Establishment of a Virtual Environment for the Development of a Technology to Monitor the Safety of Excavators

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ASAM Association for Standardization of Automation and Measuring Systems

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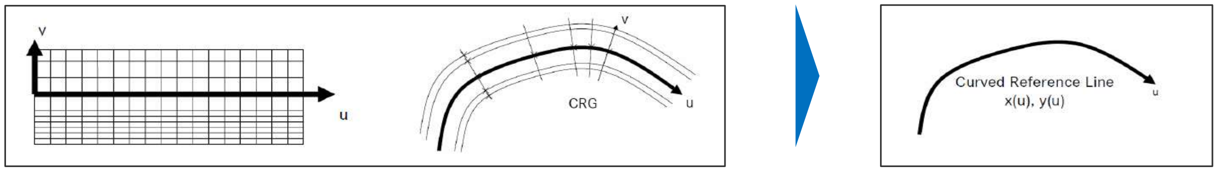
VTD use case : virtual environment for excavator safety monitoring system

Introduction of openCRG

openCRG road surface standard

Overview	Project name	OpenCRG Project
	Development company	Daimler AG, AUDI, BMW, PORSCHE, Volkswagen, VIRES
	Development period	2008 ~
Purpose	▪ To establish standardized open format that defines sophisticated road surfaces.	
Details	 • CRG road surfaces are **modeled based on the reference line**. • The reference line includes heading angle, bank angle, and slope information. • For CRG road surfaces, the reference line is described in the center, and then **the entire road is described in grid data format using each road surface information for the lateral direction of the road**. • Road surfaces can be modeled with **1mm precision**.	
Expected effects of introduction	▪ **Tire simulation, vibration simulation, and driving simulation** can be performed by modeling road surfaces exquisitely.	

Introduction of openCRG

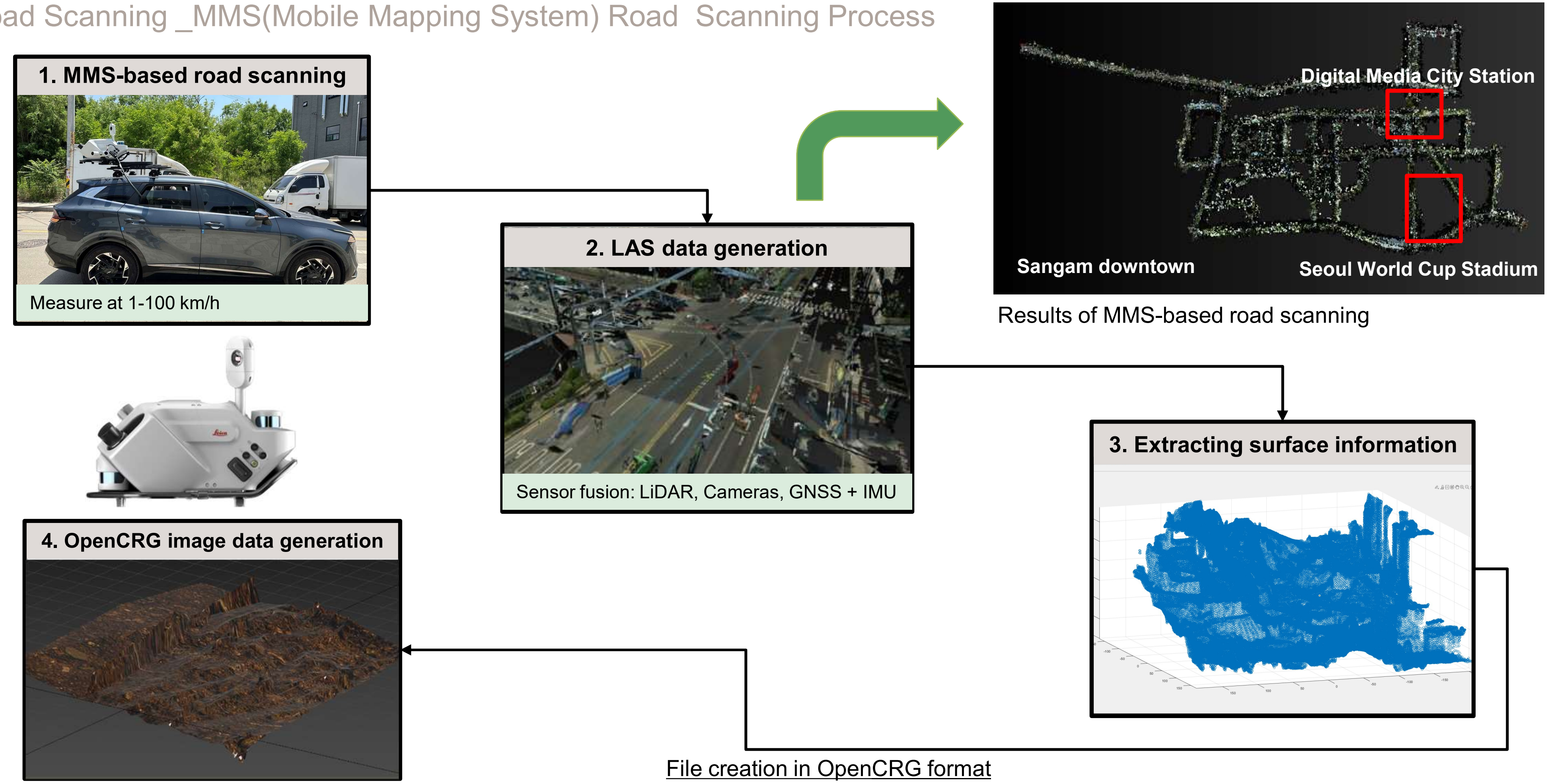
Process of conventional road surface modeling

