

Creating Driving Scenarios from Recorded Vehicle Data for Validating Lane Centering System in Highway Traffic



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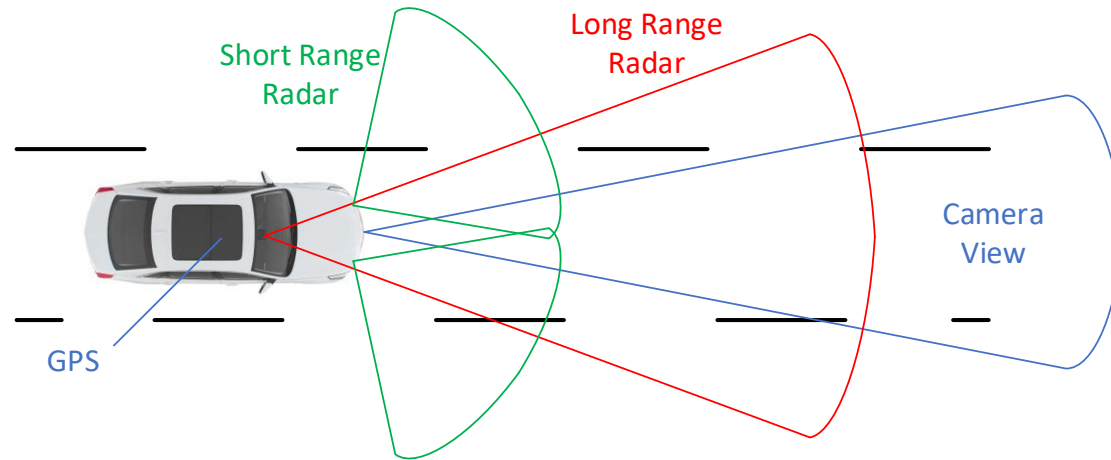
- Super Cruise – History and Future
- Lane Centering with Super Cruise
- Motivation
- Create virtual driving scenario from recorded data
- Simulate closed-loop model for lane centering system
- Conclusion
- Q & A

Super Cruise – History and Future

- Debuted in 2017 with CT6 Sedan
 - Lane Centering in addition to Full Speed Range Adaptive Cruise Control
 - Uses High-Definition Map and Front Camera to detect Lane Marks
- Automated Lane Change for 2021 Cadillac CT4 / CT5 / Escalade
 - Lane Change following Driver Request
 - Able to accelerate and decelerate slightly to search gap to change in
- Eventually will be expanded to many name plates



Lane Centering with Super Cruise on Cadillac CT6

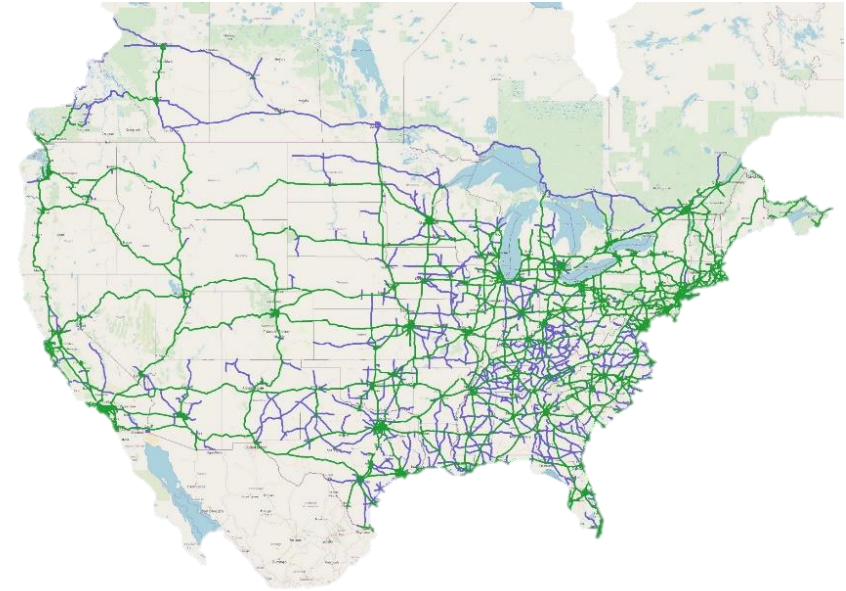


- **Sensors**
 - Pre-Scanned High Definition Map
 - Map matching with GPS
 - Camera
 - Long Range Radar
 - Short Range Radars
- **Actuation**
 - Electric Power Steering
- **Driver Monitoring System for Safety**
 - Infra-red Face Recognition
 - Steering Wheel Touch Sensor
 - Chime and Vibration Seat



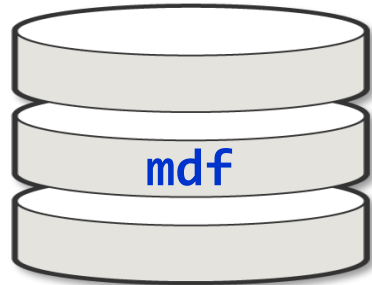
System validation for driving automation system

- Pains
 - Big data size from “tens of thousands of miles” test drive
 - Time consuming for data analysis
 - Not easy to reproduce a real-world traffic situation with closed-loop simulation
 - Hazardous test scenarios
 - Unwanted system behavior
- Virtual driving scenario from recorded data
 - Reduce development time
 - Enable closed-loop simulation to identify the root causes for unwanted system behavior



➔ How to create driving scenario from recorded data?

Create virtual driving scenario from recorded data



MDF(Measurement Data Format)



```

% Create an object to access the MF4 file.
mdfObj = mdf('RecordedData.mf4');
  
```

	Time	1 Latitude	2 Longitude	3 Vx	4 Vy
1	1.7871 sec	42.3775	-83.0382	27.4446	0
2	1.8071 sec	42.3775	-83.0382	27.4498	0
3	1.8271 sec	42.3775	-83.0382	27.4571	0
4	1.8471 sec	42.3775	-83.0382	27.4678	0
5	1.8671 sec	42.3775	-83.0382	27.4745	0
6	1.8871 sec	42.3775	-83.0382	27.4800	0
7	1.9071 sec	42.3775	-83.0382	27.4897	0
8	1.9271 sec	42.3775	-83.0382	27.5004	0
9	1.9471 sec	42.3775	-83.0382	27.5070	0

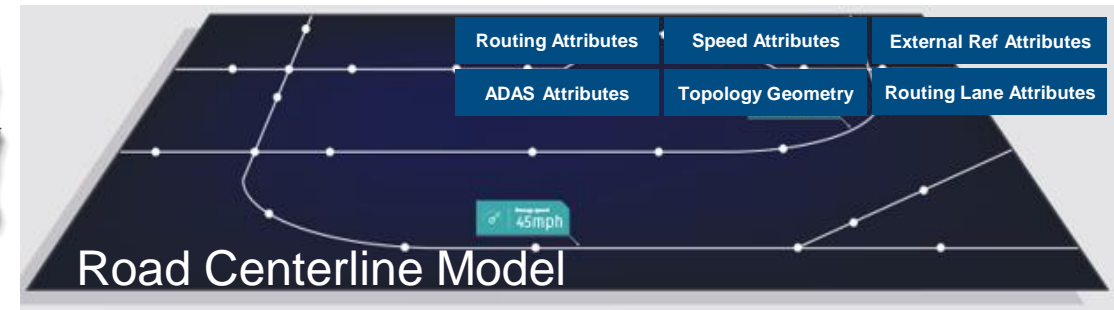
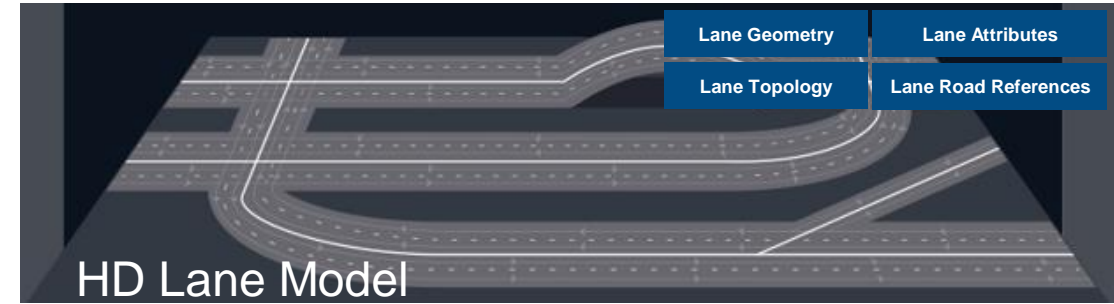
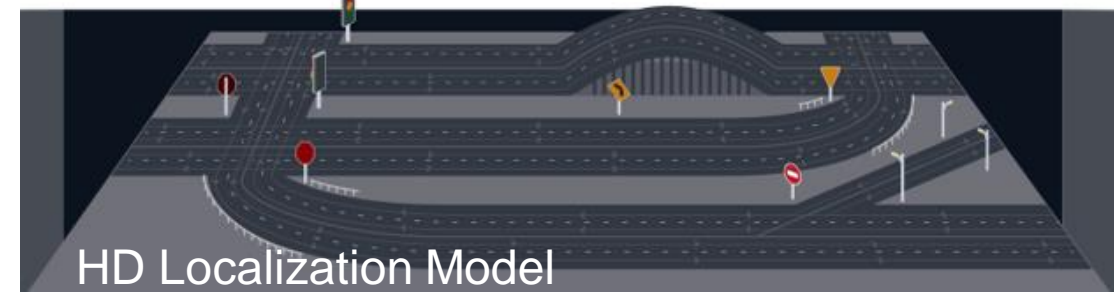
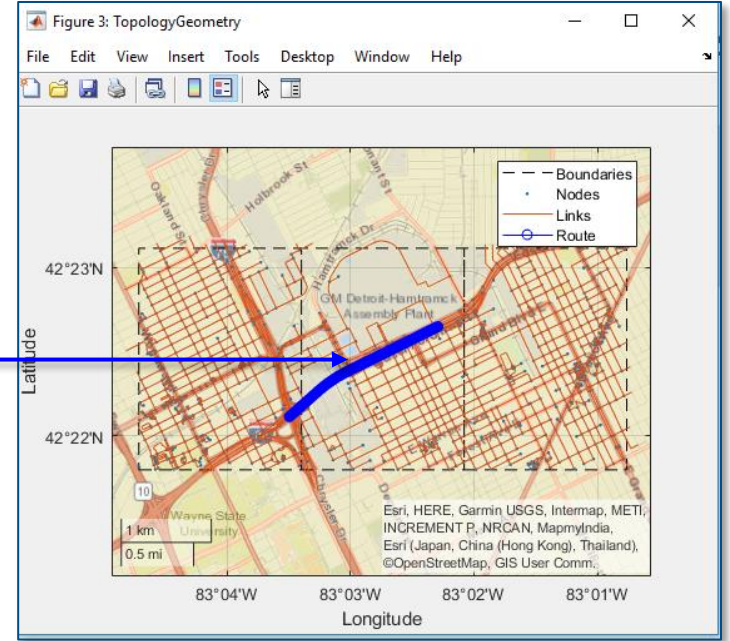
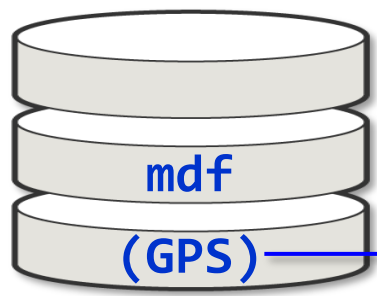
GPS

Vehicle
Data

	Time	1 lane	2 vision	3 LRR
1	1.7871 sec	1x1 struct	1x1 struct	1x1 struct
2	1.8271 sec	1x1 struct	1x1 struct	1x1 struct
3	1.8671 sec	1x1 struct	1x1 struct	1x1 struct
4	1.9071 sec	1x1 struct	1x1 struct	1x1 struct
5	1.9471 sec	1x1 struct	1x1 struct	1x1 struct
6	1.9871 sec	1x1 struct	1x1 struct	1x1 struct
7	2.0271 sec	1x1 struct	1x1 struct	1x1 struct
8	2.0671 sec	1x1 struct	1x1 struct	1x1 struct
9	2.1071 sec	1x1 struct	1x1 struct	1x1 struct
10	2.1471 sec	1x1 struct	1x1 struct	1x1 struct

On-board sensors

Create virtual driving scenario from recorded data



```

HDLMreader = hereHDLMreader(latitude, longitude);
topologyGeometry = HDLMreader.read("TopologyGeometry");
plot(topologyGeometry);
    
```

