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

Gabriel Choi, General Motors LLC
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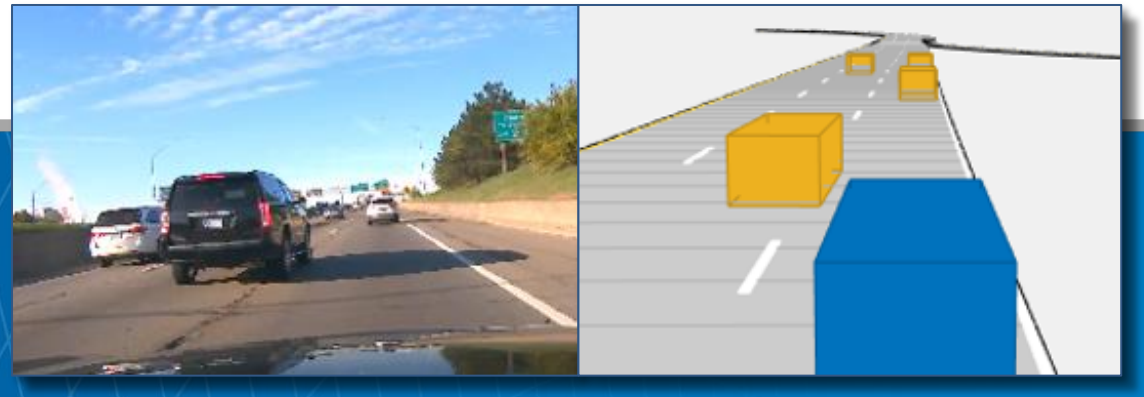


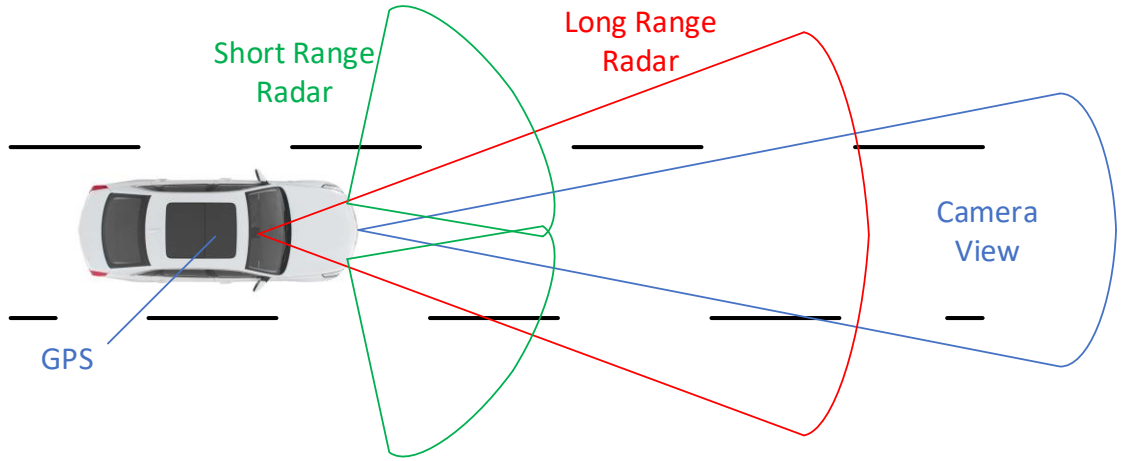
Contents

- 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

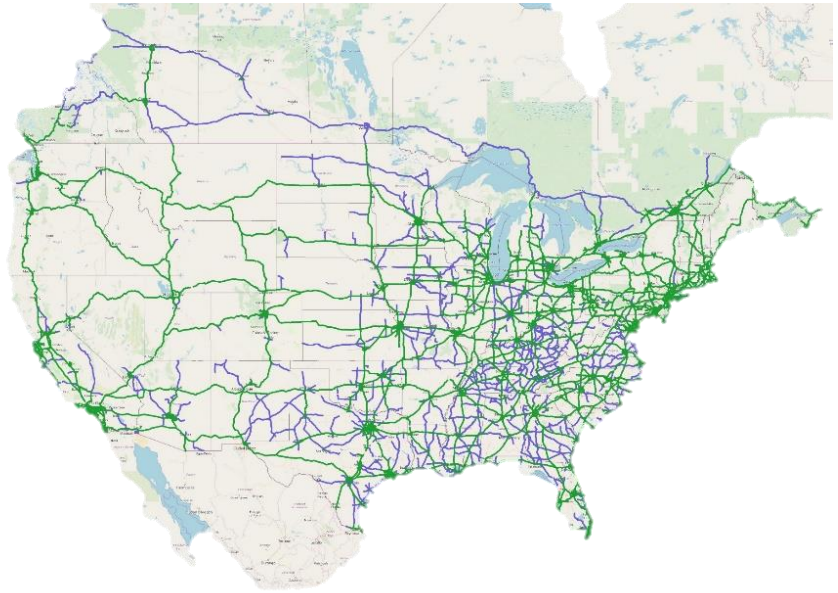
Lane Centering with Super Cruise on Cadillac CT6



- 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

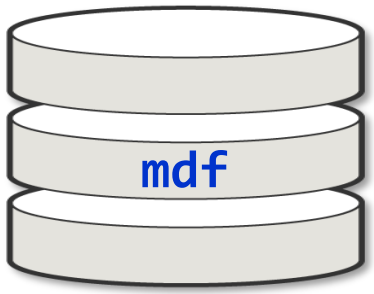


- Virtual driving scenario from recorded data
  - Reduce development time
  - Enable closed-loop simulation to identify the root causes for unwanted system behavior

➔How to create driving scenario from recorded data?

Create virtual driving scenario from recorded data

Record and select data | Reconstruct road network | Localize ego trajectory | Reconstruct target vehicles | Compare with recorded video



MDF(Measurement Data Format)


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

ego

3905x5 timetable

	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

sensor

1953x3 timetable

	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

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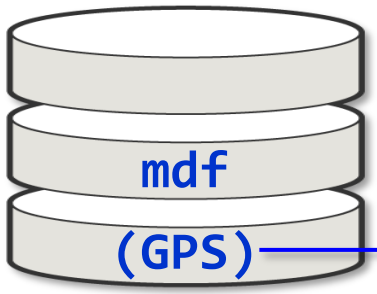
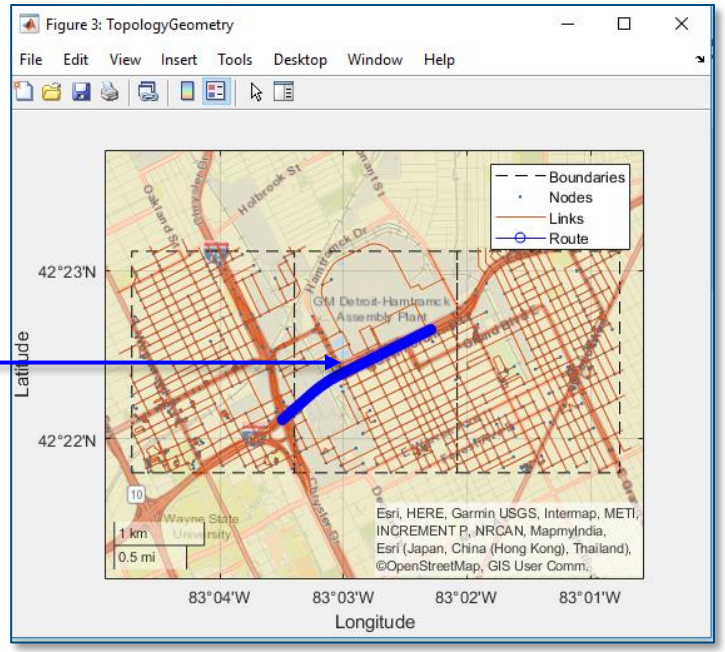
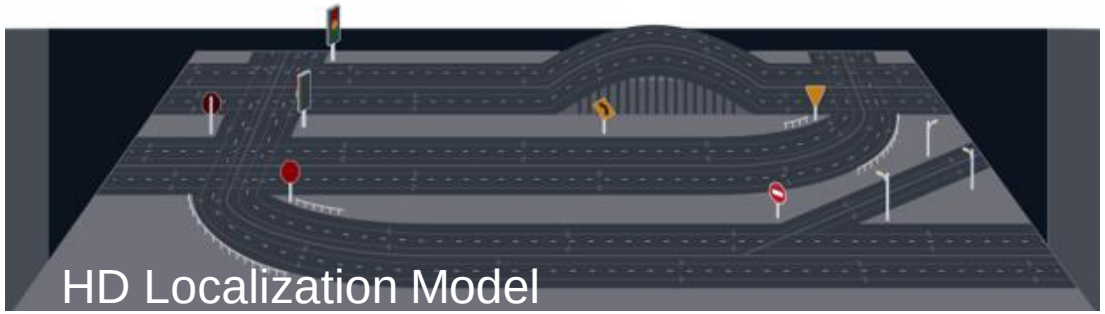
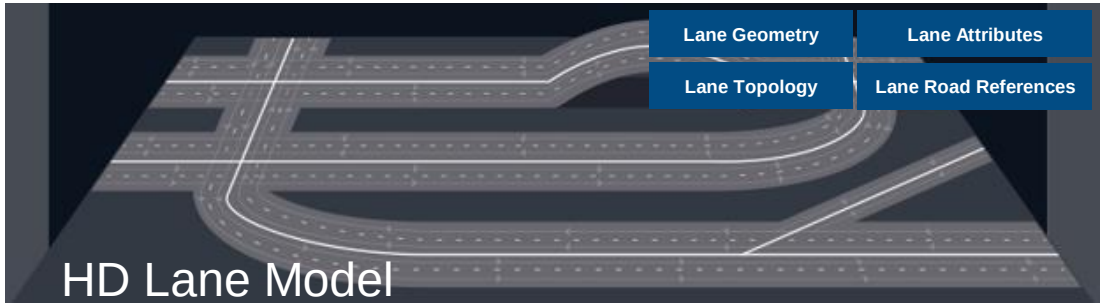
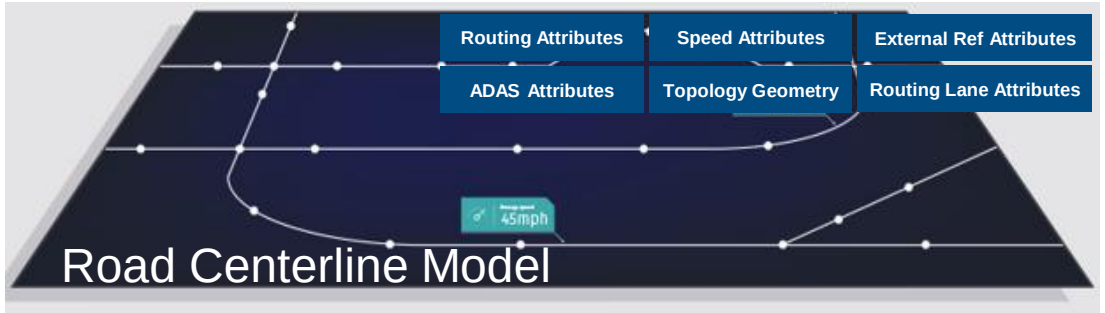





```
HDLMreader = hereHDLMReader(latitude,longitude);
topologyGeometry = HDLMreader.read("TopologyGeometry");
plot(topologyGeometry);
```







High-Definition Map with Tiled Layers

Create virtual driving scenario from recorded data

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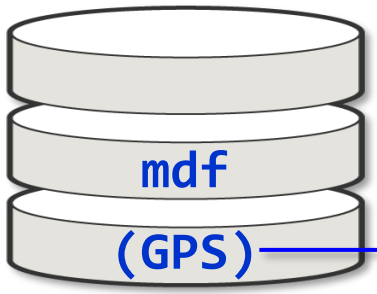

