Modeling and Simulation Technologies on Vehicle Intelligence

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Background & Motivation

Challenges on Vehicle Intelligence

Technological Advancement

Modeling Simulation
Background & Motivation

Driving environment now plays an important or even critical role on the safety and performance of intelligent driving.
Motivation: Challenges on Testing & Validation

Setting up field testing for many features can be of long-cycle and high-cost, and even impossible.

Some safety critical features can be difficult, if not impossible, to test in the field, especially during the early development stages!
Technological Advancement

Modeling on Battery and Electric Motors, onboard communication

Vehicle Dynamics

Intelligence

Electrification

driver

tire

road

weather

traffic

camera

wireless

radar

Modeling on Driving Environment and Environmental Sensing
Modeling & Simulation Plays Key Roles

Advanced Development Platform

Pure Simulation
离线纯仿真平台

RT-SIL/HIL Simulation
实时、软硬件在环仿真平台

DIL with 3D Environment
驾驶员在环三维场景仿真

In-Vehicle Test
实验车试验/标定/验证

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Tools & Method on Vehicle Intelligence

Vehicle Performance

Virtual driving environment
(road, traffic, weather, etc)

Virtual driving scenarios
(ABS/TCS/ESP/ACC, self-parking)

Vehicle Virtual Driving Environment

Environmental sensors
(radar, camera, GPS/map, V2V, V2X)

Simulated traffic participants
(cars, pedestrians, barrels, etc)

Vehicle Intelligence

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Tools & Method on Vehicle Intelligence

Driver Model

Weather Model

Traffic Models

Virtual Driving Environment with Environment & Sensor Models

Vehicle Dynamics Model

Electronic Control

Road & Field Model
Vehicle Dynamics Modeling: with High-Order, Large-Nonlinearity and High Efficiency
Vehicle Dynamics Model

- System-based modeling approach with:
  - high-order and large-nonlinearity
  - high efficiency for real-time
  - high fidelity

Vehicles have
- Sprung Mass
- Unsprung Mass
- Rear Unsprung Mass
- Front Unsprung Mass
- Wheel Spin
- Sideslip

PanoSim

- Expected trajectory
- Expected vehicle speed

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Vehicle Dynamics Model *(under Simulink)*
Vehicle Dynamics Model: *verification*

**Double-Lane Change**

Simulated speed at 80kp

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**Steering Angle**

**Yaw Rate**

**Lateral G**
Vehicle Dynamics Model: verification

Fishhook Simulation

Simulated speed at 80kph, with steering and path shown below
Vehicle Dynamics Model: verification

Fishhook Simulation

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Vehicle Dynamics Model: verification

Fishhook Simulation

![Sideslip Angle Graph](image)

![Lateral Speed Graph](image)

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Radar Modeling: with Combined Geometric and Physical Approaches
Radar Modeling

- Take into consideration of major physical factors, such as electromagnetic wave propagation (echo signals), target and its RCS estimation, and ambient noise.

- Combined geometric and physical modeling approaches to achieve **high fidelity** while maintaining real-time computational **efficiency**.
Radar Modeling
Radar Modeling

Power spectrum vs. range (B)

Power spectrum vs. range rate (B)

Power spectrum vs. azimuth angle

Cluster 1

Cluster 2

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Camera Modeling
**PanoSim**: Camera Modeling

\[ r = f \cdot \theta \]
\[ r = 2f \tan(\theta/2) \]
\[ r = f \sin(\theta) \]
\[ r = 2f \sin(\theta/2) \]

**Fisheye & Wide Angle**
Camera Modeling and Validation

**Fisheye Camera Modeling**
PanoSim: Camera Mounting & Calibration

- Take Pictures
- Record Video
- Video Playback

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PanoSim : Camera Model Applications

Traffic Sign Recognition  Distance/Speed Measurement

Object Detection  Lane Marker Detection
Highly Correlated with the Results from Real Image

Real Image  Simulated Image

Lane detection using Hough transform

Road detection using watershed algorithm

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An Integrated Software Tool
PanoSim: Six Modules with Many Functions

- Main GUIs
- VehicleBuilder
- FieldBuilder
- PanoCam
- PanoPlot/PanoAnim
- MDL Generator

- Vehicle Dynamics
- Wireless Comm
- Radar/Lidar/Camera
- Virtual Proving Ground
- Traffic
- Weather/Light

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PanoSim: Applications

Vehicle Performance

Virtual Proving Ground
(Road/Traffic/Weather)

Virtual Scenarios
(ABS/ESP/ACC/LDW/UPA)

Environmental Sensors
(Radar/Lidar/Camera/Wireless/GPS)

Traffic
(Cars/Pedestrian/Signal/Signs)

ADAS

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An Integrated Platform for Technology and Product Development of Vehicle Intelligence
PanoSim : Applications

Vehicle Performance
- Brake/Steer/Suspension
- Handling & Stability

Powertrain System
- Engine/Transmission
- Driveline & Driveability

Electronic Controls
- ABS/TCS
- ESP

ADAS
- ACC/LDW/LKA/FCW
- Autonomous Parking

Environment Sensing
- Vision-based sensing & IP
- Radar Detection
- Sensor Fusion

Intelligent Driving
- Planning & Decision
- Positioning/Navigation

Intelligent Transportation
- V2V/V2I/V2X
- Autonomous Driving
FieldBuilder : Building Testing Field

3D Virtual Proving Ground
Traffic : Traffic Modeling for ADAS

- Good **fidelity** in traffic dynamics, while maintaining sufficient computational **efficiency**
- Good **flexibility** in generating desired **disturbances** for ADAS feature development, while maintaining its nature of **randomness**
PanoSim : Virtual Testing & Verification

Collision Avoidance

Adaptive Cruise Control

Autonomous Parking

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**PanoSim**: Seamless Connection to Simulink

- Auto Simulink Model Generation
- High Efficient Numerical Simulation
Real-Time HIL/DIL Simulation
Simulation on Vehicle Intelligence Development

Extend the functionality of driver simulator with environmental sensing
Camera Modeling: Applications

Real-time HIL/DIL simulation with camera model

Virtual Driving Environment

Driver Simulator

RT Vehicle Model

Camera Model

Controller

Image Processor

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系统功能演示：
- 车辆动力学实时仿真
- 汽车ACC电子控制算法
- 环境与环境传感模拟
- 驾驶员在环动态模拟
- 车载通信及网络模拟
- 人机界面设计
- 汽车电控与智能化系统集成

行驶环境及交通模拟

传感数据处理

车辆动力学实时仿真

ACC电子控制算法

虚拟传感器

驾驶模拟器

（硬件在环）

实时车辆动力学模型

驾驶员动态模拟器

虚拟传感器

ACC控制命令

ACC警示信息

目标检测

道路识别

控制算法

原型控制器

人机界面（HMI）
Virtual Driving Environment
Virtual camera, radar, V2V
Traffic and 3D environment

Integrated Real-Time HIL/DIL
Platform with Virtual Environment

DIL Simulator
DIL simulation
HMI

RT Vehicle Controls
Prototype Controller
By-wire actuators
In-vehicle communications

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Conclusions:

➢ Field testing can be very challenging on cost, time, and flexibility, and sometimes even impossible.

➢ Virtual driving environment can be in high fidelity with models of road, traffic and weather, and environmental sensors of radar and camera (and V2V next).

➢ It is proved to be very effective in the early design, test and verification of vehicle intelligence.