High-Definition Map with Tiled Layers

Create virtual driving scenario from recorded data

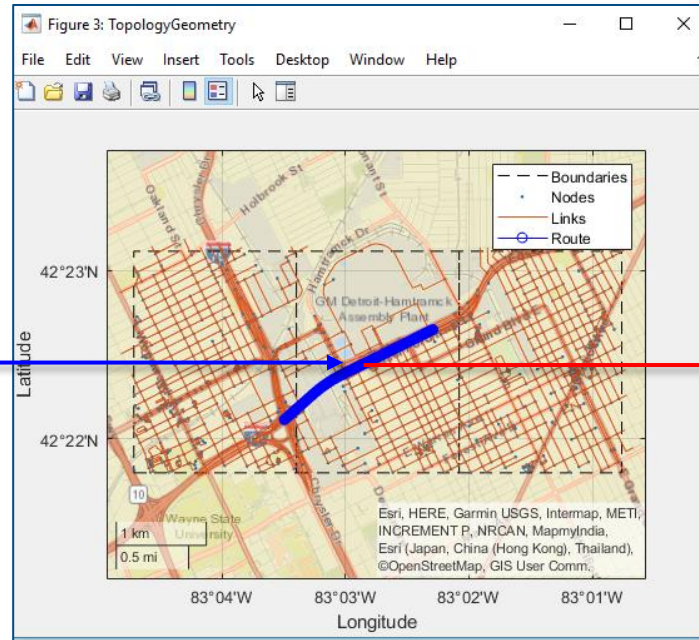
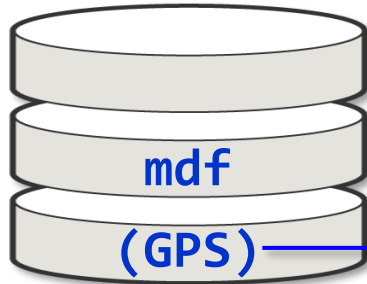
Record and
select data

Reconstruct
road network

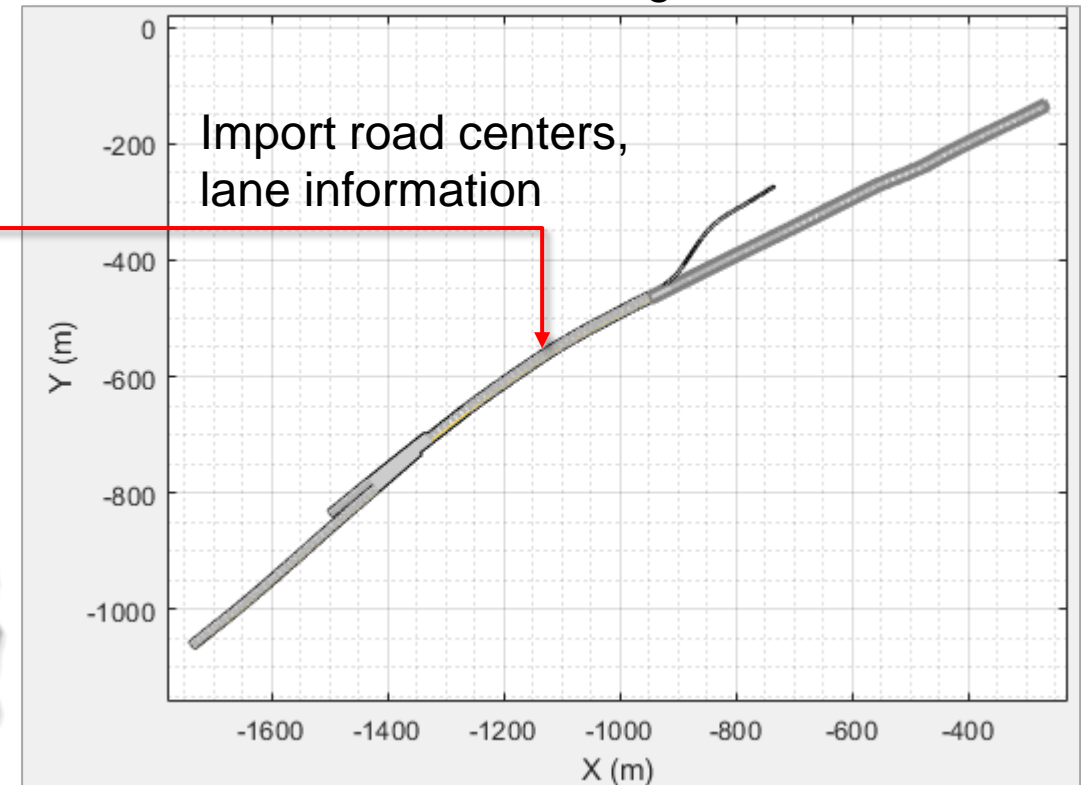
Localize ego
trajectory

Reconstruct
target vehicles

Compare with
recorded video



Create driving scenario



```
HDLMreader = hereHDLMreader(latitude,longitude);
topologyGeometry = HDLMreader.read("TopologyGeometry");
plot(topologyGeometry);
```


Create virtual driving scenario from recorded data

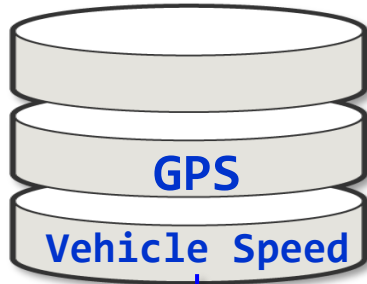
Record and
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Driving Scenario Designer - GM_session_original - Actors

DESIGNER

FILE SCENARIO SENSORS SIMULATE VIEW EXPORT

Roads Actors Scenario Canvas Ego-Centric View

1: original (ego vehicle)

Name: original Set As Ego

Class: Car

3D Display Type: Sedan

Actor Properties

Radar Cross Section

Trajectory

Wait Time at Waypoints

Constant Speed (m/s):

Waypoints

	x (m)	y (m)
1	-1.8205	0.6406
2	-3.0239	3.1114
3	-4.2581	5.5821
4	-5.3380	8.0529
5	-6.5414	10.5237
6	-7.7448	12.9945
7	-8.9790	15.4881
8	-10.2132	17.9589

trajectory(egoCar, waypoints, speeds)

X (m)

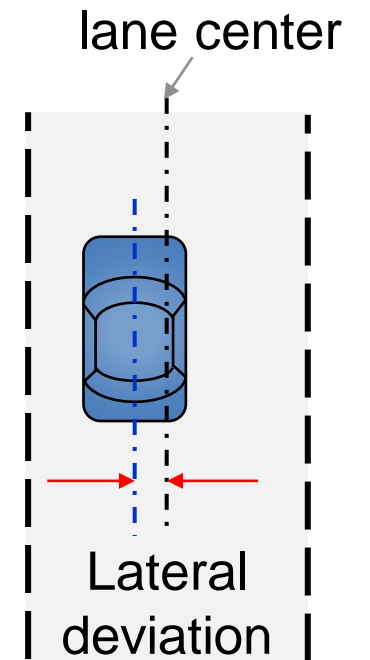
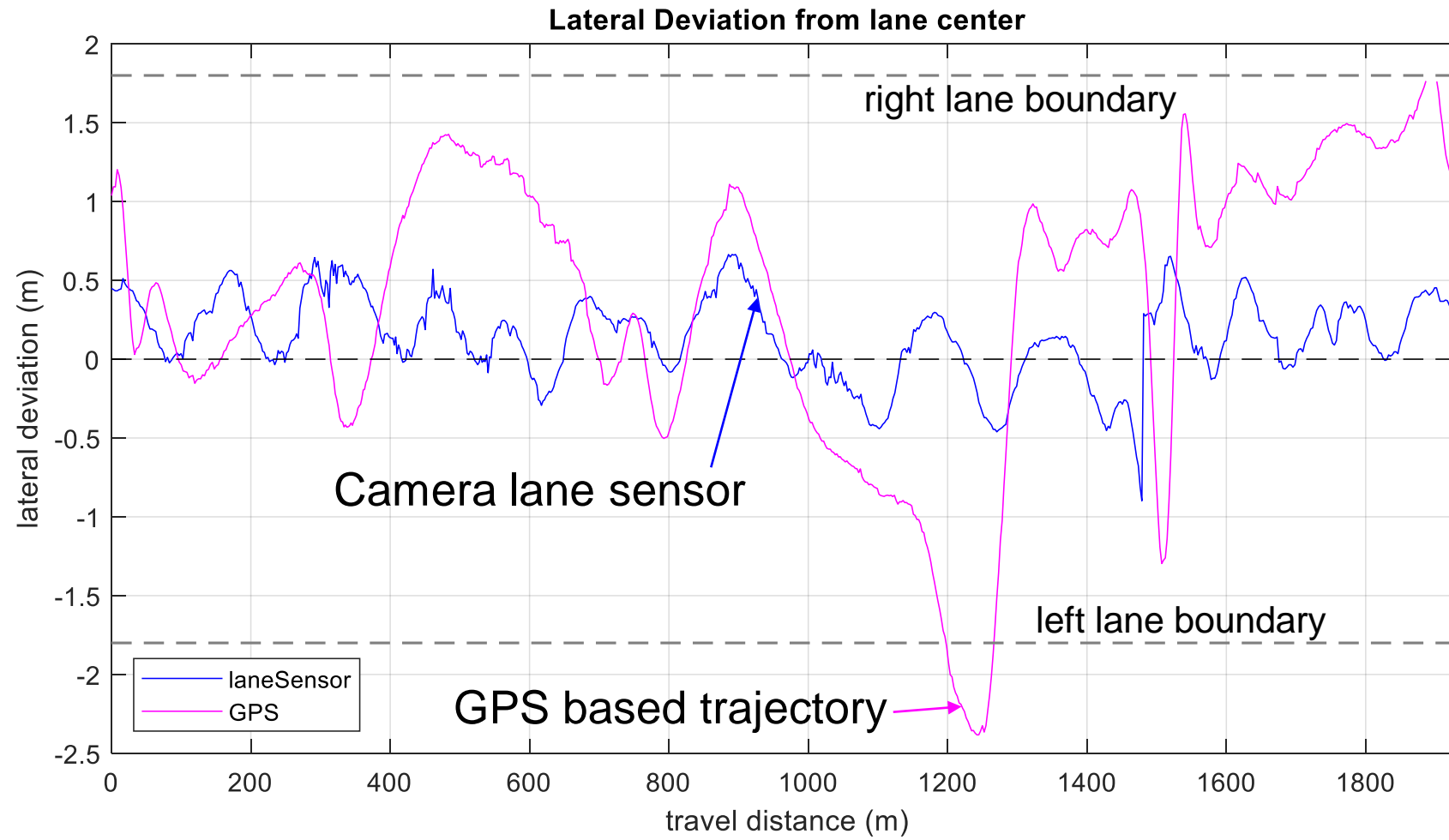
Y (m)

T=0s

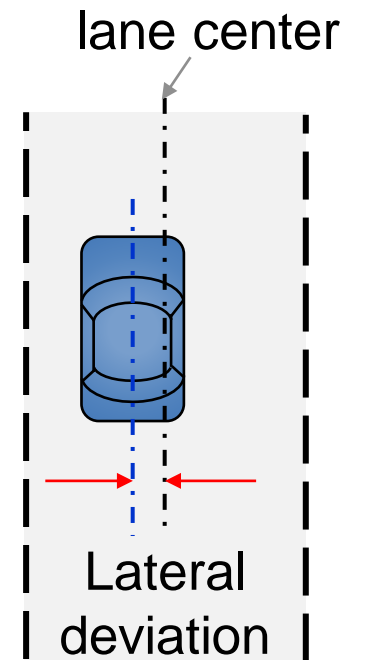
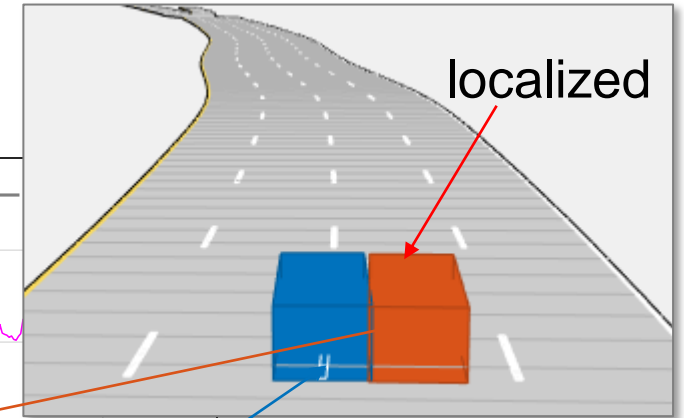
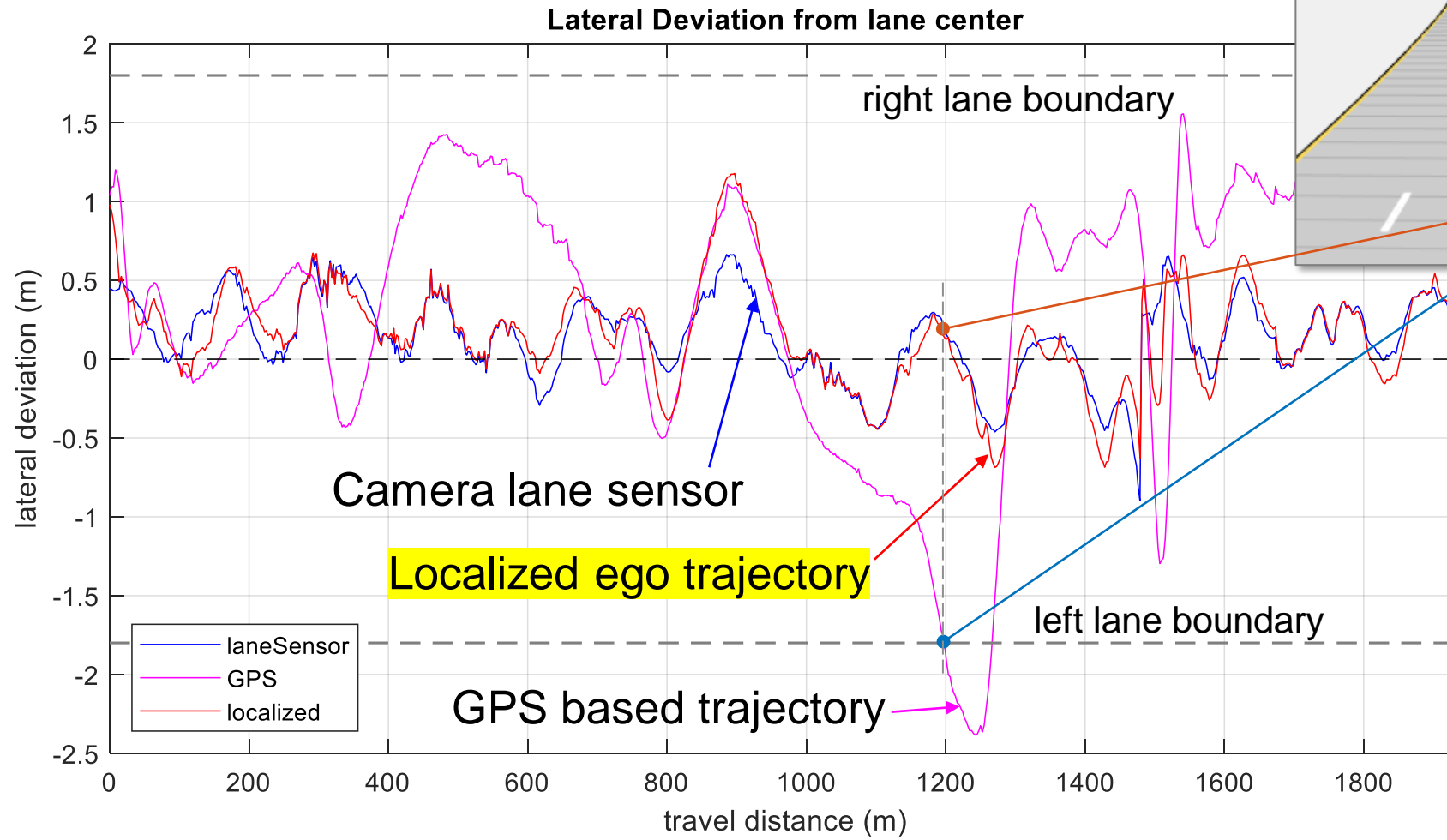
Road interactions disabled