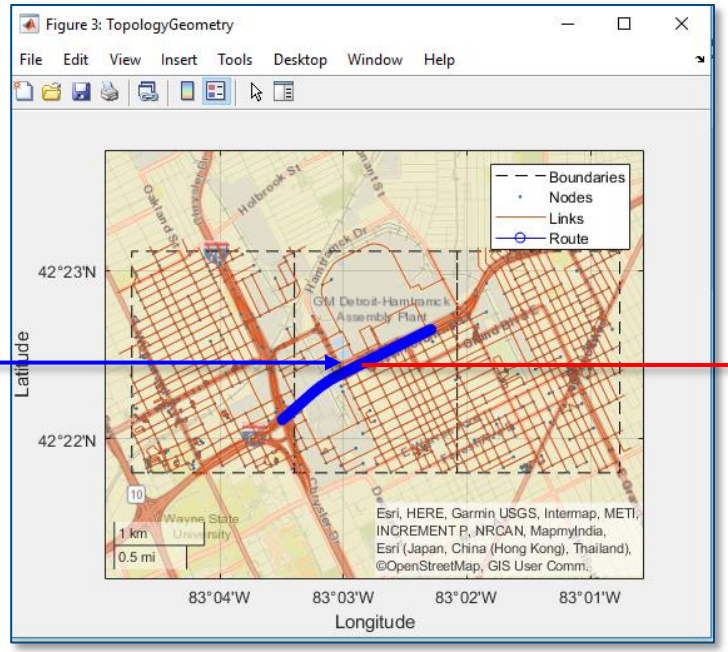


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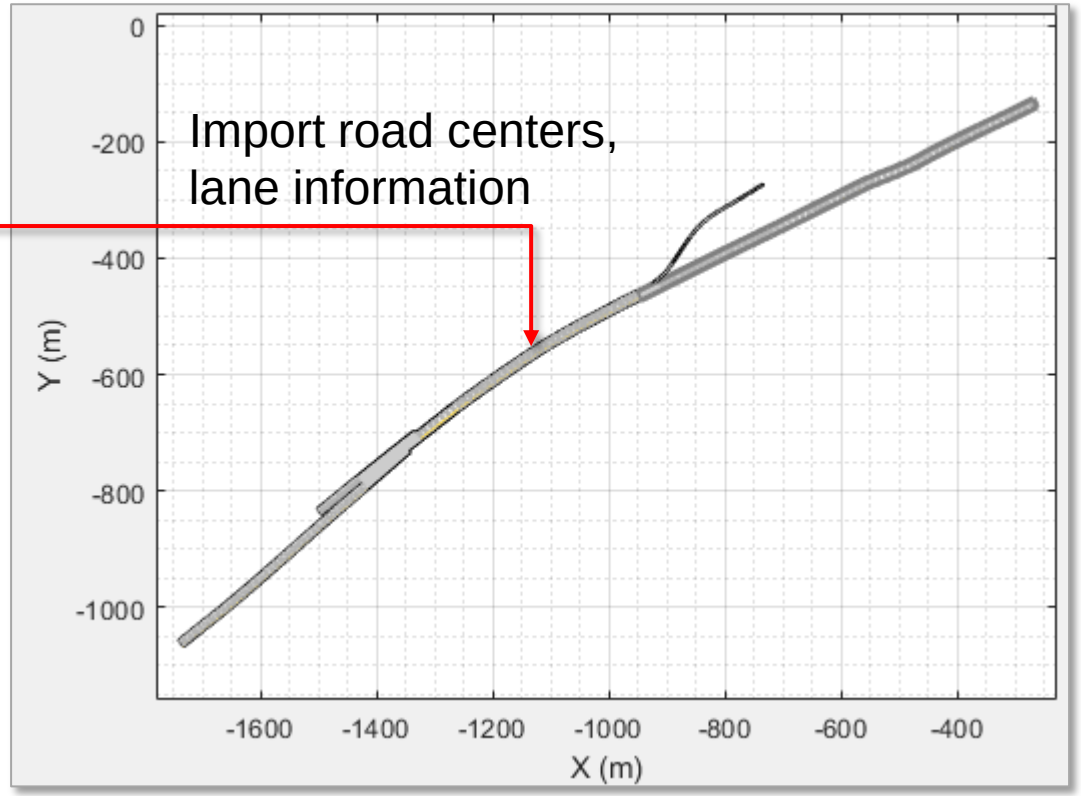
Create driving scenario



Create virtual driving scenario from recorded data

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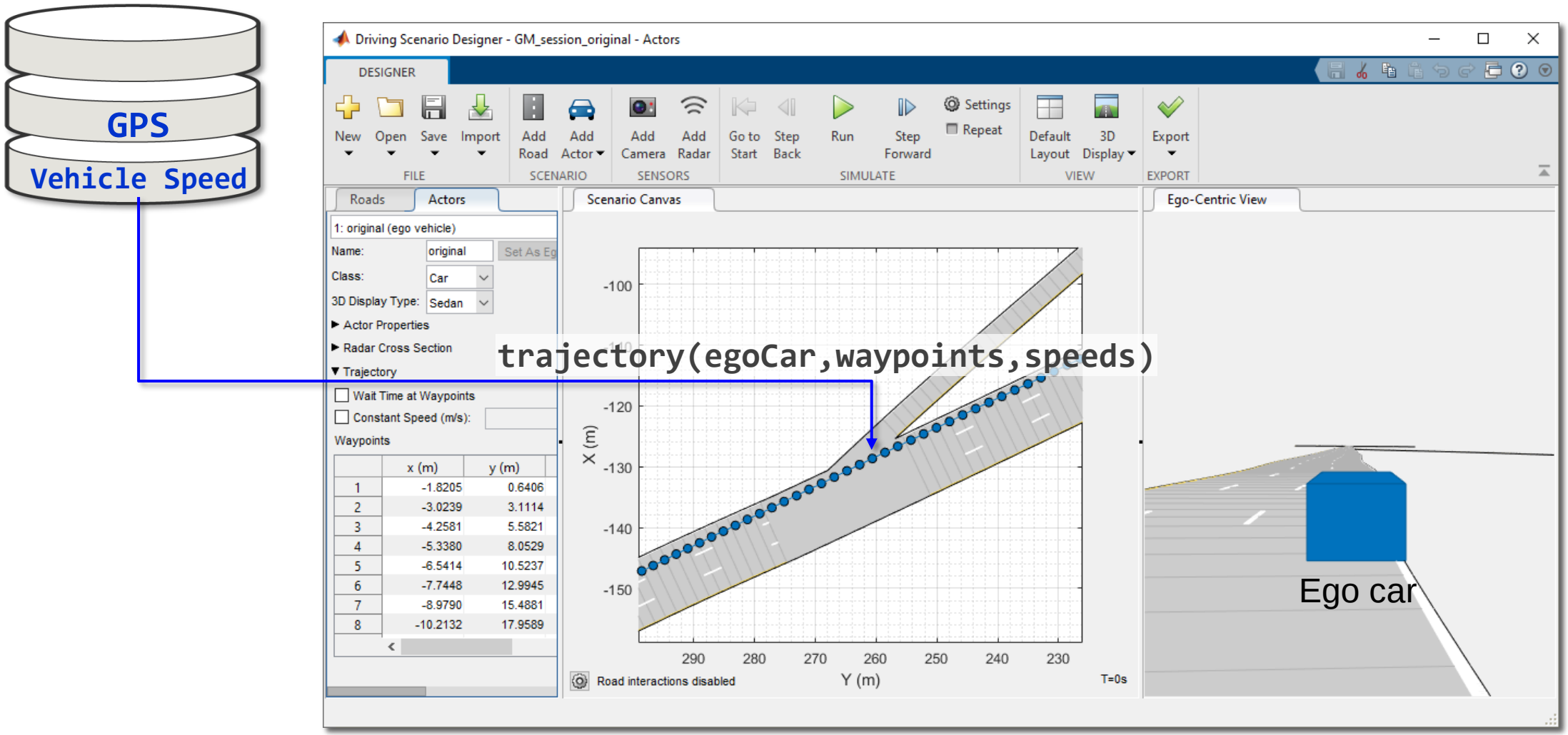
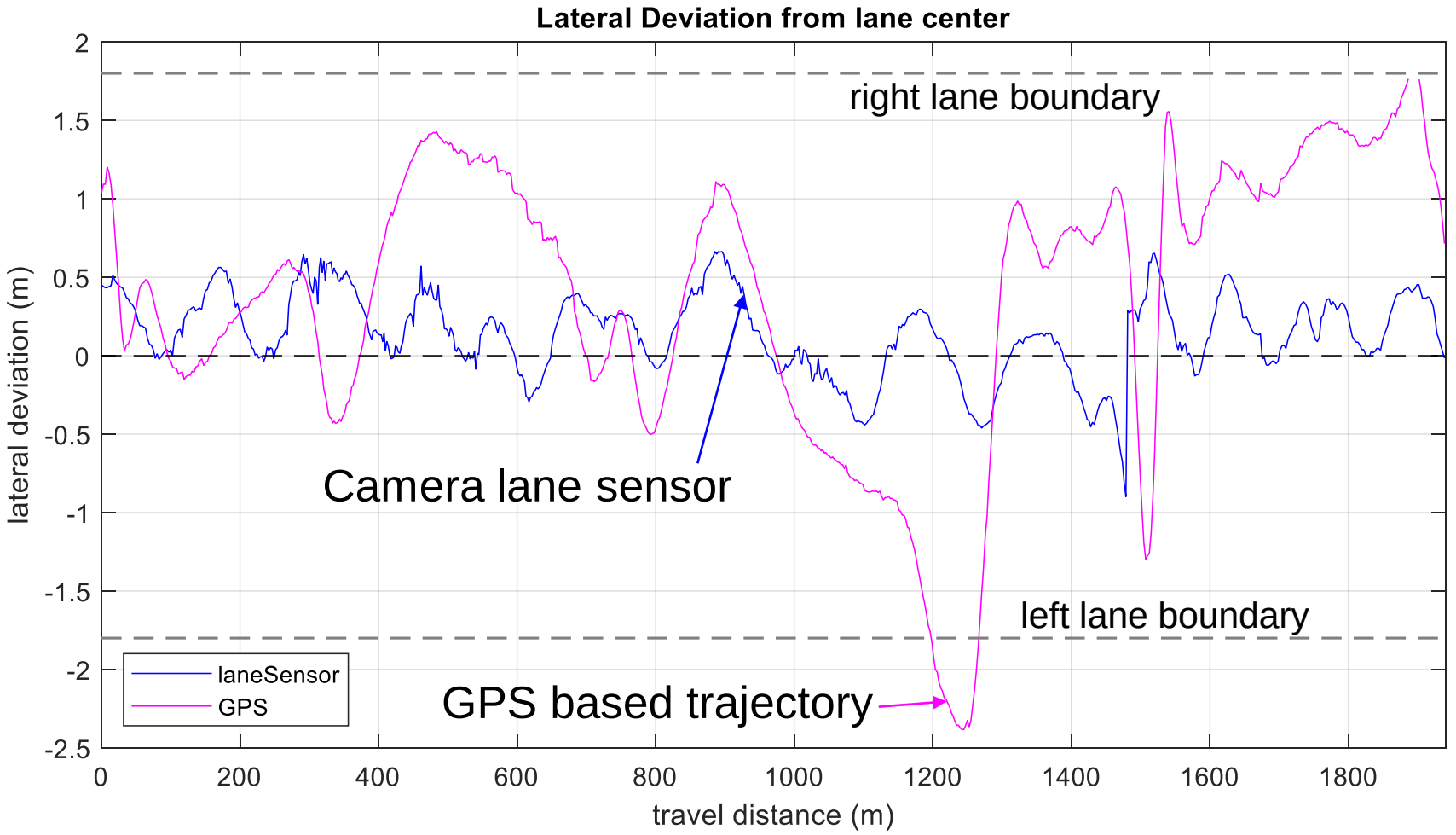
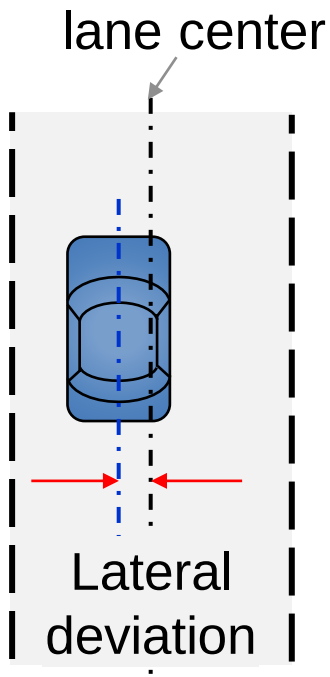
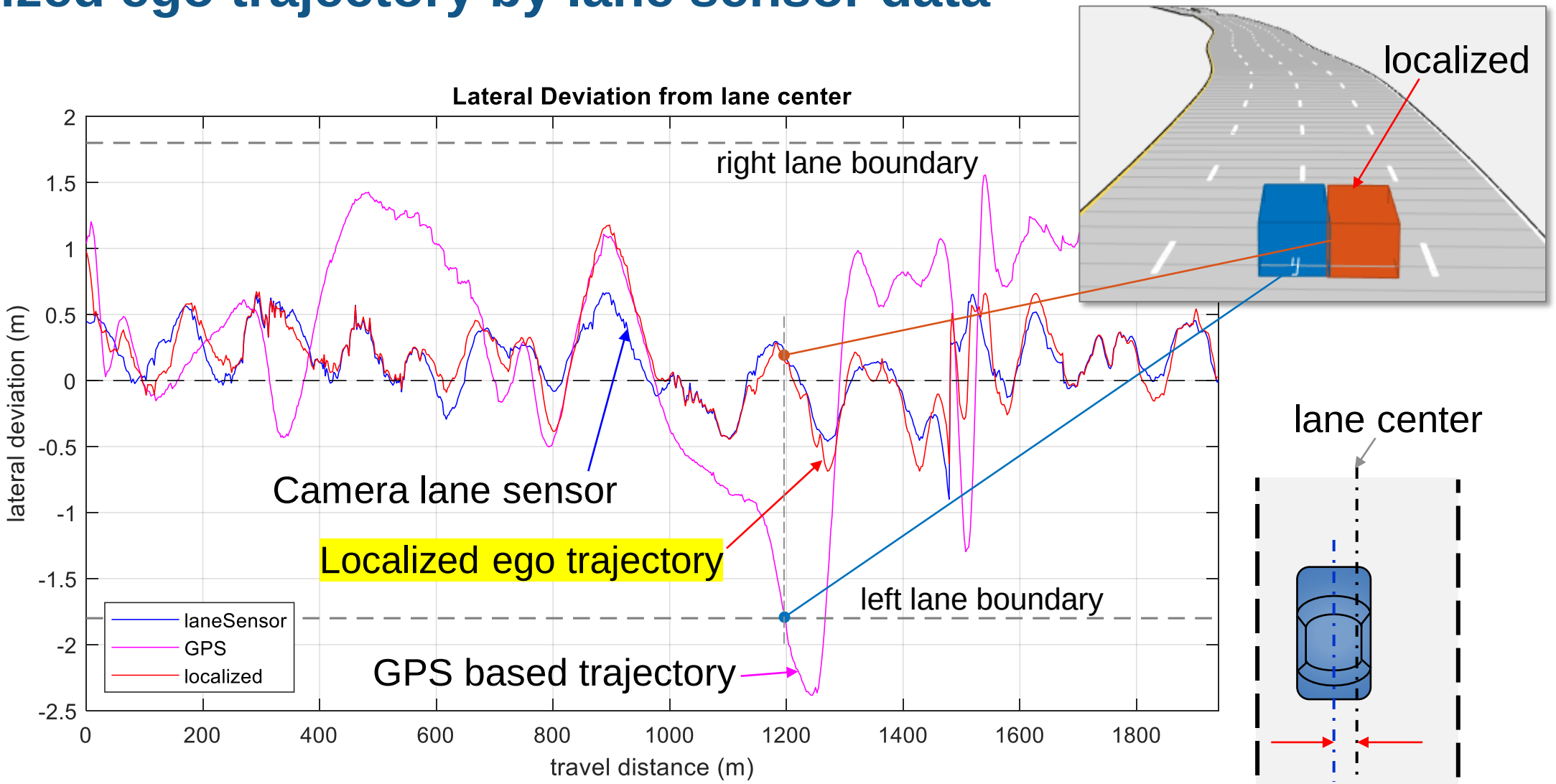


