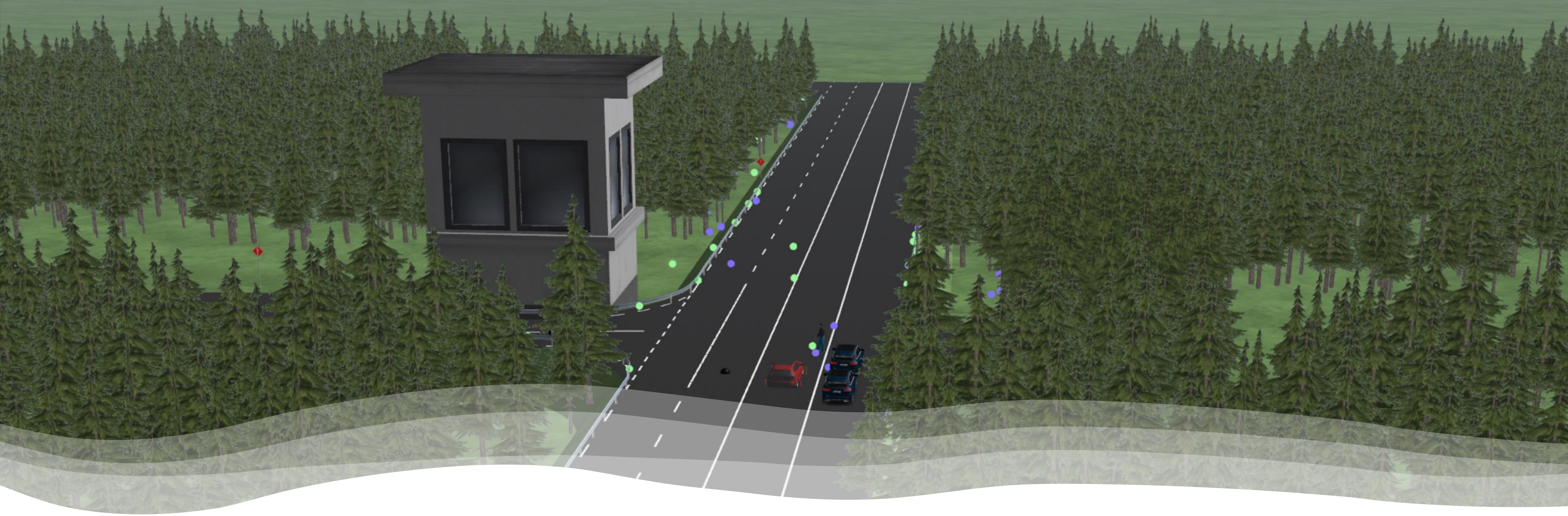

Digital Twin-Based Simulated Automotive Radar for Virtual Testing

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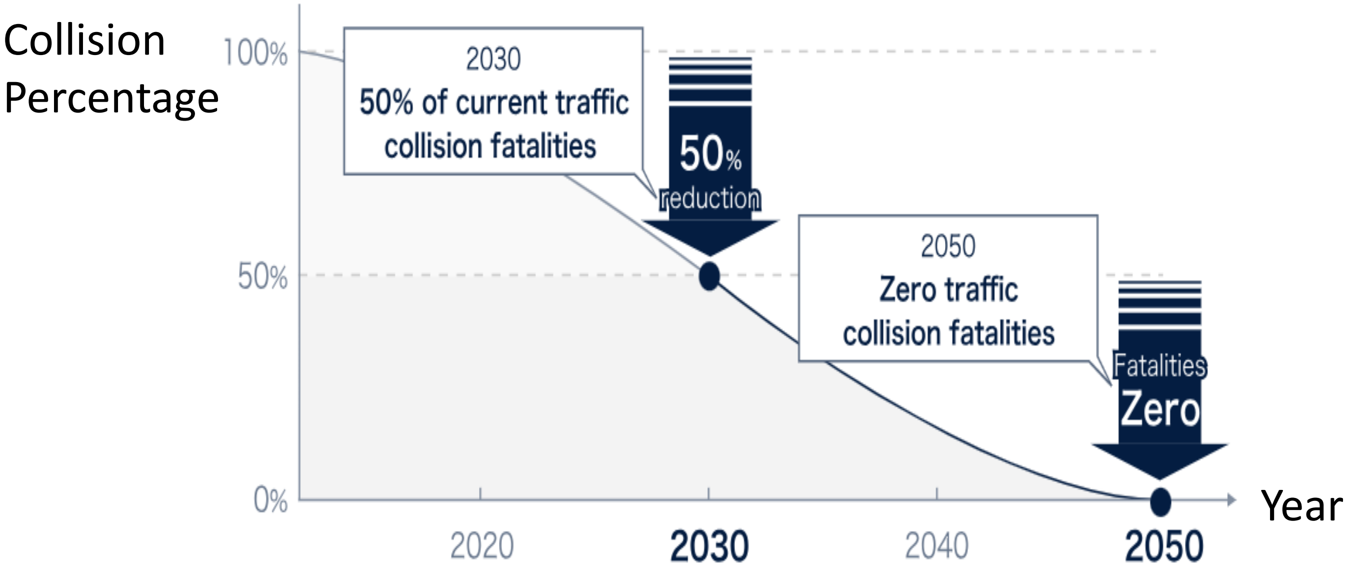
APTIV
CHALMERS UNIVERSITY OF TECHNOLOGY

This research was conducted under the EVIDENT project with funding from Vinnova.

INTRODUCTION

- Motivation



Vision Zero (EU)

"Almost every real situation will sooner or later be modeled"

- Aim

  'To what extent can simulation and virtual testing replace real-world testing?'

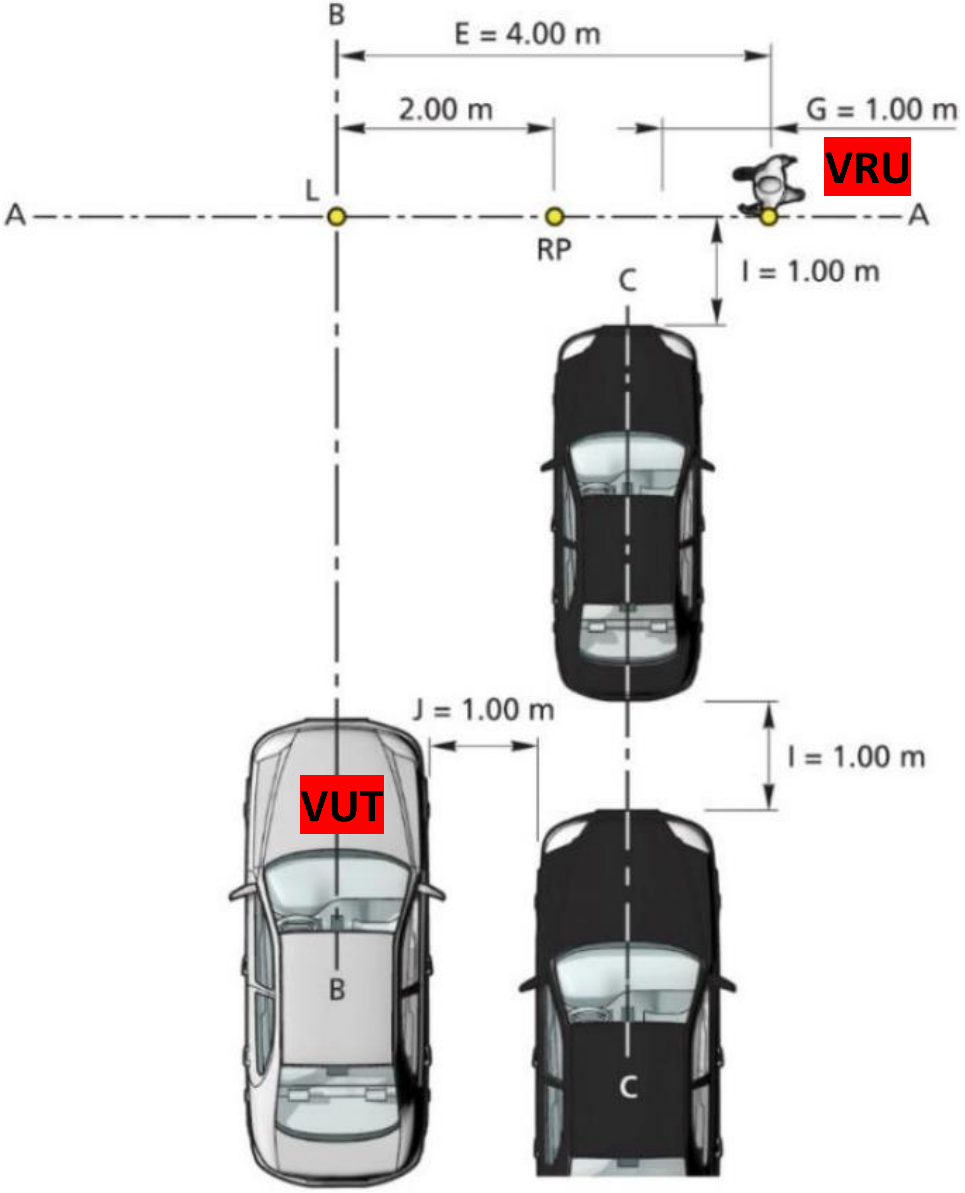
- EVIDENT Project Partners

AstaZero
University of Gothenburg
Chalmers University of Technology
RI.SE
APTIV
vti
einride
Asymptotic
ZEEKR

