A Study on the Methodology to Develop Digital Twin Virtual Drive Environment for Autonomous Driving Evaluation

PEOPLE · SOLUTIONS · STANDARDS
25 YEARS
ASAM CONNECTS

iVH

Wonyul Kang, Ph.D

2023-09-12

ASAM Association for Standardization of Automation and Measuring Systems

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1. Introduction

1.1 Research background

1.2 Virtual driving environment based on ASAM standards

0. iVH Introduction

iVH was established in 2013 based on the expertise of Modelica, the first system engineering language in Korea. (**11th year of business experience**)

The Institute of Automotive Engineering is an MBSE technology development/sales/service provider in the automotive, defense and aviation sectors. **The main commercialization products are the Cloud Computation platform and the self-driving acceleration verification development platform.**

Location

Headquarters and Labs
2nd, 3rd floor, 19th, 17th-gil, Yangjaecheon-ro, Seocho-gu, Seoul

Member

Engineer 15 people (Doctor of Automotive Engineering 2 people , Master of Science in Automotive Engineering 6 people)
Advisor a technical adviser 1 people, An advisory professor 1people)

Business Area

Engineering service
Education(VTD , Modelica, FMI)
Software Sales(VTD, VISSIM, Dymola. SFE etc)

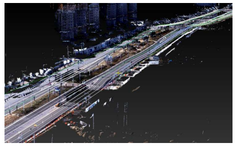
Global Partners

PTV
HEXAGON
ASAM Member
Modelon AB
Dassault System (OSD partner)
EDI GmbH

PTV GROUP
ASAM Member

Modelon Engineering Data Intelligence HEXAGON Elektrobit Leica Geosystems MODELICA DASSAULT SYSTEMES Microsoft Azure

Technique for AD

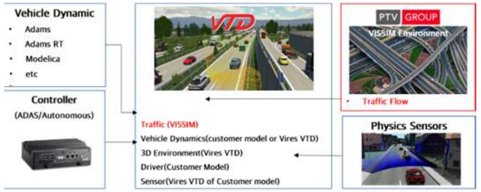


HD Map Creation Technology Based on MMS

- Development Technology of Digital Twin Road Model Based on MMS
- LAS Data-Based Road Properties (Lanes, Vehicle Width, Elevation, Guardrail, etc.) Extraction Technology
- Code-based open DRIVE generation technology

Virtual Driving Platform Development Technology

- Development of Virtual Driving Evaluation Platform for AD System Control
- Real-time-based sensor simulation technology
- AD Vehicle Monitoring Technology



VTD-3rd Part Interworking Technology

- VTD and Vehicle Dynamics Interworking Technology
- VTD and Self-driving Vehicle Controller Interworking Technology (SILS/VILS)
- A Study on the Interworking Technology of Microscopic Transportation

Success Story for AD

Title	Date	Client
Development of High Capacity BRT Self-driving Base Technology of Electric Power System	2019~	KRRI
Standardization of AI Driving Capability Evaluation and Development of Evaluation Process	2021~	KoROAD
Research and Development of Driving System and Transportation Infrastructure for Road Driving of Self-driving Vehicles	2020~2022	Korea National University of Transportation
Construction of Virtual Environment Simulator for Construction Safety	2020~2021	Kyungwoo systems
Establishment of Virtual Development System for Self-driving Using VTD	2018.07	Hyundai Motor Namyang Research
Development of Open Source Utilization Technology for Virtual Assessment Environment	2017.12	Hyundai Motor Namyang Research

1.1 Research background

"Maximizing the accelerated development of autonomous driving technology based on front loading"

Using the digital twin virtual driving test platform based on ASAM standards

Difficult to create a virtual driving environment based on real roads.

- Creating a virtual environment based on real roads **takes long**, and **technology development is difficult**.
- **Difficult to secure the accuracy** of the virtual driving environment

Limitations of conventional technologies

Databases of virtual driving base elements are not utilized much.

- Each virtual driving solution **uses its proprietary format.**
- Existing virtual driving environment **databases are not utilized much**.

Existing methods for evaluating autonomous driving functions (public road driving test)

As of 2019

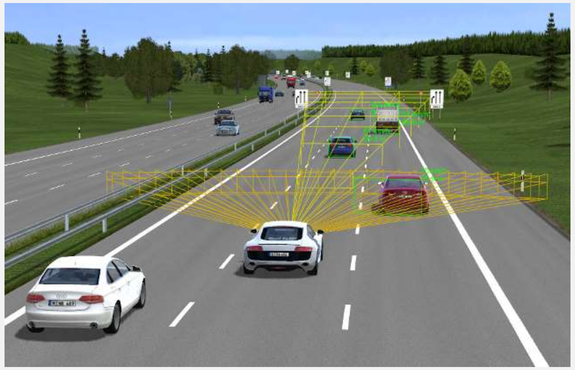
Travel distance of autonomous driving mode (mile)	108,300	1,454,137	831,040	32,054	174,845
Number of autonomous driving mode cancellations	6	110	68	3	27
Travel distance /Number of cancellations (mile)	**18,050**	**13,219**	**12,221**	**10,684**	**6,475**

1.2 Virtual driving environment based on ASAM standards

Overview of virtual driving environments

- **Road** Network/Logic
- **Road Surface**
- **Traffic Model**
- **Vehicle Model**
- **Driver Model**
- **Weather Model**
- **Sensor Emulation**

Virtual Driving Test Environments



Test Scenarios (Open Scenario)

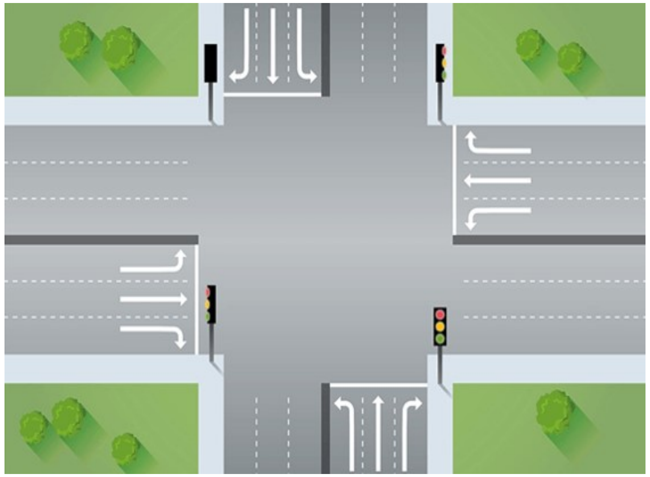
- ADAS
- Autonomous
- Fuel Consumption
- Driving Ability
- NVH
- Durability
- R&H

Driving Simulator | **HILS** | **Simulation**

1.2 Virtual driving environment based on ASAM standards

ASAM Simulation Standard

ASAM OpenDRIVE



Road Model

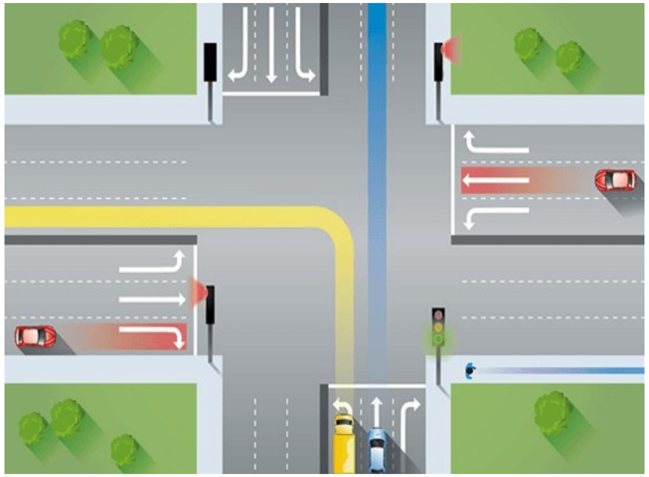
Model range: Network/Logic, Static objects
Project: openDRIVE
Format : .xodr
Advantages: A digital twin road model can be developed.

ASAM OpenCRG

Road Surface Model

Model range: Road surface
Project: openCRG
Format : .crg
Advantages: Road excitation can be created according to road surface shape.