Lateral deviation of ego vehicle from lane center





Localized ego trajectory by lane sensor data



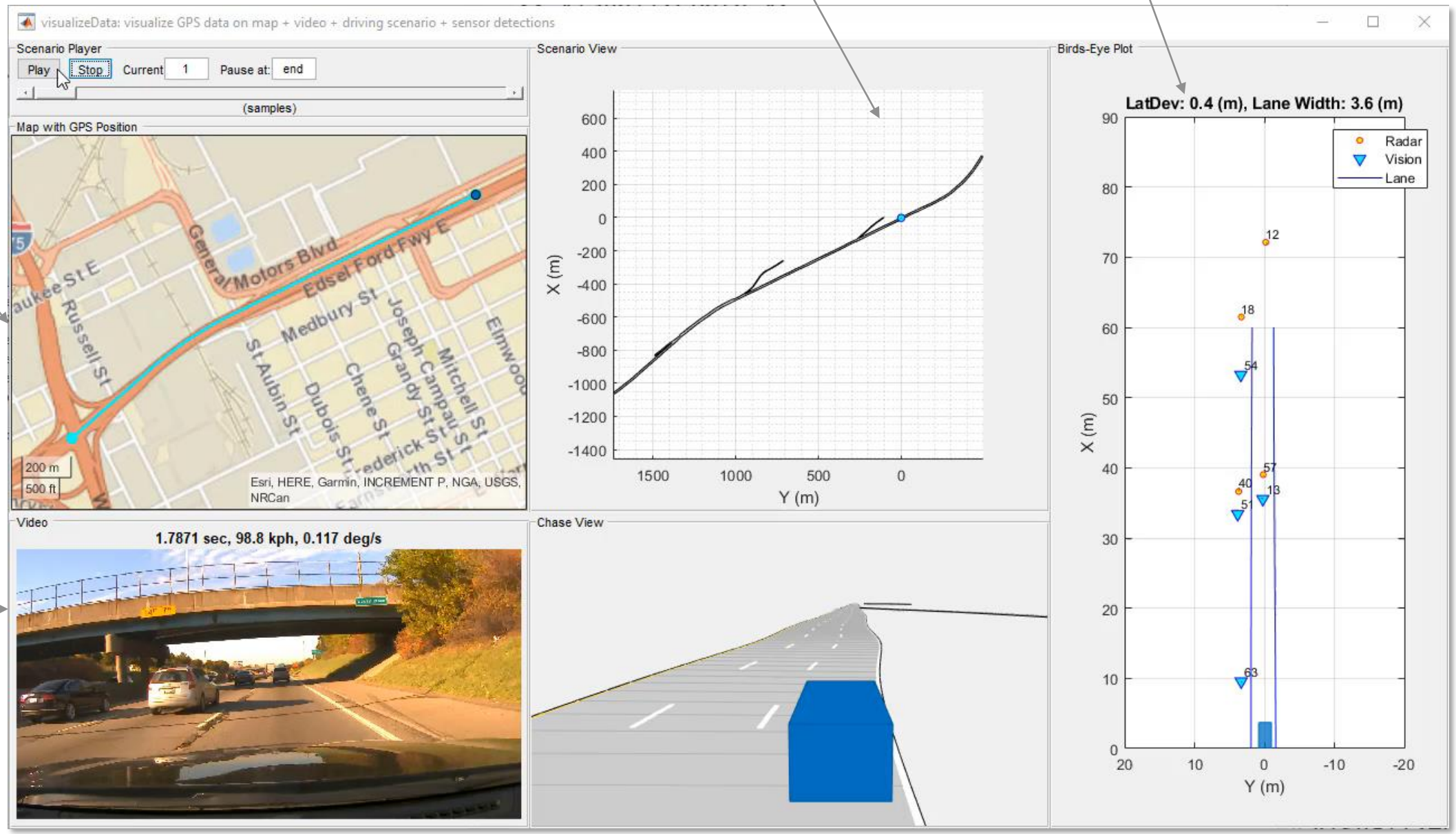
Visualize data

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

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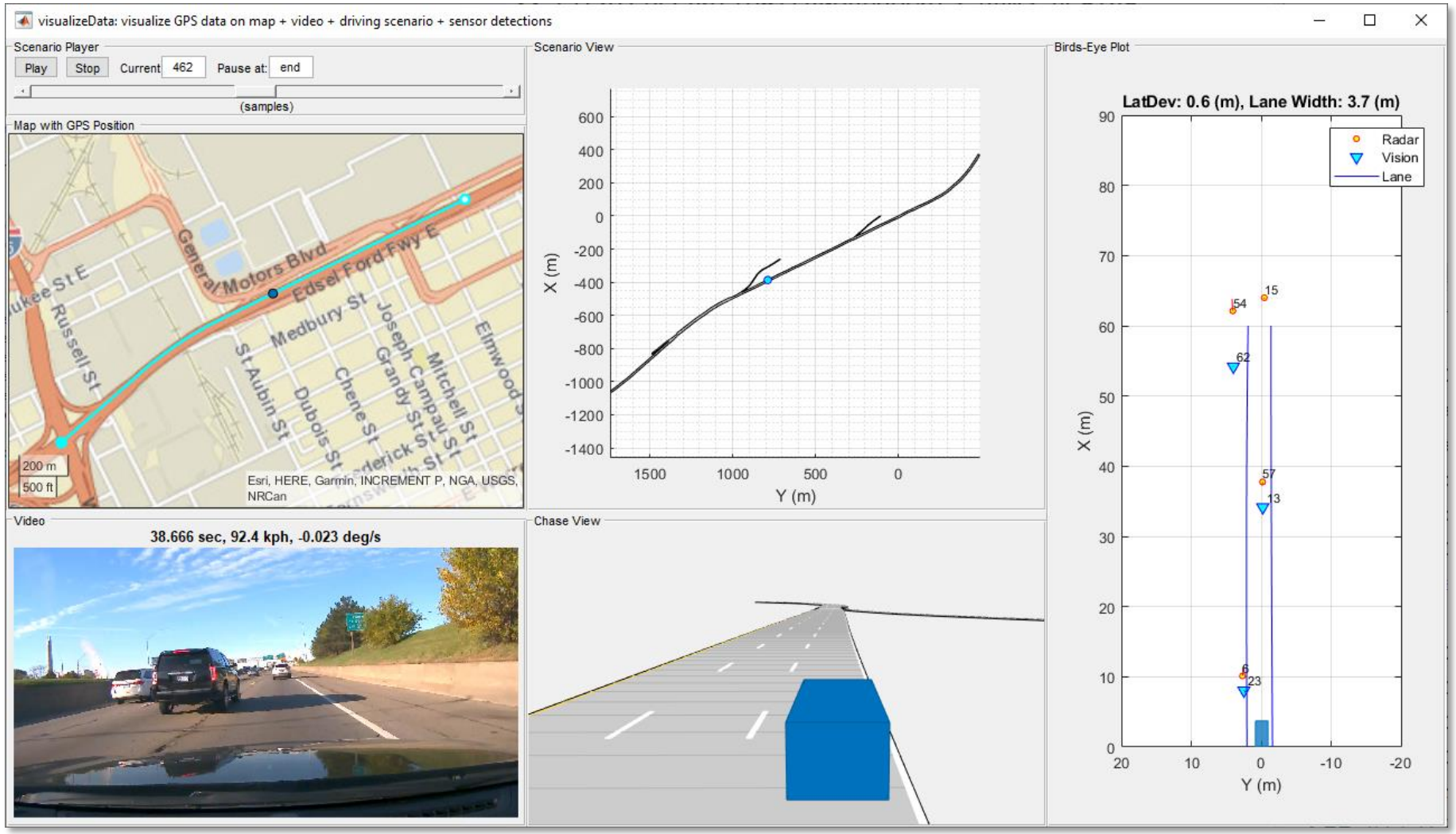

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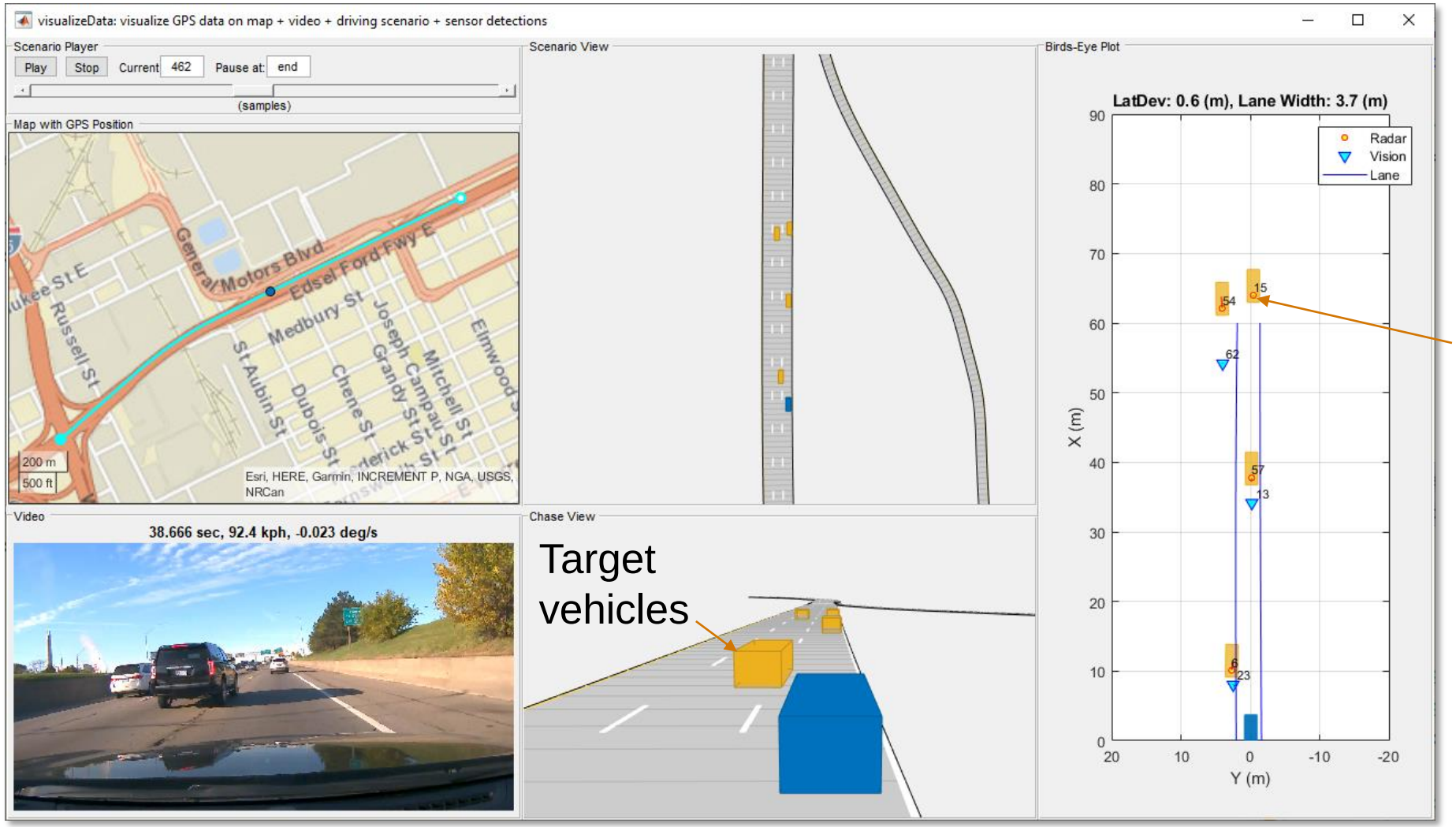