Scenario

<u>Euro NCAP: Car-to-Pedestrian Nearside Adult (CPNA)</u>

- AA - Trajectory of Pedestrian Dummy
- BB - Centerline of Vehicle Under Test (VUT)
- CC - Centerline of Obstruction Vehicles
- G - Acceleration Distance of Pedestrian Dummy
- I - Distance of Pedestrian Dummy to Front of Obstruction Vehicle
- J - Distance Between VUT and Obstruction Vehicle
- L - Impact position
- RP - Reference Point



Scenario

AEB not active

AEB active

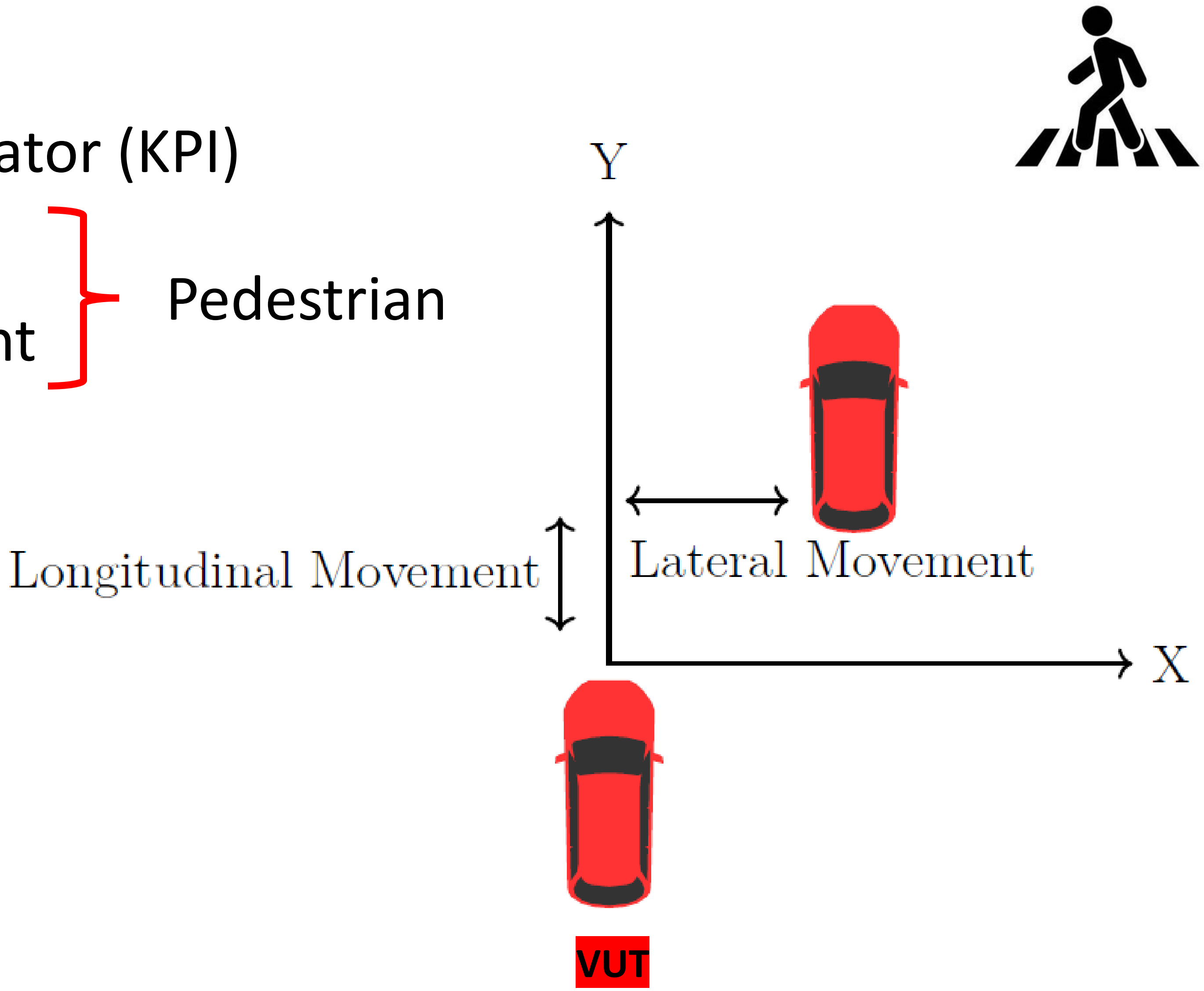
TEST CASE

Case Number	Host Speed	Pedestrian Model	Collision Point
1	15 km/h	Adult	50%
2	15 km/h	Child	50%
3	30 km/h	Adult	50%
4	30 km/h	Child	50%

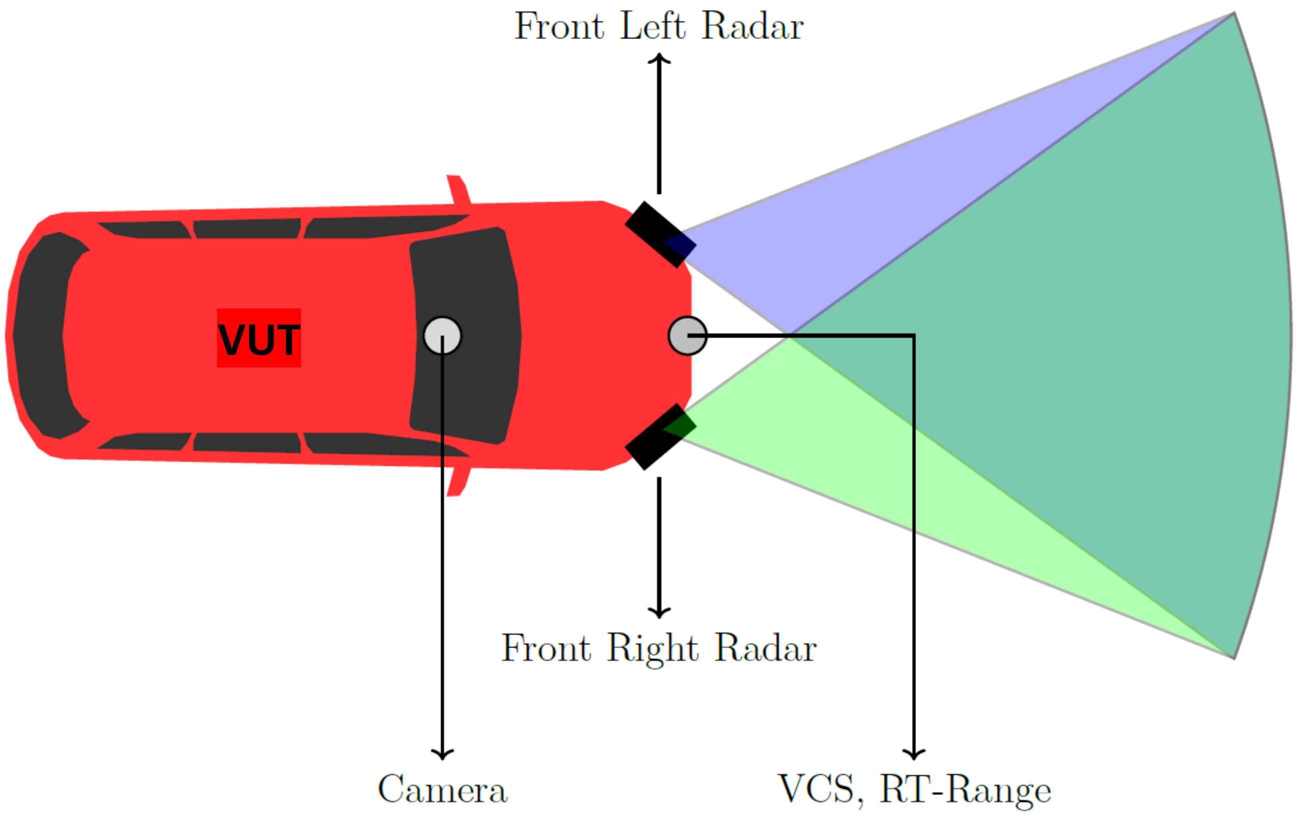
MOTION MODEL

- Key Performance Indicator (KPI)