ASAM OpenSCENARIO



Scenario Model

Model range: Dynamic elements
Related projects: openSCENARIO
format. : .xosc
Advantages: Creation of traffic flow by moving objects (pedestrians, vehicles, motorcycles, traffic lights)

2. Virtual driving environment modeling based on ASAM standards

2.1 Road network modeling

2.2 Road surface modeling

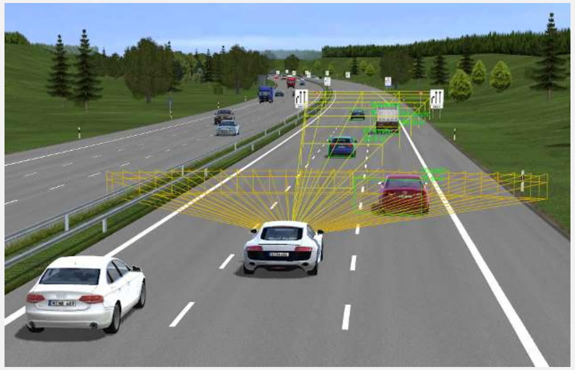
2.3 Traffic modeling

2.1 Road network modeling

Overview of virtual driving environments

Road Network/Logic	Road Surface	Traffic Model	Vehicle Model	Driver Model	Weather Model	Sensor Emulation

Virtual Driving Test Environments



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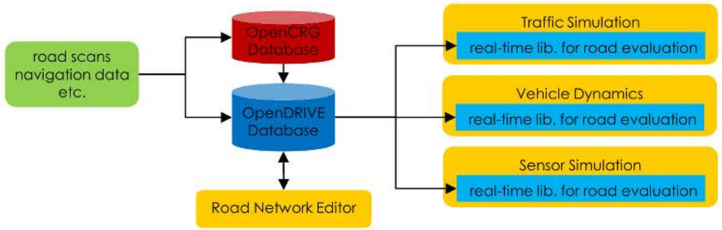
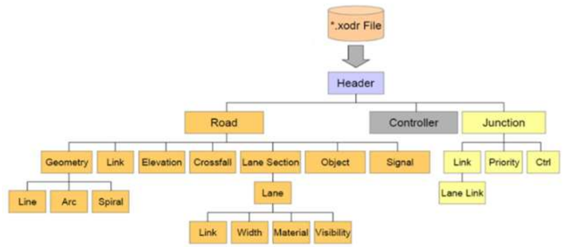
Driving Simulator	HILS	Simulation

ASAM

2.1.1 A review of the openDRIVE road logic standard

openDRIVE road standard

<table>
<tr><td rowspan="3">Overview</td><td>Project name</td><td>OpenDRIVE Project</td></tr>
<tr><td>Development companies</td><td>BMW, Daimler AG, VIRES, VTI, Rheinmetall Defence Electronics, HERE Technologies</td></tr>
<tr><td>Development period</td><td>2006 ~</td></tr>
<tr><td>Purpose</td><td colspan="2">▪ Different simulators share road data by developing standardized road data.</td></tr>
<tr><td>Details</td><td colspan="2">




▪ Users can easily modify the data structure as it has XML format and hierarchical structure.

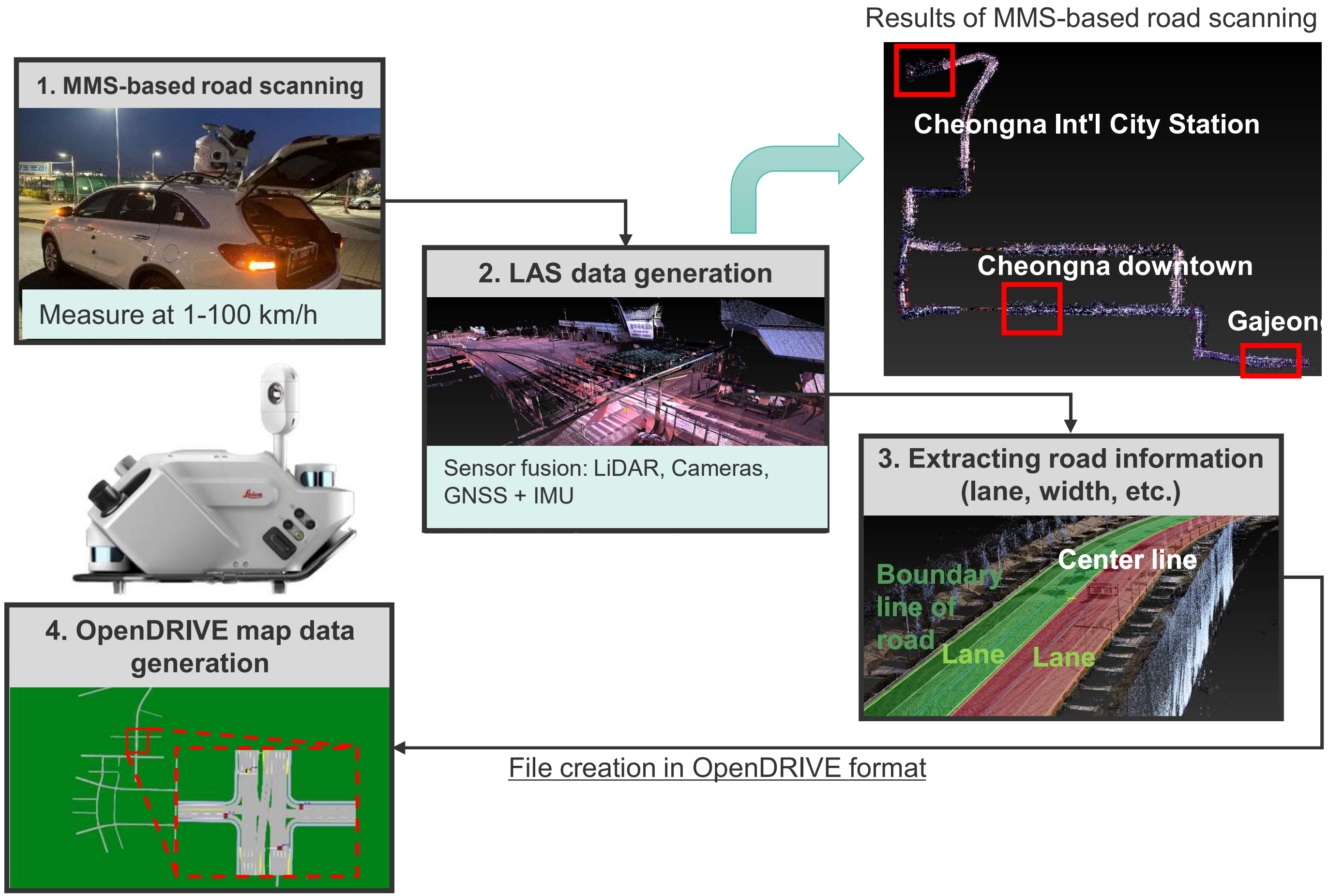
▪ Road geometry information (plane elements, lateral/vertical profile, lane width, etc.) can be mathematically defined.

▪ Customized object information can be included along with information on objects around the road.

▪ Road information can be used for vehicle dynamics, traffic simulation, sensor simulation, etc.
</td></tr>
<tr><td>Expected effects</td><td colspan="2">▪ Road modeling work efficiency can be increased by sharing standardized road information; compatible among driving simulators.
▪ Reduction of road modeling time and cost can be expected.</td></tr>
</table>

2.1.2 Real road openDRIVE generation technique based on MMS

Overview of the virtual driving road creation process based on MMS



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2.1.2 Real road openDRIVE generation technique based on MMS

Scanning real roads based on MMS

Photos of test equipment and test measurement

Key features of the Leica mobile mapping solution - Pegasus 2 Ultimate

Item	Specifications	Remark
Camera	4 ea.	12M pixels
360 degree camera	1 ea.	24MP panorama
Scanner	Z+F 9012	
Accuracy	0.015 m (vertical), 0.02 m (horizontal)	

Cheongna area road scanning

- Drove at 50 kph per hour for a round trip of 30 km.
- Generated real road image and cloud point data (generated 1 million points per second).

LAS data generation (Cheongna Int'l City Station)

- Generated LAS data by mapping cloud points and image data.