Ego car

Lateral deviation of ego vehicle from lane center



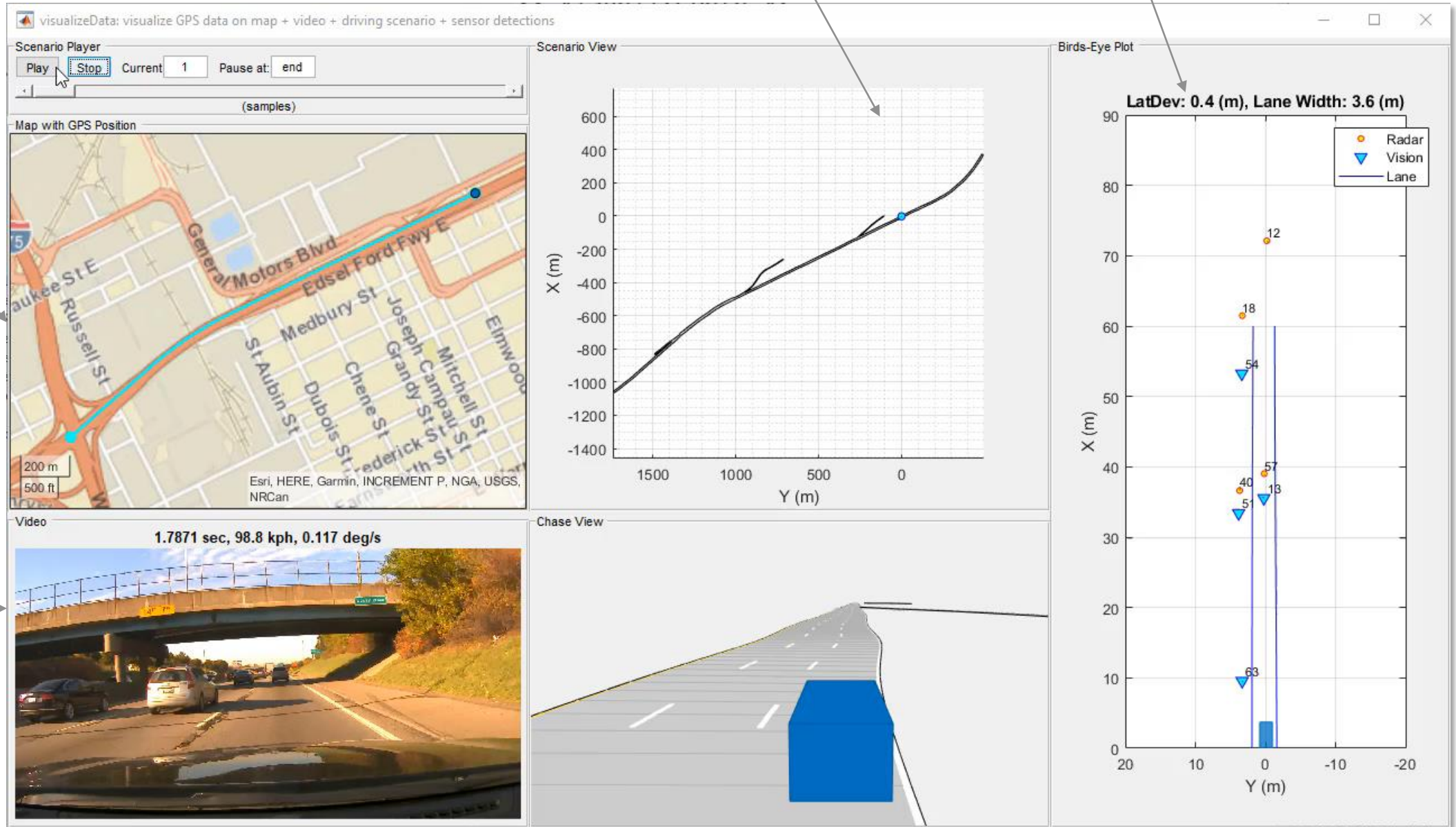
Localized ego trajectory by lane sensor data