Measurement method	Method	Limitations
	• Measuring surfaces while stopped, using the stereo camera installed on the top of the vehicle. • **Calibration is required** (for sensor height and level, etc.) **every time the vehicle moves**.	• **Measurement takes long.** • Post-processing of photo data **takes long**.
	• Measuring surfaces on the move after installing laser sensors on the vehicle. • Tracking sensor locations on the move using high-precision IMU.	• Much **external noise occurs in the sensor during measurement, such as vehicle vibration.** • **Limit to road width** that can be measured at one time.

Grid data generation

Modeling of Real Road Environment based on OpenCRG

Road Scanning _MMS(Mobile Mapping System) Road Scanning Process



Modeling of Real Road Environment based on OpenCRG

Process of road surface modeling using iVLS (iVH virtual laser sensor)

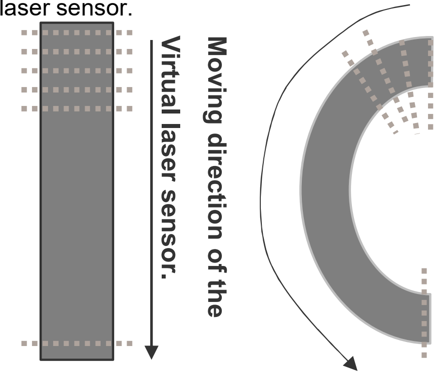
Step1. Scan roads using a 3D scanner.

- Scanning surfaces using 3D scanner equipment (1mm resolution).
- Resolution : 1mm(X) X 1mm(Y) X 1mm(Z)

- **Calibrating cloud points** and integrating data.
- Trimming cloud point data (removing cloud points except for roads).

Step2. Create grid coordinate tables (U,V) using a virtual laser scanner.

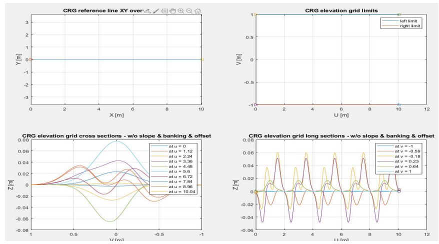
- Creating an interpolation function for measured road surface information at cloud points.
- Developing 1D virtual laser sensors based on the reference line.
- Creating U, V, Z tables based on the 1D virtual laser sensor.



