What's New in MATLAB & Simulink for Automated Driving Development

Mark Corless
Develop Automated Driving Systems
with MATLAB, Simulink, and RoadRunner

Virtual Worlds | Multidisciplinary Skills | Software Applications
--- | --- | ---
Environments | Vehicles | Algorithms
   Scenes | Sensors | Detection
   Scenarios | Dynamics | Localization

Planning | Decision & Controls

Development Platform
Analyze | Simulate | Design | Deploy | Integrate | Test
Simulate automated driving systems in virtual worlds

Lane Detections

Vehicle Detections

Tracking & Fusion

Decision & Controls

Highway Lane Following Test Bench

Scenes

Lane Detection

Vehicle Detection

Tracking & Fusion

Scene

Scenario

Sensors

Lane Following Controller

Lane Following Decision Logic

Vehicle Dynamics

Metrics
Develop automated driving algorithms for multiple disciplines

Lane Detections
- Lane Detection
  - Scenes
  - Scenarios
  - Sensors
  - Code
  - Lane Detector

Vehicle Detections
- Vehicle Detection
  - Scenes
  - Scenarios
  - Sensors
  - Code
  - Vehicle Detector

Tracking & Fusion
- Tracking & Fusion
  - Scenes
  - Scenarios
  - Sensors
  - Code
  - Vehicle Sensor Fusion

Decision & Controls
- Decision Logic
  - Scenes
  - Scenarios
  - Controls
  - Dynamics
  - Metrics
  - Code
  - Decision and Controls
Develop software applications for automated driving

Lane Detections
Vehicle Detections
Tracking & Fusion
Decision & Controls

Manage Tests

Automate Testing of Highway Lane Following

Report Results
Extend workflows to identify new scenarios to test

### Identify New Scenarios from Recorded Data
- Recorded Vehicle Data
- Label Data
- Identify Interesting Scenarios
- Generate Scenarios from Recorded Data

### Identify New Scenarios from Scenario Variations
- Author Scenario
- Generate Scenario Variations: `drivingScenario()`
- Identify Interesting Scenarios
- Add Scenarios to Regression Tests
Develop Automated Driving Systems
with MATLAB, Simulink, and RoadRunner

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Development Platform
- Analyze
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MATLAB EXPO 2021

Develop Virtual Worlds for Automated Driving

Rashmi Gopala Rao

MathWorks®
Develop **virtual worlds** for automated driving systems

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Development Platform

- Analyze
- Simulate
- Design
- Deploy
- Integrate
- Test
Design 3D scenes for automated driving applications

- OpenDRIVE
- Geographic Information System (GIS) Files
  - Point clouds
  - Orthoimagery
  - Vector data
  - Elevation data
- Custom Assets
- Third Party Simulators
  - CARLA
  - Unreal Engine®
  - Unity®
  - LGSVL
  - VIRES Virtual Test Drive
  - Metamoto
  - IPG Carmaker
  - Cognata
  - Baidu Apollo
  - Tesis Dynaware
  - TaSS PreScan
  - NVIDIA DRIVE Sim through Universal Scene Description (USD)

RoadRunner
Interactively design 3D scenes in RoadRunner
Design 3D scenes for automated driving applications

Design Scenes

RoadRunner Scene Builder

RoadRunner Asset Library

RoadRunner

Here HD Live Map

OpenDRIVE

Geographic Information System (GIS) Files
- Point clouds
- Orthoimagery
- Vector data
- Elevation data

Custom Assets

Third Party Simulators
- CARLA
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- NVIDIA DRIVE Sim through Universal Scene Description (USD)
Learn about new features to design 3D scenes

Design Lateral Profile

Design Superelevation

Import signs, poles, and barriers from HERE

Cross Section Tool
RoadRunner

Road Superelevation Tool
RoadRunner

Configure Assets to Use for Imported HERE HD Live Map Data
RoadRunner Scene Builder

R2021a

R2021a

R2021a
Design scenes and scenarios for automated driving

OpenDRIVE
OpenStreetMap
HERE HD Maps
Zenrin SD

Custom meshes

Driving Scenario Designer App

Driving scenario
- Roads
- Lane markings
- Barriers & guardrails
- Vehicle trajectories

