character vector

This property is read-only.

Name of the ULOG file, specified as a string scalar or character vector. The `FileName` is the path specified in the `filePath` input.

Data Types: `char` | `string`

`StartTime` — Start time of logging
`duration` object

This property is read-only.

Start time of logging offset from the system start time in the ULOG file, specified as a `duration` object in the `'hh:mm:ss.SSSSSS'` format.

Data Types: `duration`

`EndTime` — Timestamp of last timestamped message
`duration` object

This property is read-only.

Timestamp of the last timestamped message logged in the ULOG file, specified as a `duration` object in the `'hh:mm:ss.SSSSSS'` format.

Data Types: duration

AvailableTopics — Table of all logged topics
table

This property is read-only.

Summary of all the logged topics, specified as a table that contains the columns:

- TopicNames
- InstanceID
- StartTimestamp
- LastTimestamp
- NumMessages

Data Types: table

DropoutIntervals — Time intervals in which messages were dropped while logging
n-by-2 matrix

This property is read-only.

Time intervals in which messages were dropped while logging, specified as an *n*-by-2 matrix of duration arrays in the 'hh:mm:ss.SSSSSS' format, where *n* is the number of dropouts.

Data Types: duration

Object Functions

readTopicMsgs	Read topic messages
readSystemInformation	Read information messages
readParameters	Read parameter values
readLoggedOutput	Read logged output messages

Examples

Read Messages from ULOG File

Load the ULOG file. Specify the relative path of the file.

```
ulog = ulogreader('flight.ulg');
```

Read all topic messages.

```
msg = readTopicMsgs(ulog);
```

Specify the time interval between which to select messages.

```
d1 = ulog.StartTime;
d2 = d1 + duration([0 0 55],'Format','hh:mm:ss.SSSSSS');
```

Read messages from the topic 'vehicle_attitude' with an instance ID of 0 in the time interval [d1 d2].

```
data = readTopicMsgs(ulog,'TopicNames',{'vehicle_attitude'}, ...
'InstanceID',{0},'Time',[d1 d2]);
```

Extract topic messages for the topic.

```
vehicle_attitude = data.TopicMessages{1,1};
```

Read all system information.

```
systeminfo = readSystemInformation(ulog);
```

Read all initial parameter values.

```
params = readParameters(ulog);
```

Read all logged output messages.

```
loggedoutput = readLoggedOutput(ulog);
```

Read logged output messages in the time interval.

```
log = readLoggedOutput(ulog,'Time',[d1 d2]);
```

References

[1] PX4 Developer Guide. "ULog File Format." Accessed December 6, 2019. https://dev.px4.io/v1.9.0/en/log/ulog_file_format.html.

See Also

mavlinktlog

Introduced in R2020b

waypointTrajectory

Waypoint trajectory generator

Description

The `waypointTrajectory` System object generates trajectories using specified waypoints. When you create the System object, you can optionally specify the time of arrival, velocity, and orientation at each waypoint.

To generate a trajectory from waypoints:

1. Create the `waypointTrajectory` object and set its properties.
2. Call the object as if it were a function.

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

Creation

Syntax

```
trajectory = waypointTrajectory
trajectory = waypointTrajectory(Waypoints,TimeOfArrival)
trajectory = waypointTrajectory(Waypoints,TimeOfArrival,Name,Value)
```

Description

`trajectory = waypointTrajectory` returns a System object, `trajectory`, that generates a trajectory based on default stationary waypoints.

`trajectory = waypointTrajectory(Waypoints,TimeOfArrival)` specifies the `Waypoints` that the generated trajectory passes through and the `TimeOfArrival` at each waypoint.

`trajectory = waypointTrajectory(Waypoints,TimeOfArrival,Name,Value)` sets each creation argument or property `Name` to the specified `Value`. Unspecified properties and creation arguments have default or inferred values.

Example: `trajectory = waypointTrajectory([10,10,0;20,20,0;20,20,10],[0,0.5,10])` creates a waypoint trajectory System object, `trajectory`, that starts at waypoint `[10,10,0]`, and then passes through `[20,20,0]` after 0.5 seconds and `[20,20,10]` after 10 seconds.

Creation Arguments

Creation arguments are properties which are set during creation of the System object and cannot be modified later. If you do not explicitly set a creation argument value, the property value is inferred.

If you specify any creation argument, then you must specify both the Waypoints and TimeOfArrival creation arguments. You can specify `Waypoints` and `TimeOfArrival` as value-only arguments or name-value pairs.

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.

`SampleRate` — Sample rate of trajectory (Hz)
`100` (default) | positive scalar

Sample rate of trajectory in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `double`

`SamplesPerFrame` — Number of samples per output frame
`1` (default) | positive scalar integer

Number of samples per output frame, specified as a positive scalar integer.

Tunable: Yes

Data Types: `double`

`Waypoints` — Positions in the navigation coordinate system (m)
N-by-3 matrix

Positions in the navigation coordinate system in meters, specified as an *N*-by-3 matrix. The columns of the matrix correspond to the first, second, and third axes, respectively. The rows of the matrix, *N*, correspond to individual waypoints.

Dependencies

To set this property, you must also set valid values for the TimeOfArrival property.

Data Types: `double`

`TimeOfArrival` — Time at each waypoint (s)
N-element column vector of nonnegative increasing numbers

Time corresponding to arrival at each waypoint in seconds, specified as an *N*-element column vector. The first element of `TimeOfArrival` must be `0`. The number of samples, *N*, must be the same as the number of samples (rows) defined by `Waypoints`.

Dependencies

To set this property, you must also set valid values for the Waypoints property.

Data Types: `double`

`Velocities` — Velocity in navigation coordinate system at each waypoint (m/s)
N-by-3 matrix

Velocity in the navigation coordinate system at each way point in meters per second, specified as an *N*-by-3 matrix. The columns of the matrix correspond to the first, second, and third axes, respectively.

The number of samples, *N*, must be the same as the number of samples (rows) defined by `Waypoints`.

If the velocity is specified as a non-zero value, the object automatically calculates the course of the trajectory. If the velocity is specified as zero, the object infers the course of the trajectory from adjacent waypoints.

Dependencies

To set this property, you must also set valid values for the Waypoints and TimeOfArrival properties.

Data Types: `double`

`Course` — Horizontal direction of travel (degree)

N-element real vector

Horizontal direction of travel, specified as an *N*-element real vector in degrees. The number of samples, *N*, must be the same as the number of samples (rows) defined by `Waypoints`. If neither `Velocities` nor `Course` is specified, course is inferred from the waypoints.

Dependencies

To set this property, the `Velocities` property must not be specified in object creation.

Data Types: `double`

`GroundSpeed` — Groundspeed at each waypoint (m/s)

N-element real vector

Groundspeed at each waypoint, specified as an *N*-element real vector in m/s. If the property is not specified, it is inferred from the waypoints. The number of samples, *N*, must be the same as the number of samples (rows) defined by `Waypoints`.

Dependencies

To set this property, the `Velocities` property must not be specified at object creation.

Data Types: `double`

`Climbrate` — Climbrate at each waypoint (m/s)

N-element real vector

Climbrate at each waypoint, specified as an *N*-element real vector in degrees. The number of samples, *N*, must be the same as the number of samples (rows) defined by `Waypoints`. If neither `Velocities` nor `Course` is specified, climbrate is inferred from the waypoints.

Dependencies

To set this property, the `Velocities` property must not be specified at object creation.

Data Types: `double`

`Orientation` — Orientation at each waypoint

N-element quaternion column vector | 3-by-3-by-*N* array of real numbers

Orientation at each waypoint, specified as an *N*-element `quaternion` column vector or 3-by-3-by-*N* array of real numbers. The number of quaternions or rotation matrices, *N*, must be the same as the number of samples (rows) defined by `Waypoints`.

If `Orientation` is specified by quaternions, the underlying class must be `double`.

Dependencies

To set this property, you must also set valid values for the Waypoints and TimeOfArrival properties.

Data Types: `quaternion` | `double`

`AutoPitch` — Align pitch angle with direction of motion

`false` (default) | `true`

Align pitch angle with the direction of motion, specified as `true` or `false`. When specified as `true`, the pitch angle automatically aligns with the direction of motion. If specified as `false`, the pitch angle is set to zero (level orientation).

Dependencies

To set this property, the `Orientation` property must not be specified at object creation.

`AutoBank` — Align roll angle to counteract centripetal force

`false` (default) | `true`

Align roll angle to counteract the centripetal force, specified as `true` or `false`. When specified as `true`, the roll angle automatically counteract the centripetal force. If specified as `false`, the roll angle is set to zero (flat orientation).

Dependencies

To set this property, the `Orientation` property must not be specified at object creation.

`ReferenceFrame` — Reference frame of trajectory

`'NED'` (default) | `'ENU'`

Reference frame of the trajectory, specified as `'NED'` (North-East-Down) or `'ENU'` (East-North-Up).

Usage

Syntax

```
[position,orientation,velocity,acceleration,angularVelocity] = trajectory()
```

Description

`[position,orientation,velocity,acceleration,angularVelocity] = trajectory()` outputs a frame of trajectory data based on specified creation arguments and properties.

Output Arguments

`position` — Position in local navigation coordinate system (m)

M-by-3 matrix

Position in the local navigation coordinate system in meters, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

`orientation` — Orientation in local navigation coordinate system
M-element quaternion column vector | 3-by-3-by-*M* real array

Orientation in the local navigation coordinate system, returned as an *M*-by-1 `quaternion` column vector or a 3-by-3-by-*M* real array.

Each quaternion or 3-by-3 rotation matrix is a frame rotation from the local navigation coordinate system to the current body coordinate system.

M is specified by the SamplesPerFrame property.

Data Types: `double`

`velocity` — Velocity in local navigation coordinate system (m/s)
M-by-3 matrix

Velocity in the local navigation coordinate system in meters per second, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

`acceleration` — Acceleration in local navigation coordinate system (m/s^2)
M-by-3 matrix

Acceleration in the local navigation coordinate system in meters per second squared, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

`angularVelocity` — Angular velocity in local navigation coordinate system (rad/s)
M-by-3 matrix

Angular velocity in the local navigation coordinate system in radians per second, returned as an *M*-by-3 matrix.

M is specified by the SamplesPerFrame property.

Data Types: `double`

Object Functions

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

```
release(obj)
```

Common to All System Objects

clone	Create duplicate System object
step	Run System object algorithm
release	Release resources and allow changes to System object property values and input characteristics

reset	Reset internal states of System object
isDone	End-of-data status

Extended Capabilities

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

The object function, `waypointInfo`, does not support code generation.

Usage notes and limitations:

See "System Objects in MATLAB Code Generation" (MATLAB Coder).

See Also

Introduced in R2018b

pcplayer

Visualize streaming 3-D point cloud data

Description

Visualize 3-D point cloud data streams from devices such as Microsoft®Kinect®.

To improve performance, `pcplayer` automatically downsamples the rendered point cloud during interaction with the figure. The downsampling occurs only for rendering the point cloud and does not affect the saved points.

Creation

Syntax

```
player = pcplayer(xlimits,ylimits,zlimits)
player = pcplayer(xlimits,ylimits,zlimits,Name,Value)
```

Description

`player = pcplayer(xlimits,ylimits,zlimits)` returns a player with `xlimits`,`ylimits`, and `zlimits` set for the axes limits.

`player = pcplayer(xlimits,ylimits,zlimits,Name,Value)` returns a player with additional properties specified by one or more `Name,Value` pair arguments.

Input Arguments

`xlimits` — Range of *x*-axis coordinates
1-by-2 vector

Range of *x*-axis coordinates, specified as a 1-by-2 vector in the format [*min max*]. `pcplayer` does not display data outside these limits.

`ylimits` — Range of *y*-axis coordinates
1-by-2 vector

Range of *y*-axis coordinates, specified as a 1-by-2 vector in the format [*min max*]. `pcplayer` does not display data outside these limits.

`zlimits` — Range of *z*-axis coordinates
1-by-2 vector

Range of *z*-axis coordinates, specified as a 1-by-2 vector in the format [*min max*].`pcplayer` does not display data outside these limits.

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: `'VerticalAxisDir'`, `'Up'`.

`MarkerSize` — Diameter of marker

`6` (default) | positive scalar

Diameter of marker, specified as the comma-separated pair consisting of '`MarkerSize`' and a positive scalar. The value specifies the approximate diameter of the point marker. MATLAB graphics defines the unit as points. A marker size larger than six can reduce the rendering performance.

`VerticalAxis` — Vertical axis

`'Z'` (default) | `'X'` | `'Y'`

Vertical axis, specified as the comma-separated pair consisting of '`VerticalAxis`' and `'X'`, `'Y'`, or `'Z'`. When you reload a saved figure, any action on the figure resets the vertical axis to the *z*-axis.

`VerticalAxisDir` — Vertical axis direction

`'Up'` (default) | `'Down'`

Vertical axis direction, specified as the comma-separated pair consisting of '`VerticalAxisDir`' and `'Up'` or `'Down'`. When you reload a saved figure, any action on the figure resets the direction to the up direction.

Properties

`Axes` — Player axes handle

`axes` graphics object

Player axes handle, specified as an `axes` graphics object.

Usage

Color and Data Point Values in Figure

To view point data or modify color display values, hover over the axes toolbar and select one of the following options.

<table>
<tr><th>Feature</th><th>Description</th></tr>
<tr><td>Datatip</td><td>Click Data Tips to view the data point values for any point in the point cloud figure. For a normal point cloud, the Data Tips displays the x,y,z values. Additional data properties for the depth image and lidar are:
<table>
<tr><th>Point Cloud Data</th><th>Data Value Properties</th></tr>
<tr><td>Depth image (RGB-D sensor)</td><td>Color, row, column</td></tr>
<tr><td>Lidar</td><td>Intensity, range, azimuth angle, elevation angle, row, column</td></tr>
</table></td></tr>
</table>

Feature	Description
Background color	Click **Rotate** and then right-click in the figure for background options.
Colormap value	Click **Rotate** and then right-click in the figure for colormap options. You can modify colormap values for the coordinate and range values available, depending on the type of point cloud displayed.
View	Click **Rotate** to change the viewing angle of the point cloud figure to the *XZ*, *ZX*,*YZ*, *ZY*, *XY*, or the *YX* plane. Click **Restore View** to reset the viewing angle.

OpenGL Option

`pcplayer` supports the `'opengl'` option for the `Renderer` `figure` property only.

Object Functions

hide   Hide player figure
isOpen   Visible or hidden status for player
show   Show player
view   Display point cloud

Examples

Terminate a Point Cloud Processing Loop

Create the player and add data.

```
player = pcplayer([0 1],[0 1],[0 1]);
```

Display continuous player figure. Use the `isOpen` function to check if player figure window is open.

```
while isOpen(player)
     ptCloud = pointCloud(rand(1000,3,'single'));
     view(player,ptCloud);
end
```

Terminate while-loop by closing pcplayer figure window.

See Also

`pointCloud`

Introduced in R2020b

hide

Hide player figure

Syntax

```
hide(player)
```

Description

`hide(player)` hides the figure. To redisplay the player, use `show(player)`.

Input Arguments

`player` — Player
object

Video player, specified as a `pcplayer` object.

Introduced in R2020b

isOpen

Visible or hidden status for player

Syntax

```
isOpen(player)
```

Description

`isOpen(player)` returns `true` or `false` to indicate whether the player is visible.

Input Arguments

`player` — Player
object

Video player, specified as a `pcplayer` object.

Introduced in R2020b

show

Show player

Syntax

```
show(player)
```

Description

`show(player)` makes the player figure visible again after closing or hiding it.

Input Arguments

`player` — Player
object

Player for visualizing data streams, specified as a `pcplayer` object. Use this method to view the figure after you have removed it from display. For example, after you x-out of a figure and you want to view it again. This is particularly useful to use after a while loop that contains display code ends.

Introduced in R2020b

view

Display point cloud

Syntax

```
view(player,ptCloud)
view(player,xyzPoints)
view(player,xyzPoints,color)
view(player,xyzPoints,colorMap)
```

Description

`view(player,ptCloud)` displays a point cloud in the `pcplayer` figure window, `player`. The points, locations, and colors are stored in the `ptCloud` object.

`view(player,xyzPoints)` displays the points of a point cloud at the locations specified by the `xyzPoints` matrix. The color of each point is determined by the *z* value.

`view(player,xyzPoints,color)` displays a point cloud with colors specified by `color`.

`view(player,xyzPoints,colorMap)` displays a point cloud with colors specified by `colorMap`.

Input Arguments

`ptCloud` — Point cloud
`pointCloud` object

Point cloud, specified as a `pointCloud` object. The object contains the locations, intensities, and RGB colors to render the point cloud.

Point Cloud Property	Color Rendering Result
`Location` only	Maps the z-value to a color value in the current color map.
`Location` and `Intensity`	Maps the intensity to a color value in the current color map.
`Location` and `Color`	Use provided color.
`Location`, `Intensity`, and `Color`	Use provided color.

`player` — Player
`pcplayer` object

Player for visualizing 3-D point cloud data streams, specified as a `pcplayer` object.

`xyzPoints` — Point cloud *x*, *y*, and *z* locations
M-by-3 numeric matrix | *M*-by-*N*-by-3 numeric matrix

Point cloud *x*, *y*, and *z* locations, specified as either an *M*-by-3 or an *M*-by-*N*-by-3 numeric matrix. The *M*-by-*N*-by-3 numeric matrix is commonly referred to as an organized point cloud. The `xyzPoints` numeric matrix contains *M* or *M*-by-*N* [*x*,*y*,*z*] points. The *z* values in the numeric matrix, which generally correspond to depth or elevation, determine the color of each point.

`color` — Point cloud color
1-by-3 RGB vector | short name of color | long name of color | *M*-by-3 matrix | *M*-by-*N*-by-3 matrix

Point cloud color of points, specified as one of:

- 1-by-3 RGB vector
- short name of a MATLAB `ColorSpec` color, such as `'b'`
- long name of a MATLAB `ColorSpec` color, such as `'blue'`
- *M*-by-3 matrix
- *M*-by-*N*-by-3 matrix

You can specify the same color for all points or a different color for each point. When you set `color` to `single` or `double`, the RGB values range between [0, 1]. When you set `color` to `uint8`, the values range between [0, 255].

Points Input	Color Selection	Valid Values of `C`
`xyzPoints`	Same color for all points	1-by-3 RGB vector, or the short or long name of a MATLAB `ColorSpec` color
	Different color for each point	*M*-by-3 matrix or *M*-by-*N*-by-3 matrix containing RGB values for each point.

`colorMap` — Point cloud color map
M-by-1 vector | *M*-by-*N* matrix

Point cloud color of points, specified as one of:

- *M*-by-1 vector
- *M*-by-*N* matrix

Points Input	Color Selection	Valid Values of `C`
`xyzPoints`	Different color for each point	Vector or *M*-by-*N* matrix. The matrix must contain values that are linearly mapped to a color in the current `colormap`.

Introduced in R2020b

pointCloud

Object for storing 3-D point cloud

Description

The `pointCloud` object creates point cloud data from a set of points in 3-D coordinate system. The point cloud data is stored as an object with the properties listed in “Properties” on page 1-145. Use “Object Functions” on page 1-146 to retrieve, select, and remove desired points from the point cloud data.

Creation

Syntax

```
ptCloud = pointCloud(xyzPoints)
ptCloud = pointCloud(xyzPoints,Name,Value)
```

Description

`ptCloud = pointCloud(xyzPoints)` returns a point cloud object with coordinates specified by `xyzPoints`.

`ptCloud = pointCloud(xyzPoints,Name,Value)` creates a `pointCloud` object with properties specified as one or more `Name,Value` pair arguments. For example, `pointCloud(xyzPoints,'Color',[0 0 0])` sets the `Color` property of the point `xyzPoints` as [0 0 0]. Enclose each property name in quotes. Any unspecified properties have default values.

Input Arguments

`xyzPoints` — 3-D coordinate points
M-by-3 list of points | *M*-by-*N*-by-3 array for organized point cloud

3-D coordinate points, specified as an *M*-by-3 list of points or an *M*-by-*N*-by-3 array for an organized point cloud. The 3-D coordinate points specify the *x*, *y*, and *z* positions of a point in the 3-D coordinate space. The first two dimensions of an organized point cloud correspond to the scanning order from sensors such as RGBD or lidar. This argument sets the `Location` property.

Data Types: `single` | `double`

Output Arguments

`ptCloud` — Point cloud
`pointCloud` object

Point cloud, returned as a `pointCloud` object with the properties listed in “Properties” on page 1-145.

Properties

`Location` — Position of the points in 3-D coordinate space

M-by-3 array | *M*-by-*N*-by-3 array

This property is read-only.

Position of the points in 3-D coordinate space, specified as an *M*-by-3 or *M*-by-*N*-by-3 array. Each entry specifies the *x*, *y*, and *z* coordinates of a point in the 3-D coordinate space. You cannot set this property as a name-value pair. Use the `xyzPoints` input argument.

Data Types: `single` | `double`

`Color` — Point cloud color

[ ] (default) | *M*-by-3 array | *M*-by-*N*-by-3 array

Point cloud color, specified as an *M*-by-3 or *M*-by-*N*-by-3 array. Use this property to set the color of points in point cloud. Each entry specifies the RGB color of a point in the point cloud data. Therefore, you can specify the same color for all points or a different color for each point.

- The specified RGB values must lie within the range [0, 1], when you specify the data type for `Color` as `single` or `double`.
- The specified RGB values must lie within the range [0, 255], when you specify the data type for `Color` as `uint8`.

Coordinates	Valid assignment of `Color`
M-by-3 array	*M*-by-3 array containing RGB values for each point
M-by-*N*-by-3 array	*M*-by-*N*-by-3 array containing RGB values for each point

Data Types: `uint8`

`Normal` — Surface normals

[ ] (default) | *M*-by-3 array | *M*-by-*N*-by-3 array

Surface normals, specified as a *M*-by-3 or *M*-by-*N*-by-3 array. Use this property to specify the normal vector with respect to each point in the point cloud. Each entry in the surface normals specifies the *x*, *y*, and *z* component of a normal vector.

Coordinates	Surface Normals
M-by-3 array	*M*-by-3 array, where each row contains a corresponding normal vector.
M-by-*N*-by-3 array	*M*-by-*N*-by-3 array containing a 1-by-1-by-3 normal vector for each point.

Data Types: `single` | `double`

`Intensity` — Grayscale intensities

[ ] (default) | *M*-by-1 vector | *M*-by-*N* matrix

Grayscale intensities at each point, specified as a *M*-by-1 vector or *M*-by-*N* matrix. The function maps each intensity value to a color value in the current colormap.

Coordinates	Intensity
M-by-3 array	*M*-by-1 vector, where each row contains a corresponding intensity value.

Coordinates	Intensity
M-by-*N*-by-3 array	*M*-by-*N* matrix containing intensity value for each point.

Data Types: `single` | `double` | `uint8`

`Count` — Number of points
positive integer

This property is read-only.

Number of points in the point cloud, stored as a positive integer.

`XLimits` — Range of *x* coordinates
1-by-2 vector

This property is read-only.

Range of coordinates along *x*-axis, stored as a 1-by-2 vector.

`YLimits` — Range of *y* coordinates
1-by-2 vector

This property is read-only.

Range of coordinates along *y*-axis, stored as a 1-by-2 vector.

`ZLimits` — Range of *z* coordinates
1-by-2 vector

This property is read-only.

Range of coordinates along *z*-axis, stored as a 1-by-2 vector.

Object Functions

findNearestNeighbors	Find nearest neighbors of a point in point cloud
findNeighborsInRadius	Find neighbors within a radius of a point in the point cloud
findPointsInROI	Find points within a region of interest in the point cloud
removeInvalidPoints	Remove invalid points from point cloud
select	Select points in point cloud
copy	Copy array of handle objects

Tips

The `pointCloud` object is a `handle` object. If you want to create a separate copy of a point cloud, you can use the MATLAB `copy` method.
`ptCloudB = copy(ptCloudA)`

If you want to preserve a single copy of a point cloud, which can be modified by point cloud functions, use the same point cloud variable name for the input and output.
`ptCloud =` *pcFunction*`(ptCloud)`

Extended Capabilities

C/C++ Code Generation

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

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

Usage notes and limitations:

- GPU code generation for variable input sizes is not optimized. Consider using constant size inputs for an optimized code generation.
- GPU code generation supports the `'Color'`, `'Normal'`, and `'Intensity'` name-value pairs.
- GPU code generation supports the `findNearestNeighbors`, `findNeighborsInRadius`, `findPointsInROI`, `removeInvalidPoints`, and `select` methods.
- For very large inputs, the memory requirements of the algorithm may exceed the GPU device limits. In such cases, consider reducing the input size to proceed with code generation.

See Also

Functions

`pcplayer`

Introduced in R2020b

findNearestNeighbors

Find nearest neighbors of a point in point cloud

Syntax

```
[indices,dists] = findNearestNeighbors(ptCloud,point,K)
[indices,dists] = findNearestNeighbors( ___ ,Name,Value)
```

Description

`[indices,dists] = findNearestNeighbors(ptCloud,point,K)` returns the `indices` for the K-nearest neighbors of a query point in the input point cloud. `ptCloud` can be an unorganized or organized point cloud. The K-nearest neighbors of the query point are computed by using the Kd-tree based search algorithm.

`[indices,dists] = findNearestNeighbors( ___ ,Name,Value)` specifies options using one or more name-value arguments in addition to the input arguments in the preceding syntaxes.

Input Arguments

`ptCloud` — Point cloud
`pointCloud` object

Point cloud, specified as a `pointCloud` object.

`point` — Query point
three-element vector of form `[x,y,z]`

Query point, specified as a three-element vector of form `[x,y,z]`.

`K` — Number of nearest neighbors
positive integer

Number of nearest neighbors, specified as a positive integer.

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: `findNearestNeighbors(ptCloud,point,k,'Sort',true)`

`Sort` — Sort indices
`false` (default) | `true`

Sort indices, specified as a comma-separated pair of `'Sort'` and a logical scalar. When you set `Sort` to `true`, the returned indices are sorted in the ascending order based on the distance from a query point. To turn off sorting, set `Sort` to `false`.

`MaxLeafChecks` — Number of leaf nodes to check
`Inf` (default) | integer

Number of leaf nodes to check, specified as a comma-separated pair consisting of `'MaxLeafChecks'` and an integer. When you set this value to `Inf`, the entire tree is searched. When the entire tree is searched, it produces exact search results. Increasing the number of leaf nodes to check increases accuracy, but reduces efficiency.

Note The name-value argument `'MaxLeafChecks'` is valid only with Kd-tree based search method.

Output Arguments

`indices` — Indices of stored points
column vector

Indices of stored points, returned as a column vector. The vector contains K linear indices of the nearest neighbors stored in the point cloud.

`dists` — Distances to query point
column vector

Distances to query point, returned as a column vector. The vector contains the Euclidean distances between the query point and its nearest neighbors.

References

[1] Muja, M. and David G. Lowe. "Fast Approximate Nearest Neighbors with Automatic Algorithm Configuration". *In VISAPP International Conference on Computer Vision Theory and Applications*. 2009. pp. 331–340.

Extended Capabilities

C/C++ Code Generation

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

Usage notes and limitations:

- For code generation in non-host platforms, the value for `'MaxLeafChecks'` must be set to the default value `Inf`. If you specify values other than `Inf`, the function generates a warning and automatically assigns the default value for `'MaxLeafChecks'`.

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

Usage notes and limitations:

- For GPU code generation, the `'MaxLeafChecks'` name-value pair option is ignored.

See Also

`pointCloud`

Introduced in R2020b

findNeighborsInRadius

Find neighbors within a radius of a point in the point cloud

Syntax

```
[indices,dists] = findNeighborsInRadius(ptCloud,point,radius)
[indices,dists] = findNeighborsInRadius( ___ ,Name,Value)
```

Description

`[indices,dists] = findNeighborsInRadius(ptCloud,point,radius)` returns the `indices` of neighbors within a radius of a query point in the input point cloud. `ptCloud` can be an unorganized or organized point cloud. The neighbors within a radius of the query point are computed by using the Kd-tree based search algorithm.

`[indices,dists] = findNeighborsInRadius( ___ ,Name,Value)` specifies options using one or more name-value pair arguments in addition to the input arguments in the preceding syntaxes.

Input Arguments

`ptCloud` — Point cloud
`pointCloud` object

Point cloud, specified as a `pointCloud` object.

`point` — Query point
three-element vector of form [*x*,*y*,*z*]

Query point, specified as a three-element vector of form [*x*,*y*,*z*].

`radius` — Search radius
scalar

Search radius, specified as a scalar. The function finds the neighbors within the specified `radius` around a query point in the input point cloud.

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: `findNeighborsInRadius(ptCloud,point,radius,'Sort',true)`

`Sort` — Sort indices
`false` (default) | `true`

Sort indices, specified as a comma-separated pair of `'Sort'` and a logical scalar. When you set `Sort` to `true`, the returned indices are sorted in the ascending order based on the distance from a query point. To turn off sorting, set `Sort` to `false`.

`MaxLeafChecks` — Number of leaf nodes
`Inf` (default) | integer

Number of leaf nodes, specified as a comma-separated pair consisting of `'MaxLeafChecks'` and an integer. When you set this value to `Inf`, the entire tree is searched. When the entire tree is searched, it produces exact search results. Increasing the number of leaf nodes to check increases accuracy, but reduces efficiency.

Output Arguments

`indices` — Indices of stored points
column vector

Indices of stored points, returned as a column vector. The vector contains the linear indices of the radial neighbors stored in the point cloud.

`dists` — Distances to query point
column vector

Distances to query point, returned as a column vector. The vector contains the Euclidean distances between the query point and its radial neighbors.

References

[1] Muja, M. and David G. Lowe. "Fast Approximate Nearest Neighbors with Automatic Algorithm Configuration". *In VISAPP International Conference on Computer Vision Theory and Applications*. 2009. pp. 331–340.

Extended Capabilities

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

Usage notes and limitations:

- For code generation in non-host platforms, the value for `'MaxLeafChecks'` must be set to the default value `Inf`. If you specify values other than `Inf`, the function generates a warning and automatically assigns the default value for `'MaxLeafChecks'`.

GPU Code Generation
Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

Usage notes and limitations:

- For GPU code generation, the `'MaxLeafChecks'` name-value pair option is ignored.

See Also
`pointCloud`

Introduced in R2020b

findPointsInROI

Find points within a region of interest in the point cloud

Syntax

`indices = findPointsInROI(ptCloud,roi)`

Description

`indices = findPointsInROI(ptCloud,roi)` returns the points within a region of interest (ROI) in the input point cloud. The points within the specified ROI are obtained using a Kd-tree based search algorithm.

Input Arguments

`ptCloud` — Point cloud
`pointCloud` object

Point cloud, specified as a `pointCloud` object.

`roi` — Region of interest
six-element vector

Region of interest, specified as a six-element vector of form [*xmin*, *xmax*, *ymin*, *ymax*, *zmin*, *zmax*], where:

- *xmin* and *xmax* are the minimum and the maximum limits along the *x*-axis respectively.
- *ymin* and *ymax* are the minimum and the maximum limits along the *y*-axis respectively.
- *zmin* and *zmax* are the minimum and the maximum limits along the *z*-axis respectively.

Output Arguments

`indices` — Indices of stored points
column vector

Indices of stored points, returned as a column vector. The vector contains the linear indices of the ROI points stored in the point cloud.

References

[1] Muja, M. and David G. Lowe. "Fast Approximate Nearest Neighbors with Automatic Algorithm Configuration". *In VISAPP International Conference on Computer Vision Theory and Applications*. 2009. pp. 331–340.

Extended Capabilities

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

GPU Code Generation
Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

-

See Also
`pointCloud`

Introduced in R2020b

removeInvalidPoints

Remove invalid points from point cloud

Syntax

`[ptCloudOut,indices] = removeInvalidPoints(ptCloud)`

Description

`[ptCloudOut,indices] = removeInvalidPoints(ptCloud)` removes points with `Inf` or `NaN` coordinate values from point cloud and returns the indices of valid points.

Input Arguments

`ptCloud` — Point cloud
`pointCloud` object

Point cloud, specified as a `pointCloud` object.

Output Arguments

`ptCloudOut` — Point cloud with points removed
`pointCloud` object

Point cloud, returned as a `pointCloud` object with `Inf` or `NaN` coordinates removed.

Note The output is always an unorganized (*X*-by-3) point cloud. If the input `ptCloud` is an organized point cloud (*M*-by-*N*-by-3), the function returns the output as an unorganized point cloud.

`indices` — Indices of valid points
vector

Indices of valid points in the point cloud, specified as a vector.

Extended Capabilities

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

GPU Code Generation
Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

See Also
`pointCloud`

Introduced in R2020b

select

Select points in point cloud

Syntax

```
ptCloudOut = select(ptCloud,indices)
ptCloudOut = select(ptCloud,row,column)
ptCloudOut = select(___,'OutputSize',outputSize)
```

Description

`ptCloudOut = select(ptCloud,indices)` returns a `pointCloud` object containing only the points that are selected using linear indices.

`ptCloudOut = select(ptCloud,row,column)` returns a `pointCloud` object containing only the points that are selected using row and column subscripts. This syntax applies only if the input is an organized point cloud data of size *M*-by-*N*-by-3.

`ptCloudOut = select(___,'OutputSize',outputSize)` returns the selected points as a `pointCloud` object of size specified by `outputSize`.

Input Arguments

`ptCloud` — Point cloud
`pointCloud` object

Point cloud, specified as a `pointCloud` object.

`indices` — Indices of selected points
vector

Indices of selected points, specified as a vector.

`row` — Row indices
vector

Row indices, specified as a vector. This argument applies only if the input is an organized point cloud data of size *M*-by-*N*-by-3.

`column` — Column indices
vector

Column indices, specified as a vector. This argument applies only if the input is an organized point cloud data of size *M*-by-*N*-by-3.

`outputSize` — Size of output point cloud
`'selected'` (default) | `'full'`

Size of the output point cloud, `ptCloudOut`, specified as `'selected'` or `'full'`.

- If the size is 'selected', then the output contains only the selected points from the input point cloud, ptCloud.
- If the size is 'full', then the output is same size as the input point cloud ptCloud. Cleared points are filled with NaN and the color is set to [0 0 0].

Output Arguments

ptCloudOut — Selected point cloud
pointCloud object

Point cloud, returned as a pointCloud object.

Extended Capabilities

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

GPU Code Generation
Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

See Also

pointCloud

Introduced in R2020b

2

Methods

applyTransform

Apply forward transformation to mesh vertices

Syntax

```
transformedMesh = applyTransform(mesh,T)
```

Description

`transformedMesh = applyTransform(mesh,T)` applies the forward transformation matrix `T` to the vertices of the object mesh.

Examples

Create and Transform Cuboid Mesh

This example shows how to create an `extendedObjectMesh` object and transform the object in a way defined by a given transformation matrix.

Create a cuboid mesh of unit dimensions.

```
cuboid = extendedObjectMesh('cuboid');
```

Create a transformation matrix that is a combination of a translation, a scaling, and a rotation.

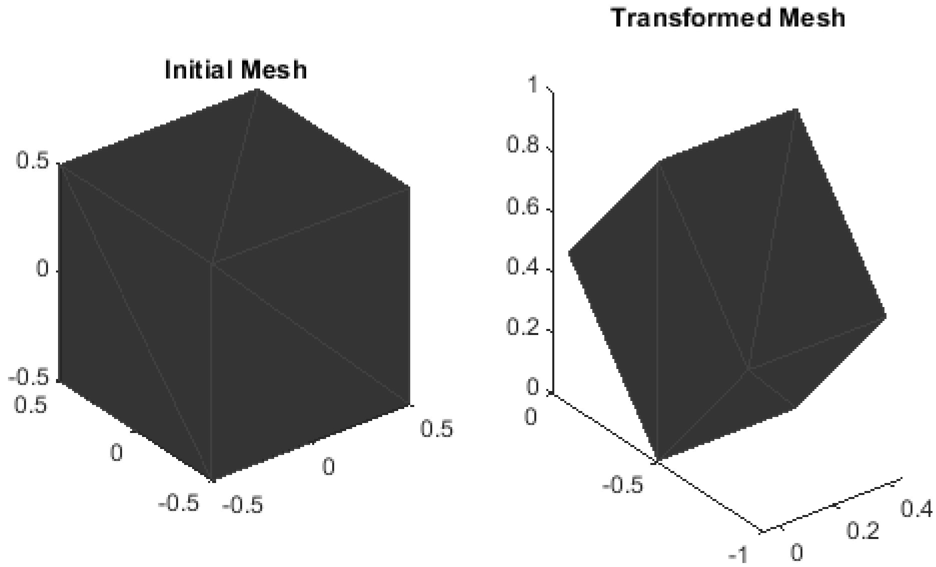
```
T = makehgtform('translate',[0.2 -0.5 0.5],'scale',[0.5 0.6 0.7],'xrotate',pi/4);
```

Transform the mesh.

```
transformedCuboid = applyTransform(cuboid,T);
```

Visualize the mesh.

```
subplot(1,2,1);
show(cuboid);
title('Initial Mesh');
subplot(1,2,2);
show(transformedCuboid);
title('Transformed Mesh');
```



Input Arguments

`mesh` — Extended object mesh
`extendedObjectMesh` object

Extended object mesh, specified as an `extendedObjectMesh` object.

`T` — Transformation matrix
4-by-4 matrix

Transformation matrix applied on the object mesh, specified as a 4-by-4 matrix. The 3-D coordinates of each point in the object mesh is transformed according to this formula:

```
[xT; yT; zT; 1] = T*[x; y; z; 1]
```

`xT`, `yT`, and `zT` are the transformed 3-D coordinates of the point.

Data Types: `single` | `double`

Output Arguments

`transformedMesh` — Transformed object mesh
`extendedObjectMesh` object

Transformed object mesh, returned as an `extendedObjectMesh` object.

See Also

Objects
`extendedObjectMesh`

Functions
`join` | `rotate` | `scale` | `scaleToFit` | `show` | `translate`

Introduced in R2020b

join

Join two object meshes

Syntax

```
joinedMesh = join(mesh1,mesh2)
```

Description

`joinedMesh = join(mesh1,mesh2)` joins the object meshes `mesh1` and `mesh2` and returns `joinedMesh` with the combined objects.

Examples

Create and Join Two Object Meshes

This example shows how to create `extendedObjectMesh` objects and join them together.

Construct two meshes of unit dimensions.

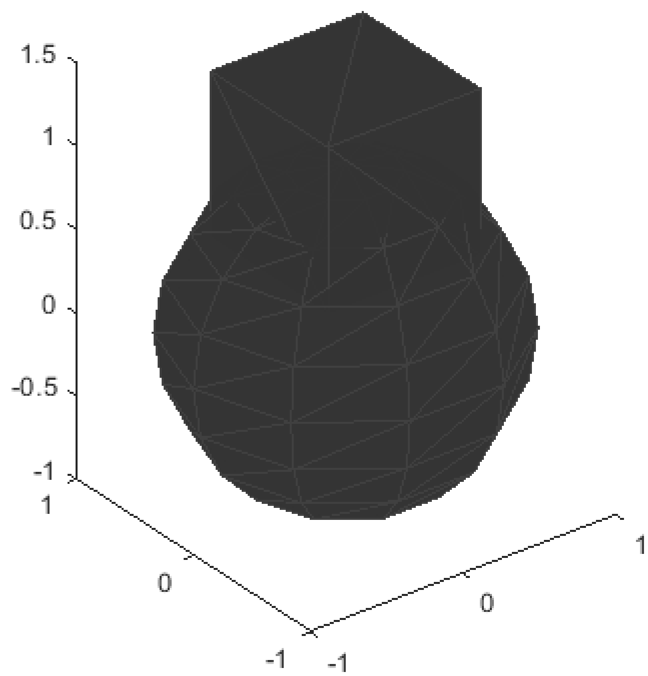
```
sph = extendedObjectMesh('sphere');
cub = extendedObjectMesh('cuboid');
```

Join the two meshes.

```
cub = translate(cub,[0 0 1]);
sphCub = join(sph,cub);
```

Visualize the final mesh.

```
show(sphCub);
```



Input Arguments

mesh1 — Extended object mesh
extendedObjectMesh object

Extended object mesh, specified as an extendedObjectMesh object.

mesh2 — Extended object mesh
extendedObjectMesh object

Extended object mesh, specified as an extendedObjectMesh object.

Output Arguments

joinedMesh — Joined object mesh
extendedObjectMesh object

Joined object mesh, specified as an extendedObjectMesh object.

See Also

Objects
extendedObjectMesh

Functions
`applyTransform` | `rotate` | `scale` | `scaleToFit` | `show` | `translate`

Introduced in R2020b

rotate

Rotate mesh about coordinate axes

Syntax

`rotatedMesh = rotate(mesh,orient)`

Description

`rotatedMesh = rotate(mesh,orient)` rotate the `mesh` object by an orientation, `orient`.

Examples

Create and Rotate Cuboid Mesh

This example shows how to create an `extendedObjectMesh` object and rotate the object.

Construct a cuboid mesh.

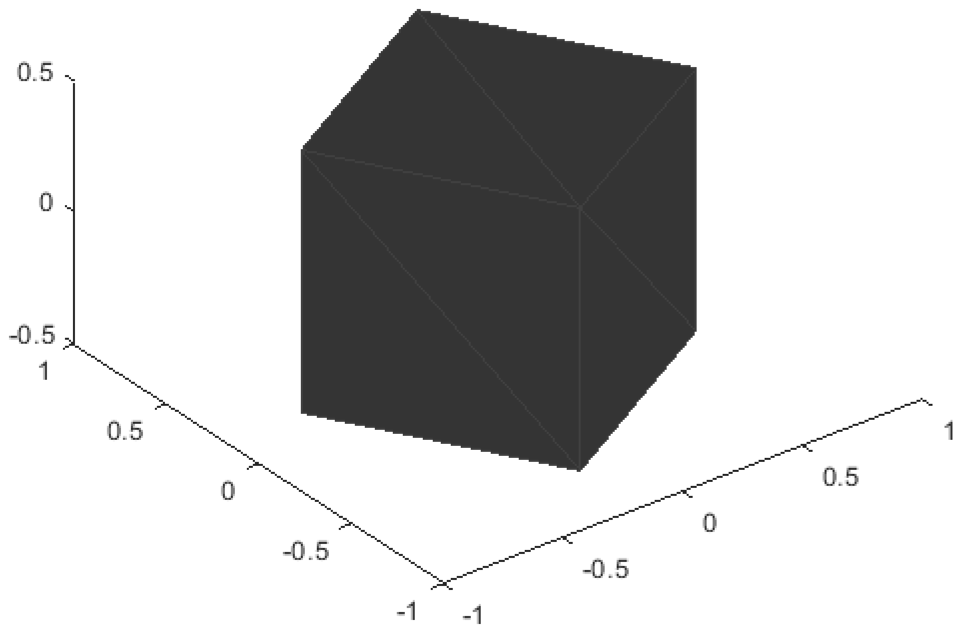
```
mesh = extendedObjectMesh('cuboid');
```

Rotate the mesh by 30 degrees around the *z* axis.

```
mesh = rotate(mesh,[30 0 0]);
```

Visualize the mesh.

```
ax = show(mesh);
```



Input Arguments

`mesh` — Extended object mesh
`extendedObjectMesh` object

Extended object mesh, specified as an `extendedObjectMesh` object.

`orient` — Description of rotation
3-by-3 orthonormal matrix | quaternion | 1-by-3 vector

Description of rotation for an object mesh, specified as:

- 3-by-3 orthonormal rotation matrix
- `quaternion`
- 1-by-3 vector, where the elements are positive rotations in degrees about the *z*, *y*, and *x* axes, in that order.

Output Arguments

`rotatedMesh` — Rotated object mesh
`extendedObjectMesh` object

Rotated object mesh, returned as an `extendedObjectMesh` object.

See Also

Objects
`extendedObjectMesh`

Functions
`applyTransform` | `join` | `scale` | `scaleToFit` | `show` | `translate`

Introduced in R2020a

scale

Scale mesh in each dimension

Syntax

```
scaledMesh = scale(mesh,scaleFactor)
scaledMesh = scale(mesh,[sx sy sz])
```

Description

`scaledMesh = scale(mesh,scaleFactor)` scales the object mesh by `scaleFactor`. `scaleFactor` can be the same for all dimensions or defined separately as elements of a 1-by-3 vector in the order *x*, *y*, and *z*.

`scaledMesh = scale(mesh,[sx sy sz])` scales the object mesh along the dimensions *x*, *y*, and *z* by the scaling factors `sx`, `sy`, and `sz`.

Examples

Create and Scale Cuboid Mesh

This example shows how to create an `extendedObjectMesh` object and scale the object.

Construct a cuboid mesh of unit dimensions.

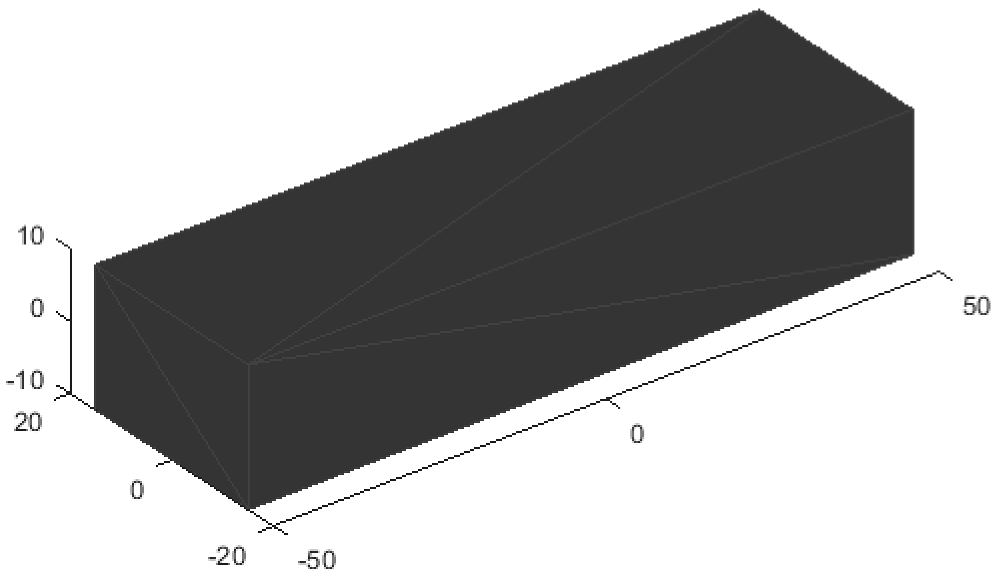
```
cuboid = extendedObjectMesh('cuboid');
```

Scale the mesh by different factors along each of the three axes.

```
scaledCuboid = scale(cuboid,[100 30 20]);
```

Visualize the mesh.

```
show(scaledCuboid);
```



Input Arguments

`mesh` — Extended object mesh
`extendedObjectMesh` object

Extended object mesh, specified as an `extendedObjectMesh` object.

`scaleFactor` — Scaling factor
positive real scalar | 1-by-3 vector

Scaling factor for the object mesh, specified as a single positive real value or as a 1-by-3 vector in the order *x*, *y*, and *z*.

Data Types: `single` | `double`

`sx` — Scaling factor for *x*-axis
positive real scalar

Scaling factor for *x*-axis, specified as a positive real scalar.

Data Types: `single` | `double`

`sy` — Scaling factor for *y*-axis
positive real scalar

Scaling factor for *y*-axis, specified as a positive real scalar.

Data Types: `single` | `double`

`sz` — Scaling factor for *z*-axis
positive real scalar

Scaling factor for *z*-axis, specified as a positive real scalar.

Data Types: `single` | `double`

Output Arguments

`scaledMesh` — Scaled object mesh
`extendedObjectMesh` object

Scaled object mesh, returned as an `extendedObjectMesh` object.

See Also

Objects
`extendedObjectMesh`

Functions
`applyTransform` | `join` | `rotate` | `scaleToFit` | `show` | `translate`

Introduced in R2020b

scaleToFit

Auto-scale object mesh to match specified cuboid dimensions

Syntax

```
scaledMesh = scaleToFit(mesh,dims)
```

Description

`scaledMesh = scaleToFit(mesh,dims)` auto-scales the object mesh to match the dimensions of a cuboid specified in the structure `dims`.

Examples

Create and Auto-scale Sphere Mesh

This example shows how to create an `extendedObjectMesh` object and auto-scale the object to the required dimensions.

Construct a sphere mesh of unit dimensions.

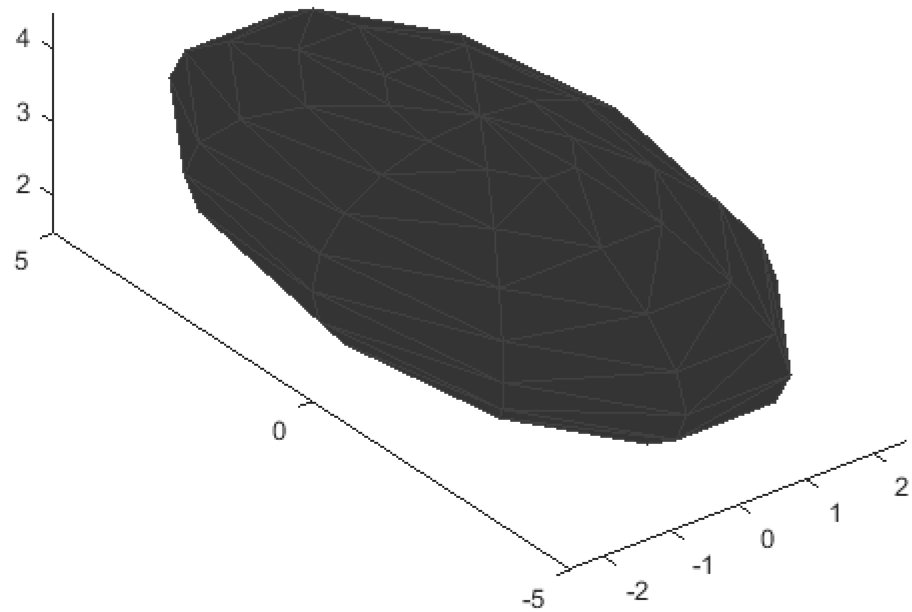
```
sph = extendedObjectMesh('sphere');
```

Auto-scale the mesh to the dimensions in `dims`.

```
dims = struct('Length',5,'Width',10,'Height',3,'OriginOffset',[0 0 -3]);
sph = scaleToFit(sph,dims);
```

Visualize the mesh.

```
show(sph);
```



Input Arguments

`mesh` — Extended object mesh
`extendedObjectMesh` object

Extended object mesh, specified as an `extendedObjectMesh`

`dims` — Cuboid dimensions
struct

Dimensions of the cuboid to scale an object mesh, specified as a `struct` with these fields:

- `Length` – Length of the cuboid
- `Width` – Width of the cuboid
- `Height` – Height of the cuboid
- `OriginOffset` – Origin offset in 3-D coordinates

All the dimensions are in meters.

Data Types: `struct`

Output Arguments

`scaledMesh` — Scaled object mesh
`extendedObjectMesh` object

Scaled object mesh, returned as an `extendedObjectMesh` object.

See Also

Objects
`extendedObjectMesh`

Functions
`applyTransform` | `join` | `rotate` | `scale` | `show` | `translate`

Introduced in R2020b

show

Display the mesh as a patch on the current axes

Syntax

```
show(mesh)
show(mesh,ax)
ax = show(mesh)
```

Description

`show(mesh)` displays the `extendedObjectMesh` as a patch on the current axes. If there are no active axes, the function creates new axes.

`show(mesh,ax)` displays the object mesh as a patch on the axes `ax`.

`ax = show(mesh)` optionally outputs the handle to the axes where the mesh was plotted.

Examples

Create and Translate Cuboid Mesh

This example shows how to create an `extendedObjectMesh` object and translate the object.

Construct a cuboid mesh.

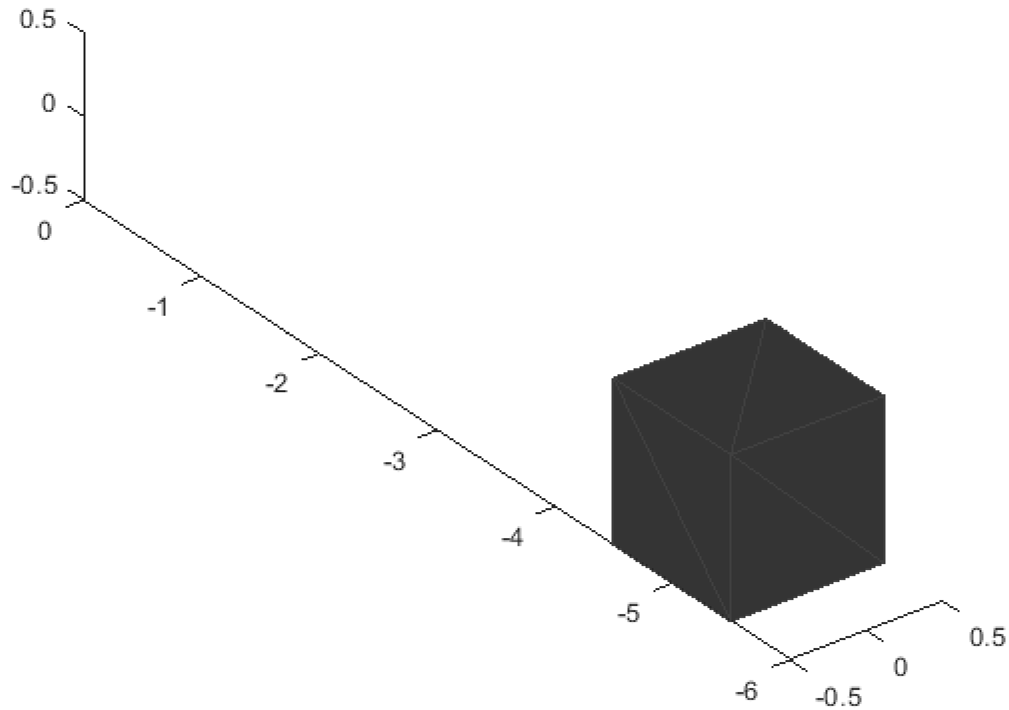
```
mesh = extendedObjectMesh('cuboid');
```

Translate the mesh by 5 units along the negative *y* axis.

```
mesh = translate(mesh,[0 -5 0]);
```

Visualize the mesh.

```
ax = show(mesh);
ax.YLim = [-6 0];
```



Input Arguments

mesh — Extended object mesh
extendedObjectMesh object

Extended object mesh, specified as an `extendedObjectMesh` object.

ax — Current axes
axes

Current axes, specified as an `axes` object.

See Also

Objects
extendedObjectMesh

Functions
applyTransform | join | rotate | scale | scaleToFit | translate

Introduced in R2020b

translate

Translate mesh along coordinate axes

Syntax

`translatedMesh = translate(mesh,deltaPos)`

Description

`translatedMesh = translate(mesh,deltaPos)` translates the object mesh by the distances specified by `deltaPos` along the coordinate axes.

Examples

Create and Translate Cuboid Mesh

This example shows how to create an `extendedObjectMesh` object and translate the object.

Construct a cuboid mesh.

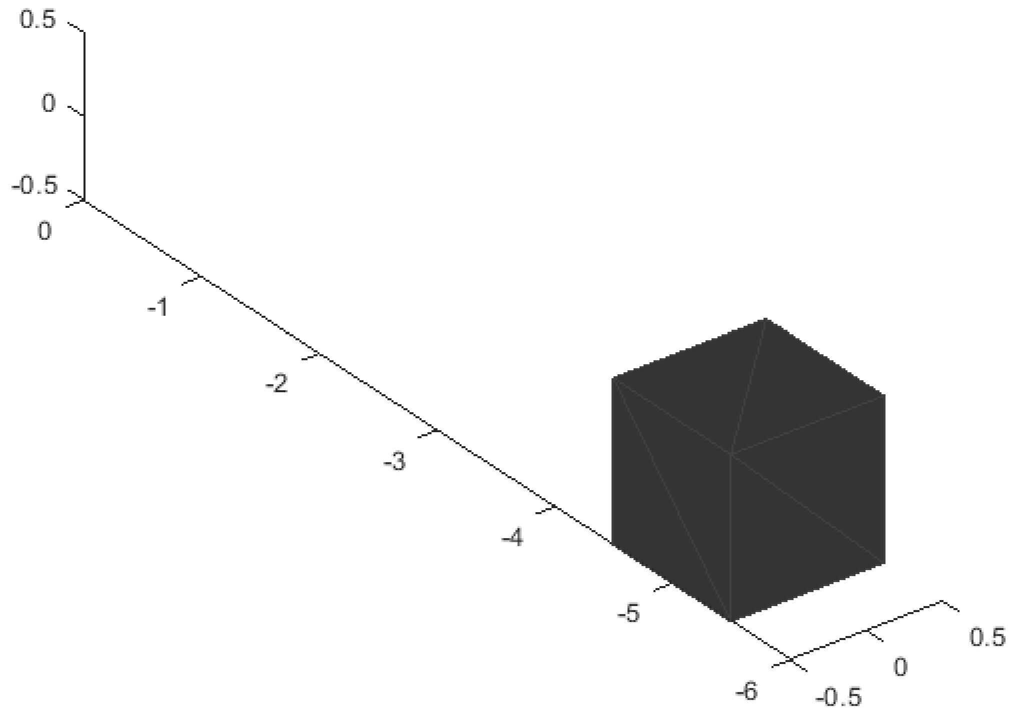
```
mesh = extendedObjectMesh('cuboid');
```

Translate the mesh by 5 units along the negative *y* axis.

```
mesh = translate(mesh,[0 -5 0]);
```

Visualize the mesh.

```
ax = show(mesh);
ax.YLim = [-6 0];
```



Input Arguments

`mesh` — Extended object mesh
`extendedObjectMesh` object

Extended object mesh, specified as an `extendedObjectMesh` object.

`deltaPos` — Translation vector
three-element, real-valued vector

Translation vector for an object mesh, specified as a three-element, real-valued vector. The three elements in the vector define the translation along the *x*, *y*, and *z* axes.

Data Types: `single` | `double`

Output Arguments

`translatedMesh` — Translated object mesh
`extendedObjectMesh` object

Translated object mesh, returned as an `extendedObjectMesh` object.

See Also

Objects
`extendedObjectMesh`

Functions
`applyTransform` | `join` | `rotate` | `scale` | `scaleToFit` | `show`

Introduced in R2020b

control

Control commands for UAV

Syntax

`controlStruct = control(uavGuidanceModel)`

Description

`controlStruct = control(uavGuidanceModel)` returns a structure that captures all the relevant control commands for the specified UAV guidance model. Use the output of this function to ensure you have the proper fields for your control. Use the control commands as an input to the `derivative` function to get the state time-derivative of the UAV.

Examples

Simulate A Multirotor Control Command

This example shows how to use the `multirotor` guidance model to simulate the change in state of a UAV due to a command input.

Create the multirotor guidance model.

```
model = multirotor;
```

Create a state structure. Specify the location in world coordinates.

```
s = state(model);
s(1:3) = [3;2;1];
```

Specify a control command, `u`, that specified the roll and thrust of the multirotor.

```
u = control(model);
u.Roll = pi/12;
u.Thrust = 1;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states as a 13-by-*n* matrix.

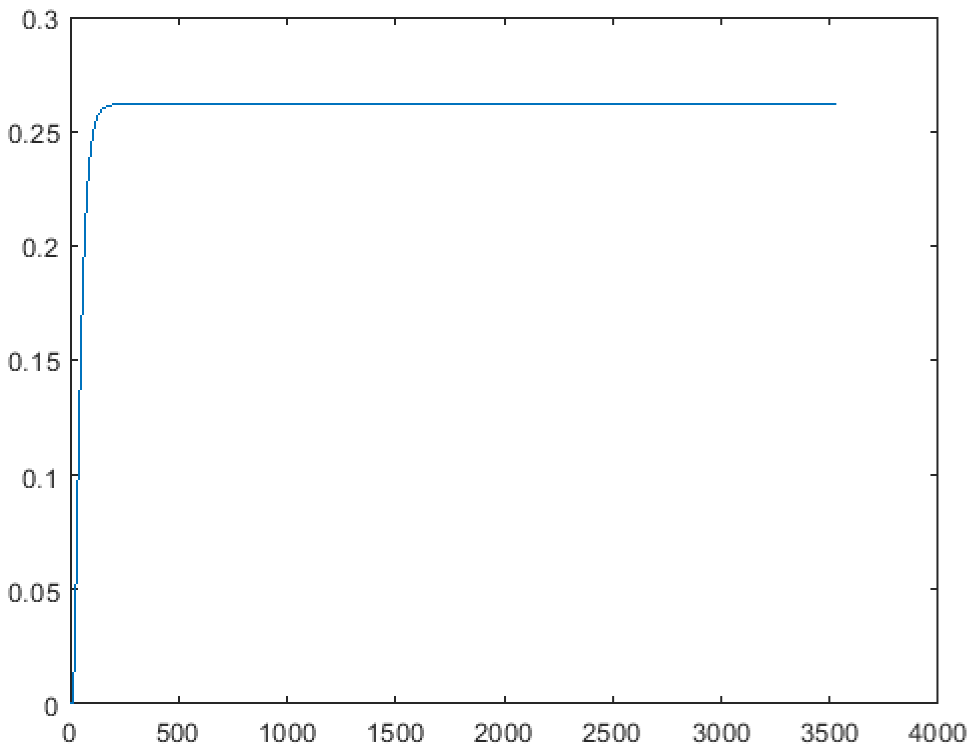
```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 3], s);
size(simOut.y)
```

```
ans = 1×2
```

```
    13          3536
```

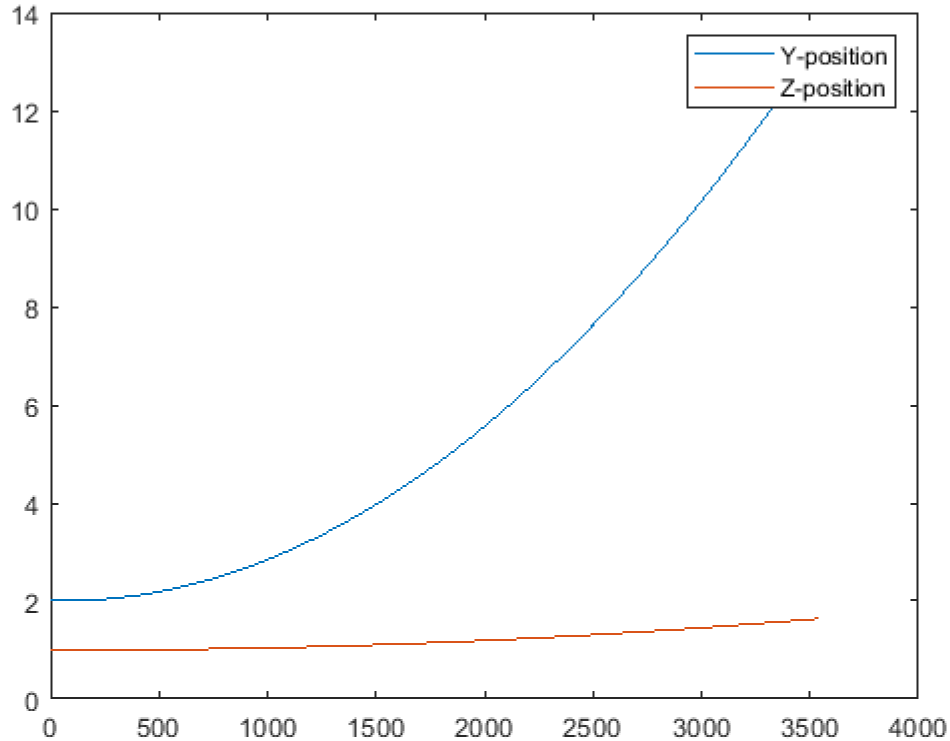
Plot the change in roll angle based on the simulation output. The roll angle (the X Euler angle) is the 9th row of the `simOut.y` output.

```
plot(simOut.y(9,:))
```



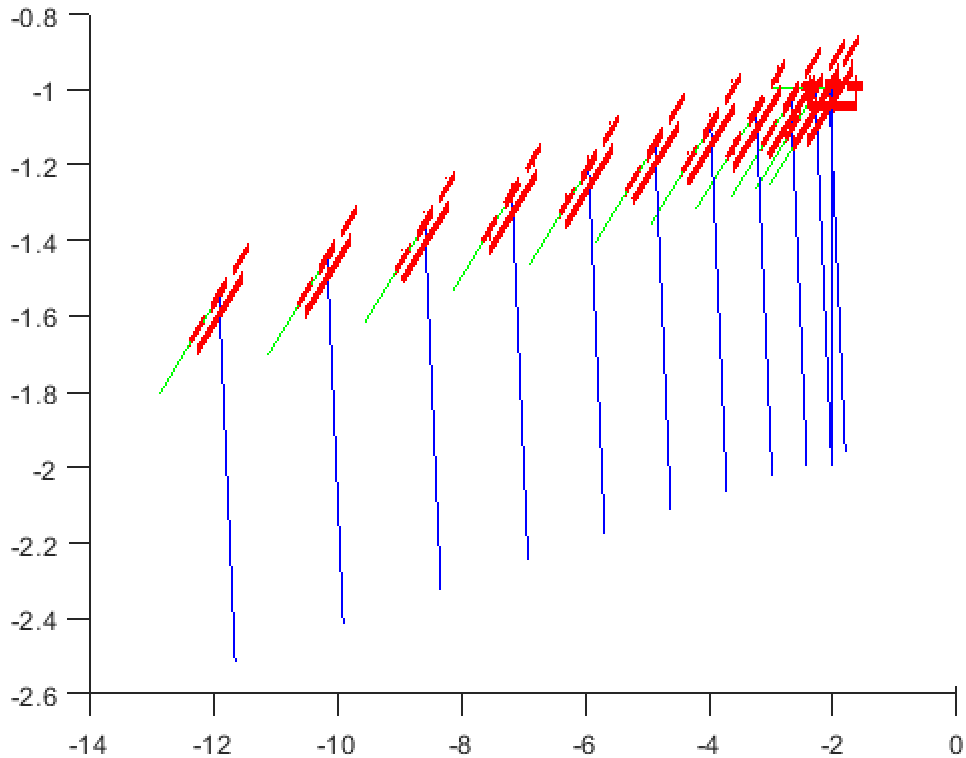
Plot the change in the Y and Z positions. With the specified thrust and roll angle, the multirotor should fly over and lose some altitude. A positive value for Z is expected as positive Z is down.

```
figure
plot(simOut.y(2,:));
hold on
plot(simOut.y(3,:));
legend('Y-position','Z-position')
hold off
```



You can also plot the multirotor trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 300th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `multirotor.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV translating in the Y-direction and losing altitude.

```
translations = simOut.y(1:3,1:300:end)'; % xyz position
rotations = eul2quat(simOut.y(7:9,1:300:end)'); % ZYX Euler
plotTransforms(translations,rotations,...
    'MeshFilePath','multirotor.stl','InertialZDirection',"down")
view([90.00 -0.60])
```



Simulate A Fixed-Wing Control Command

This example shows how to use the `fixedwing` guidance model to simulate the change in state of a UAV due to a command input.

Create the fixed-wing guidance model.

```
model = fixedwing;
```

Set the air speed of the vehicle by modifying the structure from the `state` function.

```
s = state(model);
s(4) = 5; % 5 m/s
```

Specify a control command, `u`, that maintains the air speed and gives a roll angle of `pi/12`.

```
u = control(model);
u.RollAngle = pi/12;
u.AirSpeed = 5;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

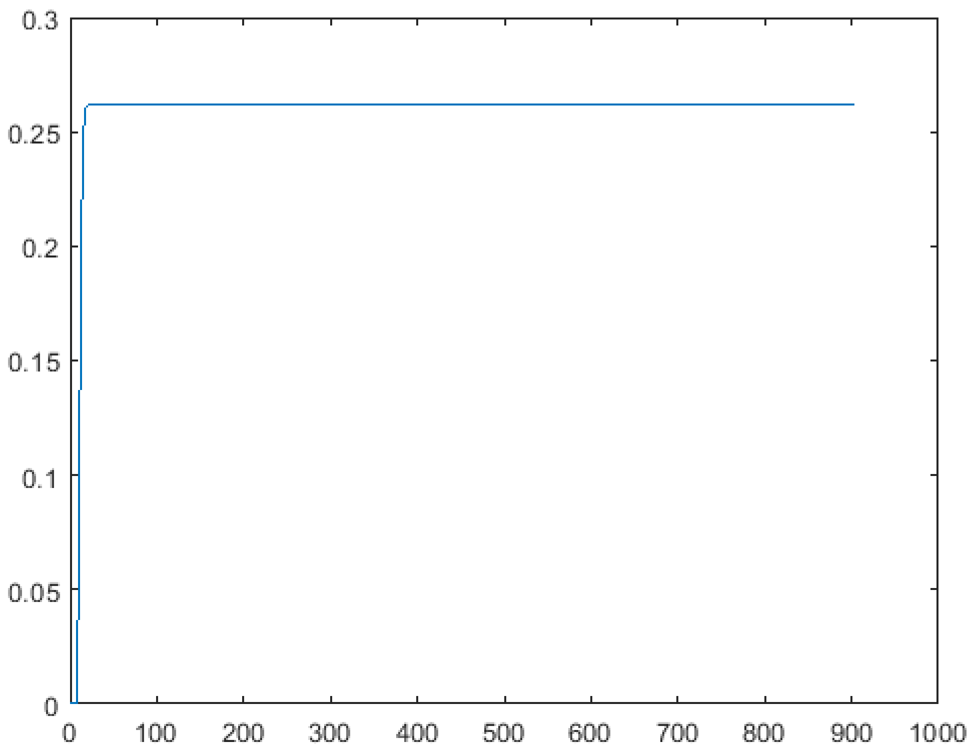
Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states based on this simulation.

```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 50], s);
size(simOut.y)
```

```
ans = 1×2

     8   904
```

Plot the change in roll angle based on the simulation output. The roll angle is the 7th row of the `simOut.y` output.

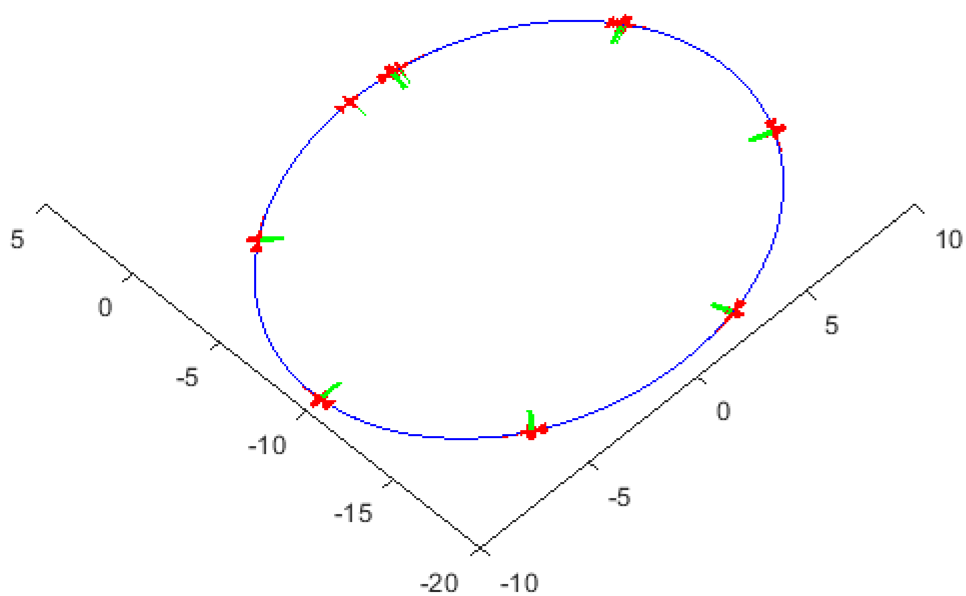
```
plot(simOut.y(7,:))
```



You can also plot the fixed-wing trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 30th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `fixedwing.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV making a constant turn based on the constant roll angle.

```
downsample = 1:30:size(simOut.y,2);
translations = simOut.y(1:3,downsample)'; % xyz-position
rotations = eul2quat([simOut.y(5,downsample)',simOut.y(6,downsample)',simOut.y(7,downsample)']);
```

```
plotTransforms(translations,rotations,...
    'MeshFilePath','fixedwing.stl','InertialZDirection',"down")
hold on
plot3(simOut.y(1,:),-simOut.y(2,:),simOut.y(3,:),'--b') % full path
xlim([-10.0 10.0])
ylim([-20.0 5.0])
zlim([-0.5 4.00])
view([-45 90])
hold off
```



Input Arguments

`uavGuidanceModel` — UAV guidance model
`fixedwing` object | `multirotor` object

UAV guidance model, specified as a `fixedwing` or `multirotor` object.

Output Arguments

`controlStruct` — Control commands for UAV
structure

Control commands for UAV, returned as a structure.

For multirotor UAVs, the guidance model is approximated as separate PD controllers for each command. The elements of the structure are control commands:

- `Roll` - Roll angle in radians.
- `Pitch` - Pitch angle in radians.
- `YawRate` - Yaw rate in radians per second. (D = 0. P only controller)
- `Thrust` - Vertical thrust of the UAV in Newtons. (D = 0. P only controller)

For fixed-wing UAVs, the model assumes the UAV is flying under the coordinated-turn condition. The guidance model equations assume zero side-slip. The elements of the structure are:

- `Height` - Altitude above the ground in meters.
- `Airspeed` - UAV speed relative to wind in meters per second.
- `RollAngle` - Roll angle along body forward axis in radians. Because of the coordinated-turn condition, the heading angular rate is based on the roll angle.

Extended Capabilities

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

See Also

Functions
`derivative` | `environment` | `ode45` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor`

Blocks
UAV Guidance Model | Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

derivative

Time derivative of UAV states

Syntax

`stateDerivative = derivative(uavGuidanceModel,state,control,environment)`

Description

`stateDerivative = derivative(uavGuidanceModel,state,control,environment)` determines the time derivative of the state of the UAV guidance model using the current state, control commands, and environmental inputs. Use the state and time derivative with `ode45` to simulate the UAV.

Examples

Simulate A Multirotor Control Command

This example shows how to use the `multirotor` guidance model to simulate the change in state of a UAV due to a command input.