Radar Detections

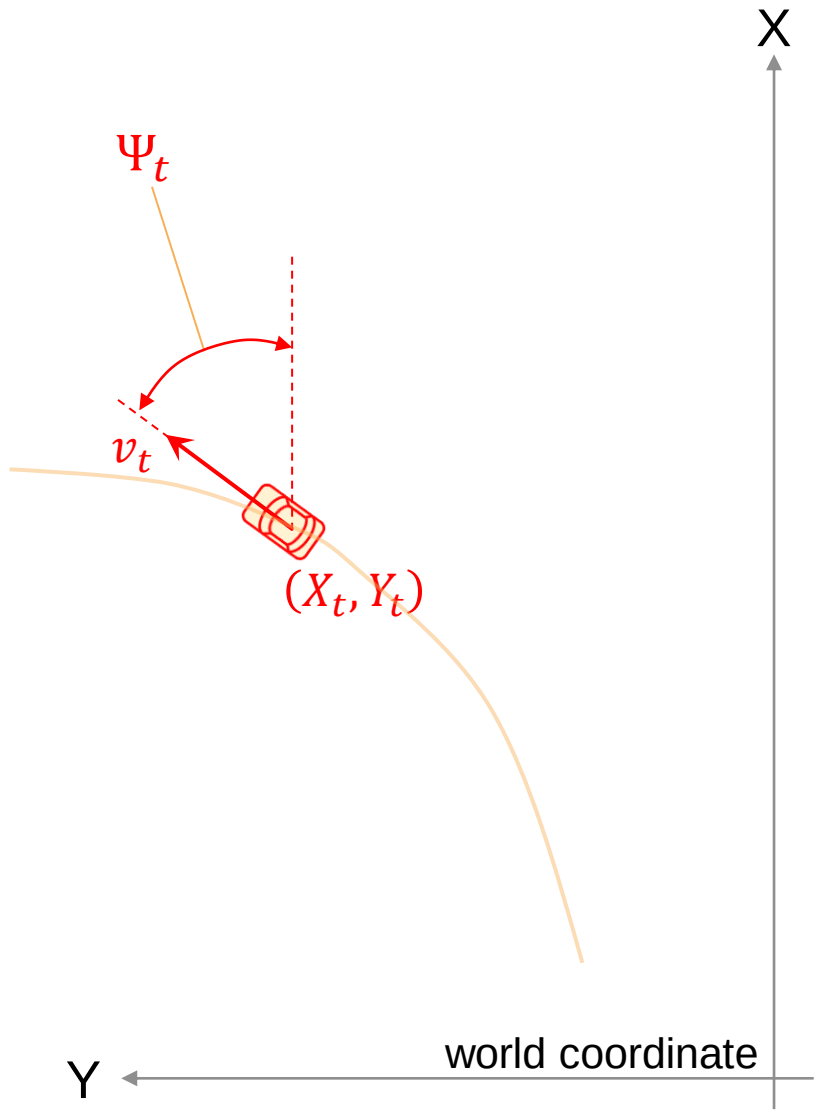
Report targets only in ego and neighbor lanes

Target vehicle trajectory

- Target vehicle trajectory is defined by a series of actor poses

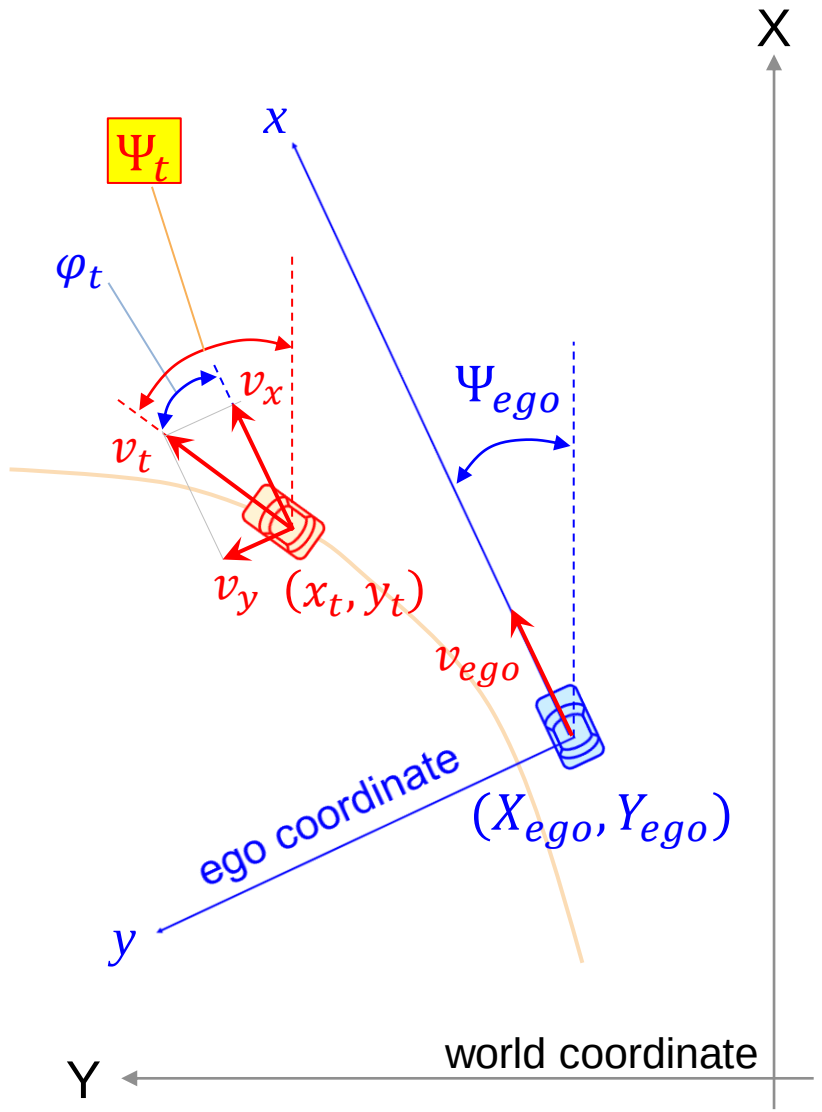
- Actor poses consist of
  - Position (X_t, Y_t)
  - Velocity v_t
  - Orientation Ψ_t

  in world coordinate

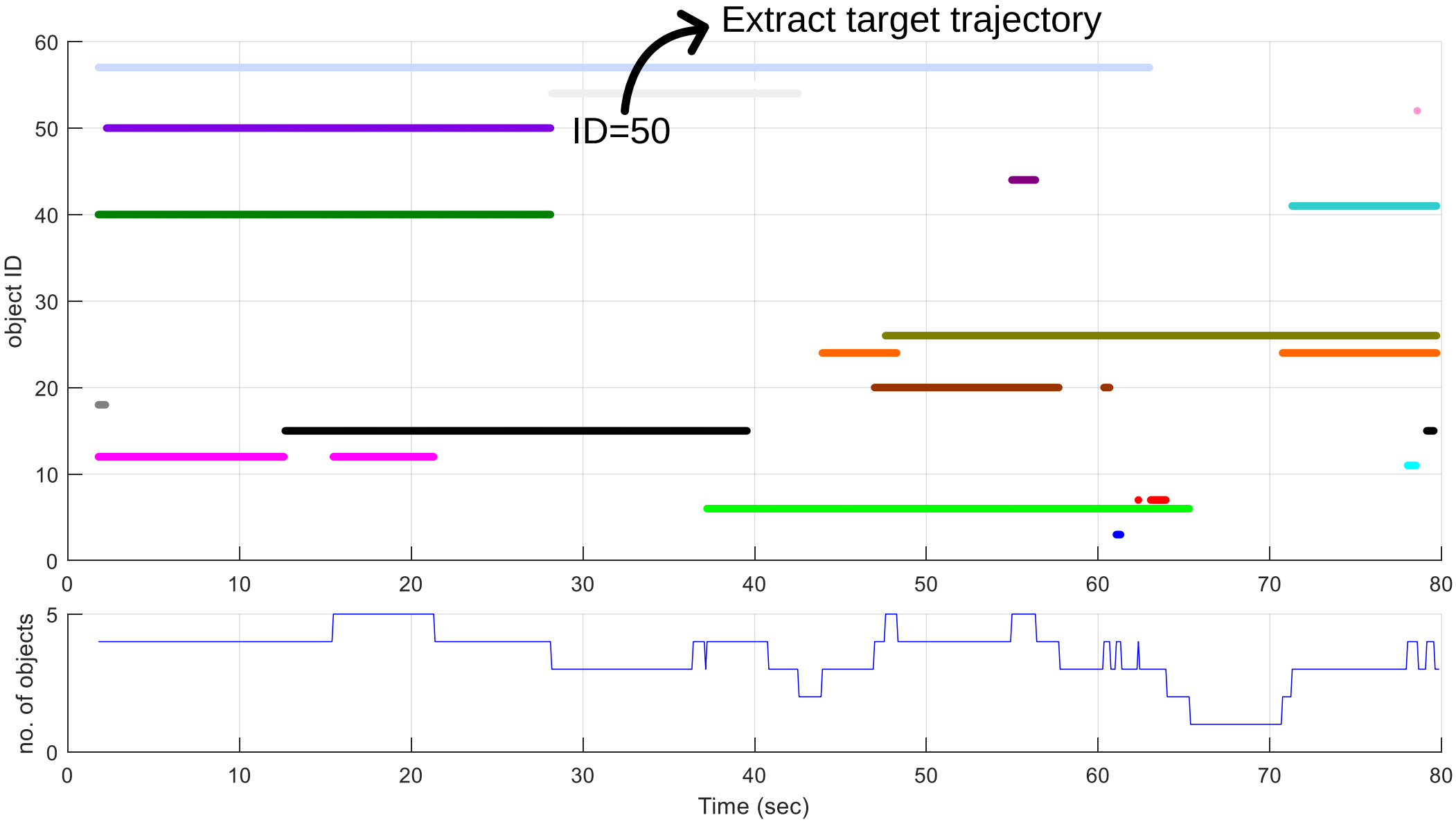


Estimate heading angle of target vehicle

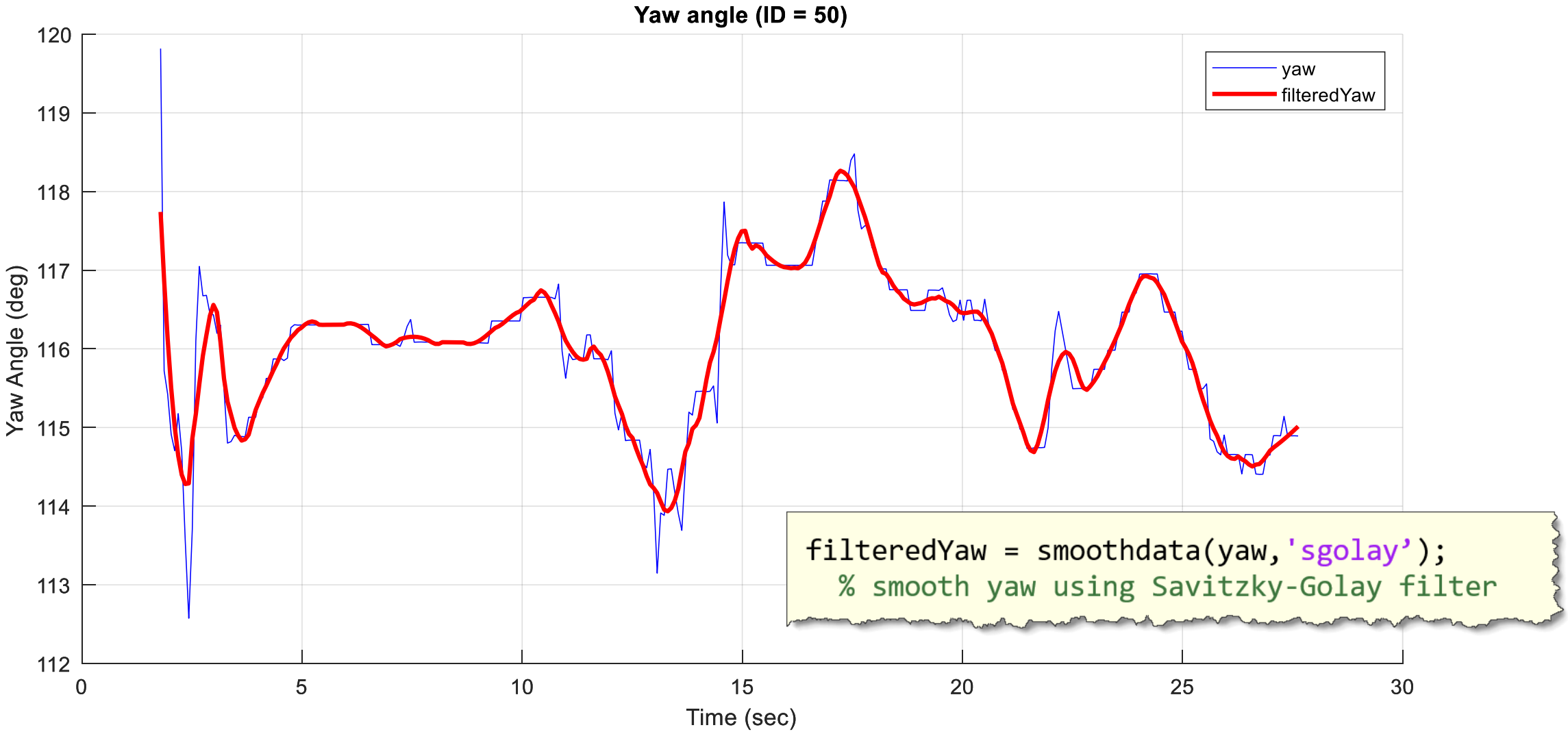
- Radar detections provides target position and velocity in ego coordinate
  - $x_t, y_t, v_x, v_y, (\varphi_t ?) \leftarrow radar\ detections$
- Estimate heading angle of target vehicle
  - Heading angle in ego coordinate
    - $\varphi_t = \tan^{-1}\left(\frac{v_y}{v_x}\right)$
  - Heading angle in 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




```
filteredYaw = smoothdata(yaw,'sgolay');
  % smooth yaw using Savitzky-Golay filter
```

