ADAS and Automated Driving Development in MATLAB and Simulink

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Automated Driving Segment Manager
Some common questions from automated driving engineers

How can I analyze & synthesize scenarios?

How can I design & deploy algorithms?

How can I integrate & test systems?
Some common questions from automated driving engineers

- How can I analyze & synthesize scenarios?
- How can I design & deploy algorithms?
- How can I integrate & test systems?
Analyze and synthesize scenarios

Real-world data workflows
- Connect
- Visualize
- Label

Enables open loop workflows

Synthetic scenario workflows
- Create scenes
- Model actors
- Model sensors

Enables open loop and closed loop workflows
Connect to recorded and live data

**CAN**
Forward Collision Warning with CAN FD and TCP/IP
Automated Driving Toolbox™
Vehicle Network Toolbox™
Instrument Control Toolbox™

**ROS**
Work with Specialized ROS Messages
ROS Toolbox™

**HERE HD Live Map**
Use HERE HD Live Map Data to Verify Lane Configurations
Automated Driving Toolbox™
Visualize vehicle data

Detections

Visualize Sensor Coverage, Detections, and Tracks
Automated Driving Toolbox™

Images

Annotate Video Using Detections in Vehicle Coordinates
Automated Driving Toolbox™

Maps

Display Data on OpenStreetMap Basemap
Automated Driving Toolbox™
Label sensor data with Ground Truth Labeler App

- Interactively label sensor data
  - Rectangular region of interest (ROI)
  - Polyline ROI
  - Pixel ROI (semantic segmentation)
  - Cuboid (lidar)
  - Scenes
- Automate labeling with built-in detection and tracking algorithms
- Register custom automation algorithms
- Register custom visualizations
- Export labels for verification or training

Ground Truth Labeler
Automated Driving Toolbox™
Updated R2020a
Visualize and label camera and lidar data

- Visualize multiple signals
- Interactively label
- Automate labeling
- Export labels

- Load multiple time-overlapped signals representing the same scene
- Synchronously explore data

Get Started with the Ground Truth Labeler
Automated Driving Toolbox™
Updated
R2020a
Visualize and label camera and lidar data

- Interactively label camera and lidar data

**Get Started with the Ground Truth Labeler**

*Automated Driving Toolbox™*

*Updated R2020a*
Visualize and label camera and lidar data

- Visualize multiple signals
- Interactively label
- Automate labeling
- Export labels

- Get started with built-in detection and tracking algorithms
- Workflow can be extended by registering custom automation algorithms

Get Started with the Ground Truth Labeler
Automated Driving Toolbox™
Updated R2020a
Visualize and label camera and lidar data

- Visualize multiple signals
- Interactively label
- Automate labeling
- Export labels

- Export to workspace or file
- Enables workflows to customize format of labels for integration with other tools

Get Started with the Ground Truth Labeler
Automated Driving Toolbox™
Updated

MATLAB R2020a
Analyze and synthesize scenarios

Real-world data workflows
- Connect
- Visualize
- Label

Synthetic scenario workflows
- Create scenes
- Model actors
- Model sensors

Enables open loop workflows
Enables open loop and closed loop workflows
Synthesize scenarios to test algorithms and systems

<table>
<thead>
<tr>
<th>Scenes</th>
<th>Cuboid</th>
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<tbody>
<tr>
<td><img src="image.png" alt="Diagram" /></td>
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<th>Testing</th>
<th>Controls, sensor fusion, planning</th>
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| Sensing      | Probabilistic vision (detection list)  
               | Probabilistic lane (detection list) 
               | Probabilistic radar (detection list) 
               | Lidar (point cloud) |
## Synthesize scenarios to test algorithms and systems

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<tr>
<th>Scenes</th>
<th><strong>Cuboid</strong></th>
<th><strong>Unreal Engine</strong></th>
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<tr>
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<td><img src="image" alt="Cuboid Scene" /></td>
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| Sensing | Probabilistic vision (detection list)  
Probabilistic lane (detection list)  
Probabilistic radar (detection list)  
Lidar (point cloud) | Monocular camera (image, labels, depth)  
Fisheye camera (image)  
Probabilistic radar (detection list)  
Lidar (point cloud) |
Graphically author scenarios with Driving Scenario Designer