Create the multirotor guidance model.

```
model = multirotor;
```

Create a state structure. Specify the location in world coordinates.

```
s = state(model);
s(1:3) = [3;2;1];
```

Specify a control command, `u`, that specified the roll and thrust of the multirotor.

```
u = control(model);
u.Roll = pi/12;
u.Thrust = 1;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states as a 13-by-*n* matrix.

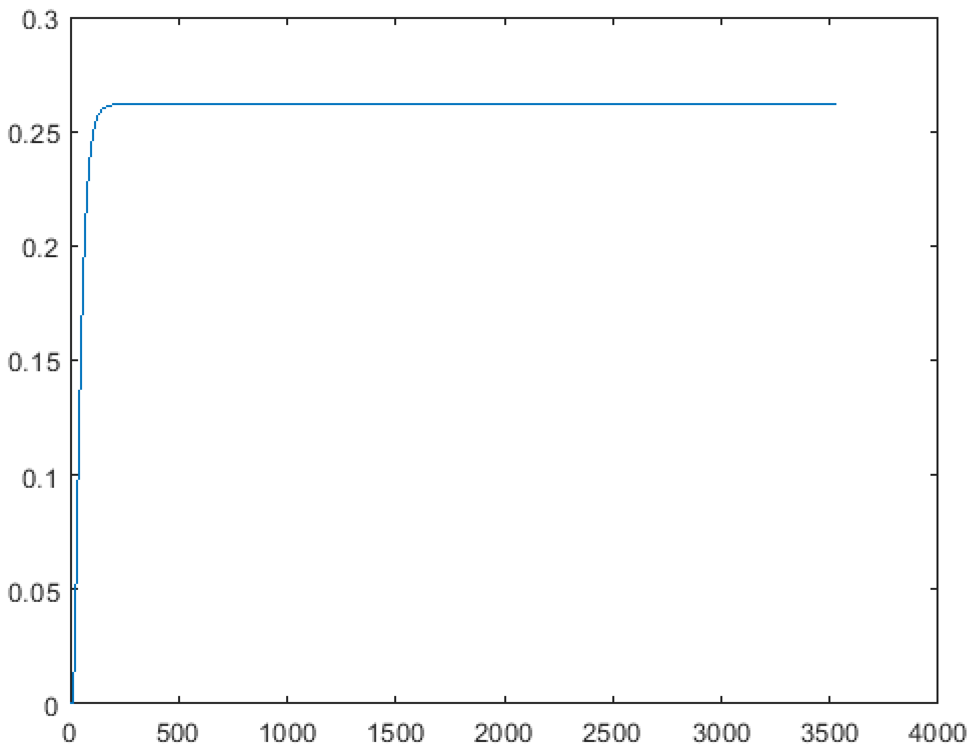
```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 3], s);
size(simOut.y)
```

```
ans = 1×2
```

```
    13          3536
```

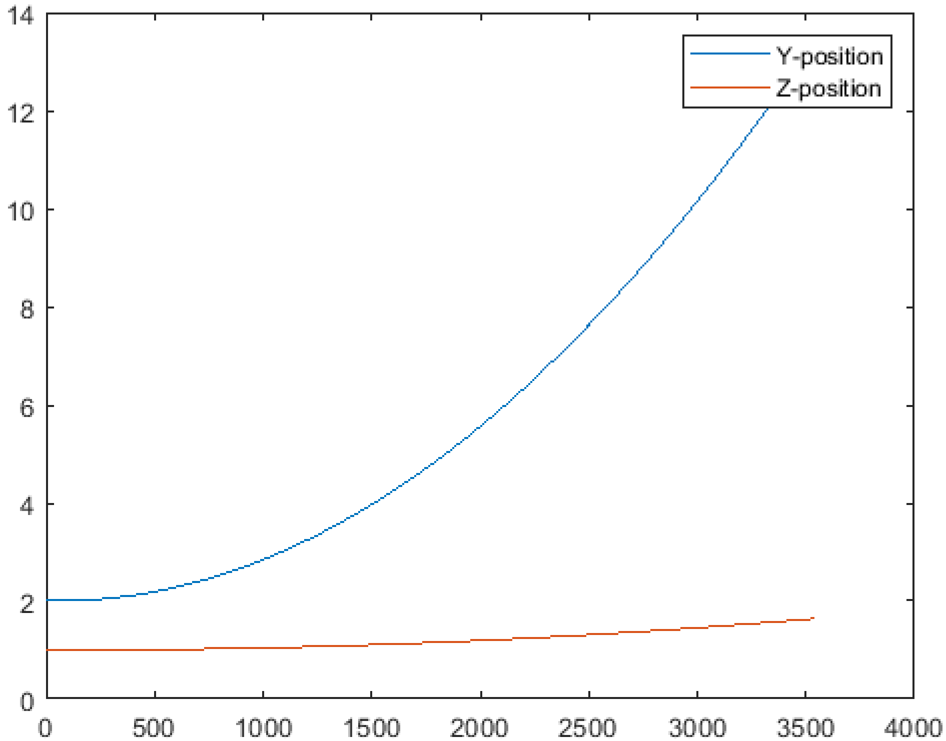
Plot the change in roll angle based on the simulation output. The roll angle (the X Euler angle) is the 9th row of the `simOut.y` output.

```
plot(simOut.y(9,:))
```



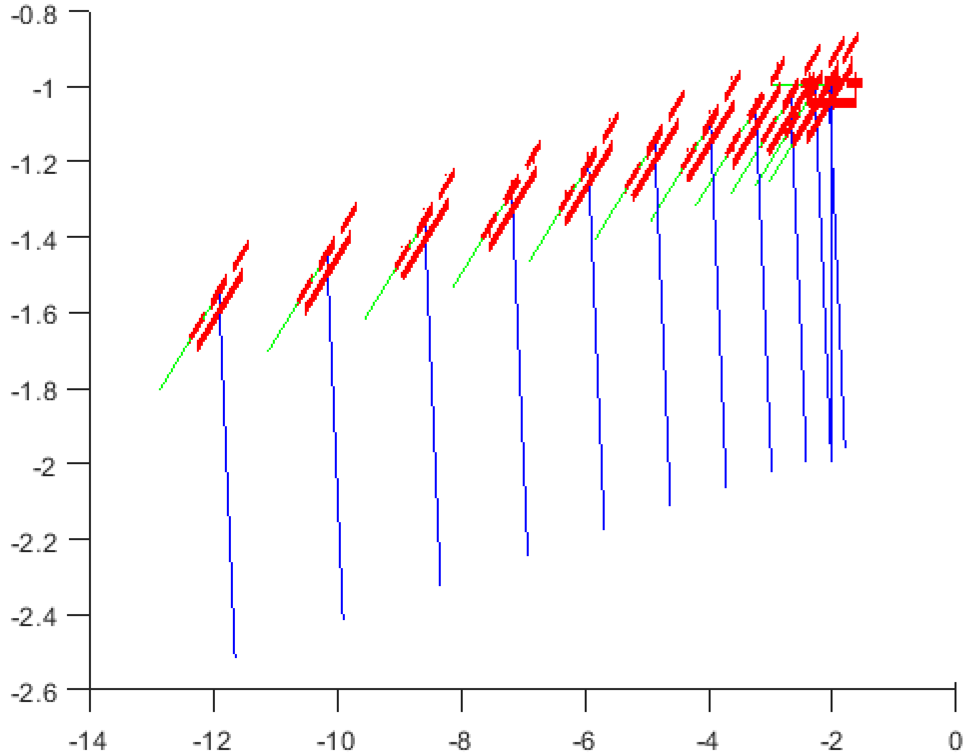
Plot the change in the Y and Z positions. With the specified thrust and roll angle, the multirotor should fly over and lose some altitude. A positive value for Z is expected as positive Z is down.

```
figure
plot(simOut.y(2,:));
hold on
plot(simOut.y(3,:));
legend('Y-position','Z-position')
hold off
```



You can also plot the multirotor trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 300th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `multirotor.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV translating in the Y-direction and losing altitude.

```
translations = simOut.y(1:3,1:300:end)'; % xyz position
rotations = eul2quat(simOut.y(7:9,1:300:end)'); % ZYX Euler
plotTransforms(translations,rotations,...
    'MeshFilePath','multirotor.stl','InertialZDirection',"down")
view([90.00 -0.60])
```



Simulate A Fixed-Wing Control Command

This example shows how to use the `fixedwing` guidance model to simulate the change in state of a UAV due to a command input.

Create the fixed-wing guidance model.

```
model = fixedwing;
```

Set the air speed of the vehicle by modifying the structure from the `state` function.

```
s = state(model);
s(4) = 5; % 5 m/s
```

Specify a control command, `u`, that maintains the air speed and gives a roll angle of `pi/12`.

```
u = control(model);
u.RollAngle = pi/12;
u.AirSpeed = 5;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

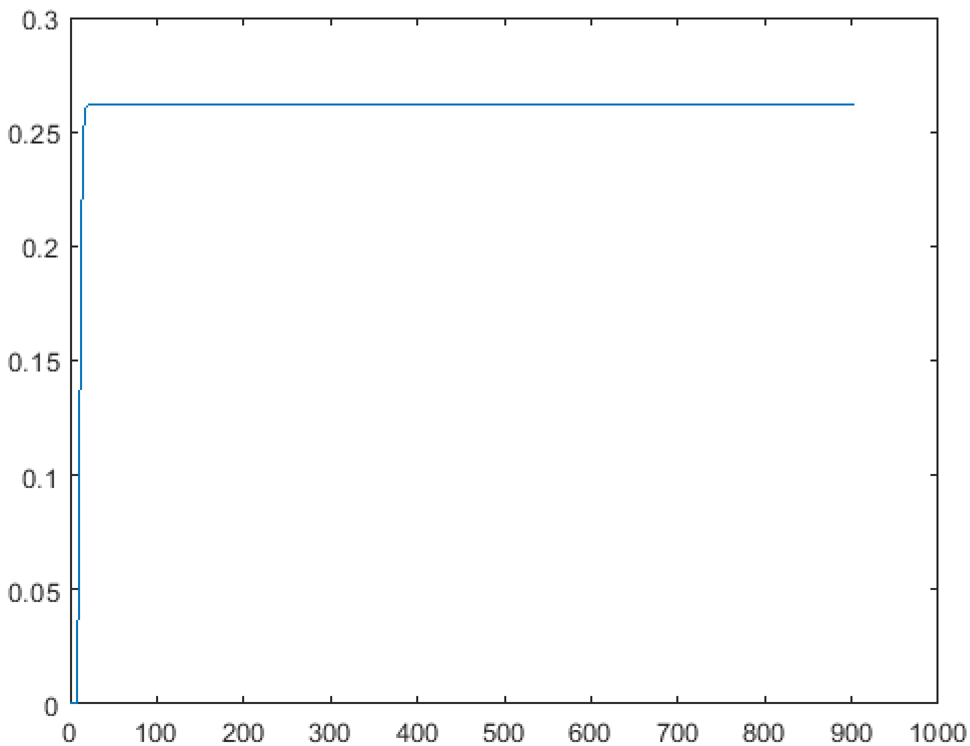
Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states based on this simulation.

```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 50], s);
size(simOut.y)
```

```
ans = 1×2

     8   904
```

Plot the change in roll angle based on the simulation output. The roll angle is the 7th row of the `simOut.y` output.

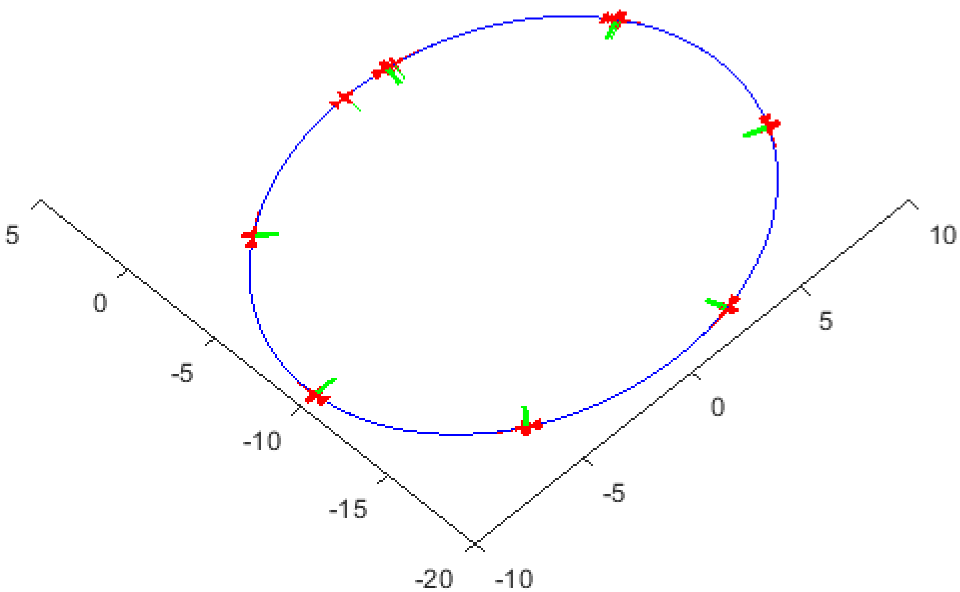
```
plot(simOut.y(7,:))
```



You can also plot the fixed-wing trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 30th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `fixedwing.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV making a constant turn based on the constant roll angle.

```
downsample = 1:30:size(simOut.y,2);
translations = simOut.y(1:3,downsample)'; % xyz-position
rotations = eul2quat([simOut.y(5,downsample)',simOut.y(6,downsample)',simOut.y(7,downsample)']);
```

```
plotTransforms(translations,rotations,...
    'MeshFilePath','fixedwing.stl','InertialZDirection',"down")
hold on
plot3(simOut.y(1,:),-simOut.y(2,:),simOut.y(3,:),'--b') % full path
xlim([-10.0 10.0])
ylim([-20.0 5.0])
zlim([-0.5 4.00])
view([-45 90])
hold off
```



Input Arguments

`uavGuidanceModel` — UAV guidance model
`fixedwing` object | `multirotor` object

UAV guidance model, specified as a `fixedwing` or `multirotor` object.

`state` — State vector
eight-element vector | thirteen-element vector

State vector, specified as a eight-element or thirteen-element vector. The vector is always filled with zeros. Use this function to ensure you have the proper size for your state vector.

For fixed-wing UAVs, the state is an eight-element vector:

- **North** - Position in north direction in meters.
- **East** - Position in east direction in meters.
- **Height** - Height above ground in meters.
- **AirSpeed** - Speed relative to wind in meters per second.
- **HeadingAngle** - Angle between ground velocity and north direction in radians.
- **FlightPathAngle** - Angle between ground velocity and north-east plane in radians.
- **RollAngle** - Angle of rotation along body *x*-axis in radians per second.
- **RollAngleRate** - Angular velocity of rotation along body *x*-axis in radians per second.

For multirotor UAVs, the state is a thirteen-element vector in this order:

- **World Position** - `[x y z]` in meters.
- **World Velocity** - `[vx vy vz]` in meters per second.
- **Euler Angles (ZYX)** - `[psi theta phi]` in radians.
- **Body Angular Rates** - `[p q r]` in radians per second.
- **Thrust** - `F` in Newtons.

`environment` — Environmental input parameters
structure

Environmental input parameters, returned as a structure. To generate this structure, use `environment`.

For fixed-wing UAVs, the fields of the structure are `WindNorth`, `WindEast`,`WindDown`, and `Gravity`. Wind speeds are in meters per second, and negative speeds point in the opposite direction. Gravity is in meters per second squared (default `9.81`).

For multirotor UAVs, the only element of the structure is `Gravity` (default `9.81`) in meters per second squared.

`control` — Control commands for UAV
structure

Control commands for UAV, specified as a structure. To generate this structure, use `control`.

For multirotor UAVs, the guidance model is approximated as separate PD controllers for each command. The elements of the structure are control commands:

- `Roll` - Roll angle in radians.
- `Pitch` - Pitch angle in radians.
- `YawRate` - Yaw rate in radians per second. (D = 0. P only controller)
- `Thrust` - Vertical thrust of the UAV in Newtons. (D = 0. P only controller)

For fixed-wing UAVs, the model assumes the UAV is flying under the coordinated-turn condition. The Guidance Model equations assume zero side-slip. The elements of the bus are:

- `Height` - Altitude above the ground in meters.
- `Airspeed` - UAV speed relative to wind in meters per second.
- `RollAngle` - Roll angle along body forward axis in radians. Because of the coordinated-turn condition, the heading angular rate is based on the roll angle.

Output Arguments

`stateDerivative` — Time derivative of state
vector

Time derivative of state, returned as a vector. The time derivative vector has the same length as the input `state`.

Extended Capabilities

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

See Also

Functions
`control` | `derivative` | `environment` | `ode45` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor`

Blocks
UAV Guidance Model | Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

environment

Environmental inputs for UAV

Syntax

`envStruct = environment(uavGuidanceModel)`

Description

`envStruct = environment(uavGuidanceModel)` returns a structure that captures all the relevant environmental variables for the specified UAV guidance model. Use this function to ensure you have the proper fields for your environmental parameters. Use the environmental inputs as an input to the `derivative` function to get the state time-derivative of the UAV.

Examples

Simulate A Multirotor Control Command

This example shows how to use the `multirotor` guidance model to simulate the change in state of a UAV due to a command input.

Create the multirotor guidance model.

```
model = multirotor;
```

Create a state structure. Specify the location in world coordinates.

```
s = state(model);
s(1:3) = [3;2;1];
```

Specify a control command, `u`, that specified the roll and thrust of the multirotor.

```
u = control(model);
u.Roll = pi/12;
u.Thrust = 1;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states as a 13-by-*n* matrix.

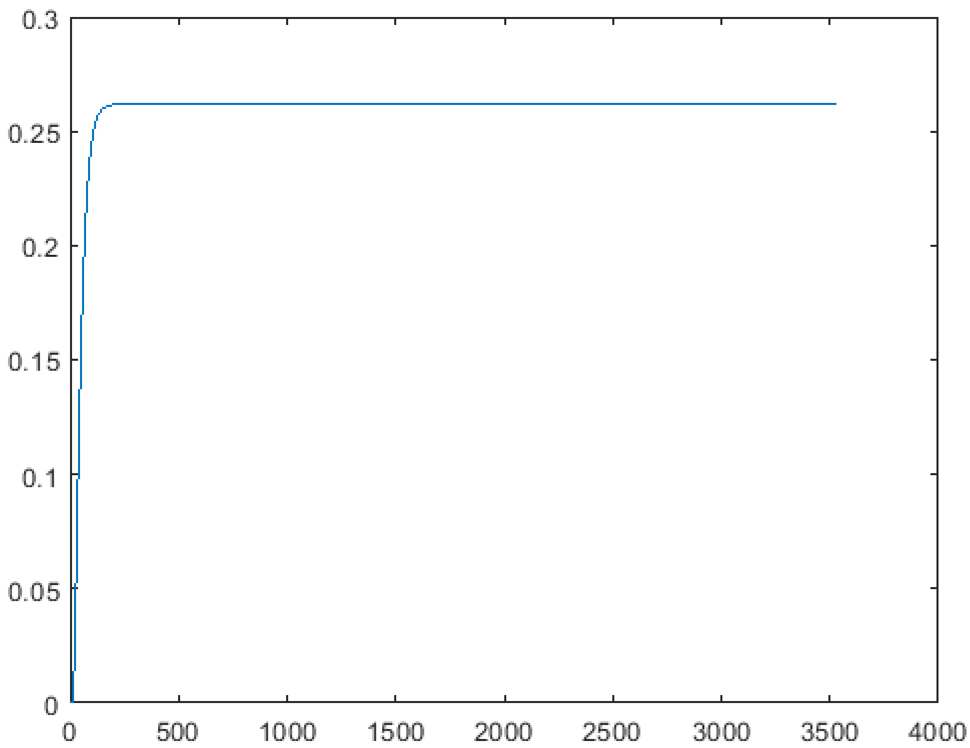
```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 3], s);
size(simOut.y)
```

```
ans = 1×2
```

```
         13          3536
```

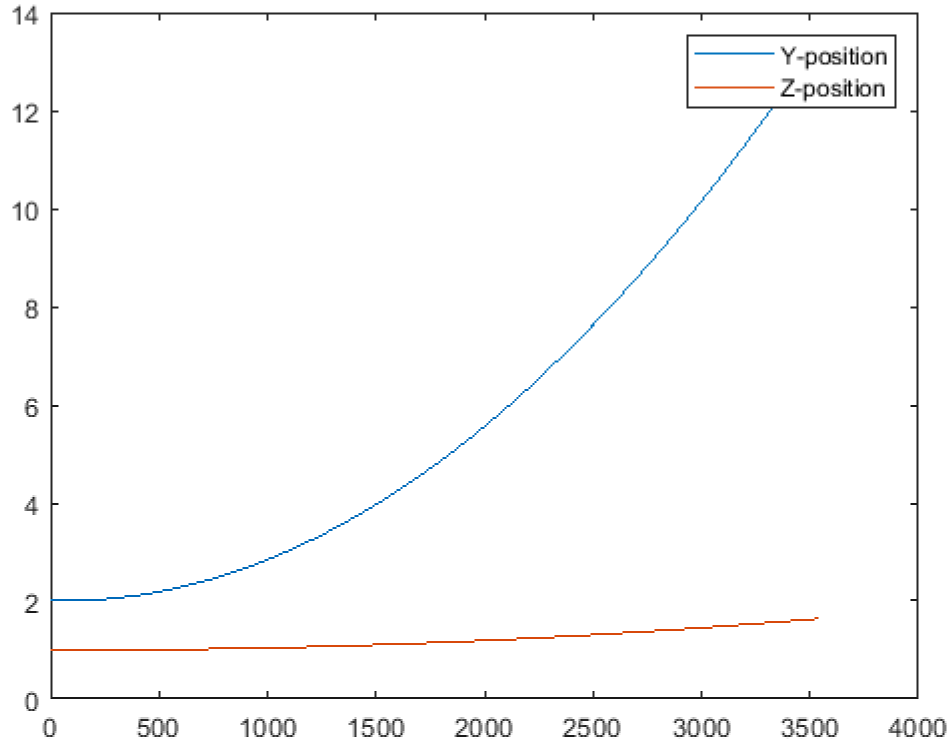
Plot the change in roll angle based on the simulation output. The roll angle (the X Euler angle) is the 9th row of the `simOut.y` output.

```
plot(simOut.y(9,:))
```



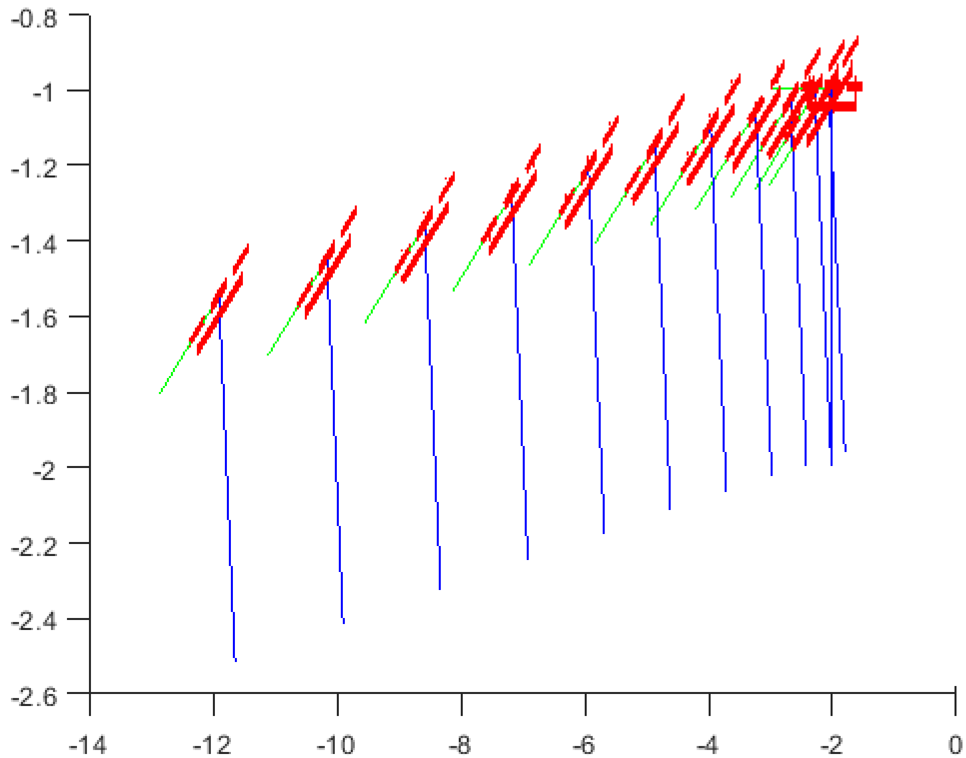
Plot the change in the Y and Z positions. With the specified thrust and roll angle, the multirotor should fly over and lose some altitude. A positive value for Z is expected as positive Z is down.

```
figure
plot(simOut.y(2,:));
hold on
plot(simOut.y(3,:));
legend('Y-position','Z-position')
hold off
```



You can also plot the multirotor trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 300th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `multirotor.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV translating in the Y-direction and losing altitude.

```
translations = simOut.y(1:3,1:300:end)'; % xyz position
rotations = eul2quat(simOut.y(7:9,1:300:end)'); % ZYX Euler
plotTransforms(translations,rotations,...
    'MeshFilePath','multirotor.stl','InertialZDirection',"down")
view([90.00 -0.60])
```



Simulate A Fixed-Wing Control Command

This example shows how to use the `fixedwing` guidance model to simulate the change in state of a UAV due to a command input.

Create the fixed-wing guidance model.

```
model = fixedwing;
```

Set the air speed of the vehicle by modifying the structure from the `state` function.

```
s = state(model);
s(4) = 5; % 5 m/s
```

Specify a control command, `u`, that maintains the air speed and gives a roll angle of `pi/12`.

```
u = control(model);
u.RollAngle = pi/12;
u.AirSpeed = 5;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

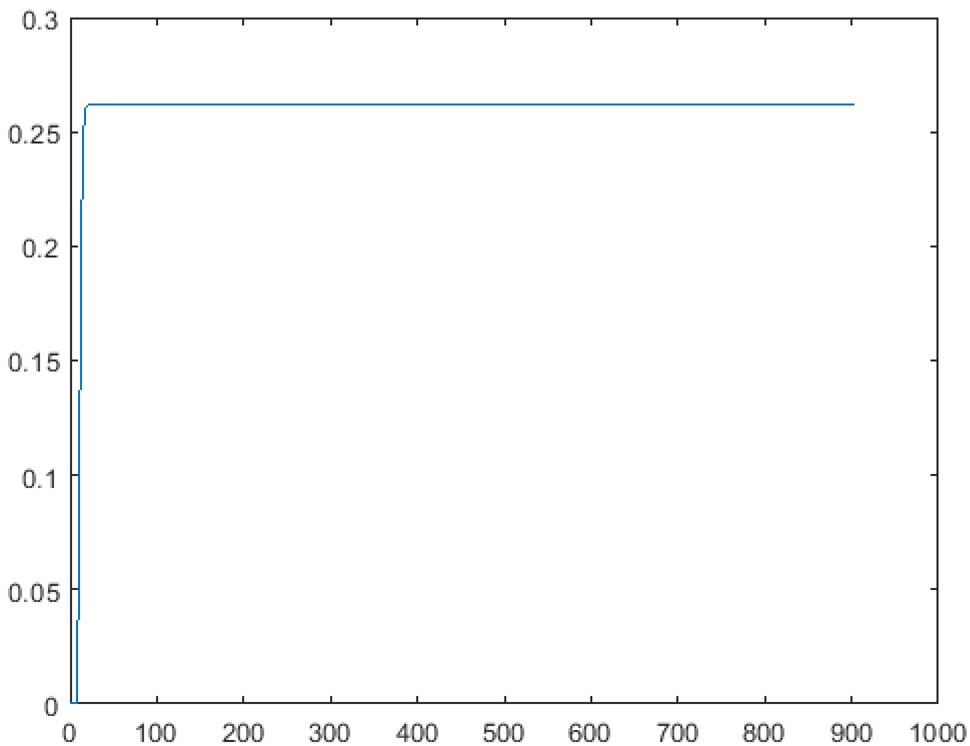
Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states based on this simulation.

```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 50], s);
size(simOut.y)
```

```
ans = 1×2

     8   904
```

Plot the change in roll angle based on the simulation output. The roll angle is the 7th row of the `simOut.y` output.

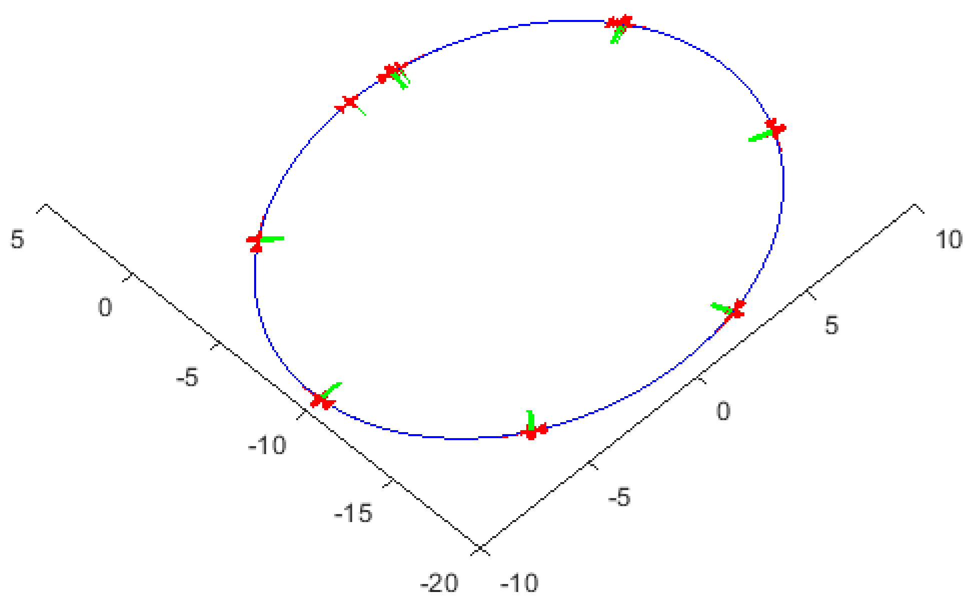
```
plot(simOut.y(7,:))
```



You can also plot the fixed-wing trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 30th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `fixedwing.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV making a constant turn based on the constant roll angle.

```
downsample = 1:30:size(simOut.y,2);
translations = simOut.y(1:3,downsample)'; % xyz-position
rotations = eul2quat([simOut.y(5,downsample)',simOut.y(6,downsample)',simOut.y(7,downsample)']);
```

```
plotTransforms(translations,rotations,...
    'MeshFilePath','fixedwing.stl','InertialZDirection',"down")
hold on
plot3(simOut.y(1,:),-simOut.y(2,:),simOut.y(3,:),'--b') % full path
xlim([-10.0 10.0])
ylim([-20.0 5.0])
zlim([-0.5 4.00])
view([-45 90])
hold off
```



Input Arguments

`uavGuidanceModel` — UAV guidance model
`fixedwing` object | `multirotor` object

UAV guidance model, specified as a `fixedwing` or `multirotor` object.

Output Arguments

`envStruct` — Environmental input parameters
structure

Environmental input parameters, returned as a structure.

For fixed-wing UAVs, the fields of the structure are `WindNorth`, `WindEast`,`WindDown`, and `Gravity`. Wind speeds are in meters per second and negative speeds point in the opposite direction. `Gravity` is in meters per second squared (default `9.81`).

For multirotor UAVs, the only element of the structure is `Gravity` (default `9.81`) in meters per second.

Extended Capabilities

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

See Also

Functions
`control` | `derivative` | `ode45` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor`

Blocks
UAV Guidance Model | Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

state

UAV state vector

Syntax

```
stateVec = state(uavGuidanceModel)
```

Description

`stateVec = state(uavGuidanceModel)` returns a state vector for the specified UAV guidance model. The vector is always filled with zeros. Use this function to ensure you have the proper size for your state vector. Use the state vector as an input to the `derivative` function or when simulating the UAV using `ode45`.

Examples

Simulate A Multirotor Control Command

This example shows how to use the `multirotor` guidance model to simulate the change in state of a UAV due to a command input.

Create the multirotor guidance model.

```
model = multirotor;
```

Create a state structure. Specify the location in world coordinates.

```
s = state(model);
s(1:3) = [3;2;1];
```

Specify a control command, `u`, that specified the roll and thrust of the multirotor.

```
u = control(model);
u.Roll = pi/12;
u.Thrust = 1;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states as a 13-by-*n* matrix.

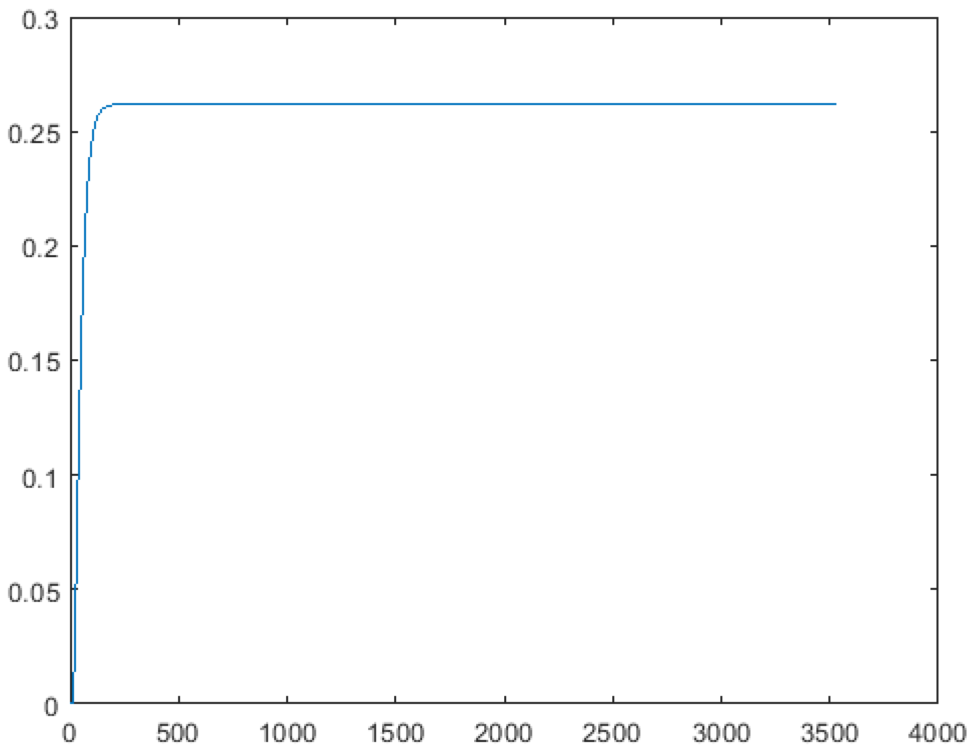
```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 3], s);
size(simOut.y)
```

```
ans = 1×2
```

```
    13          3536
```

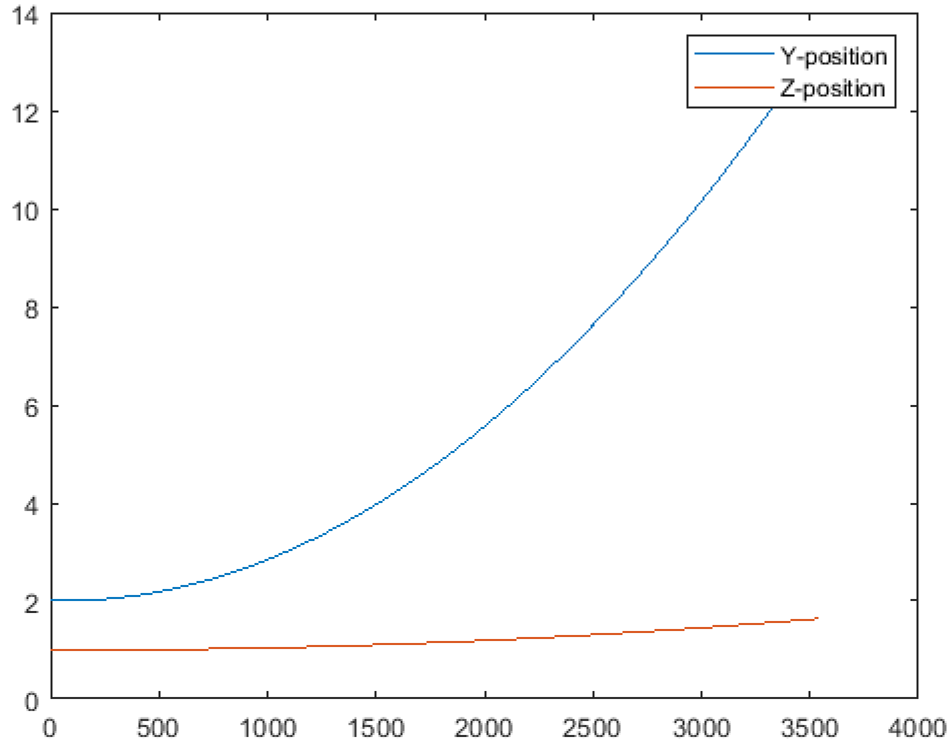
Plot the change in roll angle based on the simulation output. The roll angle (the X Euler angle) is the 9th row of the `simOut.y` output.

```
plot(simOut.y(9,:))
```



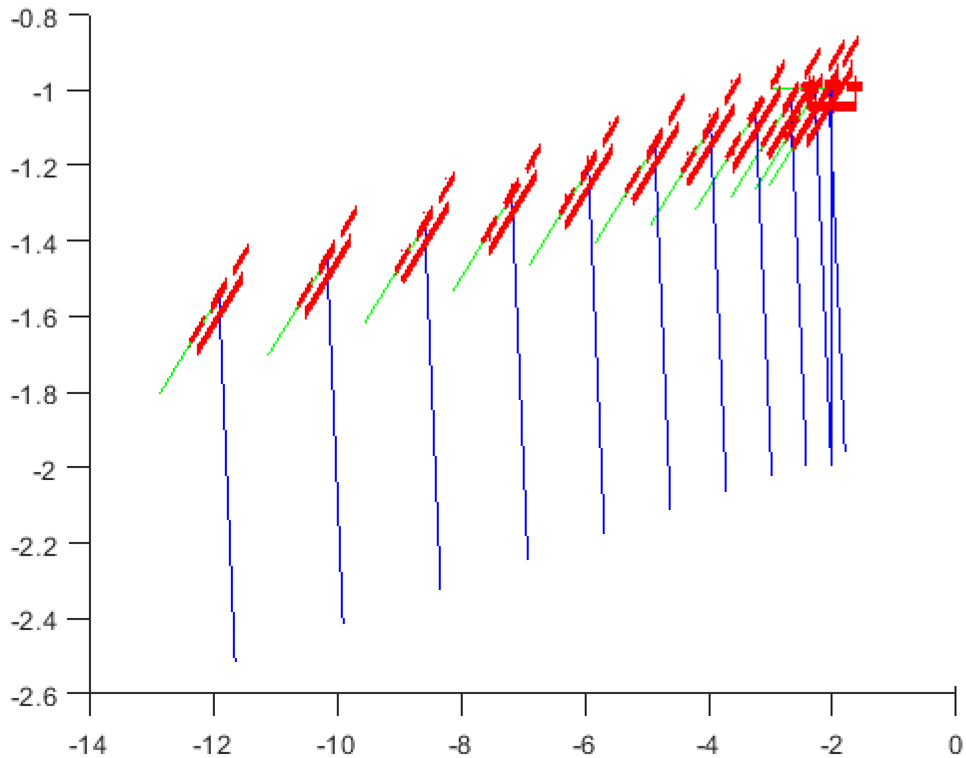
Plot the change in the Y and Z positions. With the specified thrust and roll angle, the multirotor should fly over and lose some altitude. A positive value for Z is expected as positive Z is down.

```
figure
plot(simOut.y(2,:));
hold on
plot(simOut.y(3,:));
legend('Y-position','Z-position')
hold off
```



You can also plot the multirotor trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 300th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `multirotor.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV translating in the Y-direction and losing altitude.

```
translations = simOut.y(1:3,1:300:end)'; % xyz position
rotations = eul2quat(simOut.y(7:9,1:300:end)'); % ZYX Euler
plotTransforms(translations,rotations,...
    'MeshFilePath','multirotor.stl','InertialZDirection',"down")
view([90.00 -0.60])
```



Simulate A Fixed-Wing Control Command

This example shows how to use the `fixedwing` guidance model to simulate the change in state of a UAV due to a command input.

Create the fixed-wing guidance model.

```
model = fixedwing;
```

Set the air speed of the vehicle by modifying the structure from the `state` function.

```
s = state(model);
s(4) = 5; % 5 m/s
```

Specify a control command, `u`, that maintains the air speed and gives a roll angle of `pi/12`.

```
u = control(model);
u.RollAngle = pi/12;
u.AirSpeed = 5;
```

Create a default environment without wind.

```
e = environment(model);
```

Compute the time derivative of the state given the current state, control command, and environment.

```
sdot = derivative(model,s,u,e);
```

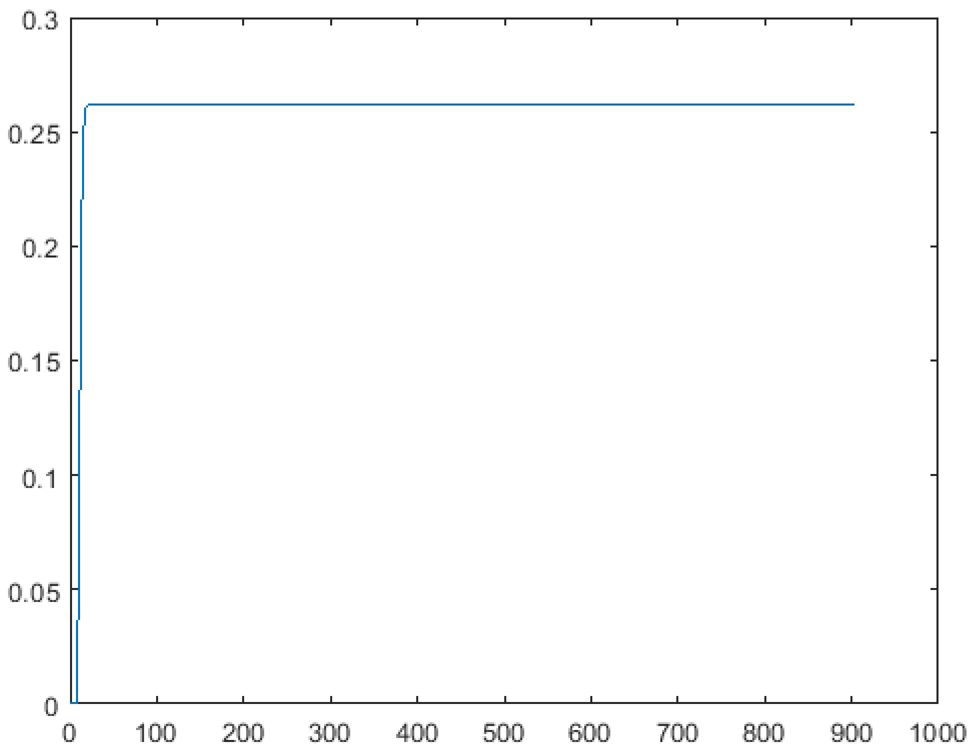
Simulate the UAV state using `ode45` integration. The `y` field outputs the fixed-wing UAV states based on this simulation.

```
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 50], s);
size(simOut.y)
```

```
ans = 1×2

     8   904
```

Plot the change in roll angle based on the simulation output. The roll angle is the 7th row of the `simOut.y` output.

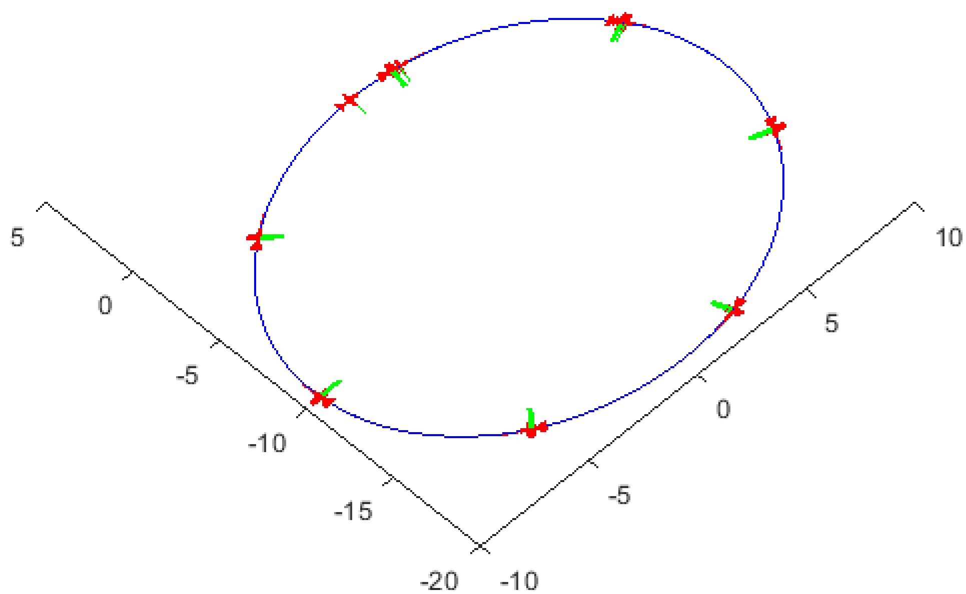
```
plot(simOut.y(7,:))
```



You can also plot the fixed-wing trajectory using `plotTransforms`. Create the translation and rotation vectors from the simulated state. Downsample (every 30th element) and transpose the `simOut` elements, and convert the Euler angles to quaternions. Specify the mesh as the `fixedwing.stl` file and the positive Z-direction as `"down"`. The displayed view shows the UAV making a constant turn based on the constant roll angle.

```
downsample = 1:30:size(simOut.y,2);
translations = simOut.y(1:3,downsample)'; % xyz-position
rotations = eul2quat([simOut.y(5,downsample)',simOut.y(6,downsample)',simOut.y(7,downsample)']);
```

```
plotTransforms(translations,rotations,...
    'MeshFilePath','fixedwing.stl','InertialZDirection',"down")
hold on
plot3(simOut.y(1,:),-simOut.y(2,:),simOut.y(3,:),'--b') % full path
xlim([-10.0 10.0])
ylim([-20.0 5.0])
zlim([-0.5 4.00])
view([-45 90])
hold off
```



Input Arguments

uavGuidanceModel — UAV guidance model
fixedwing object | multirotor object

UAV guidance model, specified as a `fixedwing` or `multirotor` object.

Output Arguments

stateVec — State vector
zeros(7,1) | zeros(13,1)

State vector, returned as a seven-element or thirteen-element vector. The vector is always filled with zeros. Use this function to ensure you have the proper size for your state vector.

For fixed-wing UAVs, the state is an eight-element vector:

- **North** - Position in north direction in meters.
- **East** - Position in east direction in meters.
- **Height** - Height above ground in meters.
- **AirSpeed** - Speed relative to wind in meters per second.
- **HeadingAngle** - Angle between ground velocity and north direction in radians.
- **FlightPathAngle** - Angle between ground velocity and north-east plane in radians.
- **RollAngle** - Angle of rotation along body *x*-axis in radians.
- **RollAngleRate** - Angular velocity of rotation along body *x*-axis in radians per second.

For multirotor UAVs, the state is a thirteen-element vector in this order:

- **World Position** - `[x y z]` in meters.
- **World Velocity** - `[vx vy vz]` in meters per second.
- **Euler Angles (ZYX)** - `[psi theta phi]` in radians.
- **Body Angular Rates** - `[p q r]` in radians per second.
- **Thrust** - `F` in Newtons.

Extended Capabilities

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

See Also

Functions
`control` | `derivative` | `environment` | `ode45` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor`

Blocks
UAV Guidance Model | Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

extract

Extract UAV flight log signals as timetables

Syntax

```
signals = extract(mapper,data,signalNames)
signals = extract(mapper,data,signalNames,timeStart)
signals = extract(mapper,data,signalNames,timeStart,timeEnd)
```

Description

`signals = extract(mapper,data,signalNames)` obtains signals with the given names `signalNames` as timetables from imported flight log, `data`. Import your flight log using `mavlinktlog` or `ulogreader`.

`signals = extract(mapper,data,signalNames,timeStart)` obtains signals with the given names with time stamps greater than or equal to `timeStart`.

`signals = extract(mapper,data,signalNames,timeStart,timeEnd)` obtains signals with the given names with time stamps within the interval `[timeStart timeEnd]` inclusive.

Input Arguments

`mapper` — Flight log signal mapping
`flightLogSignalMapping` object

Flight log signal mapping object, specified as a `flightLogSignalMapping` object.

`data` — Flight log data
table

Flight log data, specified as a table.

`signalNames` — Signal names to extract from log
string array

Signal names to extract from log, specified as a string array.

`timeStart` — Initial time stamp for signal
`duration` object

Initial time stamp for signal to extract, specified as a `duration` object.

`timeEnd` — Final time stamp for signal
`duration` object

Final time stamp for signal to extract, specified as a `duration` object.

Output Arguments

`signals` — Extracted signals
cell array

Extracted signals, returned as a cell array. Each signal name maps to an element of the cell array.

See Also

`flightLogSignalMapping` | `info` | `mapSignal` | `mavlinktlog` | `show` | `updatePlot`

Introduced in R2020b

info

Signal mapping and plot information for UAV log signal mapping

Syntax

```
signalTable = info(mapper,"Signal")
signalTable = info(mapper,"Signal",signalNames)
plotTable = info(mapper,"Plot")
signalTable = info(mapper,"Plot",plotNames)
```

Description

`signalTable = info(mapper,"Signal")` generates a table of information for the Predefined Signals on page 2-54 available and the signals mapped in the flight log signal mapping object. The table contains a list of signal names, field names, units, and whether the signal has a value function mapped to it (`IsMapped` column).

`signalTable = info(mapper,"Signal",signalNames)` generates the signal table for the specified signal names.

`plotTable = info(mapper,"Plot")` generates a table of information for the Predefined Plots on page 2-55 and custom plots available in the flight log signal mapping object. The table contains plots names, required signals, missing signals, and whether the plot is ready to plot.

`signalTable = info(mapper,"Plot",plotNames)` generates the plot table for the specified plot names.

Input Arguments

`mapper` — Flight log signal mapping
`flightLogSignalMapping` object

Flight log signal mapping object, specified as a `flightLogSignalMapping` object.

`signalNames` — Signal names
string array

Signal names, specified as a string array.

`plotNames` — Plot names
string array

Plot names, specified as a string array.

Output Arguments

`signalTable` — Table of available signals
table

Table of available signals, returned as a table. This table includes preconfigured signals and any signals you added to the flight log signal mapping object using `mapSignal`. The table has these fields:

- `SignalName` –– String scalar of the name of the signal.
- `IsMapped` –– Logical indicating if the signal is properly mapped. To update signal mapping, see `mapSignal`.
- `SignalFields` –– String scalar that lists the fields of the signal.
- `FieldUnits` –– String scalar that lists the units of each field.

`plotTable` — Table of available plots
table

Table of available plots, returned as a table. This table includes preconfigured plots and any plots you added to the flight log signal mapping object using `updatePlot`. The table has these fields:

- `PlotName` –– String scalar of the name of the plot.
- `ReadyToPlot` –– Logical indicating if the plot is configured properly. To update the plot, see `updatePlot`.
- `MissingSignals` –– String scalar that lists the signals that need to be mapped using `mapSignal`.
- `RequiredSignals` –– String scalar that lists all required signals for a specific plot name.

More About

Predefined Signals

A set of predefined signals and plots are configured in the `flightLogSignalMapping` object. Depending on your log file type, you can map specific signals to the provided signal names using `mapSignal`. You can also call `info` to view the table for your log type and see whether you have already mapped a signal to that plot type.

Specify the `SignalName` as the input to `mapSignal`. Signals with the format `SignalName#` support mapping multiple signals of the same type. Replace # with incremental integers for each signal name when calling `mapSignal`.

The predefined signals have specific names and required fields when mapping the signal.

Predefined Signals

Signal Name	Description	Fields	Unit
Accel#	Raw magnetometer reading from IMU sensor	[ax ay az]	m/s²
Airspeed#	Airspeed reading of pressure differential, indicated air speed, and temperature	[PressDiff, AirSpeed, Temp]	Pa,
AttitudeEuler	Attitude of UAV in Euler (ZYX) form	[Roll, Pitch, Yaw]	radi
AttitudeRate	Angular velocity along each body axis	[xRotRate, yRotRate, zRotRate]	rad/
AttitudeTargetEuler	Target attitude of UAV in Euler (ZYX) form	[TargetRoll, TargetPitch, TargetYaw]	radi
Barometer#	Barometer readings for absolute pressure, relative pressure, and temperature	[PressAbs, PressAltitude, Temp]	Pa,
Battery	Voltage readings for battery and remaining battery capacity (%)	[Volt1,Volt2, ... Volt16, RemainingCapacity	V, %
GPS#	GPS readings for latitude, longitude, altitude, ground speed, course angle, and number of satellites visible	[lat, long, alt, groundspeed, courseAngle, satellites]	deg deg
Gyro#	Raw body angular velocity readings from IMU sensor	[GyroX, GyroY, GyroZ]	rad/
LocalNED	Local NED coordinates estimated by the UAV	[xNED, yNED, zNED]	met
LocalNEDTarget	Target location in local NED coordinates	[xTarget, yTarget, zTarget]	met
LocalNEDVel	Local NED velocity estimated by the UAV	[vx vy vz]	m/s
LocalNEDVelTarget	Target velocity in NED in local NED	[vxTarget, vyTarget, vzTarget]	m/s
Mag#	Raw magnetometer reading from IMU sensor	[x y z]	Gs

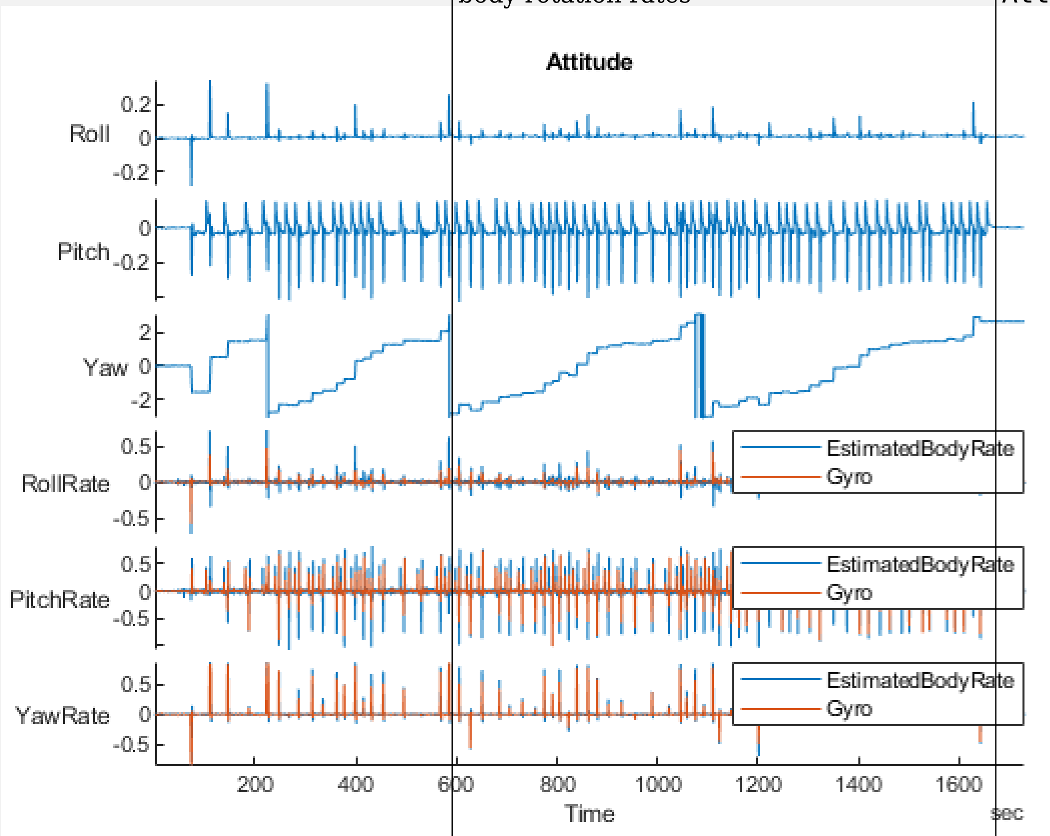
Predefined Plots

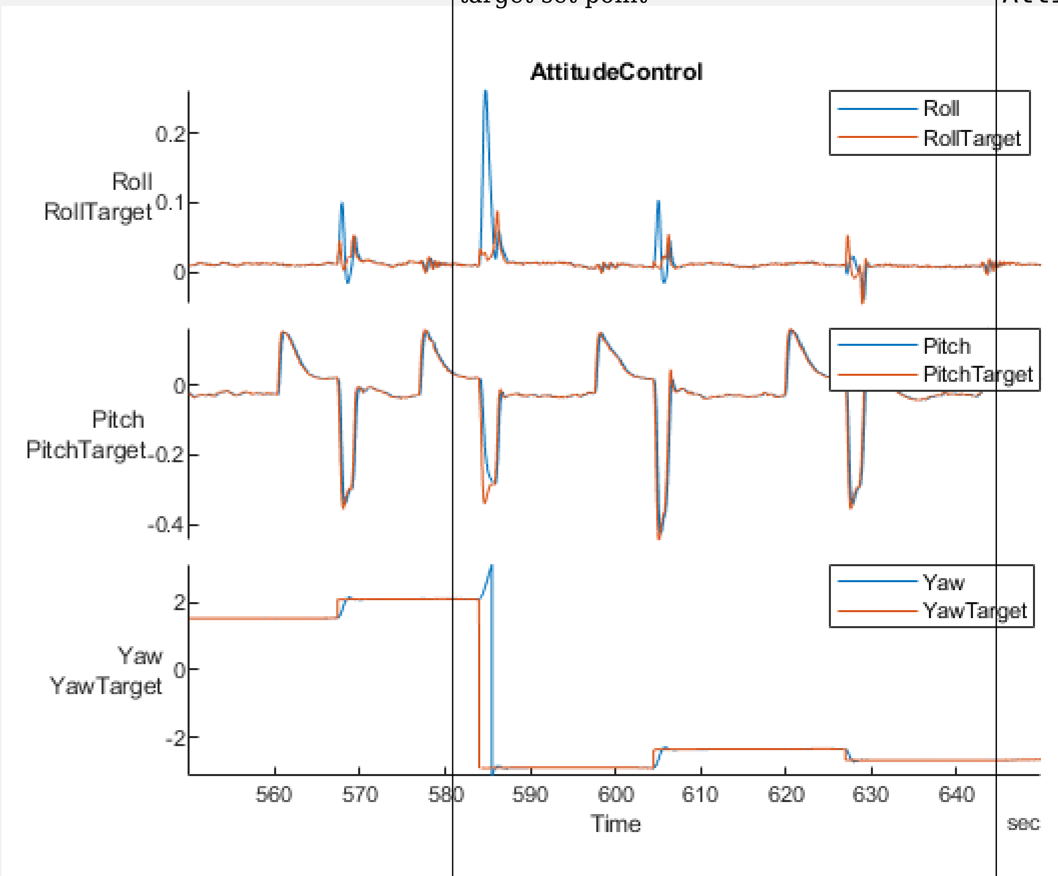
After mapping signals to the list of predefined signals using `mapSignal`, specific plots are made available when calling `show`. To view a list of available plots and their associated signals for your specific object, call `info(mapper,"Plot")`. If you want to define custom plots based on signals, use `updatePlot`.

Each predefined plot has a set of required signals that must be mapped.

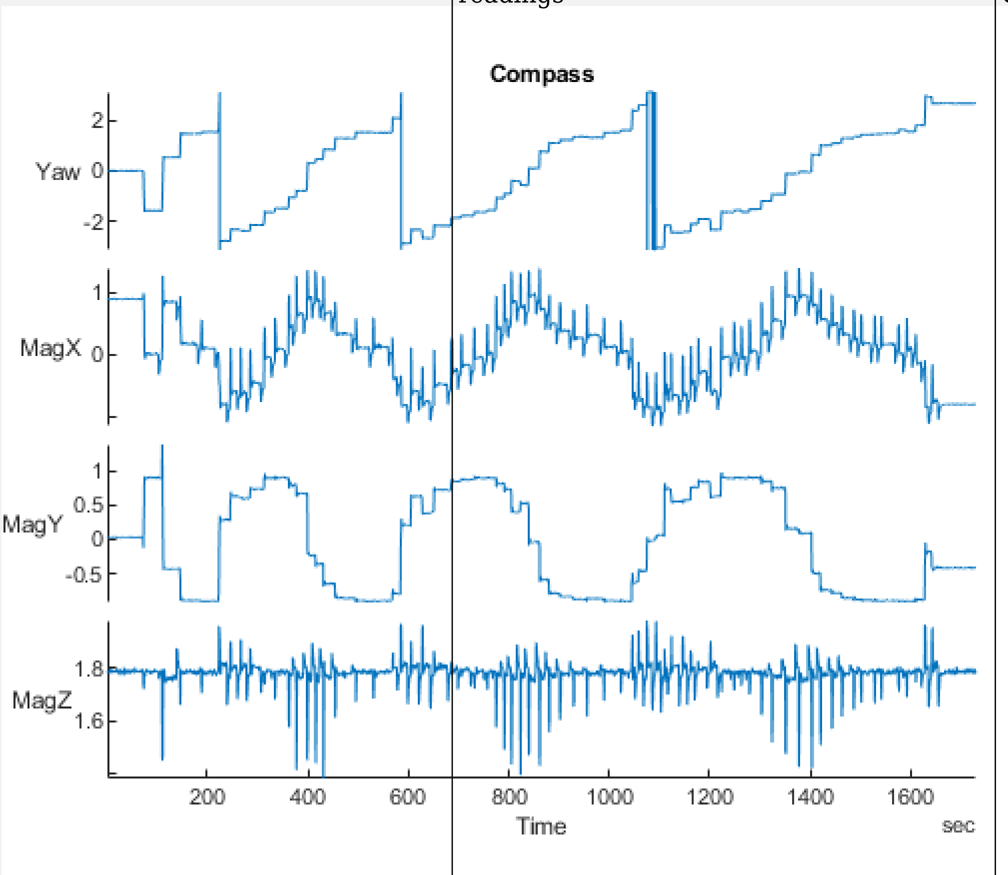
Predefined Plots

Plot	Description	Signals
`Attitude`	Stacked plot of roll, pitch, yaw angles and body rotation rates	`AttitudeEuler, AttitudeRate, Gyro#`

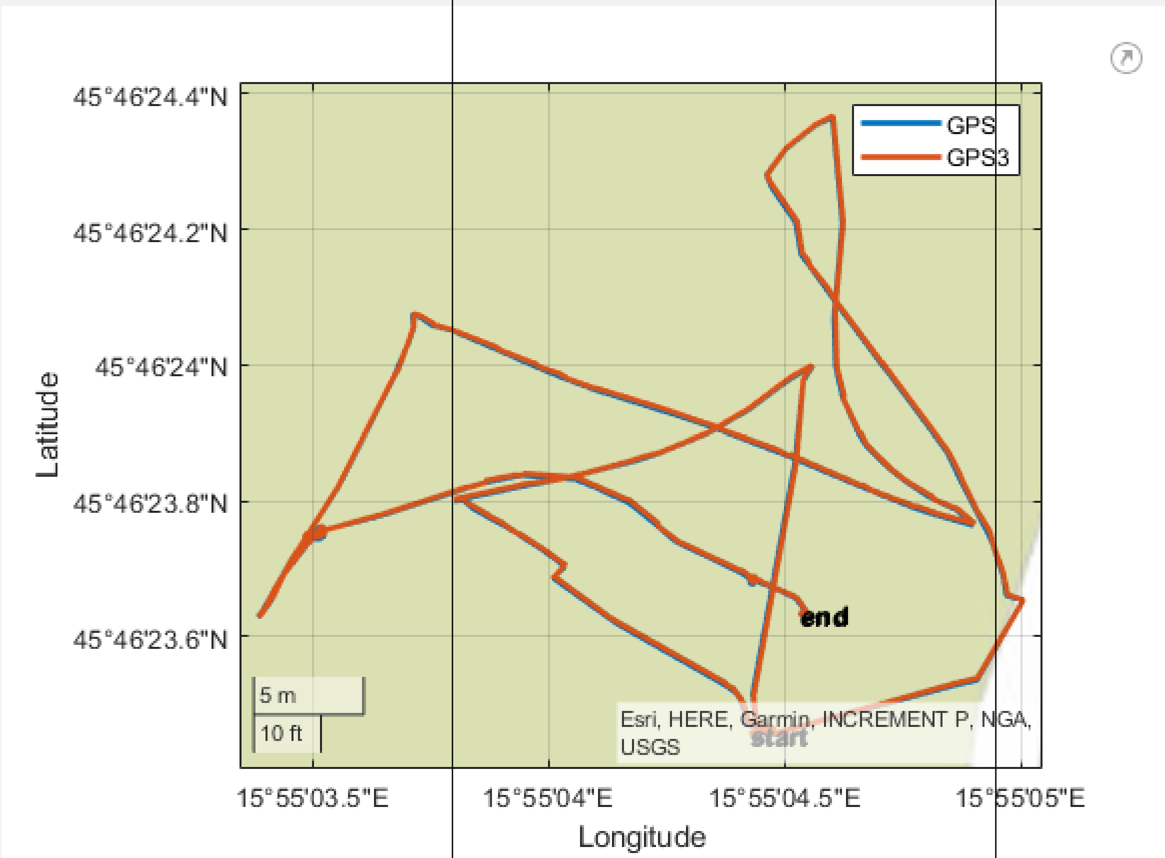


Plot	Description	Signals
AttitudeControl	Estimated attitude of UAV and the attitude target set point	AttitudeEuler, AttitudeTargetEuler
		
Battery	Battery consumption plot	Battery

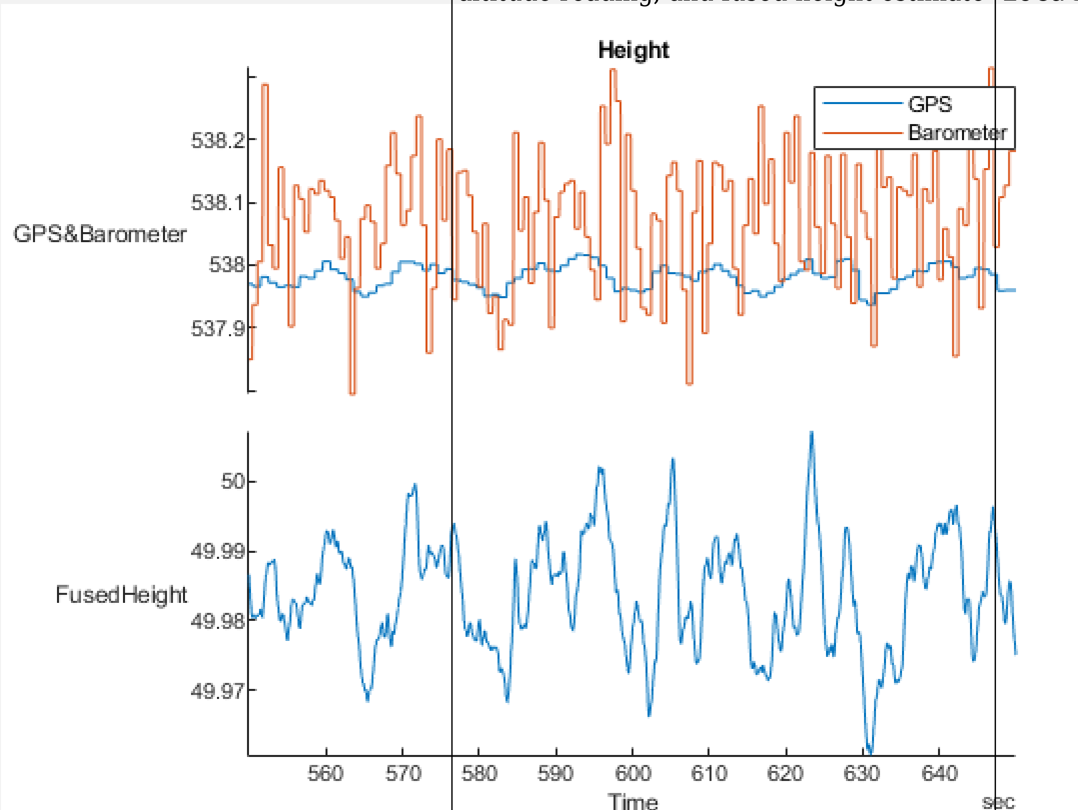
Plot	Description	Signals
`Compass`	Estimated yaw and magnetometer readings	`AttitudeEuler, Mag#, GPS#`



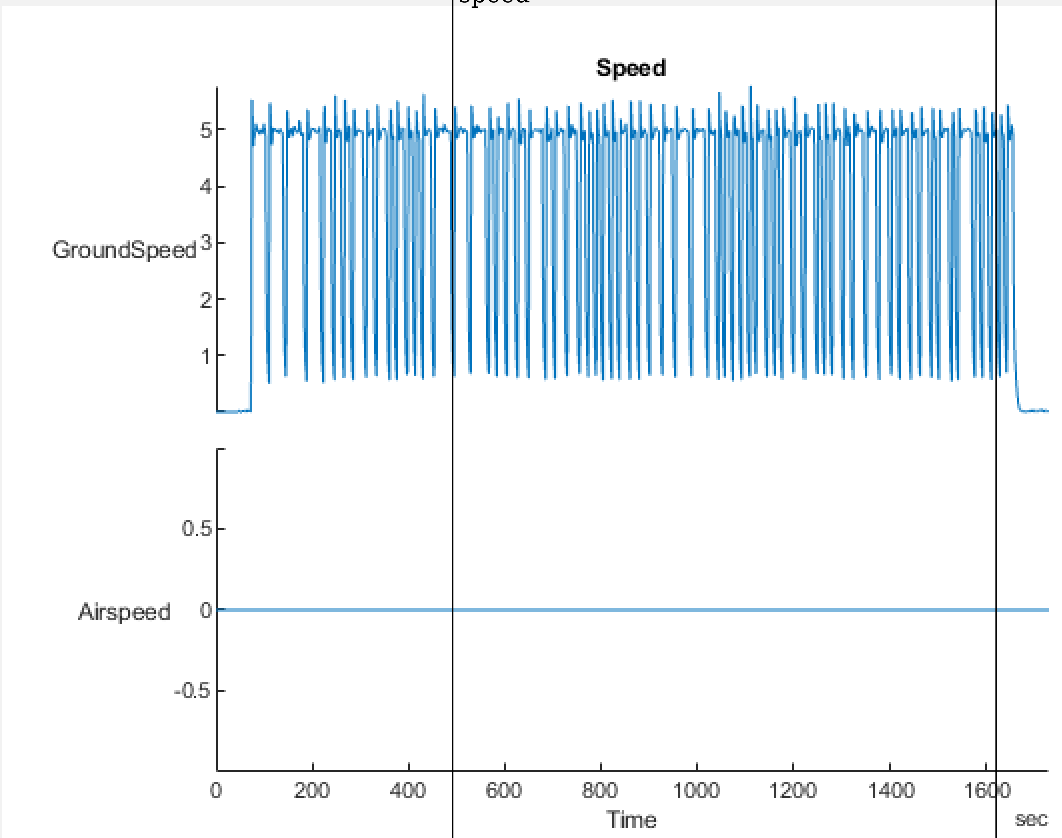
Plot	Description	Signals
GPS2D	Raw Lat-Lon plot for GPS sensor readings.	GPS#

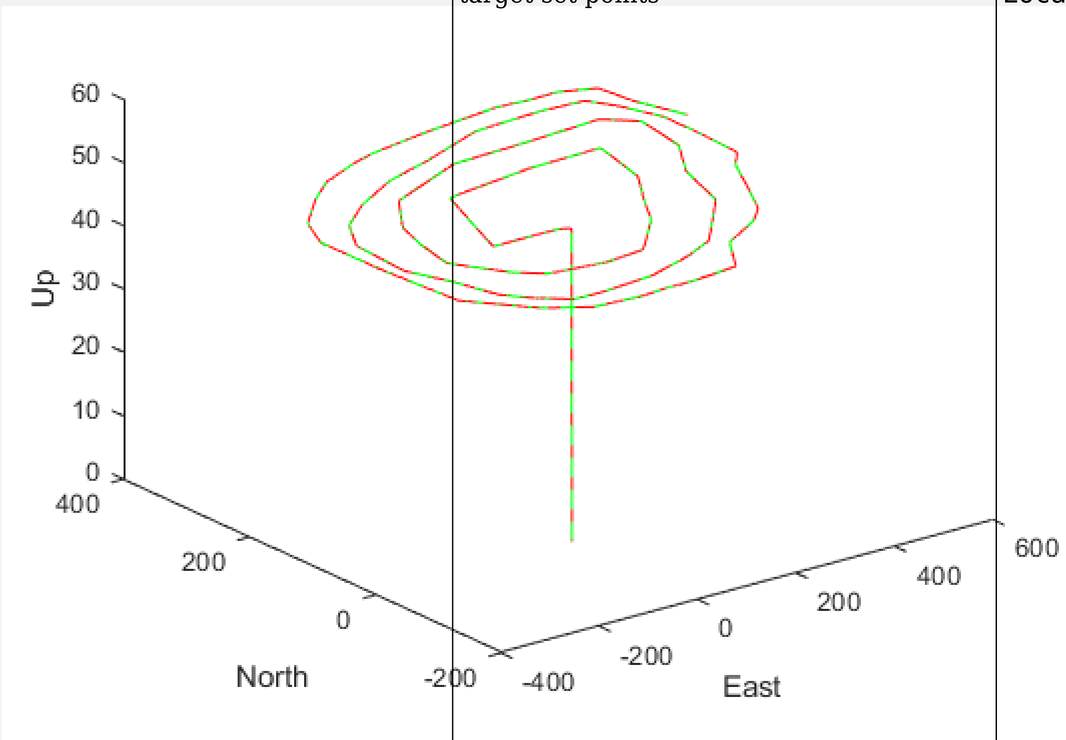


Plot	Description	Signals
Height	Stacked plots of barometer reading, GPS altitude reading, and fused height estimate	Barometer#, GPS#, LocalNED

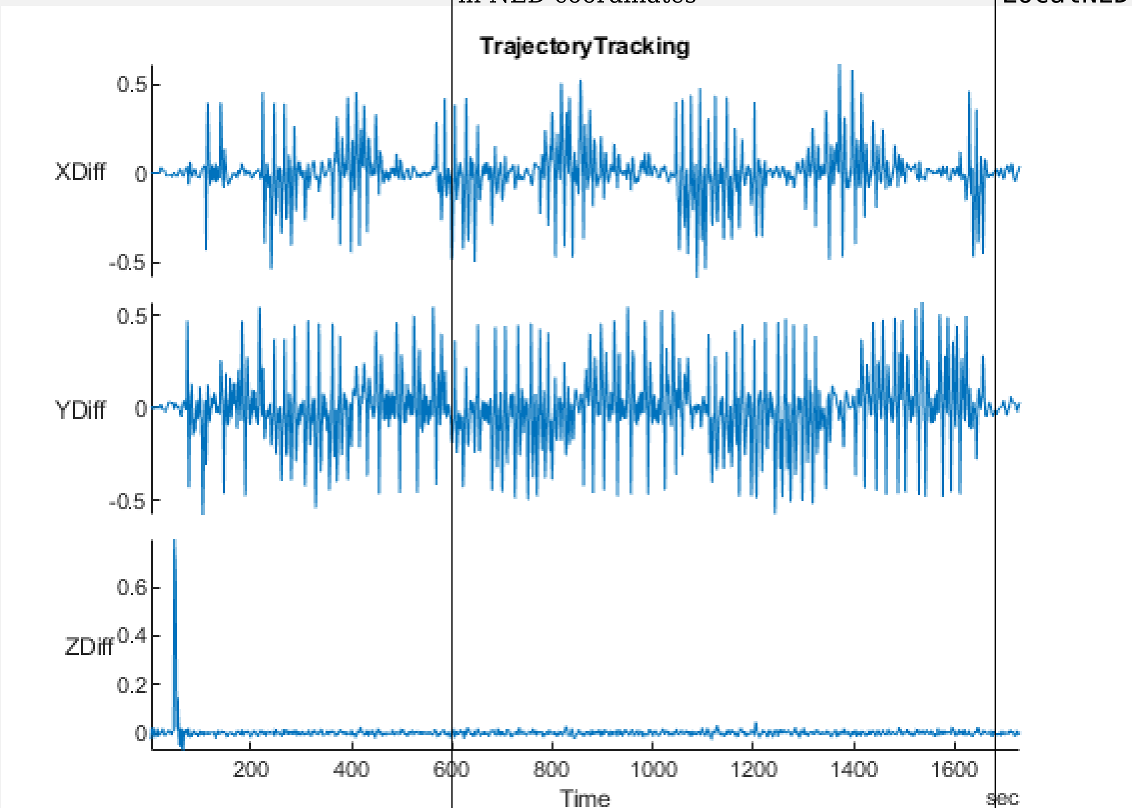


Plot	Description	Signals
Speed	Stacked plot of ground velocity and air speed	GPS#, Airspeed#

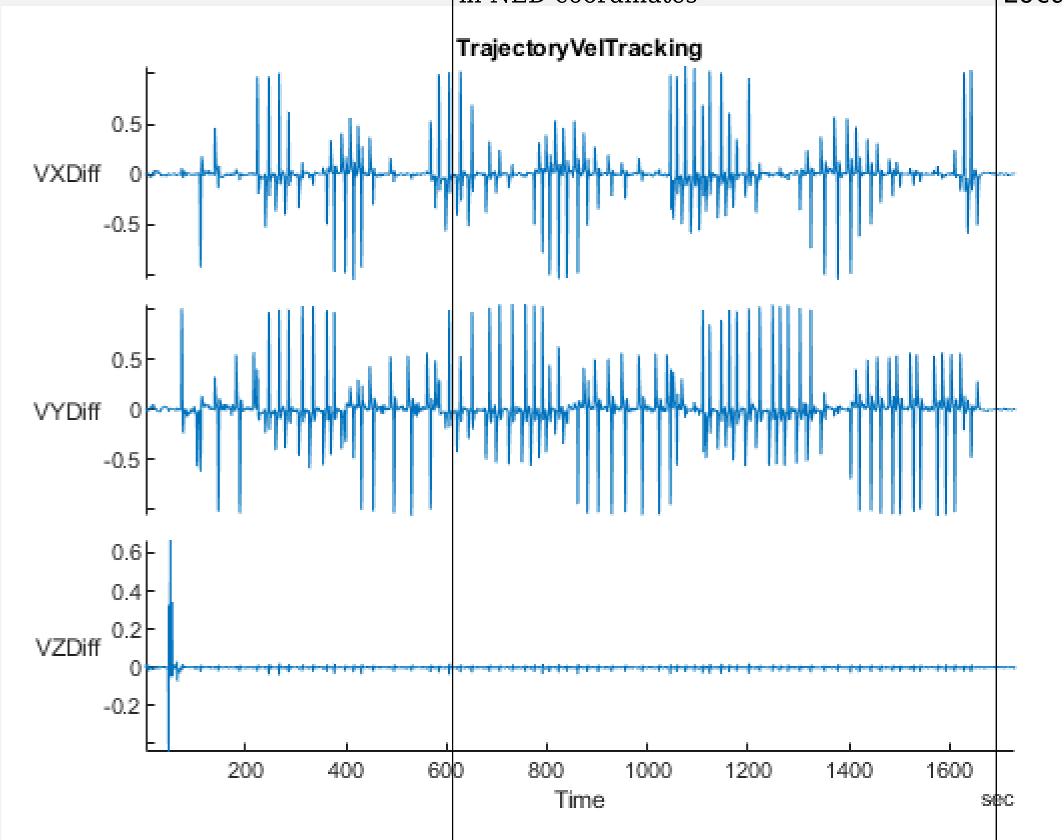


Plot	Description	Signals
`Trajectory`	Trajectory in local coordinates versus target set points	`LocalNED`, `LocalNEDTarget`
		

Plot	Description	Signals
`TrajectoryTracking`	Error between desired and actual position in NED coordinates	`LocalNED`, `LocalNEDTarget`



Plot	Description	Signals
`TrajectoryVelTracking`	Error between desired and actual velocity in NED coordinates	`LocalNEDVel`, `LocalNEDVelTarget`



See Also

`extract` | `flightLogSignalMapping` | `info` | `mapSignal` | `mavlinktlog` | `show` | `updatePlot`

Introduced in R2020b

mapSignal

Map UAV flight log signal

Syntax