Visualize data

Driving scenario view
drivingScenario

Bird's-eye plot with
sensor detections **birdsEyePlot**



Map with GPS
position
geoplayer

Video with
time stamp,
ego speed
& yaw rate
VideoReader
imshow

Create virtual driving scenario from recorded data

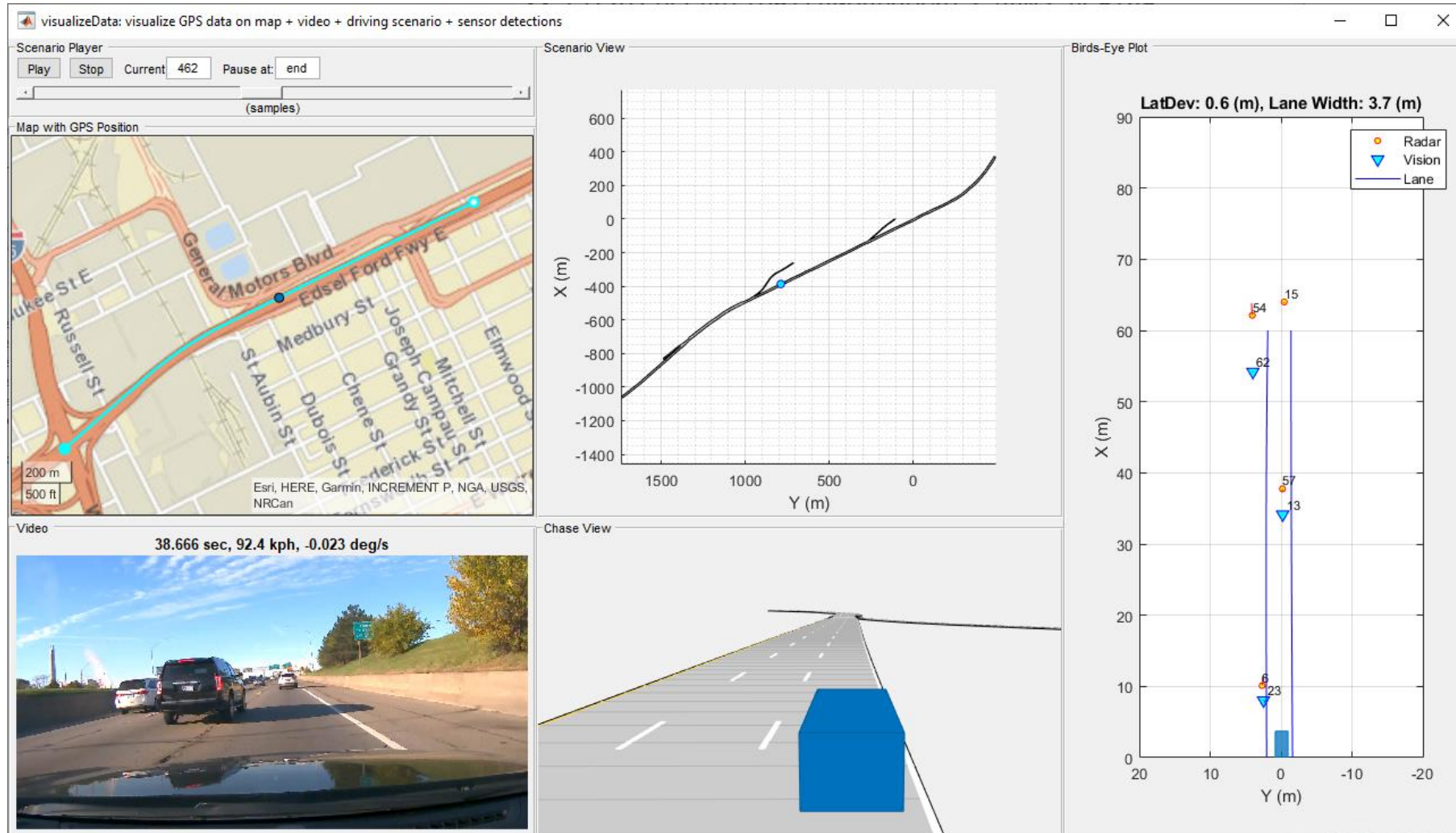
Record and
select data

Reconstruct
road network

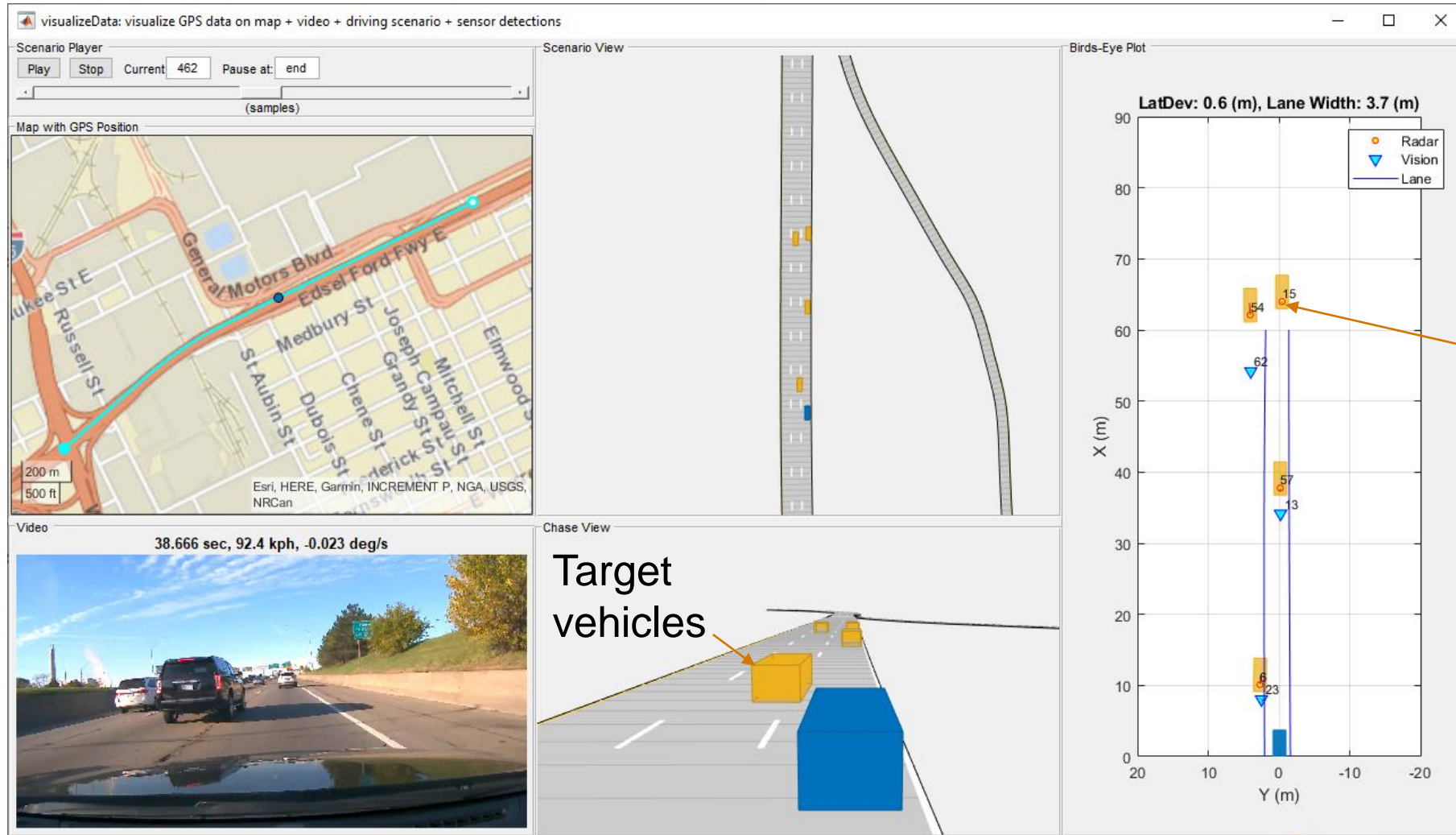
Localize ego
trajectory

Reconstruct
target vehicles

Compare with
recorded video



Create virtual driving scenario from recorded data

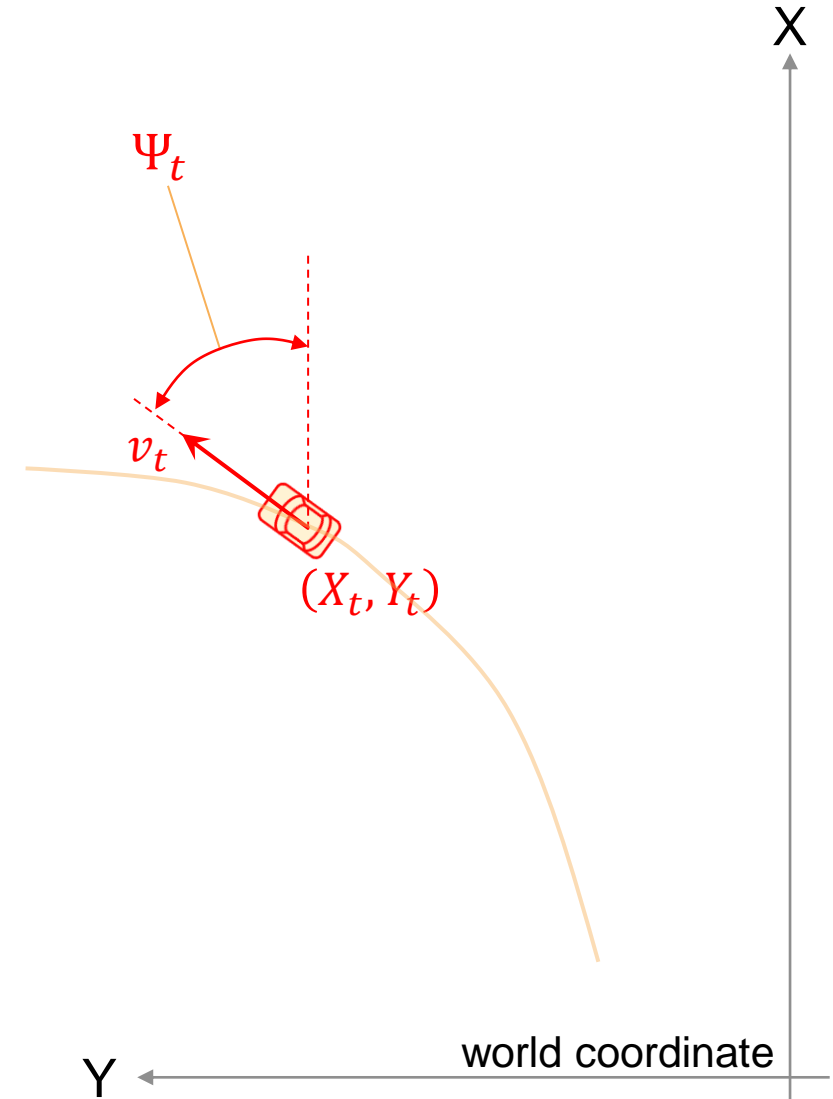


Radar
 Detections

Report
 targets only
 in ego and
 neighbor lanes

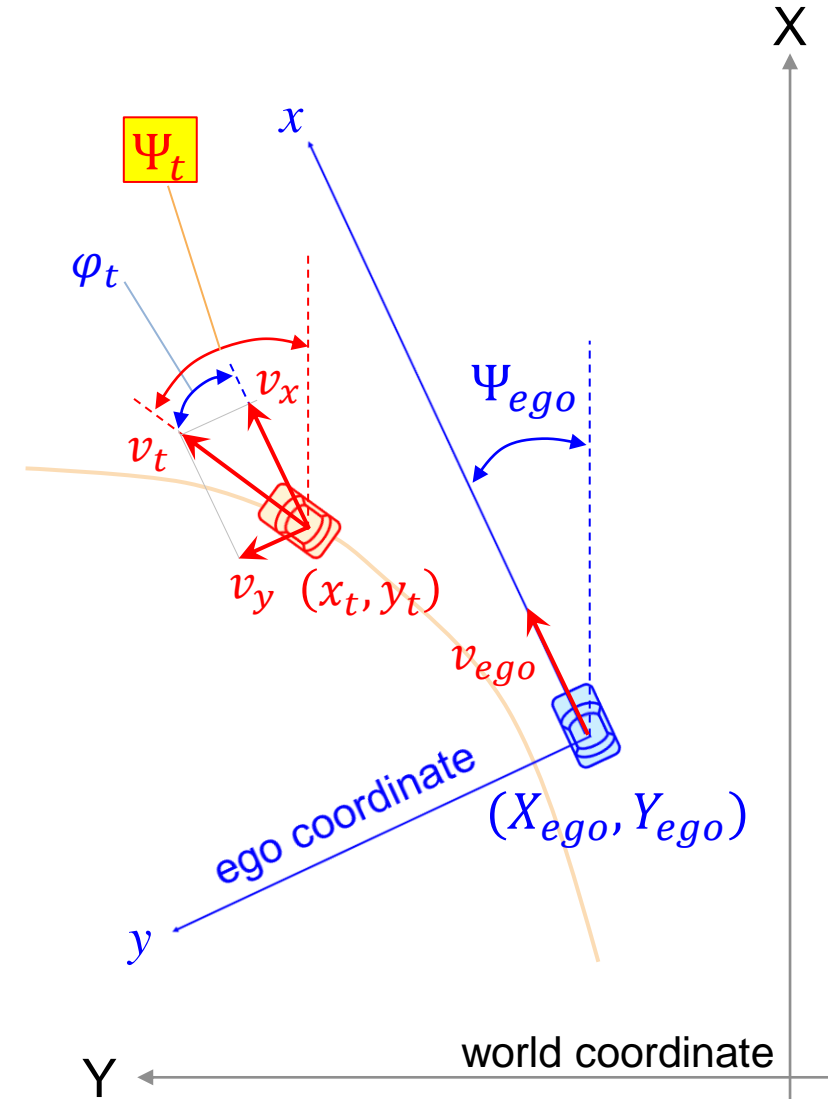
Target vehicle trajectory

- Target vehicle trajectory is defined by a series of actor poses
- Actor poses consist of
 - Position (X_t, Y_t)
 - Velocity v_t
 - Orientation Ψ_tin world coordinate