- Design scenes
  - Roads, lane markings
  - Pre-built scenes (Euro NCAP)
- Import roads
  - OpenDRIVE, HERE HD Live Map
- Add actors
  - Size, Radar cross-section (RCS)
  - Trajectories
- Export scenarios
  - MATLAB code, Simulink model

Driving Scenario Designer
Automated Driving Toolbox™
Updated R2020a
Synthesize driving scenarios from recorded data

- Import roads from OpenDRIVE
- Create ego trajectory from GPS
- Create target trajectories object lists

Scenario Generation from Recorded Vehicle Data
Automated Driving Toolbox™

MathWorks®
Model sensors in cuboid driving scenarios

- Vision object detections
- Vision lane detections
- Radar detections
- Lidar point cloud

Cuboid Driving Scenario Simulation
Automated Driving Toolbox™

Updated R2020a
Model sensors in Unreal Engine driving scenarios

- Monocular camera
  - Image
  - Depth
  - Labels
- Fisheye camera image
- Lidar point cloud
- Radar detections

3D Simulation for Automated Driving
Automated Driving Toolbox™

Updated R2020a
Model monocular camera sensor in Unreal Engine driving scenario

Define trajectory → Model monocular camera → Display image → Display depth → Display labels

Visualize Depth and Semantic Segmentation Data in 3D Environment
Automated Driving Toolbox™ R2019b
Design with cuboid and Unreal Engine driving scenarios

Prebuilt scenes

Cuboid Versions of 3D Simulation Scenes in Driving Scenario Designer
Automated Driving Toolbox™

Specify Vehicle Trajectories for 3D Simulation
Automated Driving Toolbox™

Customize 3D Scenes for Automated Driving
Automated Driving Toolbox™
Design 3D scenes for automated driving simulation

External Simulators

MATLAB & Simulink
Design scenes with road, marking, and prop assets

- Roads and markings
- Traffic signals
- Guard rails
- Trees
- Signs
- Elevation data
Design scenes and export to driving simulator

- Design scenes
- Export meshes
- Import to simulator
- Simulate

- Edit roads
- Edit road materials
- Add road markings

Exporting to CARLA
RoadRunner™
R2020a
Update 1
Design scenes and export to driving simulator

- Design scenes
- Export meshes
- Import to simulator
- Simulate

- Install plugin
- Export from RoadRunner
- Import into CARLA/Unreal

Exporting to CARLA

RoadRunner™
R2020a
Update 1
Design scenes and export to driving simulator

- Design scenes
- Export meshes
- Import to simulator
- Simulate

- Move vehicle in automated driving simulation
- Visualize pixels IDs for semantic segmentation

Exporting to CARLA
RoadRunner™ Update 1
Export scenes to file formats and driving simulators

- Export to common file formats for use in third-party applications
  - Filmbox (.fbx), OpenDRIVE (.xodr)
  - Unreal Engine®, CARLA
  - Unity®, LGSVL
  - VIRES Virtual Test Drive, Metamoto
  - IPG Carmaker, Cognata, Baidu Apollo
  - Tesis Dynaware, TaSS PreScan
  - Universal Scene Description (USD)

Exporting
RoadRunner™

R2020a Update 1
Integrate RoadRunner with MATLAB and Simulink workflows

RoadRunner
- Export scene description (.FBX, .XML)
  - RoadRunner scene
- Export OpenDRIVE (.XODR)

Unreal Engine
- Import to game

MATLAB & Simulink
- Connect to game
- Simulink model
- Import to driving scenario
Import, visualize, and edit OpenDRIVE files

Import OpenDRIVE

Visualize

Edit

Export

- Validate OpenDRIVE file
- Import and visualize
- Edit roads and scene
- Export to common driving simulator formats (including OpenDRIVE)

Importing OpenDRIVE Files

RoadRunner™

R2020a

Update 1
Analyze and synthesize scenarios

**Real-world data workflows**
- Connect
- Visualize
- Label

Enables open loop workflows

**Synthetic scenario workflows**
- Create scenes
- Model actors
- Model sensors

Enables open loop and closed loop workflows
Some common questions from automated driving engineers

How can I analyze & synthesize scenarios?

How can I design & deploy algorithms?