  Lateral Movement
  Longitudinal Movement
  } Pedestrian



EQUIPMENT



- Ground Truth Data

GPS information of VUT, VRU

Input data for simulations

Reference data

- Experimental Data

VUT and Sensor

- Simulation Data

VUT, VRU, and Sensor

DIGITAL TWIN

- "Virtual Replica"
- Fidelity Level

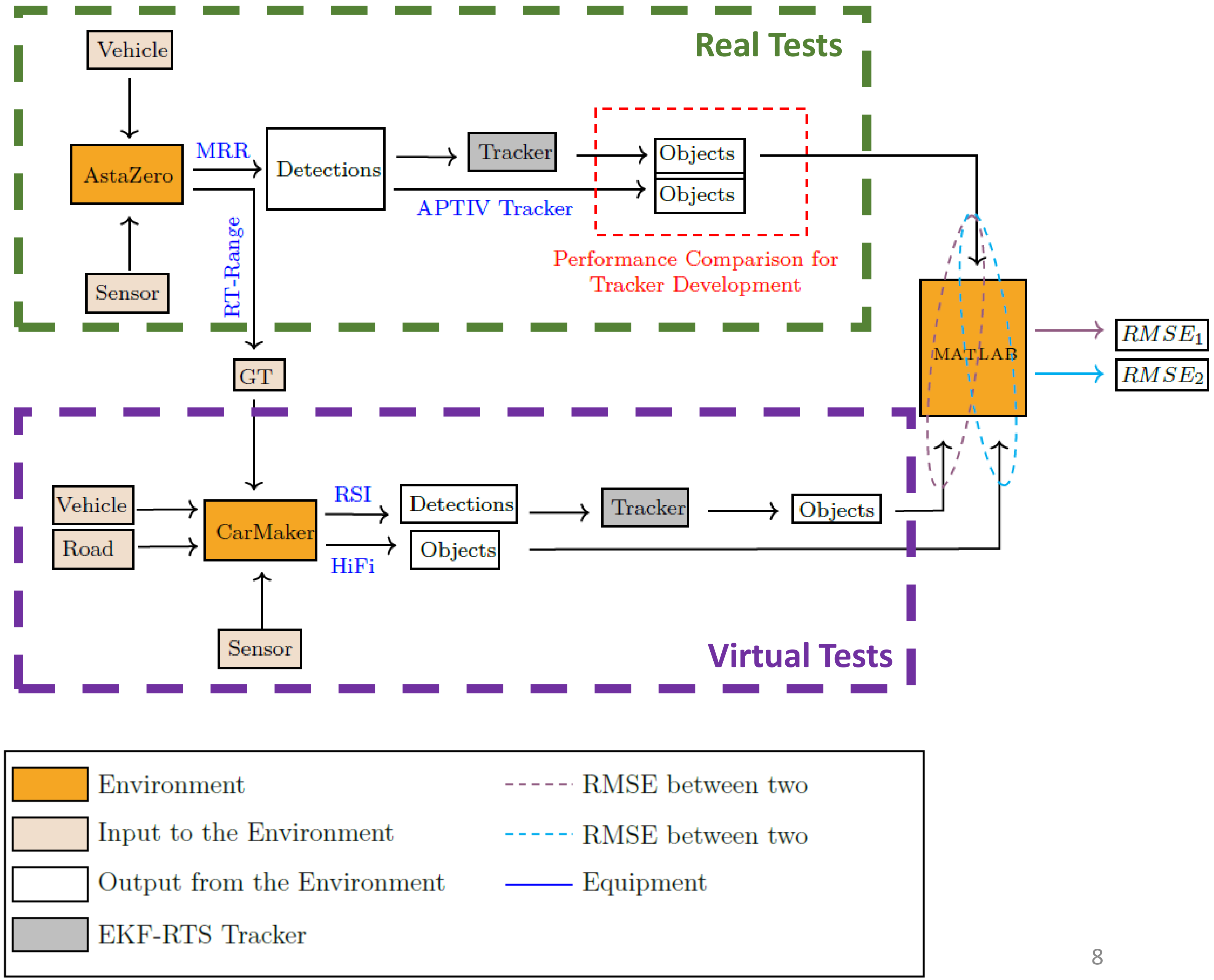
- <u>Advantages</u>

  Iterative design