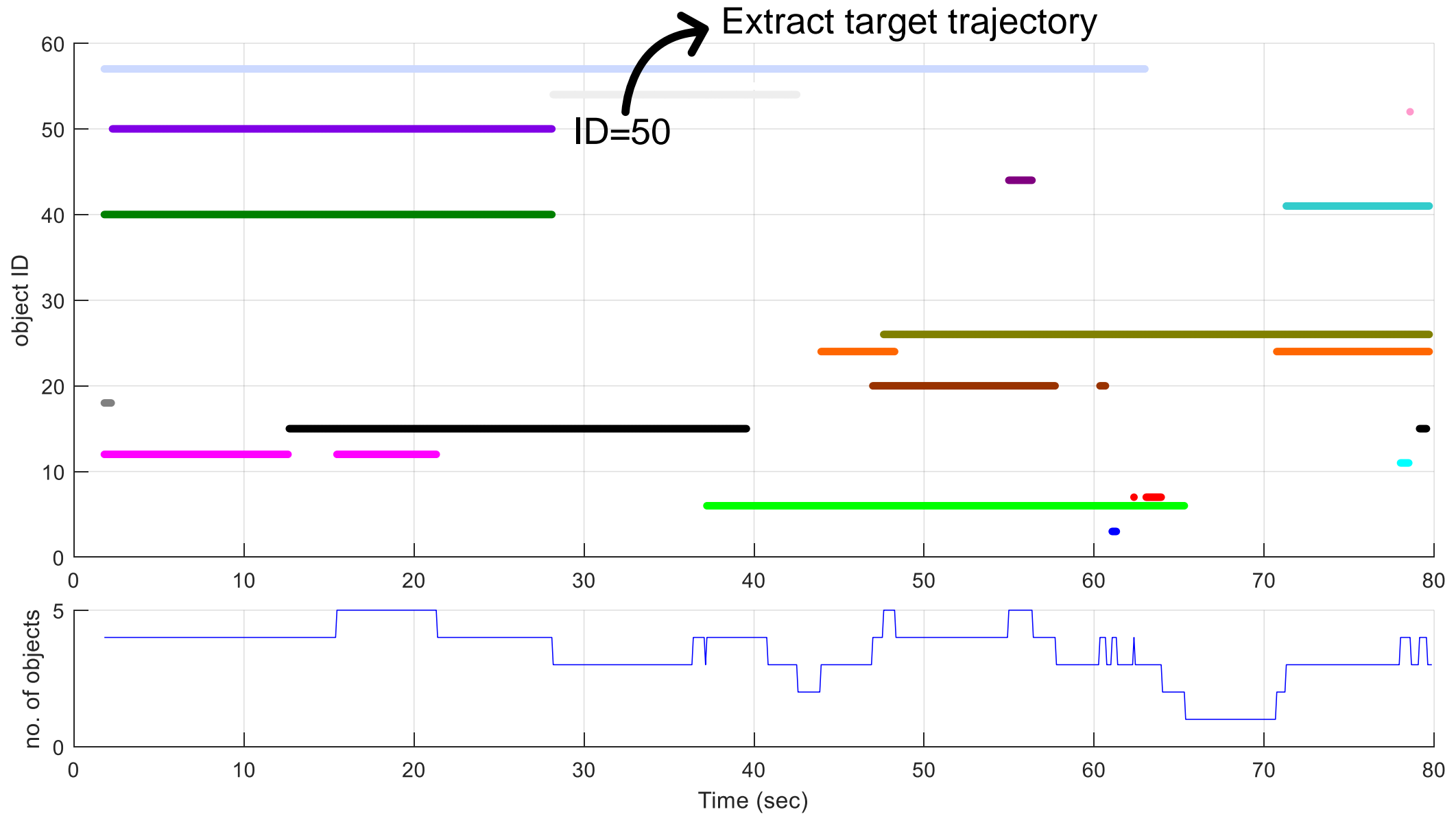


Estimate heading angle of target vehicle

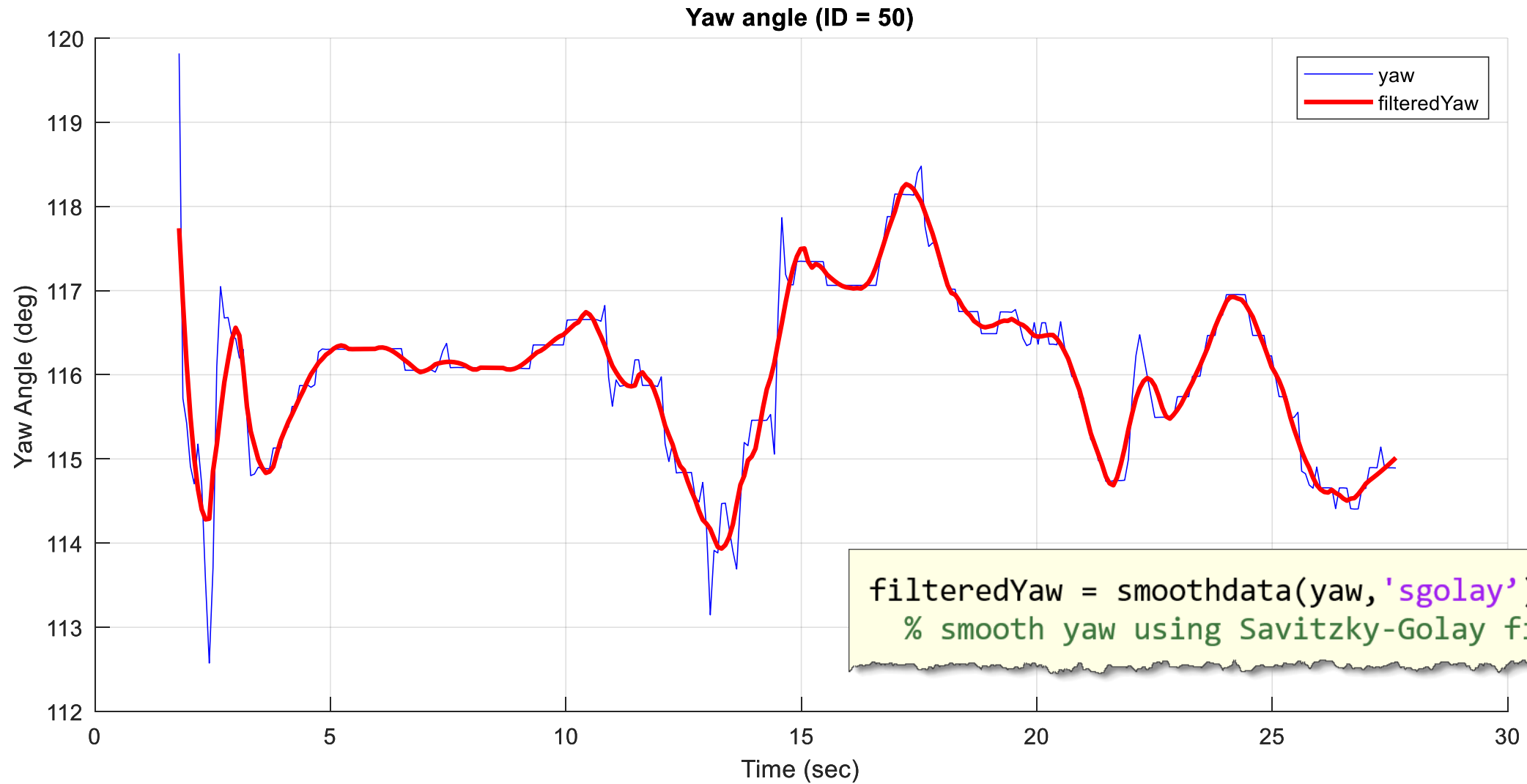
- Radar detections provides target position and velocity in ego coordinate
 - $x_t, y_t, v_x, v_y, (\varphi_t?) \leftarrow \text{radar detections}$
- Estimate heading angle of target vehicle
 - Heading angle in ego coordinate
 - $\varphi_t = \tan^{-1} \left(\frac{v_y}{v_x} \right)$
 - Heading angle in world coordinate
 - $\Psi_{target} = \varphi_t + \Psi_{ego}$
- Target position in world coordinate
 - $(X_t, Y_t) = (X_{ego}, Y_{ego}) + \mathbb{R}(\Psi_{ego}) \cdot (x_t, y_t)^T$



Extract target trajectory from radar detections



Example of estimated yaw angle



Create virtual driving scenario from recorded data

Record and
select data

Reconstruct
road network

Localize ego
trajectory

Reconstruct
target vehicles

Compare with
recorded video



Report radar
detections
in ego and
neighbor lanes

Synthesize sensors with virtual driving scenario

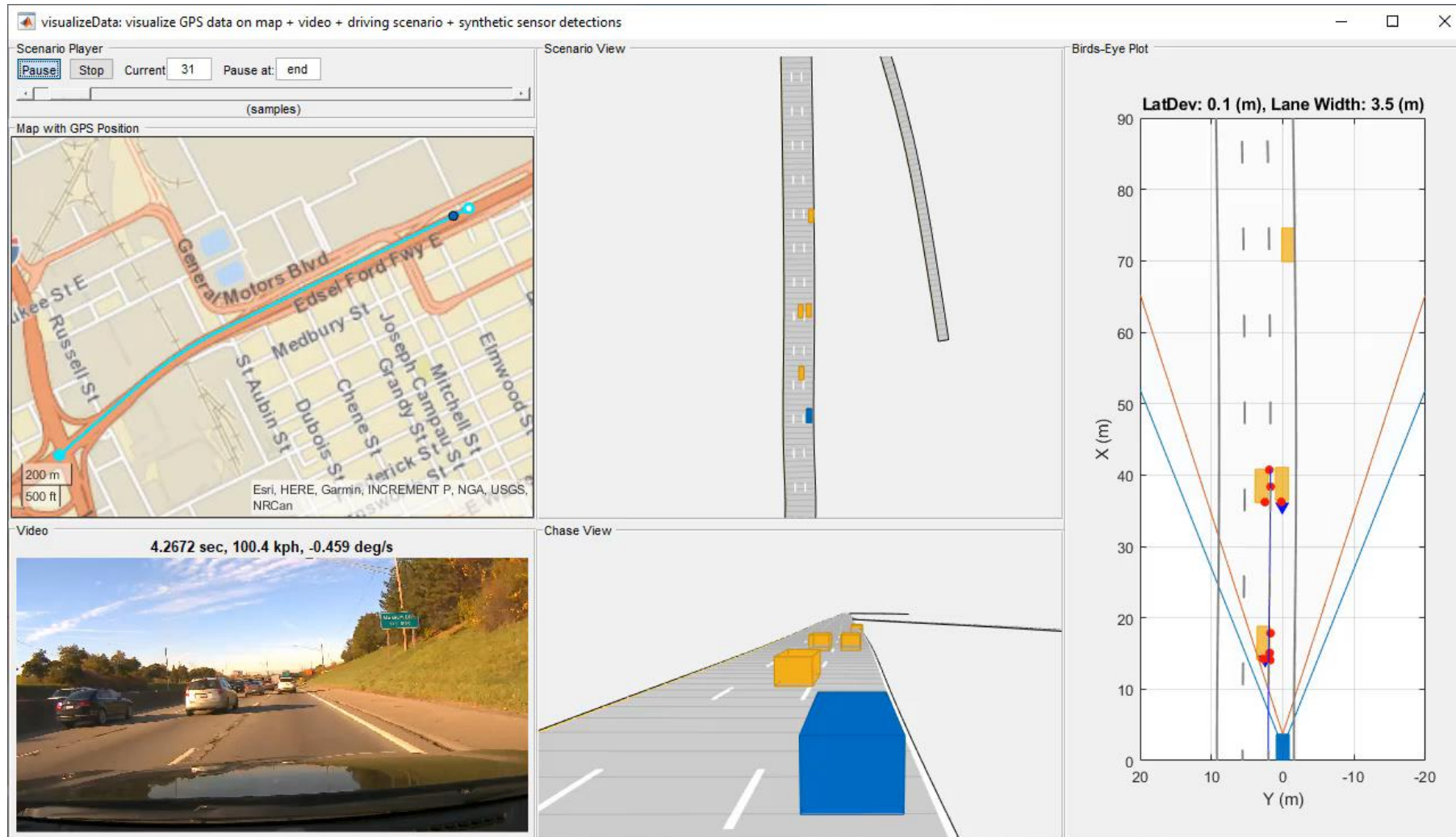
Record and
select data

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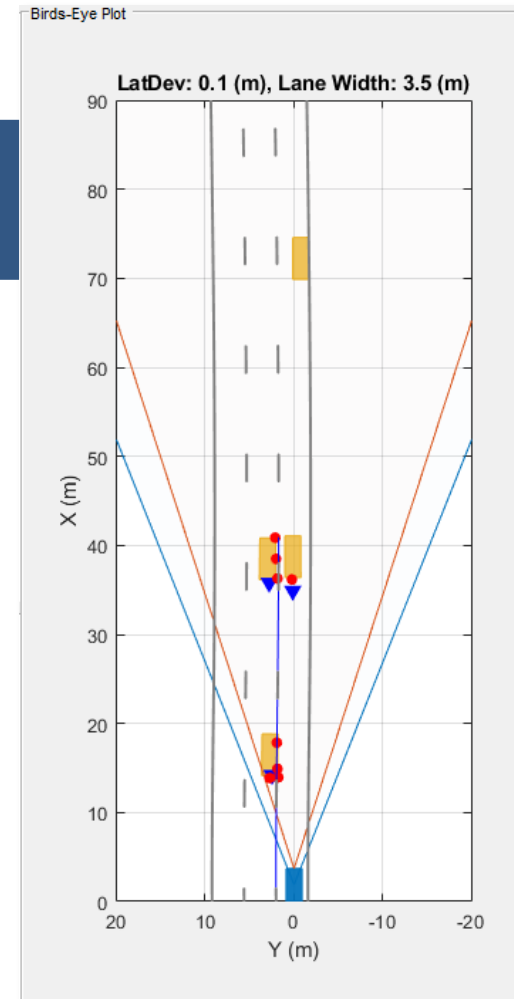
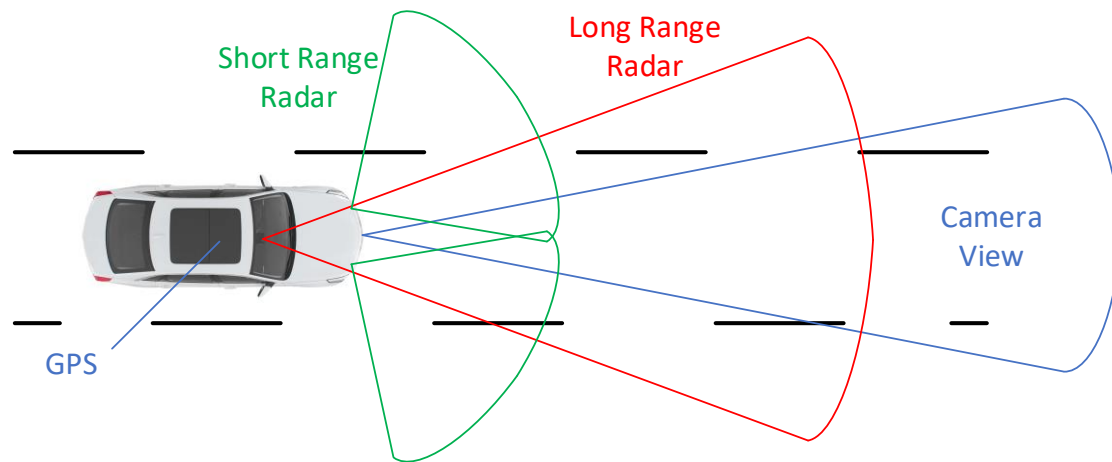
Synthesize
sensors

