MATLAB EXPO 2017
Automated Driving: Design and Verify Perception Systems

Giuseppe Ridinò
Some common questions from automated driving engineers

How can I visualize vehicle data?

How can I detect objects in images?

How can I fuse multiple detections?
Some common questions from automated driving engineers

How can I visualize vehicle data?

How can I detect objects in images?

How can I fuse multiple detections?
Examples of automated driving sensors

- Camera
- Radar-based object detector
- Vision-based object detector
- Lidar
- Inertial measurement unit
- Lane detector
Examples of automated driving sensor data

**Camera** (640 x 480 x 3)

<table>
<thead>
<tr>
<th>SensorID</th>
<th>Timestamp</th>
<th>NumDetections</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1461634696379242</td>
<td>6</td>
</tr>
</tbody>
</table>

**Vision Detector**

<table>
<thead>
<tr>
<th>TrackID</th>
<th>Position</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[22.8 3.12 2.24]</td>
<td>5</td>
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</tbody>
</table>

**Lane Detector**

<table>
<thead>
<tr>
<th>TrackID</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IsValid: 1</td>
<td>IsValid: 1</td>
</tr>
<tr>
<td></td>
<td>Confidence: 3</td>
<td>Confidence: 3</td>
</tr>
<tr>
<td></td>
<td>BoundaryType: 3</td>
<td>BoundaryType: 3</td>
</tr>
<tr>
<td></td>
<td>Offset: 1.68</td>
<td>Offset: 0.83</td>
</tr>
<tr>
<td></td>
<td>HeadingAngle: 0.002</td>
<td>Curvature: 0.000</td>
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</tbody>
</table>

**Radar Detector**

<table>
<thead>
<tr>
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<th>Timestamp</th>
<th>NumDetections</th>
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<tbody>
<tr>
<td>2</td>
<td>1461634696407521</td>
<td>23</td>
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</tbody>
</table>

**Inertial Measurement Unit**

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>YawRate</th>
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</thead>
<tbody>
<tr>
<td>1461634696379242</td>
<td>0.0040</td>
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</table>

**Lidar** (47197 x 3)

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<th>TrackID</th>
<th>Position</th>
<th>Amplitude</th>
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<tbody>
<tr>
<td></td>
<td>[57.69 3.13 0.34]</td>
<td>3</td>
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<tr>
<td></td>
<td>[35.35 19.59 0.34]</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>[56.07 17.73 0.34]</td>
<td>3</td>
</tr>
</tbody>
</table>

**Examples of automated driving sensor data**

**Vision Detector**

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Visualize sensor data

Image coordinates

Vehicle coordinates

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Visualize differences in sensor detections

Overlay data from multiple sensors
Explore logged vehicle data

- Load **video data** and corresponding **mono-camera parameters**

  ```
  >> video = VideoReader('01_city_c2s_fcw_10s.mp4')
  >> load('FCWDemoMonoCameraSensor.mat', 'sensor')
  ```

- Load **detection sensor data** and corresponding **parameters**

  ```
  >> load('01_city_c2s_fcw_10s_sensor.mat', 'vision','lane','radar')
  >> load('SensorConfigurationData.mat', 'sensorParams')
  ```

- Load **lidar point cloud data**

  ```
  >> load('01_city_c2s_fcw_10s_Lidar.mat', 'LidarPointCloud')
  ```
Learn more about visualizing vehicle data by exploring examples in the Automated Driving System Toolbox

- Plot object detectors in vehicle coordinates
  - Vision & radar detector
  - Lane detectors
  - Detector coverage areas

- Transform between vehicle and image coordinates

- Plot lidar point cloud

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Some common questions from automated driving engineers

How can I visualize vehicle data?

How can I detect objects in images?

How can I fuse multiple detections?

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How can I detect objects in images?
Train object detectors based on ground truth
Train object detectors based on ground truth

Design object detectors with the Computer Vision System Toolbox

<table>
<thead>
<tr>
<th>Machine Learning</th>
<th>Aggregate Channel Feature</th>
<th>trainACFOBJECTDETECTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascade</td>
<td>trainCASCADEOBJECTDETECTOR</td>
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</table>

<table>
<thead>
<tr>
<th>Deep Learning</th>
<th>R-CNN (Regions with Convolutional Neural Networks)</th>
<th>trainRCNNOBJECTDETECTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fast R-CNN</td>
<td>trainFASTRCNNOBJECTDETECTOR</td>
</tr>
<tr>
<td></td>
<td>Faster R-CNN</td>
<td>trainFASTERRCNNOBJECTDETECTOR</td>
</tr>
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</table>
Specify ground truth to train detector

Images → Ground Truth → Train detector → Object detector

How can I create ground truth?
Specify ground truth to train detector

Video → Ground Truth Labeler App → Ground Truth → Train detector → Object detector
Automate labeling based on a manually labeled frame with point tracker
Ground truth labeling to **train** detectors