```
mapsignal(mapper,signalName,timeFunc,valueFunc)
mapsignal(mapper,signalName,timeFunc,valueFunc,varNames)
mapsignal(mapper,signalName,timeFunc,valueFunc,varNames,varUnits)
```

Description

`mapsignal(mapper,signalName,timeFunc,valueFunc)` maps the signal with name `signalName` to a pair of function handles, `timeFunc` and `valueFunc`. These functions define the time stamps and values of signals from a flight log file, which can be imported using `mavlinktlog` or `ulogreader`. For a list of preconfigured signals and plots, see Predefined Signals on page 2-66 and Predefined Plots on page 2-67.

`mapsignal(mapper,signalName,timeFunc,valueFunc,varNames)` maps the signal with name `signalName` and specifies the variable names, `varName`, for the columns of a matrix generated from `valueFunc`.

`mapsignal(mapper,signalName,timeFunc,valueFunc,varNames,varUnits)` maps the signal with name `signalName` and specifies the units, `varUnits` for `varName`.

Input Arguments

`mapper` — Flight log signal mapping
`flightLogSignalMapping` object

Flight log signal mapping object, specified as a `flightLogSignalMapping` object.

`signalName` — Signal name to map data
string scalar | character vector

Signal name to map data, specified as a string scalar or character vector.

Example: `"Gyro"`

Data Types: `char` | `string`

`timeFunc` — Timestamps for signal
function handle

Timestamps for signal values , specified as a function handle. Typically, this function handle extracts time data from a flight log, which can be imported using `mavlinktlog` or `ulogreader`.

Example: `@(x)x.Gyro.Time`

Data Types: `function_handle`

`valueFunc` — Values for signal
function handle

Values for signal, specified as a function handle. Typically, this function handle extracts signal data from a flight log, which can be imported using `mavlinktlog` or `ulogreader`.

Example: `@(x)x.Gyro.Value`

Data Types: `function_handle`

`varNames` — Variable names for a matrix of values
string array | cell array of character vectors

Variable names for a matrix of values, specified as a string array or cell array of character vectors. Each element corresponds to a column in the matrix of values generated from `valueFunc`.

Example: `["xPos" "yPos" "zPos"]`

Data Types: `char` | `string`

`varUnits` — Variable units for a matrix of values
string array | cell array of character vectors

Variable units for a matrix of values, specified as a string array or cell array of character vectors. Each element corresponds to an element in `varNames`.

Example: `["m" "m" "rad"]`

Data Types: `char` | `string`

More About

Predefined Signals

A set of predefined signals and plots are configured in the `flightLogSignalMapping` object. Depending on your log file type, you can map specific signals to the provided signal names using `mapSignal`. You can also call `info` to view the table for your log type and see whether you have already mapped a signal to that plot type.

Specify the `SignalName` as the input to `mapSignal`. Signals with the format `SignalName#` support mapping multiple signals of the same type. Replace `#` with incremental integers for each signal name when calling `mapSignal`.

The predefined signals have specific names and required fields when mapping the signal.

Predefined Signals

Signal Name	Description	Fields	Unit
Accel#	Raw magnetometer reading from IMU sensor	[ax ay az]	m/s^2
Airspeed#	Airspeed reading of pressure differential, indicated air speed, and temperature	[PressDiff, AirSpeed, Temp]	Pa,
AttitudeEuler	Attitude of UAV in Euler (ZYX) form	[Roll, Pitch, Yaw]	radi
AttitudeRate	Angular velocity along each body axis	[xRotRate, yRotRate, zRotRate]	rad/
AttitudeTargetEuler	Target attitude of UAV in Euler (ZYX) form	[TargetRoll, TargetPitch, TargetYaw]	radi
Barometer#	Barometer readings for absolute pressure, relative pressure, and temperature	[PressAbs, PressAltitude, Temp]	Pa,
Battery	Voltage readings for battery and remaining battery capacity (%)	[Volt1,Volt2, ... Volt16, RemainingCapacity	V, %
GPS#	GPS readings for latitude, longitude, altitude, ground speed, course angle, and number of satellites visible	[lat, long, alt, groundspeed, courseAngle, satellites]	deg deg
Gyro#	Raw body angular velocity readings from IMU sensor	[GyroX, GyroY, GyroZ]	rad/
LocalNED	Local NED coordinates estimated by the UAV	[xNED, yNED, zNED]	met
LocalNEDTarget	Target location in local NED coordinates	[xTarget, yTarget, zTarget]	met
LocalNEDVel	Local NED velocity estimated by the UAV	[vx vy vz]	m/s
LocalNEDVelTarget	Target velocity in NED in local NED	[vxTarget, vyTarget, vzTarget]	m/s
Mag#	Raw magnetometer reading from IMU sensor	[x y z]	Gs

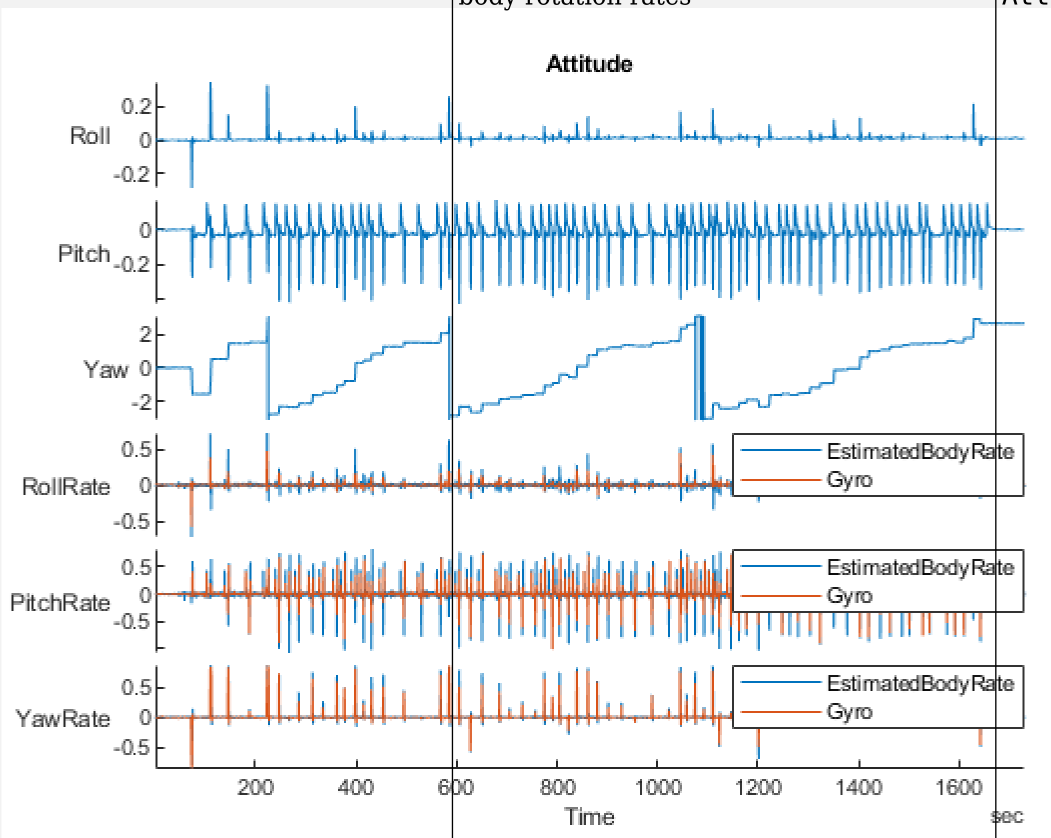
Predefined Plots

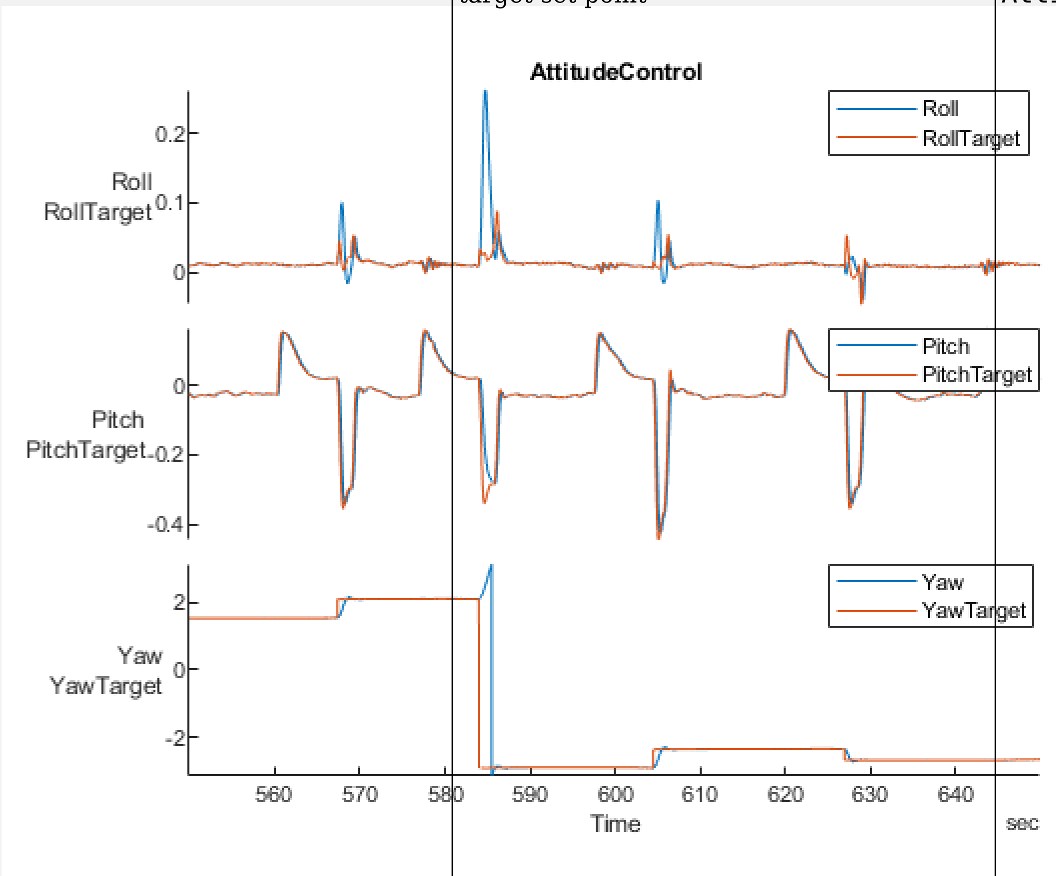
After mapping signals to the list of predefined signals using `mapSignal`, specific plots are made available when calling `show`. To view a list of available plots and their associated signals for your specific object, call `info(mapper,"Plot")`. If you want to define custom plots based on signals, use `updatePlot`.

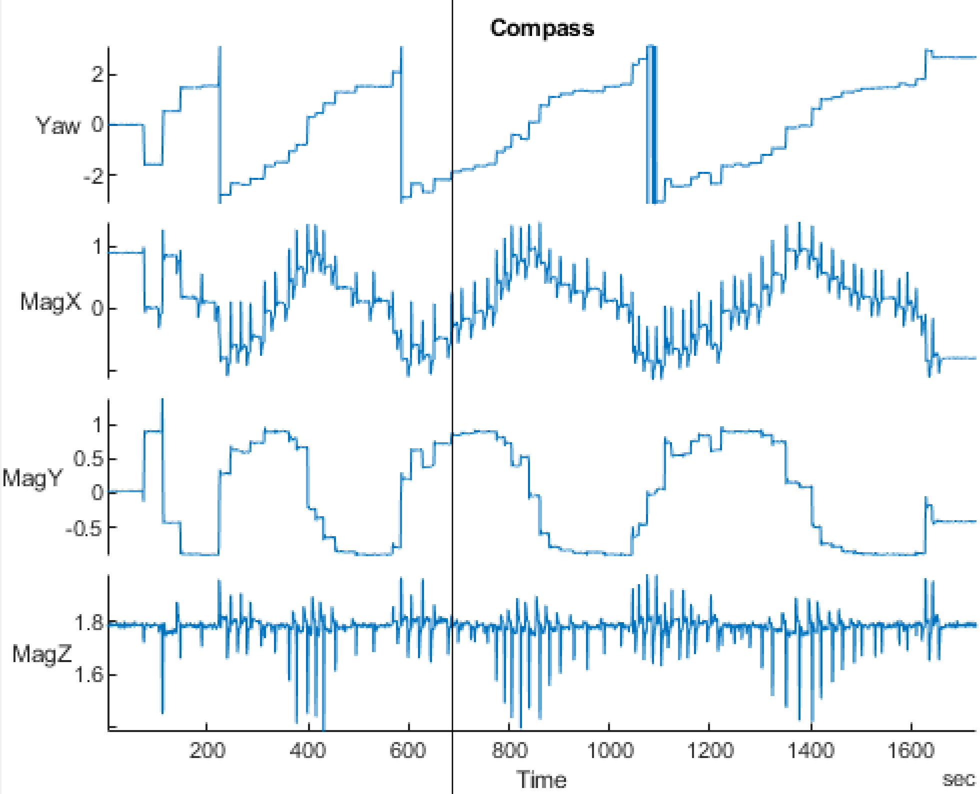
Each predefined plot has a set of required signals that must be mapped.

Predefined Plots

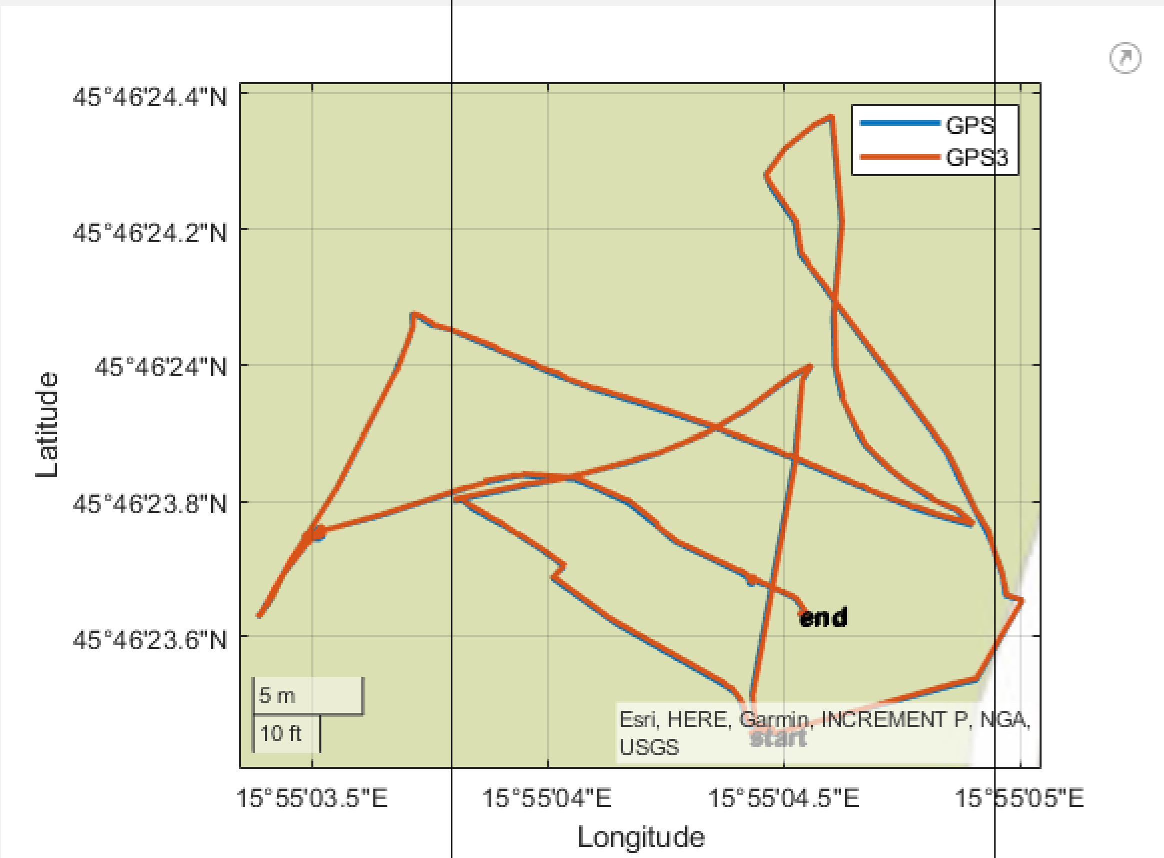
Plot	Description	Signals
`Attitude`	Stacked plot of roll, pitch, yaw angles and body rotation rates	`AttitudeEuler`, `AttitudeRate`, `Gyro#`



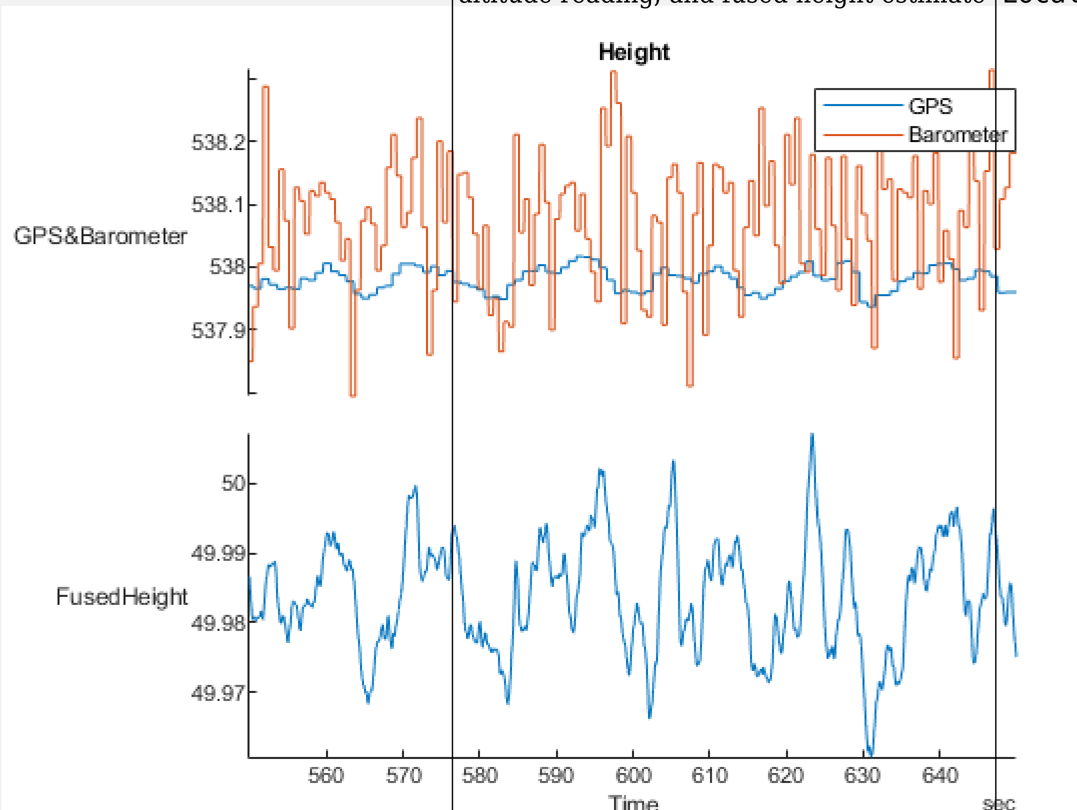
Plot	Description	Signals
`AttitudeControl`	Estimated attitude of UAV and the attitude target set point	`AttitudeEuler`, `AttitudeTargetEuler`
		
`Battery`	Battery consumption plot	`Battery`

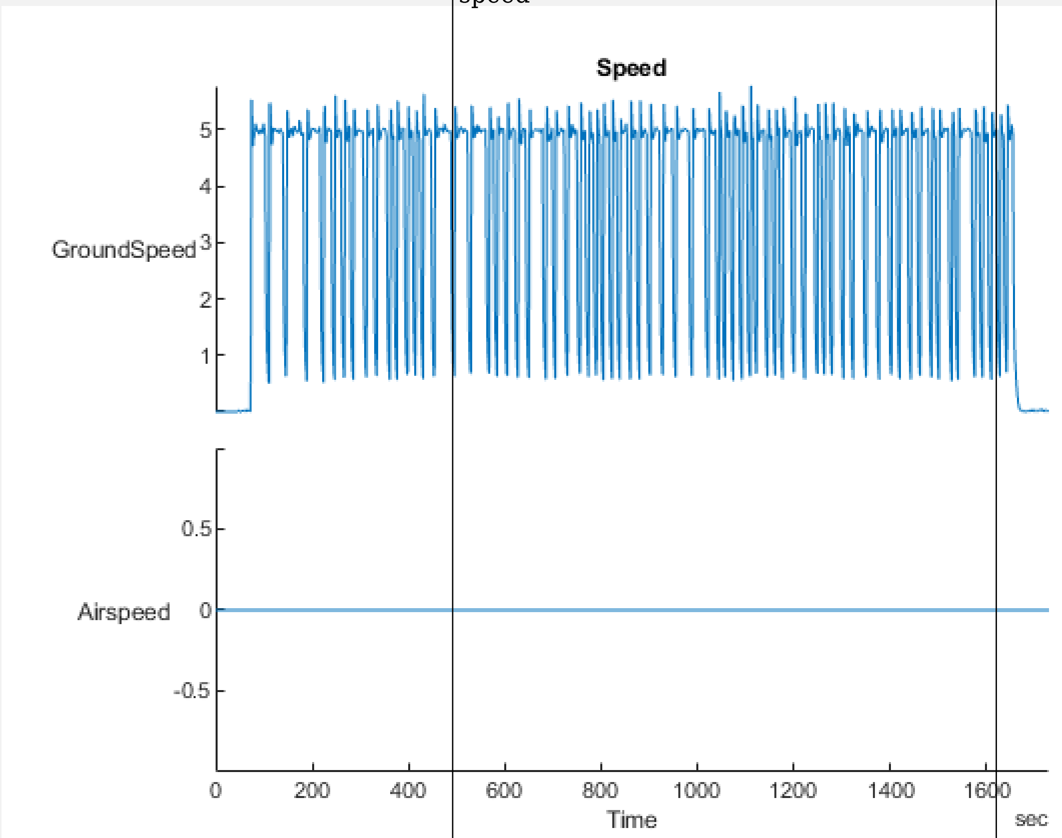
Plot	Description	Signals
`Compass`	Estimated yaw and magnetometer readings	`AttitudeEuler, Mag#, GPS#`
		

Plot	Description	Signals
GPS2D	Raw Lat-Lon plot for GPS sensor readings.	GPS#

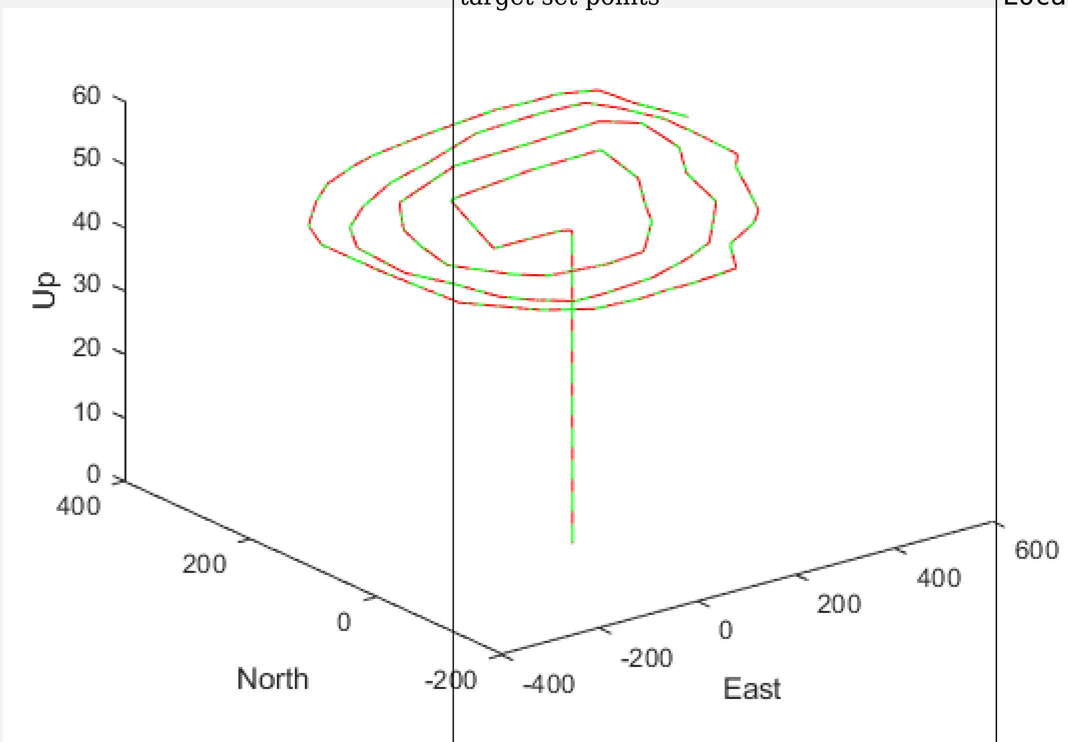


Plot	Description	Signals
`Height`	Stacked plots of barometer reading, GPS altitude reading, and fused height estimate	`Barometer#, GPS#, LocalNED`

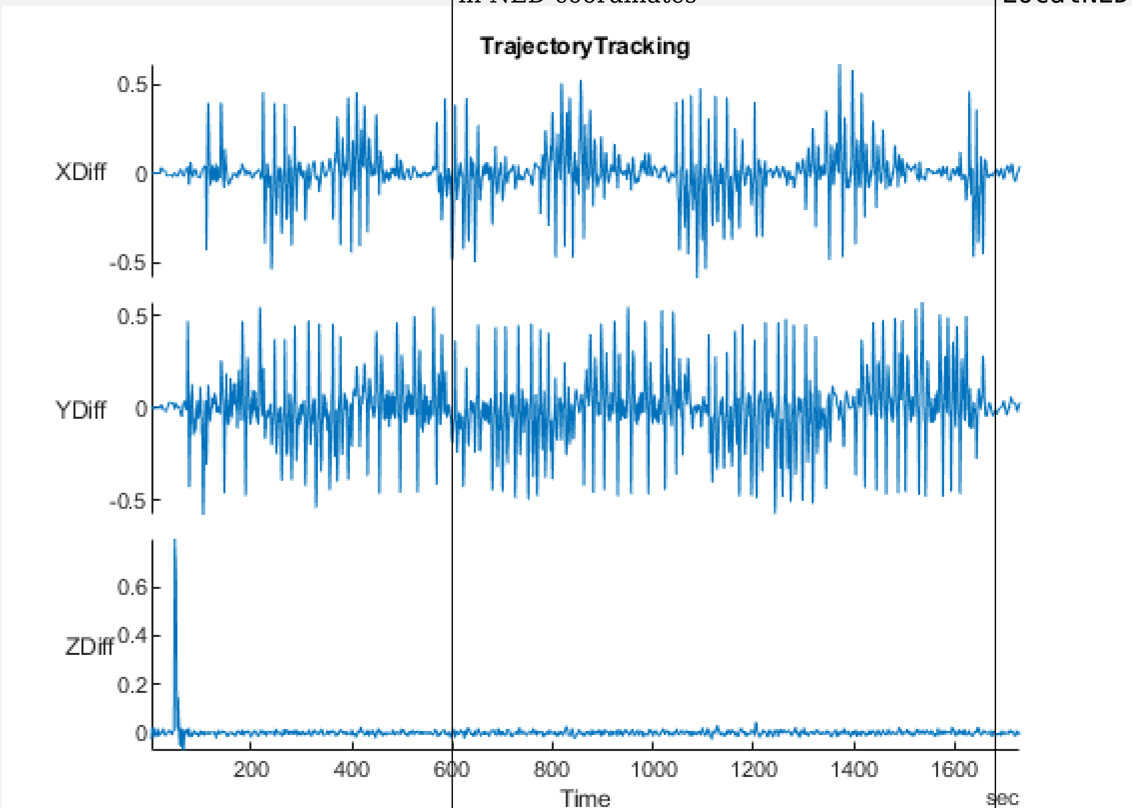


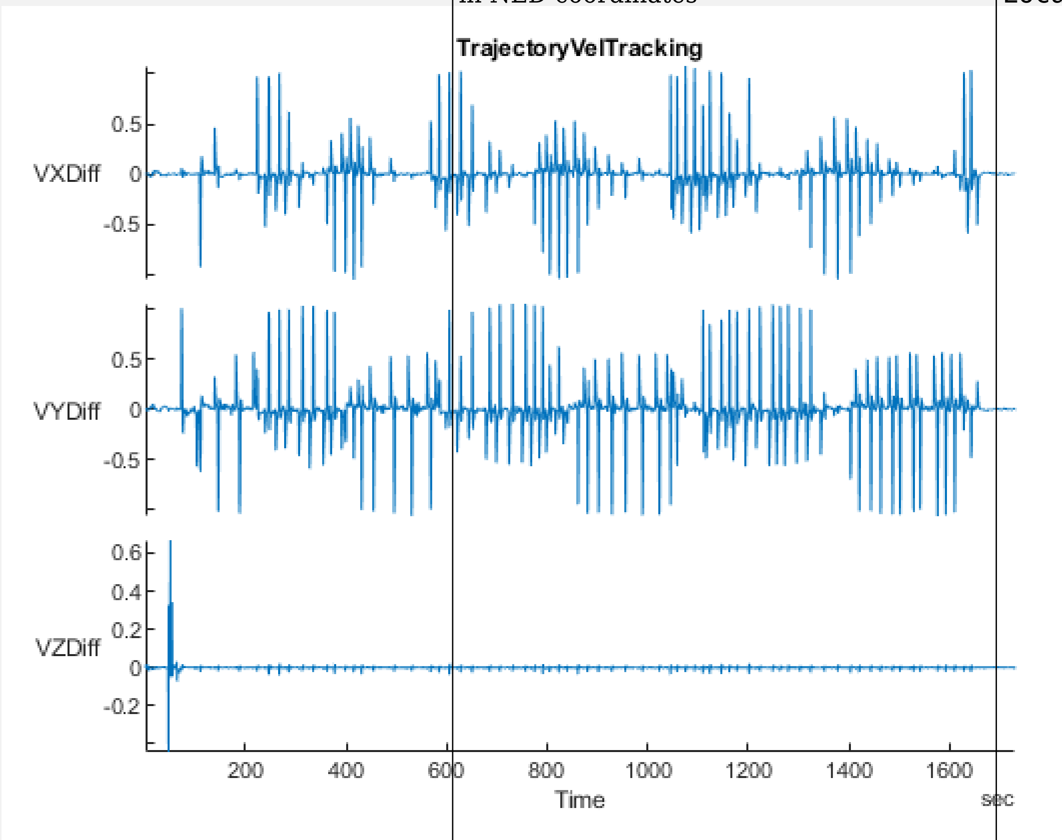
Plot	Description	Signals
`Speed` 	Stacked plot of ground velocity and air speed	`GPS#, Airspeed#`

Plot	Description	Signals
`Trajectory`	Trajectory in local coordinates versus target set points	`LocalNED`, `LocalNEDTarget`



Plot	Description	Signals
TrajectoryTracking	Error between desired and actual position in NED coordinates	LocalNED, LocalNEDTarget



Plot	Description	Signals
`TrajectoryVelTracking`	Error between desired and actual velocity in NED coordinates	`LocalNEDVel`, `LocalNEDVelTarget`
		

See Also

`extract` | `flightLogSignalMapping` | `info` | `mapSignal` | `mavlinktlog` | `show` | `updatePlot`

Introduced in R2020b

show

Display plots for inspection of UAV logs

Syntax

```
show(mapper,data)
show(mapper,data,timeStart)
show(mapper,data,timeStart,timeEnd)
show( ___ ,"PlotsToShow",plotNames)
plotStruct = show( ___ )
```

Description

`show(mapper,data)` generates all the plots stored in the flight log signal mapping object using the data from an imported flight log. For a list of preconfigured signals and plots, see Predefined Signals on page 2-78 and Predefined Plots on page 2-79.

`show(mapper,data,timeStart)` plots all data starting at the given start time.

`show(mapper,data,timeStart,timeEnd)` plots all data within the interval `[timeStart timeEnd]` inclusive.

`show( ___ ,"PlotsToShow",plotNames)` plots data using any of the previous syntaxes with plot names specified as a string array. These plot names are listed in `mapper.AvailablePlots`

`plotStruct = show( ___ )` returns the plots as a structure of plot names and figure handles.

Input Arguments

`mapper` — Flight log signal mapping
`flightLogSignalMapping` object

Flight log signal mapping object, specified as a `flightLogSignalMapping` object.

`data` — Data from flight log
table | `ulogreader` object

Data from flight log, specified as a table, `ulogreader` object, or other custom option. The data is fed directly into the plot functions specified when you call `updatePlot`.

`timeStart` — Initial time stamp for signal
`duration` object

Initial time stamp for signal to extract, specified as a `duration` object.

`timeEnd` — Final time stamp for signal
`duration` object

Final time stamp for signal to extract, specified as a `duration` object.

Output Arguments

plotStruct — Figures of individual plots
structure

Figured of individual plots, returned as a structure of plot names and associated figure handles.

More About

Predefined Signals

A set of predefined signals and plots are configured in the flightLogSignalMapping object. Depending on your log file type, you can map specific signals to the provided signal names using mapSignal. You can also call info to view the table for your log type and see whether you have already mapped a signal to that plot type.

Specify the SignalName as the input to mapSignal. Signals with the format SignalName# support mapping multiple signals of the same type. Replace # with incremental integers for each signal name when calling mapSignal.

The predefined signals have specific names and required fields when mapping the signal.

Predefined Signals

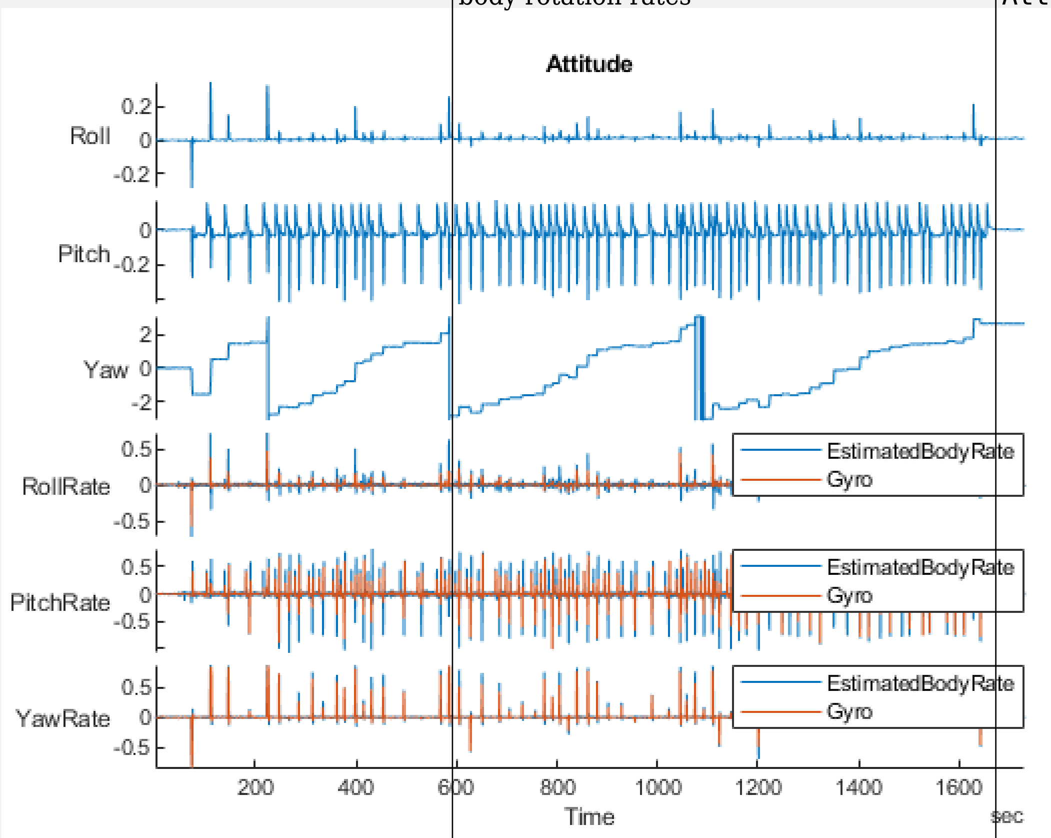
Signal Name	Description	Fields	Unit
Accel#	Raw magnetometer reading from IMU sensor	[ax ay az]	m/s^2
Airspeed#	Airspeed reading of pressure differential, indicated air speed, and temperature	[PressDiff, AirSpeed, Temp]	Pa, r
AttitudeEuler	Attitude of UAV in Euler (ZYX) form	[Roll, Pitch, Yaw]	radi
AttitudeRate	Angular velocity along each body axis	[xRotRate, yRotRate, zRotRate]	rad/
AttitudeTargetEuler	Target attitude of UAV in Euler (ZYX) form	[TargetRoll, TargetPitch, TargetYaw]	radi
Barometer#	Barometer readings for absolute pressure, relative pressure, and temperature	[PressAbs, PressAltitude, Temp]	Pa, r
Battery	Voltage readings for battery and remaining battery capacity (%)	[Volt1,Volt2, ... Volt16, RemainingCapacity	V, %
GPS#	GPS readings for latitude, longitude, altitude, ground speed, course angle, and number of satellites visible	[lat, long, alt, groundspeed, courseAngle, satellites]	degr degr
Gyro#	Raw body angular velocity readings from IMU sensor	[GyroX, GyroY, GyroZ]	rad/
LocalNED	Local NED coordinates estimated by the UAV	[xNED, yNED, zNED]	met
LocalNEDTarget	Target location in local NED coordinates	[xTarget, yTarget, zTarget]	met
LocalNEDVel	Local NED velocity estimated by the UAV	[vx vy vz]	m/s
LocalNEDVelTarget	Target velocity in NED in local NED	[vxTarget, vyTarget, vzTarget]	m/s
Mag#	Raw magnetometer reading from IMU sensor	[x y z]	Gs

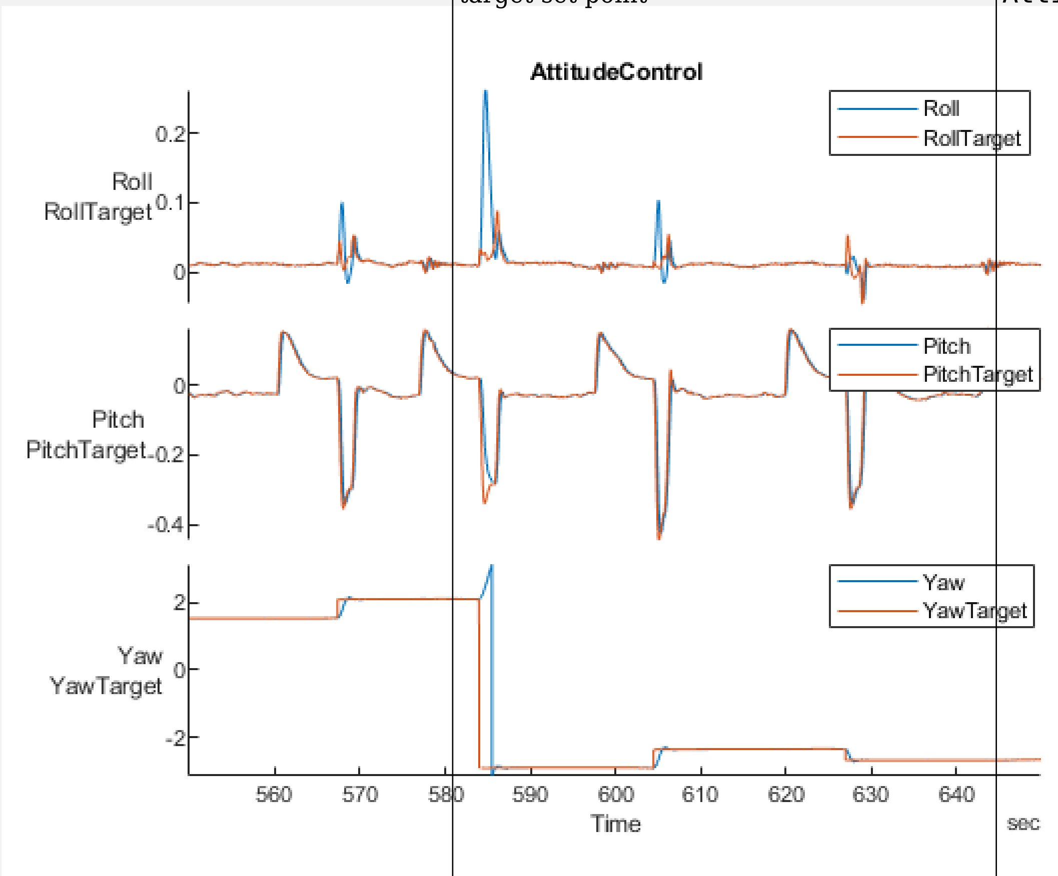
Predefined Plots

After mapping signals to the list of predefined signals using `mapSignal`, specific plots are made available when calling `show`. To view a list of available plots and their associated signals for your specific object, call `info(mapper,"Plot")`. If you want to define custom plots based on signals, use `updatePlot`.

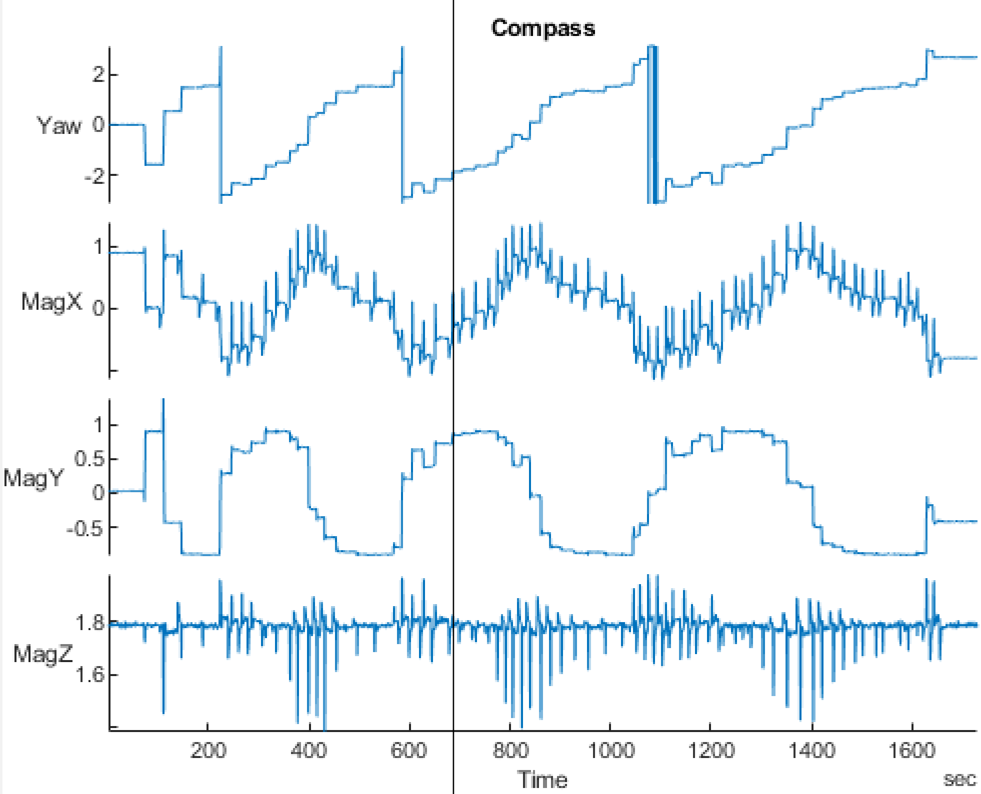
Each predefined plot has a set of required signals that must be mapped.

Predefined Plots

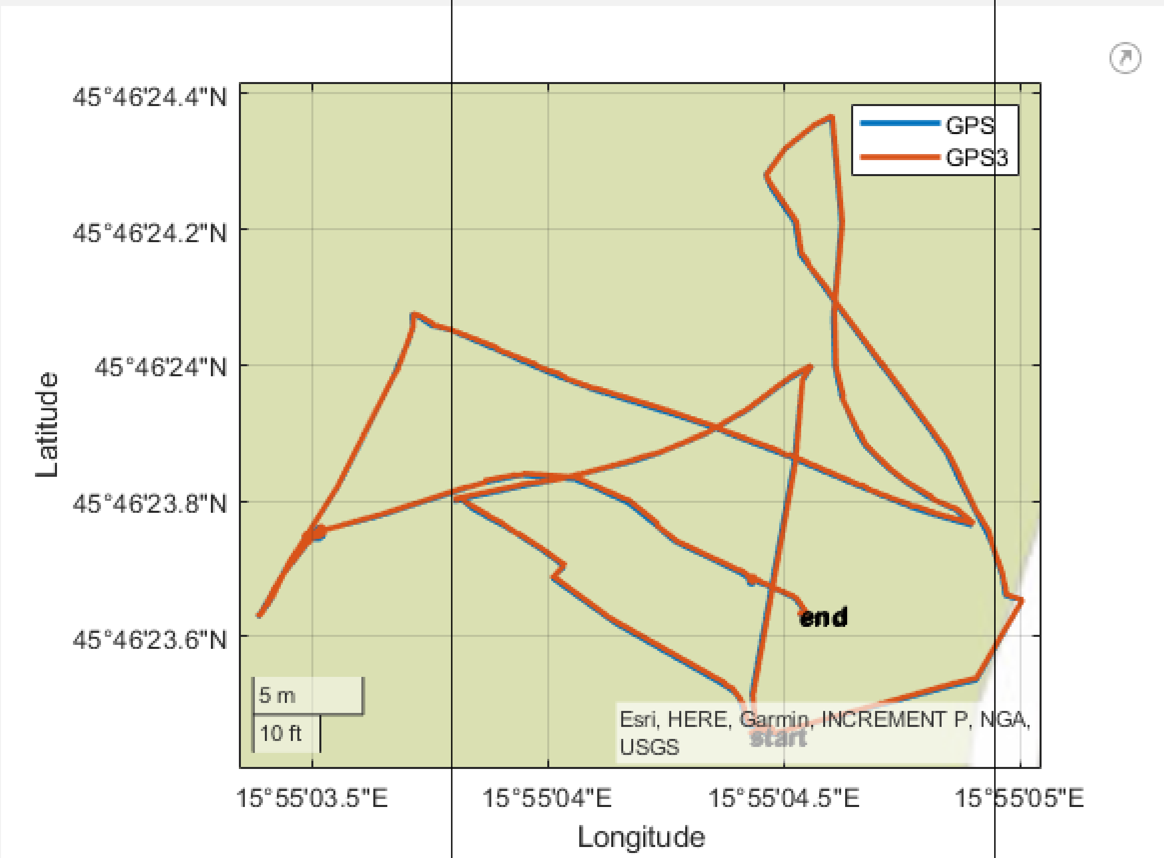
Plot	Description	Signals
`Attitude`	Stacked plot of roll, pitch, yaw angles and body rotation rates	`AttitudeEuler`, `AttitudeRate`, `Gyro#`
		

Plot	Description	Signals
`AttitudeControl` 	Estimated attitude of UAV and the attitude target set point	`AttitudeEuler`, `AttitudeTargetEuler`
`Battery`	Battery consumption plot	`Battery`

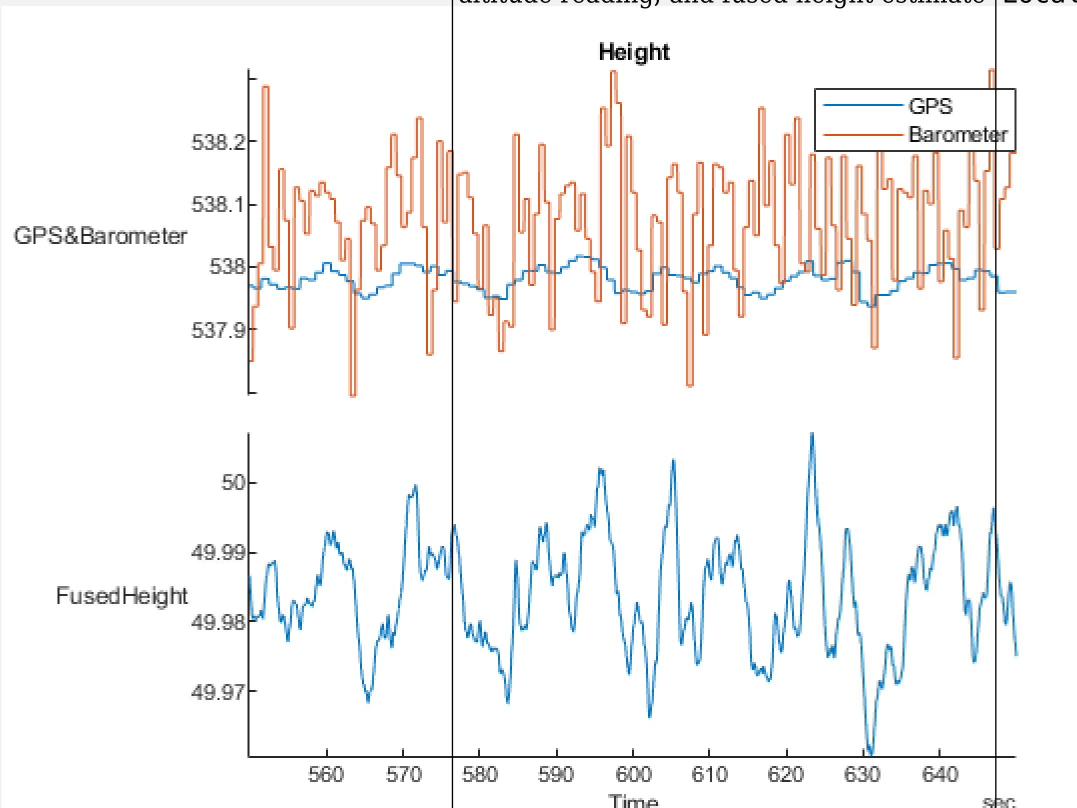
Plot	Description	Signals
`Compass`	Estimated yaw and magnetometer readings	`AttitudeEuler, Mag#, GPS#`



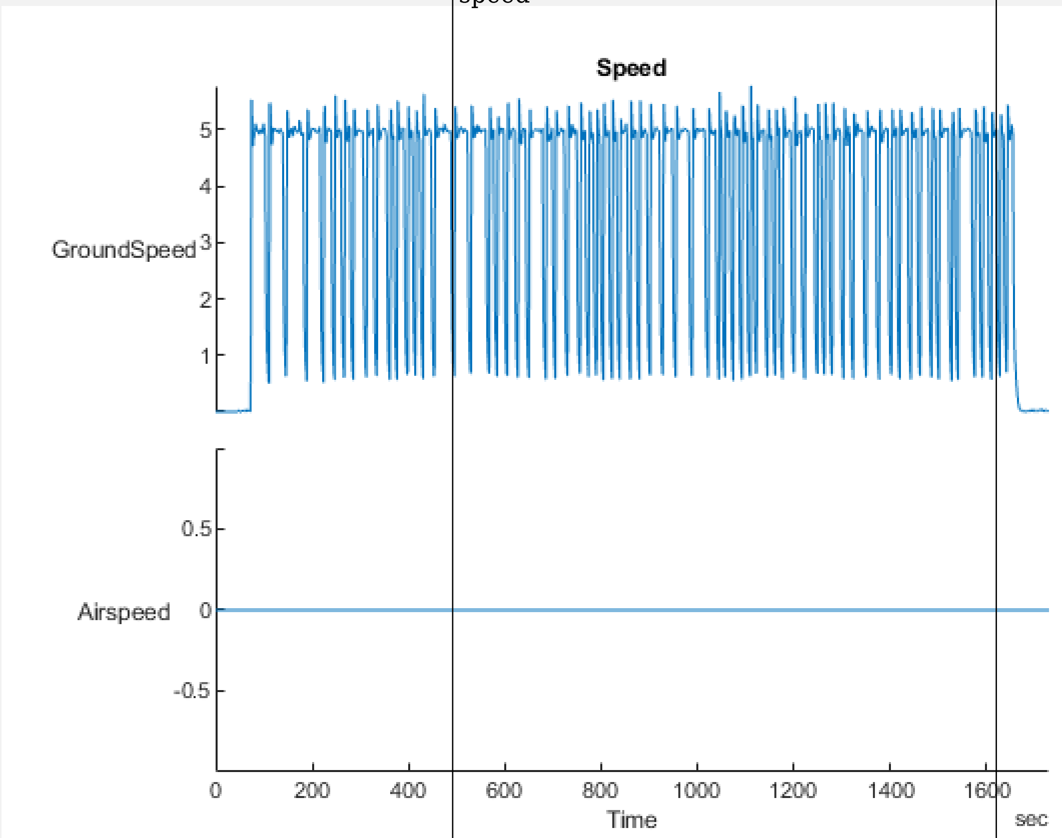
Plot	Description	Signals
GPS2D	Raw Lat-Lon plot for GPS sensor readings.	GPS#

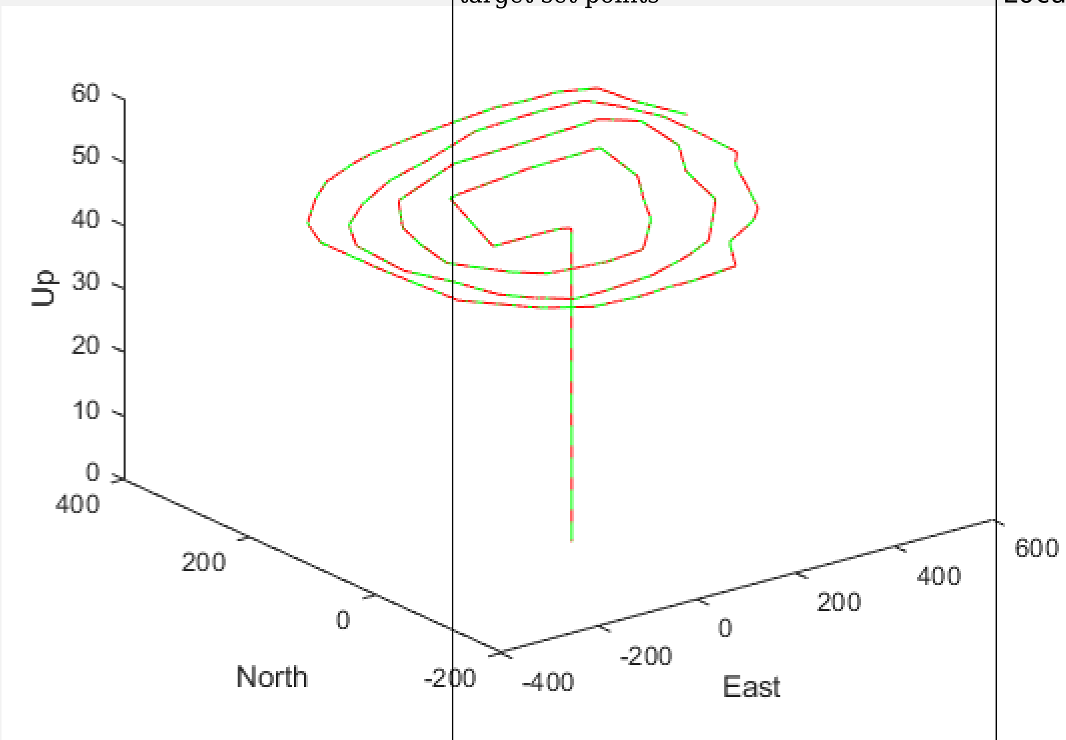


Plot	Description	Signals
`Height`	Stacked plots of barometer reading, GPS altitude reading, and fused height estimate	`Barometer#, GPS#, LocalNED`

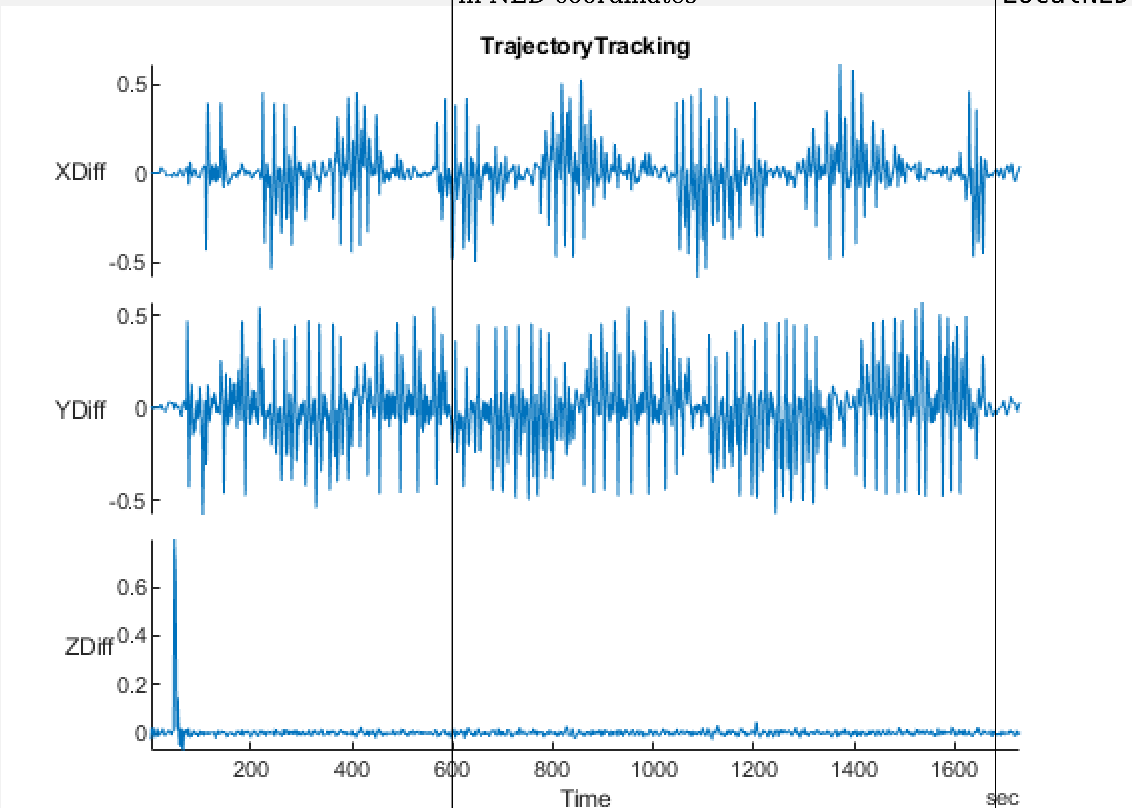


Plot	Description	Signals
Speed	Stacked plot of ground velocity and air speed	GPS#, Airspeed#

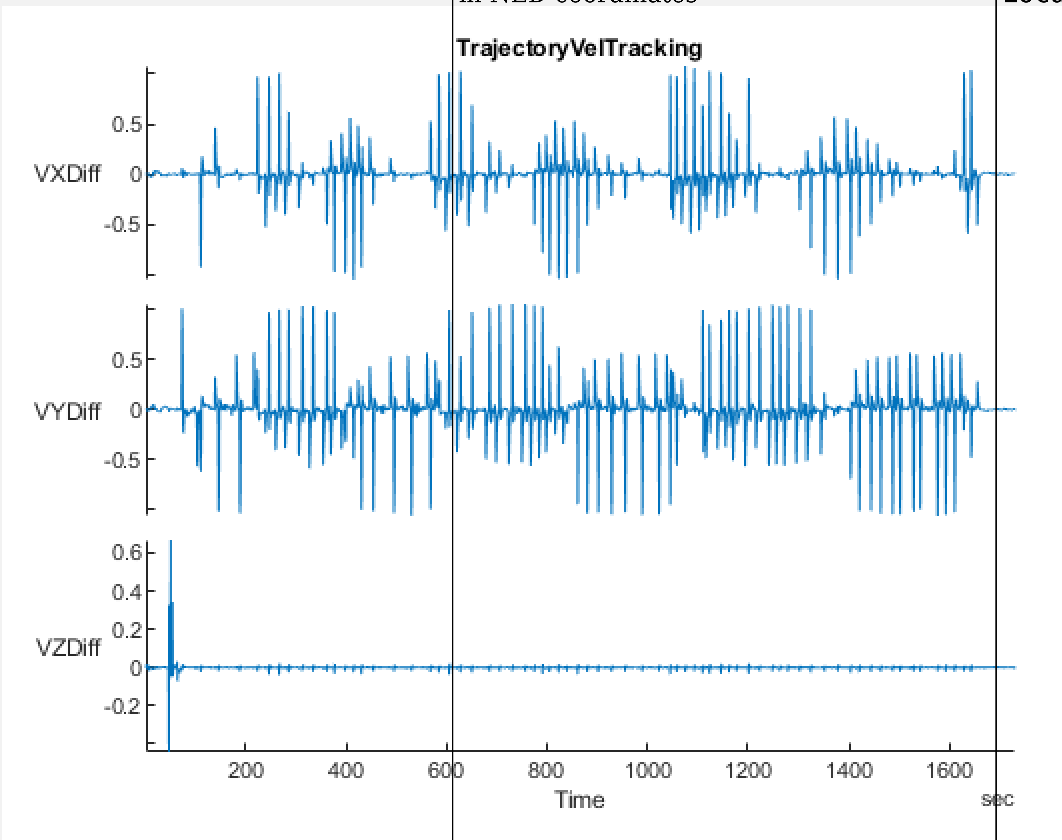


Plot	Description	Signals
`Trajectory`	Trajectory in local coordinates versus target set points	`LocalNED`, `LocalNEDTarget`
		

Plot	Description	Signals
`TrajectoryTracking`	Error between desired and actual position in NED coordinates	`LocalNED`, `LocalNEDTarget`



Plot	Description	Signals
`TrajectoryVelTracking`	Error between desired and actual velocity in NED coordinates	`LocalNEDVel`, `LocalNEDVelTarget`



See Also

`extract` | `flightLogSignalMapping` | `info` | `mapSignal` | `mavlinktlog` | `show` | `updatePlot`

Introduced in R2020b

updatePlot

Update UAV flight log plot functions

Syntax

`updatePlot(mapper,plotName,plotFunc,requiredSignals)`

Description

`updatePlot(mapper,plotName,plotFunc,requiredSignals)` adds or updates the plot with name `plotName` stored in `mapper`. Specify the plot function as a predefined plot name or function handle and the required signals for the plot. For a list of preconfigured signals and plots, see Predefined Signals on page 2-90 and Predefined Plots on page 2-91.

Input Arguments

`mapper` — Flight log signal mapping
`flightLogSignalMapping` object

Flight log signal mapping object, specified as a `flightLogSignalMapping` object.

`plotName` — Name of plot
string scalar | character vector

Name of plot, specified as a string scalar or character vector. This name is either added or updated in the `AvailablePlots` property of `mapper`.

Example: `"IMU"`

Data Types: `char` | `string`

`plotFunc` — Function for generating plot
function handle

Function for generating plot, specified as a function handle. The function is of the form:

```
f = plotFunc(signal1, signal2, ...)
```

The function takes input signals as structures with two fields, `"Names"` and `"Values"`, and generates a plot output as a figure handle using those signals.

Example: `@(acc, gyro, mag)plotIMU(acc, gyro, mag)`

Data Types: `function_handle`

`requiredSignals` — List of required signal names
string array | cell array of character vectors

List of required signal names, specified as a string array or cell array of character vectors.

Example: `["LocalNED.X" "LocalNED.Y" "LocalNED.Z"]`

Data Types: `char` | `string`

More About

Predefined Signals

A set of predefined signals and plots are configured in the `flightLogSignalMapping` object. Depending on your log file type, you can map specific signals to the provided signal names using `mapSignal`. You can also call `info` to view the table for your log type and see whether you have already mapped a signal to that plot type.

Specify the `SignalName` as the input to `mapSignal`. Signals with the format `SignalName#` support mapping multiple signals of the same type. Replace # with incremental integers for each signal name when calling `mapSignal`.

The predefined signals have specific names and required fields when mapping the signal.

Predefined Signals

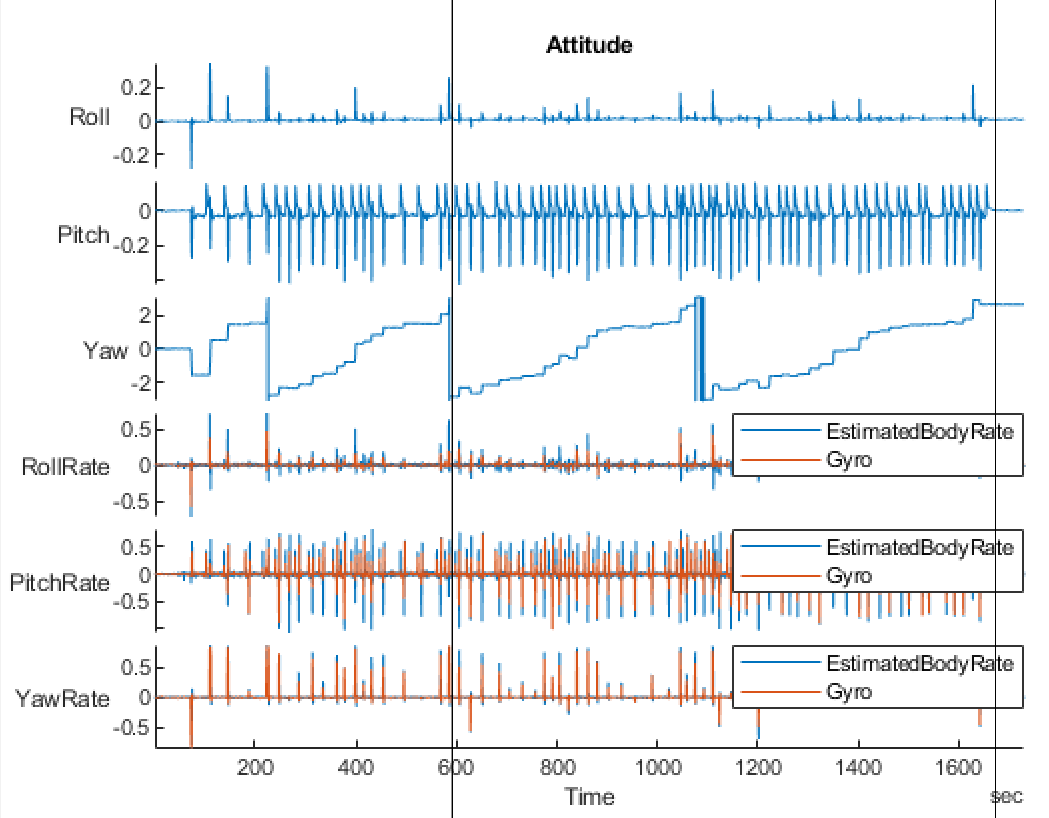
Signal Name	Description	Fields	Unit
`Accel#`	Raw magnetometer reading from IMU sensor	`[ax ay az]`	m/s^2
`Airspeed#`	Airspeed reading of pressure differential, indicated air speed, and temperature	`[PressDiff, AirSpeed, Temp]`	Pa, r
`AttitudeEuler`	Attitude of UAV in Euler (ZYX) form	`[Roll, Pitch, Yaw]`	radi
`AttitudeRate`	Angular velocity along each body axis	`[xRotRate, yRotRate, zRotRate]`	rad/
`AttitudeTargetEuler`	Target attitude of UAV in Euler (ZYX) form	`[TargetRoll, TargetPitch, TargetYaw]`	radi
`Barometer#`	Barometer readings for absolute pressure, relative pressure, and temperature	`[PressAbs, PressAltitude, Temp]`	Pa, r
`Battery`	Voltage readings for battery and remaining battery capacity (%)	`[Volt1,Volt2, ... Volt16, RemainingCapacity`	V, %
`GPS#`	GPS readings for latitude, longitude, altitude, ground speed, course angle, and number of satellites visible	`[lat, long, alt, groundspeed, courseAngle, satellites]`	degr degr
`Gyro#`	Raw body angular velocity readings from IMU sensor	`[GyroX, GyroY, GyroZ]`	rad/
`LocalNED`	Local NED coordinates estimated by the UAV	`[xNED, yNED, zNED]`	met
`LocalNEDTarget`	Target location in local NED coordinates	`[xTarget, yTarget, zTarget]`	met
`LocalNEDVel`	Local NED velocity estimated by the UAV	`[vx vy vz]`	m/s
`LocalNEDVelTarget`	Target velocity in NED in local NED	`[vxTarget, vyTarget, vzTarget]`	m/s
`Mag#`	Raw magnetometer reading from IMU sensor	`[x y z]`	Gs

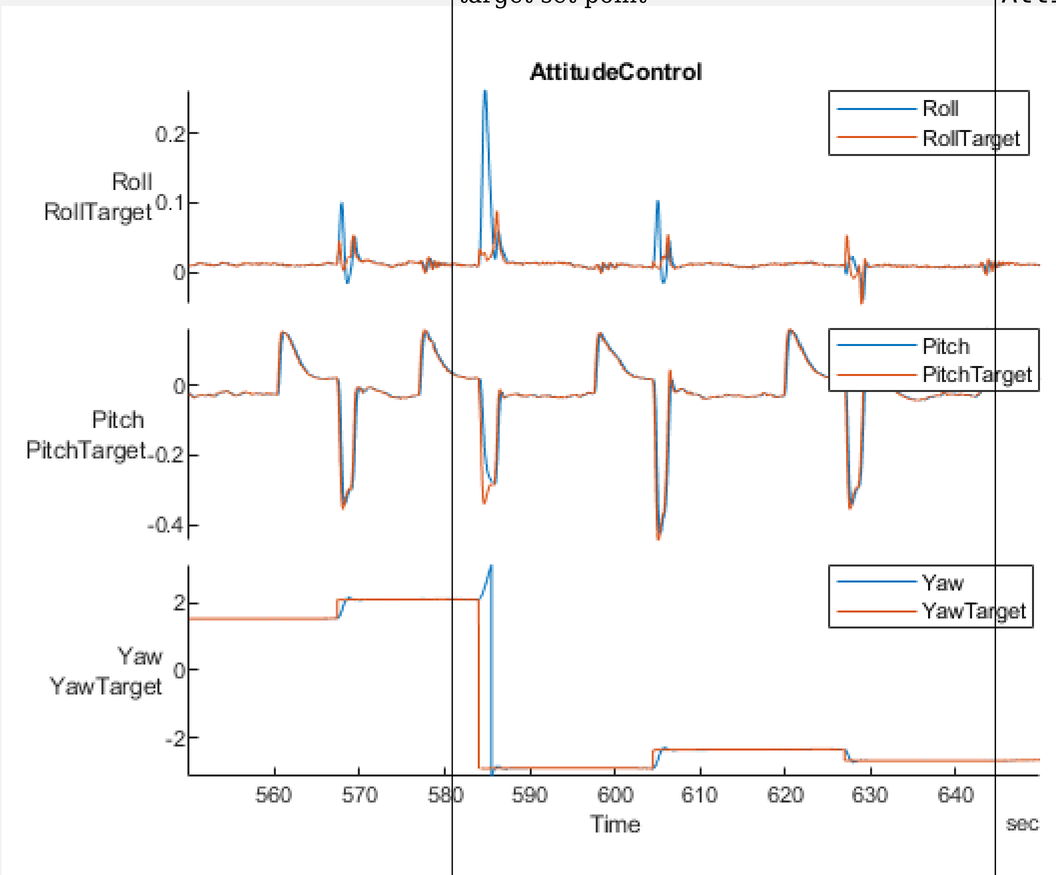
Predefined Plots

After mapping signals to the list of predefined signals using `mapSignal`, specific plots are made available when calling `show`. To view a list of available plots and their associated signals for your specific object, call `info(mapper,"Plot")`. If you want to define custom plots based on signals, use `updatePlot`.

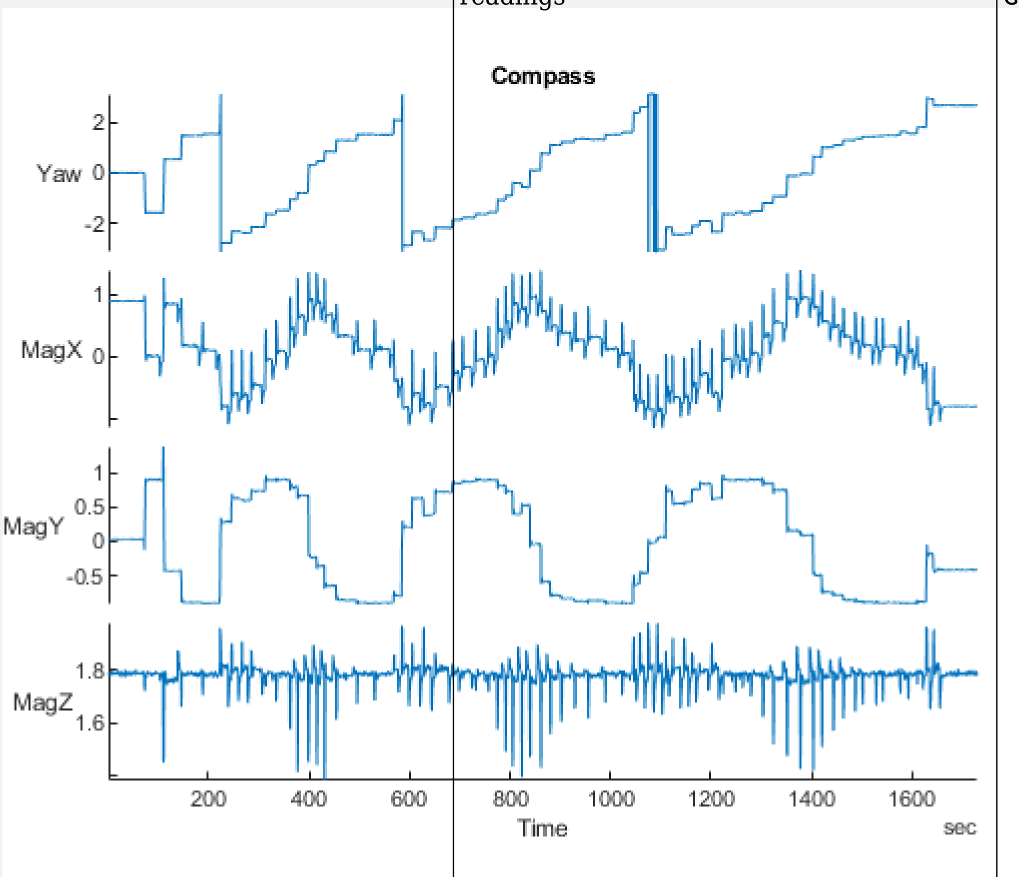
Each predefined plot has a set of required signals that must be mapped.

Predefined Plots

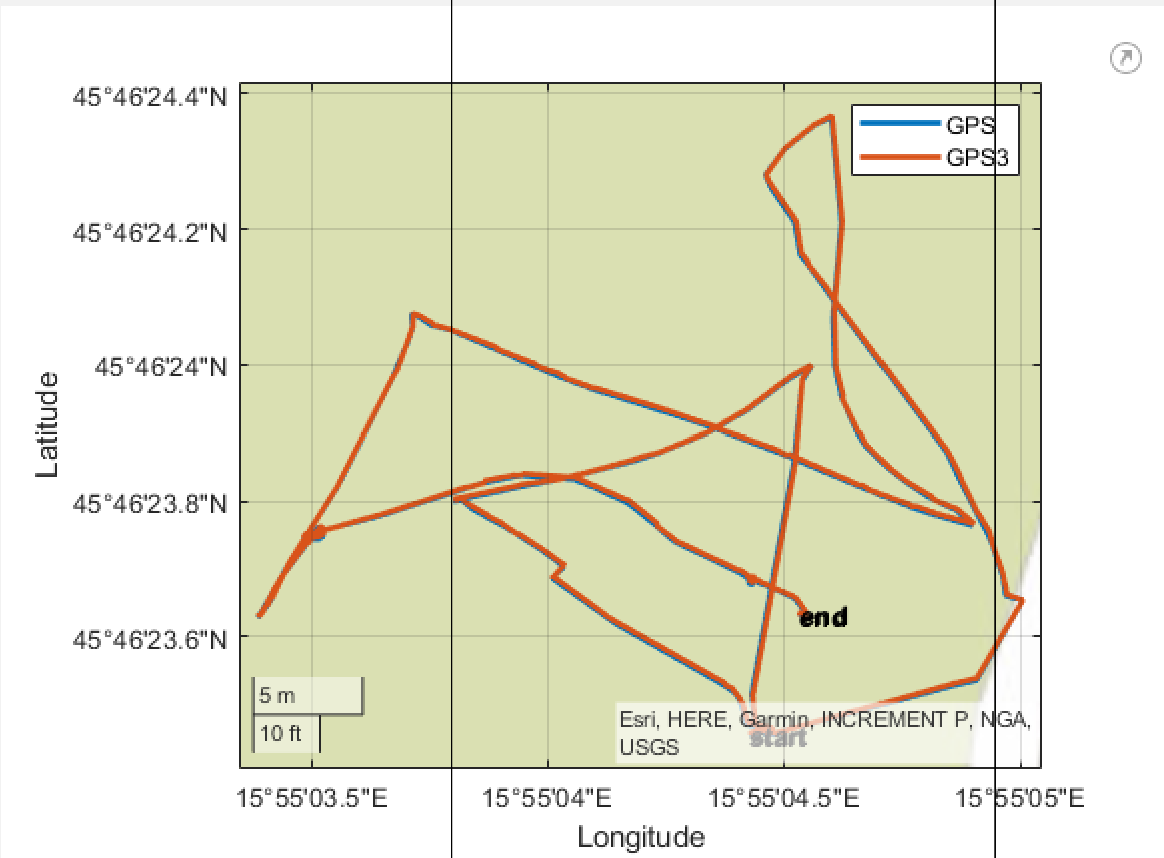
Plot	Description	Signals
`Attitude`	Stacked plot of roll, pitch, yaw angles and body rotation rates	`AttitudeEuler, AttitudeRate, Gyro#`
		

Plot	Description	Signals
`AttitudeControl` 	Estimated attitude of UAV and the attitude target set point	`AttitudeEuler`, `AttitudeTargetEuler`
`Battery`	Battery consumption plot	`Battery`

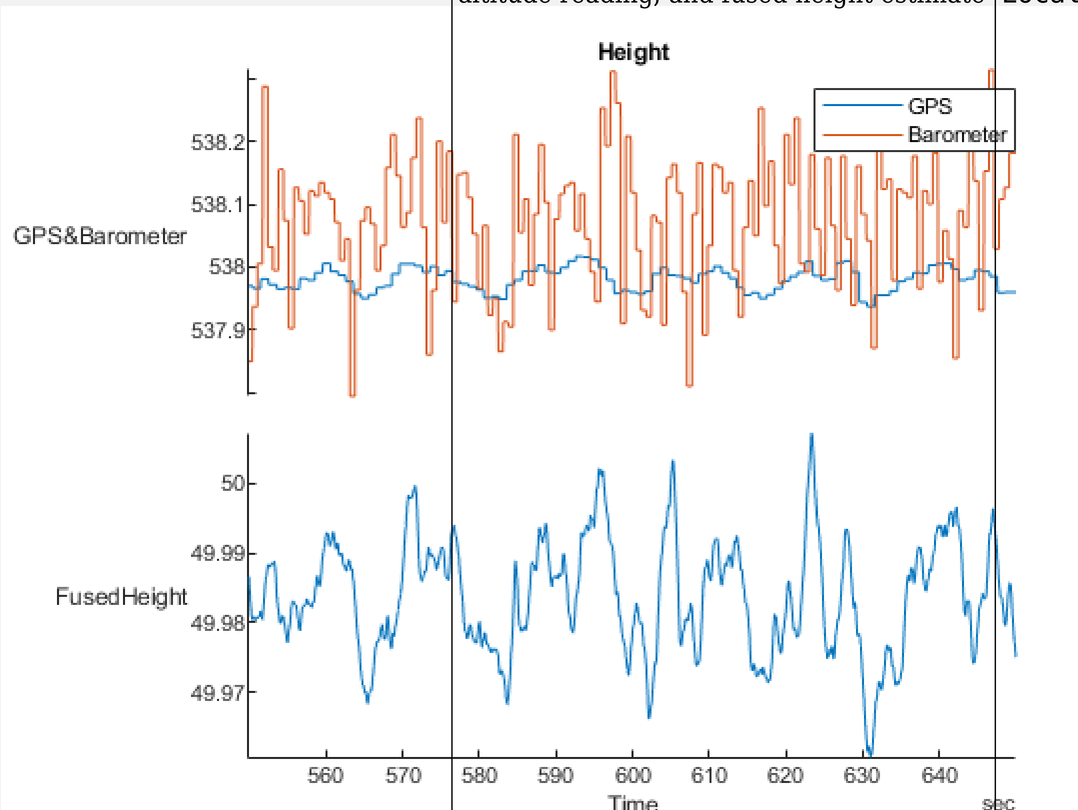
Plot	Description	Signals
`Compass`	Estimated yaw and magnetometer readings	`AttitudeEuler, Mag#, GPS#`



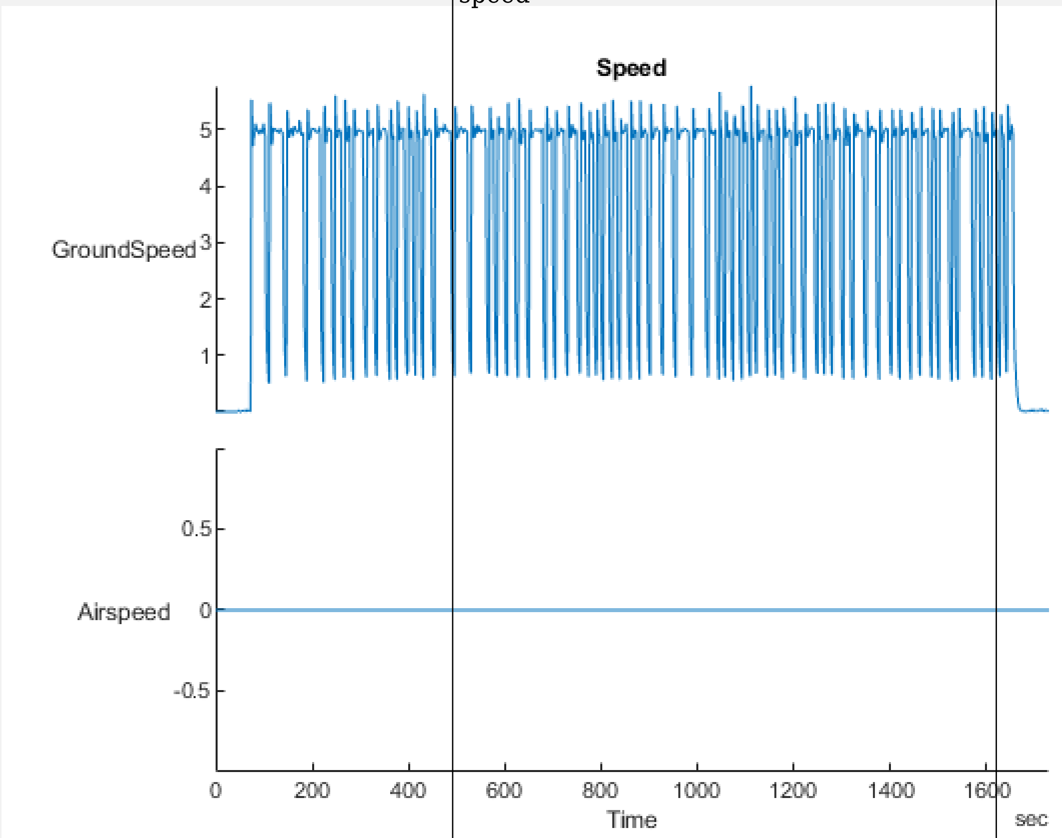
Plot	Description	Signals
GPS2D	Raw Lat-Lon plot for GPS sensor readings.	GPS#

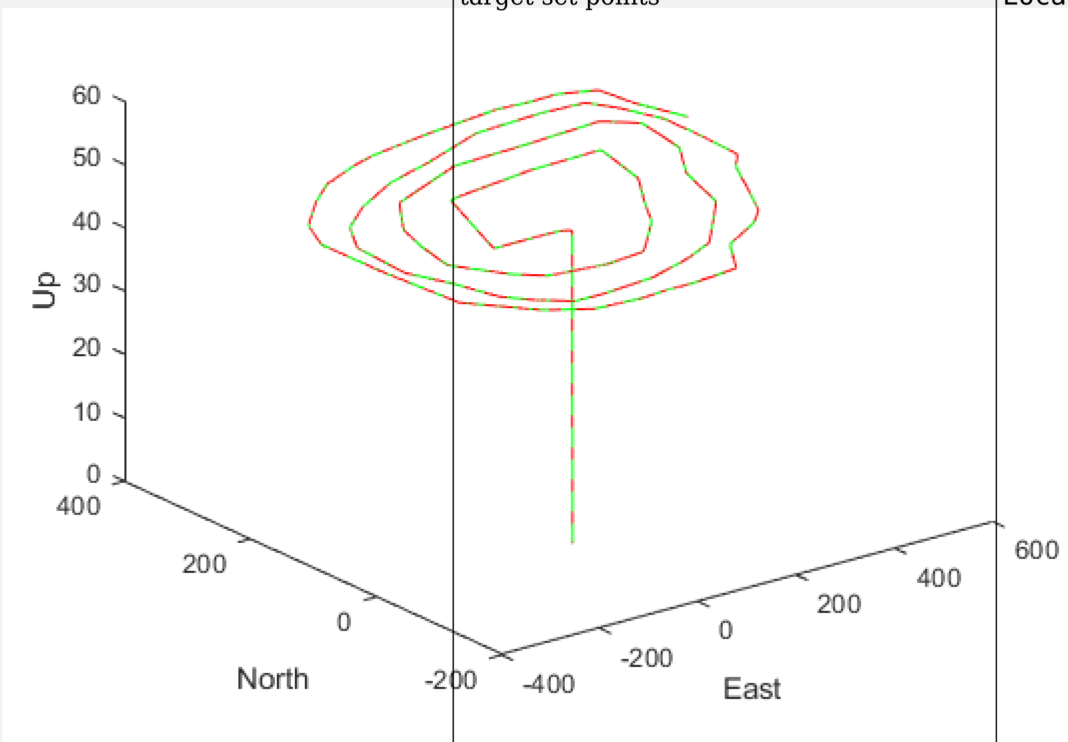


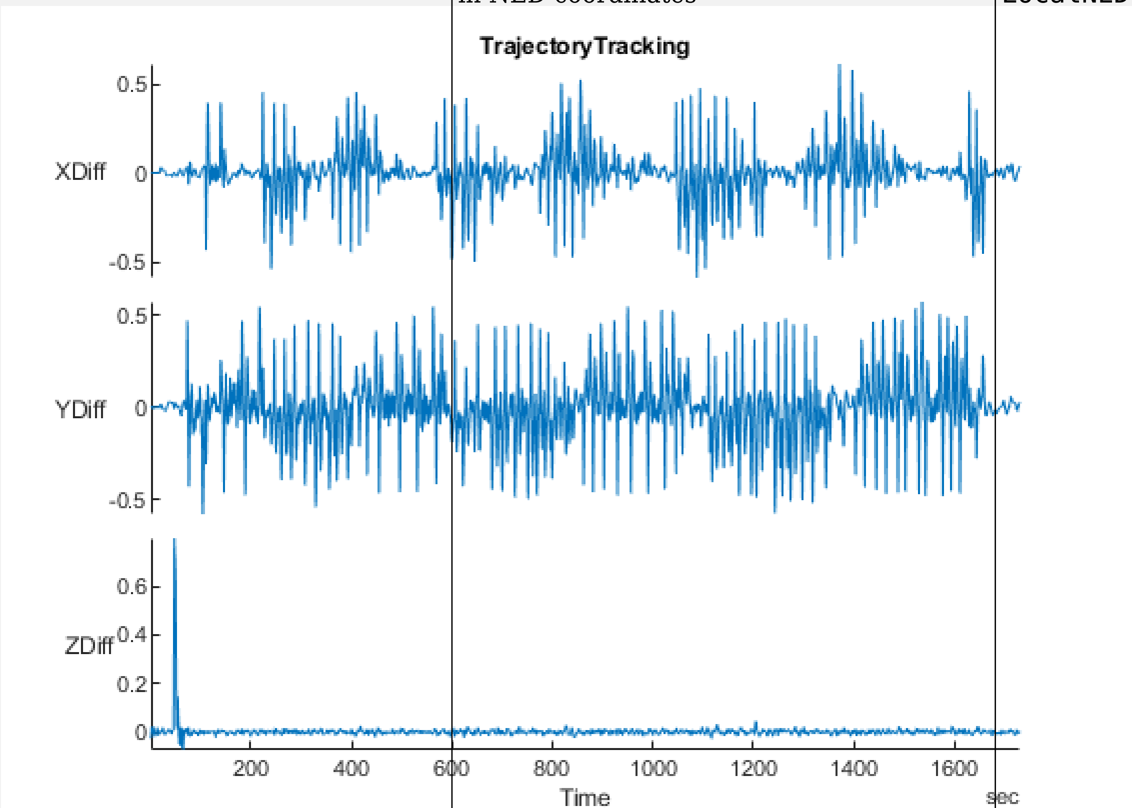
Plot	Description	Signals
`Height`	Stacked plots of barometer reading, GPS altitude reading, and fused height estimate	`Barometer#, GPS#, LocalNED`

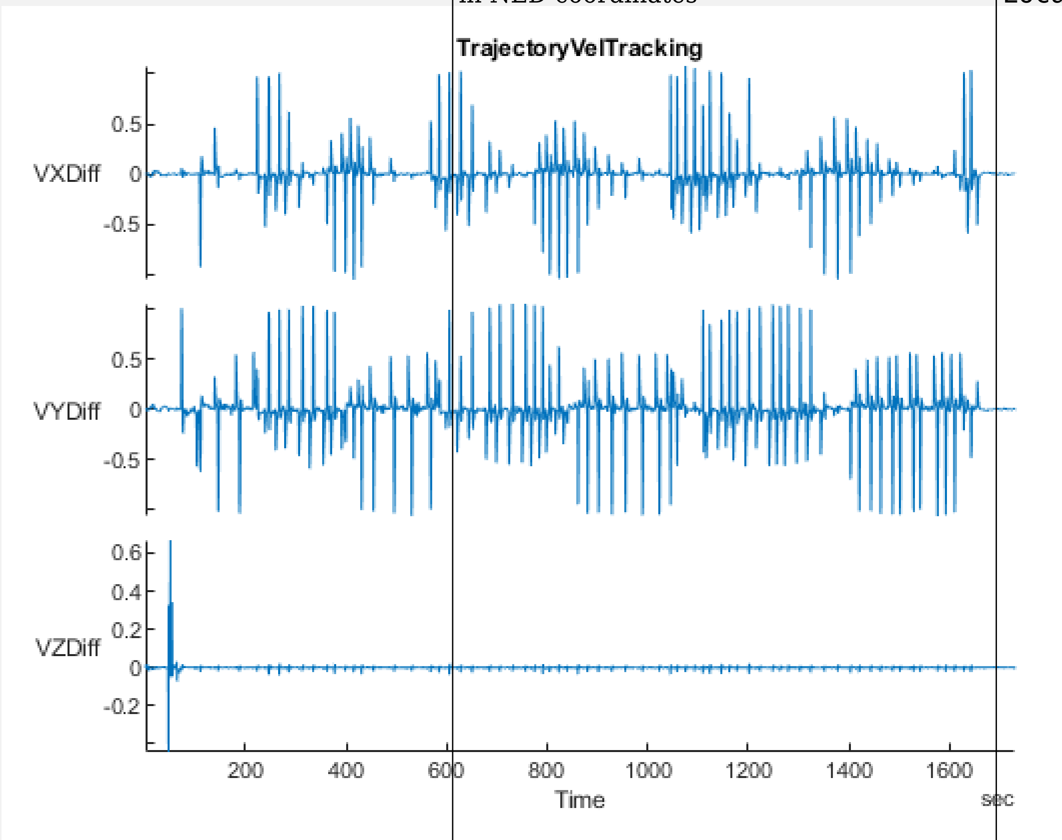


Plot	Description	Signals
`Speed`	Stacked plot of ground velocity and air speed	`GPS#, Airspeed#`



Plot	Description	Signals
`Trajectory`	Trajectory in local coordinates versus target set points	`LocalNED`, `LocalNEDTarget`
		

Plot	Description	Signals
`TrajectoryTracking`	Error between desired and actual position in NED coordinates	`LocalNED`, `LocalNEDTarget`
		

Plot	Description	Signals
`TrajectoryVelTracking`	Error between desired and actual velocity in NED coordinates	`LocalNEDVel`, `LocalNEDVelTarget`
		

See Also

`extract` | `flightLogSignalMapping` | `info` | `mapSignal` | `mavlinktlog` | `show`

Introduced in R2020b

createcmd

Create MAVLink command message

Syntax

`cmdMsg = createcmd(dialect,cmdSetting,cmdType)`

Description

`cmdMsg = createcmd(dialect,cmdSetting,cmdType)` returns a blank `COMMAND_INT` or `COMMAND_LONG` message structure based on the command setting and type. The command definitions are contained in the `mavlinkdialect` object, `dialect`.

Examples

Parse and Use MAVLink Dialect

This example shows how to parse a MAVLink XML file and create messages and commands from the definitions.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Parse and store the MAVLink dialect XML. Specify the XML path. The default `"common.xml"` dialect is provided. This XML file contains all the message and enum definitions.

```
dialect = mavlinkdialect("common.xml");
```

Create a MAVLink command from the `MAV_CMD` enum, which is an enum of MAVLink commands to send to the UAV. Specify the setting as `"int"` or `"long"`, and the type as an integer or string.

```
cmdMsg = createcmd(dialect,"long",22)
```

```
cmdMsg = struct with fields:
      MsgID: 76
    Payload: [1x1 struct]
```

Verify the command name using `num2enum`. Command 22 is a take-off command for the UAV. You can convert back to an ID using `enum2num`. Your dialect can contain many different enums with different names and IDs.

```
cmdName = num2enum(dialect,"MAV_CMD",22)
```

```
cmdName = 
"MAV_CMD_NAV_TAKEOFF"
```

```
cmdID = enum2num(dialect,"MAV_CMD",cmdName)
```

```
cmdID = 22
```

Use `enuminfo` to view the table of the `MAV_CMD` enum entries.

```
info = enuminfo(dialect,"MAV_CMD");
info.Entries{:}
```

```
ans=133×3 table
                    Name                         Value
    _____________________________________    _____    ____________________________________________

    "MAV_CMD_NAV_WAYPOINT"                     16      "Navigate to waypoint."
    "MAV_CMD_NAV_LOITER_UNLIM"                 17      "Loiter around this waypoint an unlimited a
    "MAV_CMD_NAV_LOITER_TURNS"                 18      "Loiter around this waypoint for X turns"
    "MAV_CMD_NAV_LOITER_TIME"                  19      "Loiter around this waypoint for X seconds"
    "MAV_CMD_NAV_RETURN_TO_LAUNCH"             20      "Return to launch location"
    "MAV_CMD_NAV_LAND"                         21      "Land at location"
    "MAV_CMD_NAV_TAKEOFF"                      22      "Takeoff from ground / hand"
    "MAV_CMD_NAV_LAND_LOCAL"                   23      "Land at local position (local frame only)"
    "MAV_CMD_NAV_TAKEOFF_LOCAL"                24      "Takeoff from local position (local frame o
    "MAV_CMD_NAV_FOLLOW"                       25      "Vehicle following, i.e. this waypoint repr
    "MAV_CMD_NAV_CONTINUE_AND_CHANGE_ALT"      30      "Continue on the current course and climb/d
    "MAV_CMD_NAV_LOITER_TO_ALT"                31      "Begin loiter at the specified Latitude and
    "MAV_CMD_DO_FOLLOW"                        32      "Being following a target"
    "MAV_CMD_DO_FOLLOW_REPOSITION"             33      "Reposition the MAV after a follow target c
    "MAV_CMD_DO_ORBIT"                         34      "Start orbiting on the circumference of a c
    "MAV_CMD_NAV_ROI"                          80      "Sets the region of interest (ROI) for a se
      ⋮
```

Query the dialect for a specific message ID. Create a blank MAVLink message using the message ID.

```
info = msginfo(dialect,"HEARTBEAT")
```

```
info=1×4 table
    MessageID    MessageName
    _________    ___________    __________________________________________________________________

        0        "HEARTBEAT"    "The heartbeat message shows that a system is present and respond
```

```
msg = createmsg(dialect,info.MessageID);
```

Input Arguments

dialect — MAVLink dialect
`mavlinkdialect` object

MAVLink dialect, specified as a `mavlinkdialect` object. The dialect specifies the message structure for the MAVLink protocol.

cmdSetting — Command setting
`"int"` | `"long"`

Command setting, specified as either `"int"` or `"long"` for either a `COMMAND_INT` or `COMMAND_LONG` command.

cmdType — Command type
positive integer | string

Command type, specified as either a positive integer or string. If specified as an integer, the command definition with the matching ID from the `MAV_CMD` enum in `dialect` is returned. If specified as a string, the command with the matching name is returned.

To get the command types for the `MAV_CMD` enum, use `enuminfo`:

```
enumTable = enuminfo(dialect,"MAV_CMD")
enumTable.Entries{1}
```

Output Arguments

`cmdMsg` — MAVLink command message
structure

MAVLink command message, returned as a structure with the fields:

- `MsgID`: Positive integer for message ID.
- `Payload`: Structure containing fields for the specific message definition.

See Also

Functions
`createmsg` | `enum2num` | `enuminfo` | `msginfo` | `num2enum`

Objects
`mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

Introduced in R2019a

createmsg

Create MAVLink message

Syntax

```
msg = createmsg(dialect,msgID)
```

Description

`msg = createmsg(dialect,msgID)` returns a blank message structure based on the message definitions specified in the `mavlinkdialect` object, `dialect`, and the input message ID, `msgID`.

Examples

Parse and Use MAVLink Dialect

This example shows how to parse a MAVLink XML file and create messages and commands from the definitions.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Parse and store the MAVLink dialect XML. Specify the XML path. The default `"common.xml"` dialect is provided. This XML file contains all the message and enum definitions.

```
dialect = mavlinkdialect("common.xml");
```

Create a MAVLink command from the `MAV_CMD` enum, which is an enum of MAVLink commands to send to the UAV. Specify the setting as `"int"` or `"long"`, and the type as an integer or string.

```
cmdMsg = createcmd(dialect,"long",22)
```

```
cmdMsg = struct with fields:
      MsgID: 76
    Payload: [1x1 struct]
```

Verify the command name using `num2enum`. Command 22 is a take-off command for the UAV. You can convert back to an ID using `enum2num`. Your dialect can contain many different enums with different names and IDs.

```
cmdName = num2enum(dialect,"MAV_CMD",22)
```

```
cmdName = 
"MAV_CMD_NAV_TAKEOFF"
```

```
cmdID = enum2num(dialect,"MAV_CMD",cmdName)
```

```
cmdID = 22
```

Use `enuminfo` to view the table of the `MAV_CMD` enum entries.

```
info = enuminfo(dialect,"MAV_CMD");
info.Entries{:}

ans=133×3 table
                   Name                        Value
    _____________________________________    _____    ___________________________________________

    "MAV_CMD_NAV_WAYPOINT"                     16      "Navigate to waypoint."
    "MAV_CMD_NAV_LOITER_UNLIM"                 17      "Loiter around this waypoint an unlimited a
    "MAV_CMD_NAV_LOITER_TURNS"                 18      "Loiter around this waypoint for X turns"
    "MAV_CMD_NAV_LOITER_TIME"                  19      "Loiter around this waypoint for X seconds'
    "MAV_CMD_NAV_RETURN_TO_LAUNCH"             20      "Return to launch location"
    "MAV_CMD_NAV_LAND"                         21      "Land at location"
    "MAV_CMD_NAV_TAKEOFF"                      22      "Takeoff from ground / hand"
    "MAV_CMD_NAV_LAND_LOCAL"                   23      "Land at local position (local frame only)'
    "MAV_CMD_NAV_TAKEOFF_LOCAL"                24      "Takeoff from local position (local frame c
    "MAV_CMD_NAV_FOLLOW"                       25      "Vehicle following, i.e. this waypoint repr
    "MAV_CMD_NAV_CONTINUE_AND_CHANGE_ALT"      30      "Continue on the current course and climb/c
    "MAV_CMD_NAV_LOITER_TO_ALT"                31      "Begin loiter at the specified Latitude and
    "MAV_CMD_DO_FOLLOW"                        32      "Being following a target"
    "MAV_CMD_DO_FOLLOW_REPOSITION"             33      "Reposition the MAV after a follow target c
    "MAV_CMD_DO_ORBIT"                         34      "Start orbiting on the circumference of a c
    "MAV_CMD_NAV_ROI"                          80      "Sets the region of interest (ROI) for a se
      ⋮
```

Query the dialect for a specific message ID. Create a blank MAVLink message using the message ID.

```
info = msginfo(dialect,"HEARTBEAT")

info=1×4 table
    MessageID    MessageName
    _________    ___________    ______________________________________________________________________

        0        "HEARTBEAT"    "The heartbeat message shows that a system is present and respond

msg = createmsg(dialect,info.MessageID);
```

Input Arguments

`dialect` — MAVLink dialect

`mavlinkdialect` object

MAVLink dialect, specified as a `mavlinkdialect` object. The dialect specifies the message structure for the MAVLink protocol.

`msgID` — Message ID

positive integer | string

Message ID, specified as either a positive integer or string. If specified as an integer, the message definition with the matching ID from the `dialect` is returned. If specified as a string, the message with the matching name is returned.

Output Arguments

`msg` — MAVLink message
structure

MAVLink message, returned as a structure with the fields:

- `MsgID`: Positive integer for message ID.
- `Payload`: Structure containing fields for the specific message definition.

See Also

Functions
`createcmd` | `enum2num` | `enuminfo` | `msginfo` | `num2enum`

Objects
`mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

Topics
"Tune UAV Parameters Using MAVLink Parameter Protocol"

Introduced in R2019a

enum2num

Enum value for given entry

Syntax

`enumValue = enum2num(dialect,enum,entry)`

Description

`enumValue = enum2num(dialect,enum,entry)` returns the value for the given entry in the enum.

Examples

Parse and Use MAVLink Dialect

This example shows how to parse a MAVLink XML file and create messages and commands from the definitions.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Parse and store the MAVLink dialect XML. Specify the XML path. The default `"common.xml"` dialect is provided. This XML file contains all the message and enum definitions.

```
dialect = mavlinkdialect("common.xml");
```

Create a MAVLink command from the `MAV_CMD` enum, which is an enum of MAVLink commands to send to the UAV. Specify the setting as `"int"` or `"long"`, and the type as an integer or string.

```
cmdMsg = createcmd(dialect,"long",22)
```

```
cmdMsg = struct with fields:
      MsgID: 76
    Payload: [1x1 struct]
```

Verify the command name using `num2enum`. Command 22 is a take-off command for the UAV. You can convert back to an ID using `enum2num`. Your dialect can contain many different enums with different names and IDs.

```
cmdName = num2enum(dialect,"MAV_CMD",22)
```

```
cmdName = 
"MAV_CMD_NAV_TAKEOFF"
```

```
cmdID = enum2num(dialect,"MAV_CMD",cmdName)
```

```
cmdID = 22
```

Use `enuminfo` to view the table of the `MAV_CMD` enum entries.

```
info = enuminfo(dialect,"MAV_CMD");
info.Entries{:}
```

```
ans=133×3 table
                     Name                        Value
    _____________________________________    _____    __________________________________________

    "MAV_CMD_NAV_WAYPOINT"                      16     "Navigate to waypoint."
    "MAV_CMD_NAV_LOITER_UNLIM"                  17     "Loiter around this waypoint an unlimited a
    "MAV_CMD_NAV_LOITER_TURNS"                  18     "Loiter around this waypoint for X turns"
    "MAV_CMD_NAV_LOITER_TIME"                   19     "Loiter around this waypoint for X seconds'
    "MAV_CMD_NAV_RETURN_TO_LAUNCH"              20     "Return to launch location"
    "MAV_CMD_NAV_LAND"                          21     "Land at location"
    "MAV_CMD_NAV_TAKEOFF"                       22     "Takeoff from ground / hand"
    "MAV_CMD_NAV_LAND_LOCAL"                    23     "Land at local position (local frame only)'
    "MAV_CMD_NAV_TAKEOFF_LOCAL"                 24     "Takeoff from local position (local frame c
    "MAV_CMD_NAV_FOLLOW"                        25     "Vehicle following, i.e. this waypoint repr
    "MAV_CMD_NAV_CONTINUE_AND_CHANGE_ALT"       30     "Continue on the current course and climb/c
    "MAV_CMD_NAV_LOITER_TO_ALT"                 31     "Begin loiter at the specified Latitude anc
    "MAV_CMD_DO_FOLLOW"                         32     "Being following a target"
    "MAV_CMD_DO_FOLLOW_REPOSITION"              33     "Reposition the MAV after a follow target c
    "MAV_CMD_DO_ORBIT"                          34     "Start orbiting on the circumference of a c
    "MAV_CMD_NAV_ROI"                           80     "Sets the region of interest (ROI) for a se
      ⋮
```

Query the dialect for a specific message ID. Create a blank MAVLink message using the message ID.

```
info = msginfo(dialect,"HEARTBEAT")
```

```
info=1×4 table
    MessageID    MessageName
    _________    ___________    __________________________________________________________________

        0        "HEARTBEAT"    "The heartbeat message shows that a system is present and responc
```

```
msg = createmsg(dialect,info.MessageID);
```

Input Arguments

dialect — MAVLink dialect
`mavlinkdialect` object

MAVLink dialect, specified as a `mavlinkdialect` object, which contains a parsed dialect XML for MAVLink message definitions.

enum — MAVLink enum name
string

MAVLink enum name, specified as a string.

entry — MAVLink enum entry name
string

MAVLink enum entry name, specified as a string.

Output Arguments

`enumValue` — Enum value
integer

Enum value, returned as an integer.

See Also

`enuminfo` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub` | `msginfo` | `num2enum`

External Websites
MAVLink Developer Guide

Introduced in R2019a

enuminfo

Enum definition for enum ID

Syntax

`enumTable = enuminfo(dialect,enumID)`

Description

`enumTable = enuminfo(dialect,enumID)` returns a table detailing the enumeration definition based on the given `enumID`.

Examples

Parse and Use MAVLink Dialect

This example shows how to parse a MAVLink XML file and create messages and commands from the definitions.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Parse and store the MAVLink dialect XML. Specify the XML path. The default `"common.xml"` dialect is provided. This XML file contains all the message and enum definitions.

```
dialect = mavlinkdialect("common.xml");
```

Create a MAVLink command from the `MAV_CMD` enum, which is an enum of MAVLink commands to send to the UAV. Specify the setting as `"int"` or `"long"`, and the type as an integer or string.

```
cmdMsg = createcmd(dialect,"long",22)
```

```
cmdMsg = struct with fields:
      MsgID: 76
    Payload: [1x1 struct]
```

Verify the command name using `num2enum`. Command 22 is a take-off command for the UAV. You can convert back to an ID using `enum2num`. Your dialect can contain many different enums with different names and IDs.

```
cmdName = num2enum(dialect,"MAV_CMD",22)
```

```
cmdName = 
"MAV_CMD_NAV_TAKEOFF"
```

```
cmdID = enum2num(dialect,"MAV_CMD",cmdName)
```

```
cmdID = 22
```

Use `enuminfo` to view the table of the `MAV_CMD` enum entries.

```
info = enuminfo(dialect,"MAV_CMD");
info.Entries{:}
```

```
ans=133×3 table
                 Name                        Value
    _____________________________________    _____    __________________________________________

    "MAV_CMD_NAV_WAYPOINT"                    16      "Navigate to waypoint."
    "MAV_CMD_NAV_LOITER_UNLIM"                17      "Loiter around this waypoint an unlimited a
    "MAV_CMD_NAV_LOITER_TURNS"                18      "Loiter around this waypoint for X turns"
    "MAV_CMD_NAV_LOITER_TIME"                 19      "Loiter around this waypoint for X seconds'
    "MAV_CMD_NAV_RETURN_TO_LAUNCH"            20      "Return to launch location"
    "MAV_CMD_NAV_LAND"                        21      "Land at location"
    "MAV_CMD_NAV_TAKEOFF"                     22      "Takeoff from ground / hand"
    "MAV_CMD_NAV_LAND_LOCAL"                  23      "Land at local position (local frame only)'
    "MAV_CMD_NAV_TAKEOFF_LOCAL"               24      "Takeoff from local position (local frame o
    "MAV_CMD_NAV_FOLLOW"                      25      "Vehicle following, i.e. this waypoint repr
    "MAV_CMD_NAV_CONTINUE_AND_CHANGE_ALT"     30      "Continue on the current course and climb/c
    "MAV_CMD_NAV_LOITER_TO_ALT"               31      "Begin loiter at the specified Latitude and
    "MAV_CMD_DO_FOLLOW"                       32      "Being following a target"
    "MAV_CMD_DO_FOLLOW_REPOSITION"            33      "Reposition the MAV after a follow target c
    "MAV_CMD_DO_ORBIT"                        34      "Start orbiting on the circumference of a c
    "MAV_CMD_NAV_ROI"                         80      "Sets the region of interest (ROI) for a se
      ⋮
```

Query the dialect for a specific message ID. Create a blank MAVLink message using the message ID.

```
info = msginfo(dialect,"HEARTBEAT")
```

```
info=1×4 table
    MessageID    MessageName
    _________    ___________    __________________________________________________________________

        0        "HEARTBEAT"    "The heartbeat message shows that a system is present and respond
```

```
msg = createmsg(dialect,info.MessageID);
```

Input Arguments

dialect — MAVLink dialect

`mavlinkdialect` object

MAVLink dialect, specified as a `mavlinkdialect` object, which contains a parsed dialect XML for MAVLink message definitions.

enumID — MAVLink enum ID

string

MAVLink enum ID, specified as a string.

Output Arguments

enumTable — Enum definition

table

Enum definition, returned as a table containing the message ID, name, description, and entries. The entries are given as another table with their own information listed. All this information is defined by dialect XML file.

See Also
`mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub` | `msginfo`

External Websites
MAVLink Developer Guide

Introduced in R2019a

msginfo

Message definition for message ID

Syntax

```
msgTable = msginfo(dialect,messageID)
```

Description

`msgTable = msginfo(dialect,messageID)` returns a table detailing the message definition based on the given `messageID`.

Examples

Parse and Use MAVLink Dialect

This example shows how to parse a MAVLink XML file and create messages and commands from the definitions.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Parse and store the MAVLink dialect XML. Specify the XML path. The default `"common.xml"` dialect is provided. This XML file contains all the message and enum definitions.

```
dialect = mavlinkdialect("common.xml");
```

Create a MAVLink command from the `MAV_CMD` enum, which is an enum of MAVLink commands to send to the UAV. Specify the setting as `"int"` or `"long"`, and the type as an integer or string.

```
cmdMsg = createcmd(dialect,"long",22)
```

```
cmdMsg = struct with fields:
      MsgID: 76
    Payload: [1x1 struct]
```

Verify the command name using `num2enum`. Command 22 is a take-off command for the UAV. You can convert back to an ID using `enum2num`. Your dialect can contain many different enums with different names and IDs.

```
cmdName = num2enum(dialect,"MAV_CMD",22)
```

```
cmdName = 
"MAV_CMD_NAV_TAKEOFF"
```

```
cmdID = enum2num(dialect,"MAV_CMD",cmdName)
```

```
cmdID = 22
```

Use `enuminfo` to view the table of the `MAV_CMD` enum entries.

```
info = enuminfo(dialect,"MAV_CMD");
info.Entries{:}
```

```
ans=133×3 table
                  Name                      Value
    ____________________________________    _____    __________________________________________

    "MAV_CMD_NAV_WAYPOINT"                   16      "Navigate to waypoint."
    "MAV_CMD_NAV_LOITER_UNLIM"               17      "Loiter around this waypoint an unlimited a
    "MAV_CMD_NAV_LOITER_TURNS"               18      "Loiter around this waypoint for X turns"
    "MAV_CMD_NAV_LOITER_TIME"                19      "Loiter around this waypoint for X seconds'
    "MAV_CMD_NAV_RETURN_TO_LAUNCH"           20      "Return to launch location"
    "MAV_CMD_NAV_LAND"                       21      "Land at location"
    "MAV_CMD_NAV_TAKEOFF"                    22      "Takeoff from ground / hand"
    "MAV_CMD_NAV_LAND_LOCAL"                 23      "Land at local position (local frame only)'
    "MAV_CMD_NAV_TAKEOFF_LOCAL"              24      "Takeoff from local position (local frame c
    "MAV_CMD_NAV_FOLLOW"                     25      "Vehicle following, i.e. this waypoint repr
    "MAV_CMD_NAV_CONTINUE_AND_CHANGE_ALT"    30      "Continue on the current course and climb/c
    "MAV_CMD_NAV_LOITER_TO_ALT"              31      "Begin loiter at the specified Latitude and
    "MAV_CMD_DO_FOLLOW"                      32      "Being following a target"
    "MAV_CMD_DO_FOLLOW_REPOSITION"           33      "Reposition the MAV after a follow target c
    "MAV_CMD_DO_ORBIT"                       34      "Start orbiting on the circumference of a c
    "MAV_CMD_NAV_ROI"                        80      "Sets the region of interest (ROI) for a se
      ⋮
```

Query the dialect for a specific message ID. Create a blank MAVLink message using the message ID.

```
info = msginfo(dialect,"HEARTBEAT")
```

```
info=1×4 table
    MessageID    MessageName
    _________    ___________    ________________________________________________________________

        0        "HEARTBEAT"    "The heartbeat message shows that a system is present and respond
```

```
msg = createmsg(dialect,info.MessageID);
```

Input Arguments

dialect — MAVLink dialect

`mavlinkdialect` object

MAVLink dialect, specified as a `mavlinkdialect` object, which contains a parsed dialect XML for MAVLink message definitions.

messageID — MAVLink message ID or name

integer | string

MAVLink message ID or name, specified as an integer or string.

Output Arguments

msgTable — Message definition

table

Message definition, returned as a table containing the message ID, name, description, and fields. The fields are given as another table with their own information. All this information is defined by dialect XML file.

See Also

`createmsg` | `enuminfo` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

External Websites

MAVLink Developer Guide

Introduced in R2019a

connect

Connect to MAVLink clients through UDP port

Syntax

```
connectionName = connect(mavlink,"UDP")
connectionName = connect( ___ ,Name,Value)
```

Description

`connectionName = connect(mavlink,"UDP")` connects to the `mavlinkio` client through a UDP port.

`connectionName = connect( ___ ,Name,Value)` additionally specifies arguments using name-value pairs.

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`.

Examples

Store MAVLink Client Information

Connect to a MAVLink client.

```
mavlink = mavlinkio("common.xml");
connect(mavlink,"UDP");
```

Create the object for storing the client information. Specify the system and component ID.

```
client = mavlinkclient(mavlink,1,1)
```

```
client = 
  mavlinkclient with properties:

         SystemID: 1
      ComponentID: 1
    ComponentType: "Unknown"
    AutopilotType: "Unknown"
```

Disconnect from client.

```
disconnect(mavlink)
```

Work with MAVLink Connection

This example shows how to connect to MAVLink clients, inspect the list of topics, connections, and clients, and send messages through UDP ports using the MAVLink communication protocol.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Connect to a MAVLink client using the `"common.xml"` dialect. This local client communicates with any other clients through a UDP port.

```
dialect = mavlinkdialect("common.xml");
mavlink = mavlinkio(dialect);
connect(mavlink,"UDP")
```

```
ans = 
"Connection1"
```

You can list all the active clients, connections, and topics for the MAVLink connection. Currently, there is only one client connection and no topics have received messages.

```
listClients(mavlink)
```

```
ans=1×4 table
    SystemID    ComponentID    ComponentType          AutopilotType        
    ________    ___________    _____________    _________________________

      255            1         "MAV_TYPE_GCS"    "MAV_AUTOPILOT_INVALID"
```

```
listConnections(mavlink)
```

```
ans=1×2 table
    ConnectionName      ConnectionInfo    
    ______________    ___________________

    "Connection1"     "UDP@0.0.0.0:56764"
```

```
listTopics(mavlink)
```

```
ans =

  0x5 empty table
```

Create a subscriber for receiving messages on the client. This subscriber listens for the `"HEARTBEAT"` message topic with ID equal to `0`.

```
sub = mavlinksub(mavlink,0);
```

Create a `"HEARTBEAT"` message using the `mavlinkdialect` object. Specify payload information and send the message over the MAVLink client.

```
msg = createmsg(dialect,"HEARTBEAT");
msg.Payload.type(:) = enum2num(dialect,'MAV_TYPE','MAV_TYPE_QUADROTOR');
sendmsg(mavlink,msg)
```

Disconnect from the client.

```
disconnect(mavlink)
```

Input Arguments

`mavlink` — MAVLink client connection
`mavlinkio` object

MAVLink client connection, specified as a `mavlinkio` 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: `'LocalPort',12345`

`ConnectionName` — Identifying connection name
`"Connection#"` (default) | string scalar

Identifying connection name, specified as the comma-separated pair consisting of `'ConnectionName'` and a string scalar. The default connection name is `"Connection#"`.

Data Types: `string`

`LocalPort` — Local port for UDP connection
`0` (default) | numeric scalar

Local port for UDP connection, specified as a numeric scalar. A value of `0` binds to a random open port.

Data Types: `double`

Output Arguments

`connectionName` — Identifying connection name
`"Connection#"` (default) | string scalar

Identifying connection name, specified as a string scalar. The default connection name is `"Connection#"`, where # is an integer starting at `1` and increases with each new connection created.

Data Types: `string`

See Also
`disconnect` | `mavlinkclient` | `mavlinkdialect` | `mavlinksub`

Topics
"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites
MAVLink Developer Guide

Introduced in R2019a

disconnect

Disconnect from MAVLink clients

Syntax

```
disconnect(mavlink)
disconnect(mavlink,connection)
```

Description

`disconnect(mavlink)` disconnects from all MAVLink clients connected through the `mavlinkio` client.

`disconnect(mavlink,connection)` disconnects from the specific client connection name.

Examples

Store MAVLink Client Information

Connect to a MAVLink client.

```
mavlink = mavlinkio("common.xml");
connect(mavlink,"UDP");
```

Create the object for storing the client information. Specify the system and component ID.

```
client = mavlinkclient(mavlink,1,1)
```

```
client = 
  mavlinkclient with properties:

         SystemID: 1
      ComponentID: 1
    ComponentType: "Unknown"
    AutopilotType: "Unknown"
```

Disconnect from client.

```
disconnect(mavlink)
```

Work with MAVLink Connection

This example shows how to connect to MAVLink clients, inspect the list of topics, connections, and clients, and send messages through UDP ports using the MAVLink communication protocol.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Connect to a MAVLink client using the `"common.xml"` dialect. This local client communicates with any other clients through a UDP port.

```
dialect = mavlinkdialect("common.xml");
mavlink = mavlinkio(dialect);
connect(mavlink,"UDP")
```

```
ans =
"Connection1"
```

You can list all the active clients, connections, and topics for the MAVLink connection. Currently, there is only one client connection and no topics have received messages.

```
listClients(mavlink)
```

```
ans=1×4 table
    SystemID    ComponentID    ComponentType          AutopilotType
    ________    ___________    ______________    _________________________

      255            1         "MAV_TYPE_GCS"    "MAV_AUTOPILOT_INVALID"
```

```
listConnections(mavlink)
```

```
ans=1×2 table
    ConnectionName       ConnectionInfo
    ______________    ___________________

    "Connection1"     "UDP@0.0.0.0:56764"
```

```
listTopics(mavlink)
```

```
ans =

  0x5 empty table
```

Create a subscriber for receiving messages on the client. This subscriber listens for the `"HEARTBEAT"` message topic with ID equal to `0`.

```
sub = mavlinksub(mavlink,0);
```

Create a `"HEARTBEAT"` message using the `mavlinkdialect` object. Specify payload information and send the message over the MAVLink client.

```
msg = createmsg(dialect,"HEARTBEAT");
msg.Payload.type(:) = enum2num(dialect,'MAV_TYPE','MAV_TYPE_QUADROTOR');
sendmsg(mavlink,msg)
```

Disconnect from the client.

```
disconnect(mavlink)
```

Input Arguments

`mavlink` — MAVLink client connection
`mavlinkio` object

MAVLink client connection, specified as a `mavlinkio` object.

`connection` — Connection name
string scalar

Connection name, specified as a string scalar.

See Also

`connect` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

Topics
"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites
MAVLink Developer Guide

Introduced in R2019a

listClients

List all connected MAVLink clients

Syntax

`clientTable = listConnections(mavlink)`

Description

`clientTable = listConnections(mavlink)` lists all active connections for the `mavlinkio` client connection.

Examples

Work with MAVLink Connection

This example shows how to connect to MAVLink clients, inspect the list of topics, connections, and clients, and send messages through UDP ports using the MAVLink communication protocol.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Connect to a MAVLink client using the `"common.xml"` dialect. This local client communicates with any other clients through a UDP port.

```
dialect = mavlinkdialect("common.xml");
mavlink = mavlinkio(dialect);
connect(mavlink,"UDP")
```

```
ans =
"Connection1"
```

You can list all the active clients, connections, and topics for the MAVLink connection. Currently, there is only one client connection and no topics have received messages.

```
listClients(mavlink)
```

```
ans=1×4 table
    SystemID    ComponentID    ComponentType          AutopilotType
    ________    ___________    _____________    _________________________

      255            1         "MAV_TYPE_GCS"    "MAV_AUTOPILOT_INVALID"
```

```
listConnections(mavlink)
```

```
ans=1×2 table
    ConnectionName      ConnectionInfo
    ______________    ____________________

    "Connection1"     "UDP@0.0.0.0:56764"
```

```
listTopics(mavlink)
```

```
ans =

  0x5 empty table
```

Create a subscriber for receiving messages on the client. This subscriber listens for the "HEARTBEAT" message topic with ID equal to 0.

```
sub = mavlinksub(mavlink,0);
```

Create a "HEARTBEAT" message using the mavlinkdialect object. Specify payload information and send the message over the MAVLink client.

```
msg = createmsg(dialect,"HEARTBEAT");
msg.Payload.type(:) = enum2num(dialect,'MAV_TYPE','MAV_TYPE_QUADROTOR');
sendmsg(mavlink,msg)
```

Disconnect from the client.

```
disconnect(mavlink)
```

Input Arguments

mavlink — MAVLink client connection
mavlinkio object

MAVLink client connection, specified as a mavlinkio object.

Output Arguments

clientTable — Active client info
table

Active connection info, returned as a table with SystemID, ComponentID, ConnectionType, and AutopilotType fields for each active client.

See Also

connect | listConnections | listTopics | mavlinkclient | mavlinkdialect | mavlinkio | mavlinksub

External Websites
MAVLink Developer Guide

Introduced in R2019a

listConnections

List all active MAVLink connections

Syntax

`connectionTable = listConnections(mavlink)`

Description

`connectionTable = listConnections(mavlink)` lists all active connections for the `mavlinkio` client connection.

Examples

Work with MAVLink Connection

This example shows how to connect to MAVLink clients, inspect the list of topics, connections, and clients, and send messages through UDP ports using the MAVLink communication protocol.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Connect to a MAVLink client using the `"common.xml"` dialect. This local client communicates with any other clients through a UDP port.

```
dialect = mavlinkdialect("common.xml");
mavlink = mavlinkio(dialect);
connect(mavlink,"UDP")
```

```
ans =
"Connection1"
```

You can list all the active clients, connections, and topics for the MAVLink connection. Currently, there is only one client connection and no topics have received messages.

```
listClients(mavlink)
```

```
ans=1×4 table
    SystemID    ComponentID    ComponentType         AutopilotType
    ________    ___________    _____________    _______________________

      255            1         "MAV_TYPE_GCS"    "MAV_AUTOPILOT_INVALID"
```

```
listConnections(mavlink)
```

```
ans=1×2 table
    ConnectionName       ConnectionInfo
    ______________    ___________________

    "Connection1"     "UDP@0.0.0.0:56764"
```

```
listTopics(mavlink)
```

```
ans =

  0x5 empty table
```

Create a subscriber for receiving messages on the client. This subscriber listens for the "HEARTBEAT" message topic with ID equal to 0.

```
sub = mavlinksub(mavlink,0);
```

Create a "HEARTBEAT" message using the mavlinkdialect object. Specify payload information and send the message over the MAVLink client.

```
msg = createmsg(dialect,"HEARTBEAT");
msg.Payload.type(:) = enum2num(dialect,'MAV_TYPE','MAV_TYPE_QUADROTOR');
sendmsg(mavlink,msg)
```

Disconnect from the client.

```
disconnect(mavlink)
```

Input Arguments

mavlink — MAVLink client connection
mavlinkio object

MAVLink client connection, specified as a mavlinkio object.

Output Arguments

connectionTable — Active connection info
table

Active connection info, returned as a table with ConnectionName and ConnectionInfo fields for each active connection.

See Also

connect | listClients | listTopics | mavlinkclient | mavlinkdialect | mavlinkio | mavlinksub

External Websites
MAVLink Developer Guide

Introduced in R2019a

listTopics

List all topics received by MAVLink client

Syntax

```
topicTable = listTopics(mavlink)
```

Description

`topicTable = listTopics(mavlink)` returns a table of topics received on the connected `mavlinkio` client with information on the message frequency.

Examples

Work with MAVLink Connection

This example shows how to connect to MAVLink clients, inspect the list of topics, connections, and clients, and send messages through UDP ports using the MAVLink communication protocol.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Connect to a MAVLink client using the `"common.xml"` dialect. This local client communicates with any other clients through a UDP port.

```
dialect = mavlinkdialect("common.xml");
mavlink = mavlinkio(dialect);
connect(mavlink,"UDP")
```

```
ans =
"Connection1"
```

You can list all the active clients, connections, and topics for the MAVLink connection. Currently, there is only one client connection and no topics have received messages.

```
listClients(mavlink)
```

```
ans=1×4 table
    SystemID    ComponentID    ComponentType          AutopilotType
    ________    ___________    _____________    _______________________

      255            1         "MAV_TYPE_GCS"    "MAV_AUTOPILOT_INVALID"
```

```
listConnections(mavlink)
```

```
ans=1×2 table
    ConnectionName      ConnectionInfo
    ______________    __________________

    "Connection1"     "UDP@0.0.0.0:56764"
```

```
listTopics(mavlink)
```

```
ans =

  0x5 empty table
```

Create a subscriber for receiving messages on the client. This subscriber listens for the `"HEARTBEAT"` message topic with ID equal to `0`.

```
sub = mavlinksub(mavlink,0);
```

Create a `"HEARTBEAT"` message using the `mavlinkdialect` object. Specify payload information and send the message over the MAVLink client.

```
msg = createmsg(dialect,"HEARTBEAT");
msg.Payload.type(:) = enum2num(dialect,'MAV_TYPE','MAV_TYPE_QUADROTOR');
sendmsg(mavlink,msg)
```

Disconnect from the client.

```
disconnect(mavlink)
```

Input Arguments

`mavlink` — MAVLink client connection
`mavlinkio` object

MAVLink client connection, specified as a `mavlinkio` object.

Output Arguments

`topicTable` — Topic info
table

Topic info, returned as a table with `SystemID`, `ComponentID`, `MessageID`, `MessageName`, and `MessageFrequency` fields for each topic receiving messages on the client.

See Also

`connect` | `listClients` | `listConnections` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

External Websites
MAVLink Developer Guide

Introduced in R2019a

sendmsg

Send MAVLink message

Syntax

```
sendmsg(mavlink,msg)
sendmsg(mavlink,msg,client)
```

Description

`sendmsg(mavlink,msg)` sends a message to all connected MAVLink clients in the `mavlinkio` object.

`sendmsg(mavlink,msg,client)` sends a message to the MAVLink client specified as a `mavlinkclient` object. If the client is not connected, no message is sent.

Examples

Work with MAVLink Connection

This example shows how to connect to MAVLink clients, inspect the list of topics, connections, and clients, and send messages through UDP ports using the MAVLink communication protocol.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Connect to a MAVLink client using the `"common.xml"` dialect. This local client communicates with any other clients through a UDP port.

```
dialect = mavlinkdialect("common.xml");
mavlink = mavlinkio(dialect);
connect(mavlink,"UDP")
```

```
ans = 
"Connection1"
```

You can list all the active clients, connections, and topics for the MAVLink connection. Currently, there is only one client connection and no topics have received messages.

```
listClients(mavlink)
```

```
ans=1×4 table
    SystemID    ComponentID    ComponentType          AutopilotType       
    ________    ___________    _______________    _________________________

      255            1         "MAV_TYPE_GCS"     "MAV_AUTOPILOT_INVALID"
```

```
listConnections(mavlink)
```

```
ans=1×2 table
    ConnectionName      ConnectionInfo
```

```
    _______________     ____________________

    "Connection1"     "UDP@0.0.0.0:56764"
```

```
listTopics(mavlink)
```

```
ans = 

  0x5 empty table
```

Create a subscriber for receiving messages on the client. This subscriber listens for the `"HEARTBEAT"` message topic with ID equal to `0`.

```
sub = mavlinksub(mavlink,0);
```

Create a `"HEARTBEAT"` message using the `mavlinkdialect` object. Specify payload information and send the message over the MAVLink client.

```
msg = createmsg(dialect,"HEARTBEAT");
msg.Payload.type(:) = enum2num(dialect,'MAV_TYPE','MAV_TYPE_QUADROTOR');
sendmsg(mavlink,msg)
```

Disconnect from the client.

```
disconnect(mavlink)
```

Input Arguments

`mavlink` — MAVLink client connection

`mavlinkio` object

MAVLink client connection, specified as a `mavlinkio` object.

`msg` — MAVLink message

structure

MAVLink message, specified as a structure with the fields:

- `MsgID`: Positive integer for message ID.
- `Payload`: Structure containing fields for the specific message definition.

To create a blank message, use the `createmsg` with a `mavlinkdialect` object.

`client` — MAVLink client information

`mavlinkclient` object

MAVLink client information, specified as a `mavlinkclient` object.

See Also

`connect` | `listClients` | `listConnections` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

Topics

"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites
MAVLink Developer Guide

Introduced in R2019a

serializemsg

Serialize MAVLink message to binary buffer

Syntax

```
buffer = serializemsg(mavlink,msg)
```

Description

`buffer = serializemsg(mavlink,msg)` serializes a MAVLink message structure to a binary buffer for transmission. This buffer is for manual transmission using your own communication channel. To send over UDP, see `sendmsg`.

Input Arguments

`mavlink` — MAVLink client connection
`mavlinkio` object

MAVLink client connection, specified as a `mavlinkio` object.

`msg` — MAVLink message
structure

MAVLink message, specified as a structure with the fields:

- `MsgID`: Positive integer for message ID.
- `Payload`: Structure containing fields for the specific message definition.

To create a blank message, use the `createmsg` with a `mavlinkdialect` object.

Output Arguments

`buffer` — Serialized message
vector of `uint8` integers

Serialized messaged, returned as vector of `uint8` integers.

Data Types: `uint8`

See Also

`connect` | `listClients` | `listConnections` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub` | `sendmsg`

External Websites
MAVLink Developer Guide

Introduced in R2019a

sendudpmsg

Send MAVLink message to UDP port

Syntax

`sendudpmsg(mavlink,msg,remoteHost,remotePort)`

Description

`sendudpmsg(mavlink,msg,remoteHost,remotePort)` sends the message, `msg`, to the remote UDP port specified by the host name, `remoteHost`, and port number, `remotePort`.

Input Arguments

`mavlink` — MAVLink client connection
`mavlinkio` object

MAVLink client connection, specified as a `mavlinkio` object.

`msg` — MAVLink message
structure

MAVLink message, specified as a structure with the fields:

- `MsgID`: Positive integer for message ID.
- `Payload`: Structure containing fields for the specific message definition.

To create a blank message, use the `createmsg` with a `mavlinkdialect` object.

`remoteHost` — Remote host IP address
string

Remote host IP address, specified as a string.

Example: `"192.168.1.10"`

`remotePort` — Remote host port
five-digit numeric scalar

Remote host IP address, specified as a five-digit numeric scalar.

Example: `14550`

See Also

`connect` | `listClients` | `listConnections` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub` | `sendmsg`

Topics
"Tune UAV Parameters Using MAVLink Parameter Protocol"

External Websites
MAVLink Developer Guide

Introduced in R2019a

latestmsgs

Received messages from MAVLink subscriber

Syntax

```
msgs = latestmsgs(sub,count)
```

Description

`msgs = latestmsgs(sub,count)` returns the latest received messages for the `mavlinksub` object. The messages are in a structure array in reverse-chronological order with the most recent being first. If `count` is larger than the number of stored messages, the structure array contains only the number of stored messages.

Examples

Subscribe to MAVLink Topic

Connect to a MAVLink client.

```
mavlink = mavlinkio("common.xml")
```

```
mavlink = 
  mavlinkio with properties:

        Dialect: [1x1 mavlinkdialect]
    LocalClient: [1x1 struct]
```

```
connect(mavlink,"UDP")
```

```
ans = 
"Connection1"
```

Get the client information.

```
client = mavlinkclient(mavlink,1,1);
```

Subscribe to the `"HEARTBEAT"` topic.

```
heartbeat = mavlinksub(mavlink,client,'HEARTBEAT');
```

Get the latest message. You must wait for a message to be received. Currently, no heartbeat message has been received on the `mavlink` object.

```
latestmsgs(heartbeat,1)
```

```
ans = 

  1x0 empty struct array with fields:

    MsgID
```

```
SystemID
ComponentID
Payload
Seq
```

Disconnect from client.

```
disconnect(mavlink)
```

Input Arguments

`sub` — MAVLink subscriber
`mavlinksub` object

MAVLink subscriber, specified as a `mavlinksub` object.

`count` — Number of messages
positive integer

Number of messages, specified as a positive integer. If `count` is larger than the number of stored messages, the structure array is padded with empty structs.

Output Arguments

`msgs` — Recently received messages
structure array

Recently received messages, returned as a structure array. Each structure has the fields:

- `MsgID`
- `SystemID`
- `ComponentID`
- `Payload`

The `Payload` is a structure defined by the message definition for the MAVLink dialect.

If `count` is larger than the number of stored messages, the structure array contains only the number of stored messages..

See Also
`mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

Introduced in R2019a

num2enum

Enum entry for given value

Syntax

`entry = num2enum(dialect,enum,enumValue)`

Description

`entry = num2enum(dialect,enum,enumValue)` returns the value for the given entry in the enum.

Examples

Parse and Use MAVLink Dialect

This example shows how to parse a MAVLink XML file and create messages and commands from the definitions.

NOTE: This example requires you to install the UAV Library for Robotics System Toolbox®. Call `roboticsAddons` to open the Add-ons Explorer and install the library.

Parse and store the MAVLink dialect XML. Specify the XML path. The default `"common.xml"` dialect is provided. This XML file contains all the message and enum definitions.

```
dialect = mavlinkdialect("common.xml");
```

Create a MAVLink command from the `MAV_CMD` enum, which is an enum of MAVLink commands to send to the UAV. Specify the setting as `"int"` or `"long"`, and the type as an integer or string.

```
cmdMsg = createcmd(dialect,"long",22)
```

```
cmdMsg = struct with fields:
      MsgID: 76
    Payload: [1x1 struct]
```

Verify the command name using `num2enum`. Command 22 is a take-off command for the UAV. You can convert back to an ID using `enum2num`. Your dialect can contain many different enums with different names and IDs.

```
cmdName = num2enum(dialect,"MAV_CMD",22)
```

```
cmdName = 
"MAV_CMD_NAV_TAKEOFF"
```

```
cmdID = enum2num(dialect,"MAV_CMD",cmdName)
```

```
cmdID = 22
```

Use `enuminfo` to view the table of the `MAV_CMD` enum entries.

```
info = enuminfo(dialect,"MAV_CMD");
info.Entries{:}
```

```
ans=133×3 table
                   Name                         Value

    ____________________________________        _____     __________________________________________

    "MAV_CMD_NAV_WAYPOINT"                       16       "Navigate to waypoint."
    "MAV_CMD_NAV_LOITER_UNLIM"                   17       "Loiter around this waypoint an unlimited a
    "MAV_CMD_NAV_LOITER_TURNS"                   18       "Loiter around this waypoint for X turns"
    "MAV_CMD_NAV_LOITER_TIME"                    19       "Loiter around this waypoint for X seconds"
    "MAV_CMD_NAV_RETURN_TO_LAUNCH"               20       "Return to launch location"
    "MAV_CMD_NAV_LAND"                           21       "Land at location"
    "MAV_CMD_NAV_TAKEOFF"                        22       "Takeoff from ground / hand"
    "MAV_CMD_NAV_LAND_LOCAL"                     23       "Land at local position (local frame only)"
    "MAV_CMD_NAV_TAKEOFF_LOCAL"                  24       "Takeoff from local position (local frame o
    "MAV_CMD_NAV_FOLLOW"                         25       "Vehicle following, i.e. this waypoint repr
    "MAV_CMD_NAV_CONTINUE_AND_CHANGE_ALT"        30       "Continue on the current course and climb/d
    "MAV_CMD_NAV_LOITER_TO_ALT"                  31       "Begin loiter at the specified Latitude and
    "MAV_CMD_DO_FOLLOW"                          32       "Being following a target"
    "MAV_CMD_DO_FOLLOW_REPOSITION"               33       "Reposition the MAV after a follow target c
    "MAV_CMD_DO_ORBIT"                           34       "Start orbiting on the circumference of a c
    "MAV_CMD_NAV_ROI"                            80       "Sets the region of interest (ROI) for a se
      ⋮
```

Query the dialect for a specific message ID. Create a blank MAVLink message using the message ID.

```
info = msginfo(dialect,"HEARTBEAT")
```

```
info=1×4 table
    MessageID    MessageName

    _________    ___________    ______________________________________________________________

        0        "HEARTBEAT"    "The heartbeat message shows that a system is present and respond
```

```
msg = createmsg(dialect,info.MessageID);
```

Input Arguments

dialect — MAVLink dialect
mavlinkdialect object

MAVLink dialect, specified as a `mavlinkdialect` object, which contains a parsed dialect XML for MAVLink message definitions.

enum — MAVLink enum name
string

MAVLink enum name, specified as a string.

enumValue — Enum value
integer

Enum value, specified as an integer.

Output Arguments

`entry` — MAVLink enum entry name
string

MAVLink enum entry name, returned as a string.

See Also

`enum2num` | `enuminfo` | `mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub` | `msginfo`

External Websites
MAVLink Developer Guide

Introduced in R2019a

readmsg

Read specific messages from TLOG file

Syntax

```
msgTable = readmsg(tlogReader)
msgTable = readmsg(tlogReader,Name,Value)
```

Description

`msgTable = readmsg(tlogReader)` reads all message data from the specified `mavlinkdialect` object and returns a table, `msgTable`, that contains all the messages separated by message type, system ID, and component ID.

`msgTable = readmsg(tlogReader,Name,Value)` reads specific messages based on the specified name-value pairs for filtering specific properties of the messages. You can filter by message name, system ID, component ID, and time.

Examples

Read Messages from MAVLink TLOG File

This example shows how to load a MAVLink TLOG file and select a specific message type.

Load the TLOG file. Specify the relative path of the file name.

```
tlogReader = mavlinktlog('flight.tlog');
```

Read the `'REQUEST_DATA_STREAM'` messages from the file.

```
msgData = readmsg(result,'MessageName','REQUEST_DATA_STREAM');
```

Input Arguments

`tlogReader` — MAVLink TLOG reader
`mavlinktlog` object

MAVLink TLOG reader, specified as a `mavlinktlog` 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: `'MessageID',22`

`MessageName` — Name of message in tlog
string scalar | character vector

Name of message in TLOG, specified as string scalar or character vector.

Data Types: `char` | `string`

`SystemID` — MAVLink system ID
positive integer from 1 through 255

MAVLink system ID, specified as a positive integer from 1 through 255. MAVLink protocol only supports up to 255 systems. Usually, each UAV has its own system ID, but multiple UAVs could be considered one system.

`ComponentID` — MAVLink component ID
positive integer from 1 through 255

MAVLink system ID, specified as a positive integer from 1 through 255.

`Time` — Time interval
two-element vector

Time interval between which to select messages, specified as a two-element vector in seconds.

Output Arguments

`msgTable` — Table of messages
table

Table of messages with columns:

- `MessageID`
- `MessageName`
- `ComponentID`
- `SystemID`
- `Messages`

Each row of `Messages` is a `timetable` containing the message `Payload` and the associated timestamp.

See Also

`mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinktlog`

Topics
"Visualize and Playback MAVLink Flight Log"

Introduced in R2019a

deserializemsg

Deserialize MAVLink message from binary buffer

Syntax

`msg = deserializemsg(dialect,buffer)`

Description

`msg = deserializemsg(dialect,buffer)` deserializes binary buffer data specified in `buffer` based on the specified MAVLink dialect. If a message is received as multiple buffers, you can combine them by concatenating the vectors in the proper order to get a valid message.

Input Arguments

`dialect` — MAVLink dialect
`mavlinkdialect` object

MAVLink dialect, specified as a `mavlinkdialect` object, which contains a parsed dialect XML for MAVLink message definitions.

`buffer` — Serialized message
vector of `uint8` integers

Serialized messaged, specified as vector of `uint8` integers.

Data Types: `uint8`

Output Arguments

`msg` — MAVLink message
structure

MAVLink message, returned as a structure with the fields:

- `MsgID`: Positive integer for message ID.
- `Payload`: Structure containing fields for the specific message definition.

See Also

Functions
`createcmd` | `createmsg` | `enum2num` | `enuminfo` | `msginfo` | `num2enum`

Objects
`mavlinkclient` | `mavlinkdialect` | `mavlinkio` | `mavlinksub`

Introduced in R2019a

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`

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 R2020b

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

```
quatArrayParts = compact(quatArray)
```

```
quatArrayParts = 4×4
```

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

Input Arguments

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

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

Data Types: quaternion

Output Arguments

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

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

Data Types: single | double

Extended Capabilities

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

See Also

Functions
classUnderlying | parts

Objects
quaternion

Introduced in R2020b

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 R2020b

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=4×1 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=1×4 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=2×2 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=2×2 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 R2020b

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

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

```
quaternionDistance = 5×1

   45.0000
   90.0000
  180.0000
   90.0000
   45.0000
```

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

```
angles1 = [30,0,15; ...
           30,5,15; ...
```

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

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

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

```
ans = 4×1

    6.0000
    6.0827
    6.0827
    6.0287
```

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

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

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

```
qNegative = -qPositive
```

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

Find the distance between the quaternion and its negative.

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

```
ans = 0
```

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

Input Arguments

quatA,quatB — Quaternions to calculate distance between

scalar | vector | matrix | multidimensional array

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

- `size(quatA) == size(quatB)`, or
- `numel(quatA) == 1`, or
- `numel(quatB) == 1`, or

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

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

Data Types: `quaternion`

Output Arguments

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

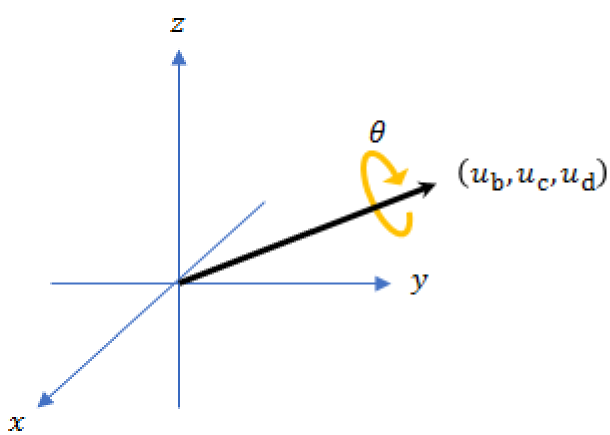
Angular distance in radians, returned as an array. The dimensions are the maximum of the union of `size(quatA)` and `size(quatB)`.

Data Types: `single` | `double`

Algorithms

The `dist` function returns the angular distance between two 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
`conj` | `parts`

Objects
`quaternion`

Introduced in R2020b

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'`:

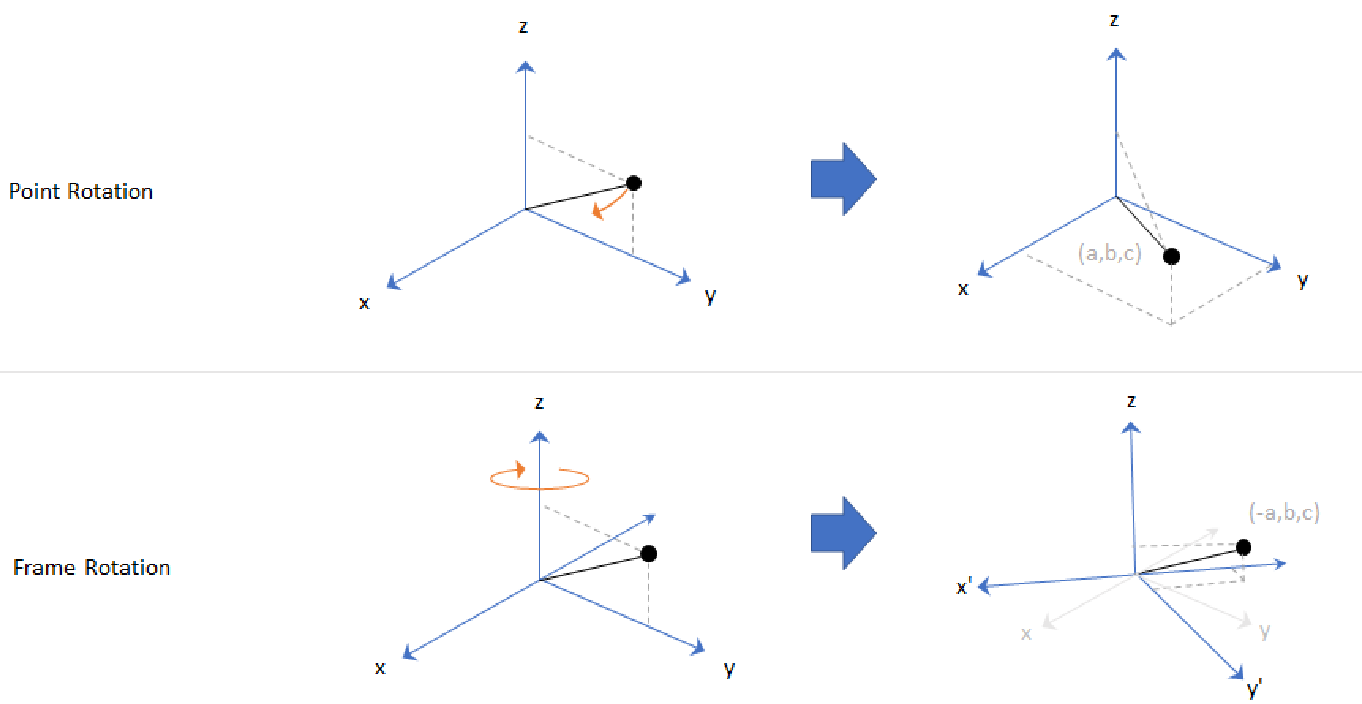
1. The first rotation is about the y-axis.
2. The second rotation is about the new z-axis.
3. The third rotation is about the new x-axis.

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 R2020b

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'`:

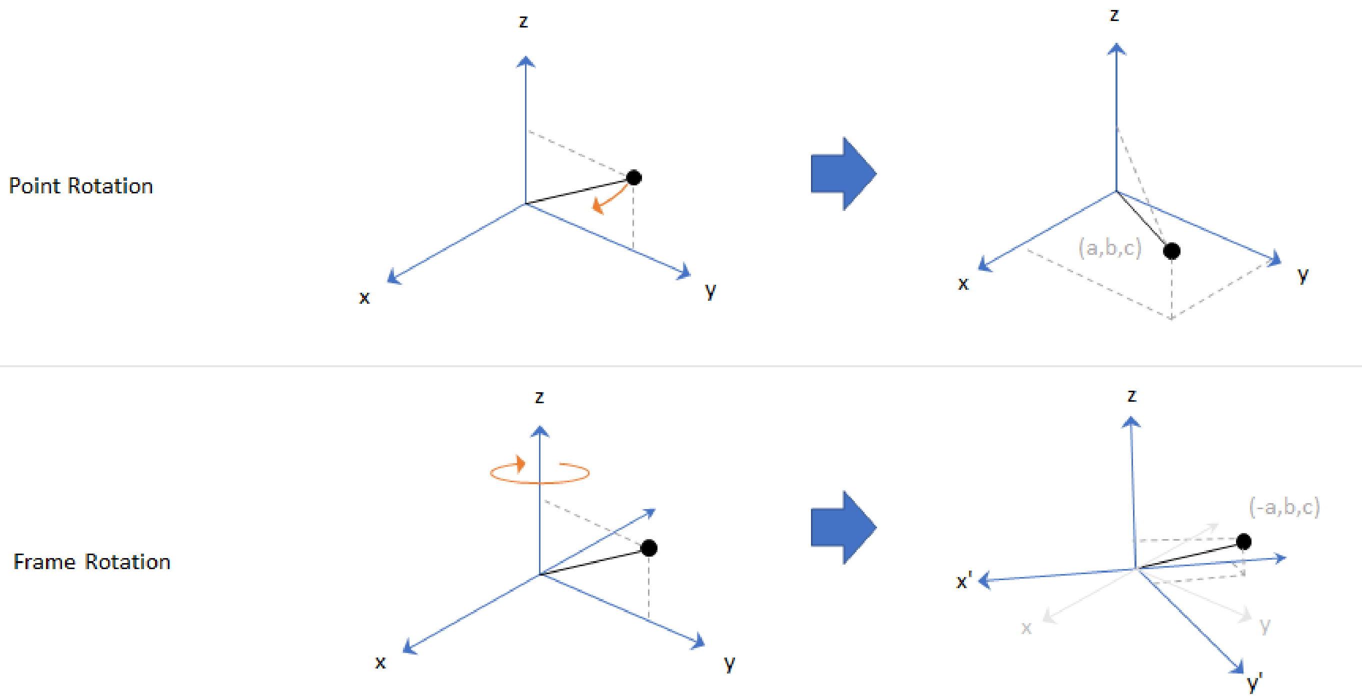
1. The first rotation is about the *y*-axis.
2. The second rotation is about the new *z*-axis.
3. The third rotation is about the new *x*-axis.

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 R2020b

exp

Exponential of quaternion array

Syntax

`B = exp(A)`

Description

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

Examples

Exponential of Quaternion Array

Create a 4-by-1 quaternion array A.

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

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

Compute the exponential of A.

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

```
B=4×1 quaternion array
     5.3525e+06 + 1.0516e+06i + 1.5774e+06j + 6.8352e+06k
        -57.359 -     89.189i -     81.081j -     64.865k
        -6799.1 +     2039.1i +     1747.8j +     3495.6k
          -6.66 +     36.931i +     39.569j +     2.6379k
```

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

B — Result
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Algorithms

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

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

Extended Capabilities

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

See Also

Functions
`log` | `power, .^`

Objects
`quaternion`

Introduced in R2020b

ldivide, .\

Element-wise quaternion left division

Syntax

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

Description

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

Examples

Divide a Quaternion Array by a Real Scalar

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

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

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

```
B = 2;
C = A.\B
```

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

Divide a Quaternion Array by Another Quaternion Array

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

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

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

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

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

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

```
C=2×2 quaternion array
         2.7 -      1.9i -      0.9j -      1.7k       1.5159 -  0.37302i -  0.15079j -  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 $A = a_1 + a_2\mathrm{i} + a_3\mathrm{j} + a_4\mathrm{k}$ and a real scalar p,

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

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

Quaternion Division by a Quaternion Scalar

Given two quaternions A and B of compatible sizes, then

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

Extended Capabilities

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

See Also

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

Objects
`quaternion`

Introduced in R2020b

log

Natural logarithm of quaternion array

Syntax

`B = log(A)`

Description

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

Examples

Logarithmic Values of Quaternion Array

Create a 3-by-1 quaternion array A.