  Various scenarios

  Easy prototyping

  Decreased costs



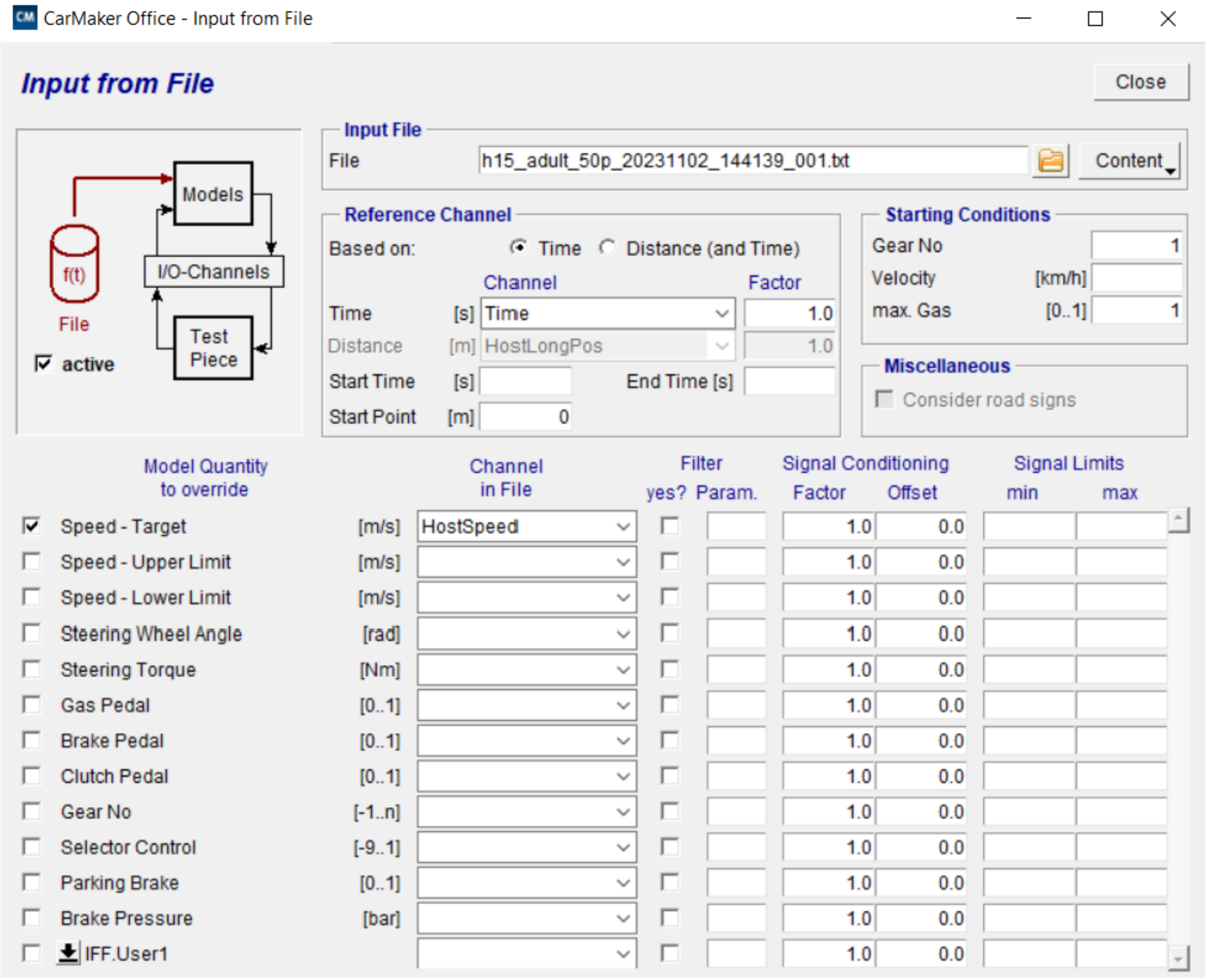
METHODS

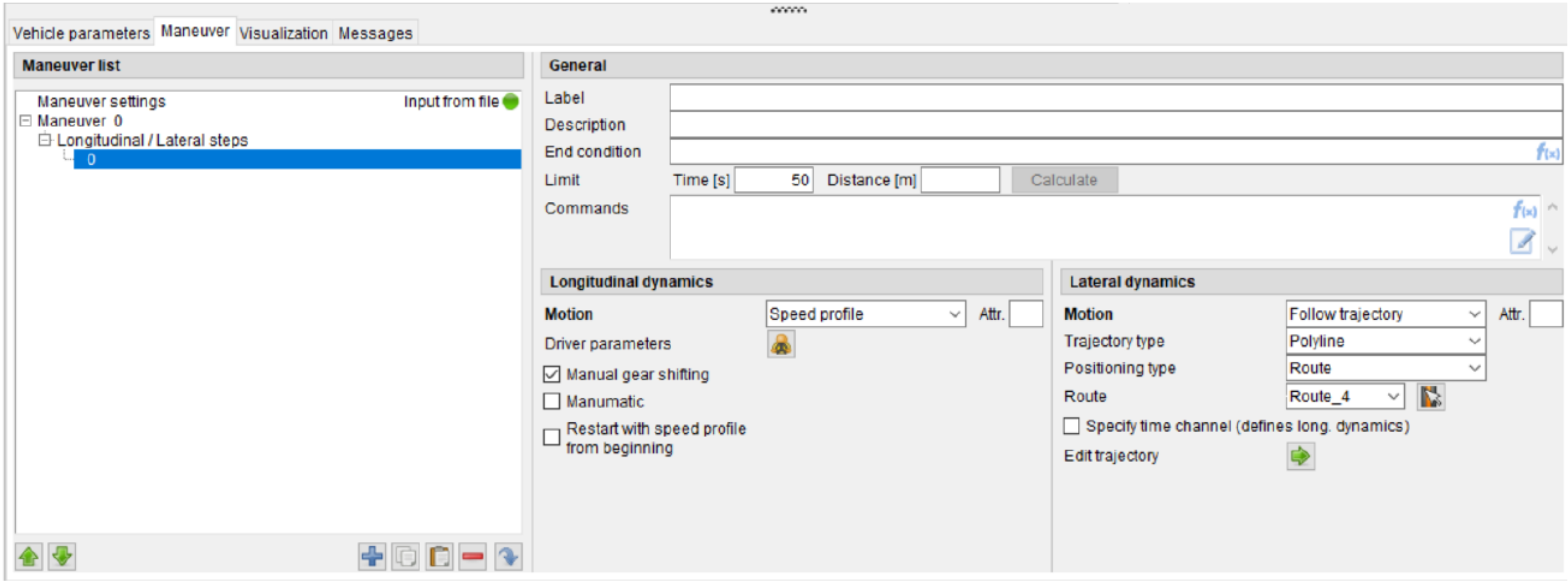
<u>Digital Twin of the Vehicle</u>

- Limits
  - Acceleration

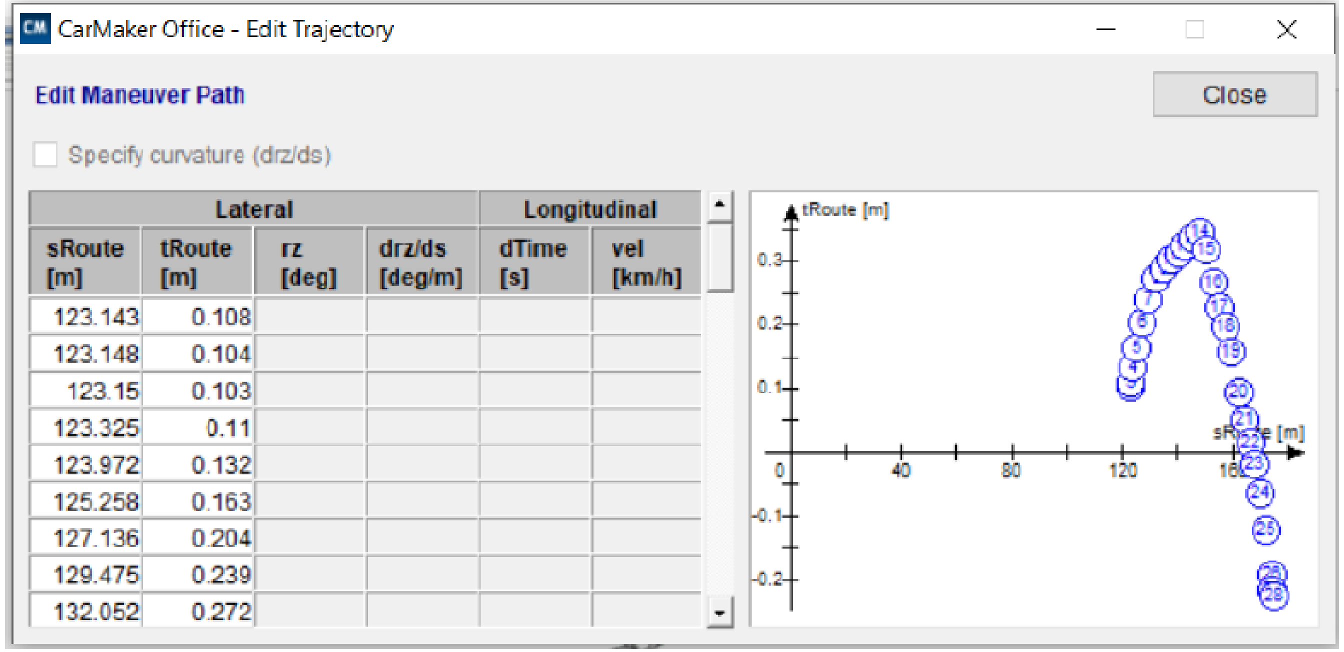
<u>Digital Twin of the Motion</u>

- Longitudinal Dynamics
  - Speed Profile
  - Timestamp
- Lateral Dynamics
  - Trajectory