OpenDRIVE
OpenSCENARIO

ds = drivingScenario();
Learn about new features to design **scenes and scenarios** (1 of 2)

**Add guardrails and barriers**

**Import OpenStreetMap**

**Import Zenrin Maps**

---

**Driving Scenario Designer**

*Automated Driving Toolbox™*

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**Import OpenStreetMap Data into Driving Scenario**

*Automated Driving Toolbox™*

---

**Import Zenrin Japan Map API 3.0 (Itsumo NAVI API 3.0) into Driving Scenario**

*Automated Driving Toolbox™*
Learn about new features to design scenes and scenarios (2 of 2)

Specify reverse motion

Export to OpenDRIVE® 1.4H

Export to OpenSCENARIO® 1.0

Create Reverse Motion Driving Scenarios Interactively
Automated Driving Toolbox™

Export Driving Scenario to OpenDRIVE File
Automated Driving Toolbox™

Export driving scenario to OpenSCENARIO
Automated Driving Toolbox™

Triggers
- Simulation time
- Actor absolute position

Actions
- Start routing/trajectory action
- Set target speed
- Change speed
- Add/remove actors
Simulate scenes and scenarios for automated driving

Design Scenes with RoadRunner

Design Driving Scenarios

Simulate with Cuboids

Typical Uses:
- Simulate controls, planning, tracking & fusion
- Simulate systems requiring truth or detection level sensors

Simulate with Unreal Engine® from Epic Games®

Typical Uses:
- Simulate systems which include detection and localization
- Visualize systems where underlying simulation is performed with cuboids
Learn about new features to simulate with Unreal Engine

- Custom meshes
- Vehicle lights
- Weather & sun position

**Prepare Custom Vehicle Mesh for the Unreal Editor**
*Automated Driving Toolbox™*

**Simulation 3D Vehicle with Ground Following**
*Automated Driving Toolbox™*

**Simulation 3D Scene Configuration**
*Automated Driving Toolbox™*
Simulate sensors for automated driving applications

Cuboid Sensors
- Radar Tracks
- Radar IQ Signals

Cuboid & Unreal Engine
- Radar Detections
- Vision Detections
- Lidar
- Lane Detections

Unreal Engine Sensors
- Monocular Camera
- Semantic Segmentation
- Depth
- Fisheye Camera

Positional Sensors
- Wheel Encoder
- Global Positioning System (GPS)
- Inertial Measurement Unit (IMU)
- Inertial Navigation System (INS)

Commonly used tools: Automated Driving Toolbox™, Radar Toolbox, Navigation Toolbox™
Simulate radar sensors at waveform and measurement levels

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<th>Raw IQ Signals</th>
<th>Detections</th>
<th>Clusters</th>
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<td>Radar Transceiver</td>
<td>Radar Toolbox</td>
<td>Driving Radar Data Generator</td>
<td>Automated Driving Toolbox™, Radar Toolbox</td>
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Waveform-level Model | Measurement-level Model
Explore example of simulating radar multipath propagation effects

Simulate Radar Ghosts due to Multipath Return
Automated Driving Toolbox™, Radar Toolbox
Label recorded sensor data

Ground Truth Labeler App

- Camera data
- Lidar data
- Custom data
- Custom automation algorithms

Automation Algorithms

- Vehicles, people, lane boundaries, point tracker, temporal interpolator

Custom user interfaces

Labels:
- Regions of Interest: cuboid, rectangular, polygon, polyline
- Pixels (semantic segmentation)
- Sublabels
- Attributes
- Scenes (events)
Learn about new features for **labeling** sensor data

- Label polygon regions of interest
- Label projected cuboids
- Automate labeling for camera and lidar

**Label Objects Using Polygons**
*Automated Driving Toolbox™*

**Ground Truth Labeler**
*Automated Driving Toolbox™*

**Automate Ground Truth Labeling Across Multiple Signals**
*Automated Driving Toolbox™ Lidar Toolbox™*

*R2021a*  
*R2020b*  
*R2021a*
Partner with MathWorks to extend virtual development workflows