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

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

Compute the logarithmic values of A.

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

```
B=3×1 quaternion array
      1.0925 + 0.40848i - 0.20543j +  1.3121k
      0.8436 + 0.14767i + 0.15872j - 0.62533k
      1.6807 - 0.53829i +   1.473j +  1.2493k
```

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `quaternion`

Algorithms

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

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

Extended Capabilities

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

See Also

Functions
`exp` | `power, .^`

Objects
`quaternion`

Introduced in R2020b

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')
```

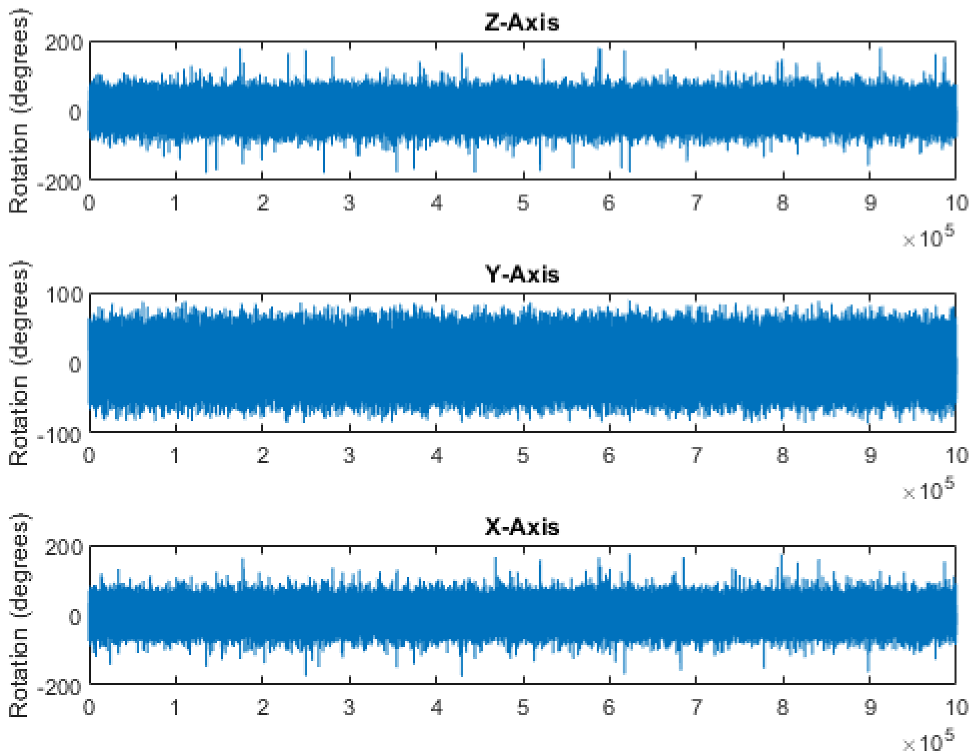
```
eulerAverage = 1×3

   45.7876   32.6452    6.0407
```

Average Out Rotational Noise

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

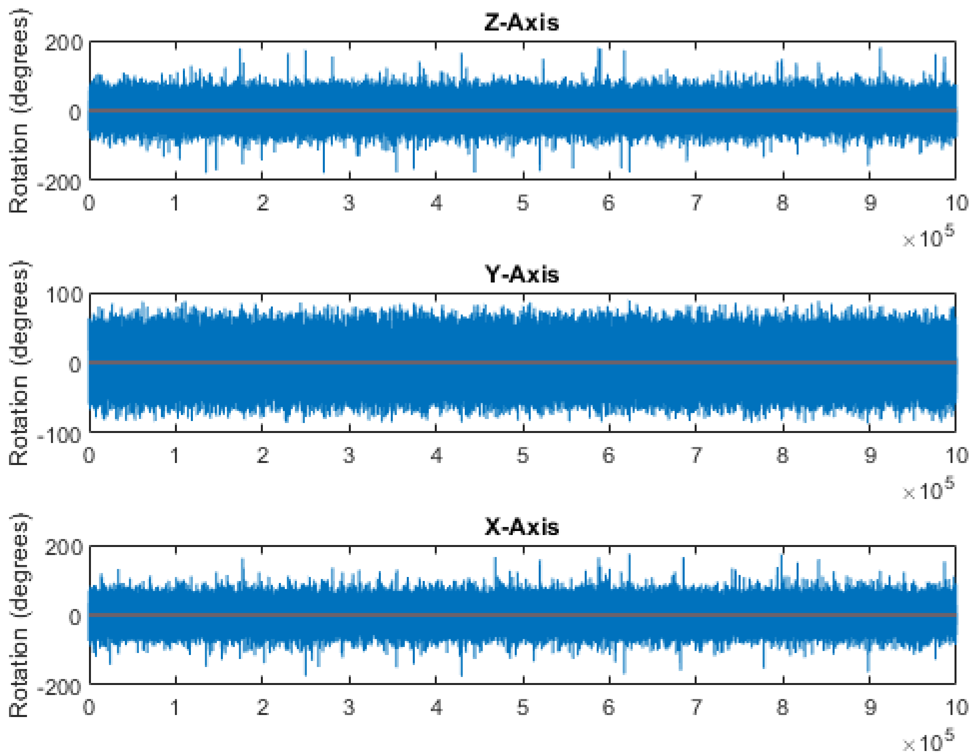
Create a vector of 1e6 quaternions whose distance, as defined by the `dist` function, from quaternion(1,0,0,0) is normally distributed. Plot the Euler angles corresponding to the noisy quaternion vector.

```
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');
```

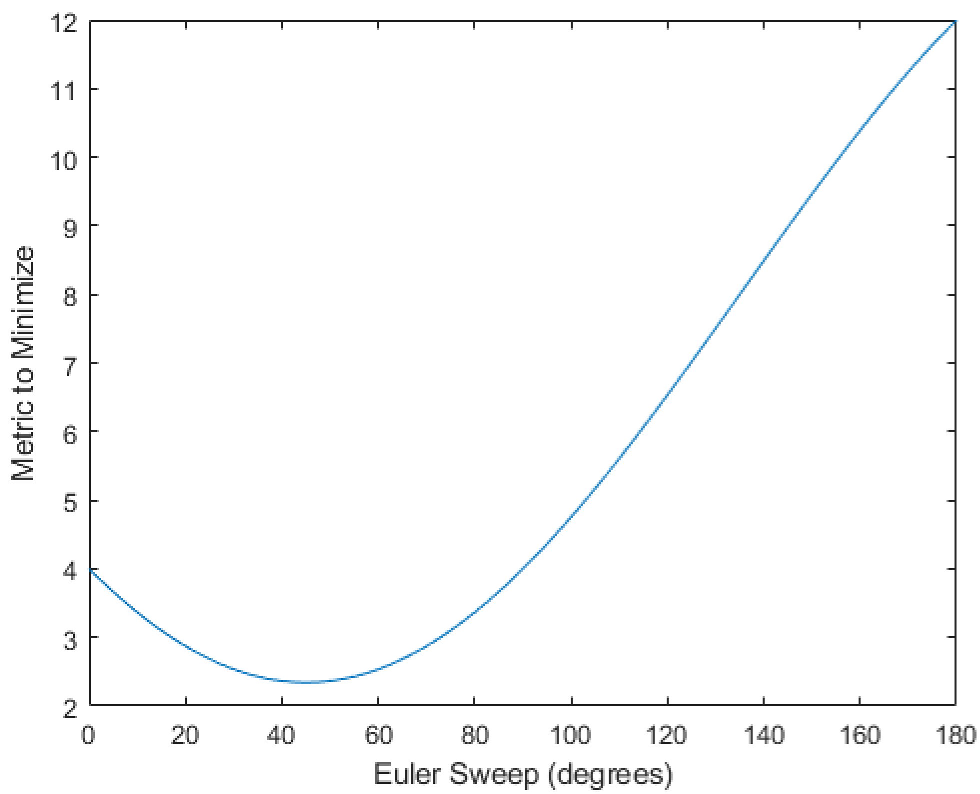
Create a quaternion sweep, `qSweep`, that represents rotations from 0 to 180 degrees about the *x*-axis.

```
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')
```

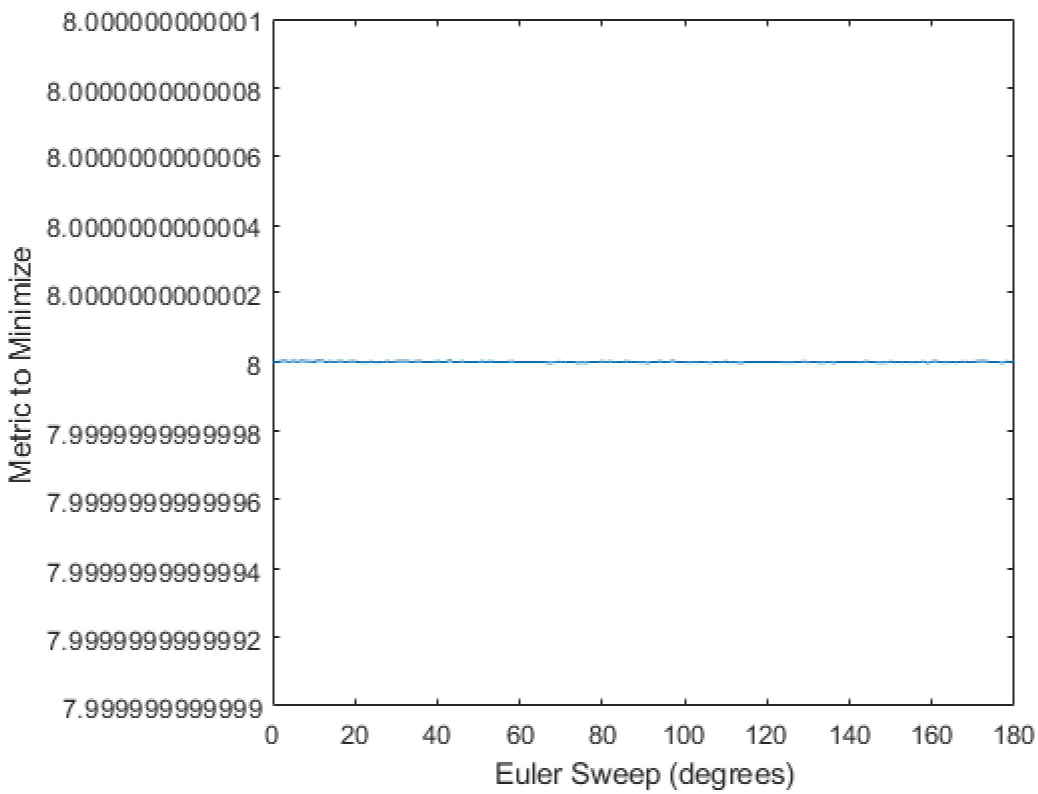
```
ans = 1×3
```

```
        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 R2020b

minus, -

Quaternion subtraction

Syntax

```
C = A - B
```

Description

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

Examples

Subtract a Quaternion from a Quaternion

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

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

Q1minusQ2 = Q1 - Q2

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

Subtract a Real Number from a Quaternion

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

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

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

Qminus1 = Q - 1

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

Input Arguments

A — Input
scalar | vector | matrix | multidimensional array

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

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

B — Input
scalar | vector | matrix | multidimensional array

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

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

Output Arguments

C — Result
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

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

Objects
`quaternion`

Introduced in R2020b

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=4×1 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=4×1 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, $q = a_q + b_q i + c_q j + d_q k$, and $p = a_p + b_p i + c_p j + d_p k$, the multiplication can be expanded as:

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

You can simplify the equation using the quaternion multiplication table:

$$\begin{aligned} z = pq &= a_p a_q + a_p b_q i + a_p c_q j + a_p d_q k \\ &+ b_p a_q i - b_p b_q + b_p c_q k - b_p d_q j \\ &+ c_p a_q j - c_p b_q k - c_p c_q + c_p d_q i \\ &+ d_p a_q k + d_p b_q j - d_p c_q i - d_p d_q \end{aligned}$$

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

Objects
`quaternion`

Introduced in R2020b

norm

Quaternion norm

Syntax

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

Description

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

Given a quaternion of the form $Q = a + b\mathrm{i} + c\mathrm{j} + d\mathrm{k}$, the norm of the quaternion is defined as $\mathrm{norm}(Q) = \sqrt{a^2 + b^2 + c^2 + d^2}$.

Examples

Calculate Quaternion Norm

Create a scalar quaternion and calculate its norm.

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

```
ans = 5.4772
```

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

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

```
ans = 5.4772
```

Input Arguments

quat — Quaternion
scalar | vector | matrix | multidimensional array

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `single` | `double`

Extended Capabilities

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

See Also

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

Objects
`quaternion`

Introduced in R2020b

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=3×1 quaternion array
     0.18257 + 0.36515i + 0.54772j +  0.7303k
     0.36515 + 0.54772i +  0.7303j + 0.18257k
     0.54772 +  0.7303i + 0.18257j + 0.36515k
```

Input Arguments

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

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

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `quaternion`

Extended Capabilities

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

See Also

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

Objects
`quaternion`

Introduced in R2020b

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=3×3 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=2×2 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

Objects
`quaternion`

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

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

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

```
qA = 2×1

     1
     5


qB = 2×1

     2
     6


qC = 2×1

     3
     7


qD = 2×1
```

```
     4
     8
```

Input Arguments

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

Quaternion, specified as a quaternion or array of quaternions.

Data Types: `quaternion`

Output Arguments

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

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

Data Types: `single` | `double`

Extended Capabilities

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

See Also

Functions
`classUnderlying` | `compact`

Objects
`quaternion`

Introduced in R2020b

power, .^

Element-wise quaternion power

Syntax

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

Description

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

Examples

Raise a Quaternion to a Real Scalar Power

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

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

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

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

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

Raise a Quaternion Array to Powers from a Multidimensional Array

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

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

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

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

```
b = 2×3

     1     0     2
     3     2     1
```

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

```
C=2×3 quaternion array
        1 +    2i +    3j +    4k        1 +    0i +    0j +    0k      -28 +    4i +    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
`exp` | `log`

Objects
`quaternion`

Introduced in R2020b

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=3×3 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=1×3 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=2×2 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 R2020b

rdivide, ./

Element-wise quaternion right division

Syntax

`C = A./B`

Description

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

Examples

Divide a Quaternion Array by a Real Scalar

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

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

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

```
B = 2;
C = A./B
```

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

Divide a Quaternion Array by Another Quaternion Array

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

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

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

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

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

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

```
C=2×2 quaternion array
          2.7 -      0.1i -      2.1j -      1.7k       2.2778 + 0.092593i -  0.46296j -  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, $A./p = A.\backslash p$.

Quaternion Division by a Quaternion Scalar

Given two quaternions A and B of compatible sizes,

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

Extended Capabilities

C/C++ Code Generation

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

See Also

Functions

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

Objects

`quaternion`

Introduced in R2020b

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=3×3 quaternion array
      0.17446 +  0.59506i -  0.73295j +  0.27976k      0.69704 - 0.060589i +  0.68679j -  0.1969
      0.21908 -  0.89875i -    0.298j +  0.23548k    -0.049744 +  0.59691i +  0.56459j +  0.5678
       0.6375 +  0.49338i -  0.24049j +  0.54068k       0.2979 -  0.53568i +  0.31819j +  0.7232
```

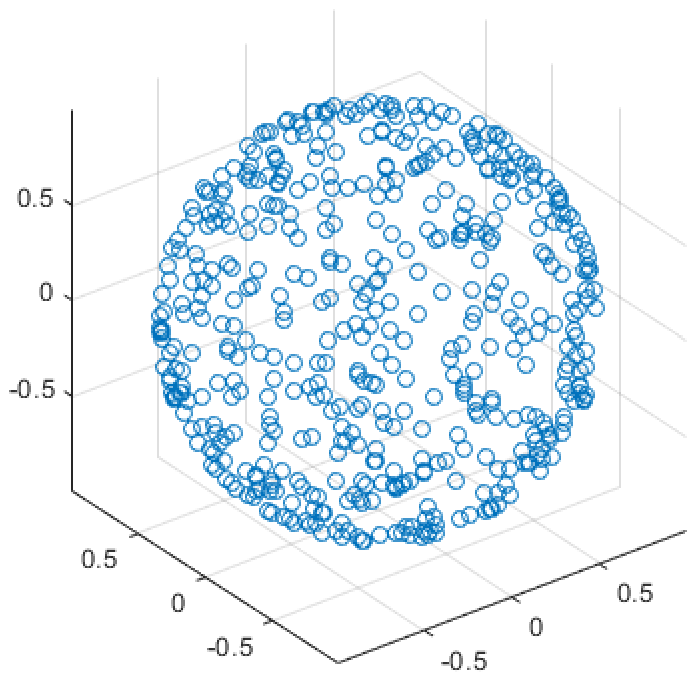
Create Uniform Distribution of Random Rotations

Create a vector of 500 random quaternions. Use rotatepoint on page 2-212 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 R2020b

rotateframe

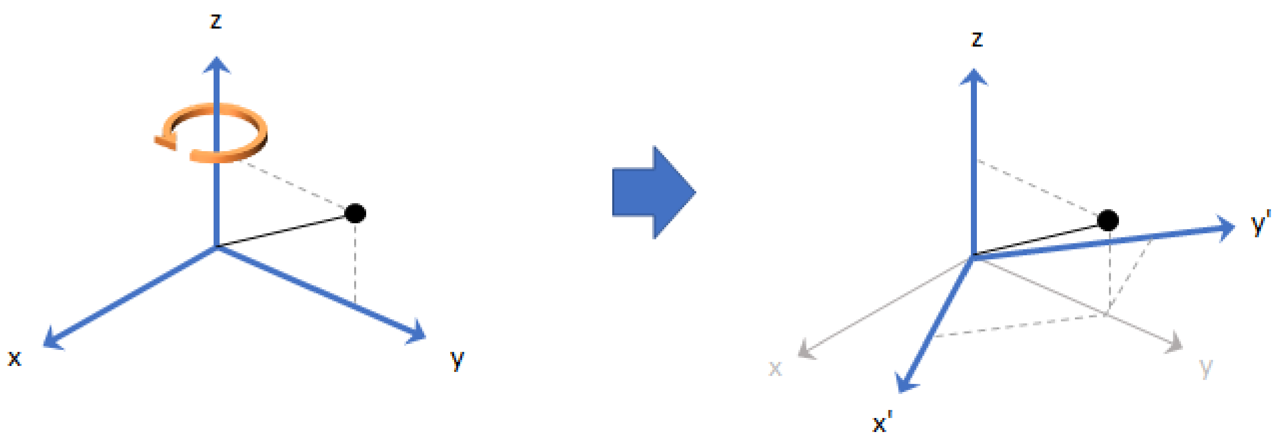
Quaternion frame rotation

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.

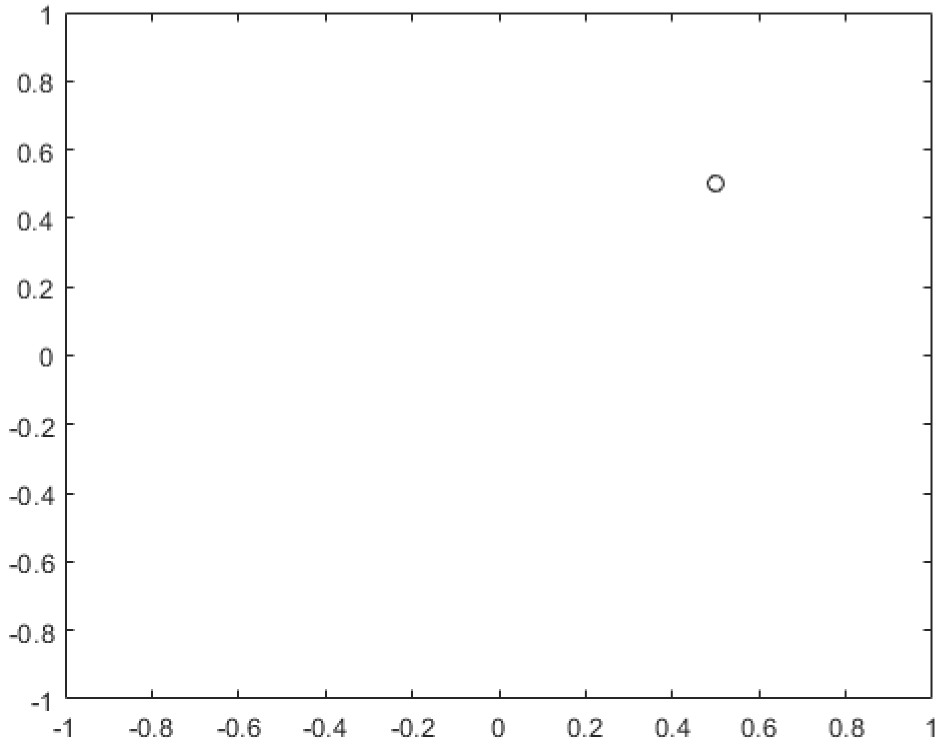


Examples

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])
```



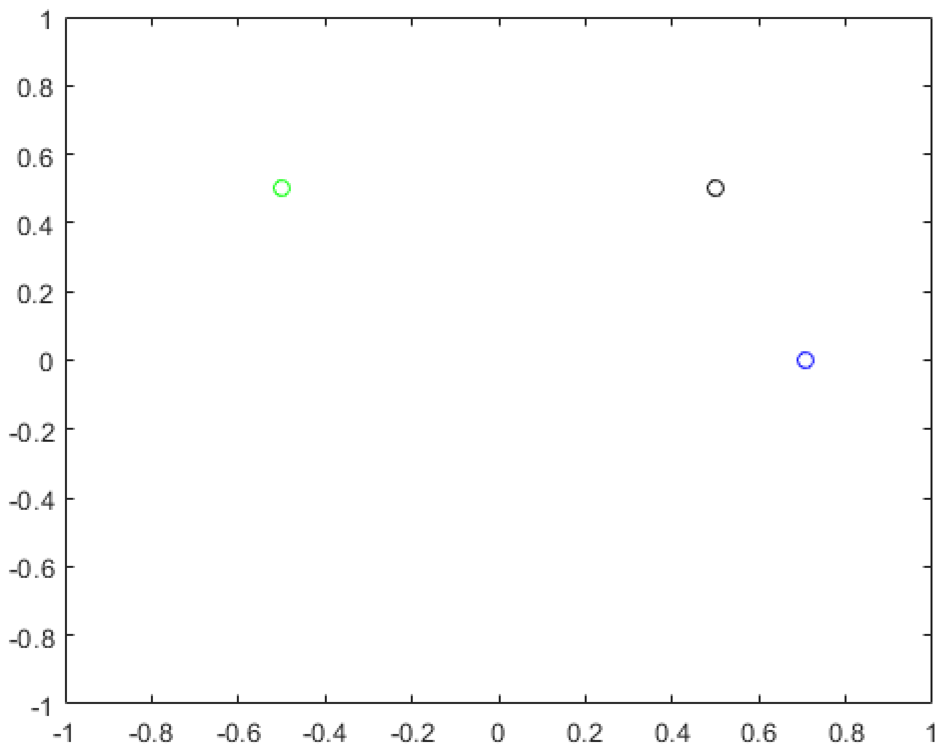
Create a quaternion vector specifying two separate rotations, one to rotate the frame 45 degrees and another to rotate the point -90 degrees about the *z*-axis. Use `rotateframe` to perform the rotations.

```
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])
```

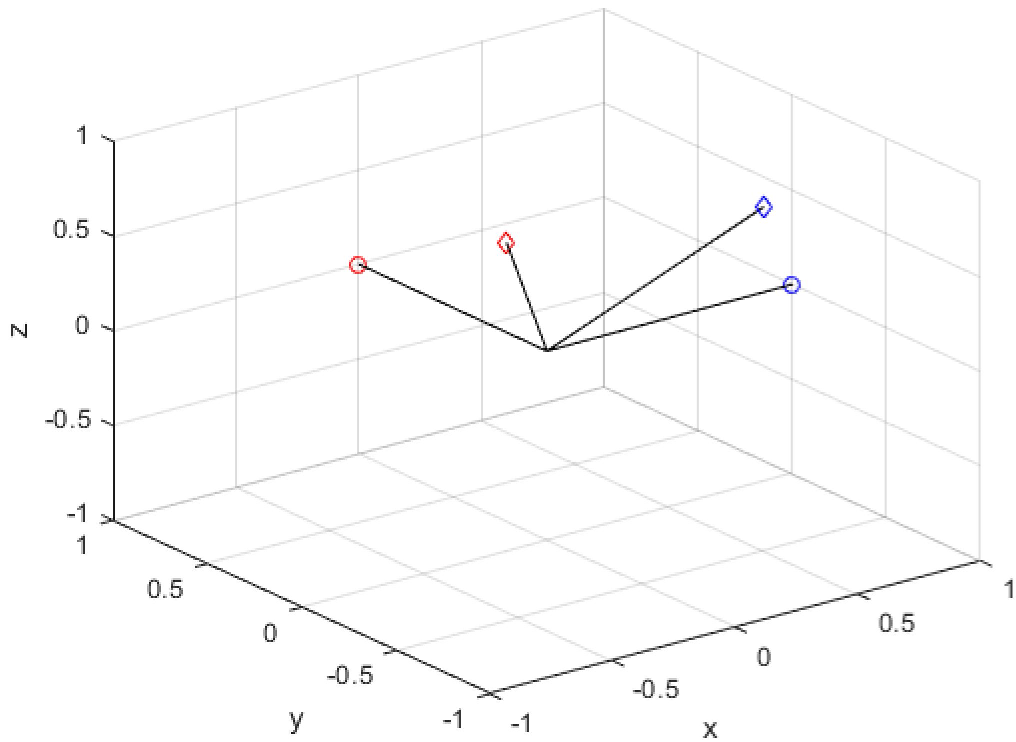
```
rP = 2×3

    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, $q = a + b\text{i} + c\text{j} + d\text{k}$, 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 R2020b

rotatepoint

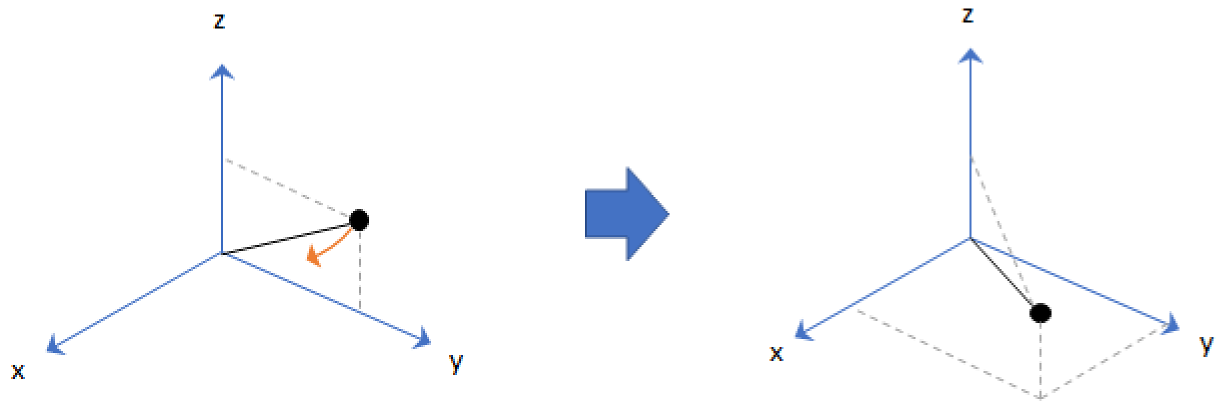
Quaternion point rotation

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.

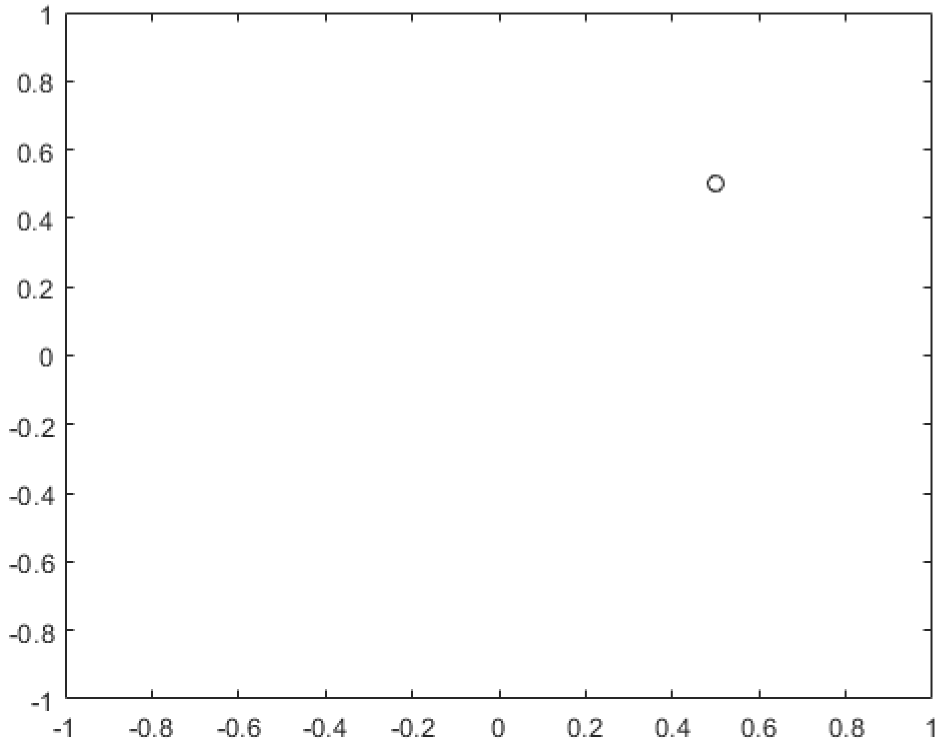


Examples

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])
```



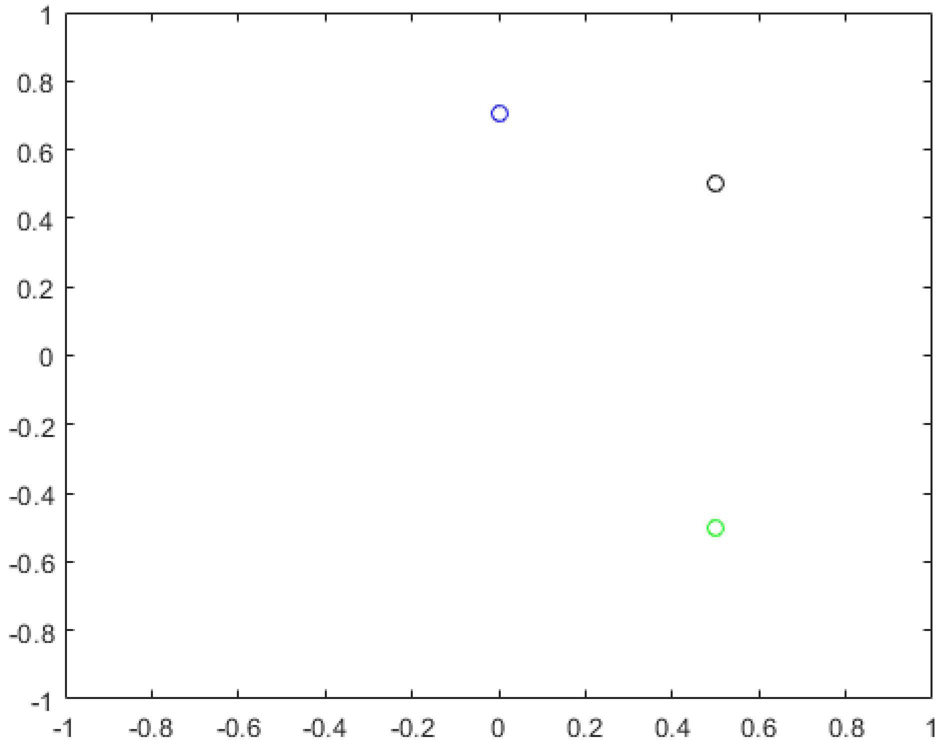
Create a quaternion vector specifying two separate rotations, one to rotate the point 45 and another to rotate the point -90 degrees about the *z*-axis. Use `rotatepoint` to perform the rotation.

```
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])
```

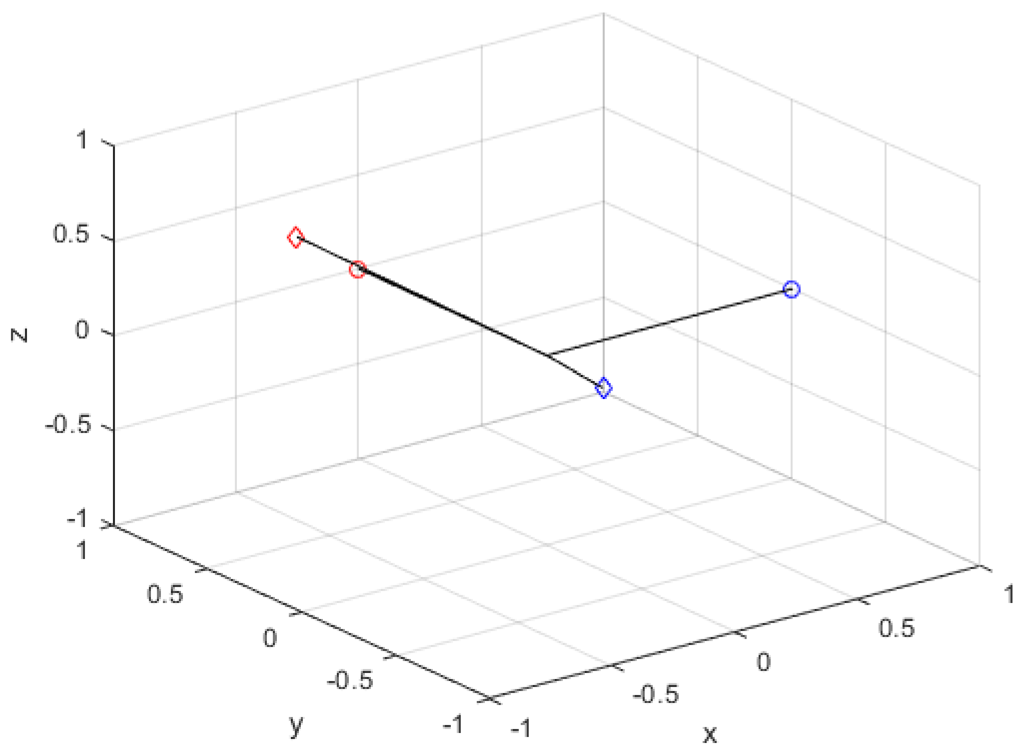
```
rP = 2×3

    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, $q = a + b\text{i} + c\text{j} + d\text{k}$, 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 R2020b

rotmat

Convert quaternion to rotation matrix

Syntax

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

Description

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

Examples

Convert Quaternion to Rotation Matrix for Point Rotation

Define a quaternion for use in point rotation.

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

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

Convert the quaternion to a rotation matrix.

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

```
rotationMatrix = 3×3

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

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

```
theta = 45;
gamma = 30;

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

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

rotationMatrixVerification = rx*ry
```

```
rotationMatrixVerification = 3×3

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

Convert Quaternion to Rotation Matrix for Frame Rotation

Define a quaternion for use in frame rotation.

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

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

Convert the quaternion to a rotation matrix.

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

```
rotationMatrix = 3×3

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

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

```
theta = 45;
gamma = 30;

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

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

rotationMatrixVerification = rx*ry
```

```
rotationMatrixVerification = 3×3

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

Convert Quaternion Vector to Rotation Matrices

Create a 3-by-1 normalized quaternion vector.

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

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

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

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

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

```
ans = 1×3

    0.9524    0.5297    0.9013
```

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

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

```
ans = 3×1

    0.9524
    0.5297
    0.9013
```

Input Arguments

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

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

Data Types: `quaternion`

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

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

Data Types: `char` | `string`

Output Arguments

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

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

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

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

Data Types: `single` | `double`

Algorithms

Given a quaternion of the form

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

the equivalent rotation matrix for frame rotation is defined as

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

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

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

References

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

Extended Capabilities

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

See Also

Functions
`euler` | `eulerd` | `rotvec` | `rotvecd`

Objects

Introduced in R2020b

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

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

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
`euler` | `eulerd` | `rotvecd`

Objects
`quaternion`

Introduced in R2020b

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
`euler` | `eulerd` | `rotvec`

Objects
`quaternion`

Introduced in R2020b

slerp

Spherical linear interpolation

Syntax

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

Description

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

Examples

Interpolate Between Two Quaternions

Create two quaternions with the following interpretation:

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

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

Call `slerp` with the 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');
```

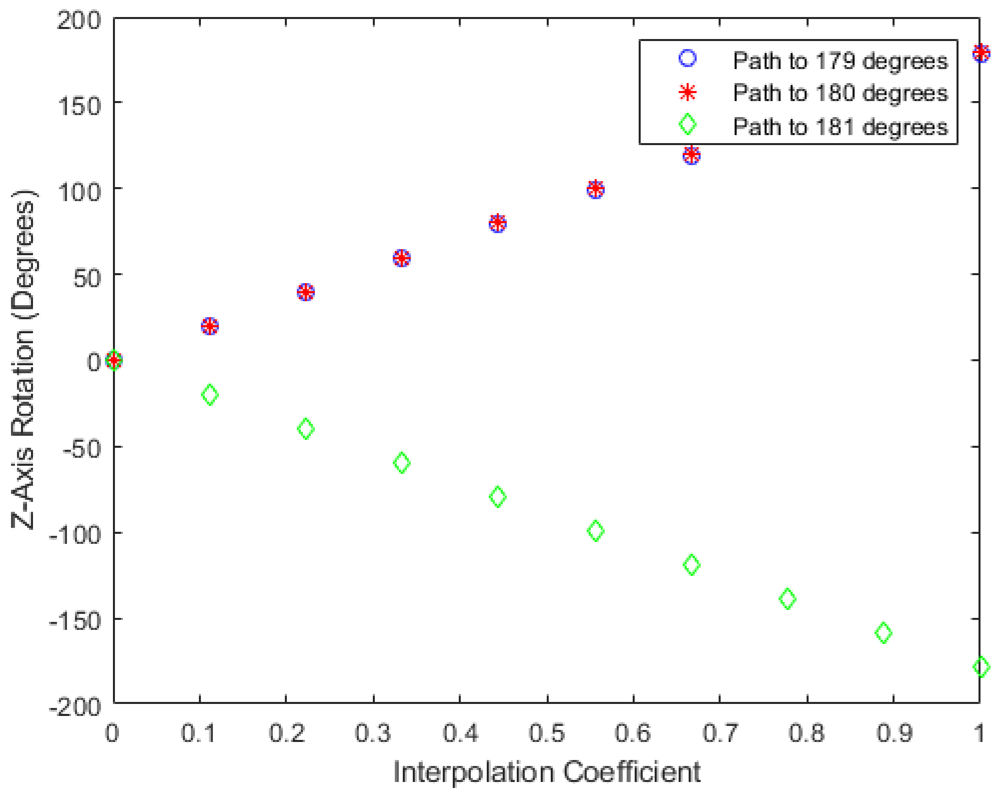
```
q181 = quaternion([181,0,0],'eulerd','ZYX','frame');
```

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.

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 R2020b

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=2×1 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=3×3 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     -2
```

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=1×3 quaternion array
           0 +       0i +       0j +       0k            1 +       0i +       0j +       0k     0
```

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

```
b=4×1 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=4×3 quaternion array
            0 +        0i +        0j +        0k      0.31877 +   3.5784i +   0.7254j -  0.12414
            0 +        0i +        0j +        0k      -1.3077 +   2.7694i - 0.063055j +   1.4897
            0 +        0i +        0j +        0k     -0.43359 -   1.3499i +  0.71474j +    1.409
            0 +        0i +        0j +        0k      0.34262 +   3.0349i -  0.20497j +   1.4172
```

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
`mtimes, *` | `prod`

Objects
`quaternion`

Introduced in R2020b

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=4×1 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=1×4 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=2×2 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=2×2 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 R2020b

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=2×2 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=2×2 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 R2020b

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=3×3 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=2×2 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 R2020b

getGraph

Graph object representing tree structure

Syntax

```
g = getGraph(frames)
g = getGraph(frames,timestamp)
```

Description

`g = getGraph(frames)` returns a MATLAB `graph` object showing the child-parent relationships between frames at the last timestamp in the `frames` `transformTree` object.

`g = getGraph(frames,timestamp)` returns a MATLAB `graph` object showing the child-parent relationships between frames at the specified timestamp.

Input Arguments

`frames` — Transform tree defining the child-parent frame relationship at given timestamps
`transformTree` object

Transform tree defining the child-parent frame relationship at given timestamps, specified as a `transformTree` object.

`timestamp` — Time for querying the frames
scalar in seconds

Time for querying the frames, specified as a scalar in seconds.

Output Arguments

g — MATLAB graph
`graph` object

MATLAB graph, specified as a `graph` object. This graph reflects the parent-child relationship of the transforms defined in the transform tree object, `frames`.

See Also

Objects
`fixedwing` | `multirotor` | `transformTree` | `uavDubinsPathSegment`

Functions
`getTransform` | `info` | `removeTransform` | `show` | `updateTransform`

Introduced in R2020b

getTransform

Get relative transform between frames

Syntax

```
tform = getTransform(frames,targetframe,sourceframe)
tform = getTransform(frames,targetframe,sourceframe,timestamp)
```

Description

`tform = getTransform(frames,targetframe,sourceframe)` returns the relative transforms that convert points in the `sourceFrame` coordinate frame to the `targetFrame`. By default, this function uses the last timestamp for both frames specified in `frames`.

`tform = getTransform(frames,targetframe,sourceframe,timestamp)` returns the relative transforms at the given timestamp. If the given time is not specified in the transform tree, `frames`, the function performs interpolation using a constant velocity assumption for linear motion, and spherical linear interpolation (SLERP) for angular motion.

Input Arguments

`frames` — Transform tree defining the child-parent frame relationship at given timestamps
`transformTree` object

Transform tree defining the child-parent frame relationship at given timestamps, specified as a `transformTree` object.

`sourceframe` — Source frame names
string scalar | character vector | string array | cell array character vector

Source frame names specified as a string scalar, character vector, string array, or cell array of character vectors. The source frame is the frame you have coordinates in, and the target frame is the frame you want to convert those coordinates to. Each element of the array corresponds to the same element in `targetframe` and the length matches the *n*-dimension of `tform`.

Data Types: `char` | `string` | `cell`

`targetframe` — Target frame names
string scalar | character vector | string array | cell array character vector

Target frame names specified as a string scalar, character vector, string array, or cell array of character vectors. The source frame is the frame you have coordinates in, and the target frame is the frame you want to convert those coordinates to. Each element of the array corresponds to the same element in `sourceframe` and the length matches the *n*-dimension of `tform`.

Data Types: `char` | `string` | `cell`

`timestamp` — Time for querying the frames
scalar in seconds | vector

Time for querying the frames, specified as a scalar or vector of scalars in seconds. For timestamps specified before the first timestamp in `frames`, the function returns `NaN` values. For timestamps specified after the last timestamp, the most recent (largest timestamp) transformation is returned.

Output Arguments

`tform` — Transformations that converts points from source frames to target frames
4-by-4 homogenous transformation matrix | 4-by-4-by-*n* matrix array

Transformations that converts points from the source frames to the target frames specified as a 4-by-4 transformation matrix or a 4-by-4-by-*n* matrix array. Each matrix in the array corresponds to the same element of `targetframe`, `sourceframe`, and `timestamp`.

See Also

Objects
`fixedwing` | `multirotor` | `transformTree` | `uavDubinsPathSegment`

Functions
`getGraph` | `info` | `removeTransform` | `show` | `updateTransform`

Introduced in R2020b

info

List all frame names and stored timestamps

Syntax

`list = info(frames)`

Description

`list = info(frames)` returns a structure array with an element for each frame containing the frame name, parent frame, and all stored timestamps.

Input Arguments

`frames` — Transform tree defining the child-parent frame relationship at given timestamps
`transformTree` object

Transform tree defining the child-parent frame relationship at given timestamps, specified as a `transformTree` object.

Output Arguments

`list` — List of frame names, parents, and timestamps
structure array

List of frame names, parents, and timestamps, specified as a structure array. The elements of the structure array are:

- `FrameNames` –– String scalars listing each frame name.
- `ParentNames` –– String scalars listing the parent of each frame. The base frame returns an empty string.
- `Timestamps` –– Vectors of timestamps for each frame. Each vector is padded with `NaN`s based on the MaxNumTransforms property of `frames`.

See Also

Objects
`fixedwing` | `multirotor` | `transformTree` | `uavDubinsPathSegment`

Functions
`getGraph` | `getTransform` | `removeTransform` | `show` | `updateTransform`

Introduced in R2020b

removeTransform

Remove frame transform relative to its parent

Syntax

```
removeTransforms(frames,framename,timestamp)
removeTransforms(frames,framename,timeStart,timeEnd)
```

Description

`removeTransforms(frames,framename,timestamp)` removes the frame transforms between the given frame name and their parent frame at the specified timestamps.

`removeTransforms(frames,framename,timeStart,timeEnd)` removes all the frame transforms for the given frame name in the time interval, `[timeStart timeEnd]`.

Input Arguments

`frames` — Transform tree defining the child-parent frame relationship at given timestamps
`transformTree` object

Transform tree defining the child-parent frame relationship at given timestamps, specified as a `transformTree` object.

`framename` — Frame name
string scalar | character vector

Frame name with transforms you want to remove, specified as a string scalar or character vector.

Data Types: `char` | `string` | `cell`

`timestamp` — Times for removing transforms
scalar in seconds | vector

Times for removing transforms, specified as a scalar or vector of scalars in seconds. These timestamps must be specified for each of the frame transforms that you want to remove.

`timeStart` — Initial time for removing transforms
scalar in seconds

Initial time for removing transforms, specified as a scalar in seconds. All transforms for the given `framename` are removed from `timeStart` to `timeEnd`.

`timeEnd` — Final time for removing transforms
scalar in seconds

Final time for removing transforms, specified as a scalar in seconds. All transforms for the given `framename` are removed from `timeStart` to `timeEnd`.

See Also

Objects
fixedwing | multirotor | transformTree | uavDubinsPathSegment

Functions
getGraph | getTransform | info | show | updateTransform

Introduced in R2020b

show

Show transform tree

Syntax

```
hAx = show(frames)
hAx = show(frames,timestamp)
hAx = show( ___ ,Name,Value)
```

Description

`hAx = show(frames)` displays the transform tree at the last timestamp in the sequence.

`hAx = show(frames,timestamp)` displays the transform tree at the specified timestamp. If the specified time is not specified in the transform tree, `frames`, the function performs interpolation using a constant velocity assumption for linear motion, and spherical linear interpolation (SLERP) for angular motion.

`hAx = show( ___ ,Name,Value)` specifies additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

`frames` — Transform tree defining the child-parent frame relationship at given timestamps
`transformTree` object

Transform tree defining the child-parent frame relationship at given timestamps, specified as a `transformTree` object.

`timestamp` — Time for querying the frames
scalar in seconds | vector

Time for querying the frames, specified as a scalar or vector of scalars in seconds. If the given time is not specified in the transform tree, `frames`, the function performs interpolation using a constant velocity assumption for linear motion, and spherical linear interpolation (SLERP) for angular motion. For timestamps specified after the last timestamp, the most recent (largest timestamp) transformation is returned.

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: `'ShowArrow',true` draws arrows between parent to child frames

`ShowArrow` — Draw arrows from parent to child frames
`false` (default) | `true`

Draw arrows from parent to child frames, specified as `true` or `false`

Data Types: `logical`

`FrameSizes` — Axis sizes for frames
`struct("root",1)` (default) | structure

Axis sizes for frames, specified as a structure. Specify each frame name as a the field with a scalar for that frame's relative size.

Example: `struct("root",2,"frameA",5)`

Data Types: `struct`

`FrameNames` — Frames to plot
all frames (default) | string scalar | character vector | string array | cell array of character vectors

Frames to plot, specified as a string, charater vector, string array, or cell array of character vectors. Use this argument to specify a subset of frame names to display in the figure.

Example: `["Frame1","Frame3","Frame9"]`

Data Types: `char` | `string` | `cell`

`Parent` — Axes on which to plot
`Axes` object

Axes on which to plot, specified as an `Axes` object.

Output Arguments

`hAx` — Axes
`Axes` object

Axes under which the transform tree is shown, returned as an `Axes` object. For more information, see `Axes Properties`.

See Also

Objects
`fixedwing` | `multirotor` | `transformTree` | `uavDubinsPathSegment`

Functions
`getGraph` | `getTransform` | `info` | `removeTransform` | `updateTransform`

Introduced in R2020b

updateTransform

Update frame transform relative to its parent

Syntax

```
updateTransform(frames,parentframe,childframe,position,orientation,timestamp)
updateTransform(frames,parentframe,childframe,tform,timestamp)
```

Description

`updateTransform(frames,parentframe,childframe,position,orientation,timestamp)` updates the relative transforms between child frames and their parents with a given position and orientation at the specified time stamps. The position and orientation are given in the parent reference frame.

`updateTransform(frames,parentframe,childframe,tform,timestamp)` updates the relative transforms between child frames and their parents with a given 4-by-4 homogenous transform, `tform`.

Input Arguments

`frames` — Transform tree defining the child-parent frame relationship at given timestamps
`transformTree` object

Transform tree defining the child-parent frame relationship at given timestamps, specified as a `transformTree` object.

`parentframe` — Parent frame names
string scalar | character vector | string array | cell array character vector

Parent frame names specified as a string scalar, character vector, string array, or cell array of character vectors. Transformations specified in `tform` or `position` and `orientation` are relative to the parent frame. Each element of `parentframe` corresponds to the same element in `childframe`.

Data Types: `char` | `string` | `cell`

`childframe` — Child frame names
string scalar | character vector | string array | cell array character vector

Child frame names specified as a string scalar, character vector, string array, or cell array of character vectors. The function attaches the child frame to the parent frame. Transformations specified in `tform` or `position` and `orientation` are relative to the parent frame. Each element of `parentframe` corresponds to the same element in `childframe`.

Data Types: `char` | `string` | `cell`

`position` — Relative position of child frame to parent
three-element `[x y z]` vector

Relative position of child frame to parent, specified as a three-element `[x y z]` vector. Specify the relative orientation in `orientation`.

`orientation` — Relative orientation of child frame to parent
three-element `[x y z]` vector

Relative orientation of child frame to parent, specified as a three-element `[x y z]` vector. Specify the relative position in `position`.

`tform` — Relative transform of child frame to parent
4-by-4 homogenous transformation matrix

Relative transform of child frame to parent, specified as a 4-by-4 homogenous transformation matrix.

`timestamp` — Time for querying the frames
scalar in seconds | vector

Time for querying the frames, specified as a scalar or vector of scalars in seconds. If the specified time is not specified in the transform tree, `frames`, the function performs interpolation using a constant velocity assumption for linear motion, and spherical linear interpolation (SLERP) for angular motion. For timestamps specified after the last timestamp, the most recent (largest timestamp) transformation is returned.

See Also

Objects
`fixedwing` | `multirotor` | `transformTree` | `uavDubinsPathSegment`

Functions
`getGraph` | `getTransform` | `info` | `removeTransform` | `show`

Introduced in R2020b

connect

Connect poses with UAV Dubins connection path

Syntax

```
[pathSegObj,pathCost] = connect(connectionObj,start,goal)
[pathSegObj,pathCost] = connect(connectionObj,start,
goal,'PathSegments','all')
```

Description

`[pathSegObj,pathCost] = connect(connectionObj,start,goal)` connects the start and goal poses using the specified `uavDubinsConnection` object. The path segment object with the lowest cost is returned.

`[pathSegObj,pathCost] = connect(connectionObj,start, goal,'PathSegments','all')` returns all possible path segments as a cell array with their associated costs.

Examples

Connect Poses of All Valid UAV Dubins Paths

This example shows how to calculate all valid UAV Dubins path segments and connect poses using the `uavDubinsConnection` object.

Calculate All Possible Path Segments

Create a `uavDubinsConnection` object.

```
connectionObj = uavDubinsConnection;
```

Define start and goal poses as [`x`, `y`, `z`, `headingAngle`] vectors.

```
startPose = [0 0 0 0]; % [meters, meters, meters, radians]
goalPose = [0 0 20 pi];
```

Calculate all possible path segments and connect the poses.

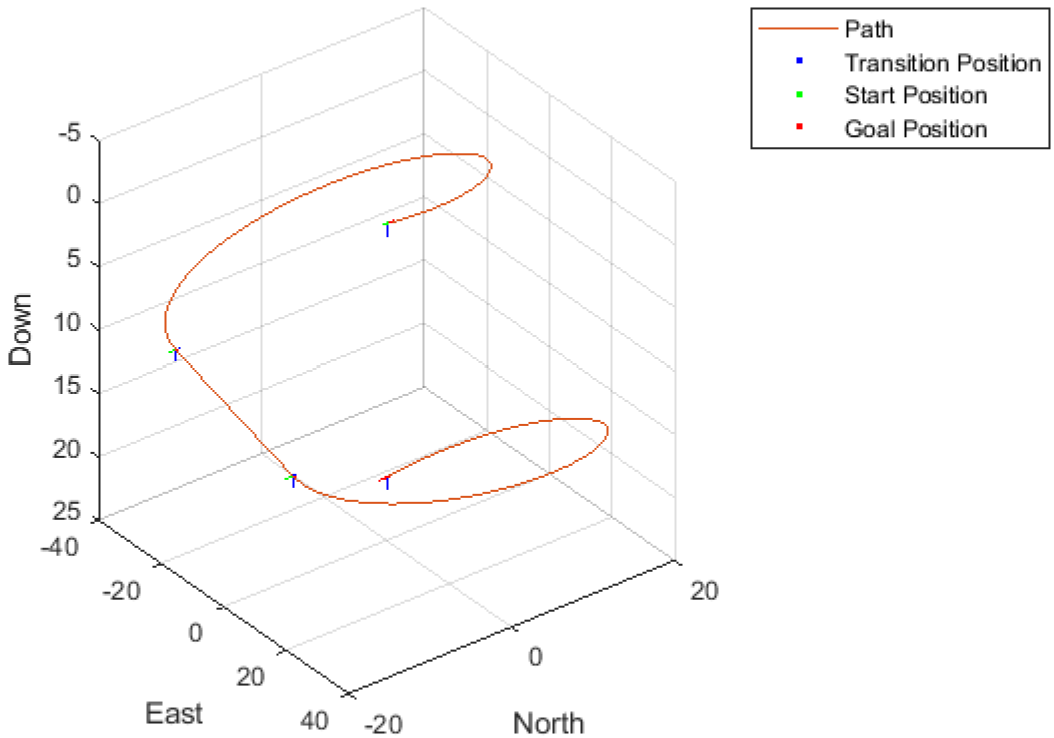
```
[pathSegObj,pathCosts] = connect(connectionObj,startPose,goalPose,'PathSegments','all');
```

Path Validation and Visualization

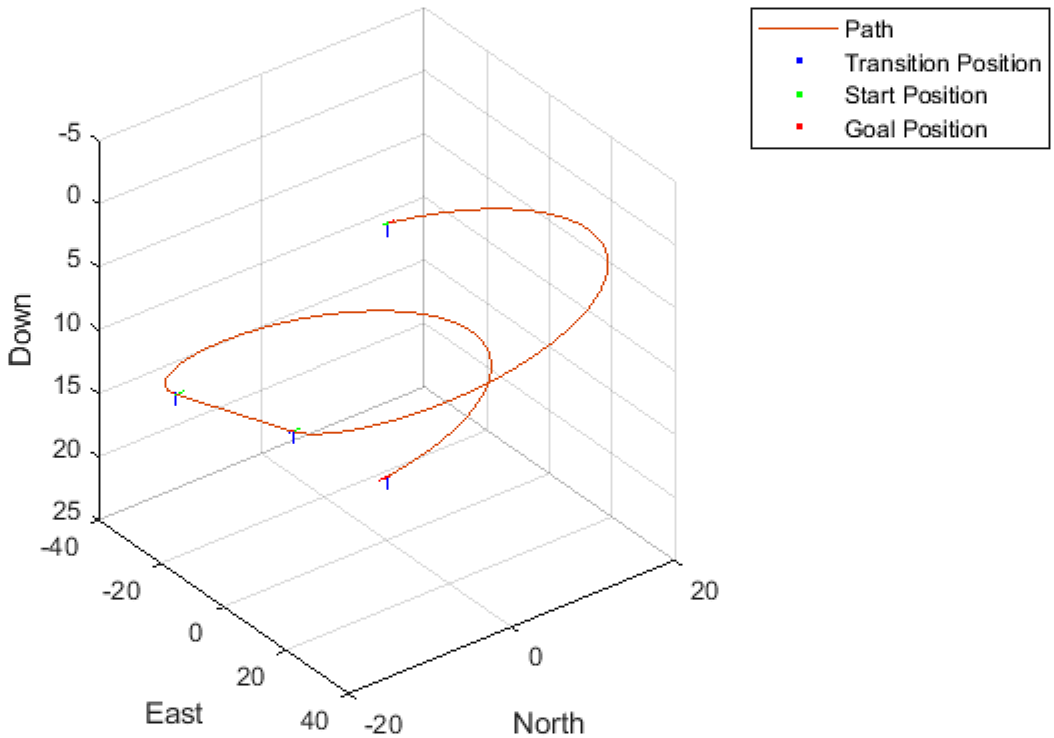
Check the validity of all the possible path segments and display the valid paths along with their motion type and path cost.

```
for i = 1:length(pathSegObj)
    if ~isnan(pathSegObj{i}.Length)
        figure
        show(pathSegObj{i})
        fprintf('Motion Type: %s\nPath Cost: %f\n',strjoin(pathSegObj{i}.MotionTypes),pathCosts(
```

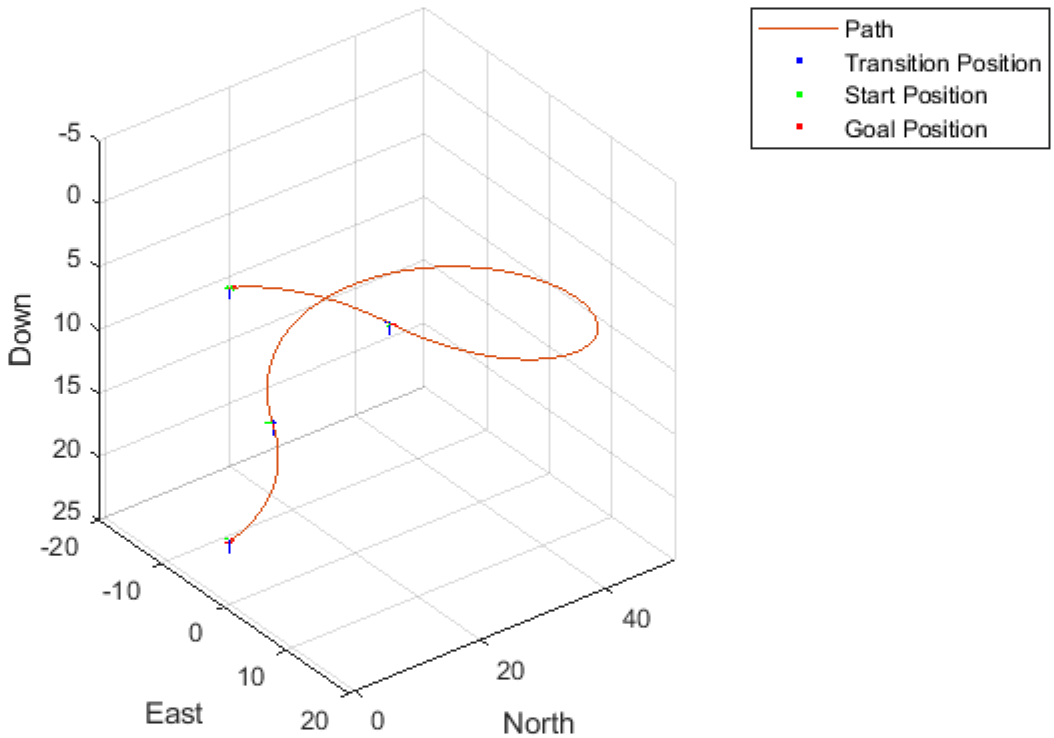
```
    end
end
```



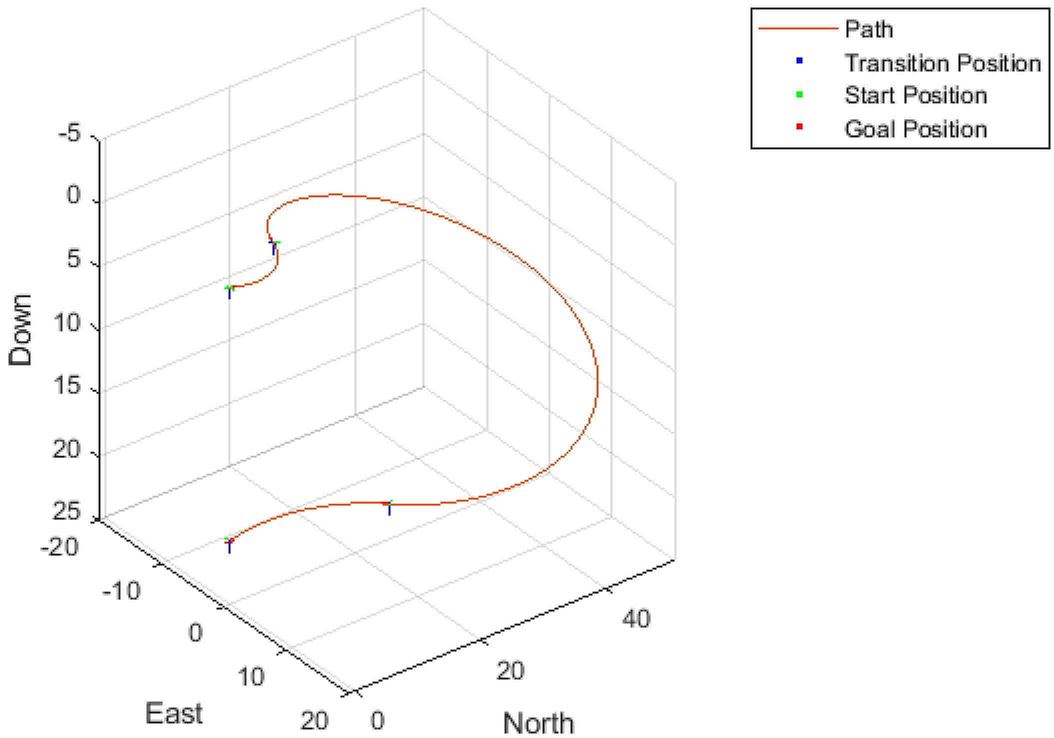

```
Motion Type: L S L N
Path Cost: 214.332271
```




```
Motion Type: R S R N
Path Cost: 214.332271
```




```
Motion Type: R L R N
Path Cost: 138.373157
```




```
Motion Type: L R L N
Path Cost: 138.373157
```

Input Arguments

`connectionObj` — Path connection type
`uavDubinsConnection` object

Path connection type, specified as a `uavDubinsConnection` object. This object defines the parameters of the connection.

`start` — Initial pose of UAV
four-element numeric vector or matrix

Initial pose of the UAV at the start of the path segment, specified as a four-element numeric vector or matrix [*x*, *y*, *z*, *headingAngle*].

x, *y*, and *z* specify the position in meters. *headingAngle* specifies the heading angle in radians. The heading angle is measured clockwise from north to east. Each row of the matrix corresponds to a different start pose.

The pose follows the north-east-down coordinate system.

The `start` and `goal` pose inputs can be any of these combinations:

- Single start pose with single goal pose.
- Multiple start poses with single goal pose.
- Single start pose with multiple goal poses.
- Multiple start poses with multiple goal poses.

`goal` — Goal pose of UAV
four-element numeric vector or matrix

Goal pose of the UAV at the end of the path segment, specified as a four-element numeric vector or matrix [*x*, *y*, *z*, *headingAngle*].

x, *y*, and *z* specify the position in meters. *headingAngle* specifies the heading angle in radians. The heading angle is measured clockwise from north to east. Each row of the matrix corresponds to a different goal pose.

The pose follows the north-east-down coordinate system.

The `start` and `goal` pose inputs can be any of these combinations:

- Single start pose with single goal pose.
- Multiple start poses with single goal pose.
- Single start pose with multiple goal poses.
- Multiple start poses with multiple goal poses.

Output Arguments

`pathSegObj` — Path segments
cell array of `uavDubinsPathSegment` objects

Path segments, returned as a cell array of `uavDubinsPathSegment` objects. The type of object depends on the input `connectionObj`. The size of the cell array depends on whether you use single or multiple `start` and `goal` poses.

By default, the function returns the path with the lowest cost for each `start` and `goal` pose.

When calling the `connect` function using the `'PathSegments','all'` name-value pair, the cell array contains all valid path segments between the specified `start` and `goal` poses.

`pathCost` — Cost of path segment
positive numeric scalar | positive numeric vector | positive numeric matrix

Cost of path segments, returned either as a positive numeric scalar, vector, or matrix. Each element of the cost vector corresponds to a path segment in `pathSegObj`.

By default, the function returns the path with the lowest cost for each `start` and `goal` pose.

Extended Capabilities

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

See Also

`uavDubinsConnection` | `uavDubinsPathSegment`

Introduced in R2019b

interpolate

Interpolate poses along UAV Dubins path segment

Syntax

```
poses = interpolate(pathSegObj,lengths)
```

Description

`poses = interpolate(pathSegObj,lengths)` interpolates poses along the path segment at the specified path lengths. Transitions between motion types are always included.

Examples

Interpolate Poses for UAV Dubins Path

This example shows how to connect poses using the `uavDubinsConnection` object and interpolate the poses along the path segment at the specified path lengths.

Connect Poses Using UAV Dubins Connection Path

Create a `uavDubinsConnection` object.

```
connectionObj = uavDubinsConnection;
```

Define start and goal poses as [`x`, `y`, `z`, `headingAngle`] vectors.

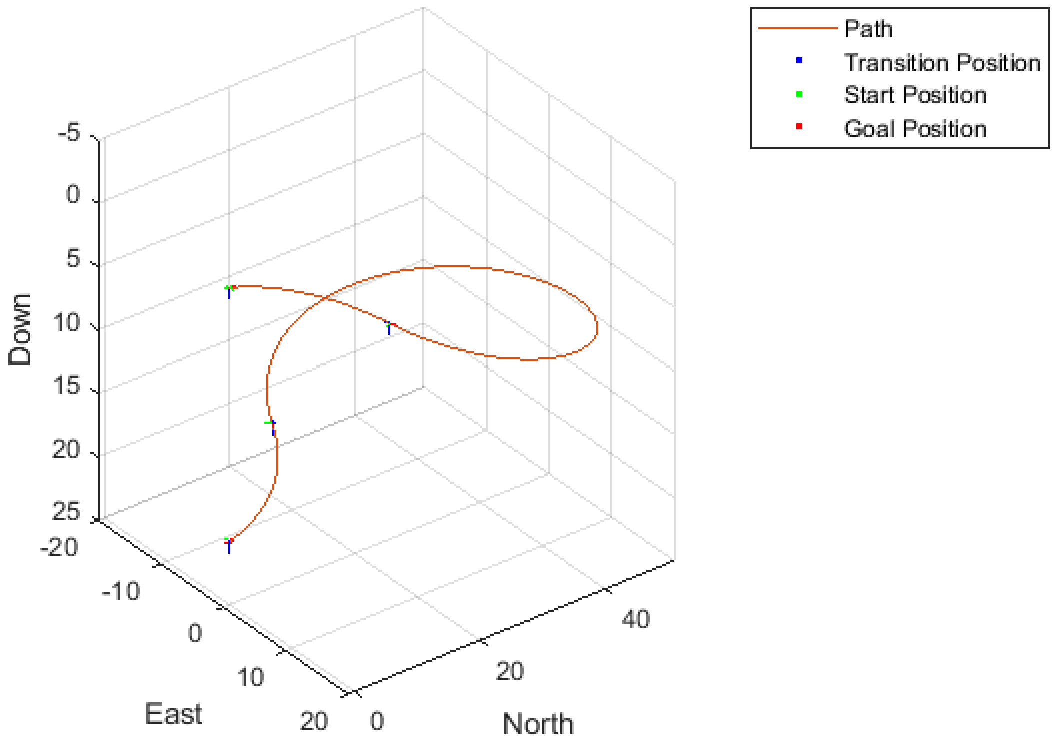
```
startPose = [0 0 0 0]; % [meters, meters, meters, radians]
goalPose = [0 0 20 pi];
```

Calculate a valid path segment and connect the poses.

```
[pathSegObj,pathCost] = connect(connectionObj,startPose,goalPose);
```

Show the generated path.

```
show(pathSegObj{1})
```



Interpolate the Poses

Specify the interval to interpolate along the path.

```
stepSize = pathSegObj{1}.Length/10;
lengths = 0:stepSize:pathSegObj{1}.Length;
```

Interpolate the poses along the path segment at the specified path lengths.