Integrate driving scenario + sensors with a close-loop system

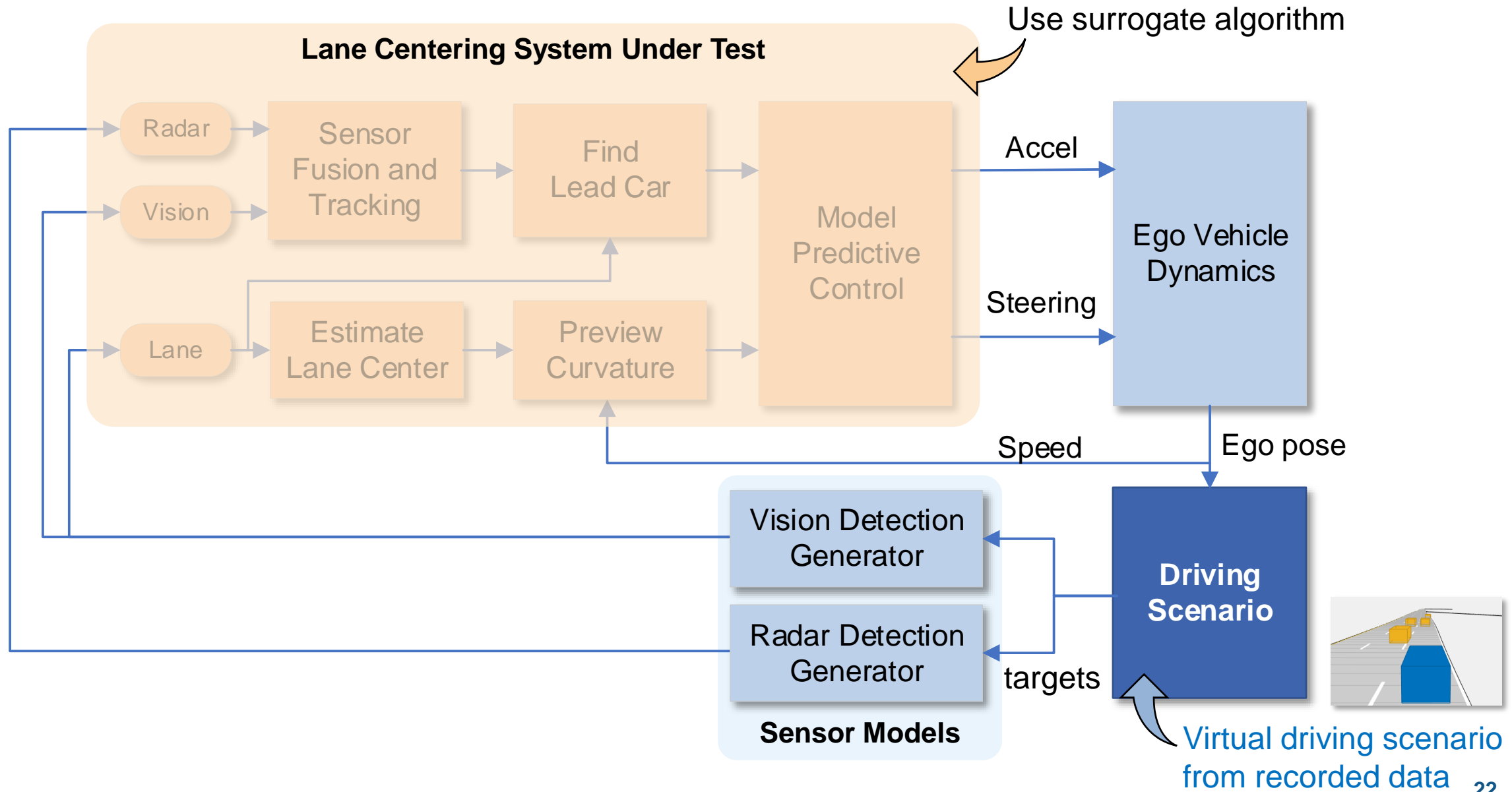


Integrate **driving scenario + sensor models** with a close-loop system

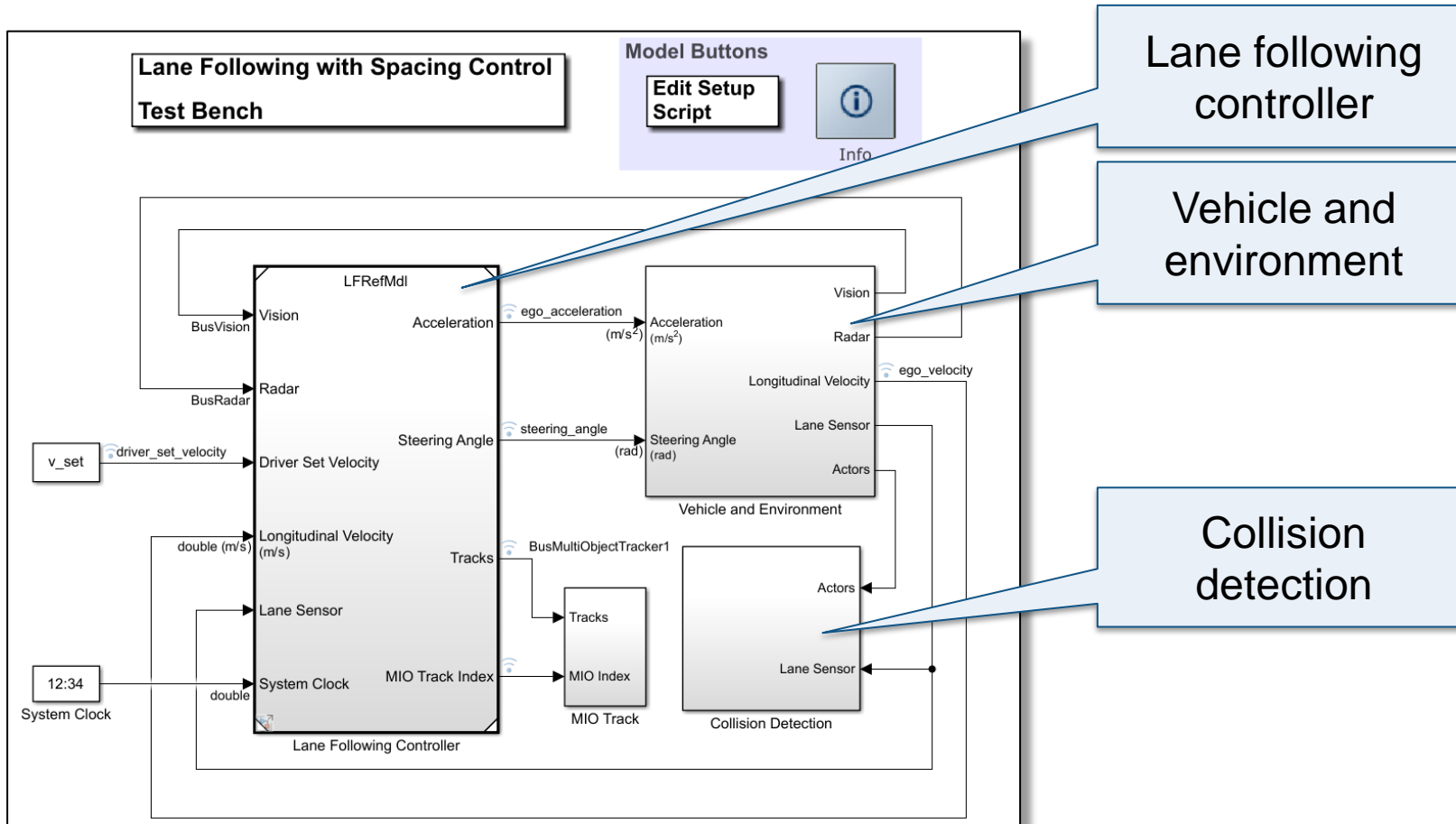
Synthesize sensors



Closed-loop system for lane centering



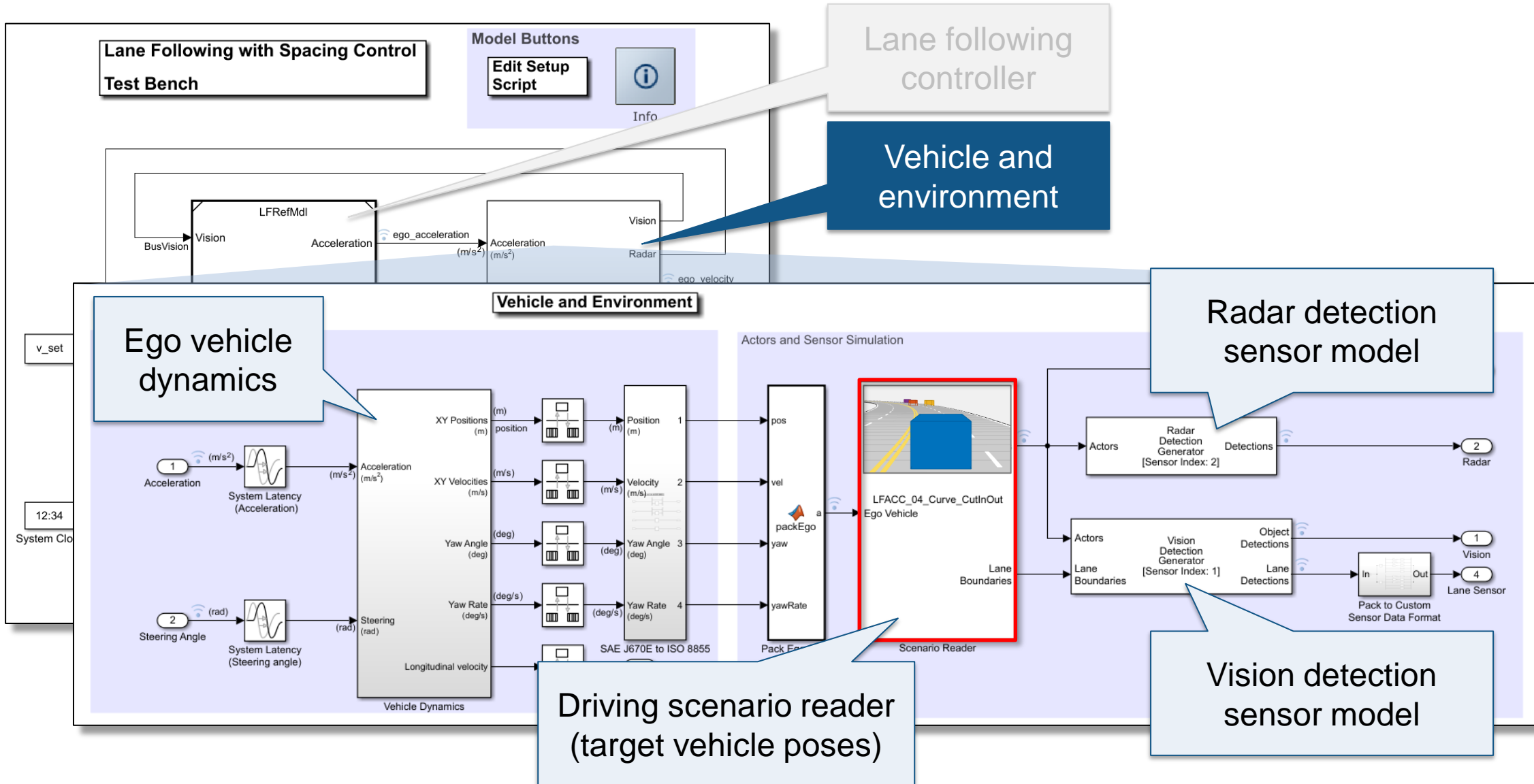
Surrogate closed-loop system for lane centering



[Lane Following Control with Sensor Fusion and Lane Detection](#)