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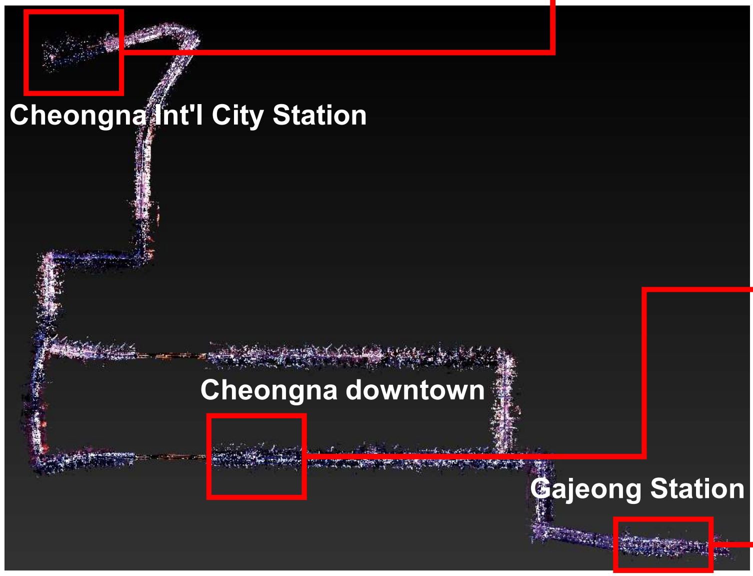
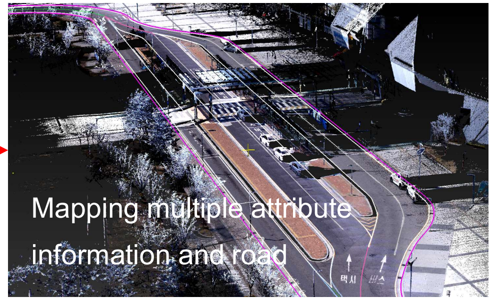
2.1.2 Real road openDRIVE generation technique based on MMS

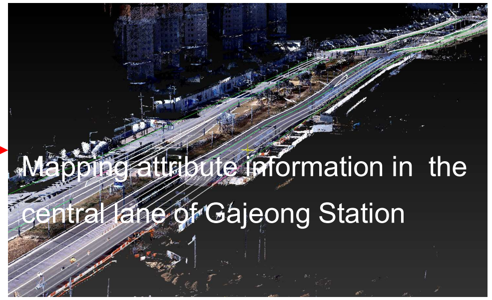
Extracting road attribute information (lane, width, guardrail, curb, etc.)

Post-processing of LAS data and road information extraction

- Entire scanning data







- Scanned BRT travel route (Bus No. 701, 702) based on MMS (300Gb)
- **Extracted road attribute information (lane, lane width, altitude, bank angle, curb, guard rail, etc.)** based on LAS (lidar cloud point + camera image) data.
- **Manual creation of the junction model**

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2.1.3 Graphic model generation technique

Unmanned aerial photography

항공 스캐닝 장비

Remo-M(항공)

- Using 2 Equipment
- Stable flight with horizontal/vertical tail control
- Provides real-time control via vehicle antenna attachment
- Supports target 3D modeling optimization
- Sensor vibration, photographing position error correction

Remocopter-700(드론)

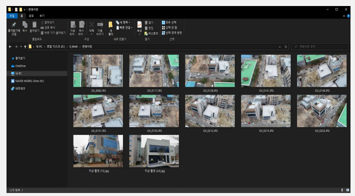
- Using 1 Equipment
- Create small orthogonal images and 3D models
- Video, still video
- Multispectral imaging

항공 데이터 기반 빌딩 및 landscape 모델링

Step 1 : Create Point cloud

- Create DEM and orthogonal images from the generated 3D point group data

Step 2 : Photo classification by building

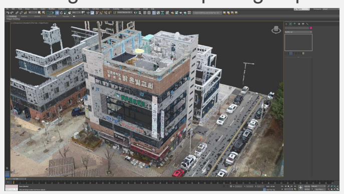


- Categorize the pictures used to create the mapping source by building

Step 3 : Photo editing

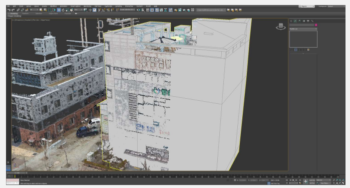
- Produce mapping sources by correcting and synthesizing angle-taken photos in the forward direction (Output: *.RGB)

Step 4 : Upload and load Point Cloud



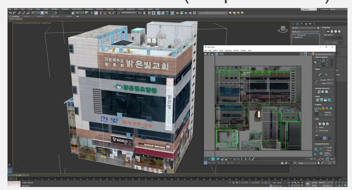
- Point Cloud Data Acquired by Drone Check and Build Building Load

Step 5 : Mesh Data



- Low polygon modeling data production based on Point Cloud Data

Step 6 : Texture



- Modeling mapping with a mapping source produced by synthesizing drone photos. (*.OBJ)

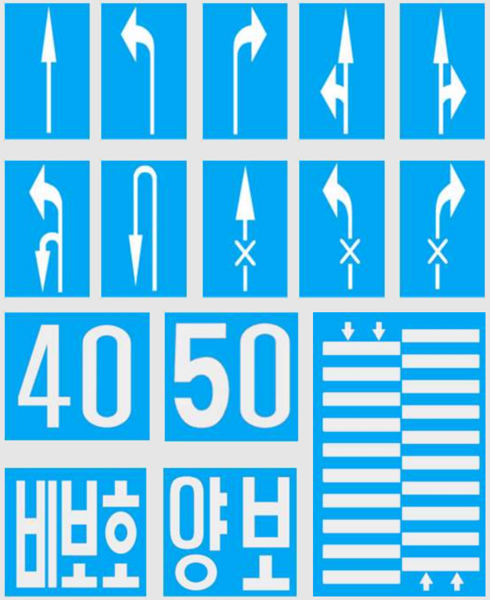
2.1.3 Graphic model generation technique

Create Korean DB

Korean Roadmark	Korean Sign	Korean Building

Korean Roadmark

Total : 36



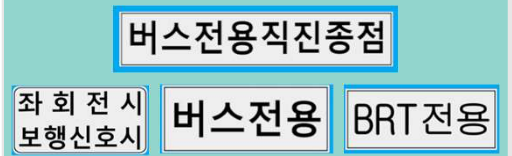
• Refer to the Enforcement Rules of the Road Traffic Act

Korean Sign

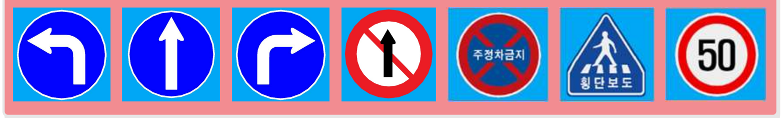
Total : 78

Road Sign : 41

Supplementary sign : 5



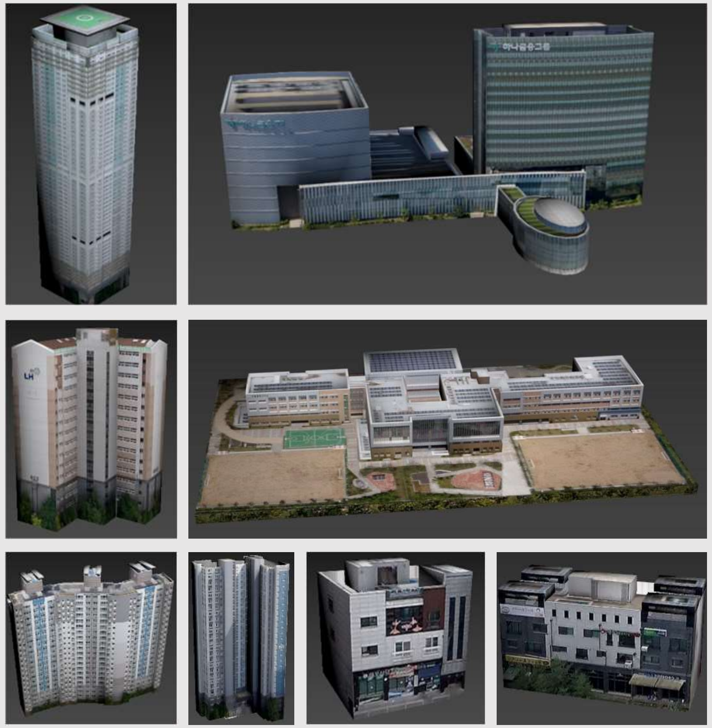
Indication sign : 32



• Refer to the Road marking rules

Korean Building

Total : 116



2.1.4 Digital Twin Road model

OpenDRIVE HD-Map

ASAM

2. Virtual driving environment modeling based on ASAM standards

2.1 Road network modeling

2.2 Road surface modeling

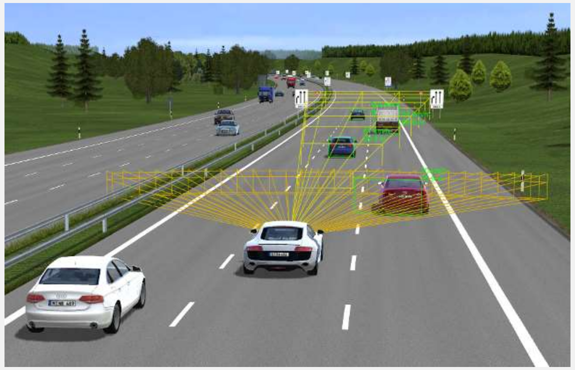
2.3 Traffic modeling

2.2 Road surface modeling

Overview of virtual driving environments

Road Network/Logic	Road Surface	Traffic Model	Vehicle Model	Driver Model	Weather Model	Sensor Emulation