```
poses = interpolate(pathSegObj{1},lengths); % [x, y, z, headingAngle, flightPathAngle, rollAngle]
```

Visualize the Transition Poses

Compute the translation and rotation matrix of the transition poses, excluding the start and goal poses. The `posesTranslation` matrix consists of the first three columns of the `poses` matrix specifying the position `x`, `y`, and `z`.

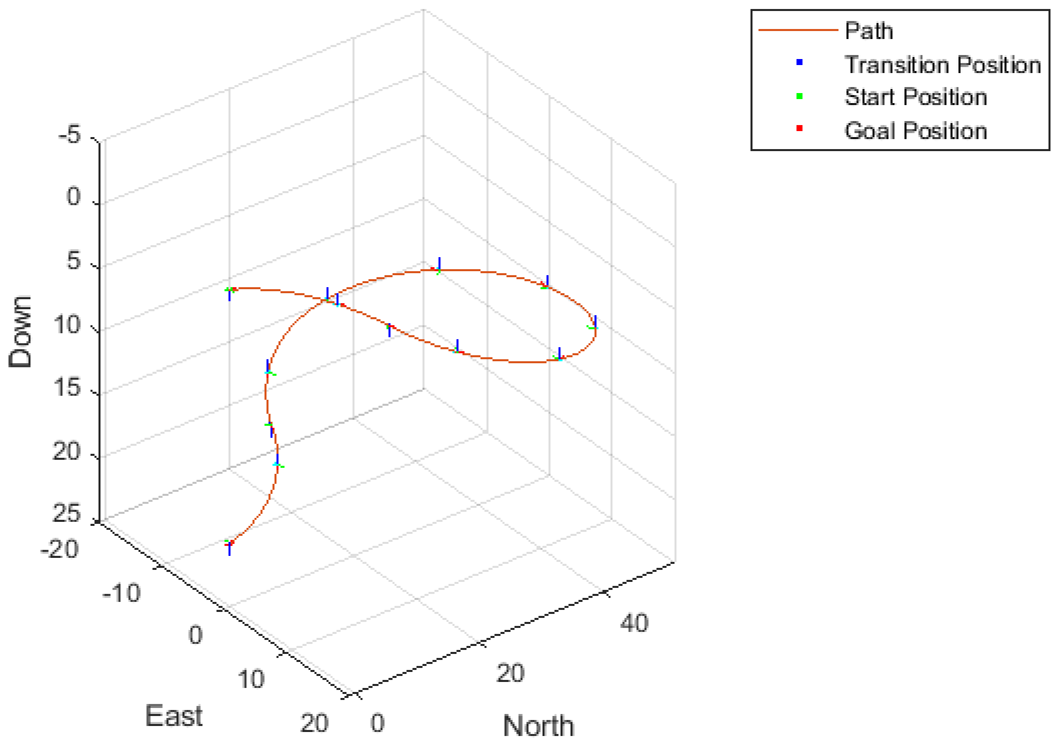
```
posesTranslation = poses(2:end-1,1:3); % [x, y, z]
```

Increment the elements of the fourth column of the `poses` matrix representing the `headingAngle` by `pi` and assign it as the first column of the rotation matrix `posesEulRot` in ZYX Euler angle representation. A column of `pi` and a column of zeros forms the second and the third columns of the `posesEulRot` matrix, respectively. Convert the `posesEulRot` matrix from Euler angles to quaternion and assign to `posesRotation`.

```
N = size(poses,1)-2;
posesEulRot = [poses(2:end-1,4)+pi,ones(N,1)*pi,zeros(N,1)]; % [headingAngle + pi, pi, 0]
posesRotation = quaternion(eul2quat(posesEulRot,'ZYX'));
```

Plot transform frame of the transition poses by specifying their translations and rotations using `plotTransforms`.

```
hold on
plotTransforms(posesTranslation,posesRotation,'MeshFilePath','fixedwing.stl','MeshColor','cyan')
```



Input Arguments

`pathSegObj` — Path segment
`uavDubinsPathSegment` object

Path segment, specified as a `uavDubinsPathSegment` object.

`lengths` — Lengths along path to interpolate poses
positive numeric vector

Lengths along path to interpolate poses, specified as a positive numeric vector in meters.

For example, specify `0:`*`stepSize`*`:pathSegObj{1}.Length` to interpolate at the interval specified by *stepSize* along the path. Transitions between motion types are always included.

Data Types: `double`

Output Arguments

poses — Interpolated poses
six-element numeric matrix

Interpolated poses along the path segment, returned as a six-element numeric matrix [*x*, *y*, *z*, *headingAngle*, *flightPathAngle*, *rollAngle*]. Each row of the matrix corresponds to a different interpolated pose along the path.

x, *y*, and *z* specify the position in meters. *headingAngle*, *flightPathAngle*, and *rollAngle* specify the orientation in radians.

Extended Capabilities

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

See Also

`show` | `uavDubinsPathSegment`

Introduced in R2019b

show

Visualize UAV Dubins path segment

Syntax

```
axHandle = show(pathSegObj)
axHandle = show(pathSegObj,Name,Value)
```

Description

`axHandle = show(pathSegObj)` plots the path segment with start and goal positions and the transitions between the motion types.

Note Plotting uses only the position and the yaw angle.

`axHandle = show(pathSegObj,Name,Value)` specifies additional name-value pair arguments to control display settings.

Examples

Connect Poses Using UAV Dubins Connection Path

This example shows how to calculate a UAV Dubins path segment and connect poses using the `uavDubinsConnection` object.

Create a `uavDubinsConnection` object.

```
connectionObj = uavDubinsConnection;
```

Define start and goal poses as [`x`, `y`, `z`, `headingAngle`] vectors.

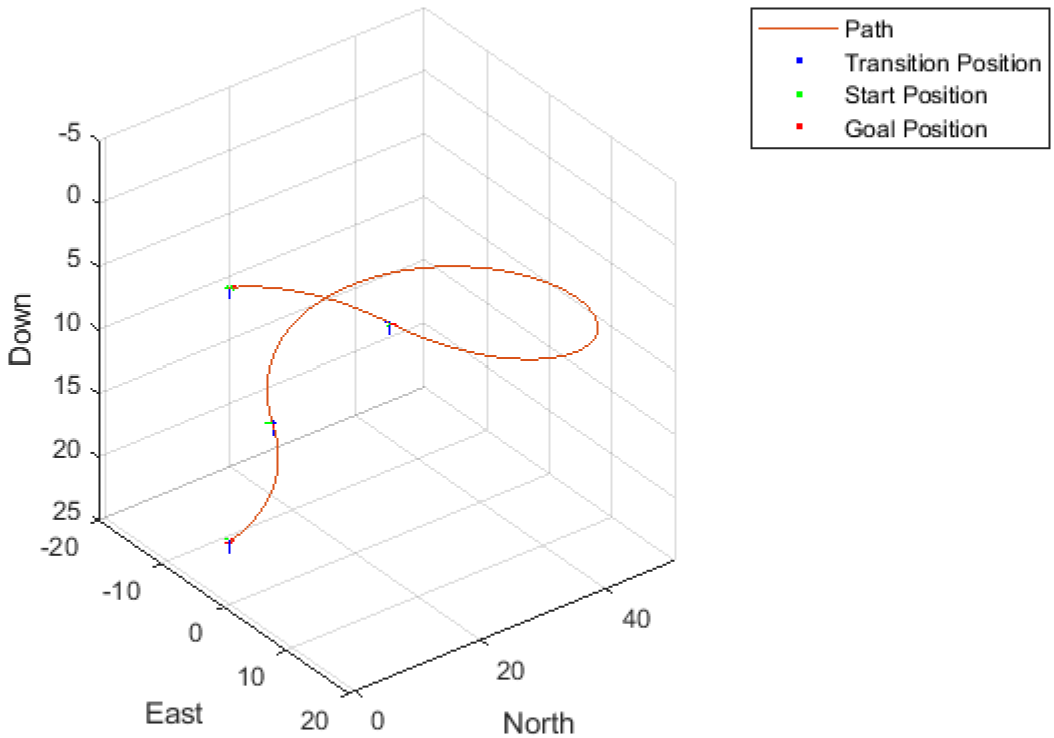
```
startPose = [0 0 0 0]; % [meters, meters, meters, radians]
goalPose = [0 0 20 pi];
```

Calculate a valid path segment and connect the poses. Returns a path segment object with the lowest path cost.

```
[pathSegObj,pathCosts] = connect(connectionObj,startPose,goalPose);
```

Show the generated path.

```
show(pathSegObj{1})
```



Display the motion type and the path cost of the generated path.

```
fprintf('Motion Type: %s\nPath Cost: %f\n',strjoin(pathSegObj{1}.MotionTypes),pathCosts);
```

```
Motion Type: R L R N
Path Cost: 138.373157
```

Input Arguments

`pathSegObj` — Path segment
`uavDubinsPathSegment` object

Path segment, specified as a `uavDubinsPathSegment` 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: `'Positions',{'start','goal'}`

`Parent` — Axes used to plot path
Axes object

Axes used to plot path, specified as the comma-separated pair consisting of `'Parent'` and an `axes` object.

Example: `'Parent',axHandle`

`Positions` — Positions to display
`{'start','goal','transitions'}` (default) | cell array of string or character vectors or vector of string scalars

Positions to display, specified as the comma-separated pair consisting of `'Positions'` and a cell array of string or character vectors or a vector of string scalars.

Options are any combination of `'start'`, `'goal'`, and `'transitions'`.

To disable all position displays, specify either as an empty cell array `{}` or empty vector `[]`.

Output Arguments

`axHandle` — Axes used to plot path
`Axes` object

Axes used to plot path, returned as an `axes` object.

See Also

`plotTransforms` | `uavDubinsPathSegment`

Introduced in R2019b

addGeoFence

Add geographical fencing to UAV platform

Syntax

```
addGeoFence(platform,type,geometries,permission)
addGeoFence( ___ ,Name,Value)
```

Description

`addGeoFence(platform,type,geometries,permission)` adds a geofence specified in ENU coordinates to the scenario.

`addGeoFence( ___ ,Name,Value)` specifies options using one or more name-value pair arguments in addition to the input arguments in the previous syntax. For example, `'UseLatLon',true` uses latitude and longitude coordinates for the *xy*-coordinates of the `geometries` input.

Input Arguments

`platform` — UAV platform
`uavPlatform` object

UAV platform in a scenario, specified as a `uavPlatform` object.

`type` — Type of mesh
`"cylinder"` | `"polygon"`

Type of mesh, specified as `"cylinder"` or `"polygon"`.

Data Types: `char` | `string`

`geometries` — Geometric parameters of mesh
cell array

Geometric parameters of the mesh, specified as a cell array with options that depend on the `type` input:

Geometry Parameters

type Input	Geometry Parameters	Description
`"cylinder"`	`{[x y height]}`	Three-element vector of the *xy*-position and height of the cylinder.
`"polygon"`	`{[endptsX endptsY] [zmin zmax]}`	End points of the polygon, specified in either clockwise or counterclockwise order. *z*-coordinates specify the minimum and maximum elevation of the polygon.

`permission` — Geofence permission
`false` or `0` | `true` or `1`

Geofence permission, specified as a `0` (`false`) or `1` (`true`), which indicates whether the UAV platform is permitted inside the geofence (`true`) or not permitted (`false`).

Data Types: `logical`

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: `'UseLatLon',true` uses latitude and longitude coordinates for the *xy*-coordinates of the `geometries` input.

`UseLatLon` — Use latitude-longitude coordinates for geofence geometry
`false` or `0` | `true` or `1`

Use latitude-longitude coordinates for the geofence geometry, specified as the comma-separated pair consisting of `'UseLatLon'` and a logical `0` (`false`) or `1`(`true`).

Data Types: `logical`

`ReferenceFrame` — Reference frame for computing UAV platform motion
string scalar

Reference frame for computing UAV platform motion, specified as the comma-separated pair consisting of `'ReferenceFrame'` and a string scalar, which matches any reference frame in the `uavScenario`.

Data Types: `char` | `string`

See Also

Functions
`checkPermission` | `move` | `read` | `updateMesh`

Objects
`uavPlatform` | `uavScenario` | `uavSensor`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

checkPermission

Check UAV platform permission based on geofencing

Syntax

```
permission = checkPermission(platform)
permission = checkPermission(platform,position)
permission = checkPermission(platform,position,Name,Value)
```

Description

`permission = checkPermission(platform)` checks whether the current UAV platform position is permitted according to the geofences.

`permission = checkPermission(platform,position)` checks whether a specific position in the scenario inertial frame is permitted.

`permission = checkPermission(platform,position,Name,Value)` specifies options using one or more name-value pair arguments. For example, `'UseLatLon',true` uses latitude, longitude, and altitude coordinates for the `positions` input.

Input Arguments

`platform` — UAV platform
`uavPlatform` object

UAV platform in a scenario, specified as a `uavPlatform` object.

`position` — UAV platform position in scenario inertial frame
`[0 0 0]` (default) | vector of the form `[x y z]`

UAV platform position in the scenario inertial frame, specified as a vector of the form `[x y z]`.

Data Types: `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: `'UseLatLon',true`uses latitude, longitude, and altitude coordinates for the `positions` input.

`UseLatLon` — Use latitude, longitude, and altitude coordinates for platform position
`0` or `false` (default) | `1` or `true`

Use latitude, longitude, and altitude coordinates for platform position, specified as the comma-separated pair `'UseLatLon'` and a logical `0` (`false`) or `1`(`true`).

Data Types: `logical`

`ReferenceFrame` — Reference frame for computing UAV platform motion
string scalar

Reference frame for computing UAV platform motion, specified as the comma-separated pair consisting of `'ReferenceFrame'` and a string scalar, which matches any reference frame in the `uavScenario`.

Data Types: `char` | `string`

Output Arguments

`permission` — Geofence permission for platform
`false` or `0` | `true` or `1`

Geofence permission for platform, returned as a `0` (`false`) or `1` (`true`), which indicates whether the UAV platform is permitted inside the geofence (`true`) or not permitted (`false`).

Data Types: `logical`

See Also

Functions
`addGeoFence` | `move` | `read` | `updateMesh`

Objects
`uavPlatform` | `uavScenario` | `uavSensor`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

move

Move UAV platform in scenario

Syntax

`move(platform,motion)`

Description

`move(platform,motion)` moves the UAV platform in the scenario according to the specified motion `motion`.

Input Arguments

`platform` — UAV platform
`uavPlatform` object

UAV platform in a scenario, specified as a `uavPlatform` object.

`motion` — UAV platform motion at current instance in scenario
16-element vector

UAV platform motion at the current instance in a UAV scenario, specified as a 16-element vector with these elements in order:

- `[x y z]` — Positions in *xyz*-axes in meters
- `[vx vy vz]` — Velocities in *xyz*-directions in meters per second
- `[ax ay az]` — Accelerations in *xyz*-directions in meters per second
- `[qw qx qy qz]` — Quaternion vector for orientation
- `[wx wy wz]` — Angular velocities in radians per second

Data Types: `double`

See Also

Functions
`addGeoFence` | `checkPermission` | `read` | `updateMesh`

Objects
`uavPlatform` | `uavScenario` | `uavSensor`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

read

Read UAV motion vector

Syntax

`[motion,LLA] = read(platform)`

Description

`[motion,LLA] = read(platform)` reads the latest motion of the UAV platform in the scenario.

Input Arguments

`platform` — UAV platform
`uavPlatform` object

UAV platform in a scenario, specified as a `uavPlatform` object.

Output Arguments

`motion` — UAV platform motion at current instance in scenario
16-element vector

UAV platform motion at the current instance in a UAV scenario, returned as a 16-element vector with these elements in order:

- `[x y z]` — Positions in *xyz*-axes in meters
- `[vx vy vz]` — Velocities in *xyz*-directions in meters per second
- `[ax ay az]` — Accelerations in *xyz*-directions in meters per second
- `[qw qx qy qz]` — Quaternion vector for orientation
- `[wx wy wz]` — Angular velocities in radians per second

Data Types: `double`

`LLA` — Latitude, longitude, and altitude coordinates of UAV platform
three-element vector of the form `[lat long alt]`

Latitude, longitude, and altitude coordinates of the UAV platform at the current instance in a UAV scenario, returned as a three-element vector of the form `[lat long alt]`.

Data Types: `double`

See Also

Functions
`addGeoFence` | `checkPermission` | `move` | `updateMesh`

Objects
`uavPlatform` | `uavScenario` | `uavSensor`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

updateMesh

Update body mesh for UAV platform

Syntax

```
updateMesh(platform,type,geometries,color,position,orientation)
updateMesh(platform,type,geometries,color,offset)
```

Description

`updateMesh(platform,type,geometries,color,position,orientation)` updates the body mesh of the UAV platform with the specified mesh type, geometry, color, position, and orientation.

`updateMesh(platform,type,geometries,color,offset)` specifies the relative mesh frame position and orientation as a homogeneous transformation matrix `offset`.

Input Arguments

`platform` — UAV platform
`uavPlatform` object

UAV platform in a scenario, specified as a `uavPlatform` object.

`type` — Type of mesh
`"fixedwing"` | `"quadrotor"` | `"cuboid"` | `"custom"`

Type of mesh, specified as `"fixedwing"`, `"quadrotor"`, `"cuboid"`, or `"custom"`.

Data Types: `string` | `char`

`geometries` — Geometric parameters of mesh
cell array

Gemetric parameters of the mesh, specified as a cell array with options that depend on the `type` input:

Geometry Parameters

input Type	Geometry Parameters	Description
"fixedwing"	{scale}	Positive scalar specifying the relative size of the fixed-wing mesh. Scale is unitless.
"quadrotor"	{scale}	Positive scalar specifying the relative size of the multirotor mesh. Scale is unitless.
"cuboid"	{[x y height]}	Three-element vector of the *xy*-position and height of the cuboid, specified in meters.
"custom"	{vertices faces}	Vertices and faces that define the mesh as two three-element vectors. Each vertex is a row of [x y z] points in meters. Each face is a row of [a b c] indices of vertex IDs, where a vertex ID is the row number of a vertex in vertices.

color — UAV platform body mesh color
RGB triplet

UAV platform body mesh color, specified as an RGB triplet.

Data Types: double

position — Relative mesh position
[0 0 0] (default) | vector of the form [x y z]

Relative mesh position in the body frame, specified as a vector of the form [x y z].

Data Types: double

orientation — Relative mesh orientation
[1 0 0 0] (default) | quaternion vector of the form [w x y z] | quaternion object

Relative mesh orientation, specified as a quaternion vector of the form [w x y z] or a quaternion object.

Data Types: double

offset — Transformation of mesh relative to body frame
4-by-4 homogeneous transformation matrix

Transform of mesh relative to the body frame, specified as a 4-by-4 homogeneous transformation matrix. The matrix maps points in the platform mesh frame to points in the body frame.

Data Types: double

See Also

Functions
addGeoFence | checkPermission | move | read

Objects
`uavPlatform` | `uavScenario` | `uavSensor`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

addInertialFrame

Define new inertial frame in UAV scenario

Syntax

```
addInertialFrame(scene,base,name,position,orientation)
addInertialFrame(scene,base,name,transformMatrix)
```

Description

`addInertialFrame(scene,base,name,position,orientation)` adds a new inertial frame to the UAV scenario `scene` by specifying the base, name, position, and orientation of the new inertial frame.

`addInertialFrame(scene,base,name,transformMatrix)` adds a new inertial frame to the UAV scenario `scene` by specifying the base, name, and transformation matrix of the new inertial frame.

Examples

Add an Inertial Frame to UAV Scenario

Create a UAV scenario. By default, the inertial frames are the ENU and the NED frames.

```
scene = uavScenario()
```

```
scene = 
  uavScenario with properties:

           UpdateRate: 10
             StopTime: Inf
    HistoryBufferSize: 100
    ReferenceLocation: [0 0 0]
         MaxNumFrames: 10
          CurrentTime: 0
            IsRunning: 0
        TransformTree: [1x1 transformTree]
       InertialFrames: ["ENU"    "NED"]
               Meshes: {}
            Platforms: [0x0 uavPlatform]
```

Add a new inertial frame named `Map` to the scenario.

```
addInertialFrame(scene,"NED","Map",[100 100 100],[1 0 0 0]);
```

You can now use the `Map` frame as a reference frame to define other objects in the scenario.

```
scene.InertialFrames(3)
```

```
ans = 
"Map"
```

Input Arguments

`scene` — UAV scenario
`uavScenario` object

UAV scenario, specified as a `uavScenario` object.

`base` — Base of new inertial frame
string scalar

Base of the new inertial frame, specified as a string scalar. The base frame must be defined in the scenario in advance.

Example: `"ENU"`

`name` — Name of new inertial frame
string scalar

Name of the new inertial frame, specified as a string scalar.

Example: `"newFrame"`

`position` — Position of new inertial frame
1-by-3 vector of scalar

Position of the new inertial frame with respect to the base frame (specified in the `base` argument), specified as a 1-by-3 vector of scalars in meters.

`orientation` — Orientation of new inertial frame
quaternion | 1-by-4 quaternion vector of scalar

Orientation of the new inertial frame with respect to the base frame (specified in the `base` argument), specified as a `quaternion` or a 1-by-4 quaternion vector of scalars. The specified orientation is from the base frame to the new inertial frame.

`transformMatrix` — Transformation matrix of new inertial frame
4-by-4 homogeneous transform matrix

Transformation matrix that maps points in the new frame (specified in the `base` argument) to the base frame, specified as a 4-by-4 homogeneous transform matrix that maps points in the base frame to the new inertial frame.

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

See Also

Introduced in R2020b

addMesh

Add new static mesh to UAV scenario

Syntax

```
addMesh(scene,type,geometry,color)
addMesh( ___ ,Name,Value)
```

Description

`addMesh(scene,type,geometry,color)` adds a static mesh to the UAV scenario `scene` by specifying the mesh type, geometry, and color.

`addMesh( ___ ,Name,Value)` specifies additional options using Name-Value pairs. Enclose each `Name` in quotes.

Examples

Add Meshes to UAV scenario

Create a UAV Scenario.

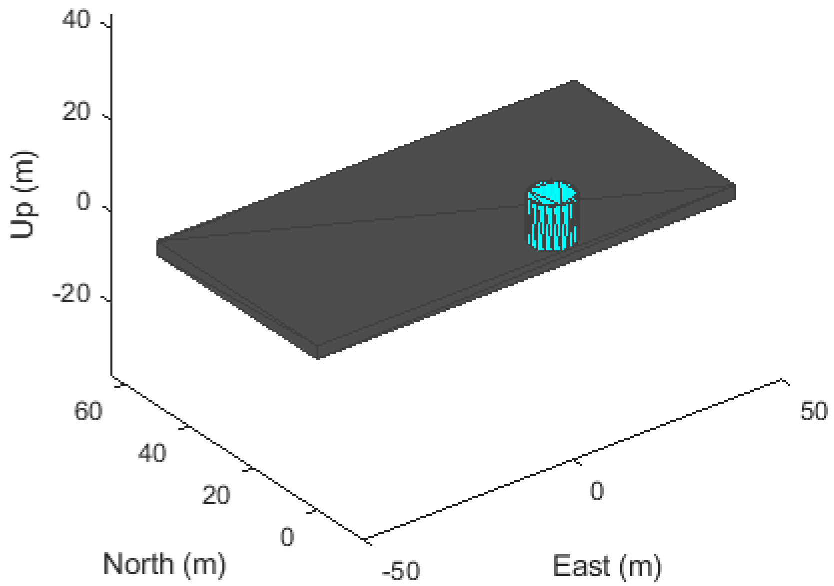
```
scene = uavScenario("UpdateRate",100,"StopTime",1);
```

Add the ground and a building as meshes.

```
addMesh(scene,"Polygon", {[-50 0; 50 0; 50 50; -50 50], [-3 0]}, [0.3 0.3 0.3]);
addMesh(scene,"Cylinder", {[10 5 5], [0 10]}, [0 1 1]);
```

Visualize the scenario.

```
show3D(scene);
```



Input Arguments

`scene` — UAV scenario
`uavScenario` object

UAV scenario, specified as a `uavScenario` object.

`type` — Mesh type
`"cylinder"` | `"polygon"`

Mesh type, specified as `"cylinder"` or `"polygon"`.

Data Types: `string`

`geometry` — Mesh geometry
cell

Mesh geometry, specified as a cell.

- When the `type` argument is specified as `"cylinder"`, the geometry must be specified in the format of `{[centerx, centery, radius],[zmin, zmax]}`. `centerx` and `centery` are the x- and y-coordinates of the center of the cylinder, respectively. `radius` is the radius of the cylinder in meters. `zmin` and `zmax` are the minimum and maximum z-axis coordinates of the cylinder in meters, respectively.

- When the `type` argument is specified as `"polygon"`, the geometry must be specified in the format of `{cornerPoints,[zmin, zmax]}`. `zmin` and `zmax` are the minimum and maximum z-axis coordinates of the polygon in meters, respectively. `conerPoints` contains the corner points of the polygon, specified as a *N*-by-2 matrix, where *N* is the number of corner points. The first column contains the x-coordinates and the second column contains the y-coordinates in meters.

`color` — Mesh color
RGB triplet

Mesh color, specified as a RGB triplet.

Example: `[1 0 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: `addMesh(scene,"Cylinder",{[46 42 5],[0 20]},[0 1 0],"UseLatLon",true)`

`UseLatLon` — Enable latitude and longitude coordinates
`false` (default) | `true`

Enable latitude and longitude coordinates, specified as `true` or `false`.

- When specified as `true`, the x and y coordinates in the `geometry` input are interpreted as longitude and latitude, respectively.
- When specified as `false`, the x and y coordinates in the `geometry` input are interpreted as Cartesian coordinates.

`ReferenceFrame` — Reference frame of geometry input
`"ENU"` (default) | `"NED"` | name of defined inertial frame

Reference frame of the geometry input, specified as an inertial frame name defined in the `InertialFrames` property of the `uavScenario` object `scene`. You can add new inertial frames to the scenario using the `addInertialFrame` object function.

See Also

Introduced in R2020b

advance

Advance UAV scenario simulation by one time step

Syntax

`isrunning = advance(scene)`

Description

`isrunning = advance(scene)` advances the UAV scenario simulation `scene` by one time step. The `UpdateRate` property of the `uavScenario` object determines the time step during simulation. The function returns the running status of the simulation. The function only updates a platform location if the platform has an assigned trajectory.

Examples

Simulate Simple UAV Scenario

Create a UAV scenario.

```
scene = uavScenario("UpdateRate",100,"StopTime",1);
```

Add the ground and a building as meshes.

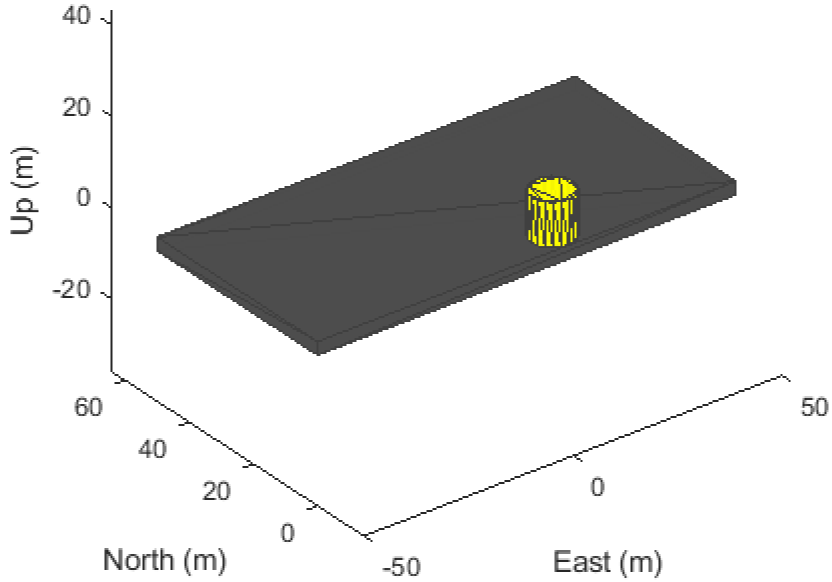
```
addMesh(scene,"Polygon", {[-50 0; 50 0; 50 50; -50 50], [-3 0]}, [0.3 0.3 0.3]);
addMesh(scene,"Cylinder", {[10 5 5], [0 10]}, [1 1 0]);
```

Create a UAV platform with a specified waypoint trajectory in the scenario. Define the mesh for the UAV platform.

```
traj = waypointTrajectory("Waypoints", [0 -20 -5; 20 0 -5], "TimeOfArrival", [0  1]);
uavPlat = uavPlatform("UAV",scene,"Trajectory", traj);
updateMesh(uavPlat,"quadrotor",{10},[1 0 0],eul2tform([0 0 0]));
```

Simulate and visualize the scenario.

```
setup(scene);
while advance(scene)
    show3D(scene);
    drawnow update
end
```




```
restart(scene);
```

Input Arguments

scene — UAV scenario
uavScenario object

UAV scenario, specified as a `uavScenario` object.

Output Arguments

isrunning — Running state of simulation
true | false

Running state of the simulation, returned as `true` or `false`. If `isrunning` is returned as `true`, then the simulation is running. If `isrunning` is returned as `false`, the simulation has stopped. A simulation stops when the stop time is reached.

See Also

Introduced in R2020b

restart

Reset simulation of UAV scenario

Syntax

```
restart(scene)
```

Description

`restart(scene)` resets the simulation of the UAV scenario `scene`. The function resets platforms' poses and sensor readings to `NaN`, resets the `CurrentTime` property of the scenario to zero, and resets the `IsRunning` property of the scenario to `false`.

Examples

Simulate Simple UAV Scenario

Create a UAV scenario.

```
scene = uavScenario("UpdateRate",100,"StopTime",1);
```

Add the ground and a building as meshes.

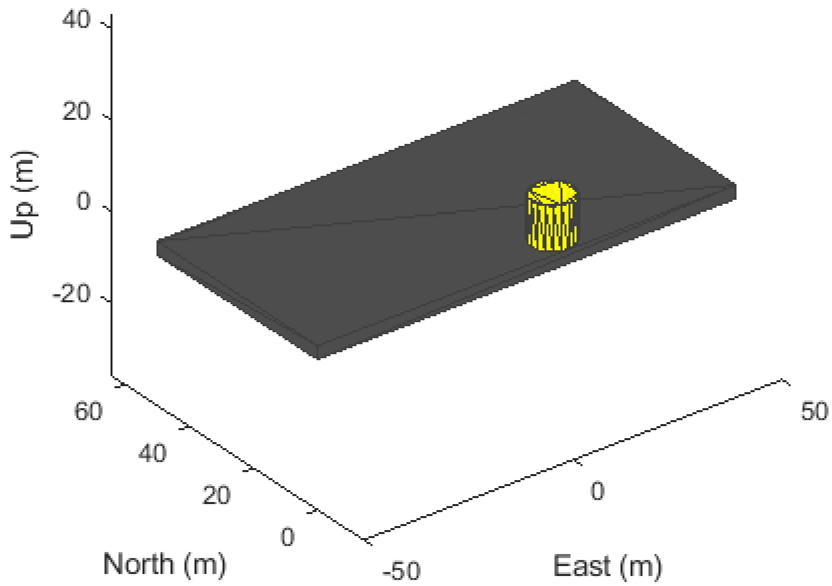
```
addMesh(scene,"Polygon", {[-50 0; 50 0; 50 50; -50 50], [-3 0]}, [0.3 0.3 0.3]);
addMesh(scene,"Cylinder", {[10 5 5], [0 10]}, [1 1 0]);
```

Create a UAV platform with a specified waypoint trajectory in the scenario. Define the mesh for the UAV platform.

```
traj = waypointTrajectory("Waypoints", [0 -20 -5; 20 0 -5], "TimeOfArrival", [0  1]);
uavPlat = uavPlatform("UAV",scene,"Trajectory", traj);
updateMesh(uavPlat,"quadrotor",{10},[1 0 0],eul2tform([0 0 0]));
```

Simulate and visualize the scenario.

```
setup(scene);
while advance(scene)
    show3D(scene);
    drawnow update
end
```




```
restart(scene);
```

Input Arguments

scene — UAV scenario
`uavScenario` object

UAV scenario, specified as a `uavScenario` object.

See Also

Introduced in R2020b

setup

Prepare UAV scenario for simulation

Syntax

```
setup(scene)
```

Description

`setup(scene)` prepares the UAV scenario `scene` for simulation and generates initial sensor readings.

Examples

Simulate Simple UAV Scenario

Create a UAV scenario.

```
scene = uavScenario("UpdateRate",100,"StopTime",1);
```

Add the ground and a building as meshes.

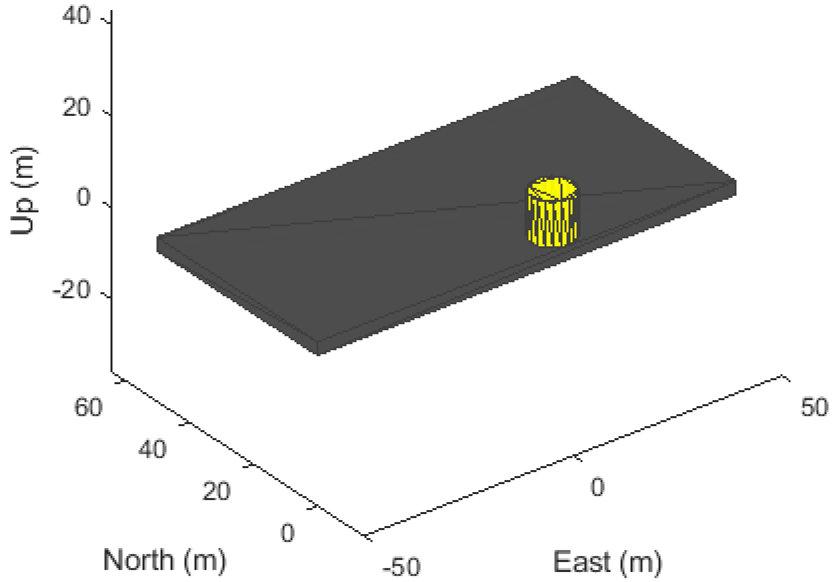
```
addMesh(scene,"Polygon", {[-50 0; 50 0; 50 50; -50 50], [-3 0]}, [0.3 0.3 0.3]);
addMesh(scene,"Cylinder", {[10 5 5], [0 10]}, [1 1 0]);
```

Create a UAV platform with a specified waypoint trajectory in the scenario. Define the mesh for the UAV platform.

```
traj = waypointTrajectory("Waypoints", [0 -20 -5; 20 0 -5], "TimeOfArrival", [0  1]);
uavPlat = uavPlatform("UAV",scene,"Trajectory", traj);
updateMesh(uavPlat,"quadrotor",{10},[1 0 0],eul2tform([0 0 0]));
```

Simulate and visualize the scenario.

```
setup(scene);
while advance(scene)
    show3D(scene);
    drawnow update
end
```




```
restart(scene);
```

Input Arguments

scene — UAV scenario
uavScenario object

UAV scenario, specified as a `uavScenario` object.

See Also

Introduced in R2020b

show

Visualize UAV scenario in 2-D

Syntax

```
ax = show(scene)
ax = show(scene,times)
ax = show( ___ ,Name,Value)
```

Description

`ax = show(scene)` visualizes the UAV scenario `scene` in 2-D with latest states of the platforms and returns the axes on which the scenario is plotted.

`ax = show(scene,times)` visualizes the UAV scenario `scene` at timestamps specified by the `times` input.

`ax = show( ___ ,Name,Value)` specifies additional options using Name-Value pairs. Enclose each `Name` in quotes.

Examples

Visualize UAV Scenario in 2D

Create a UAV scenario.

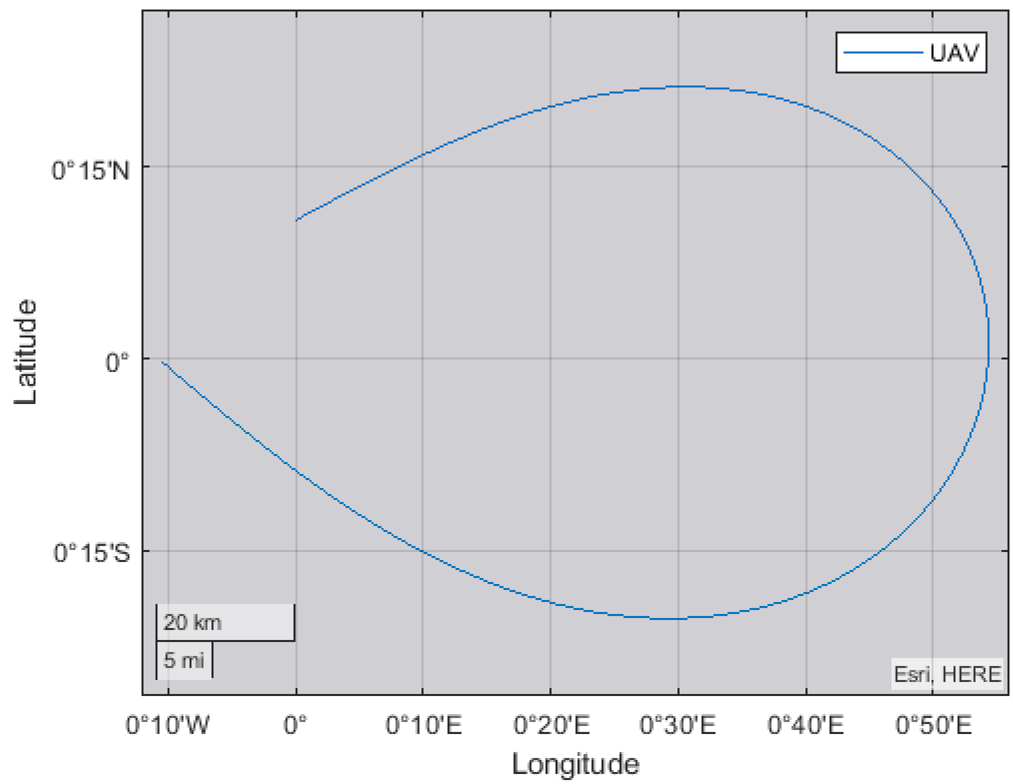
```
scene = uavScenario("UpdateRate",1,"StopTime",1000,"HistoryBufferSize",1000);
```

Create a UAV platform with a specified waypoint trajectory in the scenario.

```
traj = waypointTrajectory("Waypoints", [0 -20000 -50; 10000 100000 -50; 20000 0 -50], "TimeOfArr
uavPlat = uavPlatform("UAV",scene,"Trajectory", traj);
```

Visualize the trajectory in 2D.

```
setup(scene);
while advance(scene)
end
show(scene,0:1:1000)
```




```
ans = 
  GeographicAxes with properties:

      Basemap: 'streets-light'
     Position: [0.1300 0.1100 0.7750 0.8150]
        Units: 'normalized'

  Show all properties
```

Input Arguments

scene — UAV scenario
`uavScenario` object

UAV scenario, specified as a `uavScenario` object.

times — Time stamps
vector of nonnegative scalars

Time stamps at which to show the scenario, specified as a vector of nonnegative scalars. The specified time stamps must be saved in the scenario. To change the number of saved time stamps, use the `HistoryBufferSize` property of the `uavScenario` 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:

`Parent` — Parent axes for plotting
`geoaxes`

Parent axes for plotting the scenario, specified as a `geoaxes` object.

`MarkerSize` — Marker size
36 (default) | positive scalar

Marker size, specified as a positive scalar in points, where 1 point = 1/72 of an inch.

`ShowPlatformName` — Enable showing platform name
`true` (default) | `false`

Enable showing platform name, specified as `true` or `false`.

Output Arguments

ax — Axes on which the scenario is plotted
`geoaxes` object

Axes on which the scenario is plotted, returned as a `geoaxes` object.

See Also

Introduced in R2020b

show3D

Visualize UAV scenario in 3-D

Syntax

```
[ax,plottedFrames] = show3D(scene)
[ax,plottedFrames] = show3D(scene,time)
[ax,plottedFrames] = show3D( ___ ,Name,Value)
```

Description

`[ax,plottedFrames] = show3D(scene)` visualizes latest states of the platforms and sensors in the UAV scenario `scene` along with all static meshes. The function also returns the axes on which the scene is plotted and the frames on which each object is plotted.

`[ax,plottedFrames] = show3D(scene,time)` visualizes the UAV scenario at the specified `time`.

`[ax,plottedFrames] = show3D( ___ ,Name,Value)` specifies additional options using Name-Value pairs. Enclose each `Name` in quotes.

Examples

Create and Simulate UAV Scenario

Create a UAV scenario and set its local origin.

```
scene = uavScenario("UpdateRate",200,"StopTime",2,"ReferenceLocation",[46, 42, 0]);
```

Add an inertial frame called `MAP` to the scneario.

```
scene.addInertialFrame("ENU","MAP",trvec2tform([1 0 0]));
```

Add one ground mesh and two cylindrical obstacle meshes to the scenario.

```
scene.addMesh("Polygon", {[-100 0; 100 0; 100 100; -100 100],[-5 0]},[0.3 0.3 0.3]);
scene.addMesh("Cylinder", {[20 10 10],[0 30]}, [0 1 0]);
scene.addMesh("Cylinder", {[46 42 5],[0 20]}, [0 1 0], "UseLatLon", true);
```

Create a UAV platform with a specified waypoint trajectory in the scenario. Define the mesh for the UAV platform.

```
traj = waypointTrajectory("Waypoints", [0 -20 -5; 20 -20 -5; 20 0 -5],"TimeOfArrival",[0 1 2]);
uavPlat = uavPlatform("UAV",scene,"Trajectory",traj);
updateMesh(uavPlat,"quadrotor", {4}, [1 0 0],eul2tform([0 0 pi]));
addGeoFence(uavPlat,"Polygon", {[-50 0; 50 0; 50 50; -50 50],[0 100]},true,"ReferenceFrame","ENU"
```

Attach an INS sensor to the front of the UAV platform.

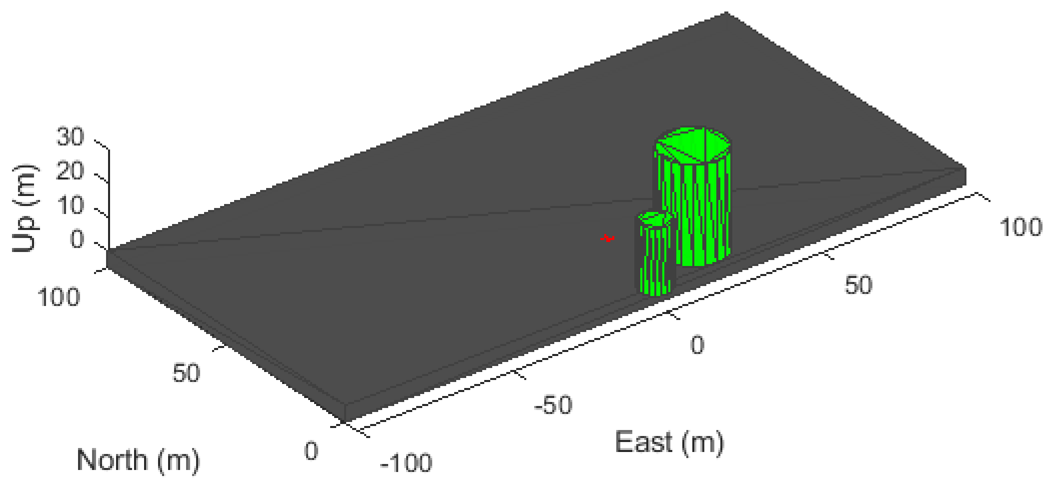
```
insModel = insSensor();
ins = uavSensor("INS",uavPlat,insModel,"MountingLocation",[4 0 0]);
```

Visualize the scenario in 3-D.

```
ax = show3D(scene);
axis(ax,"equal");
```

Simulate the scenario.

```
setup(scene);
while advance(scene)
    % Update sensor readings
    updateSensors(scene);

    % Visualize the scenario
    show3D(scene,"Parent",ax,"FastUpdate",true);
    drawnow limitrate
end
```



Input Arguments

scene — UAV scenario
uavScenario object

UAV scenario, specified as a `uavScenario` object.

time — Time stamp
nonnegative scalar

Time stamp at which to show the scenario, specified as a nonnegative scalar. The time stamp must already be saved in the scenario. To change the number of saved time stamps, use the `HistoryBufferSize` property of the `uavScenario` object, `scene`.

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` — Parent axes for plotting
`axes` | `uiaxes`

Parent axes for plotting, specified as an `axes` object or a `uiaxes` object.

`FastUpdate` — Enable updating from previous map
`false` (default) | `true`

Enable updating from previous map, specified as `true` or `false`. When specified as `true`, the function plots the map via a lightweight update to the previous map in the figure. When specified as `false`, the function plots the whole scene on the figure every time.

Output Arguments

`ax` — Axes on which the scenario is plotted
`axes` object | `uiaxes` object

Axes on which the scenario is plotted, returned as an `axes` object or a `uiaxes` object.

`plottedFrames` — Plotted frame information
structure

Plotted frame information, returned as a structure of `hgtransform` objects. The struct has two types of field names:

- Inertial frame names — The corresponding field value is a `hgtransform` object which contains the transform information from the ego frame to the ENU frame.
- UAV platform names — The corresponding field value is a structure which contains the `hgtransform` information for all frames defined on the platform.

See Also

Introduced in R2020b

updateSensors

Update sensor readings in UAV scenario

Syntax

`updateSensors(scene)`

Description

`updateSensors(scene)` updates all sensor readings based on latest states of all platforms in the UAV scenario, `scene`.

Examples

Create and Simulate UAV Scenario

Create a UAV scenario and set its local origin.

```
scene = uavScenario("UpdateRate",200,"StopTime",2,"ReferenceLocation",[46, 42, 0]);
```

Add an inertial frame called `MAP` to the scneario.

```
scene.addInertialFrame("ENU","MAP",trvec2tform([1 0 0]));
```

Add one ground mesh and two cylindrical obstacle meshes to the scenario.

```
scene.addMesh("Polygon", {[-100 0; 100 0; 100 100; -100 100],[-5 0]},[0.3 0.3 0.3]);
scene.addMesh("Cylinder", {[20 10 10],[0 30]}, [0 1 0]);
scene.addMesh("Cylinder", {[46 42 5],[0 20]}, [0 1 0], "UseLatLon", true);
```

Create a UAV platform with a specified waypoint trajectory in the scenario. Define the mesh for the UAV platform.

```
traj = waypointTrajectory("Waypoints", [0 -20 -5; 20 -20 -5; 20 0 -5],"TimeOfArrival",[0 1 2]);
uavPlat = uavPlatform("UAV",scene,"Trajectory",traj);
updateMesh(uavPlat,"quadrotor", {4}, [1 0 0],eul2tform([0 0 pi]));
addGeoFence(uavPlat,"Polygon", {[-50 0; 50 0; 50 50; -50 50],[0 100]},true,"ReferenceFrame","ENU
```

Attach an INS sensor to the front of the UAV platform.

```
insModel = insSensor();
ins = uavSensor("INS",uavPlat,insModel,"MountingLocation",[4 0 0]);
```

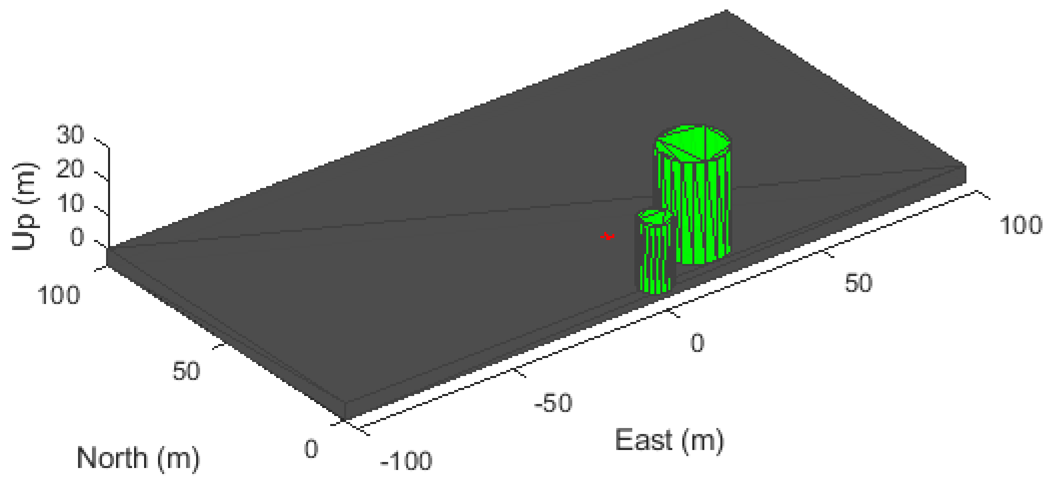
Visualize the scenario in 3-D.

```
ax = show3D(scene);
axis(ax,"equal");
```

Simulate the scenario.

```
setup(scene);
while advance(scene)
```

```
    % Update sensor readings
    updateSensors(scene);

    % Visualize the scenario
    show3D(scene,"Parent",ax,"FastUpdate",true);
    drawnow limitrate
end
```



Input Arguments

scene — UAV scenario
uavScenario object

UAV scenario, specified as a `uavScenario` object.

See Also

`gpsSensor` | `insSensor` | `uavSensor`

Introduced in R2020b

read

Gather latest reading from UAV sensor

Syntax

```
[isUpdated,t,sensorReadings] = read(sensor)
```

Description

`[isUpdated,t,sensorReadings] = read(sensor)` gathers the simulated sensor output sensor readings from the latest update of the UAV platform associated with the specified sensor `sensor`. The function returns an indicator `isUpdated` of whether the reading was updated at the simulation step in the scenario with timestamp `t`.

Input Arguments

`sensor` — UAV sensor added to platform in scenario
`uavSensor` object

UAV sensor added to a platform in a scenario, specified as a `uavSensor` object.

Output Arguments

`isUpdated` — Sensor reading update indicator
`0` or `false` | `1` or `true`

Sensor reading update indicator, returned as a logical `0` (`false`) or `1`(`true`). If the sensor reading updated at the current simulation step, the function returns this argument as `true`.

Data Types: `logical`

`t` — Timestamp of the generated sensor reading
scalar in seconds

Timestamp of the generated sensor reading, returned as a scalar in seconds.

Data Types: `double`

`sensorReadings` — Simulated sensor readings
`insSensor` output | `gpsSensor` output | `uavLidarPointCloudGenerator` output

Simulated sensor readings, which depends on the type of sensor specified in the `sensor` input argument. See the **Usage** syntax for the appropriate `insSensor`, `gpsSensor`, or `uavLidarPointCloudGenerator` System object.

See Also

Objects
`uavPlatform` | `uavScenario` | `uavSensor`

Topics
"UAV Scenario Tutorial"

Introduced in R2020b

readLoggedOutput

Read logged output messages

Syntax

```
logTable = readLoggedOutput(ulogOBJ)
logTable = readLoggedOutput(ulogOBJ,Name,Value)
```

Description

`logTable = readLoggedOutput(ulogOBJ)` reads the data of all logged output messages from the specified `ulogreader` object and returns a timetable that contains log levels and messages.

`logTable = readLoggedOutput(ulogOBJ,Name,Value)` reads specific logged output messages based on the specified name-value pairs.

Example: `readLoggedOutput(ulog,'Time',[d1 d2])`

Examples

Read Messages from ULOG File

Load the ULOG file. Specify the relative path of the file.

```
ulog = ulogreader('flight.ulg');
```

Read all topic messages.

```
msg = readTopicMsgs(ulog);
```

Specify the time interval between which to select messages.

```
d1 = ulog.StartTime;
d2 = d1 + duration([0 0 55],'Format','hh:mm:ss.SSSSSS');
```

Read messages from the topic `'vehicle_attitude'` with an instance ID of `0` in the time interval `[d1 d2]`.

```
data = readTopicMsgs(ulog,'TopicNames',{'vehicle_attitude'}, ...
'InstanceID',{0},'Time',[d1 d2]);
```

Extract topic messages for the topic.

```
vehicle_attitude = data.TopicMessages{1,1};
```

Read all system information.

```
systeminfo = readSystemInformation(ulog);
```

Read all initial parameter values.

```
params = readParameters(ulog);
```

Read all logged output messages.

```
loggedoutput = readLoggedOutput(ulog);
```

Read logged output messages in the time interval.

```
log = readLoggedOutput(ulog,'Time',[d1 d2]);
```

Input Arguments

`ulogOBJ` — ULOG file reader
`ulogreader` object

ULOG file reader, specified as a `ulogreader` 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: `'Time',[d1 d2]`

`Time` — Time interval
two-element vector

Time interval between which to select messages, specified as a two-element vector of `duration`, or a double array. The duration array is specified in the `'hh:mm:ss.SSSSSS'` format. The double array is specified in microseconds.

Example: `'Time',[d1 d2]`

Output Arguments

`logTable` — Logged output messages
timetable

Logged output messages, returned as a timetable with the columns:

- `LogLevel`
- `Messages`

See Also

Objects
`ulogreader`

Functions
`readParameters` | `readSystemInformation` | `readTopicMsgs`

Introduced in R2020b

readParameters

Read parameter values

Syntax

```
paramsTable = readParameters(ulogOBJ)
```

Description

`paramsTable = readParameters(ulogOBJ)` reads the data of all initial parameters from the specified `ulogreader` object and returns a table that contains all the parameter names with their respective values.

Examples

Read Messages from ULOG File

Load the ULOG file. Specify the relative path of the file.

```
ulog = ulogreader('flight.ulg');
```

Read all topic messages.

```
msg = readTopicMsgs(ulog);
```

Specify the time interval between which to select messages.

```
d1 = ulog.StartTime;
d2 = d1 + duration([0 0 55],'Format','hh:mm:ss.SSSSSS');
```

Read messages from the topic `'vehicle_attitude'` with an instance ID of `0` in the time interval `[d1 d2]`.

```
data = readTopicMsgs(ulog,'TopicNames',{'vehicle_attitude'}, ...
'InstanceID',{0},'Time',[d1 d2]);
```

Extract topic messages for the topic.

```
vehicle_attitude = data.TopicMessages{1,1};
```

Read all system information.

```
systeminfo = readSystemInformation(ulog);
```

Read all initial parameter values.

```
params = readParameters(ulog);
```

Read all logged output messages.

```
loggedoutput = readLoggedOutput(ulog);
```

Read logged output messages in the time interval.

```
log = readLoggedOutput(ulog,'Time',[d1 d2]);
```

Input Arguments

ulogOBJ — ULOG file reader
ulogreader object

ULOG file reader, specified as a ulogreader object.

Output Arguments

paramsTable — Initial parameters
table

Initial parameters, returned as a table with the columns:

- Parameters
- Value

See Also

Objects
ulogreader

Functions
readLoggedOutput | readSystemInformation | readTopicMsgs

Introduced in R2020b

readSystemInformation

Read information messages

Syntax

`infoTable = readSystemInformation(ulogOBJ)`

Description

`infoTable = readSystemInformation(ulogOBJ)` reads the data of information messages from the specified `ulogreader` object and returns a table that contains all the information fields with their respective values.

Examples

Read Messages from ULOG File

Load the ULOG file. Specify the relative path of the file.

```
ulog = ulogreader('flight.ulg');
```

Read all topic messages.

```
msg = readTopicMsgs(ulog);
```

Specify the time interval between which to select messages.

```
d1 = ulog.StartTime;
d2 = d1 + duration([0 0 55],'Format','hh:mm:ss.SSSSSS');
```

Read messages from the topic `'vehicle_attitude'` with an instance ID of `0` in the time interval `[d1 d2]`.

```
data = readTopicMsgs(ulog,'TopicNames',{'vehicle_attitude'}, ...
'InstanceID',{0},'Time',[d1 d2]);
```

Extract topic messages for the topic.

```
vehicle_attitude = data.TopicMessages{1,1};
```

Read all system information.

```
systeminfo = readSystemInformation(ulog);
```

Read all initial parameter values.

```
params = readParameters(ulog);
```

Read all logged output messages.

```
loggedoutput = readLoggedOutput(ulog);
```

Read logged output messages in the time interval.

```
log = readLoggedOutput(ulog,'Time',[d1 d2]);
```

Input Arguments

ulogOBJ — ULOG file reader
ulogreader object

ULOG file reader, specified as a `ulogreader` object.

Output Arguments

infoTable — System information
table

System information, returned as a table with the columns:

- `InformationField`
- `Value`

See Also

Objects
`ulogreader`

Functions
`readLoggedOutput` | `readParameters` | `readTopicMsgs`

Introduced in R2020b

readTopicMsgs

Read topic messages

Syntax

```
msgTable = readTopicMsgs(ulogOBJ)
msgTable = readTopicMsgs(ulogOBJ,Name,Value)
```

Description

`msgTable = readTopicMsgs(ulogOBJ)` reads the data of all topic messages from the specified `ulogreader` object and returns a table that contains topic names, instance ID, start timestamp, last timestamp, topic messages, and message format for all available topics.

`msgTable = readTopicMsgs(ulogOBJ,Name,Value)` reads the data pertaining to the specified name-value pairs.

Example: `readTopicMsgs(ulog,'TopicNames',{'vehicle_attitude'},'InstanceID',{0},'Time',[d1 d2])`

Examples

Read Messages from ULOG File

Load the ULOG file. Specify the relative path of the file.

```
ulog = ulogreader('flight.ulg');
```

Read all topic messages.

```
msg = readTopicMsgs(ulog);
```

Specify the time interval between which to select messages.

```
d1 = ulog.StartTime;
d2 = d1 + duration([0 0 55],'Format','hh:mm:ss.SSSSSS');
```

Read messages from the topic `'vehicle_attitude'` with an instance ID of `0` in the time interval `[d1 d2]`.

```
data = readTopicMsgs(ulog,'TopicNames',{'vehicle_attitude'}, ...
'InstanceID',{0},'Time',[d1 d2]);
```

Extract topic messages for the topic.

```
vehicle_attitude = data.TopicMessages{1,1};
```

Read all system information.

```
systeminfo = readSystemInformation(ulog);
```

Read all initial parameter values.

```
params = readParameters(ulog);
```

Read all logged output messages.

```
loggedoutput = readLoggedOutput(ulog);
```

Read logged output messages in the time interval.

```
log = readLoggedOutput(ulog,'Time',[d1 d2]);
```

Input Arguments

`ulogOBJ` — ULOG file reader
`ulogreader` object

ULOG file reader, specified as a `ulogreader` 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: `'Time',[d1 d2]`

`TopicNames` — Topic names of desired messages
cell array of character vectors | string array

Topic names of the desired messages, specified as a cell array of character vectors or a string array.

Example: `'TopicNames',{'sensor_combined','actuator_outputs'}` or `'TopicNames',["actuator_outputs","ekf2_timestamps"]`

`InstanceID` — Instance ID of topic of desired messages
cell array of positive integer scalars or vectors

Instance ID of the topic of the desired messages, specified as a cell array of positive integer scalars or vectors. Specify this name-value pair along with its corresponding `'TopicNames'` name-value pair.

Example: `'TopicNames',{'vehicle_attitude','actuator_outputs'},'InstanceID',{0,[0 1]}`

`Time` — Time interval
two-element vector

Time interval between which to select messages, specified as a two-element vector of `duration`, or a double array. The duration array is specified in the `'hh:mm:ss.SSSSSS'` format. The double array is specified in microseconds.

Example: `'Time',[d1 d2]`

Output Arguments

`msgTable` — Topic messages information
table

Topic messages information, returned as a table with the columns:

- `TopicNames`
- `InstanceID`
- `StartTimestamp`
- `LastTimestamp`
- `TopicMessages`
- `MsgFormat`

See Also

Objects
`ulogreader`

Functions
`readLoggedOutput` | `readParameters` | `readSystemInformation`

Introduced in R2020b

lookupPose

Obtain pose information for certain time

Syntax

```
[position,orientation,velocity,acceleration,angularVelocity] = lookupPose(
traj,sampleTimes)
```

Description

`[position,orientation,velocity,acceleration,angularVelocity] = lookupPose(traj,sampleTimes)` returns the pose information of the waypoint trajectory at the specified sample times. If any sample time is beyond the duration of the trajectory, the corresponding pose information is returned as `NaN`.

Input Arguments

`traj` — Waypoint trajectory
`waypointTrajectory` object

Waypoint trajectory, specified as a `waypointTrajectory` object.

`sampleTimes` — Sample times
M-element vector of nonnegative scalar

Sample times in seconds, specified as an *M*-element vector of nonnegative scalars.

Output Arguments

`position` — Position in local navigation coordinate system (m)
M-by-3 matrix

Position in the local navigation coordinate system in meters, returned as an *M*-by-3 matrix.

M is specified by the `sampleTimes` input.

Data Types: `double`

`orientation` — Orientation in local navigation coordinate system
M-element quaternion column vector | 3-by-3-by-*M* real array

Orientation in the local navigation coordinate system, returned as an *M*-by-1 `quaternion` column vector or a 3-by-3-by-*M* real array.

Each quaternion or 3-by-3 rotation matrix is a frame rotation from the local navigation coordinate system to the current body coordinate system.

M is specified by the `sampleTimes` input.

Data Types: `double`

`velocity` — Velocity in local navigation coordinate system (m/s)
M-by-3 matrix

Velocity in the local navigation coordinate system in meters per second, returned as an *M*-by-3 matrix.

M is specified by the `sampleTimes` input.

Data Types: `double`

`acceleration` — Acceleration in local navigation coordinate system (m/s^2)
M-by-3 matrix

Acceleration in the local navigation coordinate system in meters per second squared, returned as an *M*-by-3 matrix.

M is specified by the `sampleTimes` input.

Data Types: `double`

`angularVelocity` — Angular velocity in local navigation coordinate system (rad/s)
M-by-3 matrix

Angular velocity in the local navigation coordinate system in radians per second, returned as an *M*-by-3 matrix.

M is specified by the `sampleTimes` input.

Data Types: `double`

See Also

`waypointTrajectory`

Introduced in R2020a

waypointInfo

Get waypoint information table

Syntax

```
trajectoryInfo = waypointInfo(trajectory)
```

Description

`trajectoryInfo = waypointInfo(trajectory)` returns a table of waypoints, times of arrival, velocities, and orientation for the `trajectory` System object

Input Arguments

`trajectory` — Object of `waypointTrajectory`
object

Object of the `waypointTrajectory` System object.

Output Arguments

`trajectoryInfo` — Trajectory information
table

Trajectory information, returned as a table with variables corresponding to set creation properties: Waypoints, TimeOfArrival, Velocities, and Orientation.

The trajectory information table always has variables `Waypoints` and `TimeOfArrival`. If the `Velocities` property is set during construction, the trajectory information table additionally returns velocities. If the `Orientation` property is set during construction, the trajectory information table additionally returns orientation.

See Also

Introduced in R2018b

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*.

Examples

Calculate Difference Between Two Angles

```
d = angdiff(pi,2*pi)
```

```
d = 3.1416
```

Calculate Difference Between Two Angle Arrays

```
d = angdiff([pi/2 3*pi/4 0],[pi pi/2 -pi])
```

```
d = 1×3

    1.5708   -0.7854   -3.1416
```

Calculate Angle Differences of Adjacent Elements

```
angles = [pi pi/2 pi/4 pi/2];
d = angdiff(angles)
```

```
d = 1×3
```

```
   -1.5708   -0.7854    0.7854
```

Input Arguments

alpha — Angle in radians
scalar | vector | matrix | multidimensional array

Angle in radians, specified as a scalar, vector, matrix, or multidimensional array. This is the angle that is subtracted from `beta` when specified.

Example: `pi/2`

beta — Angle in radians
scalar | vector | matrix | multidimensional array

Angle in radians, specified as a scalar, vector, matrix, or multidimensional array of the same size as `alpha`. This is the angle that `alpha` is subtracted from when specified.

Example: `pi/2`

Output Arguments

delta — Difference between two angles
scalar | vector | matrix | multidimensional array

Angular difference between two angles, returned as a scalar, vector, or array. `delta` is wrapped to the interval `[-pi,pi]`.

Extended Capabilities

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

Introduced in R2015a

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`

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`

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`

Introduced in R2015a

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`

Introduced in R2015a

enu2lla

Transform local east-north-up coordinates to geodetic coordinates

Syntax

```
lla = enu2lla(xyzENU,lla0,method)
```

Description

`lla = enu2lla(xyzENU,lla0,method)` transforms the local east-north-up (ENU) Cartesian coordinates `xyzENU` to geodetic coordinates `lla`. Specify the origin of the local ENU system as the geodetic coordinates `lla0`.

Note

- The latitude and longitude values in the geodetic coordinate system use the World Geodetic System of 1984 (WGS84) standard.
- Specify altitude as height in meters above the WGS84 reference ellipsoid.

Examples

Convert ENU Coordinates to Geodetic Coordinates

This example shows how to convert local east-north-up (ENU) Cartesian coordinates to geodetic coordinates.

Specify the geodetic coordinates of the local origin. `lat0` and `lon0` specify the latitude and longitude respectively in degrees. `alt0` specifies the altitude in meters. In this example, the local origin is Zermatt, Switzerland.

```
lla0 = [46.017 7.750 1673]; % [lat0 lon0 alt0]
```

Specify the ENU coordinates of the point of interest in meters. In this example, the point of interest is the Matterhorn.

```
xyzENU = [-7134.8 -4556.3 2852.4]; % [xEast yNorth zUp]
```

Transform from local ENU to geodetic coordinates using flat earth approximation.

```
lla = enu2lla(xyzENU, lla0, 'flat')
```

```
lla = 1×3
10³ ×

    0.0460    0.0077    4.5254
```

Input Arguments

`xyzENU` — Local ENU Cartesian coordinates
three-element row vector | *n*-by-3 matrix

Local ENU Cartesian coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of points to transform. Specify each point in the form [*xEast yNorth zUp*]. *xEast*, *yNorth*, and *zUp* are the respective *x*-, *y*-, and *z*-coordinates, in meters, of the point in the local ENU system.

Data Types: `double`

`lla0` — Origin of local ENU system in geodetic coordinates
three-element row vector | *n*-by-3 matrix

Origin of the local ENU system in the geodetic coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of origin points. Specify each point in the form `[`*`lat0 lon0 alt0`*`]`. *lat0* and *lon0* specify the latitude and longitude of the origin, respectively, in degrees. *alt0* specifies the altitude of the origin in meters.

Data Types: `double`

`method` — Transformation method
`'flat'` | `'ellipsoid'`

Transformation method, specified as `'flat'` or `'ellipsoid'`. This argument specifies whether the function assumes the planet is flat or ellipsoidal.

The flat Earth approximation has these limitations:

- This transformation method assumes that the flight path and bank angle are zero.
- This transformation method assumes that the flat Earth *z*-axis is normal to the Earth at only the initial geodetic latitude and longitude. This method has higher accuracy over small distances from the initial geodetic latitude and longitude, and closer to the equator. The method calculates a longitude with higher accuracy when the variation in latitude is smaller.
- Latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Data Types: `char` | `string`

Output Arguments

`lla` — Geodetic coordinates
three-element row vector | *n*-by-3 matrix

Geodetic coordinates, returned as a three-element row vector or an *n*-by-3 matrix. *n* is the number of transformed points. Each point is in the form `[`*`lat lon alt`*`]`. *lat* and *lon* specify the latitude and longitude, respectively, in degrees. *alt* specifies the altitude in meters.

Data Types: `double`

Extended Capabilities

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

See Also

`lla2enu` | `lla2ned` | `ned2lla`

Introduced in R2020b

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`

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`

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`

Introduced in R2015a

hom2cart

Convert homogeneous coordinates to Cartesian coordinates

Syntax

`cart = hom2cart(hom)`

Description

`cart = hom2cart(hom)` converts a set of homogeneous points to Cartesian coordinates.

Examples

Convert Homogeneous Points to 3-D Cartesian Points

```
h = [0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5];
c = hom2cart(h)
```

```
c = 2×3

    0.5570    1.9150    0.3152
    1.0938    1.9298    1.9412
```

Input Arguments

`hom` — Homogeneous points
n-by-*k* matrix

Homogeneous points, specified as an *n*-by-*k* matrix, containing *n* points. *k* must be greater than or equal to 2.

Example: `[0.2785 0.9575 0.1576 0.5; 0.5469 0.9649 0.9706 0.5]`

Output Arguments

`cart` — Cartesian coordinates
n-by-(*k*–1) matrix

Cartesian coordinates, returned as an *n*-by-(*k*–1) matrix, containing *n* points. Each row of `cart` represents a point in (*k*–1)-dimensional space. *k* must be greater than or equal to 2.

Example: `[0.8147 0.1270 0.6324; 0.9058 0.9134 0.0975]`

Extended Capabilities

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

See Also
`cart2hom`

Introduced in R2015a

lla2enu

Transform geodetic coordinates to local east-north-up coordinates

Syntax

```
xyzENU = lla2enu(lla,lla0,method)
```

Description

`xyzENU = lla2enu(lla,lla0,method)` transforms the geodetic coordinates `lla` to local east-north-up (ENU) Cartesian coordinates `xyzENU`. Specify the origin of the local ENU system as the geodetic coordinates `lla0`.

Note

- The latitude and longitude values in the geodetic coordinate system use the World Geodetic System of 1984 (WGS84) standard.
- Specify altitude as height in meters above the WGS84 reference ellipsoid.

Examples

Convert Geodetic Coordinates to ENU Coordinates

This example shows how to convert geodetic coordinates to local east-north-up (ENU) Cartesian coordinates.

Specify the geodetic coordinates of the local origin. In this example, the local origin is Zermatt, Switzerland.

```
lla0 = [46.017 7.750 1673]; % [lat0 lon0 alt0]
```

Specify the geodetic coordinates of the point of interest. `lat` and `lon` specify the latitude and longitude respectively in degrees. `alt` specifies the altitude in meters. In this example, the point of interest is the Matterhorn.

```
lla = [45.976 7.658 4531]; % [lat lon alt]
```

Transform from geodetic coordinates to local ENU using flat earth approximation.

```
xyzENU = lla2enu(lla, lla0, 'flat')
```

```
xyzENU = 1×3
10³ ×

   -7.1244   -4.5572    2.8580
```

Input Arguments

lla — Geodetic coordinates
three-element row vector | *n*-by-3 matrix

Geodetic coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of points to transform. Specify each point in the form `[lat lon alt]`. *lat* and *lon* specify the latitude and longitude respectively in degrees. *alt* specifies the altitude in meters.

Data Types: `double`

lla0 — Origin of local ENU system in geodetic coordinates
three-element row vector | *n*-by-3 matrix

Origin of the local ENU system in the geodetic coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of origin points. Specify each point in the form `[lat0 lon0 alt0]`. *lat0* and *lon0* specify the latitude and longitude of the origin, respectively, in degrees. *alt0* specifies the altitude of the origin in meters.

Data Types: `double`

method — Transformation method
`'flat'` | `'ellipsoid'`

Transformation method, specified as `'flat'` or `'ellipsoid'`. This argument specifies whether the function assumes the planet is flat or ellipsoidal.

The flat Earth approximation has these limitations:

- This transformation method assumes that the flight path and bank angle are zero.
- This transformation method assumes that the flat Earth *z*-axis is normal to the Earth at only the initial geodetic latitude and longitude. This method has higher accuracy over small distances from the initial geodetic latitude and longitude, and closer to the equator. The method calculates a longitude with higher accuracy when the variation in latitude is smaller.
- Latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Data Types: `char` | `string`

Output Arguments

xyzENU — Local ENU Cartesian coordinates
three-element row vector | *n*-by-3 matrix

Local ENU Cartesian coordinates, returned as a three-element row vector or an *n*-by-3 matrix. *n* is the number of transformed points. Each point is in the form `[xEast yNorth zUp]`. *xEast*, *yNorth*, and *zUp* are the respective *x*-, *y*-, and *z*-coordinates, in meters, of the point in the local ENU system.

Data Types: `double`

Extended Capabilities

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

See Also
`enu2lla` | `lla2ned` | `ned2lla`

Introduced in R2020b

lla2ned

Transform geodetic coordinates to local north-east-down coordinates

Syntax

```
xyzNED = lla2ned(lla,lla0,method)
```

Description

`xyzNED = lla2ned(lla,lla0,method)` transforms the geodetic coordinates `lla` to local north-east-down (NED) Cartesian coordinates `xyzNED`. Specify the origin of the local NED system as the geodetic coordinates `lla0`.

Note

- The latitude and longitude values in the geodetic coordinate system use the World Geodetic System of 1984 (WGS84) standard.
- Specify altitude as height in meters above the WGS84 reference ellipsoid.

Examples

Convert Geodetic Coordinates to NED Coordinates

This example shows how to convert geodetic coordinates to local north-east-down (NED) Cartesian coordinates.

Specify the geodetic coordinates of the local origin. In this example, the local origin is Zermatt, Switzerland.

```
lla0 = [46.017 7.750 1673]; % [lat0 lon0 alt0]
```

Specify the geodetic coordinates of the point of interest. `lat` and `lon` specify the latitude and longitude respectively in degrees. `alt` specifies the altitude in meters. In this example, the point of interest is the Matterhorn.

```
lla = [45.976 7.658 4531]; % [lat lon alt]
```

Transform from geodetic coordinates to local NED using flat earth approximation.

```
xyzNED = lla2ned(lla, lla0, 'flat')
```

```
xyzNED = 1×3
10³ ×

   -4.5572   -7.1244   -2.8580
```

Input Arguments

`lla` — Geodetic coordinates

three-element row vector | *n*-by-3 matrix

Geodetic coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of points to transform. Specify each point in the form `[lat lon alt]`. *lat* and *lon* specify the latitude and longitude respectively in degrees. *alt* specifies the altitude in meters.

Data Types: `double`

`lla0` — Origin of local NED system in geodetic coordinates

three-element row vector | *n*-by-3 matrix

Origin of the local NED system with the geodetic coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of origin points. Specify each point in the form `[lat0 lon0 alt0]`. *lat0* and *lon0* specify the latitude and longitude respectively in degrees. *alt0* specifies the altitude in meters.

Data Types: `double`

`method` — Transformation method

`'flat'` | `'ellipsoid'`

Transformation method, specified as `'flat'` or `'ellipsoid'`. This argument specifies whether the function assumes the planet is flat or ellipsoidal.

The flat Earth approximation has these limitations:

- This transformation method assumes that the flight path and bank angle are zero.
- This transformation method assumes that the flat Earth *z*-axis is normal to the Earth at only the initial geodetic latitude and longitude. This method has higher accuracy over small distances from the initial geodetic latitude and longitude, and closer to the equator. The method calculates a longitude with higher accuracy when the variation in latitude is smaller.
- Latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Data Types: `char` | `string`

Output Arguments

`xyzNED` — Local NED Cartesian coordinates

three-element row vector | *n*-by-3 matrix

Local NED Cartesian coordinates, returned as a three-element row vector or an *n*-by-3 matrix. *n* is the number of transformed points. Each point is in the form `[xNorth yEast zDown]`. *xNorth*, *yEast*, and *zDown* are the respective *x*-, *y*-, and *z*-coordinates, in meters, of the point in the local NED system.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation

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

See Also

enu2lla | lla2enu | ned2lla

Introduced in R2020b

ned2lla

Transform local north-east-down coordinates to geodetic coordinates

Syntax

```
lla = ned2lla(xyzNED,lla0,method)
```

Description

`lla = ned2lla(xyzNED,lla0,method)` transforms the local north-east-down (NED) Cartesian coordinates `xyzNED` to geodetic coordinates `lla`. Specify the origin of the local NED system as the geodetic coordinates `lla0`.

Note

- The latitude and longitude values in the geodetic coordinate system use the World Geodetic System of 1984 (WGS84) standard.
- Specify altitude as height in meters above the WGS84 reference ellipsoid.

Examples

Convert NED Coordinates to Geodetic Coordinates

This example shows how to convert local north-east-down (NED) Cartesian coordinates to geodetic coordinates.

Specify the geodetic coordinates of the local origin. `lat0` and `lon0` specify the latitude and longitude respectively in degrees. `alt0` specifies the altitude in meters. In this example, the local origin is Zermatt, Switzerland.

```
lla0 = [46.017 7.750 1673]; % [lat0 lon0 alt0]
```

Specify the NED coordinates of the point of interest in meters. In this example, the point of interest is the Matterhorn.

```
xyzNED = [-4556.3 -7134.8 -2852.4]; % [xNorth yEast zDown]
```

Transform from local NED to geodetic coordinates using flat earth approximation.