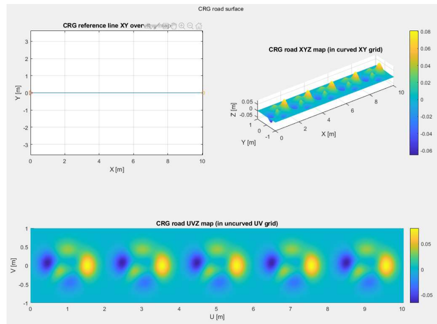
	x1	x2	x3	x4	…	xn
y1						
y2						
y3			Road Z(hight) data			
y4						
…						
yn						

Step3. Create and post-process OpenCRG road surfaces.

- **Verifying the surface using the openCRG post-processor.**
- **Checking road creation** based on the UV and XY coordinate system.

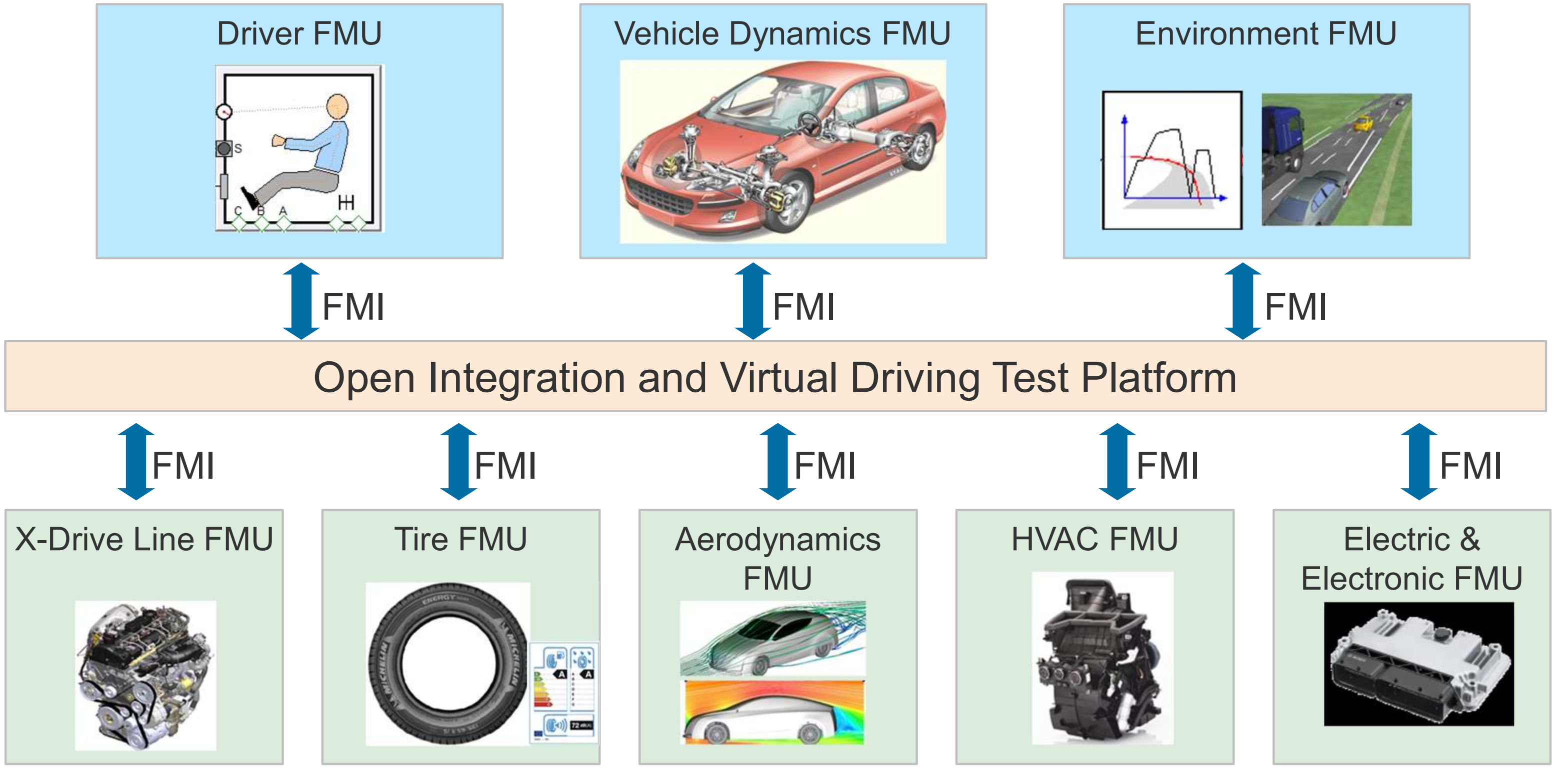