Virtual Driving Test Environments


Test Scenarios (Open Scenario)

- ADAS
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- NVH
- Durability
- R&H

Driving Simulator	HILS	Simulation

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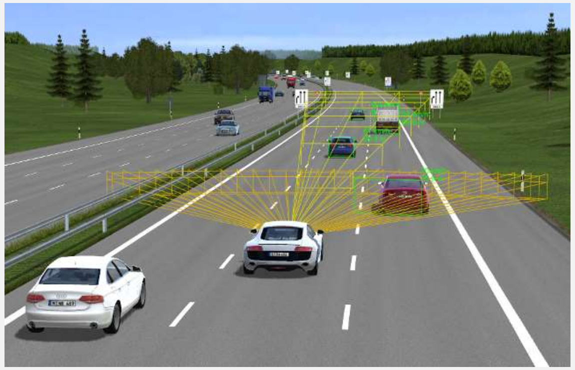

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Driving Simulator	HILS	Simulation

2.3.1 Traffic Simulation Method

Type

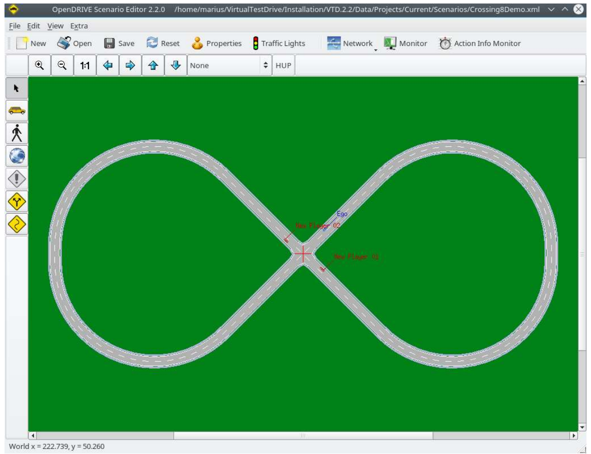
Nanoscopic Simulation

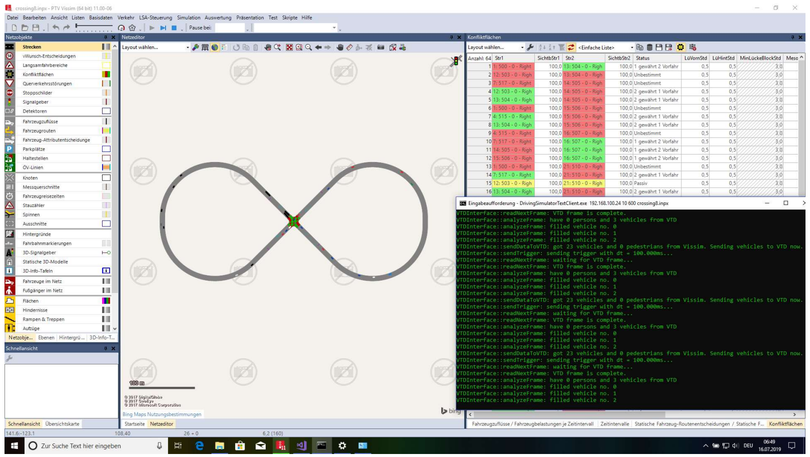
- Hundreds of participants
- Deterministic behavior
- Autonomous behavior
- SuT

Microscopic Simulation

PTV VISSIM / SUMO

- Thousands of participants
- Behavior derived from Statistics
- City-level Road Networks
- Complex Infrastructure (e.g. Traffic Lights)





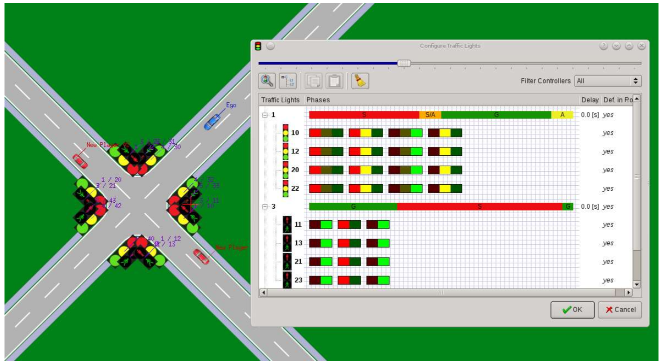
2.3.2 Creating scenario models based on random traffic

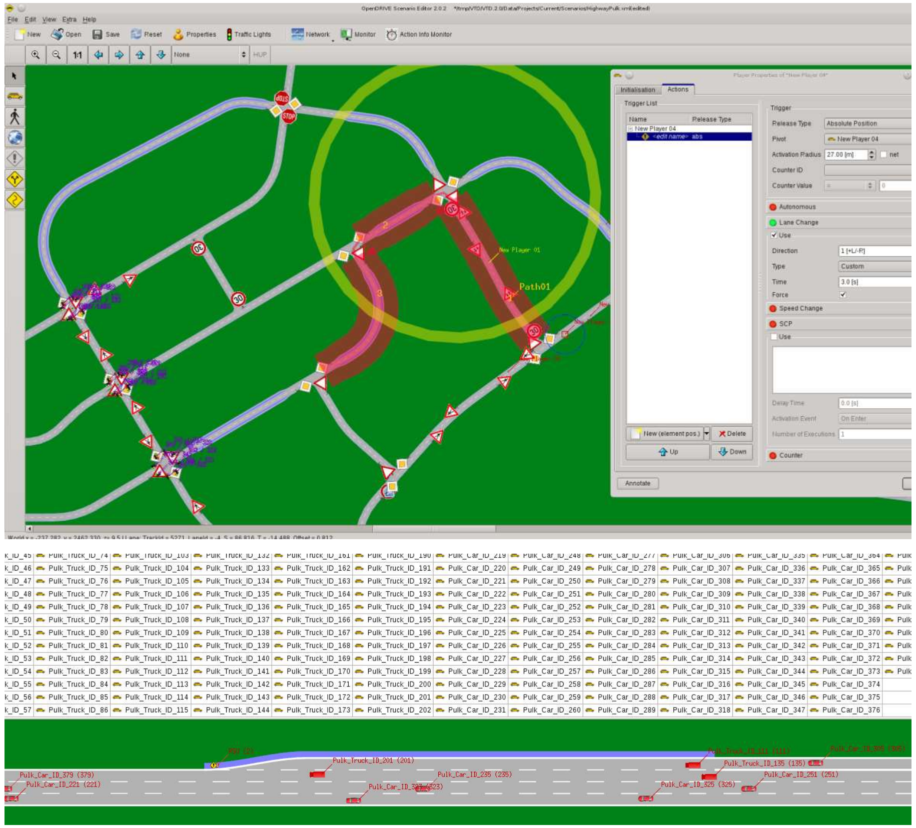
Nanoscopic Simulation

Modeling pulk traffic around the ego (control vehicle) vehicle

Random traffic modeling around the control vehicle.

- Generating surrounding traffic based on pulk traffic around the control vehicle.
- Applying real traffic flow using traffic light logic modeling.
- Modeling a representative scenario based on OpenSCENARIO.