Automated Driving Toolbox™

Surrogate closed-loop system for lane centering

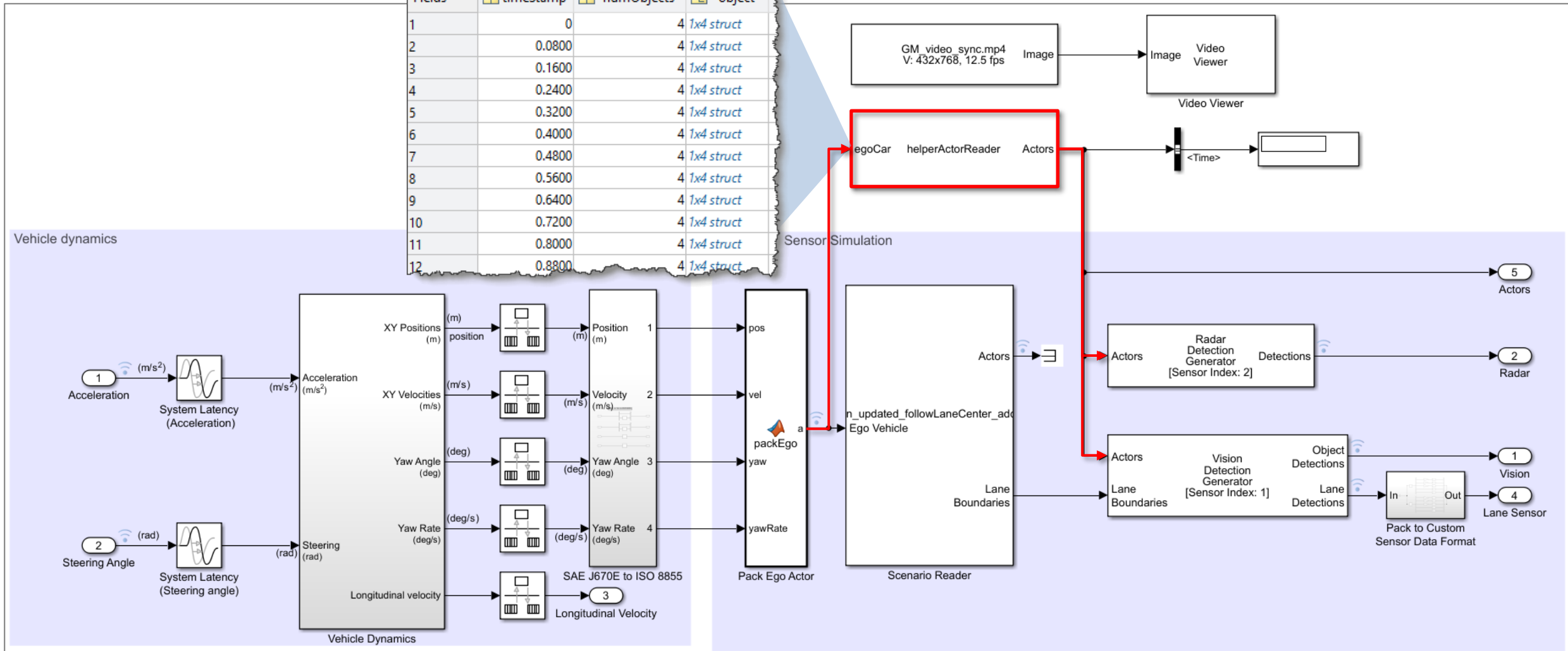


Lane centering test bench with recorded target vehicles

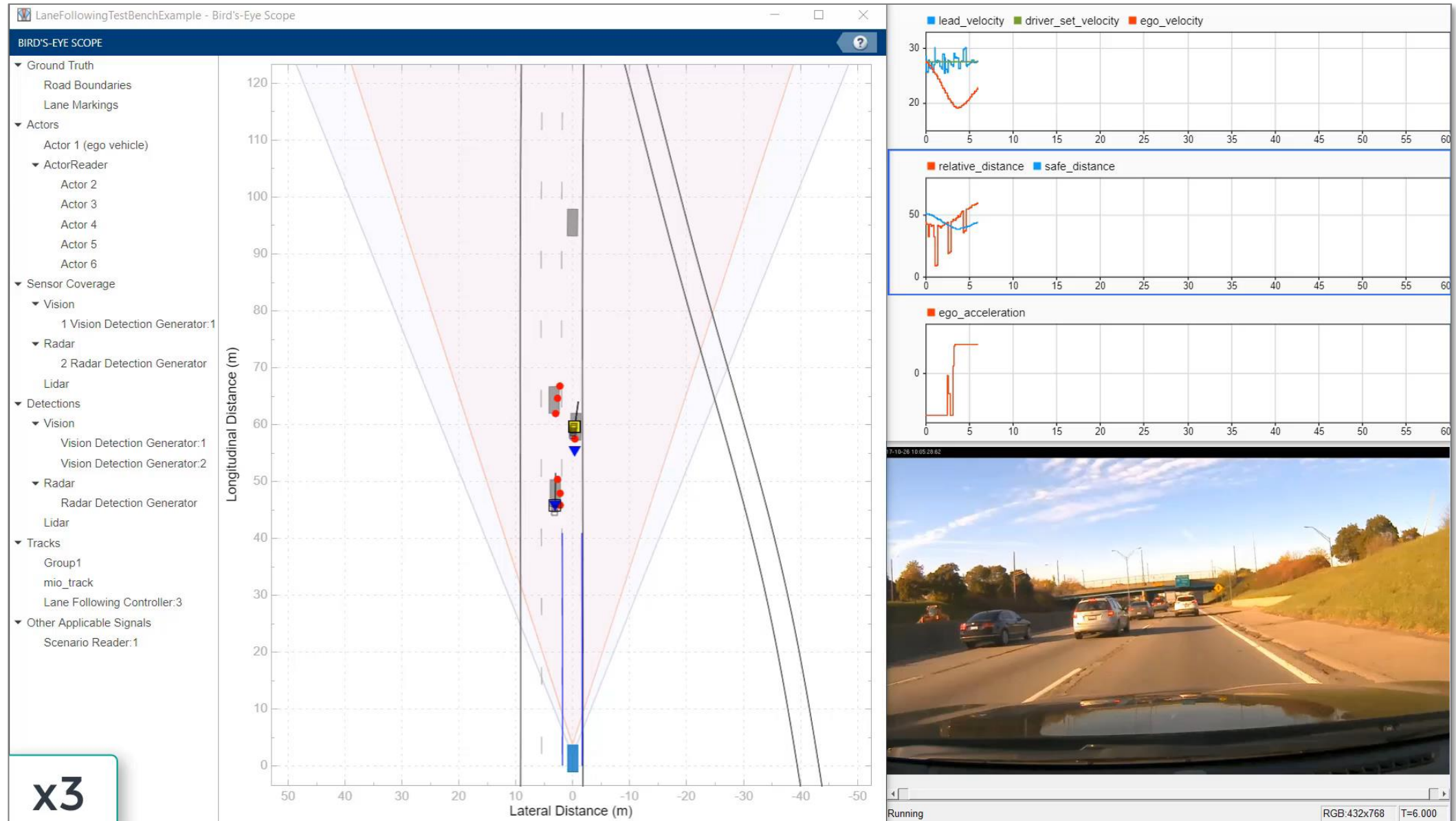
groundTruth

1x975 struct with 3 fields

Fields	timeStamp	numObjects	object
1	0	4	1x4 struct
2	0.0800	4	1x4 struct
3	0.1600	4	1x4 struct
4	0.2400	4	1x4 struct
5	0.3200	4	1x4 struct
6	0.4000	4	1x4 struct
7	0.4800	4	1x4 struct
8	0.5600	4	1x4 struct
9	0.6400	4	1x4 struct
10	0.7200	4	1x4 struct
11	0.8000	4	1x4 struct
12	0.8800	4	1x4 struct

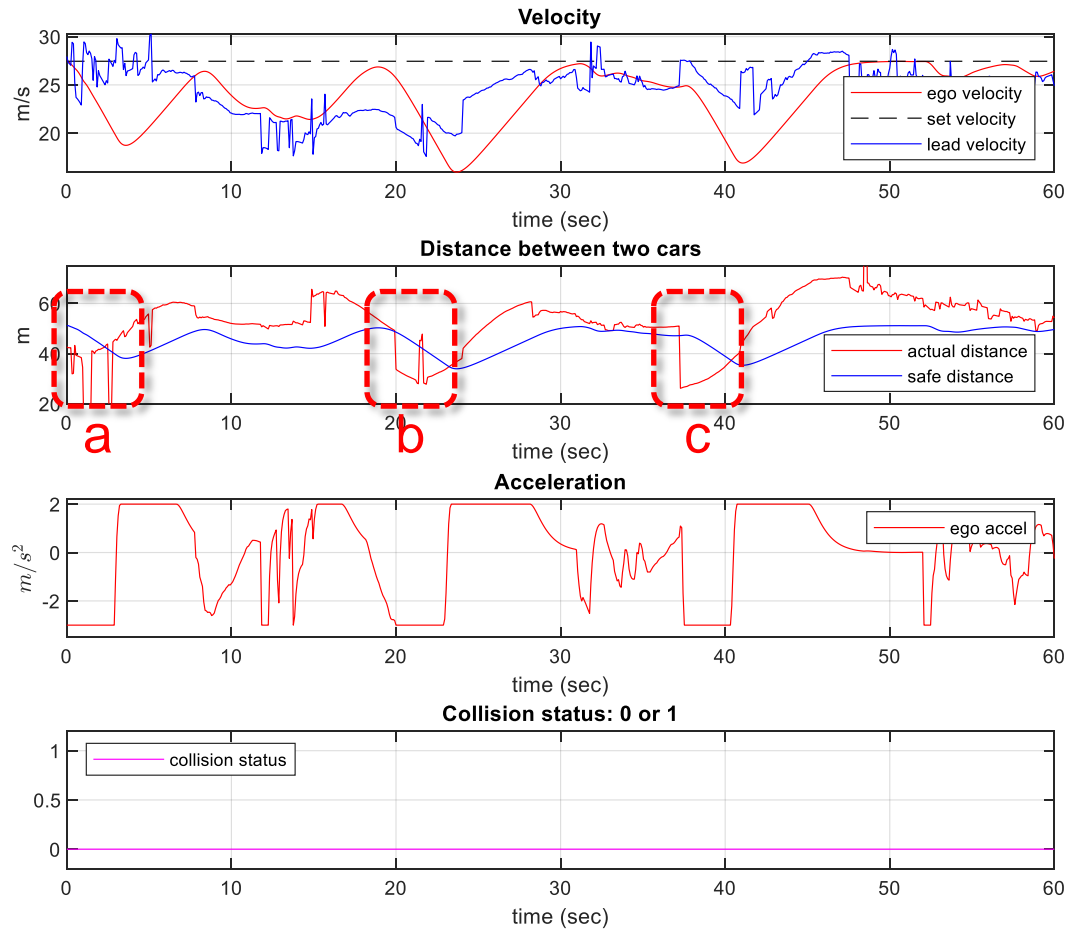


Closed-loop simulation using reconstructed virtual driving scenario

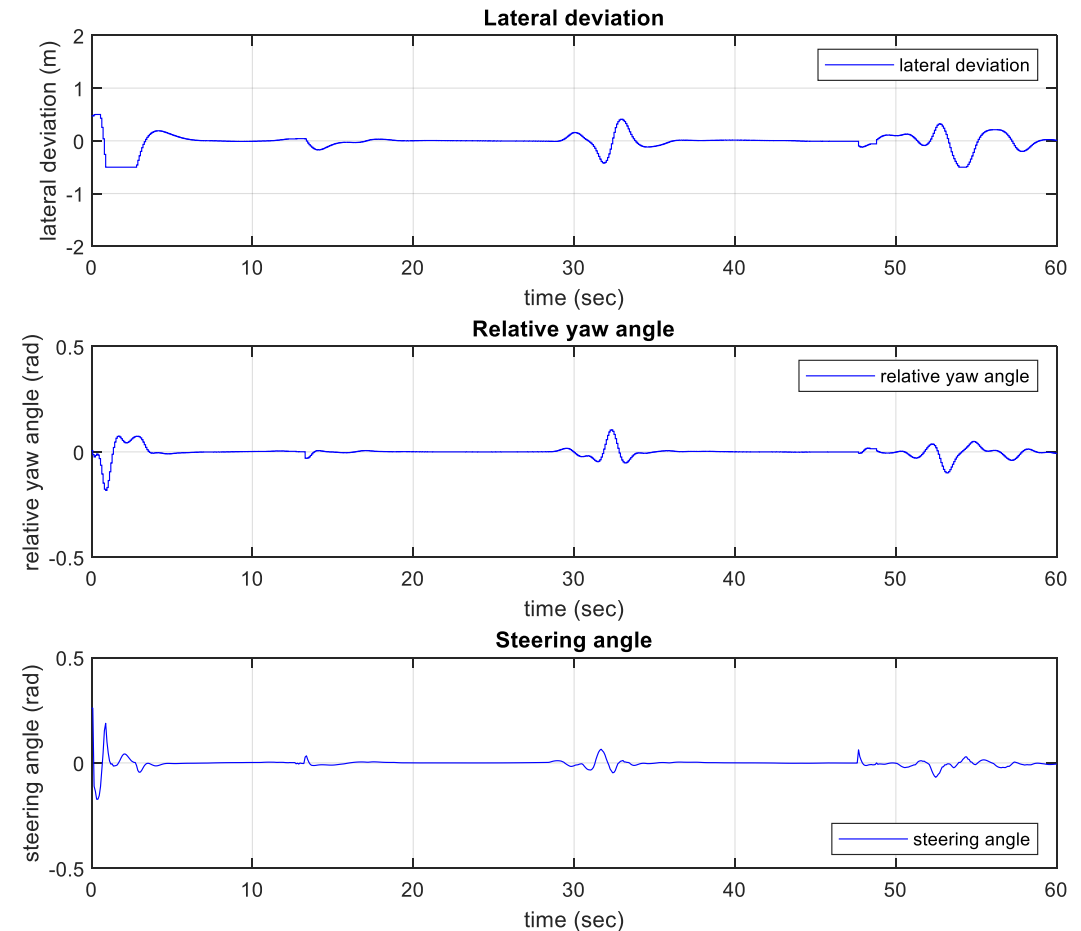


Simulation result (longitudinal & lateral control performance)

longitudinal control performance



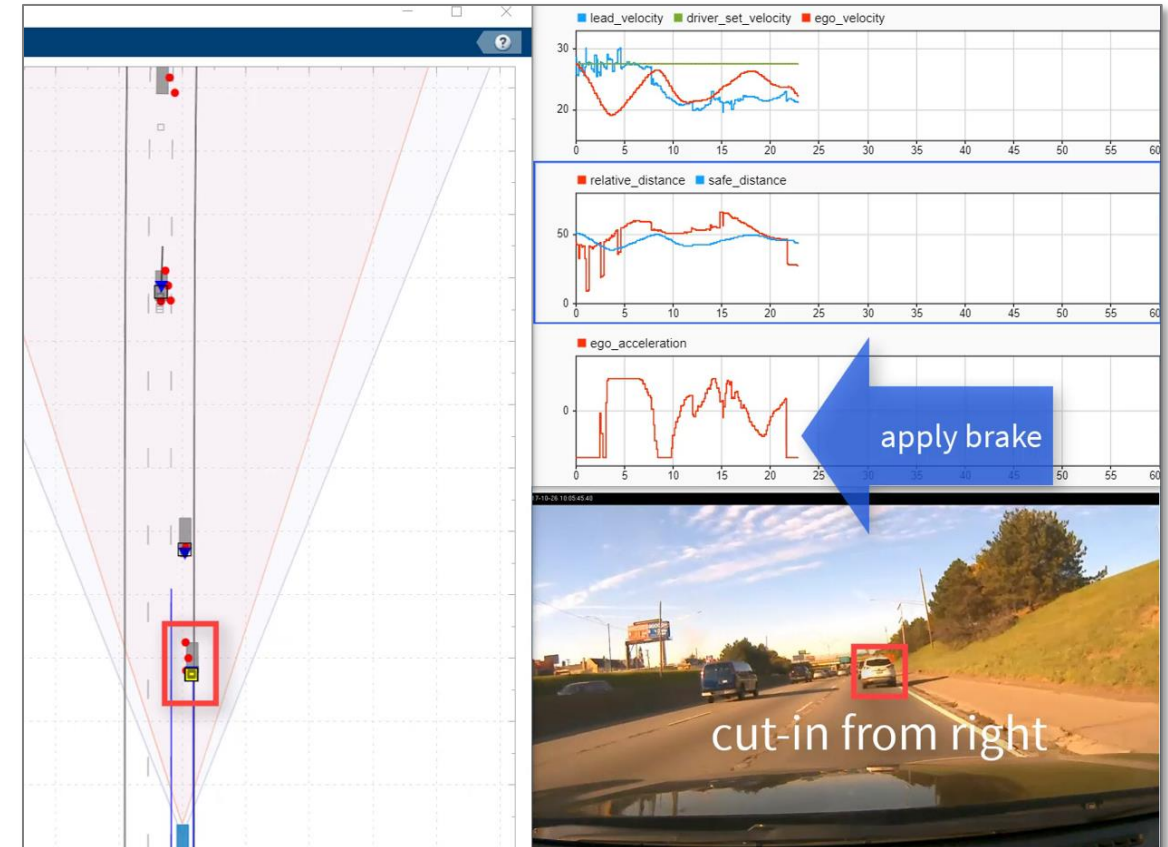
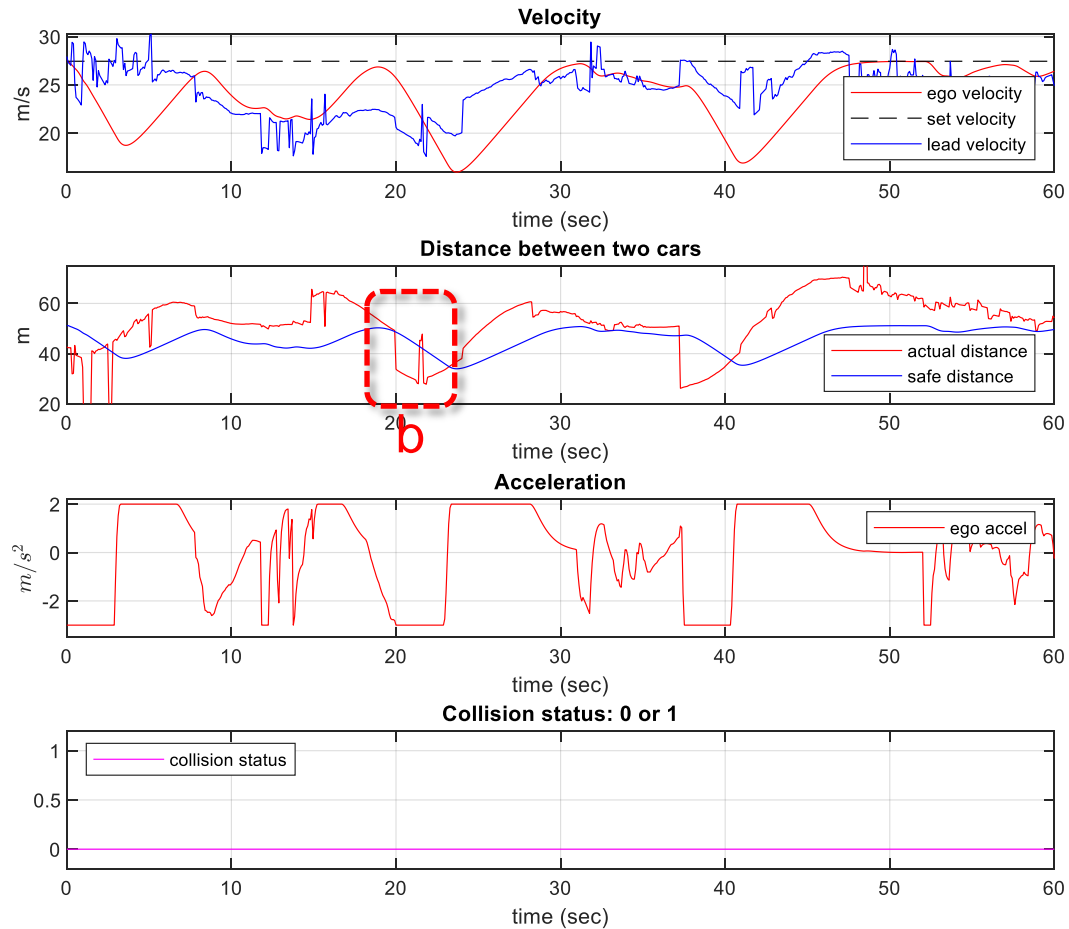
lateral control performance