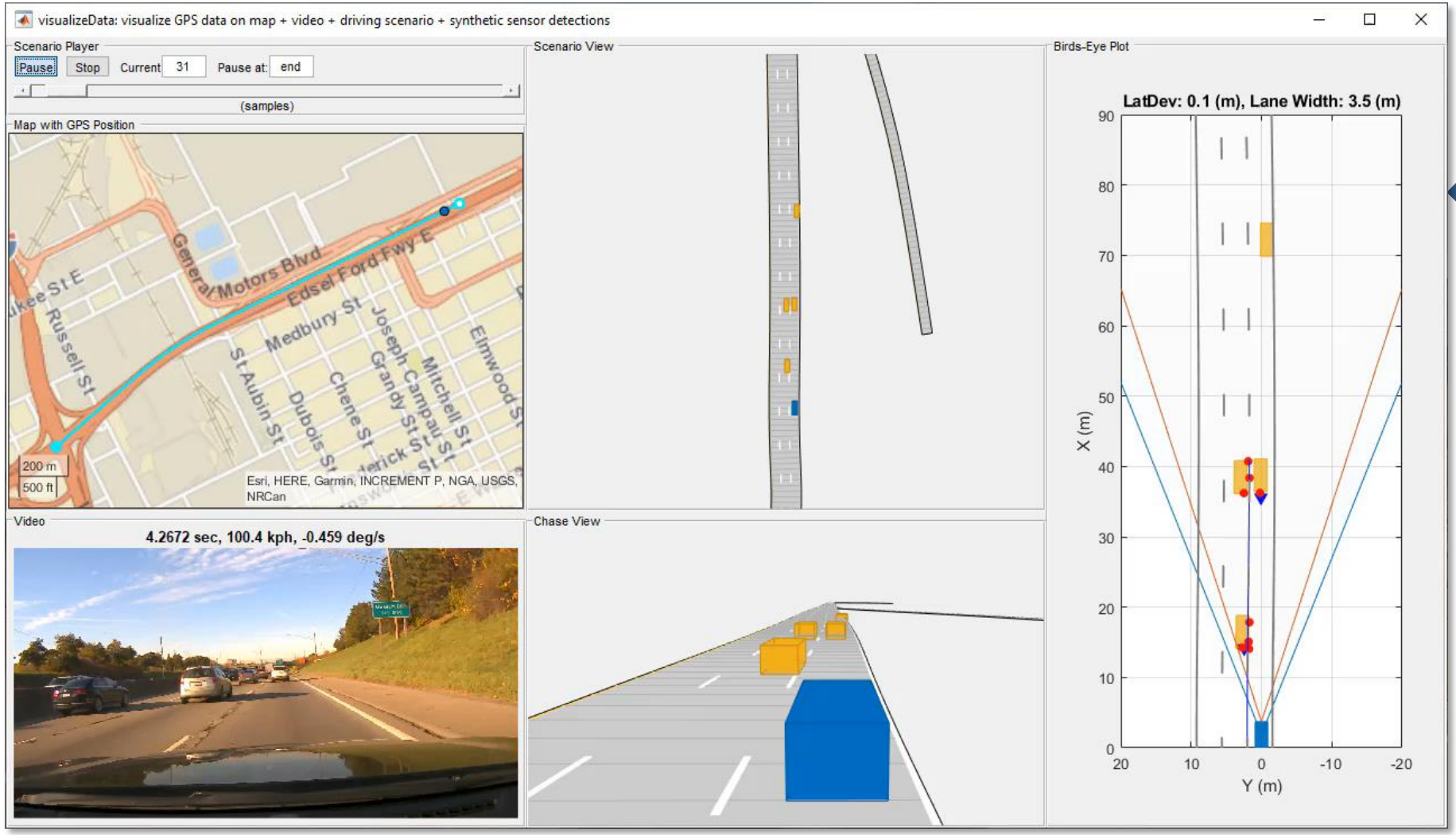
Create virtual driving scenario from recorded data

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

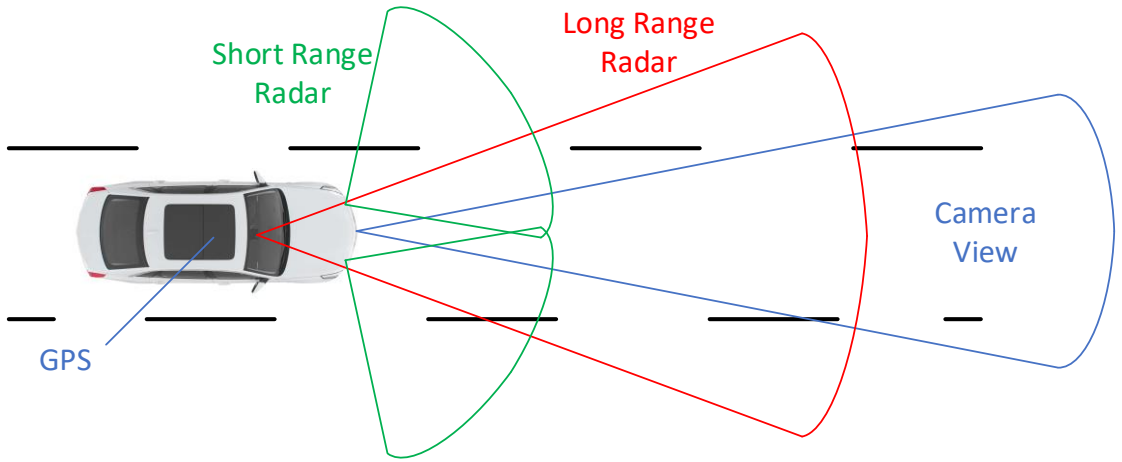
Record and select data → Reconstruct road network → Localize ego trajectory → Reconstruct target vehicles → Compare with recorded video → Synthesize sensors

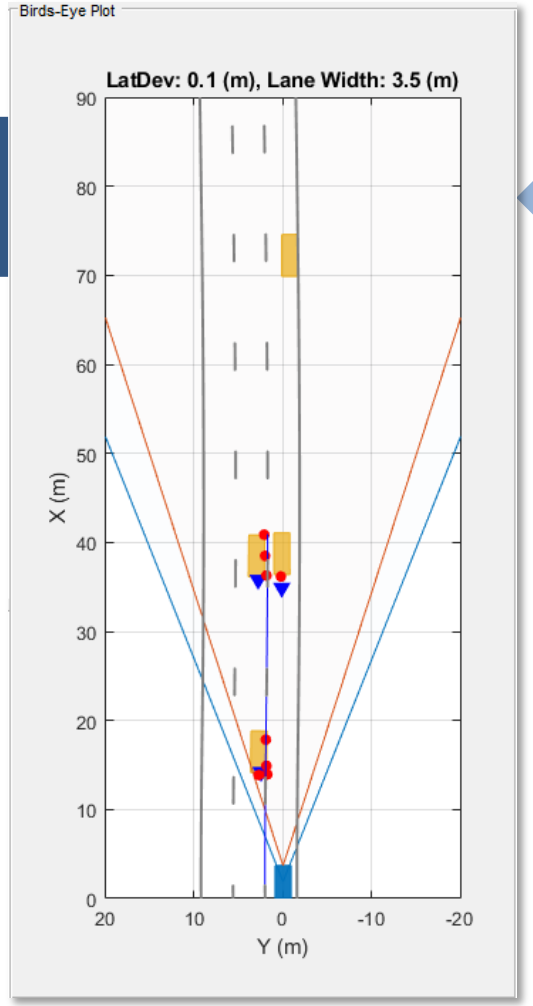


Integrate driving scenario + sensors with a close-loop system

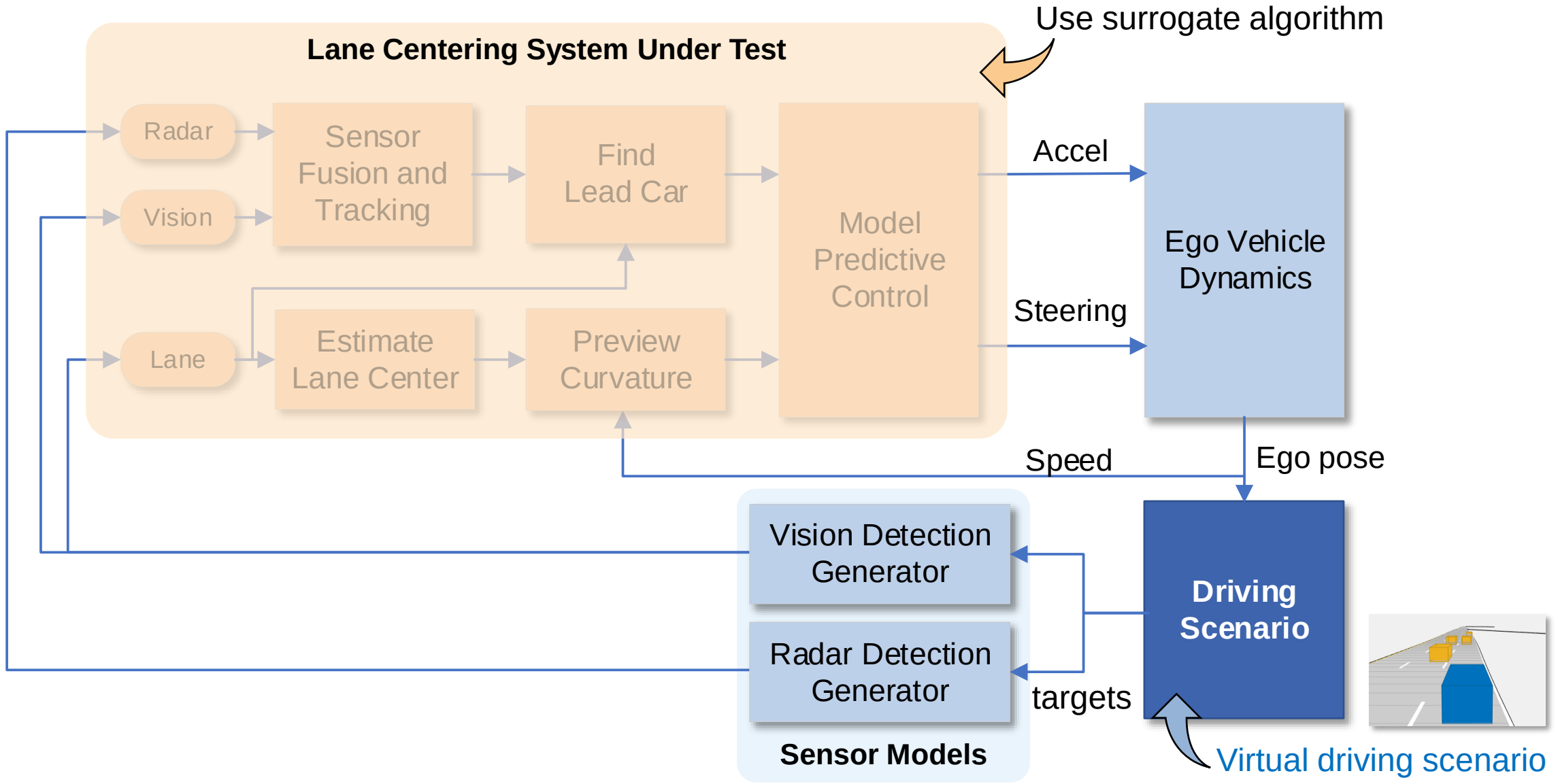
Record and select data → Reconstruct road network → Localize ego trajectory → Reconstruct target vehicles → Compare with recorded video → Synthesize sensors