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2.3.3 Creating Microscopic Traffic flow

Microscopic Simulation - VISSIM

ADAS and Autonomous Evaluation

Vehicle Dynamic

- **Adams**
- **Adams RT**
- **Modelica**
- **etc**

Controller

(ADAS/Autonomous)

Traffic (VISSIM)

Vehicle Dynamics(customer model or Vires VTD)

3D Environment(Vires VTD)

Driver(Customer Model)

Sensor(Vires VTD of Customer model)

PTV GROUP

- **Traffic Flow**

Physics Sensors

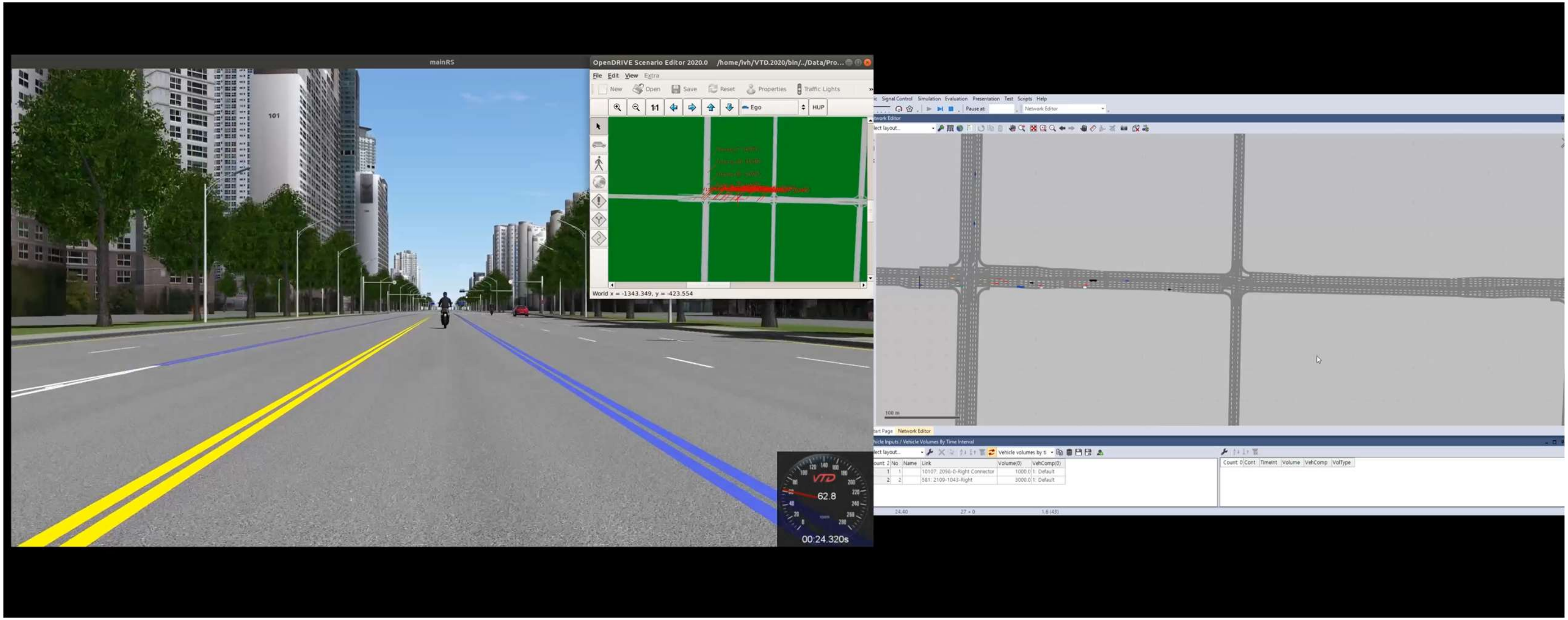
Purpose: Develop virtual testing platform for ADAS and Autonomous.

Methodology

- 3D environment model based on Vires VTD and IVH's virtual environment modeling technique.
- Vires VTD includes road, driver and vehicle model.
- Microscopic traffic model of VISSIM.(to represent real traffic environment)
- iVH's interfacing technique between VTD and autonomous controller

2.3.3 Creating Microscopic Traffic flow

VISSIM –VTD Interface Simulation



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3. Element modeling for creating a virtual driving environment (vehicle, weather, sensor)

3.1 Vehicle modeling based on Modelica

3.2 Weather modeling

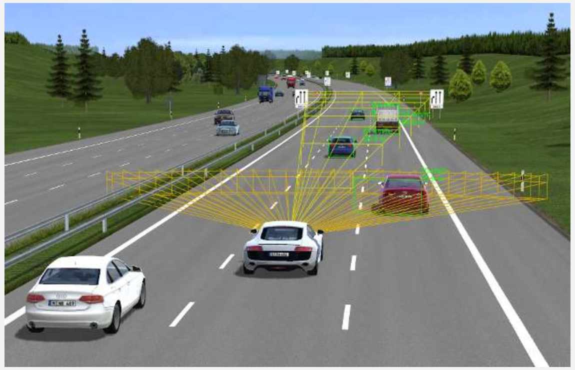
3.3 Physics sensor modeling

3.1 Vehicle Dynamics Model

Overview of virtual driving environments

Road Network/Logic	Road Surface	Traffic Model	Vehicle Model	Driver Model	Weather Model	Sensor Emulation

Virtual Driving Test Environments



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Driving Simulator	HILS	Simulation

ASAM

3.1.1 High fidelity vehicle modeling

Modelica

- Robotics
- Automotive
- Aircrafts
- Satellites
- Biomechanics
- Power plants
- Hardware-in-the-loop, real-time simulation

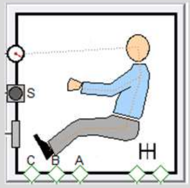
- **A language for modeling of complex physical systems**

i.e., Modelica is <u>not</u> a tool

3.1.2 High fidelity vehicle modeling

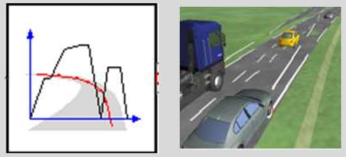
FMI (Functional mock-up Interface)

Driver FMU



Vehicle Dynamics FMU

Environment FMU



FMI | FMI | FMI

Open Integration and Virtual Driving Test Platform

FMI | FMI | FMI | FMI | FMI

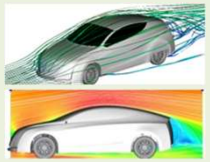
X-Drive Line FMU

- Down Sizing
- Torque vectoring
- ISG

Tire FMU

- low weight
- Rolling resistance reduction

Aerodynamics FMU



- Reduction ari resistance
- Dynamic Spoiler

HVAC FMU

- EV HVAC
- HVAC control

Electric & Electronic FMU

- Energy consumption
- VCU

3. Element modeling for creating a virtual driving environment (vehicle, weather, sensor)

3.1 BRT vehicle modeling based on Modelica

3.2 Weather modeling

3.3 Physics sensor modeling

3.2 Weather modeling

Overview of virtual driving environments

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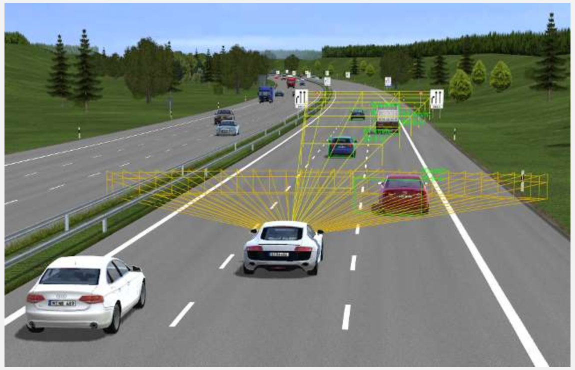

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Driving Simulator	HILS	Simulation

3.2 Weather modeling

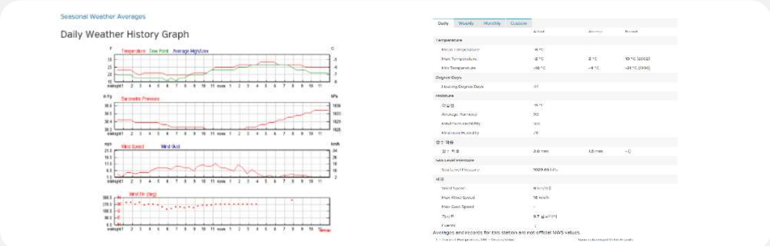
Weather modeling based on Modelica language

1. Purpose

- 현지 주행 시험 지역 환경 모델 구축

2. Method

Weather Data (1996 ~ 2016, Open source)