a,b,c : problem cases where headway distance drops below the safe distance.

Driving case (b): cut-in vehicle at low speed

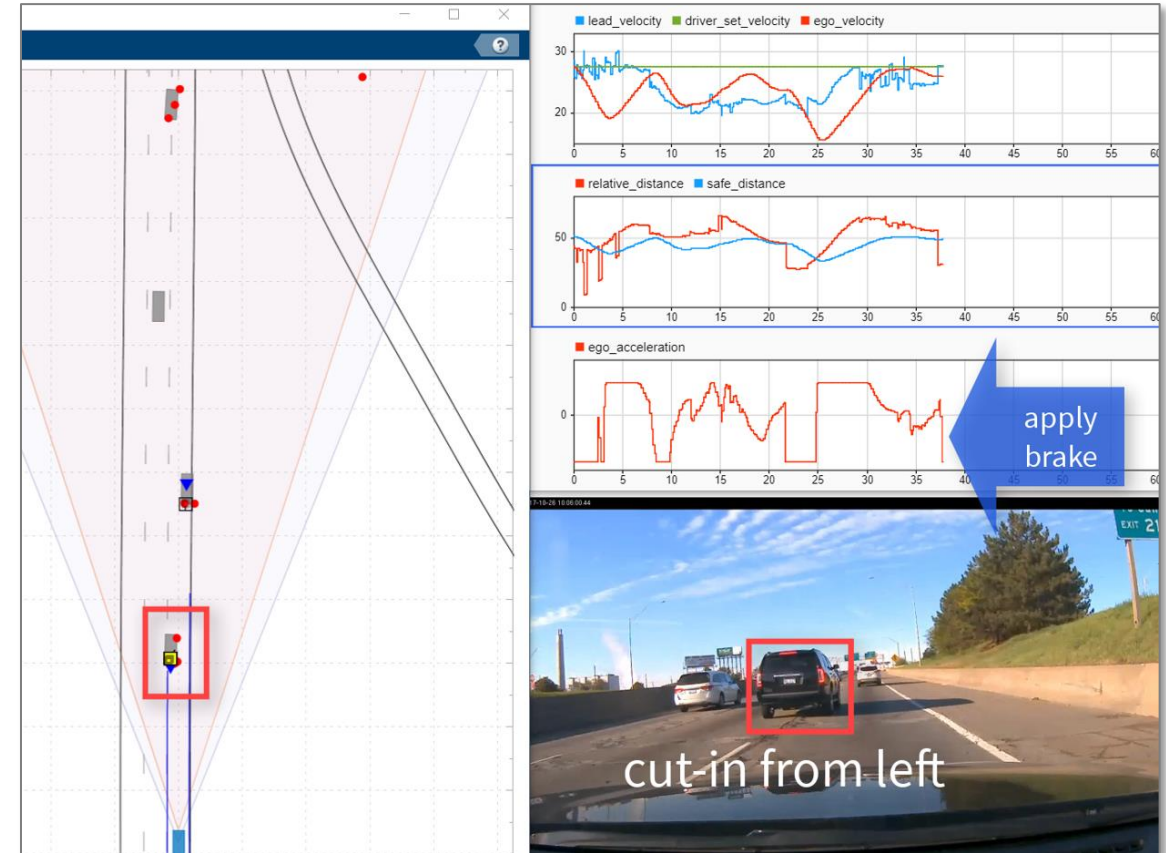
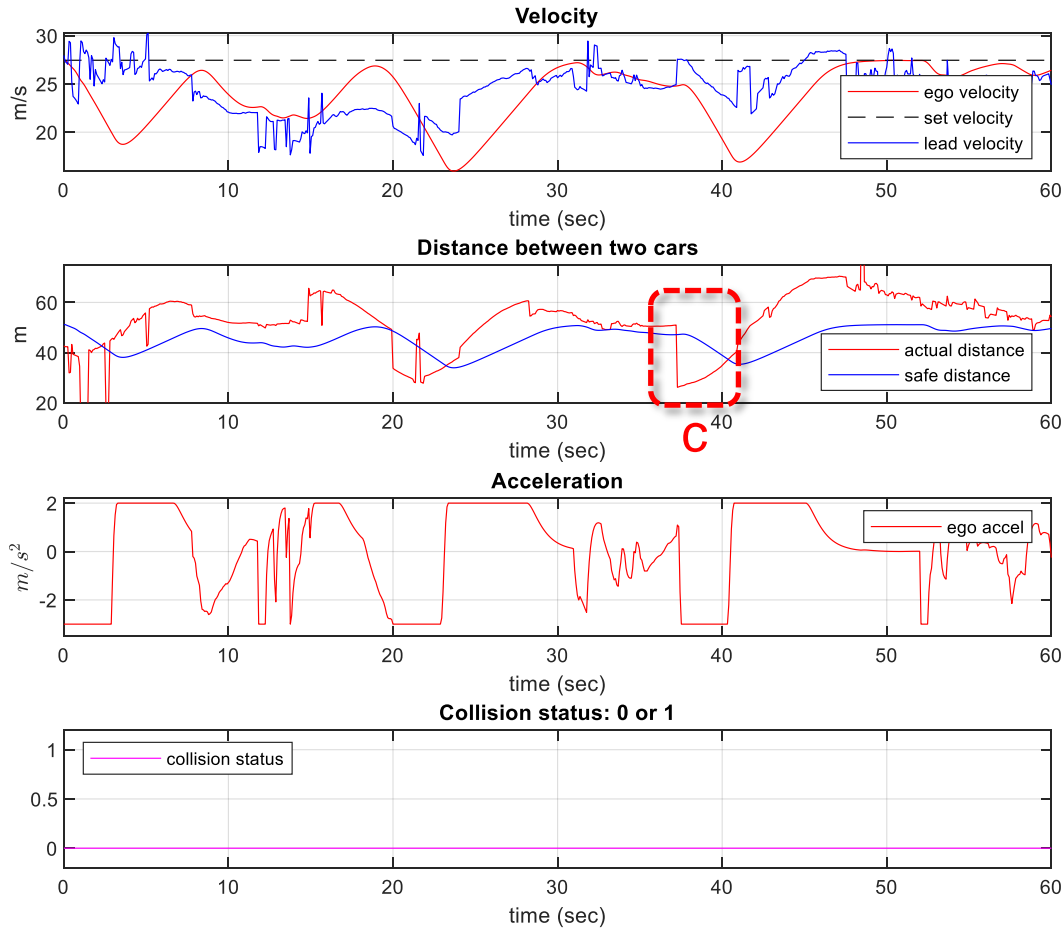
longitudinal control performance



a,b,c : problem cases where headway distance drops below the safe distance.

Driving case (c): cut-in vehicle with too close distance

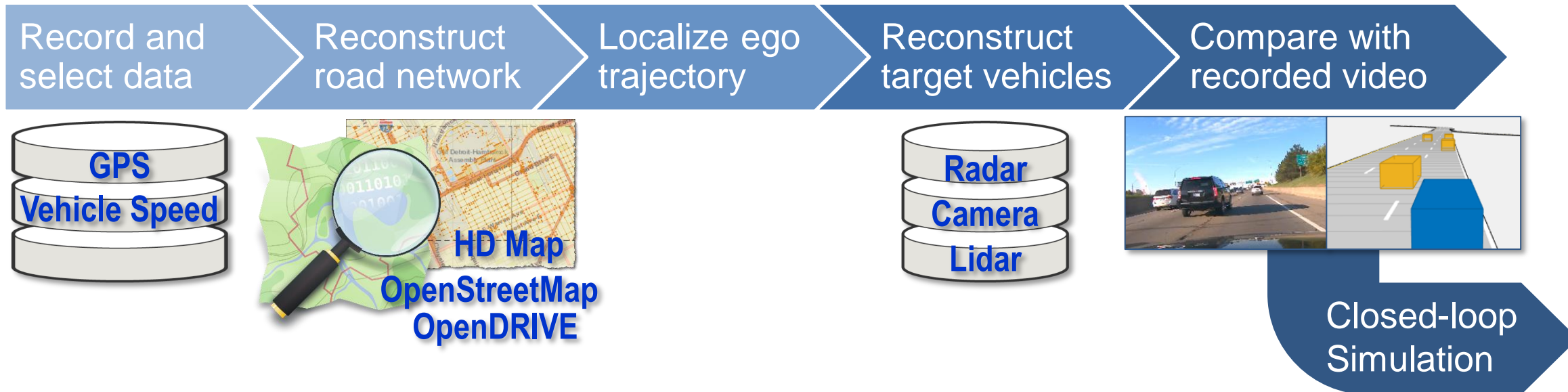
longitudinal control performance



a,b,c : problem cases where headway distance drops below the safe distance.

Conclusion


- Created virtual driving scenario from recorded data



- Reproduced real-world driving scenario in the virtual simulation environment
 - Assess functional behavior and identify root cause for problem cases
 - Reduce development time with limited resources
 - Enable repetitive tests for hazardous scenarios

Remark

- Collaborative effort between GM and MathWorks.
- This study has been published in the SAE paper.

2020-01-0718 Published 14 Apr 2020	
	<h3>Creating Driving Scenarios from Recorded Vehicle Data for Validating Lane Centering System in Highway Traffic</h3>
	Seo-Wook Park, Kunal Patil, Will Wilson, and Mark Corless The MathWorks, Inc.
	Gabriel Choi and Paul Adam General Motors LLC
	<i>Citation:</i> Park, S.-W, Patil, K., Wilson, W., Corless, M. et al., "Creating Driving Scenarios from Recorded Vehicle Data for Validating Lane Centering System in Highway Traffic," SAE Technical Paper 2020-01-0718, 2020, doi:10.4271/2020-01-0718.

Presenter contact info and poll questions

Please contact us with questions

- Gabriel Choi, General Motors LLC (gabriel.choi@gm.com)
 - Seo-Wook Park, MathWorks (spark@mathworks.com)
-
- Poll questions : I found this technique the most interesting
 1. Access mdf data
 2. Road network creation from HD map
 3. Ego vehicle localization
 4. Reconstruct target vehicles
 5. Data visualization
 6. Close-loop system integration for lane centering with Simulink
 - If you would like to an individual follow-up, please provide your name and email address in the WebEx poll area.