- Checking the 3D road shape



Modeling of Real Road Environment based on OpenCRG

FMI (Functional mock-up Interface)- Vehicle Dynamics interface



- Down Sizing
- Torque vectoring
- ISG

- low weight
- Rolling resistance reduction

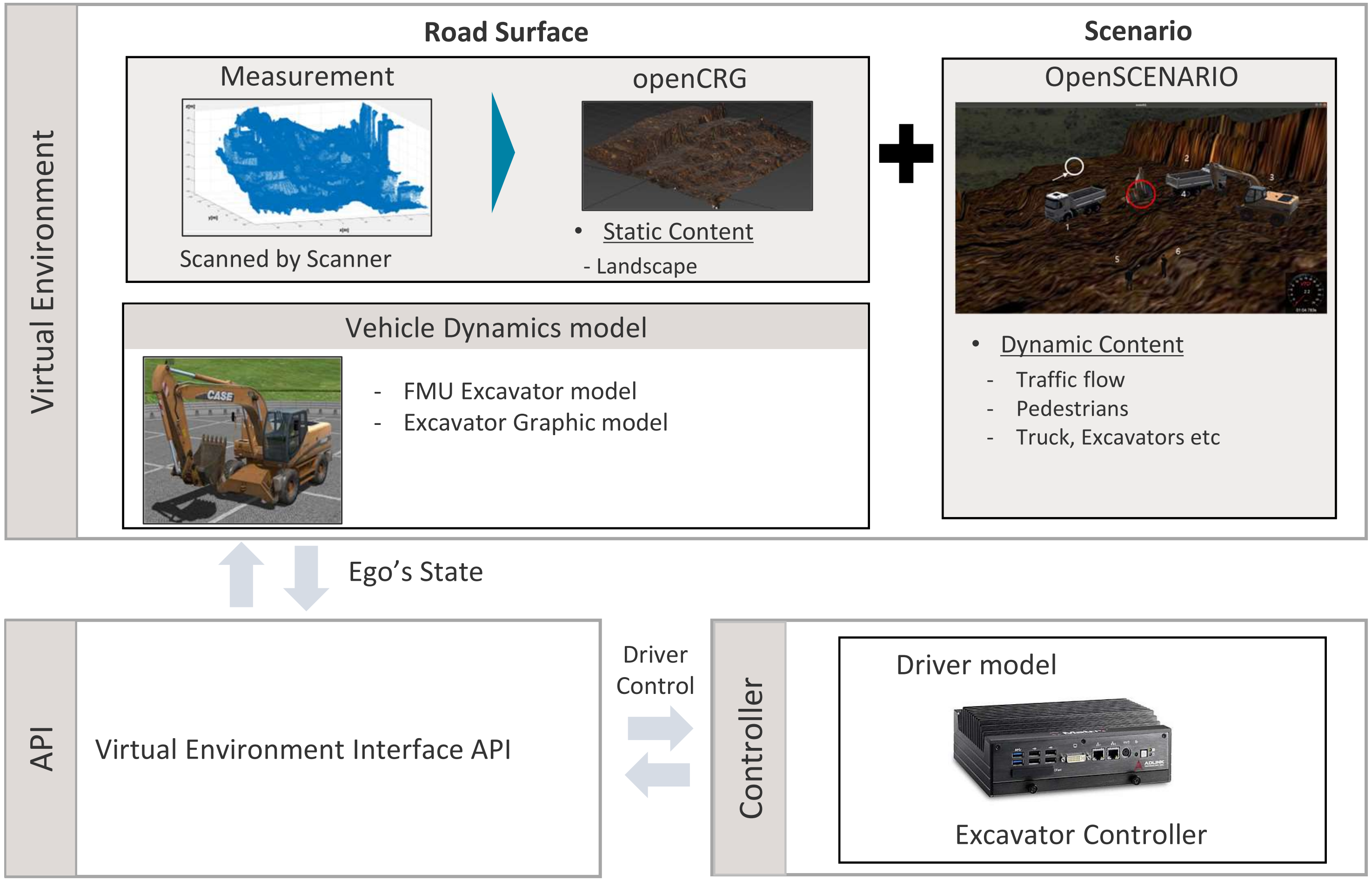
- Reduction air resistance
- Dynamic Spoiler