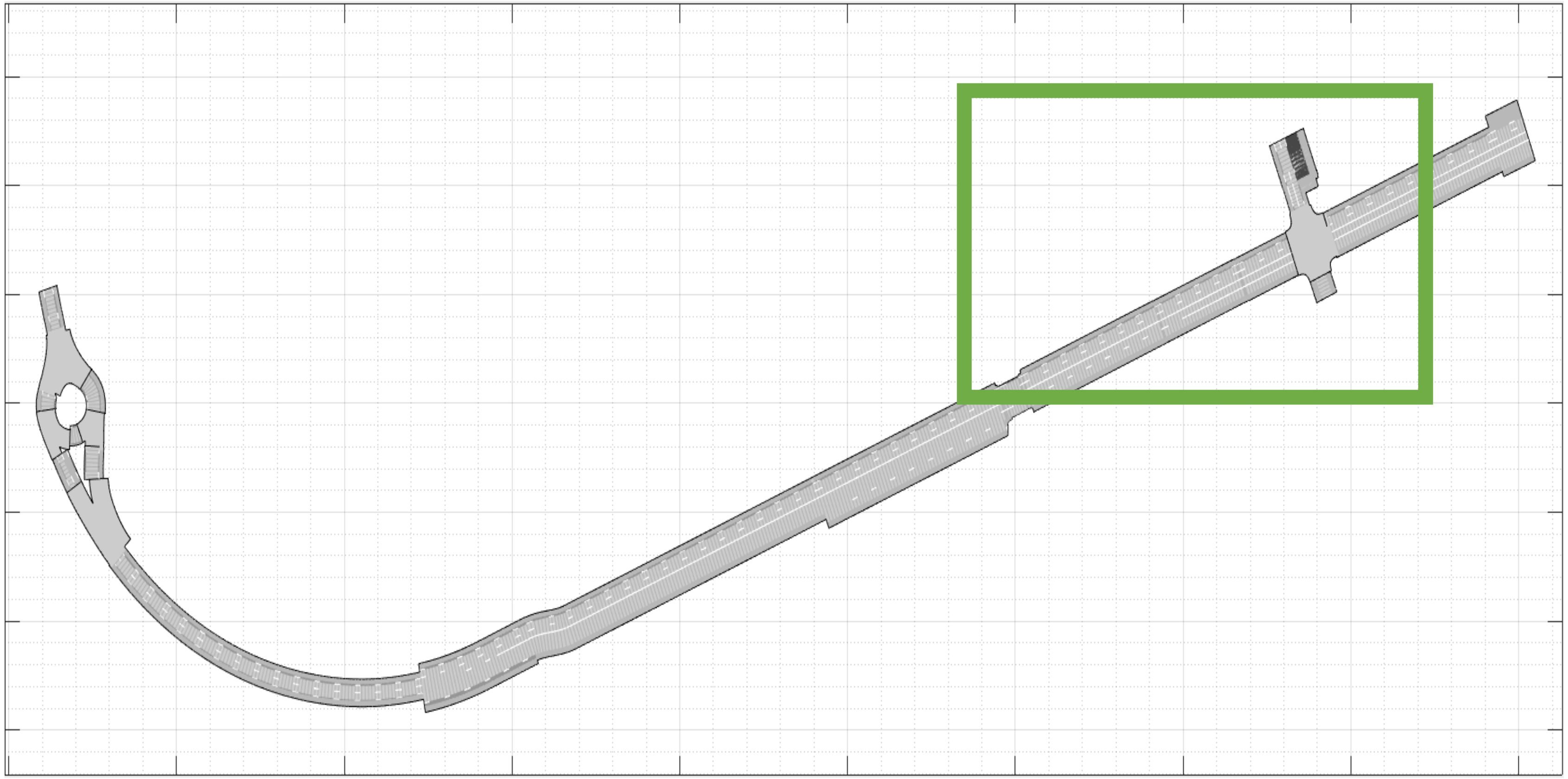
Vehicle parameters
Maneuver
Visualization
Messages
Maneuver list
Maneuver settings
Input from file
Maneuver 0
Longitudinal / Lateral steps
0
General
Label
Description
End condition
Limit
Time [s]
50
Distance [m]
Calculate
Commands
Longitudinal dynamics
Motion
Speed profile
Attr.
Driver parameters
Manual gear shifting
Manumatic
Restart with speed profile from beginning
Lateral dynamics
Motion
Follow trajectory
Attr.
Trajectory type
Polyline
Positioning type
Route
Route
Route_4
Specify time channel (defines long. dynamics)
Edit trajectory



CarMaker Office - Edit Trajectory
Edit Maneuver Path
Close
Specify curvature (drz/ds)
Lateral
Longitudinal
sRoute [m]
tRoute [m]
rz [deg]
drz/ds [deg/m]
dTime [s]
vel [km/h]
123.143 0.108
123.148 0.104
123.15 0.103
123.325 0.11
123.972 0.132
125.258 0.163
127.136 0.204
129.475 0.239
132.052 0.272
tRoute [m]
sRoute [m]
0.3
0.2
0.1
0
-0.1
-0.2
40
80
120
160

METHODS

Digital Twin of the Road



- Provided by AstaZero
- ASAM OpenDrive Format
- Lane markings, lane width, junctions included
- VUT, VRU routes have to be defined

METHODS

Digital Twin of the Pedestrian

Balloon Dummies

Property	Value
Adult Height	181 cm
Adult Width	50 cm
Child Height	114 cm
Child Width	30 cm

- **Stationary Vehicles**
  Positioning based on the scenario definition.
- **Barriers**
  Both sides of the road.
- **Buildings**
  Warehouse.
- **Trees**
  Both sides of the road.

METHODS

- Digital Twin of the Sensors

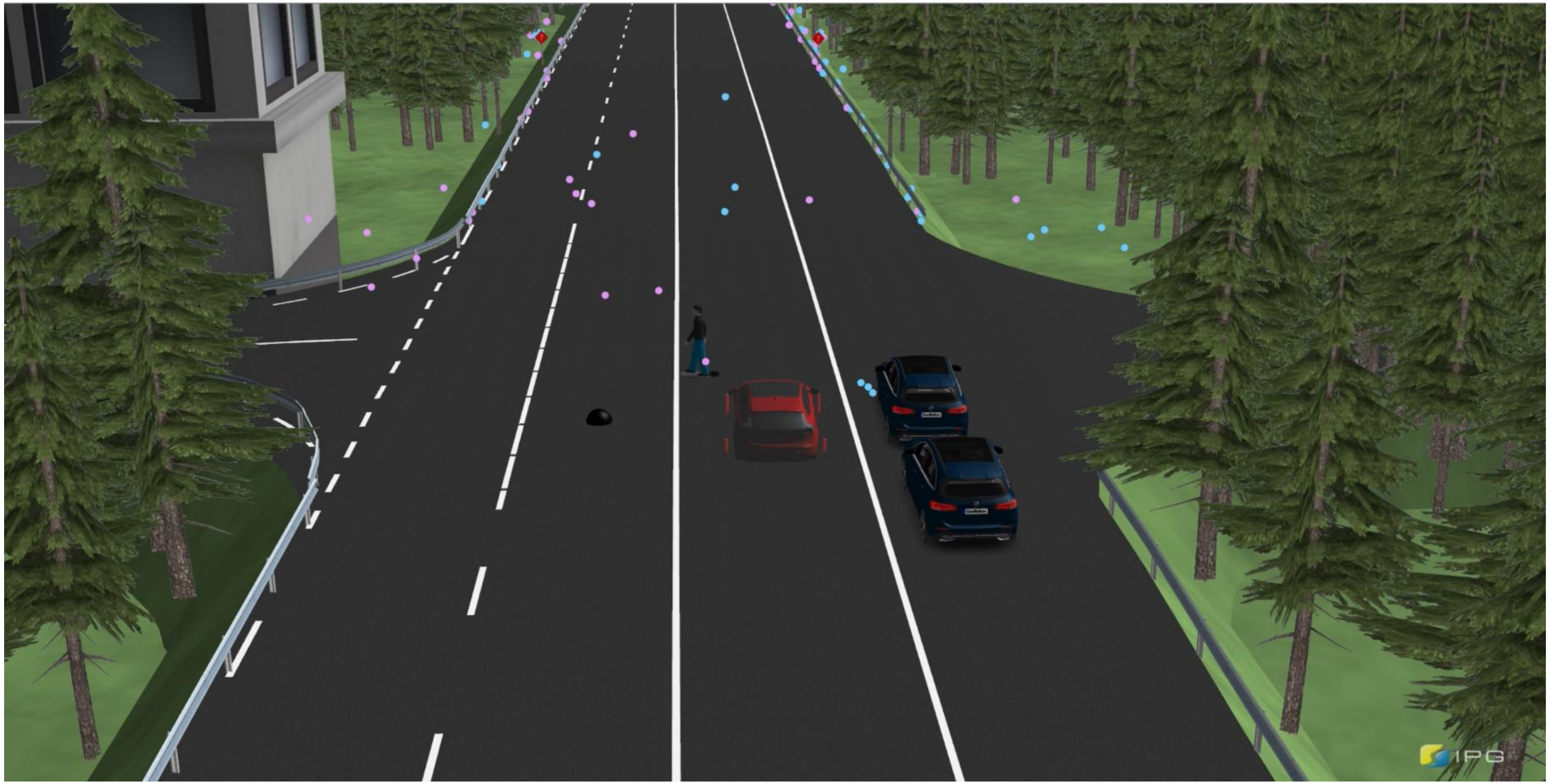
Sensor Properties Based on Technical Characteristics.