How can I integrate & test systems?
Design and deploy algorithms

Planning & control workflows
- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows
- Detection
- Object tracking & sensor fusion
- Localization
Design controls and decision logic for ADAS

Adaptive Cruise Control (longitudinal control)

Lane Keep Assist (Lateral control)

Lane Following (longitudinal + lateral control)

Adaptive Cruise Control with Sensor Fusion
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Embedded Coder®

Lane Keeping Assist with Lane Detection
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Embedded Coder®

Lane Following Control with Sensor Fusion
Model Predictive Control Toolbox™
Automated Driving Toolbox™
Embedded Coder®

MATLAB EXPO
Design planning and controls for highway lane change

- Specify road and target vehicle trajectories for scenario in MATLAB
- Read scenario from Simulink
- Visualize open loop trajectories with Driving Scenario Designer

Lane Change for Highway Driving
Navigation Toolbox™
Model Predictive Control Toolbox™
Automated Driving Toolbox™
Updated R2020a
Design planning and controls for highway lane change

- Specify terminal states candidates
- Determine optimal trajectory in Frenet coordinates

Lane Change for Highway Driving
Navigation Toolbox™
Model Predictive Control Toolbox™
Automated Driving Toolbox™
Updated R2020a
Design planning and controls for highway lane change

- Design lateral and longitudinal controls with Model Predictive Control

Lane Change for Highway Driving Navigation Toolbox™
Model Predictive Control Toolbox™
Automated Driving Toolbox™
Updated R2020a
Design planning and controls for highway lane change

- Model ego vehicle dynamics with dynamic bicycle model
- Example can be extended to included higher order vehicle dynamics

Lane Change for Highway Driving Navigation Toolbox™
Model Predictive Control Toolbox™
Automated Driving Toolbox™

Updated R2020a
Design planning and controls for highway lane change

- Plot candidate trajectories
- Plot selected ego trajectory
- Plot trajectory history

Lane Change for Highway Driving
Navigation Toolbox™
Model Predictive Control Toolbox™
Automated Driving Toolbox™
Updated R2020a
Design planning and controls for automated parking

**Design planner & controls**

![Global costmap](image)

Automated Parking Valet with Simulink

Automated Driving Toolbox™

**Deploy to ROS 2 node**

![Automated Parking Valet: ROS 2 node for Path Planner](image)

Automated Parking Valet with ROS 2 in Simulink

Automated Driving Toolbox™

ROS Toolbox™

Embedded Coder®

**Design with nonlinear MPC**

![Parking Valet using Nonlinear Model Predictive Control](image)

Parking Valet using Nonlinear Model Predictive Control

Automated Driving Toolbox™

Model Predictive Control Toolbox™

Navigation Toolbox™
Design and deploy algorithms

Planning & control workflows
- Motion planning
- Decision logic
- Longitudinal controls
- Lateral controls

Perception workflows
- Detection
- Object tracking & sensor fusion
- Localization
Deploy deep learning networks

NVIDIA GPU

Code Generation for Object Detection by Using Single Shot Multibox Detector
Deep Learning Toolbox™
GPU Coder™

R2020a

Intel MKL-DNN

Generate C++ Code for Object Detection Using YOLO v2 and Intel MKL-DNN
Deep Learning Toolbox™
MATLAB Coder®

R2019a

ARM

Code Generation for Semantic Segmentation Application on ARM Neon
Deep Learning Toolbox™
MATLAB Coder®

R2020a
Track-level Fusion of Radar and Lidar Data

1. **3-D Lidar**
   - Point cloud
   - Detect bounding boxes
   - 3D cuboid of clustered detections

2. **2-D Radar**
   - Unclustered detections
   - Track radar
   - 2D rectangular tracks

3. **Track lidar**
   - 3D cuboid tracks

4. **Fuse tracks**
   - 3D cuboid tracks

**Automated Driving Toolbox™**
**Computer Vision Toolbox™**
**Sensor Fusion and Tracking Toolbox™**

**Track-Level Fusion of Radar and Lidar Data**
Fuse lidar point cloud with radar detections

- Create scene
- Add actors
- Add lidar point cloud sensor
- Add radar detection sensor

**Track-Level Fusion of Radar and Lidar Data**
*Automated Driving Toolbox™*
*Computer Vision Toolbox™*
*Sensor Fusion and Tracking Toolbox™*

R2020a
Fuse lidar point cloud with radar detections

- Remove ground plane
- Segment and cluster detections
- Fit bounding box to clusters

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™

R2020a
Fuse lidar point cloud with radar detections

- Design conventional joint probabilistic data association (JPDA) multi-object tracker
- Track vehicles during lane change with interacting multiple model unscented Kalman filter (IMM-UKF)