- EV HVAC
- HVAC control

- Energy consumption
- VCU

Application1: Virtual Environment for Excavator Safety Monitoring System

Development of a toolchain for evaluating the intelligent safety monitoring system of the excavator



Application1: Virtual Environment for Excavator Safety Monitoring System

Development of road surface models for construction sites based on iVLS

Step1. Scan road surface using drone.

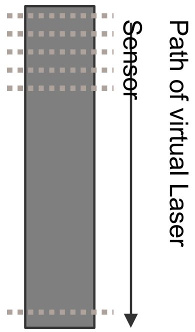
- surface scanning using drone(100mm resolution)
- Resolution: 100mm X 100mm

- Generate point cloud data using stereo camera → generate the same data as cloud point by lidar scanner
- Working area Selection

- **100m x 50m** Selection of test regions and data trimming

Step2. Generate grid coordinate table (u,v) using virtual laser sensor

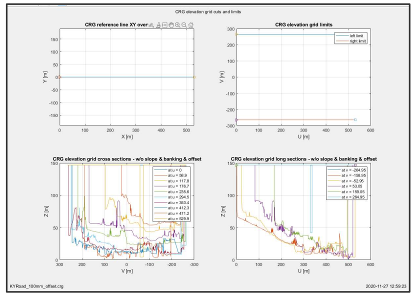
- Generating interpolation functions for road surface information
- Predefine iVLS Driving Path (0.1m length)
- Create U,V,Z tables based on iVLS



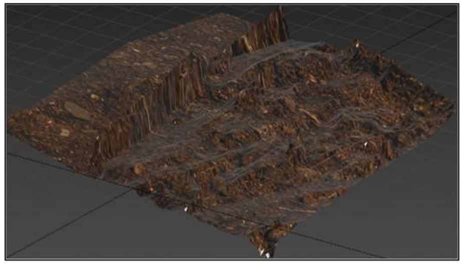
	v1	v2	v3	v4	…	vn
u1						
u2						
u3			Road elevation data			
u4						
…						
un						