Ford identifies events in recorded data

BMW automates labeling display images

GM generate scenarios from recorded data

Using MATLAB on Apache Spark for ADAS Feature Usage Analysis and Scenario Generation
MathWorks Automotive Engineer Conference 2020

Automated Verification of Automotive Infotainment
MathWorks Automotive Conference 2020 – Europe

Creating Driving Scenarios from Recorded Vehicle Data for Validating Lane Centering Systems
MathWorks Automotive Conference 2020 – North America
Develop **virtual worlds** for automated driving systems

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Development Platform

- Analyze
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- Test
Develop **multidisciplinary skills** for automated driving
Design planning and control algorithms for automated driving

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<th>Emergency Braking</th>
<th>Adaptive Cruise Control</th>
<th>Lane Following</th>
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<td>![Emergency Braking Image]</td>
<td>![Adaptive Cruise Control Image]</td>
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<th>Traffic Light Negotiation</th>
<th>Parallel Parking</th>
<th>Parking Lot</th>
<th>Reinforcement Learning</th>
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Commonly used tools: Automated Driving Toolbox, Model Predictive Control Toolbox, Stateflow, Navigation Toolbox, Reinforcement Learning, Robotics System Toolbox
Explore updated example:
Design planning and controls for highway lane change

- Generates an optimal trajectory in Frenet space
- Implement driving maneuver behavior depending on surrounding traffic conditions
- Collision checking using dynamic capsule-based objects

Highway Lane Change
Navigation Toolbox™, Model Predictive Control Toolbox™, Automated Driving Toolbox™
Explore new examples to design **planning and controls** algorithms

- **Planning for truck parking**
  - Truck and Trailer Automatic Parking Using Multistage Nonlinear MPC
  - Model Predictive Control Toolbox
  - Robotics System Toolbox

- **Parking with reinforcement learning**
  - Train PPO Agent for Automatic Parking Valet
    - Reinforcement Learning Toolbox
    - Model Predictive Control Toolbox

- **Planning for urban**
  - Motion Planning in Urban Environments Using Dynamic Occupancy Grid Map
  - Automated Driving Toolbox, Navigation Toolbox
  - Sensor Fusion and Tracking Toolbox
Design **tracking and fusion** algorithms for automated driving

<table>
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<tr>
<th>Radar &amp; Vision</th>
<th>Lidar &amp; Radar</th>
<th>Vehicle to Vehicle</th>
<th>Occupancy Grids</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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<th>Camera</th>
<th>Lidar</th>
<th>Radar with Multipath</th>
<th>Lane Boundaries</th>
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Commonly used tools: Automated Driving Toolbox, Tracking and Fusion Toolbox, Radar Toolbox
Explore new example:
Track vehicles in presence of multipath radar reflections

Highway Vehicle Tracking with Multipath Radar Reflections
Automated Driving Toolbox™, Sensor Fusion and Tracking Toolbox™, Radar Toolbox™
Explore new example:
Track multiple lane boundaries

Lane Detections → GNN Tracker → Lane Tracks

Lane Detections

Lane Tracks

Parametric coefficients

Parametric coefficients

Track Multiple Lane Boundaries with a Global Nearest Neighbor Tracker
Automated Driving Toolbox™, Sensor Fusion and Tracking Toolbox™
Explore new example:
Track objects in urban environment with grid-based tracking

Grid-based Tracking in Urban Environments Using Multiple Lidars
Automated Driving Toolbox™, Sensor Fusion and Tracking Toolbox™
Design **detection** and **localization** algorithms for automated driving

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<th>Lanes</th>
<th>Objects</th>
<th>Semantic Segmentation</th>
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<td><img src="image1" alt="Lane Image" /></td>
<td><img src="image2" alt="Object Image" /></td>
<td><img src="image3" alt="Semantic Image" /></td>
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<th>SLAM</th>
<th>Maps</th>
<th>Inertial Fusion</th>
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<td><img src="image4" alt="SLAM Image" /></td>
<td><img src="image5" alt="Map Image" /></td>
<td><img src="image6" alt="Inertial Image" /></td>
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Explore new examples to design lidar detection algorithms

- **Lanes**
  - Lane Detection in 3-D Lidar Point Cloud
    - Lidar Toolbox™
  - Updated R2021a