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

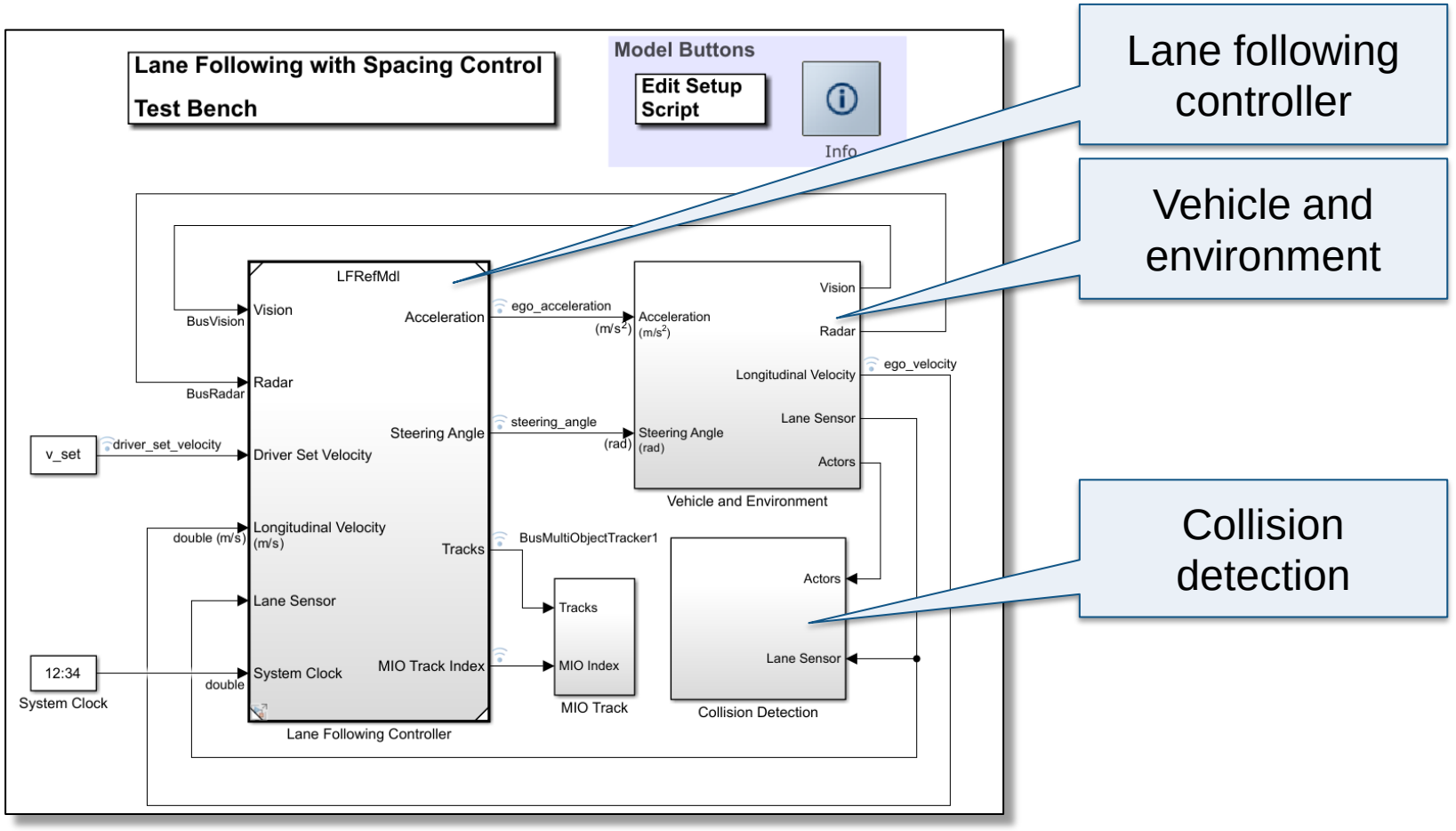




Closed-loop system for lane centering



Surrogate closed-loop system for lane centering



Lane following controller

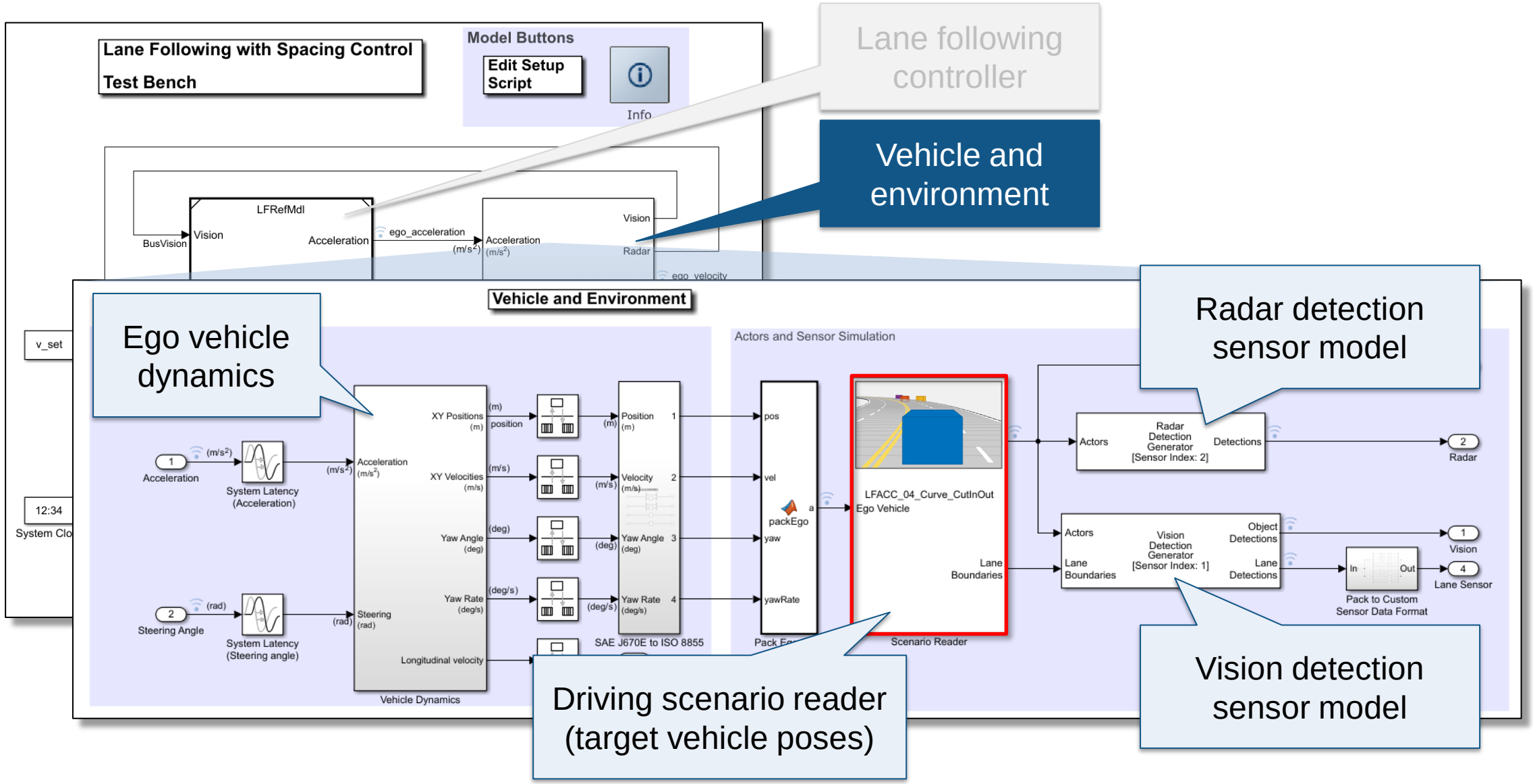
Vehicle and environment

Collision detection

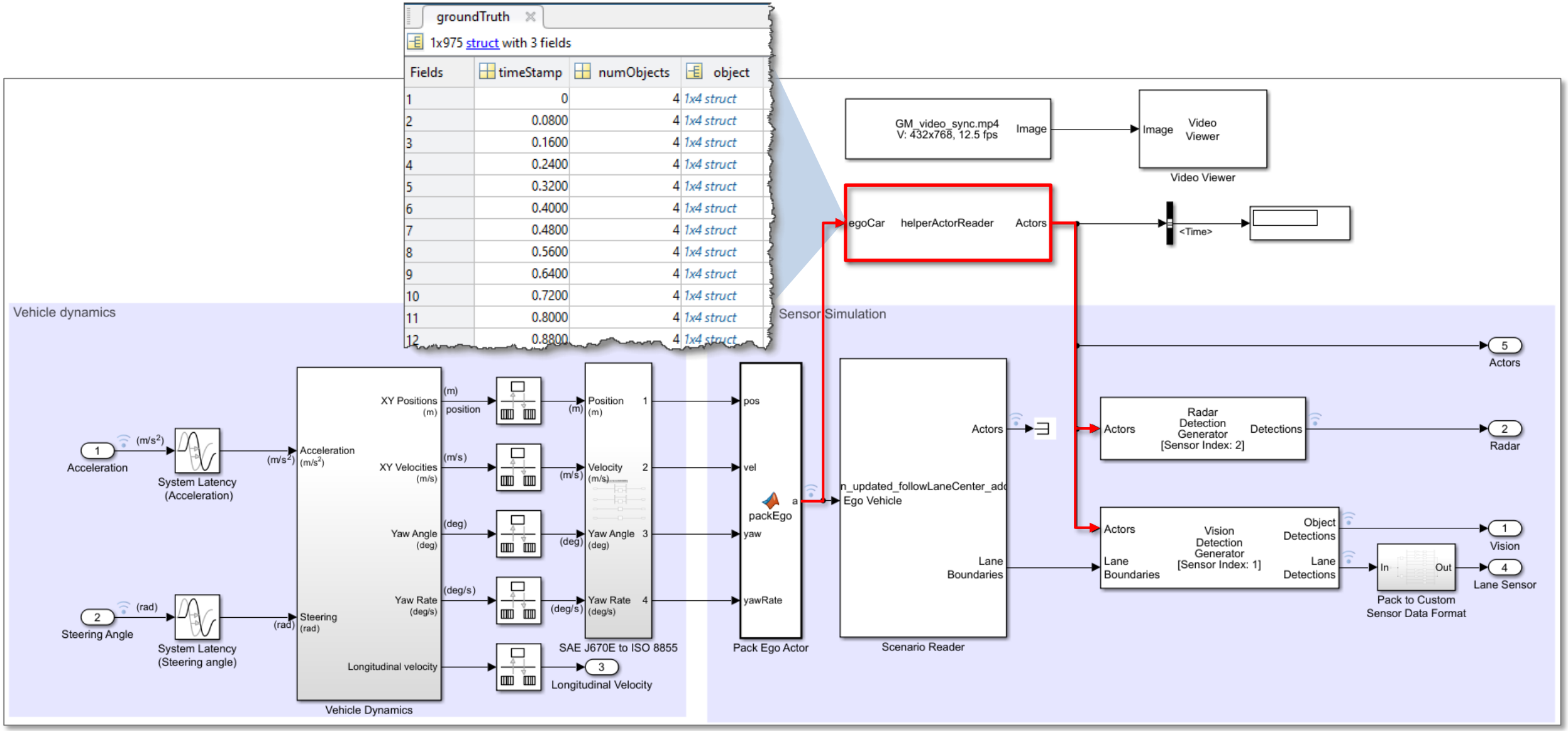
[Lane Following Control with Sensor Fusion and Lane Detection](#)

Automated Driving Toolbox™

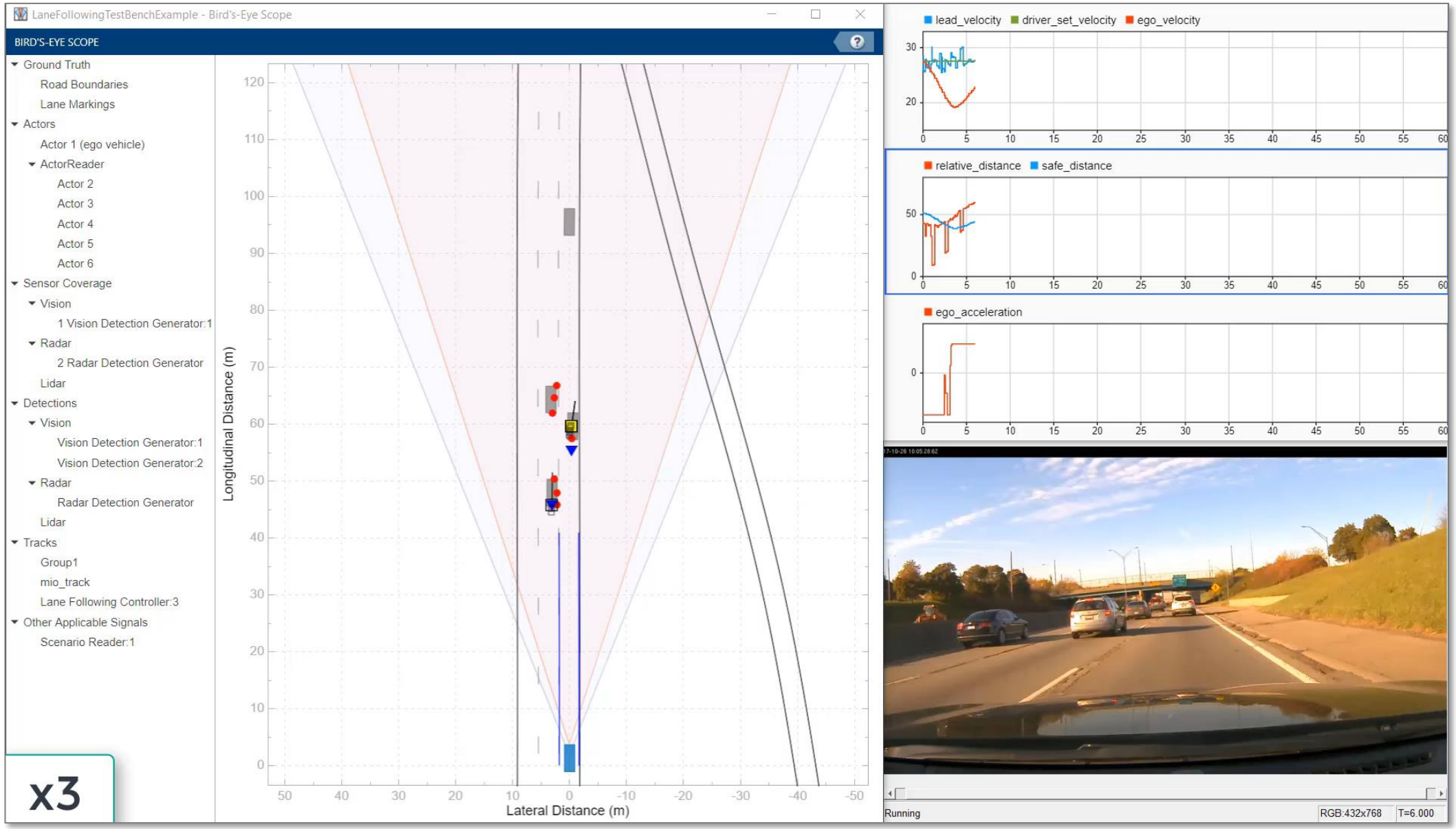
Surrogate closed-loop system for lane centering