- Video
  - Ground Truth Labeler App
  - Ground Truth
  - Train detector
  - Object detector

Ground truth labeling to **evaluate** detectors

- Video
  - Object detector
  - Detections
  - Evaluate detections
  - Ground Truth Labeler App
  - Ground truth
Customize Ground Truth Labeler App

Add custom image reader with `groundTruthDataSource`
Customize Ground Truth Labeler App

Add custom automation algorithm

driving.automation.AutomationAlgorithm
Customize Ground Truth Labeler App

Add connection to other tools with `driving.connector.Connector`
Learn more about detecting objects in images by exploring examples in the Automated Driving System Toolbox.

- Label detections with Ground Truth Labeler App
- Add automation algorithm for lane tracking
- Extend connectivity of Ground Truth Labeler App

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Learn more about detecting objects in images by exploring examples in the Automated Driving System Toolbox.

- Train object detector using deep learning and machine learning techniques
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- Explore pre-trained pedestrian detector

- Explore lane detector using coordinate transforms for mono-camera sensor model

Train a Deep Learning Vehicle Detector
Track Pedestrians from a Moving Car
Visual Perception Using Monocular Camera
Some common questions from automated driving engineers

How can I detect objects in images?

How can I fuse multiple detections?

How can I visualize vehicle data?
Example of radar and vision detections of a vehicle

Can we fuse detections to better track the vehicle?
Fuse detections with multi-object tracker

Vision and radar detections to be fused
Synthesize scenario to test tracker
Test tracker against synthesized data

All detections fused into a single track
Track multiple object detections

Multi-Object Tracker

- Assigns detections to tracks
- Creates new tracks
- Updates existing tracks
- Removes old tracks

- Predicts and updates state of track
- Supports linear, extended, and unscented Kalman filters

Object Detections

Tracks

Time
Measurement
Measurement Noise

Track Manager

Tracking Filter

Time
State
State Covariance
Track ID
Age
Is Confirmed
Is Coasted

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Examples of Kalman Filter (KF) initialization functions

<table>
<thead>
<tr>
<th></th>
<th>Linear KF (trackingKF)</th>
<th>Extended KF (trackingEKF)</th>
<th>Unscented KF (trackingUKF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant velocity</td>
<td>initcvkf</td>
<td>initcvekf</td>
<td>initcvukf</td>
</tr>
<tr>
<td>Constant acceleration</td>
<td>initcakf</td>
<td>initcaekf</td>
<td>initcaukf</td>
</tr>
<tr>
<td>Constant turn</td>
<td>Not applicable</td>
<td>initctekf</td>
<td>initctukf</td>
</tr>
</tbody>
</table>
Fuse and track multiple detections from different sensors

Radar Detections
- Time
- Position
- Velocity

Vision Detections
- Time
- Position
- Velocity

Object Packer

Object Detections
- Time
- Measurement
- Measurement Noise

Multi-Object Tracker
- Track Manager
- Kalman Filter

Tracks
- Time
- State
- State Covariance
- Track ID
- Age
- Is Confirmed
- Is Coasted

- Typically unique to application and sensors
- Map sensor readings into measurement matrix
- Specify measurement noise for each sensor
Explore demo to learn more about fusing detections

Forward Collision Warning Using Sensor Fusion
product demo illustrates
- Packing sensor data into object detections
- Initializing Kalman filter
- Configuring multi-object tracker
Virtual scenario generation

- Specify driving scenario and roads
- Add ego vehicle
- Add target vehicle and pedestrian actor
- Play scenario with chase plot
- Create birds eye plot to view sensor detections
- Play scenario with sensor models
Simulate effects of vision detection sensor

**Range Effects**
- Range measurement accuracy degrades with distance to object.

**Angle Measurement Accuracy**
- Angle measurement accuracy consistent throughout coverage area.

**Occlusion Effects**
- Partially or completely occluded objects are not detected.

**Road Elevation Effects**
- Objects in coverage area may not be detected because they appear above the horizon line.
- Large range measurement errors may be introduced for detected objects.
Learn more about sensor fusion
by exploring examples in the Automated Driving System Toolbox

- **Design**
  - multi-object tracker based on logged vehicle data

- **Generate C/C++ code from algorithm which includes a multi-object tracker**

- **Synthesize driving scenario to test multi-object tracker**
The Automated Driving System Toolbox helps you...

**Visualize vehicle data**
- Plot sensor detections
- Plot coverage areas
- Transform between image and vehicle coordinates

**Detect objects in images**
- Train deep learning networks
- Label ground truth
- Connect to other tools

**Fuse multiple detections**
- Design multi-object tracker
- Generate C/C++
- Synthesize driving scenarios

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