Step3. OpenCRG road modeling & postprocess

- Verification of openCRG using postprocessor

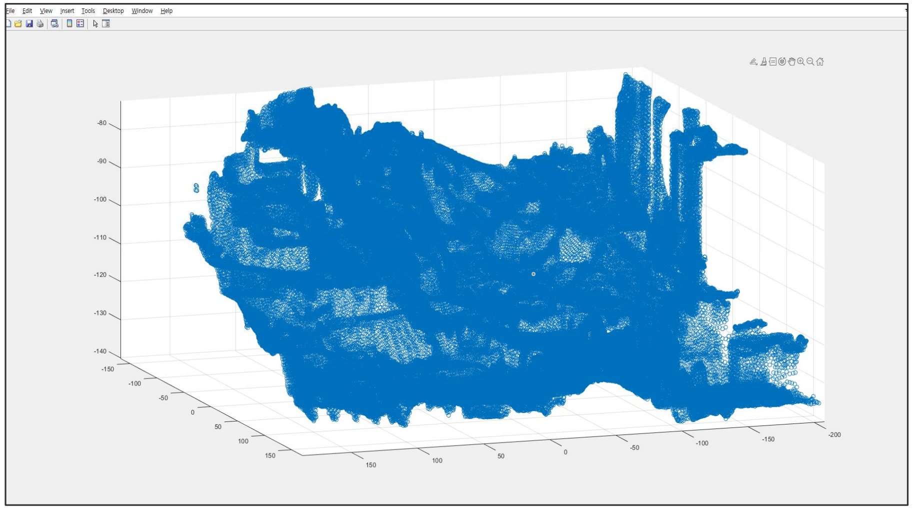


- 3D Graphic model(.flt) generation

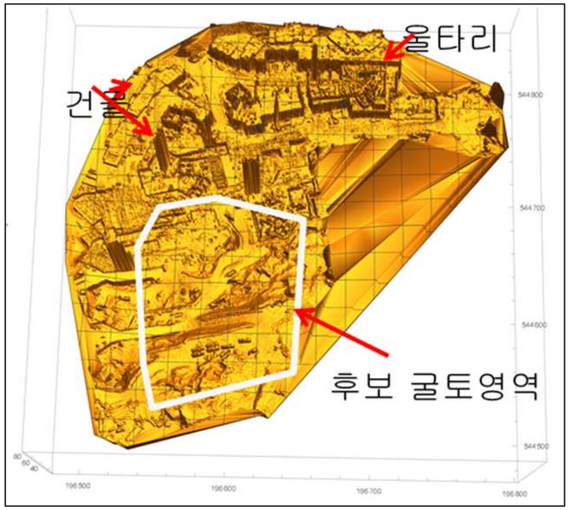


Application1: Virtual Environment for Excavator Safety Monitoring System

Development of road surface models for construction sites based on iVLS



- 10,751,977 cloud points (300m*200m)



- Extract cloud points for 100m*50m area

- Securing openCRG modeling technology for large areas beyond openCRG modeling technology for the existing road width sizes
- Construction Site Texture Modeling Based on 3D Editing Tools

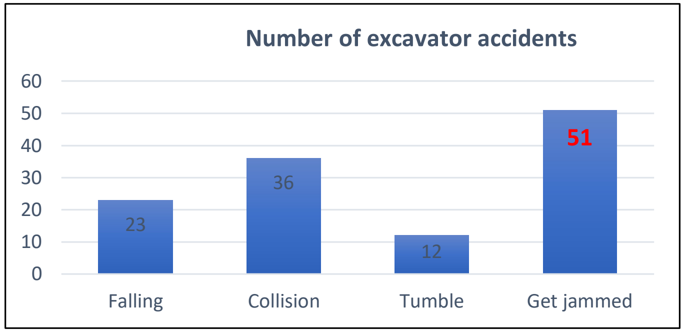
Application1: Virtual Environment for Excavator Safety Monitoring System

Creating and verifying an environment for evaluating the intelligent safety monitoring system for excavators

Application1: Virtual Environment for Excavator Safety Monitoring System

Creating and verifying an environment for evaluating the intelligent safety monitoring system for excavators