```
lla = ned2lla(xyzNED, lla0, 'flat')
```

```
lla = 1×3
10³ ×

    0.0460    0.0077    4.5254
```

Input Arguments

`xyzNED` — Local NED Cartesian coordinates

three-element row vector | *n*-by-3 matrix

Local NED Cartesian coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of points to transform. Specify each point in the form `[xNorth yEast zDown]`. *xNorth*, *yEast*, and *zDown* are the respective *x*-, *y*-, and *z*-coordinates, in meters, of the point in the local NED system.

Data Types: `double`

`lla0` — Origin of local NED system in geodetic coordinates

three-element row vector | *n*-by-3 matrix

Origin of the local NED system with the geodetic coordinates, specified as a three-element row vector or an *n*-by-3 matrix. *n* is the number of origin points. Specify each point in the form `[lat0 lon0 alt0]`. *lat0* and *lon0* specify the latitude and longitude respectively in degrees. *alt0* specifies the altitude in meters.

Data Types: `double`

`method` — Transformation method

`'flat'` | `'ellipsoid'`

Transformation method, specified as `'flat'` or `'ellipsoid'`. This argument specifies whether the function assumes the planet is flat or ellipsoidal.

The flat Earth approximation has these limitations:

- This transformation method assumes that the flight path and bank angle are zero.
- This transformation method assumes that the flat Earth *z*-axis is normal to the Earth at only the initial geodetic latitude and longitude. This method has higher accuracy over small distances from the initial geodetic latitude and longitude, and closer to the equator. The method calculates a longitude with higher accuracy when the variation in latitude is smaller.
- Latitude values of +90 and -90 may return unexpected values because of singularity at the poles.

Data Types: `char` | `string`

Output Arguments

`lla` — Geodetic coordinates

three-element row vector | *n*-by-3 matrix

Geodetic coordinates, returned as a three-element row vector or an *n*-by-3 matrix. *n* is the number of transformed points. Each point is in the form `[lat lon alt]`. *lat* and *lon* specify the latitude and longitude, respectively, in degrees. *alt* specifies the altitude in meters.

Data Types: `double`

Extended Capabilities

C/C++ Code Generation

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

See Also
enu2lla | lla2enu | lla2ned

Introduced in R2020b

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
`eul2quat` | `hom2cart` | `quaternion` | `rotm2quat` | `tform2quat`

Introduced in R2018b

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`

Introduced in R2015a

quat2eul

Convert quaternion to Euler angles

Syntax

```
eul = quat2eul(quat)
eul = quat2eul(quat,sequence)
```

Description

`eul = quat2eul(quat)` converts a quaternion rotation, `quat`, to the corresponding Euler angles, `eul`. The default order for Euler angle rotations is `"ZYX"`.

`eul = quat2eul(quat,sequence)` converts a quaternion into Euler angles. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Convert Quaternion to Euler Angles

```
quat = [0.7071 0.7071 0 0];
eulZYX = quat2eul(quat)
```

```
eulZYX = 1×3

         0         0    1.5708
```

Convert Quaternion to Euler Angles Using ZYZ Axis Order

```
quat = [0.7071 0.7071 0 0];
eulZYZ = quat2eul(quat,'ZYZ')
```

```
eulZYZ = 1×3

    1.5708   -1.5708   -1.5708
```

Input Arguments

quat — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

sequence — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these 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`

Introduced in R2015a

quat2rotm

Convert quaternion to rotation matrix

Syntax

```
rotm = quat2rotm(quat)
```

Description

`rotm = quat2rotm(quat)` converts a quaternion `quat` to an orthonormal rotation matrix, `rotm`. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

Examples

Convert Quaternion to Rotation Matrix

```
quat = [0.7071 0.7071 0 0];
rotm = quat2rotm(quat)
```

```
rotm = 3×3

    1.0000         0         0
         0   -0.0000   -1.0000
         0    1.0000   -0.0000
```

Input Arguments

`quat` — Unit quaternion
n-by-4 matrix | n-element vector of `quaternion` objects

Unit quaternion, specified as an *n*-by-4 matrix or n-element vector of `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Output Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, returned as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also
`quaternion` | `rotm2quat`

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 `quaternion` objects containing *n* quaternions. If the input is a matrix, each row is a quaternion vector of the form $q = [w\ x\ y\ z]$, with *w* as the scalar number.

Example: `[0.7071 0.7071 0 0]`

Output Arguments

`tform` — Homogeneous transformation
4-by-4-by-*n* matrix

Homogeneous transformation matrix, returned as a 4-by-4-by-*n* matrix of *n* homogeneous transformations. When using the rotation matrix, premultiply it with the coordinates to be rotated (as opposed to postmultiplying).

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

Extended Capabilities

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

See Also
`quaternion` | `tform2quat`

Introduced in R2015a

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`

Introduced in R2015a

rotm2eul

Convert rotation matrix to Euler angles

Syntax

```
eul = rotm2eul(rotm)
eul = rotm2eul(rotm,sequence)
```

Description

`eul = rotm2eul(rotm)` converts a rotation matrix, `rotm`, to the corresponding Euler angles, `eul`. The input rotation matrix must be in the premultiply form for rotations. The default order for Euler angle rotations is `"ZYX"`.

`eul = rotm2eul(rotm,sequence)` converts a rotation matrix to Euler angles. The Euler angles are specified in the axis rotation sequence, `sequence`. The default order for Euler angle rotations is `"ZYX"`.

Examples

Convert Rotation Matrix to Euler Angles

```
rotm = [0 0 1; 0 1 0; -1 0 0];
eulZYX = rotm2eul(rotm)
```

```
eulZYX = 1×3

         0    1.5708         0
```

Convert Rotation Matrix to Euler Angles Using ZYZ Axis Order

```
rotm = [0 0 1; 0 -1 0; -1 0 0];
eulZYZ = rotm2eul(rotm,'ZYZ')
```

```
eulZYZ = 1×3

   -3.1416   -1.5708   -3.1416
```

Input Arguments

`rotm` — Rotation matrix
3-by-3-by-*n* matrix

Rotation matrix, specified as a 3-by-3-by-*n* matrix containing *n* rotation matrices. Each rotation matrix has a size of 3-by-3 and is orthonormal. The input rotation matrix must be in the premultiply form for rotations.

Note Rotation matrices that are slightly non-orthonormal can give complex outputs. Consider validating your matrix before inputting to the function.

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

`sequence` — Axis rotation sequence
`"ZYX"` (default) | `"ZYZ"` | `"XYZ"`

Axis rotation sequence for the Euler angles, specified as one of these 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`

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`

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`

Introduced in R2015a

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`

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`

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`

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`

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`

Introduced in R2015a

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`

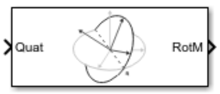
Introduced in R2015a

Blocks

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.

`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™.

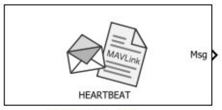
See Also

`axang2quat` | `eul2tform` | `trvec2tform`

Introduced in R2017b

MAVLink Blank Message

Create blank MAVLink message bus by specifying payload information and MAVLink message type
Library: UAV Toolbox / MAVLink



MAVLink Blank Message

Description

The MAVLink Blank Message block creates a Simulink® nonvirtual bus representing a MAVLink packet based on the specified Message ID, System ID, Component ID, Sequence, Payload information, and MAVLink message type.

Payload information is another nonvirtual bus within the MAVLink packet bus. The block creates Simulink buses for the MAVLink packet and the corresponding message that work with MAVLink Serializer and MAVLink Deserializer blocks. On each sample hit, the block outputs a blank or zero signal for the payload for the designated message type.

All elements of the bus other than the Message ID, System ID, and Component ID are initialized to `0`. The only exception is the `mavlink_version` field in the HEARTBEAT message of the `common.xml` dialect which is initialized to `3`.

Ports

Output

`Msg` — MAVLink packet
nonvirtual bus

MAVLink packet, returned as a Simulink nonvirtual bus. The bus contains the fields Message ID, System ID, Component ID, Sequence, and Payload. The Payload is another nonvirtual bus corresponding to the MAVLink message type that you selected in the **MAVLink message type** parameter. The Message ID is initialized to the numeric value of the selected MAVLink message ID. The System ID and Component ID are initialized to the corresponding **System ID** and **Component ID** parameters.

Data Types: `bus`

Parameters

`MAVLink dialect source` — Source for specifying the MAVLink message definition
`Select from standard MAVLink dialects` (default) | `Specify your own`

Source for specifying the MAVLink message definition XML name, specified as one of the following:

- `Select from standard MAVLink dialects` - Use this option to select a definition XML among the 12 commonly used message definition XML names listed in the **MAVLink dialect** parameter.

- `Specify your own` - Enter an XML name in the text box that appears for the **MAVLink dialect** parameter.

`MAVLink dialect` — Message definition to parse for MAVLink messages
`common.xml` (default)

MAVLink message definition file (`.xml`) to parse for MAVLink messages, specified as a string.

If the **MAVLink dialect source** parameter is set to `Select from standard MAVLink dialects`, you need to select a message definition among the available message definition names from the drop down list.

If the **MAVLink dialect source** parameter is set to `Specify your own`, you need to specify the message definition file (`.xml`) that is on current MATLAB path or you can provide the full path of the xml file.

`MAVLink version` — MAVLink protocol version
`2` (default) | `1`

MAVLink protocol version that is used to serialize and deserialize the MAVLink messages.

`MAVLink Message type` — MAVLink message
`HEARTBEAT` (default)

MAVLink message, specified as a string. Click **Select** to select from a full list of available MAVLink messages that depends on the values that you selected for **MAVLink dialect** and **MAVLink version** parameters.

Data Types: `string`

`System ID` — System ID of the sender
`1` (default)

MAVLink system ID, specified as a positive integer between 1 and 255. MAVLink protocol only supports up to 255 systems. Each UAV has its own system ID, but multiple UAVs can be considered as one system.

Data Types: `uint8`

`Component ID` — Component ID of the sender
`1` (default)

MAVLink component ID, specified as a positive integer between 1 and 255.

Data Types: `uint8`

`Sample time` — Interval between outputs
`inf` (default) | scalar

The default value (`inf`) indicates that the block output never changes. If you use this value, the simulation and code generation are faster by eliminating the need to recompute the block output. For other values, the block outputs a new blank message at each interval of Sample time.

For more information, see “Specify Sample Time” (Simulink)Specify Sample Time (Simulink).

Data Types: `uint8`

Tip

You can change the values for the desired fields in Payload bus by using a Bus Assignment block and then pass the MAVLink packet bus to the MAVLink Serializer block as an input.

Extended Capabilities

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

Usage and Limitations:

- The C/C++ code generated for the block can be deployed only on a Linux target.

See Also

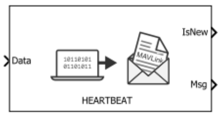
MAVLink Serializer | MAVLink Deserializer

Introduced in R2020b

MAVLink Deserializer

Convert serialized `uint8` MAVLink data stream to Simulink nonvirtual bus

Library: UAV Toolbox / MAVLink



MAVLink Deserializer

Description

The MAVLink Deserializer block receives a `uint8` buffer and decodes the buffer for MAVLink messages. Once the block receives the MAVLink message for the selected MAVLink message type, the block outputs a Simulink nonvirtual bus representing a MAVLink packet containing the Message ID, System ID, Component ID, Sequence, and Payload information corresponding to the selected MAVLink message type.

At each simulation step, the block decodes the input `uint8` buffer and retrieves the MAVLink messages that are received after decoding. If a new message for the selected MAVLink message type has been received, the block retrieves that message from the list of received messages and converts it to a Simulink nonvirtual bus signal.

The MAVLink decoding logic in the block takes care of scenarios where a MAVLink packet has been received partially from a communication channel. The MAVLink Deserializer block internally stores the current state of parsing and resumes decoding from the previous step when the new buffer has been received over the communication channel. If the complete MAVLink packet has been received and the received checksum matches the computed checksum for the received bytes, then this indicates that a MAVLink message has been received. Storing the state of parsing ensures that the block can decode MAVLink packets received in multiple parts.

By default, the block outputs the latest received MAVLink message for the selected MAVLink message type (if received). This behavior can be changed by selecting **Queue Messages in output** parameter. In this case, all the received MAVLink messages for the desired type are queued and at each Simulation step, the block outputs the oldest message.

Ports

Input

`Data` — MAVLink data stream

The `uint8` byte stream that contains serialized MAVLink packets. The byte stream is usually received over a communication channel such as UDP, TCP, or Serial. At each sample time, the communication channel receives data and returns a byte stream that contains one or more MAVLink packets. The byte stream can also return a MAVLink packet partially in over multiple sample times. This input port accepts variable-length signals.

Data Types: `uint8`

`Length` — Length of valid MAVLink data at Data input port

Optional input port to include the length of valid MAVLink data. To enable this port, select the **Input data stream length is available** parameter. Use this option when you know the exact length of the valid MAVLink data in the data stream.

This option is useful when you have a communication channel receive peripheral that outputs partially received data that contains trailing zeros. Such peripherals also output the length of the actual number of valid data bytes received. You can connect the length output of the peripheral directly with the **Length** input port of MAVLink Deserializer block, so that trailing zeros in the input byte stream do not affect the decoding logic.

Data Types: `uint16`

Output

`IsNew` — New message indicator
`0` | `1`

New MAVLink message indicator returned as a logical. A value of `1` indicates that a new message is available since the last sample was received by the block. This output can be used to trigger subsystems tp process new messages received from the MAVLink Deserializer block.

Data Types: `Boolean`

`Msg` — MAVLink packet
nonvirtual bus

MAVLink packet, returned as a nonvirtual bus. The type of Payload in the MAVLink packet is a Simulink bus corresponding to the MAVLink message specified in the MAVLink message type parameter. The block outputs blank messages until it receives a message on the message name that you specify. The **Msg** port outputs this new message. If a new message is not available, it outputs the last received MAVLink message. If a message has not been received since the start of the simulation, **Msg** port outputs a blank MAVLink message.

Data Types: `bus`

Parameters

Main

`MAVLink dialect source` — Source for specifying the MAVLink message definition
`Select from standard MAVLink dialects` (default) | `Specify your own`

Source for specifying the MAVLink message definition XML name, specified as one of the following:

- `Select from standard MAVLink dialects` - Use this option to select a definition xml among the 12 commonly used message definition XML names listed in the **MAVLink dialect** parameter.
- `Specify your own` - Enter an XMLl name in the text box that appears for the **MAVLink dialect** parameter.

`MAVLink dialect` — Message definition to parse for MAVLink messages
`common.xml` (default)

MAVLink message definition file (`.xml`) to parse for MAVLink messages, specified as a string.

If the **MAVLink dialect source** parameter is set to `Select from standard MAVLink dialects`, you need to select a message definition among the available message definition names from the dropdown list.

If the parameter **MAVLink dialect source** parameter is set to `Specify your own`, you need to specify the message definition file (`.xml`) that is on the current MATLAB path, or you can provide the full path of the XML file.

`MAVLink version` — MAVLink protocol version

`2` (default) | `1`

MAVLink protocol version that the block uses to serialize and deserialize the MAVLink messages.

`MAVLink Message type` — MAVLink message

`HEARTBEAT` (default)

MAVLink message, specified as a string. Click **Select** to select from a full list of available MAVLink messages. The list varies based on the values that you selected for **MAVLink dialect** and **MAVLink version** parameters.

Data Types: `string`

Advanced

`Input data stream length is available` — Length of valid MAVLink data in the input byte stream is known

`off` (default) | `on`

When you select this option, the MAVLink Deserializer block provides an additional input port called **Length**. This input port can be used to pass the actual length of MAVLink data (if known) in the input byte stream. The input byte stream is cropped for this length.

This option is useful when you have a communication channel receive peripheral that outputs partially received data that contains trailing zeros. Such peripherals also output length of the actual number of valid data bytes received. You can connect the length output of the peripheral directly to the **Length** input port of MAVLink Deserializer block so that trailing zeros in the input byte stream do not affect the decoding logic.

`Filter output MAVLink messages by System ID` — Filter received messages by System ID

`off` (default) | `on`

Select this option to filter the received MAVLink messages for the System ID value mentioned in the **System ID** parameter. This option helps you to filter the received messages by both System ID and Component ID.

`System ID` — System ID value

`1` (default) | scalar in the range `[0,255]`

Specify the System ID value to use while filtering the decoded MAVLink messages. The block outputs the received MAVLink messages whose System ID matches the specified value and whose Message ID matches the MAVLink message (selected in the **MAVLink Message type** parameter).

Dependencies

To enable this parameter, select **Filter Output MAVLink messages by System ID**.

`Filter output MAVLink messages by Component ID` — Filter received messages by System ID and Component ID
`off` (default) | `on`

Select this option to filter the received MAVLink messages for the both the System ID and the Component ID mentioned in the **System ID** and **Component ID** parameters, respectively.

Dependencies

This parameter appears only if you select the **Filter output MAVLink messages by System ID** parameter.

`Component ID` — Component ID value
`1` (default) | `[0,255]`

Specify the Component ID value to use while filtering the decoded MAVLink messages. The block outputs those received MAVLink messages whose System ID and Component ID values match the specified values in the **System ID** and **Component ID** parameters, respectively, and whose Message ID matches the MAVLink message (selected in the **MAVLink Message type** parameter).

Dependencies

To enable this parameter, select **Filter Output MAVLink messages by Component ID**.

`Queue MAVLink messages in output` — Enable queuing of the received MAVLink messages
`off` (default) | `on`

Select this option to output messages using the first-in-first-out pattern. If you do not select this option, the MAVLink Deserializer block outputs the latest received MAVLink message for the selected **MAVLink message type** (and with matching System ID and Component ID if those parameters are selected) at each simulation step. If more than one message matches the given parameters that are received in a simulation step, the latest message is passed as output, and the rest are discarded. You can reverse this behavior by selecting this option.

When you select this parameter, the behavior of the MAVLink Deserializer block at each simulation step is:

- The block stores the decoded MAVLink messages matching the selected MAVLink message type (and matching System ID and Component ID if the those parameters are selected) in a queue. If there are no messages among the received messages that match the required parameters, no messages are queued.
- If the queue is not empty, the first message in the queue is sent as an output first, and the signal at **IsNew** port is set to `1`.

Selecting the **Queue MAVLink messages in output** parameter makes the **Number of messages to be queued** parameter visible. You can fix the size of the queue by setting the value of this parameter.

`Number of messages to be queued` — Size of MAVLink message queue
`50` (default) | scalar in the range (`0,65535`]

Specify the size of the queue to be used to store the received MAVLink messages matching the desired parameters.

Dependencies

To enable this parameter, select **Queue MAVLink messages in output**.

Tips

To speed up the conversion of the received serialized data, it is recommended that you apply the following settings in the communication channel receive block:

- Read the data at the highest rate possible to ensure that no packets are dropped. Use the **IsNew** output of MAVLink Deserializer along with the logic to use MAVLink messages to know if the output of the block is a new message or not.
- If the receive block outputs any number of bytes that are received irrespective of the data size requested (partial receive), mention the data read size as a large number and use the length of actual number of bytes received as an input to MAVLink Deserializer block (use the **Length** input port).

Extended Capabilities

C/C++ Code Generation

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

Usage and Limitations:

- The C/C++ code generated for the block can be deployed only on a Linux target.

See Also

MAVLink Blank Message | MAVLink Serializer

Topics

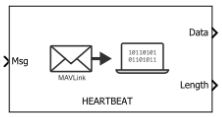
"Exchange Data for MAVLink Microservices like Mission Protocol and Parameter Protocol Using Simulink"

Introduced in R2020b

MAVLink Serializer

Serialize messages of MAVLink packet by converting Simulink nonvirtual bus to `uint8` data stream

Library: UAV Toolbox / MAVLink



MAVLink Serializer

Description

The MAVLink Serializer block accepts a Simulink nonvirtual bus and converts it into a `uint8` MAVLink data stream. The nonvirtual bus represents a MAVLink packet containing the Message ID, System ID, Component ID, Sequence, and Payload information corresponding to the selected MAVLink message. Payload information is another nonvirtual bus within the MAVLink packet bus.

MAVLink v2 removes trailing zeros in the payload. Therefore, the length of the payload in the serialized MAVLink data can be less than the maximum payload length of a selected MAVLink message type.

The **Data** port outputs the MAVLink data stream, and the length of the output data is the maximum possible length for the selected MAVLink message. If the length of the serialized data is less than the maximum possible length, trailing zeros are added to the data stream. The **Length** port outputs the true length of the serialized MAVLink data.

Ports

Input

`Msg` — MAVLink packet

nonvirtual bus

MAVLink packet as a nonvirtual bus. This is the output of the MAVLink Blank Message block in which the values for Message ID, System ID, and Component ID are already initialized. The fields in the Payload bus can be modified using a Bus Assignment block before passing it as an input to MAVLink Serializer block.

Data Types: `bus`

Output

`Data` — MAVLink data stream

The serialized MAVLink data for the input MAVLink message bus. MAVLink protocol version 2 removes trailing zeros in the payload. Therefore, the length of the payload in the serialized data can be less than the maximum payload length of the MAVLink message in the dialect. In this case, the block outputs the serialized data stream with the trailing zeros included.

Data Types: `uint8`

`Length` — Length of the serialized data

The true length of the serialized data including headers and payload. This might be less than the maximum possible length for a MAVLink message depending on how many trailing zeros are removed in the MAVLink payload during serialization.

Data Types: `uint16`

Parameters

`MAVLink dialect source` — Source for specifying the MAVLink message definition
`Select from standard MAVLink dialects` (default) | `Specify your own`

Source for specifying the MAVLink message definition XML name, specified as one of the following:

- `Select from standard MAVLink dialects` - Use this option to select a definition XML among the 12 commonly used message definition XML names listed in the **MAVLink dialect** parameter.
- `Specify your own` - Enter an XML name in the text box that appears for the **MAVLink dialect** parameter.

`MAVLink dialect` — Message definition to parse for MAVLink messages
`common.xml` (default)

MAVLink message definition file (`.xml`) to parse for MAVLink messages, specified as a string.

If the **MAVLink dialect source** parameter is set to `Select from standard MAVLink dialects`, you need to select a message definition among the available message definition names from the dropdown list.

If the **MAVLink dialect source** parameter is set to `Specify your own`, you need to specify the message definition file (`.xml`) that is on current MATLAB path or you can provide the full path of the XML file.

`MAVLink version` — MAVLink protocol version
2 (default) | 1

MAVLink protocol version that is used to serialize and deserialize the MAVLink messages.

`MAVLink Message type` — MAVLink message
HEARTBEAT (default)

MAVLink message, specified as a string. Click **Select** to select from a full list of available MAVLink messages that are specific to the values that you selected for **MAVLink dialect** and **MAVLink version** parameters.

Data Types: `string`

Tip

You can change the values for the desired fields in the Payload in the output of the MAVLink Blank message by using a Bus Assignment block and then pass the MAVLink packet bus to the MAVLink Serializer block as an input.

Extended Capabilities

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

Usage and Limitations:

- The C/C++ code generated for the block can be deployed only on a Linux target.

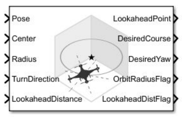
See Also
MAVLink Blank Message | MAVLink Deserializer

Topics
"Exchange Data for MAVLink Microservices like Mission Protocol and Parameter Protocol Using Simulink"

Introduced in R2020b

Orbit Follower

Orbit location of interest using UAV
Library: UAV Toolbox / Algorithms



Description

The Orbit Follower block generates course and yaw controls for following a circular orbit around a location of interest based on the unmanned aerial vehicle's (UAV's) current pose. Select a **UAV type** of fixed-wing or multirotor UAVs. You can specify any orbit center location, orbit radius, and turn direction. A lookahead distance, **LookaheadDistance**, is used for tuning the path tracking and generating the **LookaheadPoint** output.

Ports

Input

Pose — Current UAV pose
`[x y z course]` vector

Current UAV pose, specified as an `[x y z course]` vector. `[x y z]` is the UAV's position in NED coordinates (north-east-down) specified in meters. `course` is the angle between ground velocity and north direction in radians per second.

Example: `[1,1,-10,pi/4]`

Data Types: `single` | `double`

`Center` — Center of orbit
`[x y z]` vector

Center of orbit, specified as an `[x y z]` vector. `[x y z]` is the orbit center position in NED coordinates (north-east-down) specified in meters.

Example: `[5,5,-10]`

Data Types: `single` | `double`

`Radius` — Radius of orbit
positive scalar

Radius of orbit, specified as a positive scalar in meters.

Example: `5`

Data Types: `single` | `double`

`TurnDirection` — Direction of orbit
scalar

Direction of orbit, specified as a scalar. Positive values indicate a clockwise turn as viewed from above. Negative values indicate a counter-clockwise turn. A value of `0` automatically determines the value based on the input to **Pose**.

Example: `-1`

Data Types: `single` | `double`

`LookaheadDistance` — Lookahead distance for tracking orbit
positive scalar

Lookahead distance for tracking the orbit, specified as a positive scalar. Tuning this value helps adjust how tightly the UAV follows the orbit circle. Smaller values improve tracking, but can lead to oscillations in the path.

Example: 2

Data Types: `single` | `double`

`ResetNumTurns` — Reset for counting turns
numeric signal

Reset for counting turns, specified as a numeric signal. Any rising signal triggers a reset of the **NumTurns** output.

Example: 2

Dependencies

To enable this input, select `rising` for **External reset**.

Data Types: `single` | `double`

Output

`LookaheadPoint` — Lookahead point on path
`[x y z]` position vector

Lookahead point on path, returned as an `[x y z]` position vector in meters.

Data Types: `double`

`DesiredCourse` — Desired course
numeric scalar

Desired course, returned as numeric scalar in radians in the range of `[-pi, pi]`. The UAV course is the angle of direction of the velocity vector relative to north measured in radians. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: `double`

`DesiredYaw` — Desired yaw
numeric scalar

Desired yaw, returned as numeric scalar in radians in the range of `[-pi, pi]`. The UAV yaw is the forward direction of the UAV (regardless of the velocity vector) relative to north measured in radians. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: `double`

`OrbitRadiusFlag` — Orbit radius flag
`0` (default) | `1`

Orbit radius flag, returned as `0` or `1`. `0` indicates orbit radius is not saturated, `1` indicates orbit radius is saturated to minimum orbit radius value specified.

Data Types: `uint8`

`LookaheadDistFlag` — Lookahead distance flag
`0` (default) | `1`

Lookahead distance flag, returned as `0` or `1`. `0` indicates lookahead distance is not saturated, `1` indicates lookahead distance is saturated to minimum lookahead distance value specified.

Data Types: `uint8`

`CrossTrackError` — Cross track error from UAV position to path
positive numeric scalar

Cross track error from UAV position to path, returned as a positive numeric scalar in meters. The error measures the perpendicular distance from the UAV position to the closest point on the path.

Dependencies

This port is only visible if **Show CrossTrackError output port** is checked.

Data Types: `double`

`NumTurns` — Number of times the UAV has completed the orbit
numeric scalar

Number of times the UAV has completed the orbit, returned as a numeric scalar. As the UAV circles the center point, this value increases or decreases based on the specified **Turn Direction**. Decimal values indicate partial completion of a circle. If the UAV cross track error exceeds the lookahead distance, the number of turns is not updated.

NumTurns is reset whenever **Center**, **Radius**, or **TurnDirection** are changed. You can also use the **ResetNumTurns** input.

Dependencies

This port is only visible if **Show NumTurns output port** is checked.

Parameters

`UAV type` — Type of UAV
`fixed-wing` (default) | `multirotor`

Type of UAV, specified as either `fixed-wing` or `multirotor`.

This parameter is non-tunable.

`Minimum orbit radius (m)` — Minimum orbit radius
`1` (default) | positive numeric scalar

Minimum orbit radius, specified as a positive numeric scalar in meters.

When input to the orbit **Radius** port is less than the minimum orbit radius, the **OrbitRadiusFlag** is returned as `1` and the orbit radius value is specified as the value of minimum orbit radius.

This parameter is non-tunable.

`Minimum lookahead distance (m)` — Minimum lookahead distance
`0.1` (default) | positive numeric scalar

Minimum lookahead distance, specified as a positive numeric scalar in meters.

When input to the **LookaheadDistance** port is less than the minimum lookahead distance, the **LookaheadDistFlag** is returned as `1` and the lookahead distance value is specified as the value of minimum lookahead distance.

This parameter is non-tunable.

`External reset` — Reset trigger source
`none` (default) | `rising`

Select `rising` to enable the **ResetNumTurns** block input.

This parameter is non-tunable.

`Show CrossTrackError output port` — Output cross track error
`off` (default) | `on`

Output cross track error from the **CrossTrackError** port.

This parameter is non-tunable.

`Show NumTurns output port` — Output UAV waypoint status
`off` (default) | `on`

Output UAV waypoint status from the **Status** port.

This parameter is non-tunable.

Extended Capabilities

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

See Also

Blocks
UAV Guidance Model | Waypoint Follower

Functions
`control` | `derivative` | `environment` | `ode45` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor` | `uavOrbitFollower` | `uavWaypointFollower`

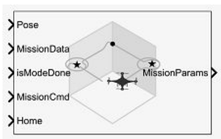
Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"

“Tuning Waypoint Follower for Fixed-Wing UAV”

Introduced in R2019a

Path Manager

Compute and execute a UAV autonomous mission
Library: UAV Toolbox / Algorithms



Description

The Path Manager block computes mission parameters for an unmanned aerial vehicle (UAV) by sequentially switching between mission points specified in the **MissionData** input port. The **MissionCmd** input port changes the execution order at runtime. The block supports both multirotor and fixed-wing UAV types.

Ports

Input

`Pose` — Current UAV pose

four-element column vector

Current UAV pose, specified as a four-element column vector of `[`*`x`*`;`*`y`*`;`*`z`*`;`*`courseAngle`*`]`. *x*, *y*, and *z* is the current position of the UAV in north-east-down (NED) coordinates specified in meters. *courseAngle* specifies the heading angle in radians in the range `[-pi, pi]`.

Data Types: `single` | `double`

`MissionData` — UAV mission data

`UAVPathManagerBus` bus

UAV mission data, specified as a `UAVPathManagerBus` bus. The `UAVPathManagerBus` bus has the three bus elements `mode`, `position`, and `params`.

You can use the Constant block to specify the mission data as an *n*-by-1 array of structures and set the output data type to `Bus:UAVPathManagerBus`. *n* is the number of mission points. The fields of each structure are:

- `mode` — Mode of the mission point, specified as an 8-bit unsigned integer between 1 and 6.
- `position` — Position of the mission point, specified as a three-element column vector of `[`*`x`*`;`*`y`*`;`*`z`*`]`. *x*, *y*, and *z* is the position in north-east-down (NED) coordinates specified in meters.
- `params` — Parameters of the mission point, specified as a four-element column vector.

The values assigned to the fields, in turn, are assigned to their corresponding bus elements in the `UAVPathManagerBus` bus.

This table describes the types of `mode` and the corresponding values for the `position` and `params` fields in a mission point structure.

mode	position	params	Mode description
uint8(1)	[*x*;*y*;*z*]	[0;0;0;0]	**Takeoff** — Take off from the ground and travel toward the specified position
uint8(2)	[*x*;*y*;*z*]	[*yaw*;*radius*;0;0] *yaw* — Yaw angle in radians in the range [-pi, pi] *radius* — Transition radius in meters	**Waypoint** — Navigate to waypoint
uint8(3)	[*x*;*y*;*z*] *x*, *y*, and *z* is the center of the circular orbit in NED coordinates specified in meters	[*radius*;*turnDir*;*numTurns*;0] *radius* — Radius of the orbit in meters *turnDir* — Turn direction, specified as one of these: • 1 — Clockwise turn • –1 — Counter-clockwise turn • 0 — Automatic selection of turn direction *numTurns* — Number of turns	**Orbit** — Orbit along the circumference of a circle defined by the parameters
uint8(4)	[*x*;*y*;*z*]	[0;0;0;0]	**Land** — Land at the specified position
uint8(5)	[*x*;*y*;*z*] The launch position is specified in the Home input port	[0;0;0;0]	**RTL** — Return to launch position
uint8(6)	[*x*;*y*;*z*]	[*p1*;*p2*;*p3*;*p4*] *p1*, *p2*, *p3*, and *p4* are user-specified parameters corresponding to a custom mission point	**Custom** — Custom mission point

Example: [struct('mode',uint8(1),'position',[0;0;100],'params',[0;0;0;0])]

Data Types: bus

`IsModeDone` — Determine if mission point was executed
0 (default) | 1

Determine if the mission point was executed, specified as `0` (`true`) or `1` (`false`).

Data Types: `Boolean`

`MissionCmd` — Command to change mission
`uint8(0)` (default) | 8-bit unsigned integer between 0 and 3

Command to change mission at runtime, specified as an 8-bit unsigned integer between 0 and 3.

This table describes the possible mission commands.

Mission Command	Description
`uint8(0)`	**Default** — Execute the mission from first to the last mission point in the sequence
`uint8(1)`	**Hold** — Hold at the current mission point Loiter around the current position for fixed-wing and hover at the current position for multirotor UAVs
`uint8(2)`	**Repeat** — Repeat the mission after reaching the last mission point
`uint8(3)`	**RTL** — Execute return to launch (RTL) mode After **RTL**, the mission resumes if the `MissionCmd` input is changed to **Default** or **Repeat**

Data Types: `uint8`

`Home` — UAV home location
three-element column vector

UAV home location, specified as a three-element column vector of `[x;y;z]`. *x*, *y*, and *z* is the position in north-east-down (NED) coordinates specified in meters.

Data Types: `single` | `double`

Output

`MissionParams` — UAV mission parameters
`UAVPathManagerBus` bus

UAV mission parameters, returned as a 2-by-1 array of buses of the type `UAVPathManagerBus`. The first element of the bus array is the current mission point, and the second element of the bus array is the previous mission point.

This table describes the output mission parameters depending on the mission mode.

Current Mission Mode	Output Mission Parameters			
	Mission Points	**mode**	**position**	**params**
Takeoff	First bus element: Current	uint8(1)	[*x*;*y*;*z*]	[0;0;0;0]
	Second bus element: Previous	mode of the previous mission point	position of the previous mission point	params of the previous mission point
Waypoint	First bus element: Current	uint8(2)	[*x*;*y*;*z*]	[*yaw*;*radius*;0;0] *yaw* — Yaw angle in radians in the range [-pi, pi] *radius* — Transition radius in meters
	Second bus element: Previous	mode of the previous mission point	position of the previous mission point	• [*yaw*;*radius*;0;0] if the previous mission point was **Takeoff** • [*courseAngle*;*radius*;0;0] otherwise *courseAngle* — Angle of the line segment between the previous and the current position, specified in radians in the range [-pi, pi]

Current Mission Mode	Output Mission Parameters			
	Mission Points	mode	position	params
Orbit	First bus element: Current	`uint8(3)`	[*x*;*y*;*z*] *x*, *y*, and *z* is the center of the circular orbit in NED coordinates specified in meters	[*radius*;*turnDir*;*numTurns*;0] *radius* — Radius of the orbit in meters *turnDir* — Turn direction, specified as one of these: • `1` — Clockwise turn • `–1` — Counter-clockwise turn • `0` — Automatic selection of turn direction *numTurns* — Number of turns
	Second bus element: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point
Land	First bus element: Current	`uint8(4)`	[*x*;*y*;*z*]	[0;0;0;0]
	Second bus element: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point
RTL	First bus element: Current	`uint8(5)`	[*x*;*y*;*z*] The launch position is specified in the `Home` input port	[0;0;0;0]
	Second bus element: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point
Custom	First bus element: Current	`uint8(6)`	[*x*;*y*;*z*]	[*p1*;*p2*;*p3*;*p4*] *p1*, *p2*, *p3*, and *p4* are user-specified parameters corresponding to a custom mission point

Current Mission Mode	Output Mission Parameters			
	Mission Points	mode	position	params
	Second bus element: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point

At start of simulation, the previous mission point is set to the **Armed** mode.

mode	position	params
`uint8(0)`	[*x*;*y*;*z*] `position` of the UAV at simulation start.	`[-1;-1;-1;-1]`

Set the end mission point to **RTL** or **Land** mode, else the end mission point is automatically set to **Hold** mode.

This table describes the output mission parameters when the input to the **MissionCmd** input port is set to **Hold** mode.

UAV Type	Output Mission Parameters			
	Mission Points	mode	position	params
Multirotor	First bus element: Current	`uint8(7)`	[*x*;*y*;*z*]	`[-1;-1;-1;-1]`
	Second bus element: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point
Fixed-Wing	First bus element: Current	`uint8(7)`	[*x*;*y*;*z*] *x*, *y*, and *z* is the center of the circular orbit in NED coordinates specified in meters	[*radius*;*turnDir*;-1;-1] *radius* — Loiter radius is specified in the `Loiter radius` parameter *turnDir* — Turn direction is specified as `0` for automatic selection of turn direction
	Second bus element: Previous	`mode` of the previous mission point	`position` of the previous mission point	`params` of the previous mission point

Data Types: `bus`

Parameters

`UAV type` — Type of UAV
`multirotor` (default) | `fixed-wing`

Type of UAV, specified as either `multirotor` or `fixed-wing`.

Tunable: No

`Loiter radius` — Loiter radius for fixed-wing UAV
25 (default) | positive numeric scalar

Loiter radius for the fixed-wing UAV, specified as a positive numeric scalar in meters.

Dependencies: To enable this parameter, set the **UAV type** parameter to `fixed-wing`.

Tunable: No

`Data type` — Data type of input mission bus
`double` (default) | `single`

Data type of the input mission bus, specified as either `double` or `single`.

Tunable: No

`Mission bus name` — Name of input mission bus
`'UAVPathManagerBus'` (default)

Name of the input mission bus, specified as `'UAVPathManagerBus'`.

Tunable: No

Extended Capabilities

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

See Also

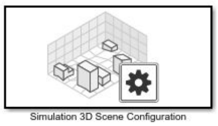
Guidance Model | Orbit Follower | Waypoint Follower

Introduced in R2020b

Simulation 3D Scene Configuration

Scene configuration for 3D simulation environment

Library: UAV Toolbox / Simulation 3D



Description

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

You can simulate from a set of prebuilt scene or from your own custom scenes. Scene customization requires the UAV Toolbox Interface for Unreal Engine Projects support package. For more details, see "Customize Unreal Engine Scenes for UAVs".

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

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

For more information about execution order, see "Block Execution Order".

Parameters

Scene Selection

`Scene source` — Source of scene

`Default Scene` (default) | `Unreal Executable` | `Unreal Editor`

Source of the scene in which to simulate, specified as one of the options in the table.

Option	Description
`Default Scene`	Simulate in the default, prebuilt scene specified in the **Scene name** parameter.

Option	Description
`Unreal Executable`	Simulate in a scene that is part of an Unreal Engine executable file. Specify the executable file in the **File name** parameter. Specify the scene in the **Scene** parameter. Select this option to simulate in custom scenes that have been packaged into an executable for faster simulation.
`Unreal Editor`	Simulate in a scene that is part of an Unreal Engine project (`.uproject`) file and is open in the Unreal® Editor. Specify the project file in the **Project** parameter. Select this option when developing custom scenes. By clicking **Open Unreal Editor**, you can co-simulate within Simulink and the Unreal Editor and modify your scenes based on the simulation results.

`Scene name` — Name of prebuilt 3D scene

`US city block` (default)

Name of the prebuilt 3D scene in which to simulate, specified as one of these options. For details about a scene, see its listed corresponding reference page.

- `US city block` —

The UAV Toolbox Interface for Unreal Engine Projects contains customizable versions of these scenes. For details about customizing scenes, see "Customize Unreal Engine Scenes for UAVs".

Dependencies

To enable this parameter, set **Scene source** to `Default Scene`.

`File name` — Name of Unreal Engine executable file

`MathWorks_Aerospace.exe` (default) | valid executable file name

Name of the Unreal Engine executable file, specified as a valid executable file name. You can either browse for the file or specify the full path to the file, using backslashes. To specify a scene from this file to simulate in, use the **Scene** parameter.

By default, **File name** is set to `VehicleSimulation.exe`, which is on the MATLAB search path.

Example: `C:\Local\WindowsNoEditor\AutoVrtlEnv.exe`

Dependencies

To enable this parameter, set **Scene source** to `Unreal Executable`.

Scene — Name of scene from executable file

`/Game/Maps/USCityBlock` (default) | path to valid scene name

Name of a scene from the executable file specified by the **File name** parameter, specified as a path to a valid scene name.

When you package scenes from an Unreal Engine project into an executable file, the Unreal Editor saves the scenes to an internal folder within the executable file. This folder is located at the path /Game/Maps. Therefore, you must prepend /Game/Maps to the scene name. You must specify this path using forward slashes. For the file name, do not specify the .umap extension. For example, if the scene from the executable in which you want to simulate is named myScene.umap, specify **Scene** as /Game/Maps/myScene.

Alternatively, you can browse for the scene in the corresponding Unreal Engine project. These scenes are typically saved to the Content/Maps subfolder of the project. This subfolder contains all the scenes in your project. The scenes have the extension .umap. Select one of the scenes that you packaged into the executable file specified by the **File name** parameter. Use backward slashes and specify the .umap extension for the scene.

By default, **Scene** is set to /Game/Maps/USCityBlock, which is a scene from the default MathWorks_Aerospace.exe executable file specified by the **File name** parameter. This scene corresponds to the prebuilt **Straight Road** scene.

Example: /Game/Maps/scene1

Example: C:\Local\myProject\Content\Maps\scene1.umap

Dependencies

To enable this parameter, set **Scene source** to Unreal Executable.

Project — Name of Unreal Engine project file

valid project file name

Name of the Unreal Engine project file, specified as a valid project file name. You can either browse for the file or specify the full path to the file, using backslashes. The file must contain no spaces. To simulate scenes from this project in the Unreal Editor, click **Open Unreal Editor**. If you have an Unreal Editor session open already, then this button is disabled.

To run the simulation, in Simulink, click **Run**. Before you click **Play** in the Unreal Editor, wait until the Diagnostic Viewer window displays this confirmation message:

```
In the Simulation 3D Scene Configuration block, you set the scene source to 'Unreal Editor'.
In Unreal Editor, select 'Play' to view the scene.
```

This message confirms that Simulink has instantiated the scene actors, including the vehicles and cameras, in the Unreal Engine 3D environment. If you click **Play** before the Diagnostic Viewer window displays this confirmation message, Simulink might not instantiate the actors in the Unreal Editor.

Dependencies

To enable this parameter, set **Scene source** to Unreal Editor.

Scene Parameters

Scene view — Configure placement of virtual camera that displays scene

Scene Origin (default) | vehicle name

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

- If your model contains no Simulation 3D UAV Vehicle blocks, then during simulation, you view the scene from a camera positioned at the scene origin.

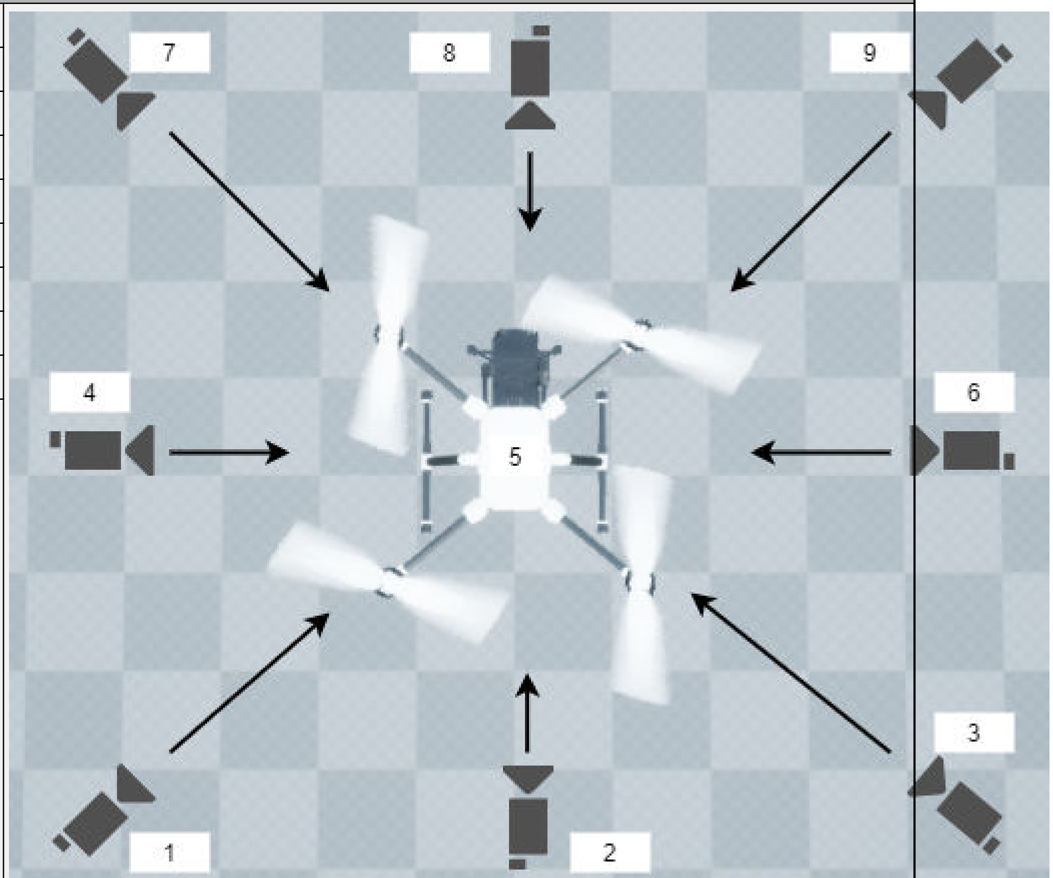
- If your model contains at least one vehicle block, then by default, you view the scene from behind the first vehicle that was placed in your model. To change the view to a different vehicle, set **Scene view** to the name of that vehicle. The **Scene view** parameter list is populated with all the **Name** parameter values of the vehicle blocks contained in your model.

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

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

To smoothly change the camera views, use these key commands.

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



For additional camera controls, use these key commands.

Key	Camera Control
Tab	Cycle the view between all vehicles in the scene.
Mouse scroll wheel	Control the camera distance from the vehicle.

Key	Camera Control
L	Toggle a camera lag effect on or off. When you enable the lag effect, the camera view includes: • Position lag, based on the vehicle translational acceleration • Rotation lag, based on the vehicle rotational velocity This lag enables improved visualization of overall vehicle acceleration and rotation.
F	Toggle the free camera mode on or off. When you enable the free camera mode, you can use the mouse to change the pitch and yaw of the camera. This mode enables you to orbit the camera around the vehicle.

`Sample time` — Sample time of visualization engine
(default) | scalar greater than or equal to 0.01

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

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

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

`Display 3D simulation window` — Unreal Engine visualization
on (default) | `off`

Select whether to run simulations in the 3D visualization environment without visualizing the results, that is, in headless mode.

Consider running in headless mode in these cases:

- You want to run multiple 3D simulations in parallel to test models in different Unreal Engine scenarios.

Dependencies

To enable this parameter, set **Scene source** to `Default Scene` or `Unreal Executable`.

Extended Capabilities

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

See Also

Simulation 3D Fisheye Camera | Simulation 3D UAV Vehicle | Simulation 3D Camera | Simulation 3D Lidar

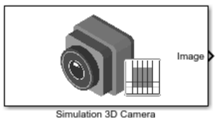
Topics
"Unreal Engine Simulation for Unmanned Aerial Vehicles"

“How Unreal Engine Simulation for UAVs Works”
“Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”

Introduced in R2020b

Simulation 3D Camera

Camera sensor model with lens in 3D simulation environment
Library: UAV Toolbox / Simulation 3D

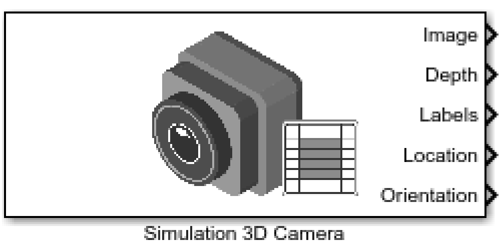


Description

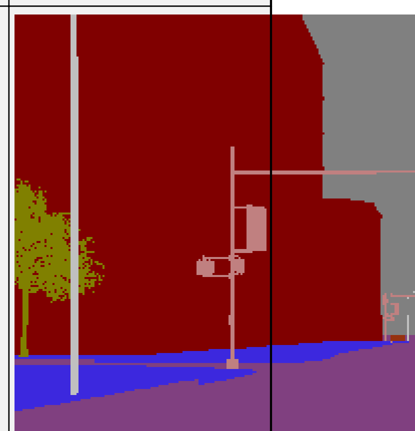
The Simulation 3D Camera block provides an interface to a camera with a lens in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The sensor is based on the ideal pinhole camera model, with a lens added to represent a full camera model, including lens distortion. For more details, see "Algorithms" on page 4-43.

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

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



The table summarizes the ports and how to enable them.

Port	Description	Parameter for Enabling Port	Sample Visualization
Image	Outputs an RGB image captured by the camera	n/a	
Depth	Outputs a depth map with values from 0 m to 1000 meters	**Output depth**	
Labels	Outputs a semantic segmentation map of label IDs that correspond to objects in the scene	**Output semantic segmentation**	
Location	Outputs the location of the camera in the world coordinate system	**Output location (m) and orientation (rad)**	n/a
Orientation	Outputs the orientation of the camera in the world coordinate system	**Output location (m) and orientation (rad)**	n/a

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

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

For more information about execution order, see "Block Execution Order".

Ports

Output

`Image` — 3D output camera image

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

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

Data Types: `int8` | `uint8`

`Depth` — Object depth from 0 m to 1000 m

m-by-*n* array of object depths

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

Dependencies

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

Data Types: `double`

`Labels` — Label identifiers

m-by-*n* array of label identifiers

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

The table shows the object IDs used in the default scenes that are selectable from the Simulation 3D Scene Configuration block. If you are using a custom scene, in the Unreal Editor, you can assign new object types to unused IDs. If a scene contains an object that does not have an assigned ID, that object is assigned an ID of `0`. The detection of lane markings is not supported.

ID	Type
`0`	None/default
`1`	Building
`2`	*Not used*
`3`	Other
`4`	*Not used*

ID	Type
5	Pole
6	*Not used*
7	Road
8	Sidewalk
9	Vegetation
10	Vehicle
11	*Not used*
12	Generic traffic sign
13	Stop sign
14	Yield sign
15	Speed limit sign
16	Weight limit sign
17-18	*Not used*
19	Left and right arrow warning sign
20	Left chevron warning sign
21	Right chevron warning sign
22	*Not used*
23	Right one-way sign
24	*Not used*
25	School bus only sign
26-38	*Not used*
39	Crosswalk sign
40	*Not used*
41	Traffic signal
42	Curve right warning sign
43	Curve left warning sign
44	Up right arrow warning sign
45-47	*Not used*
48	Railroad crossing sign
49	Street sign
50	Roundabout warning sign
51	Fire hydrant
52	Exit sign
53	Bike lane sign
54-56	*Not used*
57	Sky

ID	Type
58	Curb
59	Flyover ramp
60	Road guard rail
61-66	*Not used*
67	Deer
68-70	*Not used*
71	Barricade
72	Motorcycle
73-255	*Not used*

Dependencies

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

Data Types: `uint8`

`Location` — Sensor location
real-valued 1-by-3 vector

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

Dependencies

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

Data Types: `double`

`Orientation` — Sensor orientation
real-valued 1-by-3 vector

Roll, pitch, and yaw sensor orientation about the *X*-axis, *Y*-axis, and *Z*-axis of the scene. The **Orientation** values are in the world coordinates of the scene. These values are positive in the clockwise direction when looking in the positive directions of these axes. Units are in radians.

Dependencies

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

Data Types: `double`

Parameters

Mounting

`Sensor identifier` — Unique sensor identifier
`1` (default) | positive integer

Unique sensor identifier, specified as a positive integer. In a multisensor system, the sensor identifier distinguishes between sensors. When you add a new sensor block to your model, the **Sensor**

identifier of that block is *N* + 1. *N* is the highest **Sensor identifier** value among existing sensor blocks in the model.

Example: 2

`Parent name` — Name of parent to which sensor is mounted
`Scene Origin` (default) | *`vehicle name`*

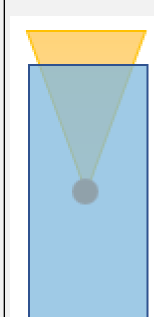
Name of the parent to which the sensor is mounted, specified as `Scene Origin` or as the name of a vehicle in your model. The vehicle names that you can select correspond to the **Name** parameters of the Simulation 3D Vehicle blocks in your model. If you select `Scene Origin`, the block places a sensor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

Example: `SimulinkVehicle1`

`Mounting location` — Sensor mounting location
`Origin` (default)

Sensor mounting location.

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

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
`Origin`	Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle 	[0, 0, 0]

Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the *X*-axis, *Y*-axis, and *Z*-axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

The (*X*, *Y*, *Z*) mounting location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D UAV Vehicle block to which you are mounting. To obtain the (*X*, *Y*, *Z*) mounting locations for a vehicle type, see the reference page for that vehicle.

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

`Specify offset` — Specify offset from mounting location

`off` (default) | `on`

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

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

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

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

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

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward .
- The *Z*-axis points up.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then *X*, *Y*, and *Z* are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see "Coordinate Systems for Unreal Engine Simulation in UAV Toolbox".

Example: `[0,0,0.01]`

Dependencies

To enable this parameter, select **Specify offset**.

`Relative rotation [Roll, Pitch, Yaw] (deg)` — Rotational offset relative to mounting location

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

Rotational offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form [*Roll*, *Pitch*, *Yaw*] . Roll, pitch, and yaw are the angles of rotation about the *X*-, *Y*-, and *Z*-axes, respectively. Units are in degrees.

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

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward .

- The *Z*-axis points up.
- Roll, pitch, and yaw are clockwise-positive when looking in the forward direction of the *X*-axis, *Y*-axis, and *Z*-axis, respectively. If you view a scene from a 2D top-down perspective, then the yaw angle (also called the orientation angle) is counterclockwise-positive, because you are viewing the scene in the negative direction of the *Z*-axis.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then *X*, *Y*, and *Z* are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”.

Example: `[0,0,10]`

Dependencies

To enable this parameter, select **Specify offset**.

`Sample time` — Sample time

`-1` (default) | positive scalar

Sample time of the block in seconds, specified as a positive scalar. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to `-1`, the block inherits its sample time from the Simulation 3D Scene Configuration block.

Parameters

These intrinsic camera parameters are equivalent to the properties of a `cameraIntrinsics` object. To obtain the intrinsic parameters for your camera, use the **Camera Calibrator** app.

`Focal length (pixels)` — Focal length of camera

`[1109, 1109]` (default) | 1-by-2 positive integer vector

Focal length of the camera, specified as a 1-by-2 positive integer vector of the form [*fx*, *fy*]. Units are in pixels.

$$fx = F \times sx$$
$$fy = F \times sy$$

where:

- *F* is the focal length in world units, typically millimeters.
- [*sx*, *sy*] are the number of pixels per world unit in the *x* and *y* direction, respectively.

This parameter is equivalent to the `FocalLength` property of a `cameraIntrinsics` object.

`Optical center (pixels)` — Optical center of camera

`[640, 360]` (default) | 1-by-2 positive integer vector

Optical center of the camera, specified as a 1-by-2 positive integer vector of the form [*cx*,*cy*]. Units are in pixels.

This parameter is equivalent to the `PrincipalPoint` property of a `cameraIntrinsics` object.

`Image size (pixels)` — Image size produced by camera
`[720, 1280]` (default) | 1-by-2 positive integer vector

Image size produced by the camera, specified as a 1-by-2 positive integer vector of the form [*mrows*,*ncols*]. Units are in pixels.

This parameter is equivalent to the `ImageSize` property of a `cameraIntrinsics` object.

`Radial distortion coefficients` — Radial distortion coefficients
`[0, 0]` (default) | real-valued 1-by-2 nonnegative vector | real-valued 1-by-3 nonnegative vector

Radial distortion coefficients, specified as a real-valued 1-by-2 or 1-by-3 nonnegative vector. Radial distortion occurs when light rays bend more than the edges of a lens than they do at its optical center. The distortion is greater when the lens is smaller. The block calculates the radial-distorted location of a point. Units are dimensionless.

This parameter is equivalent to the `RadialDistortion` property of a `cameraIntrinsics` object.

`Tangential distortion coefficients` — Tangential distortion coefficients
`[0, 0]` (default) | real-valued 1-by-2 nonnegative vector

Tangential distortion coefficients, specified as a real-valued 1-by-2 nonnegative vector. Tangential distortion occurs when the lens and the image plane are not parallel. The coordinates are expressed in world units. Units are dimensionless.

This parameter is equivalent to the `TangentialDistortion` property of a `cameraIntrinsics` object.

`Axis skew` — Skew angle of camera axes
`0` (default) | nonnegative scalar

Skew angle of the camera axes, specified as a nonnegative scalar. If the *X*-axis and *Y*-axis are exactly perpendicular, then the skew must be `0`. Units are dimensionless.

This parameter is equivalent to the `Skew` property of a `cameraIntrinsics` object.

Ground Truth

`Output depth` — Output depth map
`off` (default) | `on`

Select this parameter to output a depth map at the **Depth** port.

`Output semantic segmentation` — Output semantic segmentation map of label IDs
`off` (default) | `on`

Select this parameter to output a semantic segmentation map of label IDs at the **Labels** port.

`Output location (m) and orientation (rad)` — Output location and orientation of sensor
`off` (default) | `on`

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

Tips

- To visualize the camera images that are output by the **Image** port, use a Video Viewer or To Video Display block.

  To learn how to visualize the depth and semantic segmentation maps that are output by the **Depth** and **Labels** ports, see the “Depth and Semantic Segmentation Visualization Using Unreal Engine Simulation” example.
- Because the Unreal Engine can take a long time to start between simulations, consider logging the signals that the sensors output. You can then use this data to develop perception algorithms in MATLAB. See “Configure a Signal for Logging” (Simulink).

Algorithms

The block uses the camera model proposed by Jean-Yves Bouguet [1]. The model includes:

- The pinhole camera model [2]
- Lens distortion [3]

The pinhole camera model does not account for lens distortion because an ideal pinhole camera does not have a lens. To accurately represent a real camera, the full camera model used by the block includes radial and tangential lens distortion.

For more details, see “What Is Camera Calibration?” (Computer Vision Toolbox)

References

[1] Bouguet, J. Y. *Camera Calibration Toolbox for Matlab*. http://www.vision.caltech.edu/bouguetj/calib_doc

[2] Zhang, Z. "A Flexible New Technique for Camera Calibration." *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 22, No. 11, 2000, pp. 1330–1334.

[3] Heikkila, J., and O. Silven. “A Four-step Camera Calibration Procedure with Implicit Image Correction.” *IEEE International Conference on Computer Vision and Pattern Recognition*. 1997.

Extended Capabilities

C/C++ Code Generation

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

See Also

Blocks

Simulation 3D Fisheye Camera | Simulation 3D UAV Vehicle | Simulation 3D Scene Configuration | Simulation 3D Lidar

Apps

Camera Calibrator

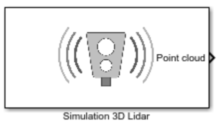
Objects
`cameraIntrinsics`

Topics
"Coordinate Systems for Unreal Engine Simulation in UAV Toolbox"
"Choose a Sensor for Unreal Engine Simulation"
"Apply Semantic Segmentation Labels to Custom Scenes"
"What Is Camera Calibration?" (Computer Vision Toolbox)
"Depth Estimation From Stereo Video" (Computer Vision Toolbox)
"Semantic Segmentation Using Deep Learning" (Computer Vision Toolbox)

Introduced in R2020b

Simulation 3D Lidar

Lidar sensor model in 3D simulation environment
Library: UAV Toolbox / Simulation 3D



Description

The Simulation 3D Lidar block provides an interface to the lidar sensor in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The block returns a point cloud with the specified field of view and angular resolution. You can also output the distances from the sensor to object points. In addition, you can output the location and orientation of the sensor in the world coordinate system of the scene.

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

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

- Simulation 3D Scene Configuration — `0`
- Simulation 3D Lidar — `1`

For more information about execution order, see “Block Execution Order”.

Ports

Output

`Point cloud` — Point cloud data
m-by-*n*-by-3 array of positive real-valued [*x*, *y*, *z*] points

Point cloud data, returned as an *m*-by-*n*-by 3 array of positive, real-valued [*x*, *y*, *z*] points. *m* and *n* define the number of points in the point cloud, as shown in this equation:

$$m \times n = \frac{V_{FOV}}{V_{RES}} \times \frac{H_{FOV}}{H_{RES}}$$

where:

- V_{FOV} is the vertical field of view of the lidar, in degrees, as specified by the **Vertical field of view (deg)** parameter.
- V_{RES} is the vertical angular resolution of the lidar, in degrees, as specified by the **Vertical resolution (deg)** parameter.

- H_{FOV} is the horizontal field of view of the lidar, in degrees, as specified by the **Horizontal field of view (deg)** parameter.
- H_{RES} is the horizontal angular resolution of the lidar, in degrees, as specified by the **Horizontal resolution (deg)** parameter.

Each *m*-by-*n* entry in the array specifies the *x*, *y*, and *z* coordinates of a detected point in the sensor coordinate system. If the lidar does not detect a point at a given coordinate, then *x*, *y*, and *z* are returned as `NaN`.

Data Types: `single`

`Distance` — Distance to object points
m-by-*n* positive real-valued matrix

Distance to object points measured by the lidar sensor, returned as an *m*-by-*n* positive real-valued matrix. Each *m*-by-*n* value in the matrix corresponds to an [*x*, *y*, *z*] coordinate point returned by the **Point cloud** output port.

Dependencies

To enable this port, on the **Parameters** tab, select **Distance outport**.

Data Types: `single`

`Location` — Sensor location
real-valued 1-by-3 vector

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

Dependencies

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

Data Types: `double`

`Orientation` — Sensor orientation
real-valued 1-by-3 vector

Roll, pitch, and yaw sensor orientation about the *X*-axis, *Y*-axis, and *Z*-axis of the scene. The **Orientation** values are in the world coordinates of the scene. These values are positive in the clockwise direction when looking in the positive directions of these axes. Units are in radians.

Dependencies

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

Data Types: `double`

Parameters

Mounting

`Sensor identifier` — Unique sensor identifier
`1` (default) | positive integer

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

Example: 2

`Parent name` — Name of parent to which sensor is mounted
`Scene Origin` (default) | *`vehicle name`*

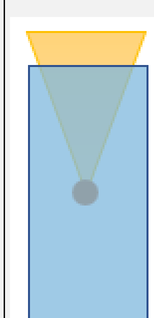
Name of the parent to which the sensor is mounted, specified as `Scene Origin` or as the name of a vehicle in your model. The vehicle names that you can select correspond to the **Name** parameters of the Simulation 3D Vehicle blocks in your model. If you select `Scene Origin`, the block places a sensor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

Example: `SimulinkVehicle1`

`Mounting location` — Sensor mounting location
`Origin` (default)

Sensor mounting location.

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

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
`Origin`	Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle 	[0, 0, 0]

Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the *X*-axis, *Y*-axis, and *Z*-axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

The (*X*, *Y*, *Z*) mounting location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D UAV Vehicle block to which you are mounting. To obtain the (*X*, *Y*, *Z*) mounting locations for a vehicle type, see the reference page for that vehicle.

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

`Specify offset` — Specify offset from mounting location

`off` (default) | `on`

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

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

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

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

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

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward .
- The *Z*-axis points up.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then *X*, *Y*, and *Z* are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”.

Example: `[0,0,0.01]`

Dependencies

To enable this parameter, select **Specify offset**.

`Relative rotation [Roll, Pitch, Yaw] (deg)` — Rotational offset relative to mounting location

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

Rotational offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form [*Roll*, *Pitch*, *Yaw*] . Roll, pitch, and yaw are the angles of rotation about the *X*-, *Y*-, and *Z*-axes, respectively. Units are in degrees.

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

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward .

- The *Z*-axis points up.
- Roll, pitch, and yaw are clockwise-positive when looking in the forward direction of the *X*-axis, *Y*-axis, and *Z*-axis, respectively. If you view a scene from a 2D top-down perspective, then the yaw angle (also called the orientation angle) is counterclockwise-positive, because you are viewing the scene in the negative direction of the *Z*-axis.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then *X*, *Y*, and *Z* are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”.

Example: `[0,0,10]`

Dependencies

To enable this parameter, select **Specify offset**.

`Sample time` — Sample time

`-1` (default) | positive scalar

Sample time of the block in seconds, specified as a positive scalar. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to `-1`, the block inherits its sample time from the Simulation 3D Scene Configuration block.

Parameters

`Detection range (m)` — Maximum distance measured by lidar sensor

`120` (default) | positive scalar

Maximum distance measured by the lidar sensor, specified as a positive scalar. Points outside this range are ignored. Units are in meters.

`Range resolution (m)` — Resolution of lidar sensor range

`0.002` (default) | positive real scalar

Resolution of the lidar sensor range, in meters, specified as a positive real scalar. The range resolution is also known as the quantization factor. The minimal value of this factor is D_{range} / 2^{24}, where D_{range} is the maximum distance measured by the lidar sensor, as specified in the **Detection range (m)** parameter.

`Vertical field of view (deg)` — Vertical field of view

`40` (default) | positive scalar

Vertical field of view of the lidar sensor, specified as a positive scalar. Units are in degrees.

`Vertical resolution (deg)` — Vertical angular resolution

`1.25` (default) | positive scalar

Vertical angular resolution of the lidar sensor, specified as a positive scalar. Units are in degrees.

`Horizontal field of view (deg)` — Horizontal field of view
`360` (default) | positive scalar

Horizontal field of view of the lidar sensor, specified as a positive scalar. Units are in degrees.

`Horizontal resolution (deg)` — Horizontal angular (azimuth) resolution
`0.16` (default) | positive scalar

Horizontal angular (azimuth) resolution of the lidar sensor, specified as a positive scalar. Units are in degrees.

`Distance outport` — Output distance to measured object points
`off` (default) | `on`

Select this parameter to output the distance to measured object points at the **Distance** port.

Ground Truth

`Output location (m) and orientation (rad)` — Output location and orientation of sensor
`off` (default) | `on`

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

Tips

- To visualize point clouds that are output by the **Point cloud** port, you can use a `pcplayer` object in a MATLAB Function block.
- The Unreal Engine can take a long time to start up between simulations, consider logging the signals that the sensors output. You can then use this data to develop perception algorithms in MATLAB. See “Configure a Signal for Logging” (Simulink).

Extended Capabilities

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

See Also

Blocks
Simulation 3D Camera | Simulation 3D Fisheye Camera | Simulation 3D Scene Configuration | Simulation 3D UAV Vehicle

Objects
`pcplayer` | `pointCloud`

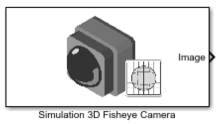
Topics
“Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”
“Choose a Sensor for Unreal Engine Simulation”

Introduced in R2020b

Simulation 3D Fisheye Camera

Fisheye camera sensor model in 3D simulation environment

Library: UAV Toolbox / Simulation 3D



Description

The Simulation 3D Fisheye Camera block provides an interface to a camera with a fisheye lens in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The sensor is based on the fisheye camera model proposed by Scaramuzza [1] on page 4-57. The block outputs an image with the specified camera distortion and size. You can also output the location and orientation of the camera in the world coordinate system of the scene.

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

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

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

For more information about execution order, see “How Unreal Engine Simulation for UAVs Works”.

Ports

Output

`Image` — 3D output camera image

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

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

Data Types: `int8` | `uint8`

`Location` — Sensor location

real-valued 1-by-3 vector

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

Dependencies

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

Data Types: `double`

`Orientation` — Sensor orientation

real-valued 1-by-3 vector

Roll, pitch, and yaw sensor orientation about the *X*-axis, *Y*-axis, and *Z*-axis of the scene. The **Orientation** values are in the world coordinates of the scene. These values are positive in the clockwise direction when looking in the positive directions of these axes. Units are in radians.

Dependencies

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

Data Types: `double`

Parameters

Mounting

`Sensor identifier` — Unique sensor identifier

`1` (default) | positive integer

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

Example: `2`

`Parent name` — Name of parent to which sensor is mounted

`Scene Origin` (default) | *`vehicle name`*

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

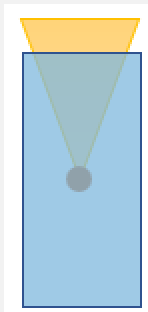
Example: `SimulinkVehicle1`

`Mounting location` — Sensor mounting location

`Origin` (default)

Sensor mounting location.

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

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
`Origin`	Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle 	[0, 0, 0]

Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the *X*-axis, *Y*-axis, and *Z*-axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

The (*X*, *Y*, *Z*) mounting location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D UAV Vehicle block to which you are mounting. To obtain the (*X*, *Y*, *Z*) mounting locations for a vehicle type, see the reference page for that vehicle.

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

`Specify offset` — Specify offset from mounting location

`off` (default) | `on`

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

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

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

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

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

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward .
- The *Z*-axis points up.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then *X*, *Y*, and *Z* are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”.

Example: `[0,0,0.01]`

Dependencies

To enable this parameter, select **Specify offset**.

`Relative rotation [Roll, Pitch, Yaw] (deg)` — Rotational offset relative to mounting location

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

Rotational offset relative to the mounting location of the sensor, specified as a real-valued 1-by-3 vector of the form [*Roll*, *Pitch*, *Yaw*] . Roll, pitch, and yaw are the angles of rotation about the *X*-, *Y*-, and *Z*-axes, respectively. Units are in degrees.

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

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward .
- The *Z*-axis points up.
- Roll, pitch, and yaw are clockwise-positive when looking in the forward direction of the *X*-axis, *Y*-axis, and *Z*-axis, respectively. If you view a scene from a 2D top-down perspective, then the yaw angle (also called the orientation angle) is counterclockwise-positive, because you are viewing the scene in the negative direction of the *Z*-axis.

The origin is the mounting location specified in the **Mounting location** parameter. This origin is different from the vehicle origin, which is the geometric center of the vehicle.

If you mount the sensor to the scene origin by setting **Parent name** to `Scene Origin`, then *X*, *Y*, and *Z* are in the world coordinates of the scene.

For more details about the vehicle and world coordinate systems, see “Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”.

Example: `[0,0,10]`

Dependencies

To enable this parameter, select **Specify offset**.

`Sample time` — Sample time

`-1` (default) | positive scalar

Sample time of the block in seconds, specified as a positive scalar. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to `-1`, the block inherits its sample time from the Simulation 3D Scene Configuration block.

Parameters

These intrinsic camera parameters are equivalent to the properties of a `fisheyeIntrinsics` object. To obtain the intrinsic parameters for your camera, use the **Camera Calibrator** app.

`Distortion center (pixels)` — Center of distortion
`[640, 360]` (default) | real-valued 1-by-2 vector

Center of distortion, specified as real-valued 2-element vector. Units are in pixels.

`Image size (pixels)` — Image size produced by camera
`[720, 1280]` (default) | real-valued 1-by-2 vector of positive integers

Image size produced by the camera, specified as a real-valued 1-by-2 vector of positive integers of the form [*mrows*,*ncols*]. Units are in pixels.

`Mapping coefficients` — Polynomial coefficients for projection function
`[320, 0, 0, 0]` (default) | real-valued 1-by-4 vector

Polynomial coefficients for the projection function described by Scaramuzza's Taylor model [1], specified as a real-valued 1-by-4 vector of the form `[a0 a2 a3 a4]`.

Example: `[320, -0.001, 0, 0]`

`Stretch matrix` — Transforms point from sensor plane to camera plane
`[1, 0; 0, 1]` (default) | real-valued 2-by-2 matrix

Transforms a point from the sensor plane to a pixel in the camera image plane. The misalignment occurs during the digitization process when the lens is not parallel to sensor.

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

Ground Truth

`Output location (m) and orientation (rad)` — Output location and orientation of sensor
`off` (default) | `on`

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

Tips

- To visualize the camera images that are output by the **Image** port, use a Video Viewer or To Video Display block.
- Because the Unreal Engine can take a long time to start up between simulations, consider logging the signals that the sensors output. You can then use this data to develop perception algorithms in MATLAB. See “Configure a Signal for Logging” (Simulink).

References

[1] Scaramuzza, D., A. Martinelli, and R. Siegwart. "A Toolbox for Easy Calibrating Omindirectional Cameras." *Proceedings to IEEE International Conference on Intelligent Robots and Systems (IROS 2006)*. Beijing, China, October 7–15, 2006.

Extended Capabilities

C/C++ Code Generation

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

See Also

Blocks

Simulation 3D Camera | Simulation 3D Lidar | Simulation 3D Scene Configuration | Simulation 3D UAV Vehicle

Apps

Camera Calibrator

Objects

`fisheyeIntrinsics`

Topics

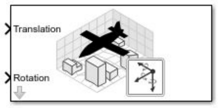
"Coordinate Systems for Unreal Engine Simulation in UAV Toolbox"
"Choose a Sensor for Unreal Engine Simulation"
"Apply Semantic Segmentation Labels to Custom Scenes"
"Fisheye Calibration Basics" (Computer Vision Toolbox)

Introduced in R2019b

Simulation 3D UAV Vehicle

Place UAV vehicle in 3D visualization

Library: UAV Toolbox / Simulation 3D



Description

The Simulation 3D UAV Vehicle block implements an unmanned aerial vehicle (UAV) in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The block uses the input (*X*, *Y*, *Z*) position and input (*roll*, *pitch*, *yaw*) attitude of the UAV in the simulation.

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

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

- Simulation 3D Scene Configuration — `0`
- Simulation 3D Vehicle — `-1`

For more information about execution order, see “Block Execution Order”.

Ports

Input

`Translation` — Translation of vehicle relative to scene
vector

Translated position of the vehicle relative to the Unreal Engine scene origin. Translation vector defines the *X*, *Y*, and *Z* positions, in meters, of the vehicle using the Unreal Engine world coordinate frame. For more information on the coordinate systems, see “Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”.

Data Types: `double`

`Rotation` — Rotation of vehicle relative to scene
vector

Rotation of the vehicle relative to the Unreal Engine inertial reference frame. The rotation vector defines the *Yaw*, *Pitch*, and *Roll* values, in degrees, of the vehicle rotation relative to the Unreal Engine world coordinate frame. For more information on the coordinate systems, see “Coordinate Systems for Unreal Engine Simulation in UAV Toolbox”.

Data Types: `double`

Parameters

Vehicle Parameters

`Type` — Type of vehicle
`Quadcopter` (default) | `Fixed wing`

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

- `Quadcopter` — **Quadcopter**
- `Fixed wing` — **Fixed wing**

`Color` — Color of vehicle
`Black` (default) | `Orange` | `Yellow` | `Green` | `Blue` | `Red` | `White` | `Silver`

Select the color of the vehicle.

`Name` — Name of vehicle
`SimulinkVehicle1` (default) | vehicle name

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

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

Initial Values

`Initial Translation (m)` — Initial vehicle position
`[0, 0, 0]` (default) | real-valued 1-by-3 vector

Initial vehicle position along the *X*-axis, *Y*-axis, and *Z*-axis in the inertial *Z*-down coordinate system, in m.

`Initial Rotation (rad)` — Initial angle of vehicle rotation
`[0, 0, 0]` (default) | real-valued 1-by-3 vector

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

Sample Time

`Sample time` — Sample time
`-1` (default) | positive scalar

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

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

Extended Capabilities

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

See Also

Blocks
Simulation 3D Fisheye Camera | Simulation 3D Lidar | Simulation 3D Scene Configuration | Simulation 3D UAV Vehicle

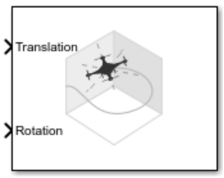
Tools
Fixed Wing Aircraft | **Quadrotor**

Topics
"Coordinate Systems for Unreal Engine Simulation in UAV Toolbox"
"Choose a Sensor for Unreal Engine Simulation"

Introduced in R2020b

UAV Animation

Animate UAV flight path using translations and rotations
Library: UAV Toolbox / Utilities



Description

The UAV Animation block animates a unmanned aerial vehicle (UAV) flight path based on an input array of translations and rotations. A visual mesh is displayed for either a fixed-wing or multirotor at the given position and orientation. Click the **Show animation** button in the block mask to bring up the figure after simulating.

Ports

Input

`Translation` — *xyz*-positions

`[x y z]` vector

xyz-positions specified as an `[x y z]` vector.

Example: `[1 1 1]`

`Rotation` — Rotations of UAV body frames

`[w x y z]` quaternion vector

Rotations of UAV body frames relative to the inertial frame, specified as a `[w x y z]` quaternion vector.

Example: `[1 0 0 0]`

Parameters

`UAV type` — Type of UAV mesh to display

`Multirotor` (default) | `FixedWing`

Type of UAV mesh to display, specified as either `FixedWing` or `Multirotor`.

`UAV size` — Size of frame and attached mesh

`1` (default) | positive numeric scalar

Size of frame and attached mesh, specified as positive numeric scalar.

`Inertial frame z-axis direction` — Direction of positive *z*-axis of inertial frame

`Down` (default) | `Up`

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. The parameter defines the rotation between the inertia frame and plot frame. Set this parameter to `Down` if the inertial frame is following 'North-East-Down' configuration.

`Sample time` — Interval between outputs
–1 (default) | scalar

Interval between outputs, specified as a scalar. In simulation, the sample time follows simulation time and not actual wall-block time.

This default value indicates that the block sample time is *inherited*.

For more information about the inherited sample time type, see "Specify Sample Time" (Simulink).

Extended Capabilities

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

See Also

Functions
`plotTransforms` | `state`

Objects
`fixedwing` | `multirotor` | `uavWaypointFollower`

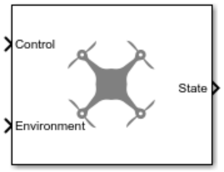
Blocks
Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

Guidance Model

Reduced-order model for UAV
Library: UAV Toolbox / Algorithms



Description

The Guidance Model block represents a small unmanned aerial vehicle (UAV) guidance model that estimates the UAV state based on control and environmental inputs. The model approximates the behavior of a closed-loop system consisting of an autopilot controller and a fixed-wing or multirotor kinematic model for 3-D motion. Use this block as a reduced-order guidance model to simulate your fixed-wing or multirotor UAV. Specify the **ModelType** to select your UAV type. Use the **Initial State** tab to specify the initial state of the UAV depending on the model type. The **Configuration** tab defines the control parameters and physical parameters of the UAV.

Ports

Input

`Control` — Control commands
bus

Control commands sent to the UAV model, specified as a bus. The name of the input bus is specified in **Input/Output Bus Names**.

For multirotor UAVs, the model is approximated as separate PD controllers for each command. The elements of the bus are control command:

- `Roll` - Roll angle in radians.
- `Pitch` - Pitch angle in radians.
- `YawRate` - Yaw rate in radians per second. (D = 0. P only controller)
- `Thrust` - Vertical thrust of the UAV in Newtons. (D = 0. P only controller)

For fixed-wing UAVs, the model assumes the UAV is flying under the coordinated-turn condition. The guidance model equations assume zero side-slip. The elements of the bus are:

- `Height` - Altitude above the ground in meters.
- `Airspeed` - UAV speed relative to wind in meters per second.
- `RollAngle` - Roll angle along body forward axis in radians. Because of the coordinated-turn condition, the heading angular rate is based on the roll angle.

`Environment` — Environmental inputs
bus

Environmental inputs, specified as a bus. The model compensates for these environmental inputs when trying to achieve the commanded controls.

For fixed-wing UAVs, the elements of the bus are `WindNorth`, `WindEast`,`WindDown`, and `Gravity`. Wind speeds are in meters per second and negative speeds point in the opposite direction. `Gravity` is in meters per second squared.

For multirotor UAVs, the only element of the bus is `Gravity` in meters per second squared.

Data Types: `bus`

Output

`State` — Simulated UAV state
bus

Simulated UAV state, returned as a bus. The block uses the `Control` and `Environment` inputs with the guidance model equations to simulate the UAV state.

For multirotor UAVs, the state is a five-element bus:

- **WorldPosition** - `[x y z]` in meters.
- **WorldVelocity** - `[vx vy vz]` in meters per second.
- **EulerZYX** - `[psi phi theta]` Euler angles in radians.
- **BodyAngularRateRPY** - `[r p q]` in radians per second along the `xyz`-axes of the UAV.
- **Thrust** - `F` in Newtons.

For fixed-wing UAVs, the state is an eight-element bus:

- **North** - Position in north direction in meters.
- **East** - Position in east direction in meters.
- **Height** - Height above ground in meters.
- **AirSpeed** - Speed relative to wind in meters per second.
- **HeadingAngle** - Angle between ground velocity and north direction in radians.
- **FlightPathAngle** - Angle between ground velocity and north-east plane in radians.
- **RollAngle** - Angle of rotation along body *x*-axis in radians per second.
- **RollAngleRate** - Angular velocity of rotation along body *x*-axis in radians per second.

Data Types: `bus`

Parameters

`ModelType` — UAV guidance model type
`MultirotorGuidance` (default) | `FixedWingGuidance`

UAV guidance model type, specified as `MultirotorGuidance` or `FixedWingGuidance`. The model type determines the elements of the UAV `State` and the required `Control` and `Environment` inputs.

Tunable: No

DataType — Input and output numeric data types
double (default) | single

Input and output numeric data types, specified as either double or single. Choose the data type based on possible software or hardware limitations.

Tunable: No

Simulate using — Type of simulation to run
Interpreted execution (default) | Code generation

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

Tunable: No

Initial State — Initial UAV state tab
multiple table entries

Initial UAV state tab, specified as multiple table entries. All entries on this tab are nontunable.

For multirotor UAVs, the initial state is:

- **World Position** - [x y z] in meters.
- **World Velocity** - [vx vy vz] in meters per second.
- **Euler Angles (ZYX)** - [psi phi theta] in radians.
- **Body Angular Rates** - [p q r] in radians per second.
- **Thrust** - F in Newtons.

For fixed-wing UAVs, the initial state is:

- **North** - Position in north direction in meters.
- **East** - Position in east direction in meters.
- **Height** - Height above ground in meters.
- **Air Speed** - Speed relative to wind in meters per second.
- **Heading Angle** - Angle between ground velocity and north direction in radians.
- **Flight Path Angle** - Angle between ground velocity and north-east plane in radians.
- **Roll Angle** - Angle of rotation along body *x*-axis in radians per second.
- **Roll Angle Rate** - Angular velocity of rotation along body *x*-axis in radians per second.

Tunable: No

Configuration — UAV controller configuration tab
multiple table entries

UAV controller configuration tab, specified as multiple table entries. This tab allows you to configure the parameters of the internal control behaviour of the UAV. Specify the proportional (P) and derivative (D) gains for the dynamic model and the UAV mass in kilograms (for multirotor).

For multirotor UAVs, the parameters are:

- **PD Roll**
- **PD Pitch**
- **P YawRate**
- **P Thrust**
- **Mass**(kg)

For fixed-wing UAVs, the parameters are:

- **P Height**
- **P Flight Path Angle**
- **PD Roll**
- **P Air Speed**
- **Min/Max Flight Path Angle** (`[min max]` angle in radians)

Tunable: No

`Input/Output Bus Names` — Simulink bus signal names tab
multiple entries of character vectors

Simulink bus signal names tab, specified as multiple entries of character vectors. These buses have a default name based on the UAV model and input type. To use multiple guidance models in the same Simulink model, specify different bus names that do not intersect. All entries on this tab are nontunable.

More About

UAV Coordinate Systems

The UAV Toolbox uses the North-East-Down (NED) coordinate system convention, which is also sometimes called the local tangent plane (LTP). The UAV position vector consists of three numbers for position along the northern-axis, eastern-axis, and vertical position. The down element complies with the right-hand rule and results in negative values for altitude gain.

The ground plane, or earth frame (NE plane, D = 0), is assumed to be an inertial plane that is flat based on the operation region for small UAV control. The earth frame coordinates are $[x_e,y_e,z_e]$. The body frame of the UAV is attached to the center of mass with coordinates $[x_b,y_b,z_b]$. x_b is the preferred forward direction of the UAV, and z_b is perpendicular to the plane that points downwards when the UAV travels during perfect horizontal flight.

The orientation of the UAV (body frame) is specified in ZYX Euler angles. To convert from the earth frame to the body frame, we first rotate about the z_e-axis by the yaw angle, ψ. Then, rotate about the intermediate y-axis by the pitch angle, ϕ. Then, rotate about the intermediate x-axis by the roll angle, Θ.

The angular velocity of the UAV is represented by $[p,q,r]$ with respect to the body axes, $[x_b,y_b,z_b]$.

UAV Fixed-Wing Guidance Model Equations

For fixed-wing UAVs, the following equations are used to define the guidance model of the UAV. Use the `derivative` function to calculate the time-derivative of the UAV state using these governing equations. Specify the inputs using the `state`, `control`, and `environment` functions.

The UAV position in the earth frame is [x_e, y_e, h] with orientation as heading angle, flight path angle, and roll angle, [χ, γ, ϕ] in radians.

The model assumes that the UAV is flying under a coordinated-turn condition, with zero side-slip. The autopilot controls airspeed, altitude, and roll angle. The corresponding equations of motion are:

$$\dot{x}_e = V_g \cos\chi \cos\gamma$$

$$\dot{y}_e = V_g \sin\chi \cos\gamma$$

$$\dot{h} = V_g \sin\gamma$$

$$\dot{\chi} = \frac{g\cos(\chi - \psi)}{V_g}\tan\phi$$

$$V_g \sin(\gamma^c) = min\left(max\left(k_h(h^c - h), -V_g\right), V_g\right)$$

$$\dot{\gamma} = k_\gamma(\gamma^c - \gamma)$$

$$\dot{V}_a = k_{V_a}(V_a^c - V_a)$$

$$\frac{g\cos(\chi - \psi)}{V_g}\tan(\phi^c) = k_\chi(\chi^c - \chi)$$

$$\ddot{\phi} = k_{P\phi}(\phi^c - \phi) + k_{D\phi}(-\dot{\phi})$$

V_a and V_g denote the UAV air and ground speeds.

The wind speed is specified as [V_{w_n},V_{w_e},V_{w_d}] for the north, east, and down directions. To generate the structure for these inputs, use the `environment` function.

k_* are controller gains. To specify these gains, use the `Configuration` property of the `fixedwing` object.

From these governing equations, the model gives the following variables:

$$[x_e \quad y_e \quad h \quad V_a \quad \chi \quad \gamma \quad \phi \quad \dot{\phi}]$$

These variables match the output of the `state` function.

UAV Multirotor Guidance Model Equations

For multirotors, the following equations are used to define the guidance model of the UAV. To calculate the time-derivative of the UAV state using these governing equations, use the `derivative` function. Specify the inputs using `state`, `control`, and `environment`.

The UAV position in the earth frame is $[x_e, y_e, z_e]$ with orientation as ZYX Euler angles, $[\psi, \Theta, \phi]$ in radians. Angular velocities are $[p, q, r]$ in radians per second.

The UAV body frame uses coordinates as $[x_b, y_b, z_b]$.

The rotation matrix that rotates from world to body frame is:

$$R_b^e = \begin{bmatrix} c_\theta c_\psi & c_\psi s_\phi s_\theta - c_\phi s_\psi & c_\phi c_\psi s_\theta + s_\phi s_\psi \\ c_\theta s_\psi & c_\phi c_\psi + s_\phi s_\theta s_\psi & -c_\psi s_\phi + c_\phi s_\theta s_\psi \\ -s_\theta & c_\theta s_\phi & c_\phi c_\theta \end{bmatrix}$$

The cos(x) and sin(x) are abbreviated as c_x and s_x.

The acceleration of the UAV center of mass in earth coordinates is governed by:

$$m \begin{bmatrix} \ddot{x}_e \\ \ddot{y}_e \\ \ddot{z}_e \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} + R_b^e \begin{bmatrix} 0 \\ 0 \\ -F_{thrust} \end{bmatrix}$$

m is the UAV mass, g is gravity, and F_{thrust} is the total force created by the propellers applied to the multirotor along the $-z_b$ axis (points upwards in a horizontal pose).

The closed-loop roll-pitch attitude controller is approximated by the behavior of 2 independent PD controllers for the two rotation angles, and 2 independent P controllers for the yaw rate and thrust. The angular velocity, angular acceleration, and thrust are governed by:

$$J = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta} \end{bmatrix}$$

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\sin\theta \\ 0 & \cos\phi & \sin\phi\cos\theta \\ 0 & -\sin\phi & \cos\phi\cos\theta \end{bmatrix} \begin{bmatrix} KP_{\phi}\left(\dot{\phi}^{c} - \dot{\phi}\right) + KD_{\phi}\left(-\dot{\phi}\right) \\ KP_{\theta}(\theta^{c} - \theta) + KD_{\theta}\left(-\dot{\theta}\right) \\ KP_{\psi}\left(\dot{\psi}^{c} - \dot{\psi}\right) \end{bmatrix}$$

$$\dot{F}_{thrust} = KP_F(F_{thrust}^{c} - F_{thrust})$$

This model assumes the autopilot takes in commanded roll, pitch, yaw rate, [ψ^c, Θ^c, $\dot{\phi}^c$] and a commanded total thrust force, $F^c{}_{thrust}$. The structure to specify these inputs is generated from `control`.

The P and D gains for the control inputs are specified as KP_α and KD_α, where α is either the rotation angle or thrust. These gains along with the UAV mass, *m*, are specified in the `Configuration` property of the `multirotor` object.

From these governing equations, the model gives the following variables:

$$[x_e \quad y_e \quad z_e \quad \dot{x}_e \quad \dot{y}_e \quad \dot{z}_e \quad \psi \quad \theta \quad \phi \quad p \quad q \quad r \quad F_{thrust}]$$

These variables match the output of the `state` function.

References

[1] Randal W. Beard and Timothy W. McLain. "Chapter 9." *Small Unmanned Aircraft Theory and Practice*, NJ: Princeton University Press, 2012.

[2] Mellinger, Daniel, and Nathan Michael. "Trajectory Generation and Control for Precise Aggressive Maneuvers with Quadrotors." *The International Journal of Robotics Research*. 2012, pp. 664-74.

Extended Capabilities

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

See Also

Functions
`control` | `derivative` | `environment` | `ode45` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor` | `uavWaypointFollower`

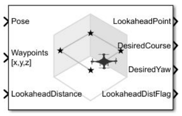
Blocks
Waypoint Follower

Topics
"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

Waypoint Follower

Follow waypoints for UAV
Library: UAV Toolbox / Algorithms



Description

The Waypoint Follower block follows a set of waypoints for an unmanned aerial vehicle (UAV) using a lookahead point. The block calculates the lookahead point, desired course, and desired yaw given a UAV position, a set of waypoints and a lookahead distance. Specify a set of waypoints and tune the lookahead distance and transition radius parameters for navigating the waypoints. The block supports both multirotor and fixed-wing UAV types.

Ports

Input

`Pose` — Current UAV pose
`[x y z chi]` vector

Current UAV pose, specified as a `[x y z chi]` vector. This pose is used to calculate the lookahead point based on the input to the **LookaheadDistance** port. `[x y z]` is the current position in meters. `chi` is the current course in radians.

Example: `[0.5;1.75;-2.5;pi]`

Data Types: `single` | `double`

`Waypoints` — Set of waypoints
n-by-3 matrix | *n*-by-4 matrix | *n*-by-5 matrix

Set of waypoints for the UAV to follow, specified as a matrix with number of rows, *n*, equal to the number of waypoints. The number of columns depend on the **Show Yaw input variable** and the **Transition radius source** parameter.

Each row in the matrix has the first three elements as an `[x y z]` position in the sequence of waypoints.

If **Show Yaw input variable** is checked, specify the desired yaw angle, `yaw`, as the fourth element in radians.

If **Show Yaw input variable** is unchecked, and **Transition radius source** is `external`, the transition radius is the fourth element of the vector in meters.

If **Show Yaw input variable** is checked, and **Transition radius source** is `external`, the transition radius is the fifth element of the vector in meters.

The block display updates as the size of the waypoint matrix changes.

Data Types: single | double

LookaheadDistance — Lookahead distance
positive numeric scalar

Lookahead distance along the path, specified as a positive numeric scalar in meters.

Data Types: single | double

Output

LookaheadPoint — Lookahead point on path
[x y z] position vector

Lookahead point on path, returned as an [x y z] position vector in meters.

Data Types: single | double

DesiredCourse — Desired course
numeric scalar

Desired course, returned as numeric scalar in radians in the range of [-pi, pi]. The UAV course is the angle of direction of the velocity vector relative to north measured in radians. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: single | double

DesiredYaw — Desired yaw
numeric scalar

Desired yaw, returned as numeric scalar in radians in the range of [-pi, pi]. The UAV yaw is the forward direction of the UAV regardless of the velocity vector relative to north measured in radians. The desired yaw is computed using linear interpolation between the yaw angle for each waypoint. For fixed-wing type UAV, the values of desired course and desired yaw are equal.

Data Types: single | double

LookaheadDistFlag — Lookahead distance flag
0 (default) | 1

Lookahead distance flag, returned as 0 or 1. 0 indicates lookahead distance is not saturated, 1 indicates lookahead distance is saturated to minimum lookahead distance value specified.

Data Types: uint8

CrossTrackError — Cross track error from UAV position to path
positive numeric scalar

Cross track error from UAV position to path, returned as a positive numeric scalar in meters. The error measures the perpendicular distance from the UAV position to the closest point on the path.

Dependencies

This port is only visible if **Show CrossTrackError output port** is checked.

Data Types: single | double

Status — Status of waypoint navigation
0 | 1

Status of waypoint navigation, returned as `0` or `1`. When the follower has navigated all waypoints, the block outputs `1`. Otherwise, the block outputs `0`.

Dependencies

This port is only visible if **Show UAV Status output port** is checked.

Parameters

`UAV type` — Type of UAV

`fixed-wing` (default) | `multirotor`

Type of UAV, specified as either `fixed-wing` or `multirotor`.

This parameter is non-tunable.

`StartFrom` — Waypoint start behavior

`first` (default) | `closest`

Waypoint start behavior, specified as either `first` or `closest`.

When set to `first`, the UAV flies to the first path segment between waypoints. If the set of waypoints input in `Waypoints` changes, the UAV restarts at the first path segment.

When set to `closest`, the UAV flies to the closest path segment between waypoints. When the waypoints input changes, the UAV recalculates the closest path segment.

This parameter is non-tunable.

`Transition radius source` — Source of transition radius

`internal` (default) | `external`

Source of transition radius, specified as either `internal` or `external`. If specified as `internal`, the transition radius for each waypoint is set using the **Transition radius (r)** parameter in the block mask. If specified as `external`, specify each waypoints transition radius independently using the input from the **Waypoints** port.

When the UAV is within the transition radius, the block transitions to following the next path segment between waypoints.

This parameter is non-tunable.

`Transition radius (r)` — Transition radius for waypoints

`10` (default) | positive numeric scalar

Transition radius for waypoints, specified as a positive numeric scalar in meters.

When the UAV is within the transition radius, the block transitions to following the next path segment between waypoints.

This parameter is non-tunable.

`Minimum lookahead distance (m)` — Minimum lookahead distance

`0.1` (default) | positive numeric scalar

Minimum lookahead distance, specified as a positive numeric scalar in meters.

When input to the **LookaheadDistance** port is less than the minimum lookahead distance, the **LookaheadDistFlag** is returned as `1` and the lookahead distance value is specified as the value of minimum lookahead distance.

This parameter is non-tunable.

`Show Yaw input variable` — Accept yaw input for waypoints
`off` (default) | `on`

Accept yaw inputs for waypoints when selected. If selected, the **Waypoints** input accepts yaw inputs for each waypoint.

`Show CrossTrackError output port` — Output cross track error
`off` (default) | `on`

Output cross track error from the **CrossTrackError** port.

This parameter is non-tunable.

`Show UAV Status output port` — Output UAV waypoint status
`off` (default) | `on`

Output UAV waypoint status from the **Status** port.

This parameter is non-tunable.

`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`.

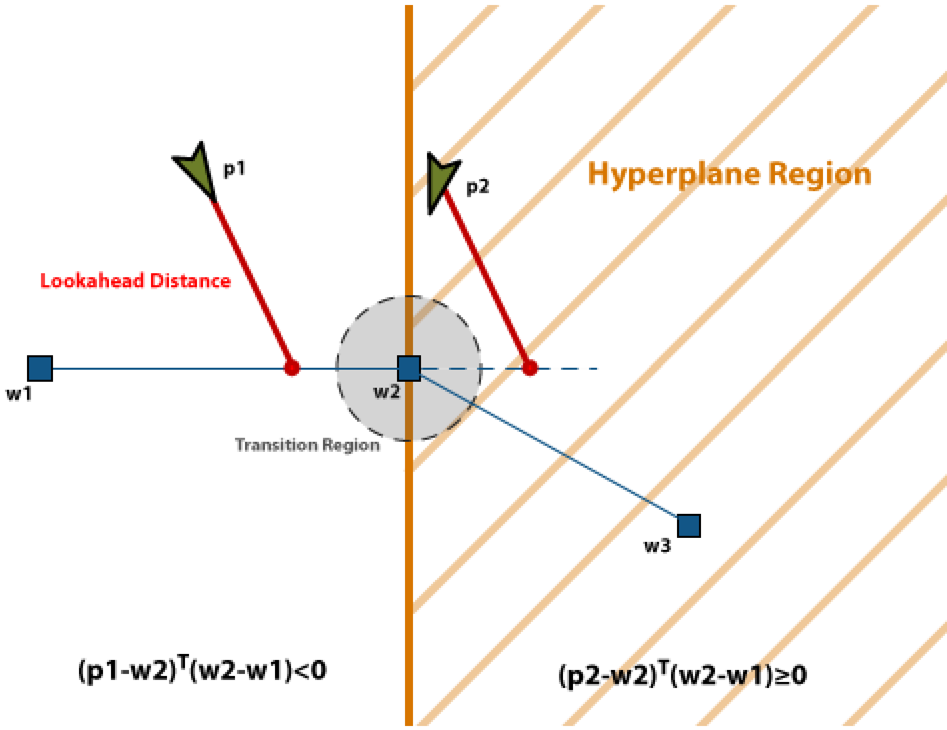
This parameter is non-tunable.

Tunable: No

More About

Waypoint Hyperplane Condition

When following a set of waypoints, the first waypoint may be ignored based on the pose of the UAV. Due to the nature of the lookahead distance used to track the path, the waypoint follower checks if the UAV is near the next waypoint to transition to the next path segment using a transition region. However, there is also a condition where the UAV transitions when outside of this region. A 3-D hyperplane is drawn at the next waypoint. If the UAV pose is inside this hyperplane, the waypoint follower transitions to the next waypoint. This behavior helps to ensure the UAV follows an achievable path.



The hyperplane condition is satisfied if:

$(p\text{-}w1)^{T} (w2\text{-}w1) \geq 0$

p is the UAV position, and *w1* and *w2* are sequential waypoint positions.

If you find this behavior limiting, consider adding more waypoints based on your initial pose to force the follower to navigate towards your initial waypoint.

References

[1] Park, Sanghyuk, John Deyst, and Jonathan How. "A New Nonlinear Guidance Logic for Trajectory Tracking." *AIAA Guidance, Navigation, and Control Conference and Exhibit*, 2004.

Extended Capabilities

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

See Also

Blocks
Orbit Follower | UAV Guidance Model

Functions
`control` | `derivative` | `environment` | `ode45` | `plotTransforms` | `state`

Objects
`fixedwing` | `multirotor` | `uavWaypointFollower`

Topics

"Approximate High-Fidelity UAV model with UAV Guidance Model block"
"Tuning Waypoint Follower for Fixed-Wing UAV"

Introduced in R2018b

Apps

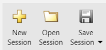
Flight Log Analyzer

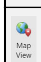
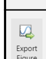
Analyze UAV autopilot flight logs

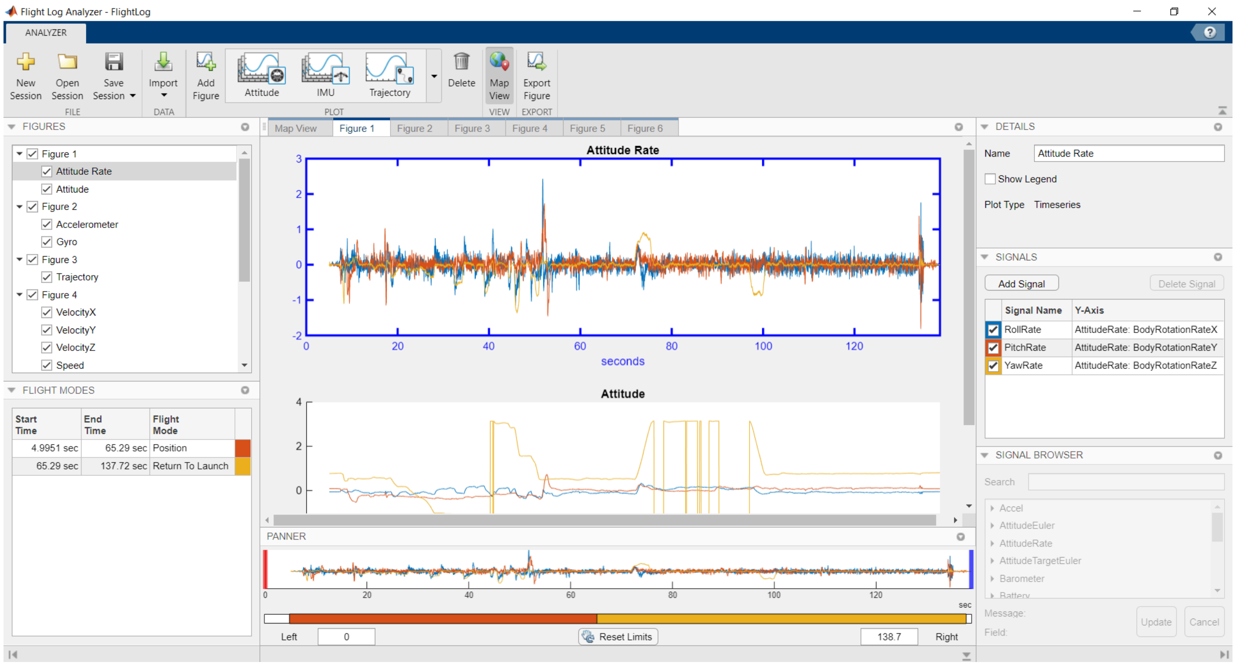
Description

The **Flight Log Analyzer** app enables you to load and analyze UAV autopilot flight log data, as well as create a customized series of plots.

To use the app:

	Click **New Session** to create a new session. You can open saved app sessions by clicking **Open Session**. You can save your progress to a MAT-file (`.mat`) by clicking **Save Session**.
	To load a ULOG file (`.ulg`) or MAT-file containing a `ulogreader` object, select **Import** > **From ULOG**. To load a TLOG file (`.tlog`) or MAT-file containing a `mavlinktlog` object, select **Import** > **From TLOG**. Select **Import** > **From Workspace** to load a `ulogreader` object, `mavlinktlog` object, or custom log data and a `flightLogSignalMapping` object from the workspace.

	Click **Add Figure** to add a new figure for plotting. You can add one or more predefined or custom plots to a figure from the plot gallery. To see all available plots in the plot gallery, click the down arrow on the right side of the gallery. **Predefined Plots** • **Attitude** — Adds plots for roll, pitch, yaw angles, as well as body rotation rates • **IMU** — Adds plots for an accelerometer and gyroscope • **Trajectory** — Adds a 3-D plot for the UAV trajectory and reference trajectory • **Velocity** — Adds plots for velocity in the *x*-, *y*-, and *z*-directions, as well as groundspeed and airspeed • **Compass** — Adds plots for a magnetometer, estimated yaw, and course angle • **Height** — Adds a plot for GPS, a barometer, and estimated altitude **Custom Plots** • **Timeseries** — Adds a blank plot for timeseries data • **XY** — Adds a blank plot for 2-D data • **XYZ** — Adds a blank plot for 3-D data You can delete the selected figure or plot by clicking **Delete**.
	Click **Map View** to view or hide the satellite image map with logged GPS data. **Note** The app requires internet access to retrieve satellite imagery.
	Click **Export Figure** to export the currently selected figure as a `.fig` file.



Open the Flight Log Analyzer App

- MATLAB Toolstrip: On the **Apps** tab, under **Control System Design and Analysis**, click **Flight Log Analyzer**.
- MATLAB command prompt: Enter `flightLogAnalyzer`.

Examples

Analyze Flight Log from ULOG File

Use the **Flight Log Analyzer** app to load and analyze UAV autopilot flight log data from a ULOG file.

Open the Flight Log Analyzer App

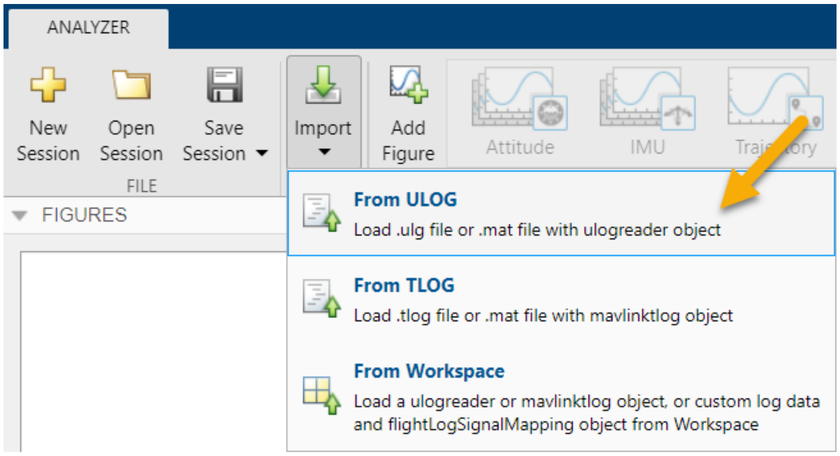
In the **Apps** tab, under **Control System Design and Analysis,** click **Flight Log Analyzer**.

Alternatively, you can use the `flightLogAnalyzer` function from the MATLAB command prompt:

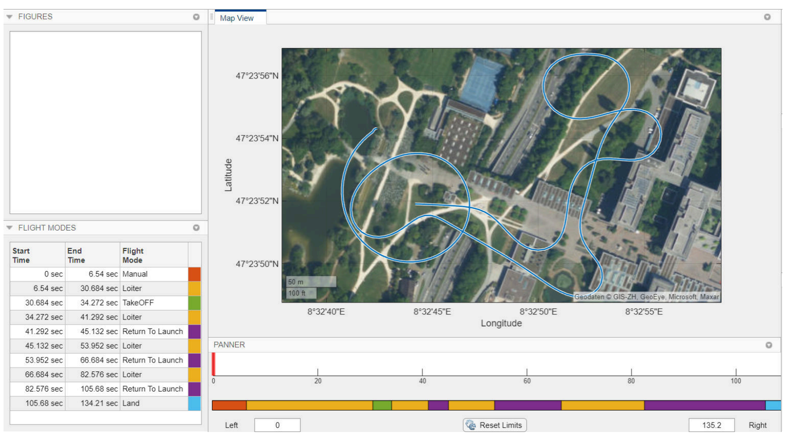
```
flightLogAnalyzer
```

Import a ULOG File

Select **Import** > **From ULOG** to load the UAV flight log data from a ULOG (`.ulg`) file.

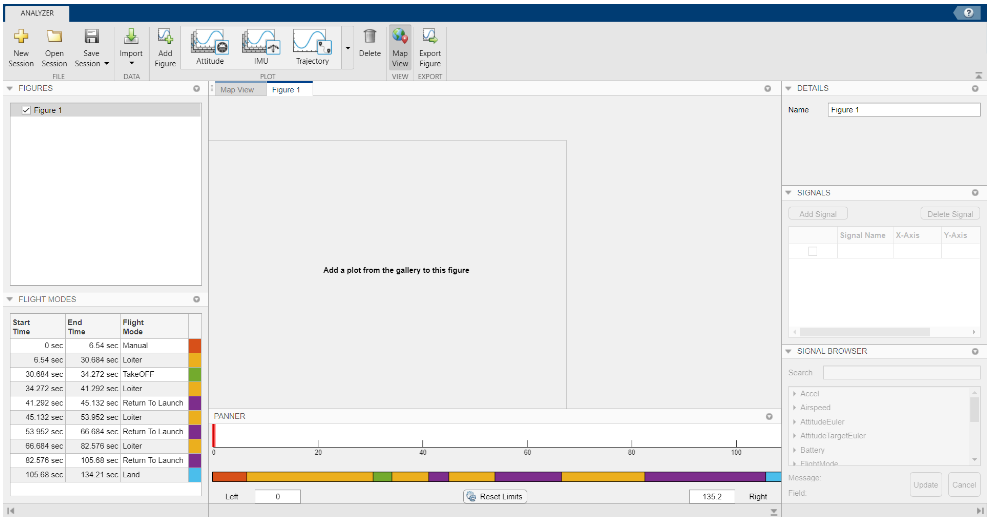


By default, the app displays a satellite map with logged GPS data and the flight modes as a table. The flight modes, along with their corresponding start and end times, are tabulated in the **Flight Modes** pane.



Create Figures and Plots

1 To create a new figure for plotting, click **Add Figure**. The app adds an empty figure to the plotting pane.



You can continue adding additional figures using this process.

2 The app adds a figure item corresponding to the new figure to the list in the **Figures** pane. Select the check box to the left of the listed figure item to show all plots in the figure. Clear the check box to hide them.

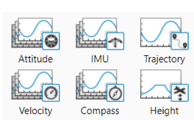
3 To rename a figure, select the associated figure item in the **Figures** pane, click the **Name** box in the **Details** pane, and type a new name.

4 To delete a figure, select the figure item in the **Figures** pane and click **Delete** on the app toolstrip. Deleting a figure deletes all plots in the figure.

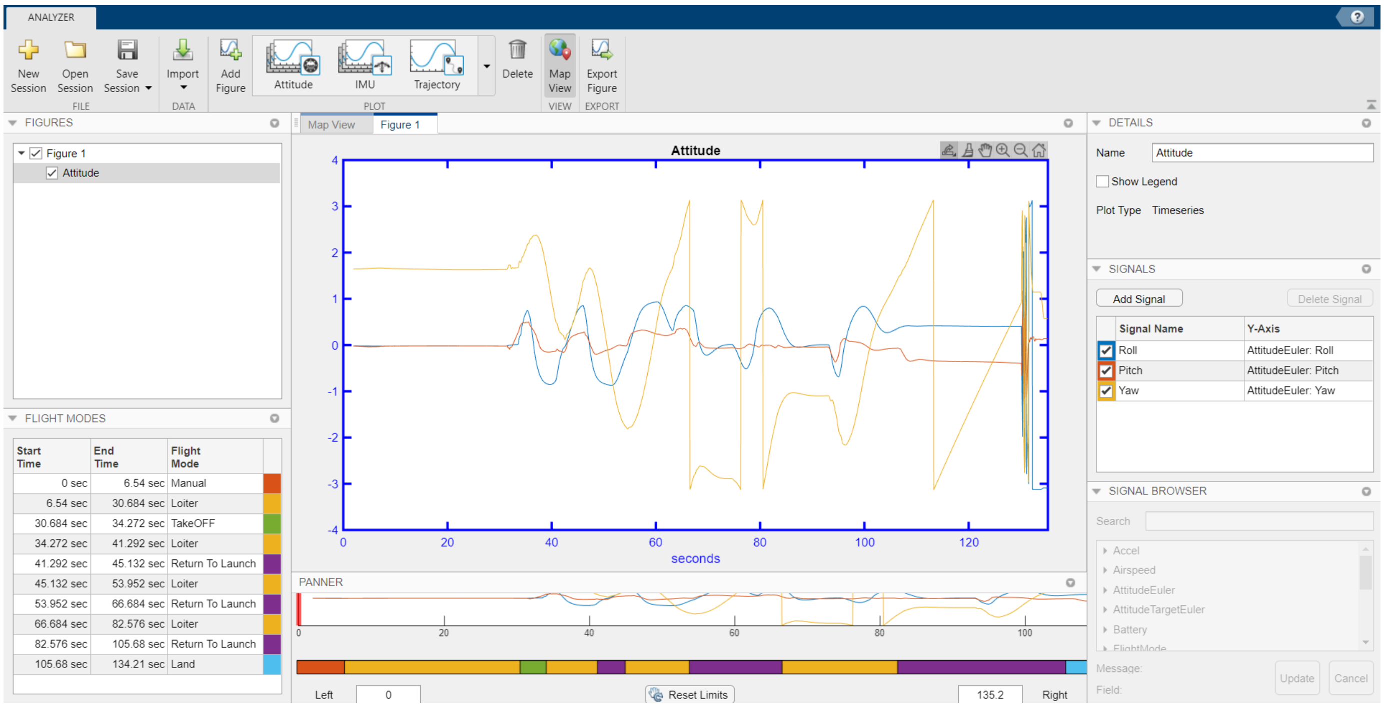
Creating a figure enables the plot gallery. You can add one or more predefined plots or custom plots to a figure from the plot gallery.

Add a Predefined Plot

1 To add a predefined plot to a figure, select one of the six predefined plots from the plot gallery.



2 For example, click **Attitude** to add plots for rotation angles and rotation rates to the figure.



You can continue adding additional plots to a figure using this process.

3 The app adds a plot item corresponding to the new plot under the associated figure item in the **Figures** pane. Select the check box to the left of the listed plot item to show the plot in the figure. Clear the check box to hide the plot.

4 To rename a plot, select the associated plot item in the **Figures** pane, click the **Name** box in the **Details** pane, and type a new name.

5 Select the **Show Legend** check box in the **Details** pane to show the legend on the plot. Clear the check box to hide the legend.

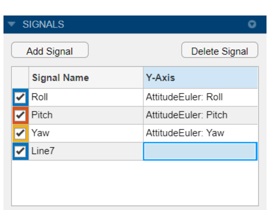
6 To delete a plot, select the plot item in the **Figures** pane and click **Delete** on the app toolstrip.

Edit Plot Signals

1 The **Signals** pane displays the signals in the selected plot as a table. The **Signal Name** column contains the names of the signals. The subsequent columns each contain the data associated with that signal for a specific axis.

2 Select the check box in front of a signal item to show that signal in the plot, and clear the check box to hide the signal. The color around the check box is the color of the signal in the plot.

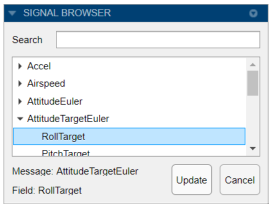
3 To add a new signal to the selected plot, click **Add Signal**.



To rename the signal, double-click signal in the **Signal Name** column and type a new name.

4 To add or update the signal data, double-click the data field for the desired signal in the corresponding column to enable the **Signal Browser** pane. Choose from available signals.

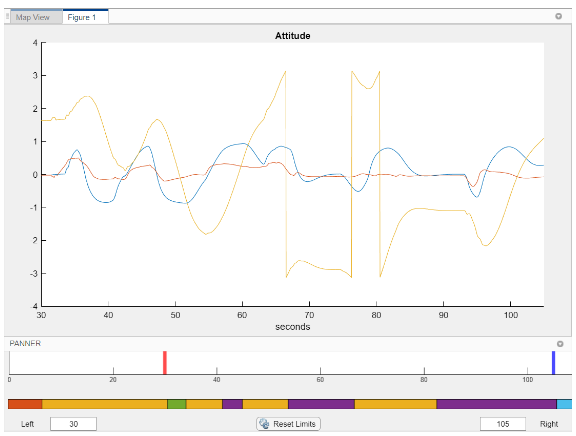
5 Select one of the signals from the **Signal Browser** pane and click **Update**.



6 To delete a signal, select a signal from the **Signals** pane and click **Delete Signal**.

Change the Plot Focus Using the Panner

1 For timeseries plots, use the **Panner** to focus on data segments in the *x*-axis range. The **Panner** is a strip plot beneath the main plot. To focus on a section of the main plot, drag the red and blue handles to the start and end positions, respectively, of the desired data segment.



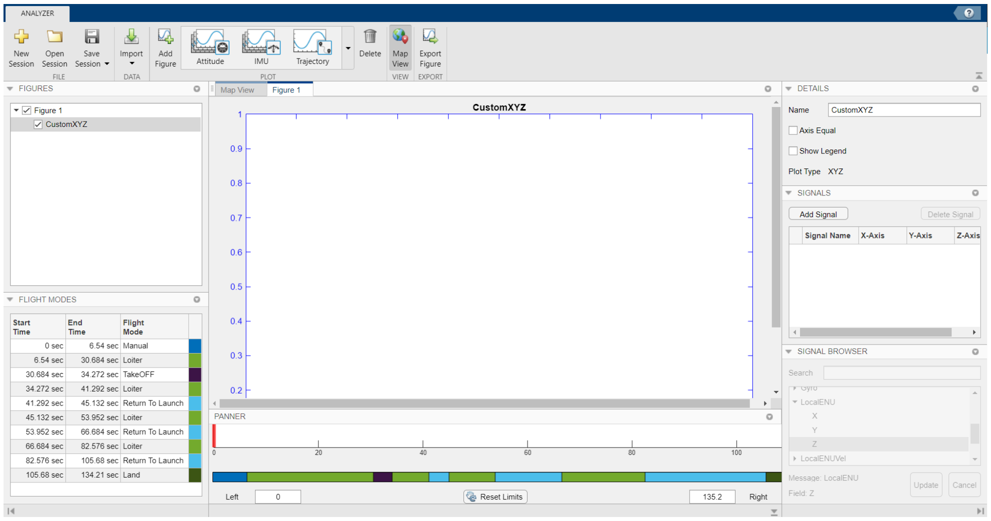
2 You can also move the handles by typing new values in the **Left** and **Right** boxes, beneath the strip plot. To reset the handles to their default values, click **Reset Limits**.

3 The color next to each flight mode in the **Flight Modes** pane represents that flight mode in the color bar under the strip plot in the **Panner** pane.

Add a Custom Plot

1 To add a custom plot to a figure, select one of the three custom plots from the plot gallery. You can add the new plot to the previously created figure or to a new figure.

2 For example, click **XYZ** to add a blank plot for 3-D data.



3 To add a signal to the plot, click **Add Signal** in the **Signals** pane.

4 To rename the signal, double-click signal in the **Signal Name** column and type a new name.

5 To add signal data to the **X-Axis**, **Y-Axis**, and **Z-Axis** columns, double-click the data field for the desired signal in the corresponding column to enable the **Signal Browser** pane. Choose from the available signals.

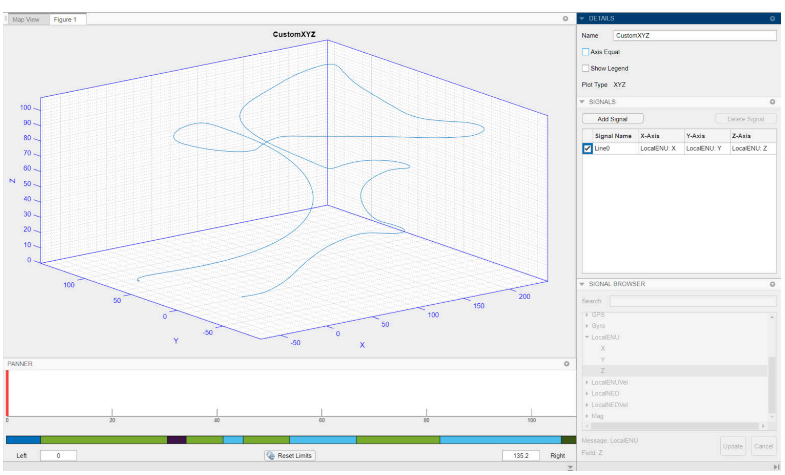
6 For example, to create a trajectory plot in local east-north-up (ENU) Cartesian coordinates:

   a Double-click the **X-Axis** data field for the desired signal and find the **LocalENU** signal group in the **Signal Browser** pane.

   b Expand the group and select the signal **X**.

   c Click **Update** to update the signal with **X-Axis** data.

   d Repeat these steps to update the **Y-Axis** and **Z-Axis** fields with **Y** and **Z** data, respectively, to create a 3-D trajectory plot.



Click **Export Figure** to export the current figure as a `.fig` file.

You can save the **Flight Log Analyzer** app session by clicking **Save Session**. The app writes the current state of the app to a `.mat` file that you can load by clicking **Open Session**.

Programmatic Use

`flightLogAnalyzer` opens the **Flight Log Analyzer** app, which enables you to analyze UAV autopilot flight logs.

More About

Flight Modes

This table describes the types of flight modes:

Flight mode	Description
Manual	Manual remote control mode
TakeOFF	Take off from the ground and travel towards the specified position
Orbit	Orbit in the specified turn direction for the specified number of turns along the circumference of a circle with a specified radius and a center at the specified position
Loiter	A fixed-wing UAV circle around the specified position at the specified radius
Hold	Hold at the current position A fixed-wing UAV loiters around the current position, and a multirotor UAV hovers at the current position
Return To Launch	Return to the launch position
Land	Land at the specified position

See Also

Objects
`flightLogSignalMapping` | `mavlinktlog` | `ulogreader`

Introduced in R2020b

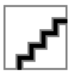
Scenes

US City Block

US city block Unreal Engine environment

Description

The **US City Block** scene is an Unreal Engine environment of a US city block that contains 15 intersections and 30 traffic lights. The scene is rendered using the Unreal Engine from Epic Games.

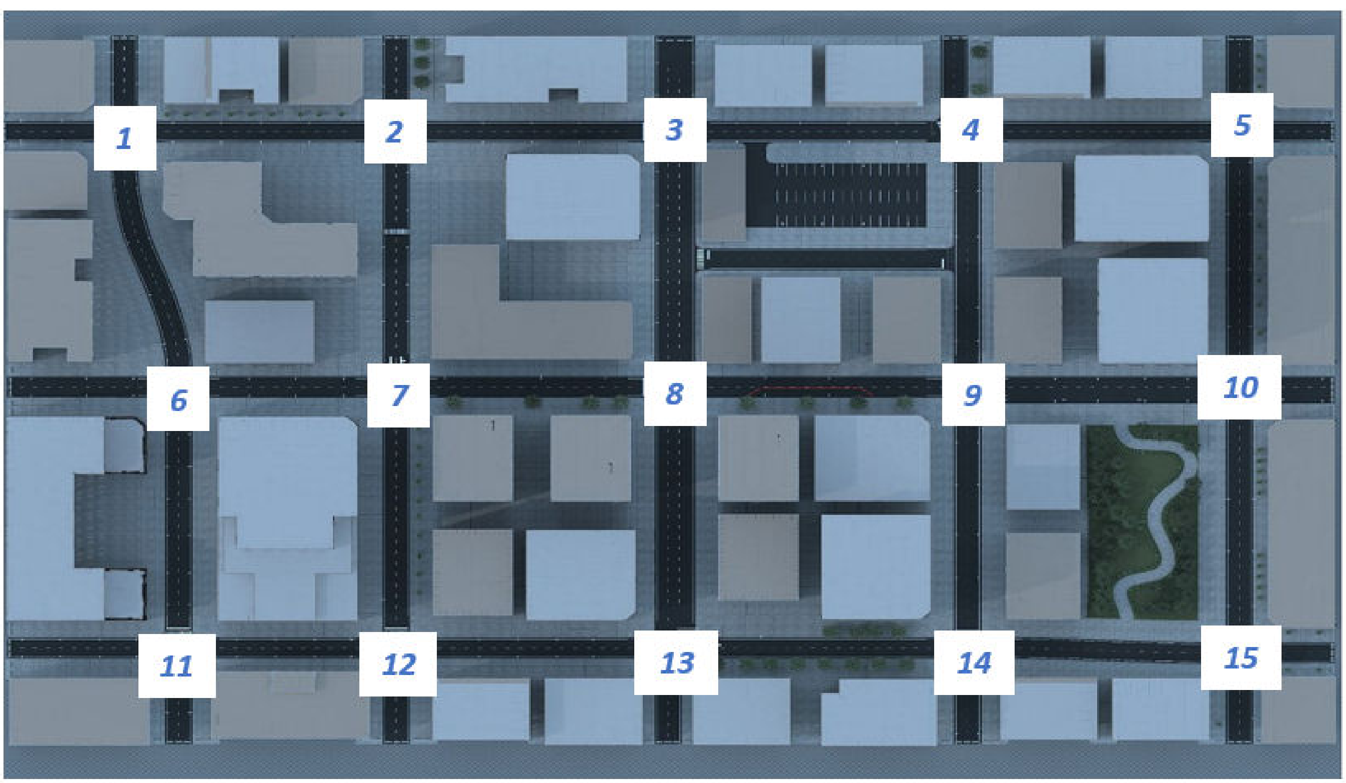


To simulate a UAV flight in this scene:

1. Add a Simulation 3D Scene Configuration block to your Simulink model.
2. In this block, set the **Scene source** parameter to `Default Scenes`.
3. Set the enabled **Scene name** parameter to `US city block`.

Intersections

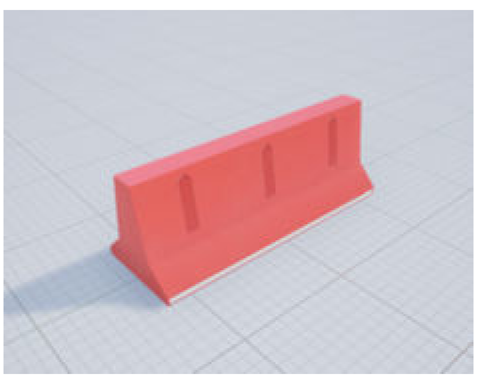
The US city block scene has 15 intersections, as indicated in this diagram.



This table provides the intersection locations in the world coordinate system. Dimensions are in m.

Intersection	Center Location		
	X (m)	Y (m)	Z (m)
1	-202.60	-108	.01
2	-112.60	-108	.01
3	-20.38	-108	.01
4	74.58	-108	.01
5	166.40	-108	.01
6	-184.60	0	.01
7	-112.60	0	.01
8	-20.34	0	.01
9	76.40	0	.01
10	166.46	0	.01
11	-184.60	110.50	.01
12	-112.60	110.50	.01
13	-22.60	110.50	.01
14	76.40	110.50	.01
15	166.40	112.50	.01

Barrier



This table provides the object names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
Barrier	SM_Barrier	163.5	-146.95	0	0	0	90°
	SM_Barrier 2	166.35	-146.95	0	0	0	90°

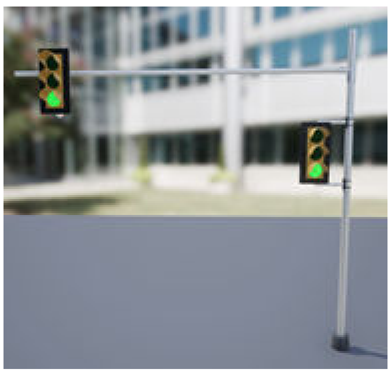
Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrier 3	169.2	-146.95	0	0	0	90°
	SM_Barrier 7	163.5	150.15	0	0	0	90°
	SM_Barrier 8	166.35	150.15	0	0	0	90°
	SM_Barrier 9	169.2	150.15	0	0	0	90°
	SM_Barrier 11	197.05	109.65	0	0	0	-180°
	SM_Barrier 13	197.05	112.5	0	0	0	-180°
	SM_Barrier 14	197.05	115.34	0	0	0	-180°
	SM_Barrier 18	197.05	-2.9	0	0	0	-180°
	SM_Barrier 19	197.05	-0.05	0	0	0	-180°
	SM_Barrier 20	197.05	2.8	0	0	0	-180°
	SM_Barrier 21	-240.5	107.65	0	0	0	-180°
	SM_Barrier 22	197.05	-110.9	0	0	0	-180°
	SM_Barrier 24	197.05	5.6	0	0	0	-180°
	SM_Barrier 27	197.05	-108.05	0	0	0	-180°
	SM_Barrier 28	197.05	-105.25	0	0	0	-180°
	SM_Barrier 31	-240.5	110.5	0	0	0	-180°
	SM_Barrier 32	-240.5	113.35	0	0	0	-180°
	SM_Barrier 36	-240.1	-2.9	0	0	0	-180°
	SM_Barrier 37	-240.1	-0.05	0	0	0	-180°
	SM_Barrier 38	-240.1	2.8	0	0	0	-180°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrier 43	-242.15	110.9	0	0	0	-180°
	SM_Barrier 44	-242.15	-108.05	0	0	0	-180°
	SM_Barrier 45	-242.15	-105.25	0	0	0	-180°
	SM_Barrier 48	73.4	150.15	0	0	0	90°
	SM_Barrier 49	76.25	150.15	0	0	0	90°
	SM_Barrier 50	79.1	150.15	0	0	0	90°
	SM_Barrier 54	-25.55	150.15	0	0	0	90°
	SM_Barrier 55	-22.7	150.15	0	0	0	90°
	SM_Barrier 56	-19.85	150.15	0	0	0	90°
	SM_Barrier 59	-115.3	150.15	0	0	0	90°
	SM_Barrier 60	-112.45	150.15	0	0	0	90°
	SM_Barrier 61	-109.6	150.15	0	0	0	90°
	SM_Barrier 66	69.25	-147.35	0	0	0	90°
	SM_Barrier 68	75.45	-147.5	0.15	0	0	90°
	SM_Barrier 69	72.45	-147.5	0.15	0	0	90°
	SM_Barrier 70	-25.55	-146.45	0	0	0	90°
	SM_Barrier 71	-22.15	-146.45	0	0	0	90°
	SM_Barrier 72	-18.65	-146.45	0	0	0	90°
	SM_Barrier 75	-115.3	-147.6	0	0	0	90°
	SM_Barrier 76	-112.45	-147.6	0	0	0	90°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrier 77	-109.6	-147.6	0	0	0	90°
	SM_Barrier 84	-15.45	-146.45	0	0	0	90°
	SM_Barrier 88	-187.5	150.15	0	0	0	90°
	SM_Barrier 89	-184.65	150.15	0	0	0	90°
	SM_Barrier 90	-181.8	150.15	0	0	0	90°
	SM_Barrier 94	-205.6	-147.4	0	0	0	90°
	SM_Barrier 95	-202.75	-147.4	0	0	0	90°
	SM_Barrier 96	-199.9	-147.4	0	0	0	90°
	SM_Barrier 101	44.15	3.05	0	0	0	-50°
	SM_Barrier 102	39.15	0.55	0	0	0	-90°
	SM_Barrier 103	41.95	1.3	0	0	0	-50°
	SM_Barrier 104	36.5	.55	0	0	0	-90°
	SM_Barrier 105	33.85	.55	0	0	0	-90°
	SM_Barrier 106	31.2	.55	0	0	0	-90°
	SM_Barrier 107	28.45	.55	0	0	0	-90°
	SM_Barrier 108	25.8	.55	0	0	0	-90°
	SM_Barrier 109	23.15	.55	0	0	0	-90°
	SM_Barrier 110	20.5	.55	0	0	0	-90°
	SM_Barrier 111	17.95	.55	0	0	0	-90°
	SM_Barrier 112	15.3	.55	0	0	0	-90°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrier 113	12.65	.55	0	0	0	-90°
	SM_Barrier 114	10.0	.55	0	0	0	-90°
	SM_Barrier 115	7.01	1.38	0	0	0	-125°
	SM_Barrier 116	4.75	3.05	0	0	0	-125°

Traffic Lights



The US City Scene contains 30 traffic lights, two at each of the 15 intersections. Each intersection has a traffic light group. If you have the “Customize Unreal Engine Scenes for UAVs” for customizing scenes, you can control the timing of the traffic lights.

This table provides the traffic light names and locations in the world coordinate system. Dimensions are in m. Only one of the traffic lights in the group can be green at a time. The traffic lights are green for 10 s and yellow for 3 s. At the start of the simulation, the first traffic lights in the group are green (for example, `SM_TrafficLights1_3` and `SM_TrafficLights2_4`). The second lights in the group are red (for example, `SM_TrafficLights1_4` and `SM_TrafficLights2_3`).

Intersection	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
1	TrafficLightGroup	SM_TrafficLights1_3	-196.55	-100.65	0	0	0	-90°
		SM_TrafficLights1_4	-210.20	-113.40	0	0	0	0

Intersection	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
2	TrafficLightGroup2	SM_TrafficLights2_4	-120.40	-113.50	0	0	0	0
		SM_TrafficLights2_3	-106.35	98.35	0	0	0	-90°
3	TrafficLightGroup3	SM_TrafficLights3_1	-13.10	-116.20	0.2	0	0	90°
		SM_TrafficLights3_4	-30.60	-113.80	0	0	0	0
4	TrafficLightGroup4	SM_TrafficLights4_4	64.80	-113.0	0	0	0	0
		SM_TrafficLights4_3	71.40	-100.30	0	0	0	-100°
5	TrafficLightGroup5	SM_TrafficLights5_1	171.50	-115.70	0	0	0	90°
		SM_TrafficLights5_4	157.40	-113.50	0	0	0	0
6	TrafficLightGroup6	SM_TrafficLights6_3	-189.60	7.40	0	0	0	-90°
		SM_TrafficLights6_2	-177.30	5.70	0	0	0	180°

Intersection	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
7	TrafficLightGroup7	SM_TrafficLights7_3	-117.80	7.70	0.2	0	0	-90°
		SM_TrafficLights7_2	-105.20	5.50	0	0	0	180°
8	TrafficLightGroup8	SM_TrafficLights8_2	-10.90	5.60	0	0	0	180°
		SM_TrafficLights8_1	-13.10	-7.60	0.1	0	0	90°
9	TrafficLightGroup9	SM_TrafficLights9_3	70.90	9.20	0	0	0	-90°
		SM_TrafficLights9_2	85.90	7.60	0.2	0	0	180°
10	TrafficLightGroup10	SM_TrafficLights10_2	173.70	7.50	0	0	0	180°
		SM_TrafficLights10_1	172.10	-7.70	0	0	0	90°
11	TrafficLightGroup11	SM_TrafficLights11_3	-189.80	118.45	0	0	0	-90°
		SM_TrafficLights11_4	-191.05	104.55	0	0	0	0

Intersection	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
12	TrafficLightGroup12	SM_TrafficLights12_4	-120.50	105.40	0	0	0	0
		SM_TrafficLights12_3	-117.60	117.60	0	0	0	-90°
13	TrafficLightGroup13	SM_TrafficLights13_1	-12.80	102.50	0	0	0	90°
		SM_TrafficLights13_4	-30.50	105.30	0	0	0	0
14	TrafficLightGroup14	SM_TrafficLights14_4	69.30	105.30	0	0	0	0
		SM_TrafficLights14_3	70.90	118.70	0	0	0	-90°
15	TrafficLightGroup15	SM_TrafficLights15_1	171.40	105.20	0	0	0	90°
		SM_TrafficLights15_4	158.40	107.20	0	0	0	0

Tips

- If you have the UAV Toolbox Interface for Unreal Engine Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named `USCityBlock`.

  For more details on customizing scenes, see “Customize Unreal Engine Scenes for UAVs”.

See Also

"Coordinate Systems for Unreal Engine Simulation in UAV Toolbox" | Simulation 3D Scene Configuration

7

Vehicles

Quadrotor

Quadrotor vehicle dimensions

Description

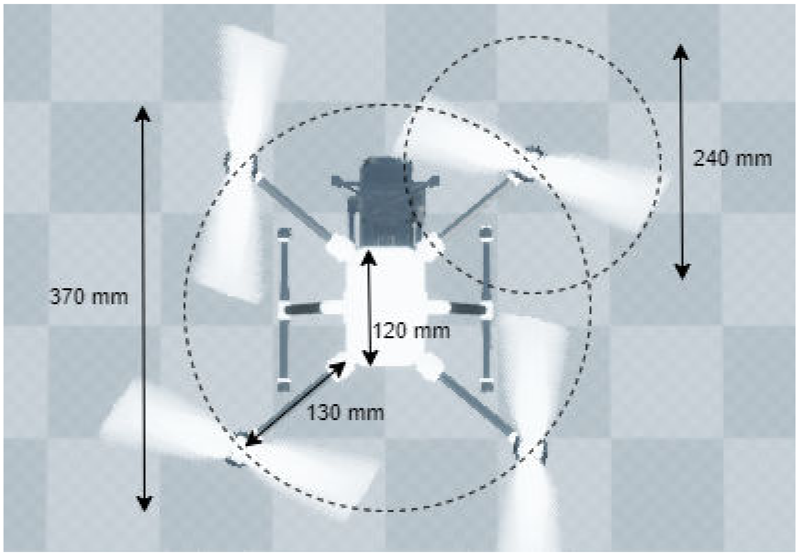
Quadrotot is one of the UAVs that you can use within the Unreal Engine simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The origin is located at the center of the camera gimbal located on the underside of the aircraft. For detailed specifications of the vehicle dimensions , see the **Dimensions** section.

To add this type of vehicle to the Unreal Engine simulation environment:

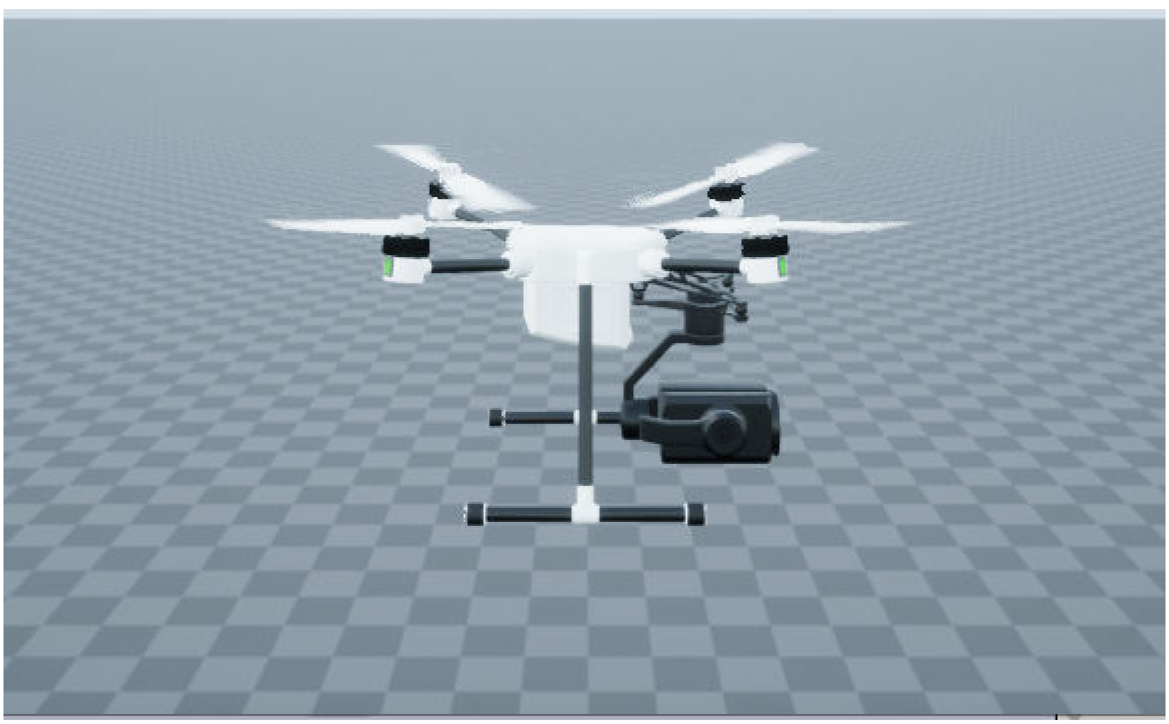
1. Add a Simulation 3D UAV Vehicle block to your Simulink model.
2. In the block, set the **Type** parameter to `Quadrotor`.

Dimensions

`Top-down view` — Vehicle width dimensions
diagram



`Side view` — Vehicle length, front overhang, and rear overhang dimensions
diagram



`Front view` — Tire width and front axle dimensions
diagram

`Rear view` — Vehicle height and rear axle dimensions
diagram

Sensor Mounting Locations

See Also
Simulation 3D UAV Vehicle | Simulation 3D Scene Configuration

Topics
"Unreal Engine Simulation for Unmanned Aerial Vehicles"
"Coordinate Systems for Unreal Engine Simulation in UAV Toolbox"

Fixed Wing Aircraft

Fixed wing aircraft dimensions

Description

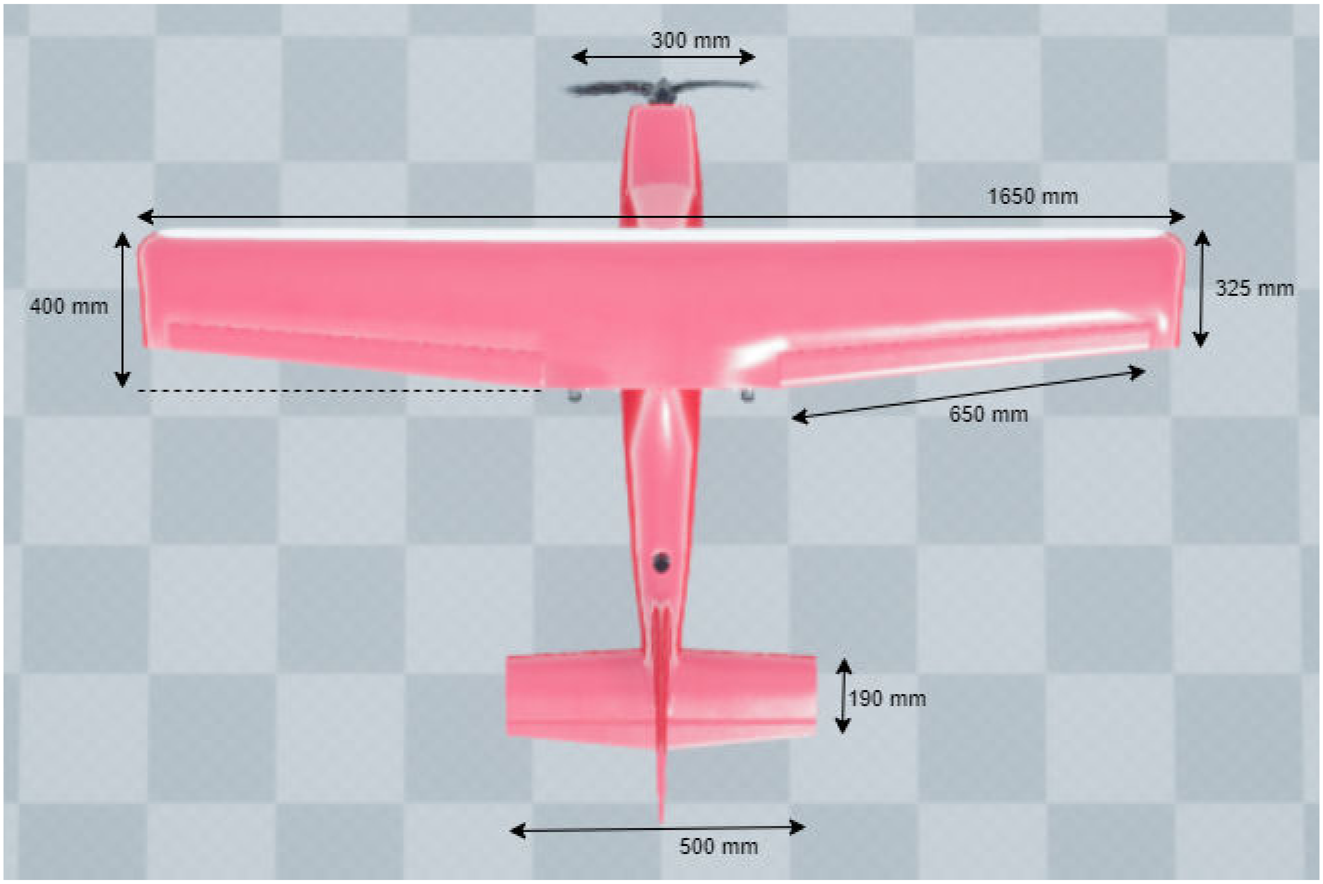
Fixed Wing Aircraft is one of the vehicles that you can use within the Unreal Engine simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The origin is located at the center of the camera gimbal located on the underside of the aircraft. For detailed specifications of the vehicle dimensions , see the **Dimensions** section.

To add this type of vehicle to the 3D simulation environment:

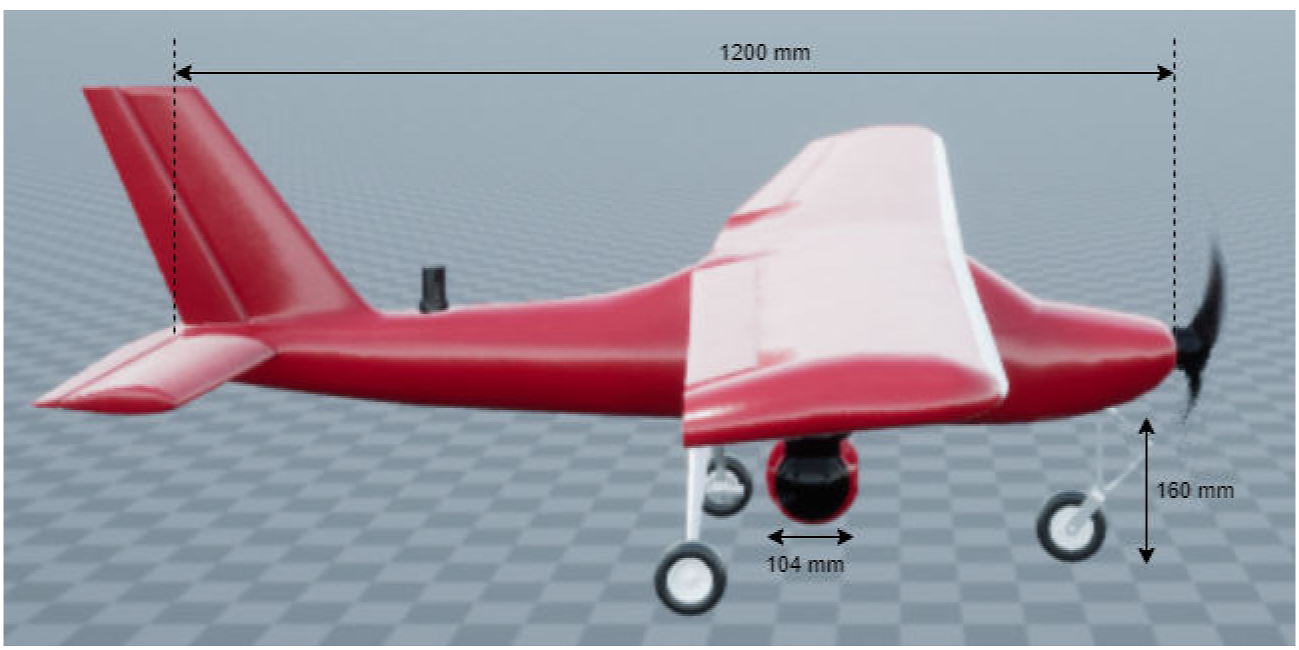
1. Add a Simulation 3D UAV Vehicle block to your Simulink model.
2. In the block, set the **Type** parameter to `Fixed wing`.

Dimensions

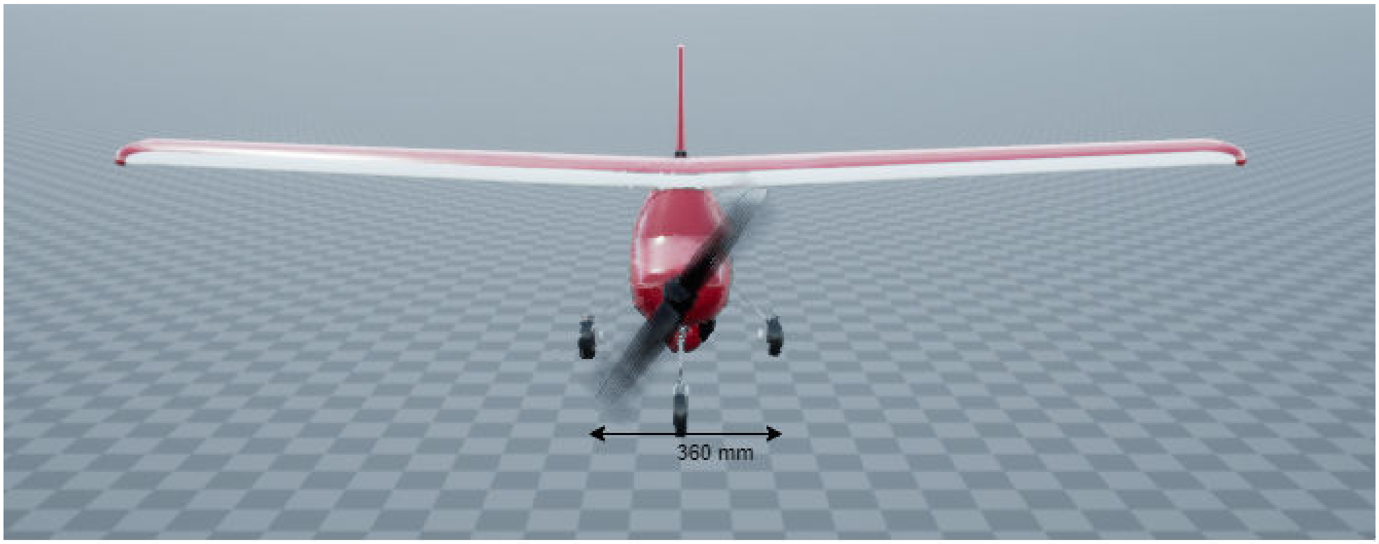
`Top-down view` — Vehicle width dimensions
diagram



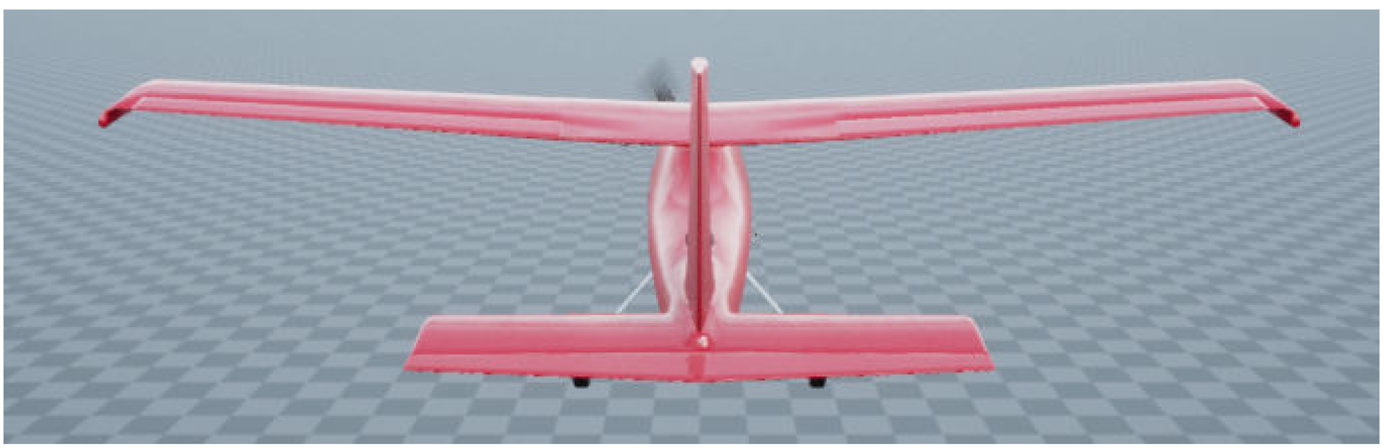
Side view — Vehicle length, landing gear height, and camera dimensions
diagram



`Front view` — Tire width dimensions
diagram



`Rear view` — Vehicle height and rear axle dimensions
diagram



Sensor Mounting Locations

See Also

Simulation 3D UAV Vehicle | Simulation 3D Scene Configuration

Topics

"How Unreal Engine Simulation for UAVs Works"
"Coordinate Systems for Unreal Engine Simulation in UAV Toolbox"