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™

MATLAB®
Fuse lidar point cloud with radar detections

- Design extended object tracker with Gaussian Mixture probability hypothesis density filter (GM-PHD)

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™

R2020a
Fuse lidar point cloud with radar detections

- Design track level fusion
- Visualize

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™

MATLAB EXPO
Fuse lidar point cloud with radar detections

- Synthesize scenario
- Detect lidar
- Track lidar
- Track radar
- Fuse tracks
- Assess metrics
  - Assess missed tracks
  - Assess false tracks
  - Assess generalized optimal sub-pattern assignment metric (GOSPA)

Track-Level Fusion of Radar and Lidar Data
Automated Driving Toolbox™
Computer Vision Toolbox™
Sensor Fusion and Tracking Toolbox™
Design object tracking and sensor fusion algorithms

Introduction to Tracking Metrics
Sensor Fusion and Tracking Toolbox™

Tuning a Multi-Object Tracker
Sensor Fusion and Tracking Toolbox™

Generate C Code for a Tracker
Sensor Fusion and Tracking Toolbox™
MATLAB Coder®
Design localization algorithms

Inertial fusion of IMU & GPS

Estimate Position and Orientation of a Ground Vehicle
Sensor Fusion and Tracking Toolbox™

SLAM (Camera)

Monocular Visual Simultaneous Localization and Mapping (SLAM)
Automated Driving Toolbox™
Computer Vision Toolbox™

SLAM (Lidar)

Design Lidar SLAM Algorithm using 3D Simulation Environment
Automated Driving Toolbox™
Computer Vision Toolbox™
Navigation Toolbox™
Design and deploy algorithms

Planning & control workflows
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- Lateral controls

Perception workflows
- Detection
- Object tracking & sensor fusion
- Localization
Some common questions from automated driving engineers

- How can I analyze & synthesize scenarios?
- How can I design & deploy algorithms?
- How can I integrate & test systems?
Integrate and test systems

Integration workflows
- MATLAB & Simulink
- C / C++
- CAN
- ROS
- FMI
- FMU
- Python
- ...

Testing workflows
- Requirements
- Automation
- Functional assessment
- Code assessment
Integrate with hand code and other tools

Over 150 interfaces to 3rd party modeling and simulation tools
Integrate vision detection, sensor fusion, and controls

Model scenario & sensors
Integrate algorithms
Model dynamics
Simulate system
Review results

- Create Unreal Engine scene
- Specify target trajectories
- Model camera and radar sensors
- Model ego vehicle dynamics
- Specify system metrics

**Highway Lane Following**
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Updated R2020a
Integrate vision detection, sensor fusion, and controls

- Model scenario & sensors
- Integrate algorithms
- Model dynamics
- Simulate system
- Review results

- Visualize system behavior with Unreal Engine
- Visualize lane detections
- Visualize vehicle detections
- Visualize control signals
- Log simulation data

Highway Lane Following Automated Driving Toolbox™
Model Predictive Control Toolbox™
Updated R2020a
Integrate and test systems

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Testing workflows
- Requirements
- Automation
- Functional assessment
- Code assessment
Automate testing for highway lane following perception and controls

- Author and associate requirements and scenarios

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™
Automate testing for highway lane following perception and controls

- Automate test execution and reporting
- Execute simulations in parallel

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™

MATLAB EXPO
Automate testing for highway lane following perception and controls

- Assess system metrics
- Assess lane detection metrics

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™
Automate testing for highway lane following perception and controls

- Link to requirements
- Automate tests
- Assess functionality
- Integrate code
- Assess code

- Generate algorithm code
- Test with Software-in-the-Loop (SIL) simulation
- Workflow could be extended to test hand coded algorithms

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
Simulink Requirements™
Simulink Coverage™

MATLAB EXPO
Automate testing for highway lane following perception and controls

- Assess functionality
- Assess code coverage

Automate Testing for Highway Lane Following
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Simulink Test™
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Simulink Coverage™
Integrate and test systems

Integration workflows
- MATLAB & Simulink
- C / C++
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Testing workflows
- Requirements
- Automation
- Functional assessment
- Code assessment
MATLAB and Simulink enable automated driving engineers to...

- analyze & synthesize scenarios
- design & deploy algorithms
- integrate & test systems