Property	Value	Unit	Radar Model	Sensor Type
Operating Frequency	76.5	GHz	HiFi & RSI	FL&FR
FOV (azimuth)	150	deg	HiFi & RSI	FL&FR
FOV (elevation)	10	deg	HiFi & RSI	FL&FR
Maximum Range	150	m	HiFi & RSI	FL&FR
Probability of Detection	0.5	-	HiFi	FL&FR
Probability of False Alarm	10^{-4}	-	HiFi	FL&FR

- Radar HiFi
- Radar RSI (Ray Tracing Based Model)

Radar Pipeline: data processing, filtering, clustering, tracking

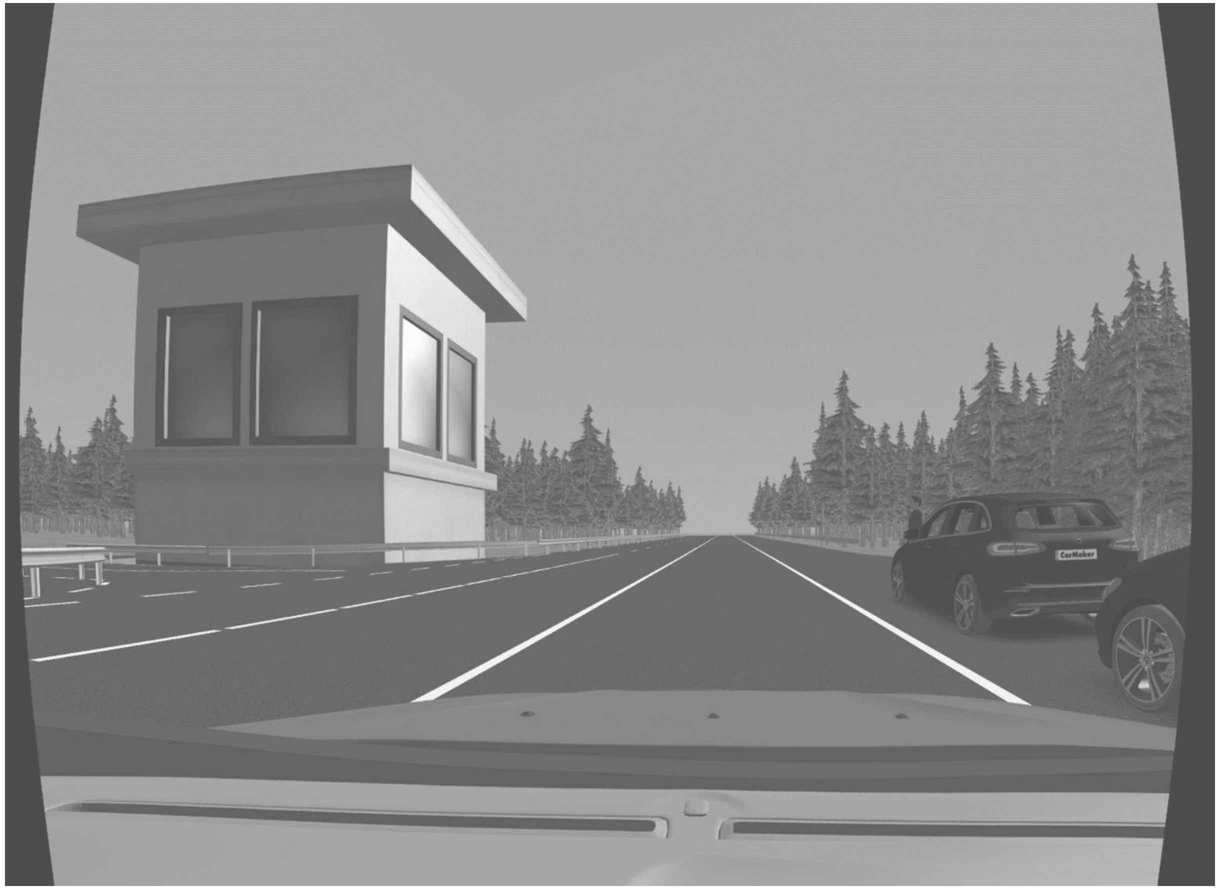
DETECTIONS (RSI Radar)



OBJECTS (HiFi Radar)

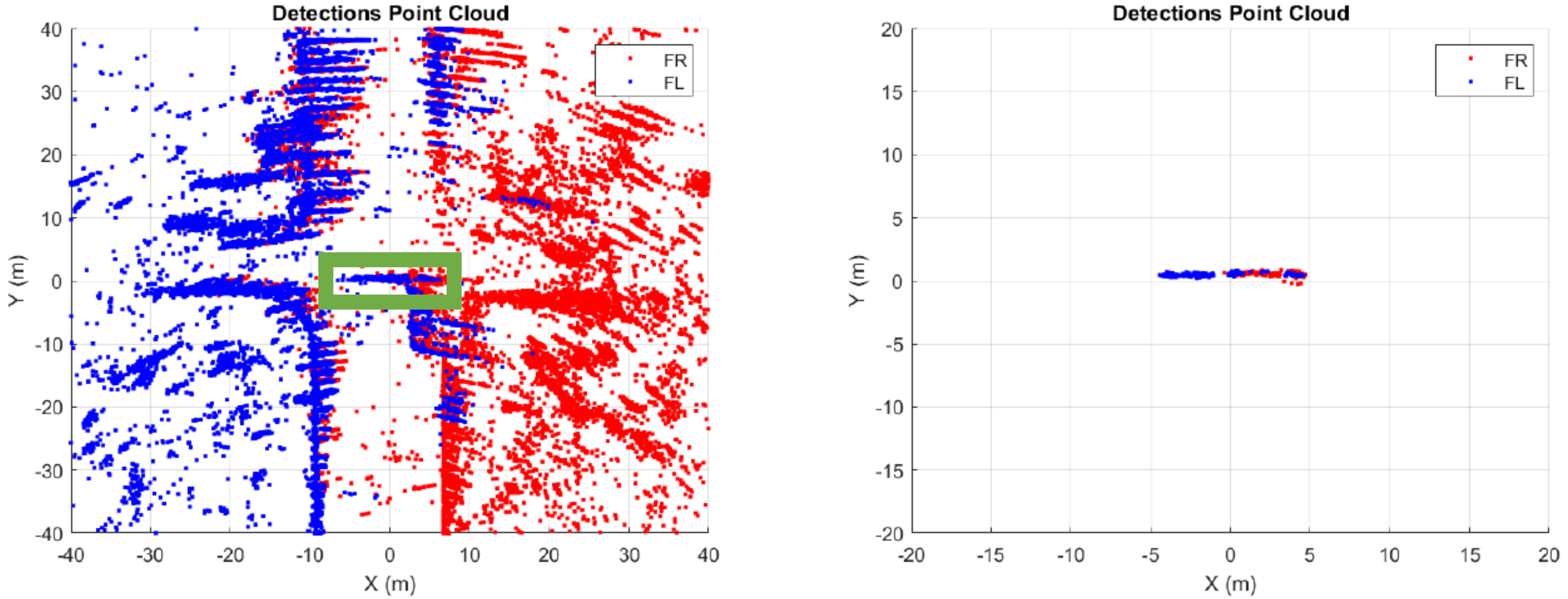
Camera View (Side-by-Side Comparison)

Test Track (AstaZero)

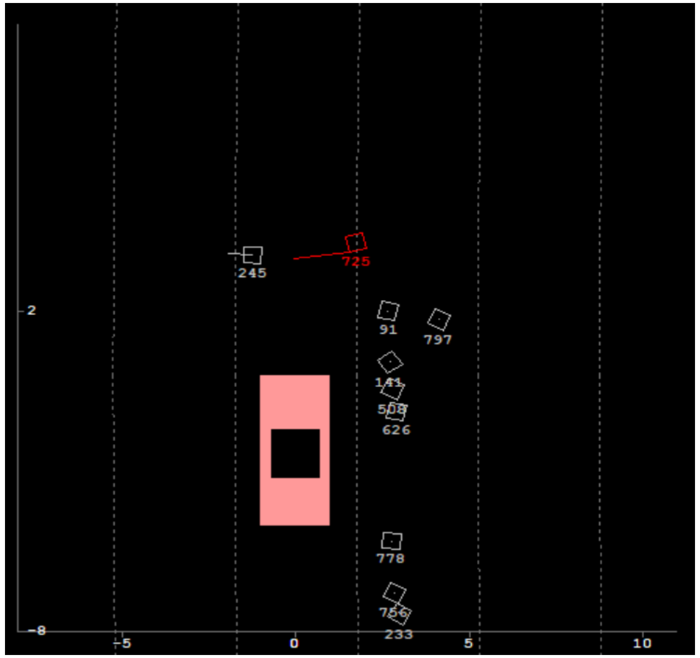


Simulation Environment (CarMaker)