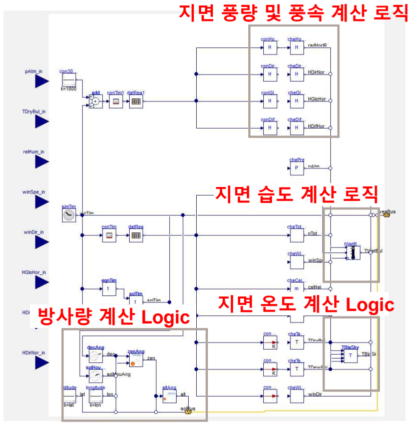


Modelica based Environmental Model

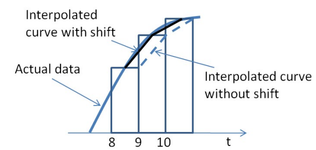
```
model Constant "Atmosphere with constant conditions"
  extends Interfaces.Base(
  redeclare final function windVelocity = Internal.constantWindVelocity ( windVelocity=v),
  redeclare final function density = Internal.constantDensity (density=rho),
  redeclare final function temperature = Internal.constantTemperature (temperature=T),
  redeclare final function pressure = Internal.constantPressure (pressure=p));
  parameter Modelica.SIunits.Velocity[3] v=zeros(3) "Wind velocity";
  parameter Modelica.SIunits.Density rho=1 "Density";
  parameter Modelica.SIunits.Temperature T=300 "Temperature";
  parameter Modelica.SIunits.Pressure p=1e5 "Pressure";

  a

end Constant;
```

3. Results

- Development of weather library based on Modelica



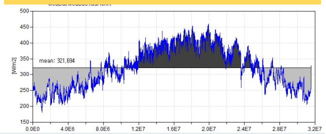
Interpolation Logic



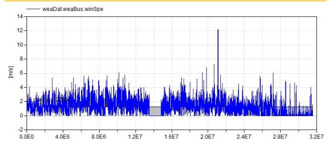
- 날씨정보의 시간 간격은 30분 또는 그이상임
- 실제 데이터와 동일한 결과를 도출 할 수 있는 Interpolation 방법 개발

- 입력 데이터(34개 기상 정보 정의)

<Radiation: 평균 321.694>



<바람: 평균 1.3 m/s>



3.2 Weather modeling

Applying VTD real-time weather models

- VTD weather models can change climate conditions such as rain, snow, and fog in real time during simulation.
- Users can set the position of the sun at their own discretion, and test the robustness of autonomous driving mode under backlight (the sun is in front of the driver).
- Raindrops on the windshield and wiper operation when it rains can be simulated.
- Friction coefficient for the road surface can be set.

3. Element modeling for creating a virtual driving environment (vehicle, weather, sensor)

3.1 BRT vehicle modeling based on Modelica

3.2 Weather modeling

3.3 Physics sensor modeling

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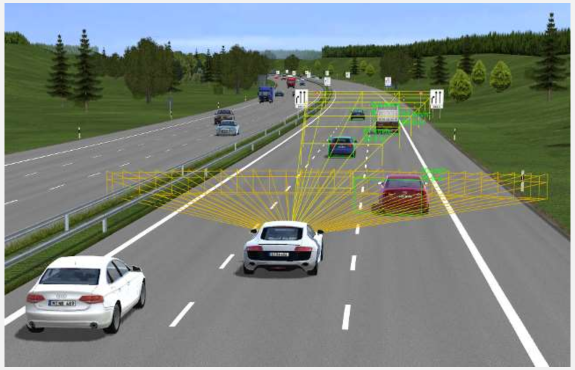
3.3 Physics sensor modeling

Overview of virtual driving environments

Road Network/Logic | Road Surface | Traffic Model | Vehicle Model | Driver Model | Weather Model | **Sensor Emulation**

Virtual Driving Test Environments



Test Scenarios (Open Scenario)

- ADAS
- Autonomous
- Fuel Consumption
- Driving Ability
- NVH
- Durability
- R&H

Driving Simulator | HILS | Simulation

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3.3 Physics sensor modeling

Raytracing Rendering

- Particle, ray and wave based physical measurement methods shall be approximated

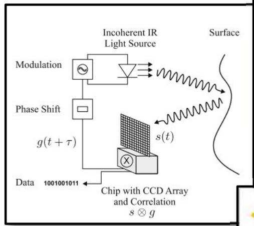
  Emitter type of Sensor type

  Ray : Camera, Lidar

  Wave: Ridar

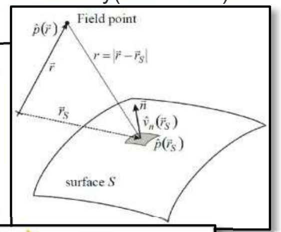
- Physics-oriented modeling of
  - sensor data acquisition process
  - related systematic and stochastic distortion effects
  - material, surface and emitter properties

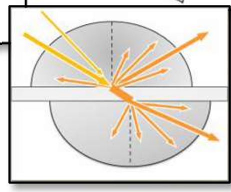
Way(Refraction)



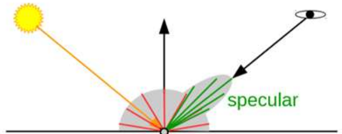
[Source: Keller, Kolb]

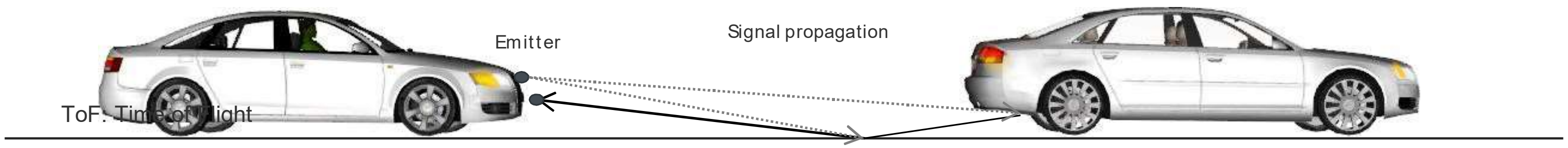
Ray(Reflection)





BRDF (Specular)





10 E. Roth, T. Calapoglu, et al.

3.3 Physics sensor modeling

Raytracing Rendering

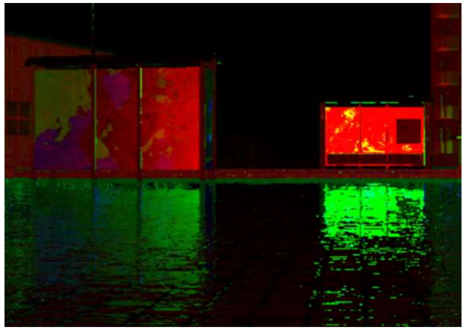
Building shape on vehicle surface

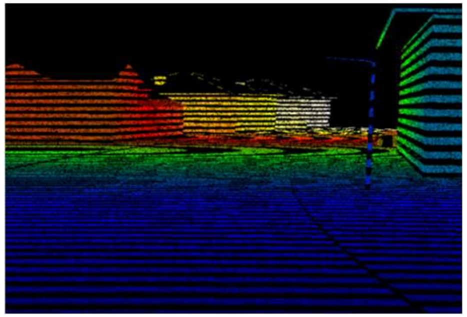
Rainfall Puddles on Roads and Projection Phenomenon of Peripheral Environment

- Supports Physically Realistic Materials-based landing for simulation reflecting light reflection characteristics
- Apply BRDF (Bidirectional Radiance Distribution Function) to reflect opposite and diffuse reflection characteristics of light
- VTD reflects all the material information (light characteristics) for the object and is basically provided.
- During PBR (Physical Based Rendering) simulation, scenario evaluation is possible, such as simulation of incorrect recognition of the vehicle or pedestrian shape reflected by rainwater or misrecognition of objects projected onto the vehicle surface.