Lane centering test bench with recorded target vehicles

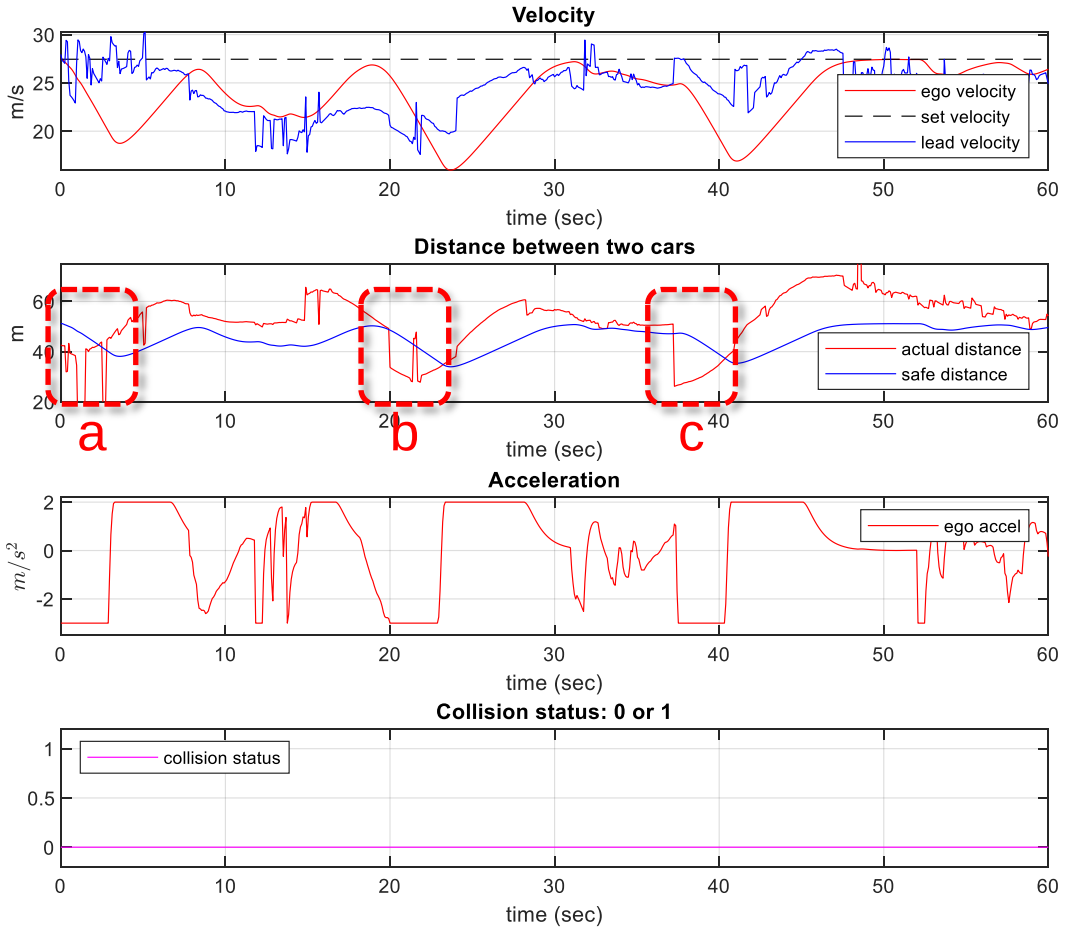


Closed-loop simulation using reconstructed virtual driving scenario

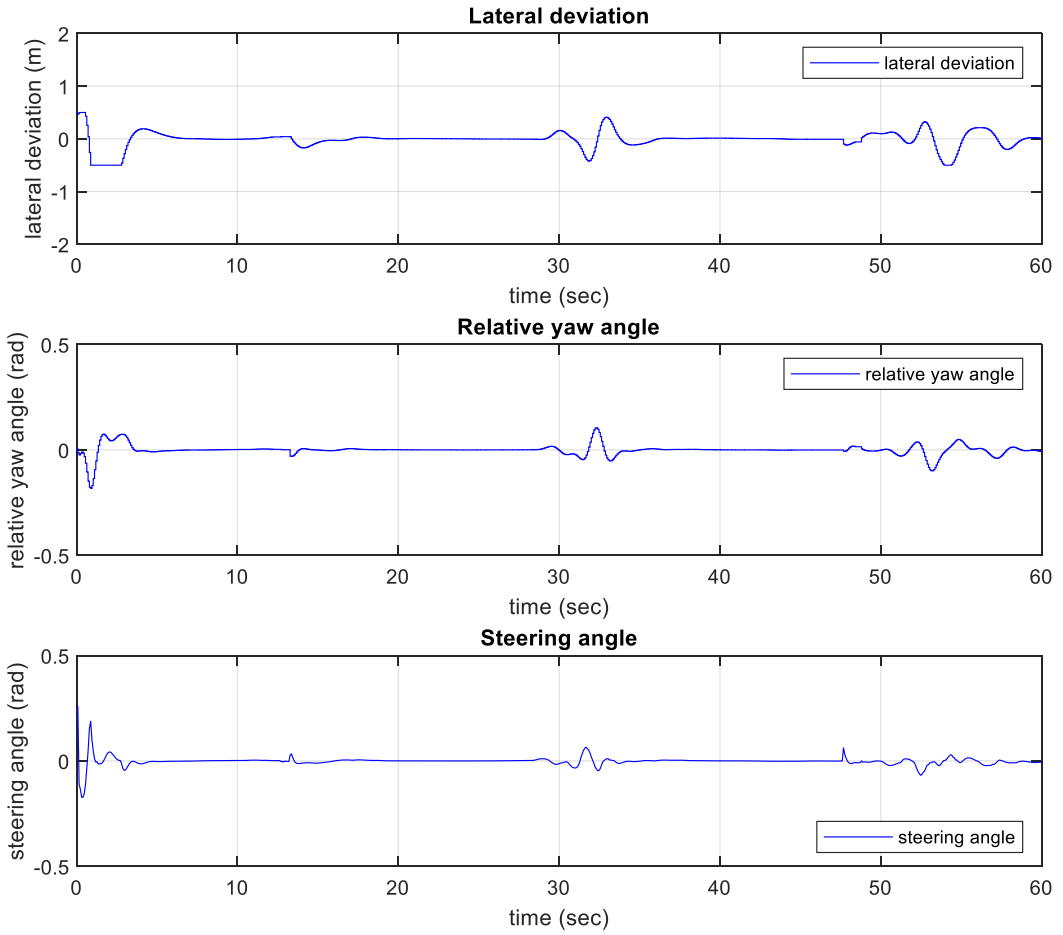


Simulation result (longitudinal & lateral control performance)

longitudinal control performance



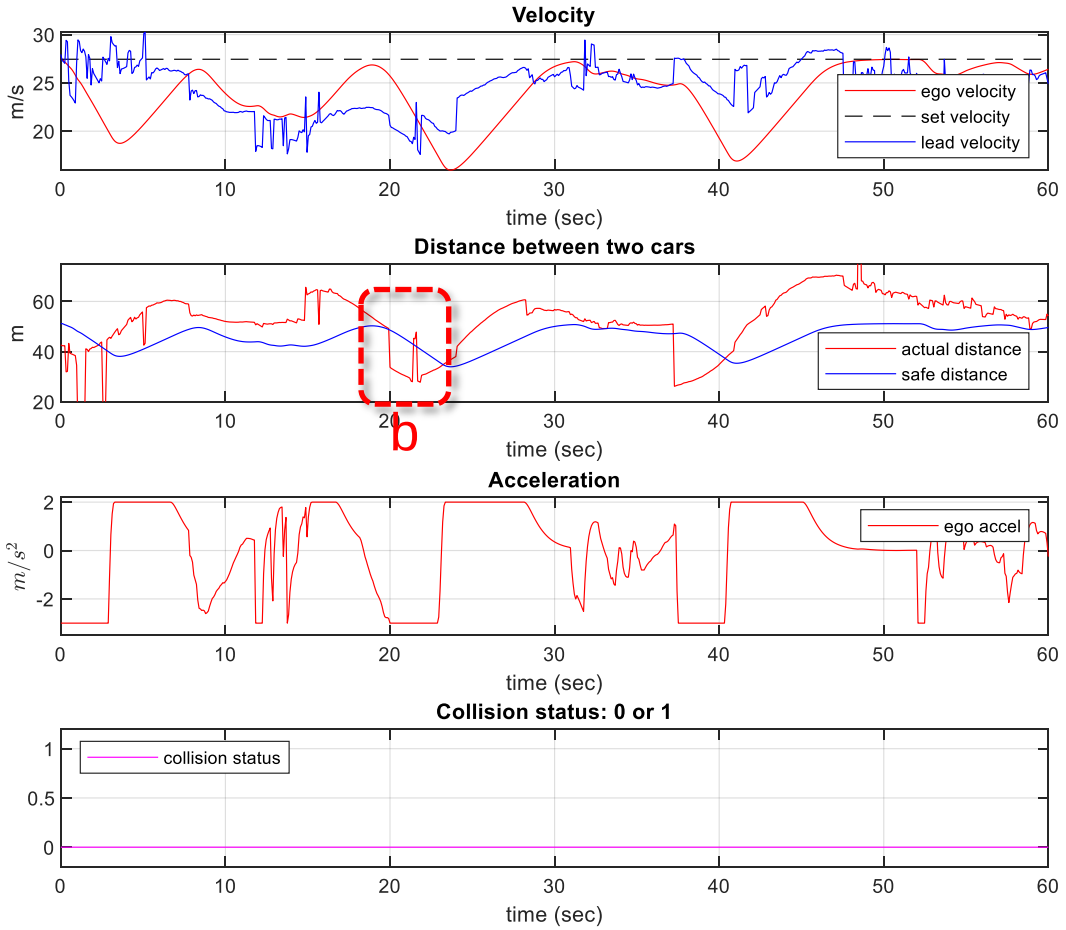
lateral control performance

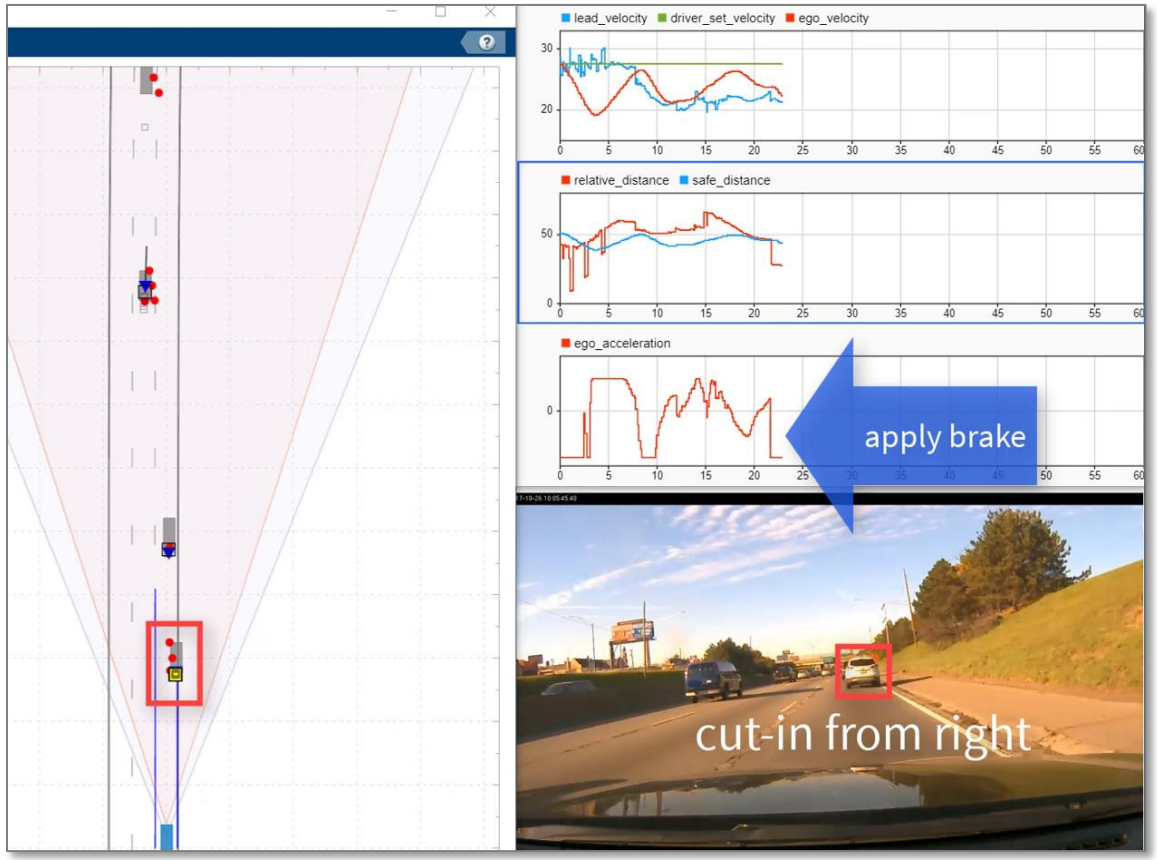


a,b,c : problem cases where headway distance drops below the safe distance.