APTIV MRR Radar Sensor Output

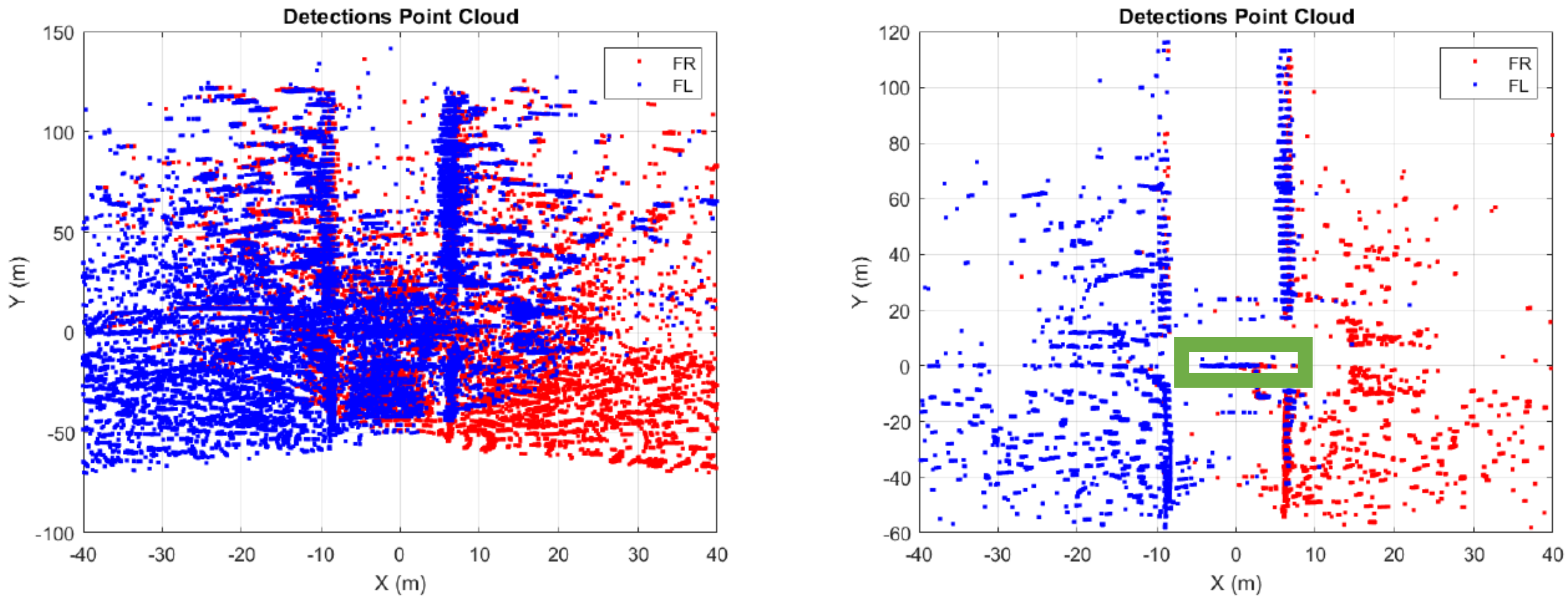


APTIV MRR Radar Sensor Output from Real Data Collection (Unfiltered Data on the Left, Filtered Data on the Right).



Visualization Tool

IPG CarMaker RSI Radar Sensor Output



IPG CarMaker Radar Sensor Output from Synthetic Data Collection (Unfiltered Data on the Left, Filtered Data on the Right).

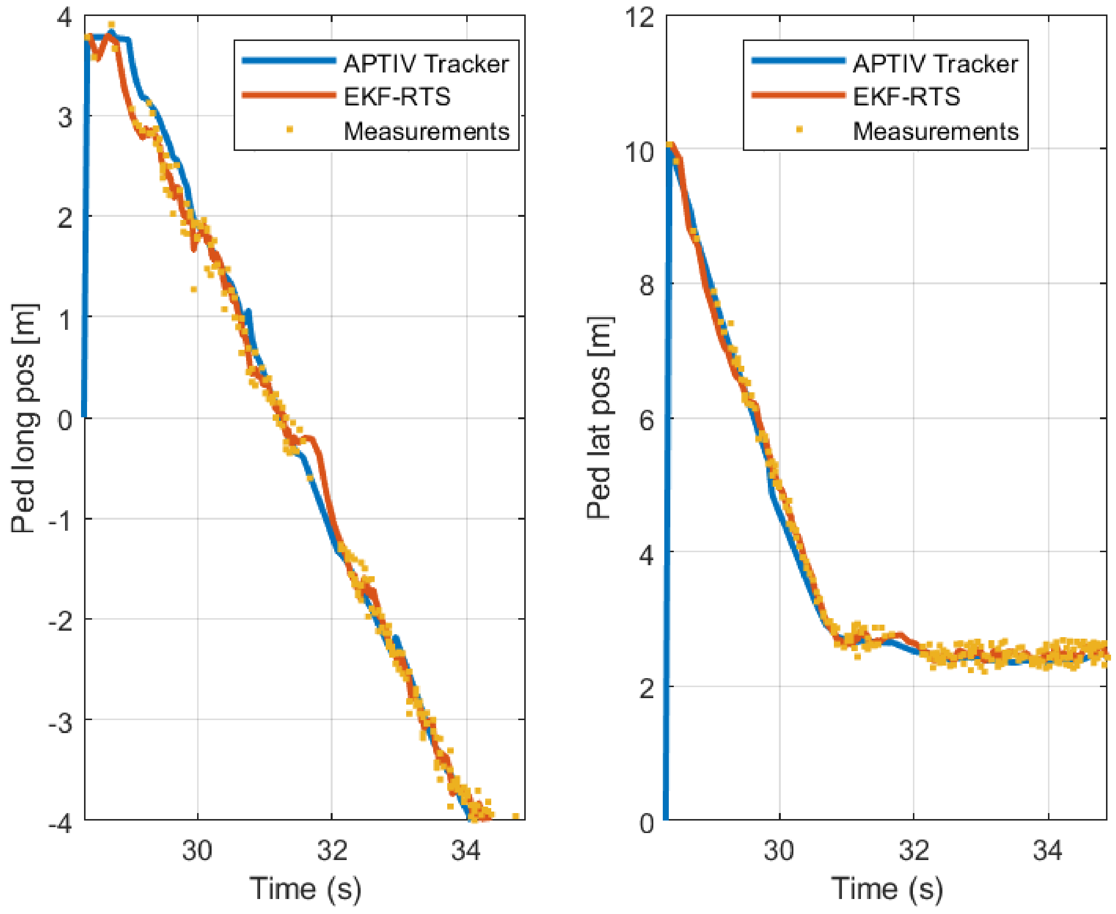
RSI Radar Object Tracking

Tracker

- Extended Kalman Filter (Forward Pass)
- Rauch–Tung–Striebel Smoothing (Backward Pass)