3.3 Physics sensor modeling

Lidar Physics Sensor





- Support for parallel processing of NVIDIA CUDA Platform based on Lidar sensor simulation→ Guaranteed Realtime
- Hit map (3-point hit calculation) Output data and VTD lidar sensor calculates up to ray reflected 3 times.
- Output Relative distance data
- Provides raw data such as x, y, z, and intensity information of cloud points

3.3 Physics sensor modeling

Velodyne lidar sensor modeling

Velodyne

- 16 channels
- 32 channels
- 64 channels

udp

ROS environment

Interface

Environment

Velodyne

(Raw Data Format)

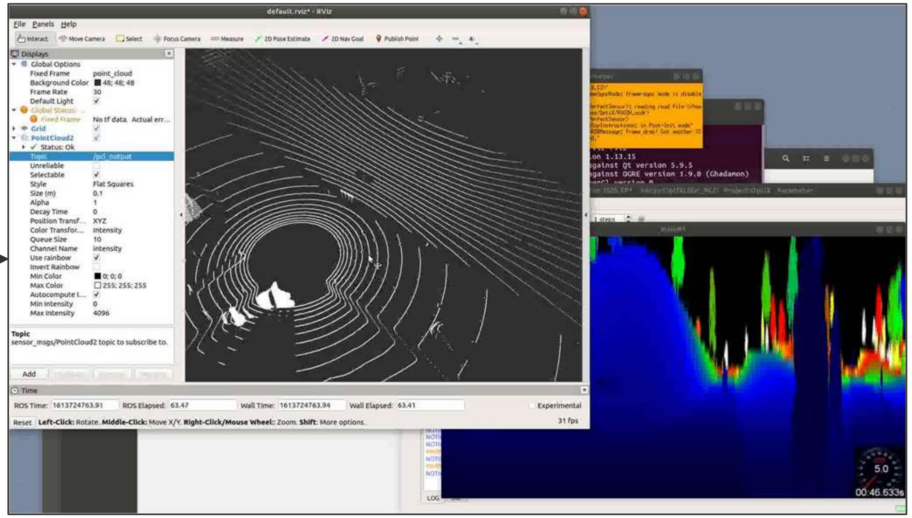
- 16 channels (600rpm)
- 32 channels (600rpm)

udp

Driver Logic

Autonomous Driving

Vehicle Logic



- Using VTD physics sensor models
- Modeling Velodyne 16 to 64 channel sensors
- Cloud point data linkage based on ROS
- Creating an environment for sharing hardware raw data

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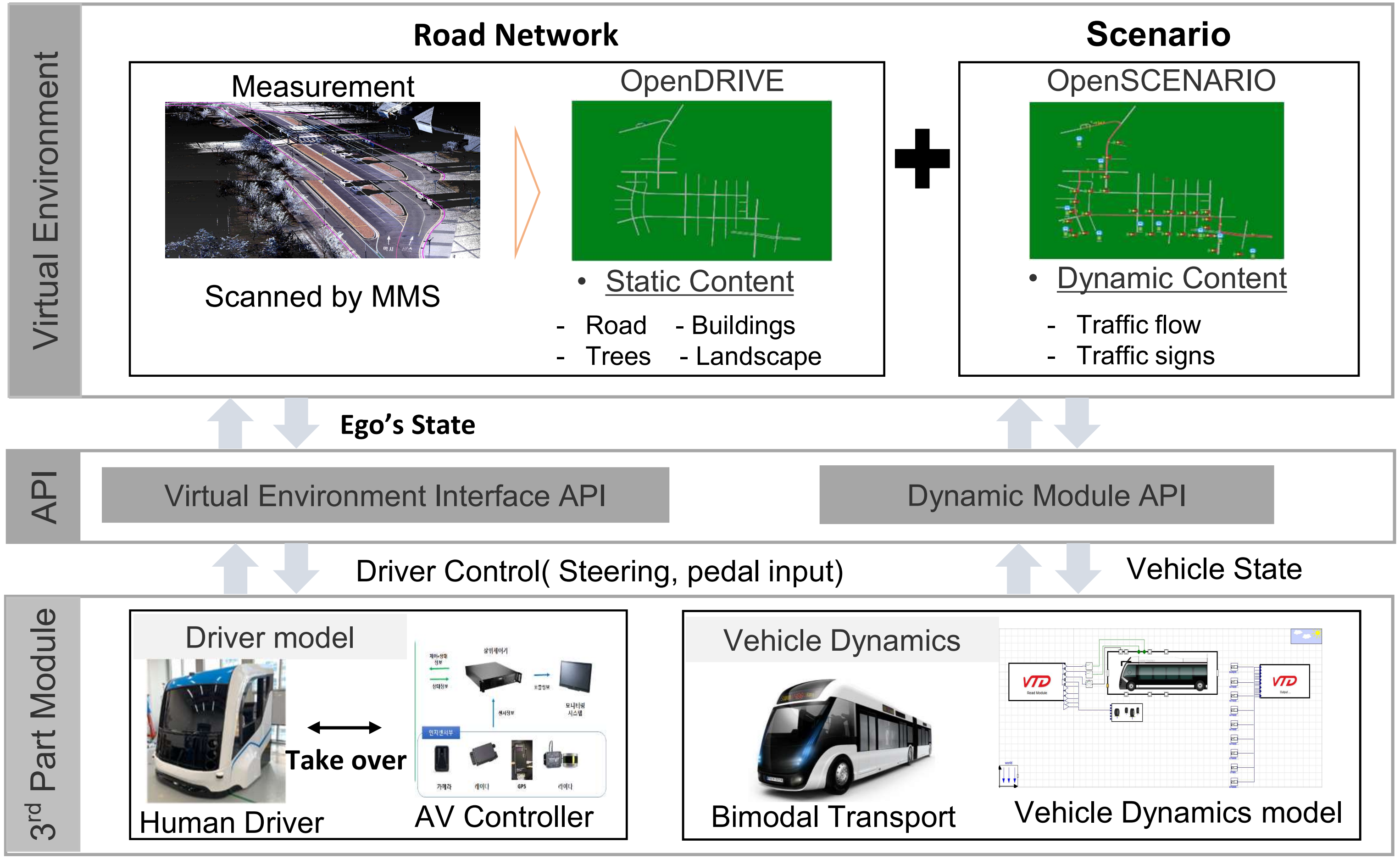
4. Application

4.1 Development of fundamental autonomous driving technology for high-occupancy BRT

4.2 Development of Multi-Communication Network Load Balancing Technology

4.1 Study on the application of electric large-capacity BRT autonomous driving fundamental technology

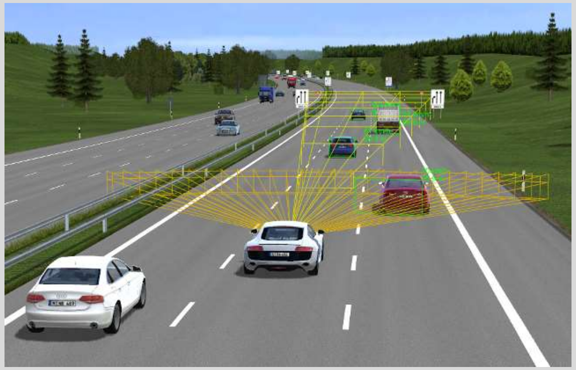
Overview of application case study 1



4.1 Study on the application of electric large-capacity BRT autonomous driving fundamental technology

Road Network/Logic -MMS HD Map	Road Surface	Traffic Model -Pulk Traffic	Vehicle Model -Dymola	Driver Model -KRRI Controller	Weather Model - Sunny	Sensor Emulation -Physics sensors

Virtual Driving Test Environment


Test Scenarios (Open Scenario)

- ADAS
- Autonomous
- Fuel Consumption
- Driving Ability
- NVH
- Durability
- R&H

Driving Simulator	HILS	Simulation

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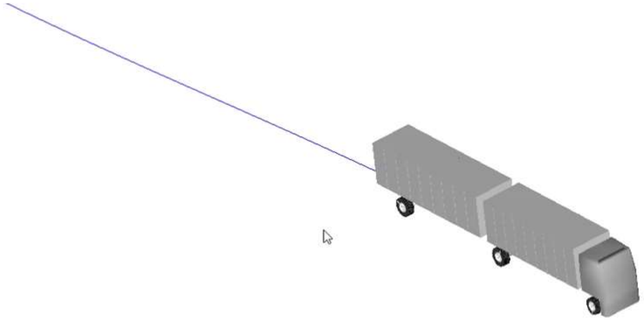
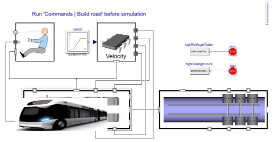
4.1 Study on the application of electric large-capacity BRT autonomous driving fundamental technology

Modeling high-capacity bendy bus

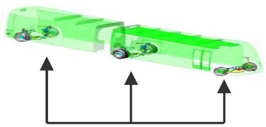


Chassis system



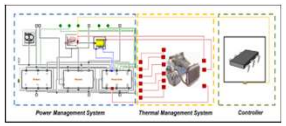
- Developing a chassis system simulating bimodal behavior.

AWS steering wheel



- Developing a multi-axis steering model for Implementing AWS functions.