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

longitudinal control performance

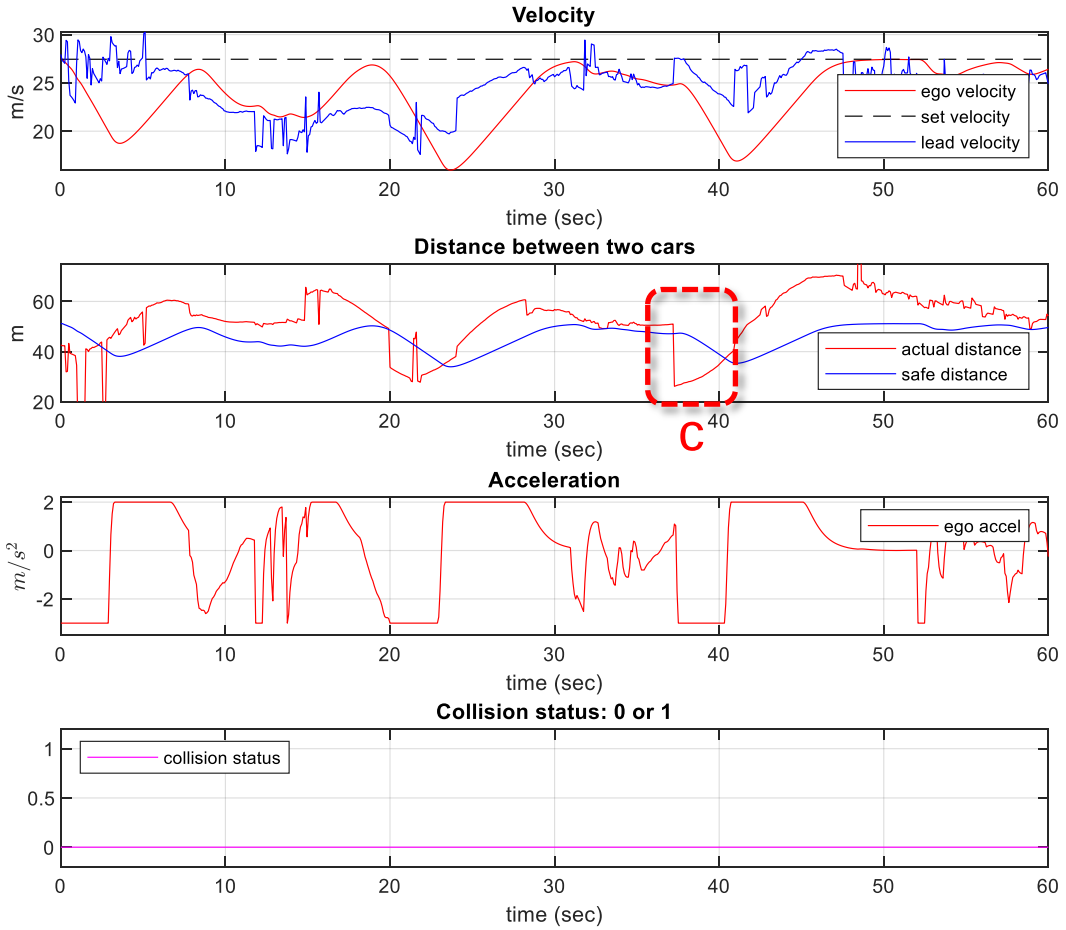


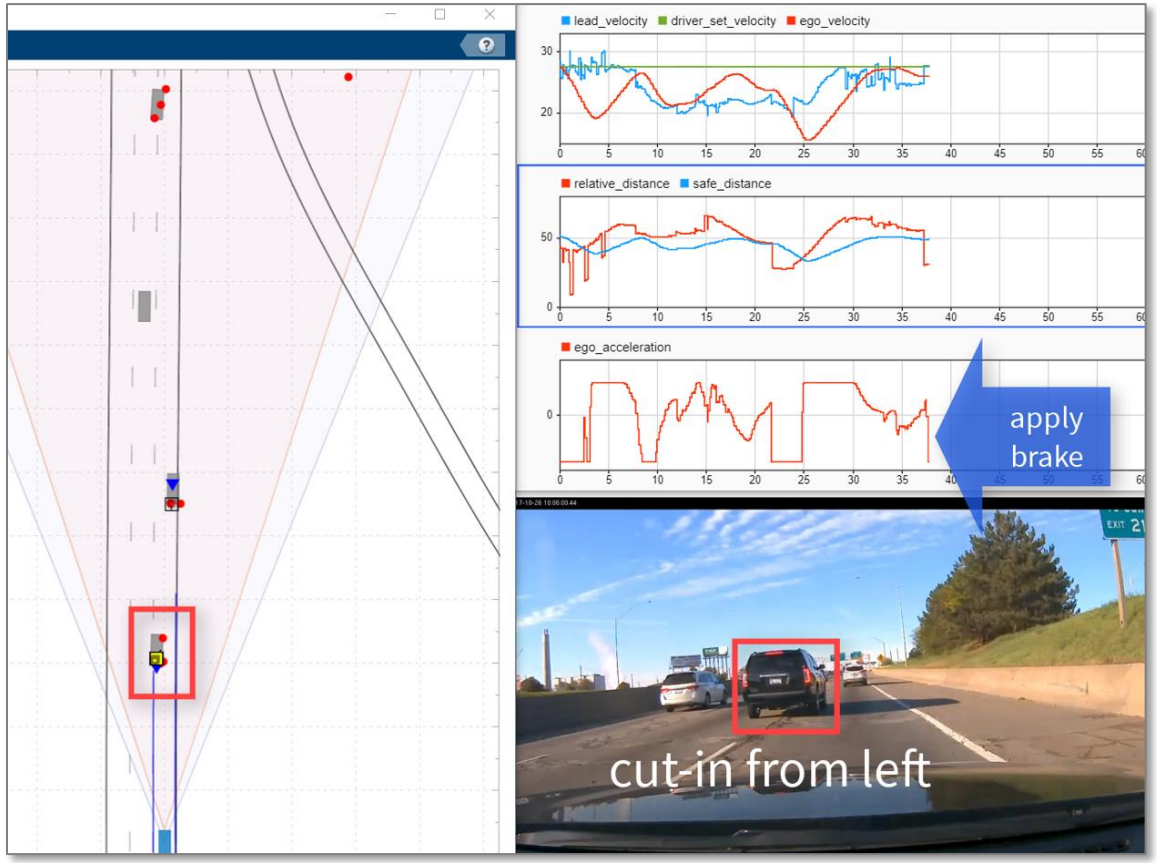


a,b,c : problem cases where headway distance drops below the safe distance.

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

longitudinal control performance

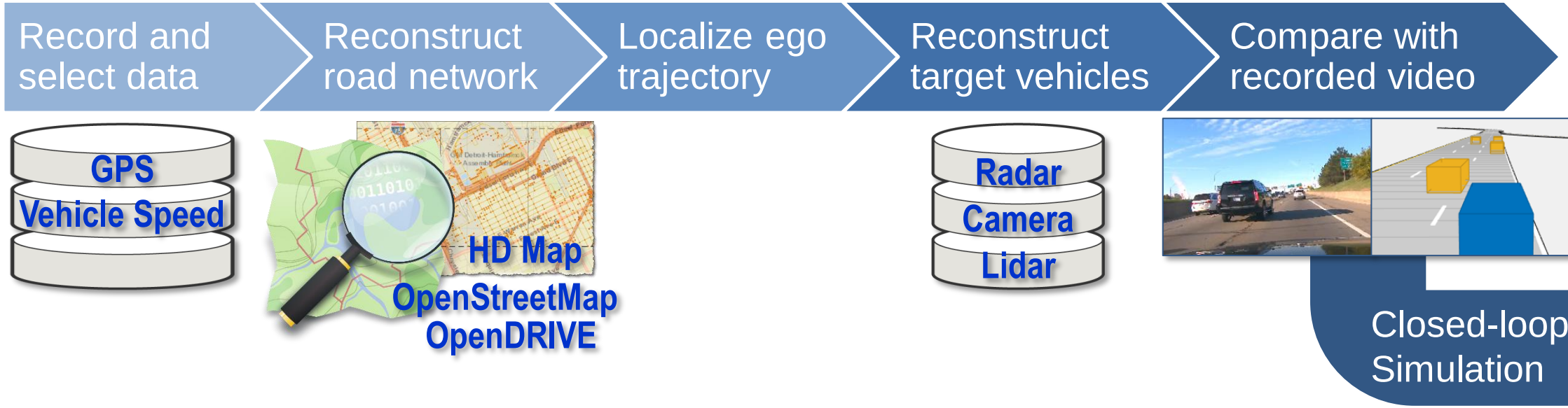




a,b,c : problem cases where headway distance drops below the safe distance.

Conclusion

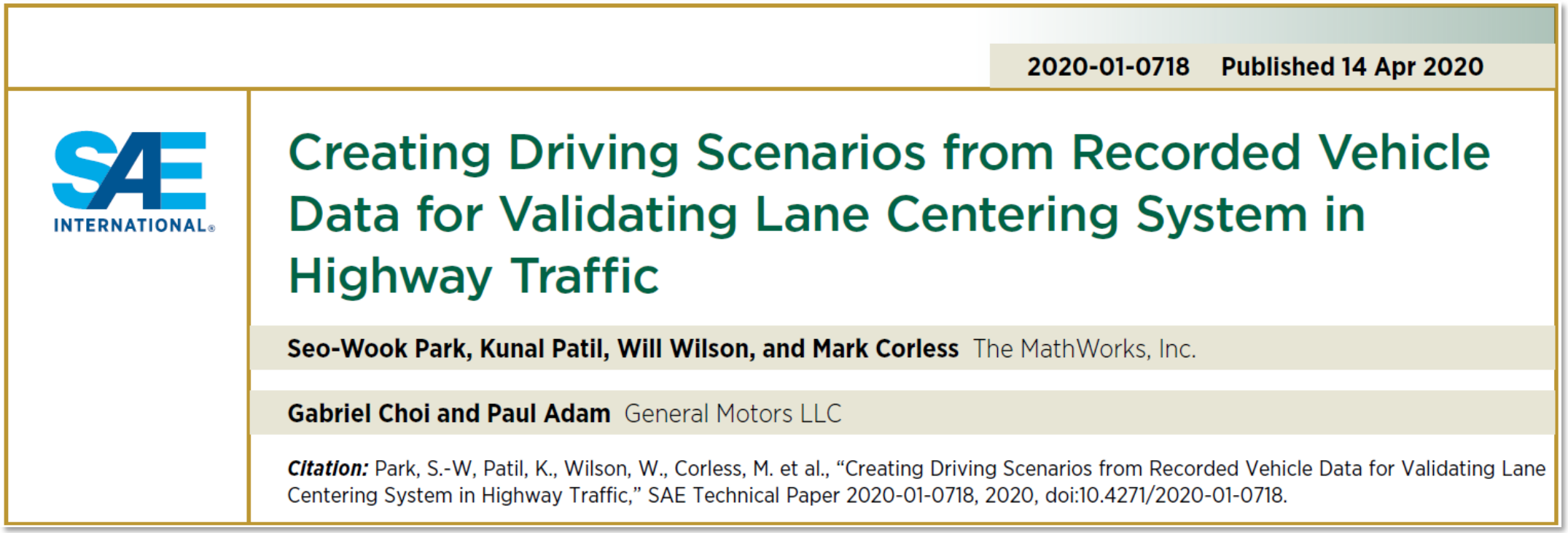
- Created virtual driving scenario from recorded data



- 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.



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Gabriel Choi and Paul Adam General Motors LLC

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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.