- **Semantic segmentation**
  - Lidar Point Cloud Semantic Segmentation Using SqueezeSegV2
    - Deep Learning Network
    - Lidar Toolbox™, Deep Learning Toolbox™
  - Updated R2021a

- **PointPillars**
  - Lidar 3-D Object Detection Using PointPillars Deep Learning
    - Lidar Toolbox™, Deep Learning Toolbox™
  - Updated R2021a
Explore example of designing **localization** algorithms with **map data**

- Read traffic sign information from HERE HD Live Map
- Match signs detected by the onboard sensors with signs stored map data
- Improve localization accuracy by combining GPS measurements with map data

**Localization Correction Using Traffic Sign Data from HERE HD Maps**

*Automated Driving Toolbox™*
Explore new examples to design **SLAM** algorithms

**SLAM = Simultaneous Localization and Mapping**

- **Monocular camera**
- **Stereo camera**
- **Lidar**

*Develop Visual SLAM Algorithm Using Unreal Engine Simulation*

*Automated Driving Toolbox™*
*Computer Vision Toolbox™*
*Navigation Toolbox™*

*Stereo Visual Simultaneous Localization and Mapping*

*Computer Vision Toolbox™*

*Design Lidar SLAM Algorithm using 3D Simulation Environment*

*Automated Driving Toolbox™*
*Computer Vision Toolbox™*
*Navigation Toolbox™*
Develop **software applications** for automated driving

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**Development Platform**

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Develop **software** applications for automated driving

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<th>ROS / ROS 2.0</th>
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- Continuous Integration
- Automated Testing
- Code Analysis
- ISO 26262

Commonly used tools: MATLAB Coder, Embedded Coder, GPU Coder, HDL Coder, ROS Toolbox, AUTOSAR Blockset, DDS Blockset, Simulink Test, Simulink Coverage, Polyspace, IEC Certification Kit,
Explore new example:
Generate C/C++ or GPU code from vision detectors in Simulink

- Generate code, verify functionality, and measure execution time with Software-In-the-Loop (SIL)

**CPU**: Intel® Xeon® @ 3.60GHz, **GPU**: Quadro K620

**YOLOv2**
- **CPU - MKLDNN**
- **GPU - cuDNN**
- **GPU - tensorRT**
Explore new examples of generating C/C++ code

Deploy lane detection to C/C++

Deploy controls to C/C++

Deploy planning to C/C++

Generate Code for Lane Marker Detector
Automated Driving Toolbox™
Embedded Coder

Generate Code for Highway Lane Following Controller
Automated Driving Toolbox™
Model Predictive Control Toolbox™
Embedded Coder

Generate Code for Highway Lane Change Planner
Automated Driving Toolbox™
Navigation Toolbox™
Embedded Coder
Explore new example:
Deploy parking valet planning and controls to ROS / ROS 2.0

Automated Parking Valet with ROS in Simulink
Automated Parking Valet with ROS 2 in Simulink

ROS Toolbox, Embedded Coder®, Automated Driving Toolbox™, Model Predictive Control Toolbox™
Explore new example:
ISO26262 for decision and controls

- Architect system and software designs
- Trace requirements, architecture, design, and verification artifacts
- Perform static and dynamic verification at model and code level

Highway Lane Following: A Model-Based Design Example for ISO 26262:2018
IEC Certification Kit, Automated Driving Toolbox™, System Composer™, Embedded Coder®,
Simulink Requirements™, Simulink Coverage™, Simulink Test™, Polyspace Bug Finder™
Partner with MathWorks to adopt algorithm development workflows

Hitachi Automotive develops controls

"The generated code for the QP solver was extremely efficient, so there was no need for us to explore other solvers."

Hitachi Automotive Systems Develops a Model Predictive Controller for Adaptive Cruise Control with Model-Based Design
User Story – 2020

AVL develops planning & controls

Advantages of Level 2+ Advanced Driver Assistance Application Prototyping Using Model-Based Design
MathWorks Automotive Conference 2020 – Europe

Nippon Sharyo develops sensor fusion

Sensor fusion development for large heavy-duty automatic transport vehicles
MathWorks Expo 2020 – Japan
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