Dynamometer



- Modeling series hybrid models (diesel engine, motor).

Tire model

- Modeling tire factor design variables.

4.1 Study on the application of electric large-capacity BRT autonomous driving fundamental technology

Running real road vehicle tests

BRT dynamics test method

Acceleration Test

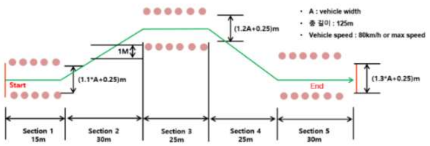
- Driving speed : 70 kph
- Steering input : 0

Deceleration Test

- Driving speed : 70 kph
- Steering input : 0

DLC Test

- Driving speed : Over70 kph
- Steering input : Follow to road



Evaluation Index

$$Error(\%) = \sqrt{\frac{1}{n}\sum\left(\frac{y_s - y_t}{y_t}\right)^2} \times 100$$

y_s = Simulation results, y_t = Mesured value

Preparing for BRT tests

Running public road tests

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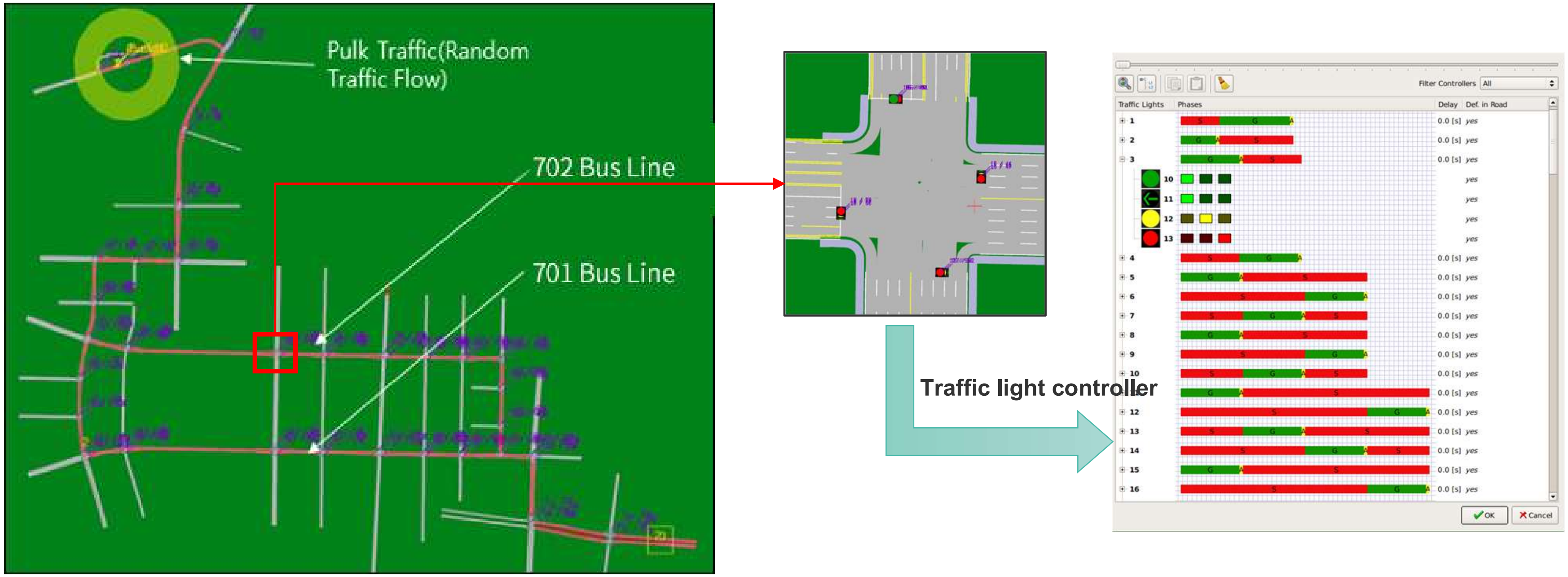
4.1 Study on the application of electric large-capacity BRT autonomous driving fundamental technology

Test scenario modeling



- Development of traffic models for BRT travel routes
  - Generating surrounding traffic based on pulk traffic for BRT traffic routes
  - Creating **round-trip travel scenarios** for Bus No. 701 and 702
  - **Departing after staying** at the bus stop **for 30 seconds**

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4.1 Study on the application of electric large-capacity BRT autonomous driving fundamental technology

Virtual test platform for evaluating BRT control logic

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4.1 Study on the application of electric large-capacity BRT autonomous driving fundamental technology

Evaluating BRT control logic

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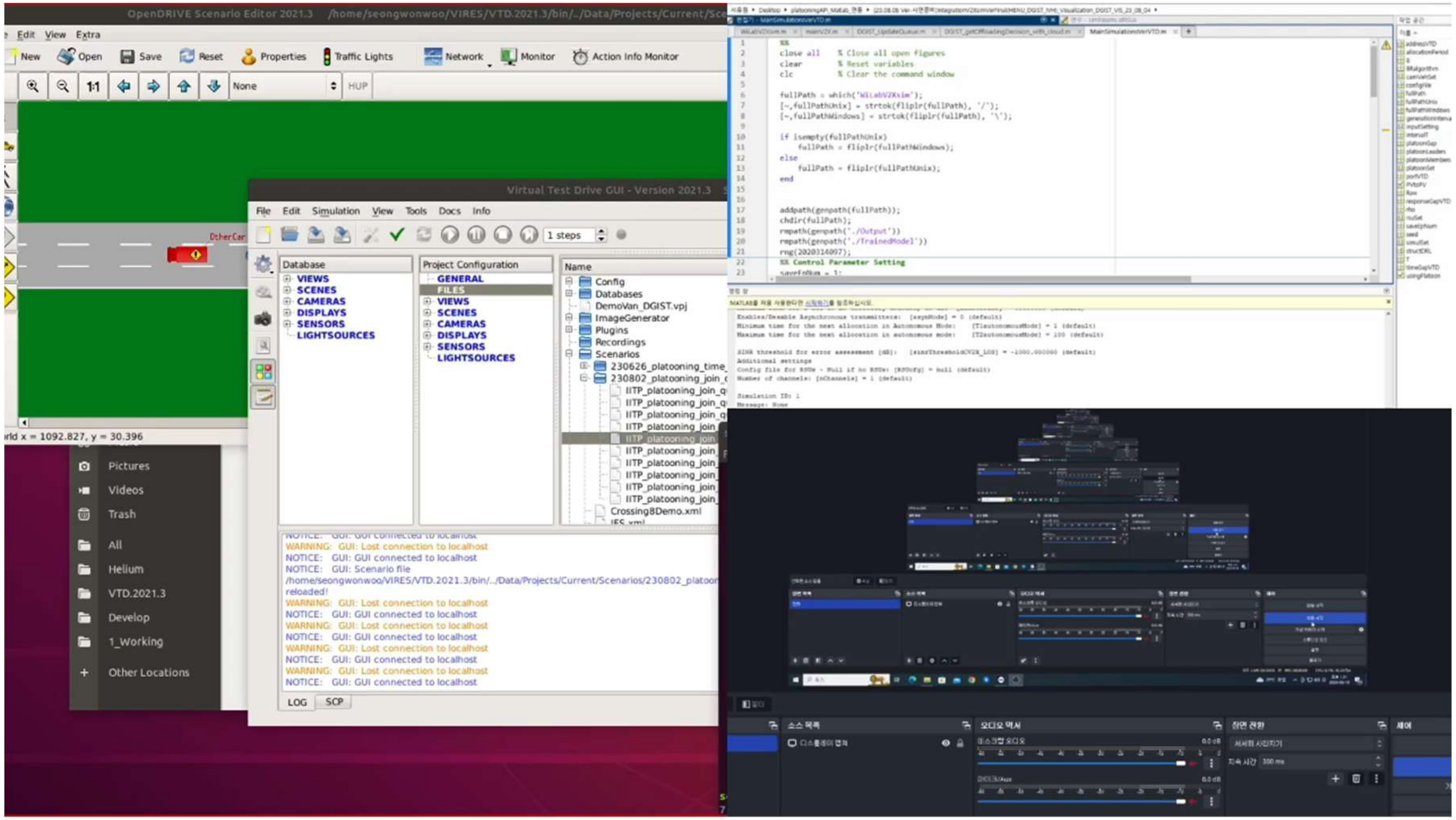
4.2 Development of Multi-Communication Network Load Balancing Technology



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