Performance Criteria

- Comparison with APTIV Tracker



RESULTS

- Simulation-to-Reality Gap
- Sensor Fidelity
- Sensitivity Analysis

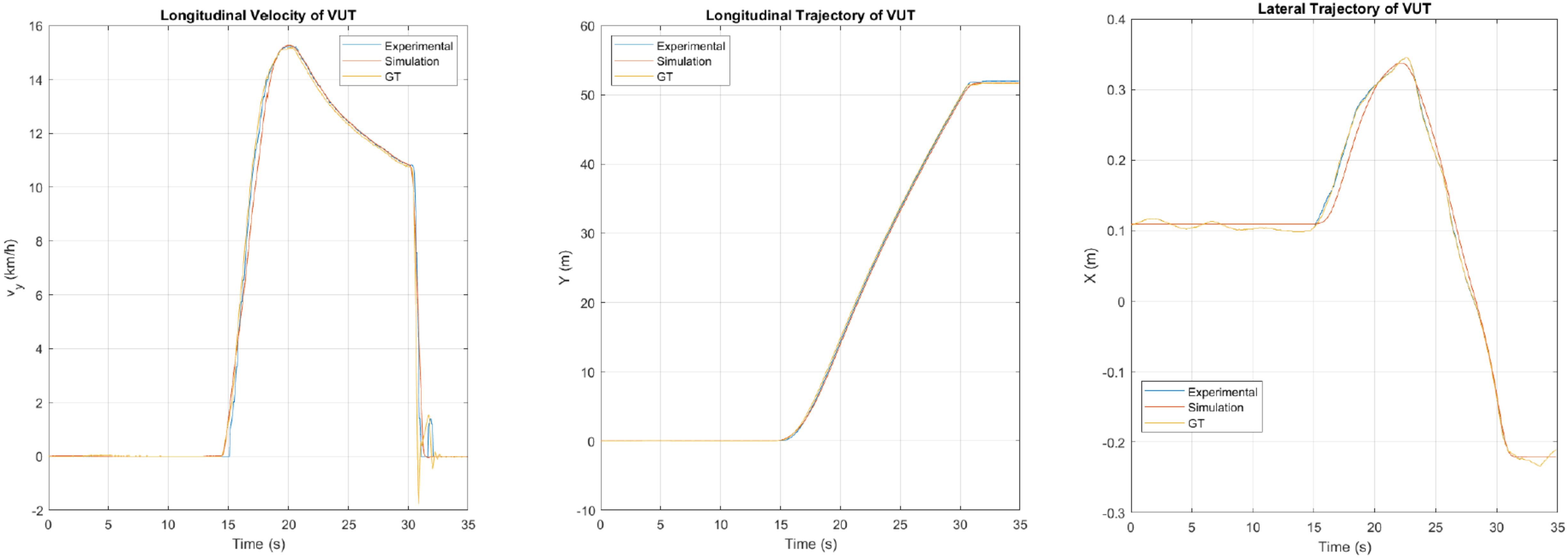
$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

y_i: Experimental Data
$\hat{y}_i$: Simulation Data

Simulation-to-Reality Gap

- **RQ:** Does the proposed method allow comparability to the simulation-to-reality?



Simulation-to-Reality Gap

- **RQ:** How does the simulation-to-reality gap vary among the different test runs?

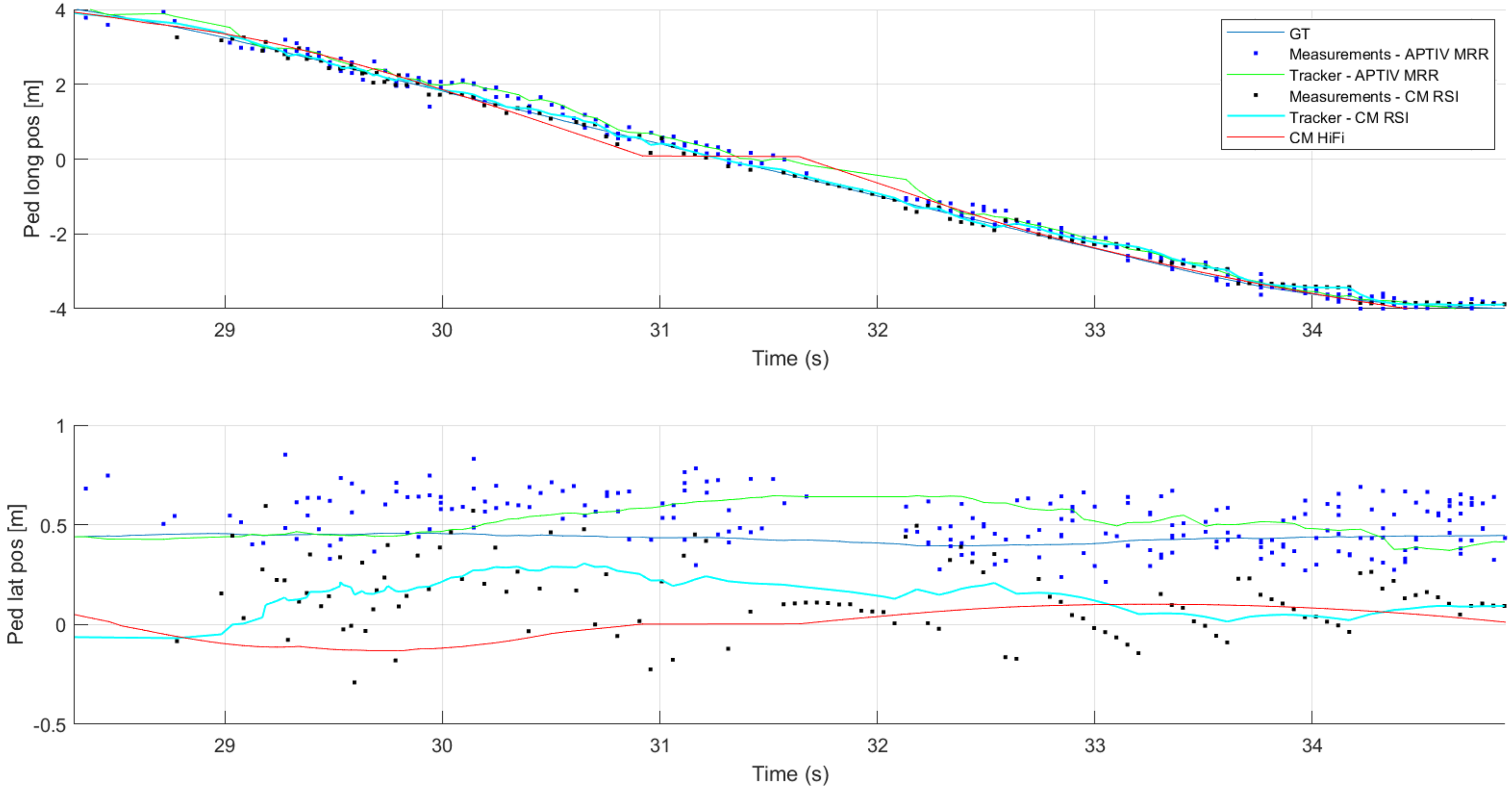
  Given the limitations: Vehicle model, driver profile, input data (speed, steering angle).

  Lower speeds usually indicate better results.

Case Number	Host Speed	Pedestrian Model	MAE (Long)	MAE (Lat)
1	15 km/h	Adult	0.18	≈ 0
2	15 km/h	Child	0.36	≈ 0
3	30 km/h	Adult	0.4	≈ 0
4	30 km/h	Child	3.86	≈ 0

Sensor Fidelity

- **RQ:** Does the proposed method allow comparability to the sensor fidelity?



Case 1: Host 15 km/h, Adult

Sensor Fidelity

Root Mean Square Error Values between Simulated and Real Data for Pedestrian Longitudinal Movement Tracking - RMSE(m).

Case	RMSE (HiFi)	RMSE (RSI)	RMSE (m)
h15 Adult	0.24	0.21	0.013
h15 Child	0.23	0.21	0.016
h30 Adult	0.35	0.31	0.014
h30 Child	0.10	0.11	0.026

Root Mean Square Error Values between Simulated and Real Data for Pedestrian Lateral Movement Tracking - RMSE(m).

Case	RMSE (HiFi)	RMSE (RSI)	RMSE (m)
h15 Adult	0.50	0.39	0.18
h15 Child	0.92	0.80	0.48
h30 Adult	0.67	0.5	0.57
h30 Child	3.63	3.6	4.01

- **RQ:** How does the fidelity of the sensor model affect the execution efficiently representing the necessary degree of fidelity?

RSI > HiFi, due to object merging.

Sensitivity Analysis

- **RQ:** Which parameters have a strong influence on the performance of simulations? How do these parameters influence the simulation results?
  - Sensor Parameters

    Noise bandwidth

    Number of rays

    Number of reflection points
  - Environmental Parameters

    Temperature

    Rain Rate

    Speed of Wind

    Angle of Wind

CONCLUSION & FUTURE RESEARCH

SUMMARY

- Successful tracking of pedestrians considering the limiting factors (vehicle dynamics, lower fidelity twins)
- Higher fidelity radar sensor provides better tracking however it is not a cost-effective solution.
- RQ: Virtual testing a promising method to accelerate the development of autonoumous vehicles, and holds the potential to replace physical tests to some extent however requires the use of high fidelity components.

FUTURE RESEARCH

- Further research should focus on analysis with higher fidelity components, HiL setups, sensor fusion with other sensors.

QUESTIONS?

This research was conducted under the EVIDENT project with funding from Vinnova.

Funding from: VINNOVA Sweden's Innovation Agency