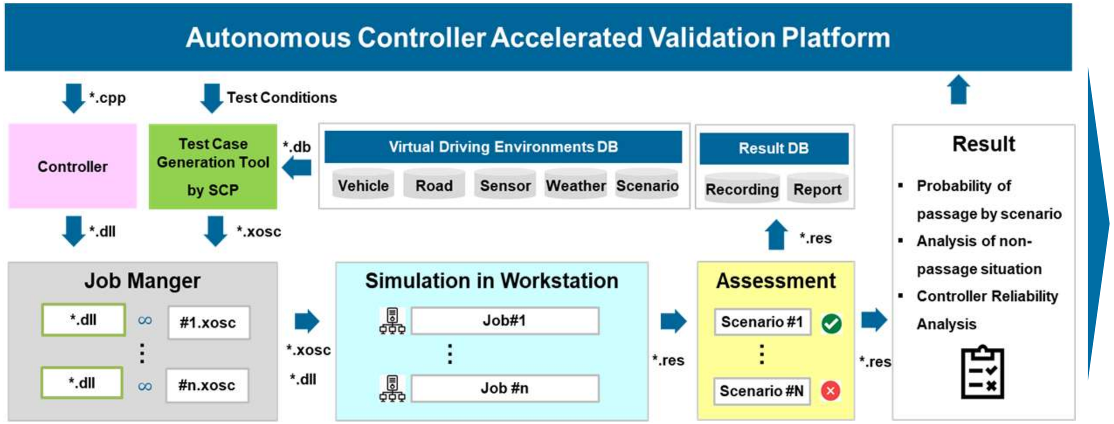
Cases of excavator accidents

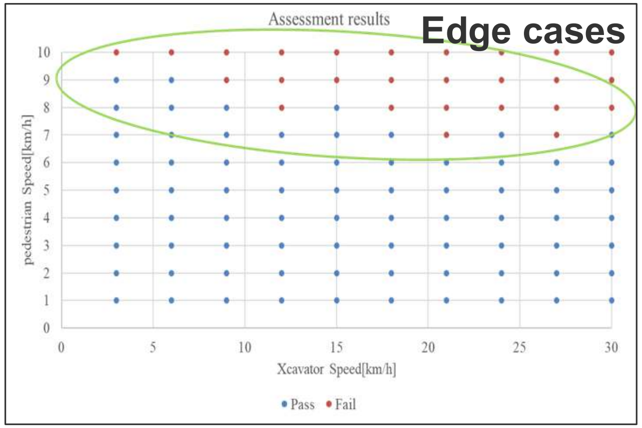


Representative scenario

Number	Type	X (m)	Y (m)	Z (m)
1	vehicle	3.5	29.0	2.2
2	Vehicle	-6.4	36.6	4.2
3	Vehicle	-3.2	50.3	5.8
4.	pedestrian	-4.7	39.5	4.5
5	pedestrian	11.0	47.0	3.4
6	pedestrian	8.6	48.0	4.0

Creating an environment for test automation





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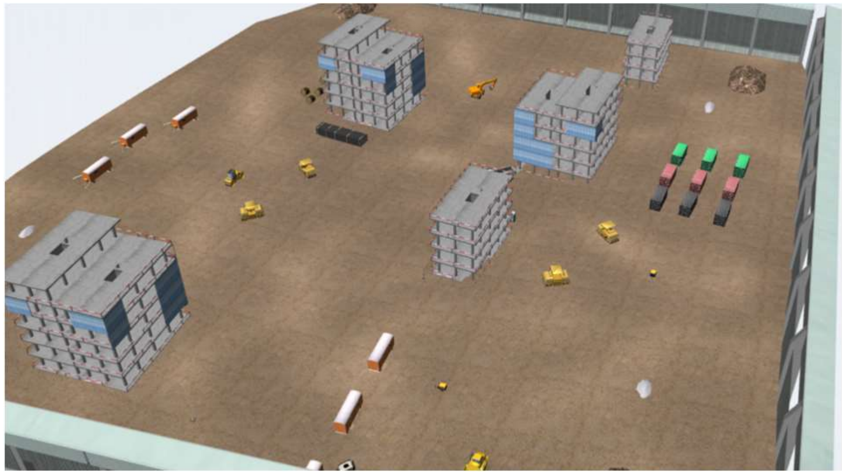
Application2: Creating Virtual Environment Recognition Datasets

Motivation of actual construction site environment

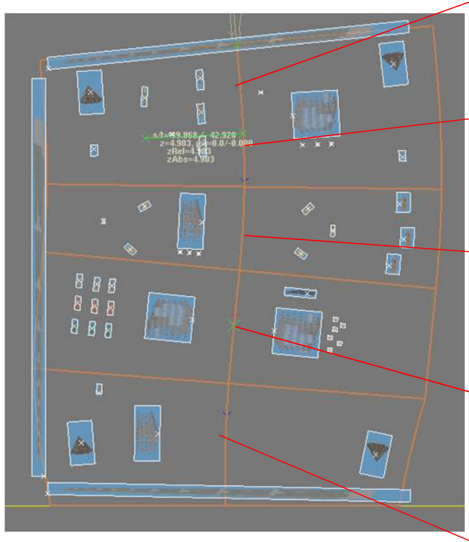
Real construction site

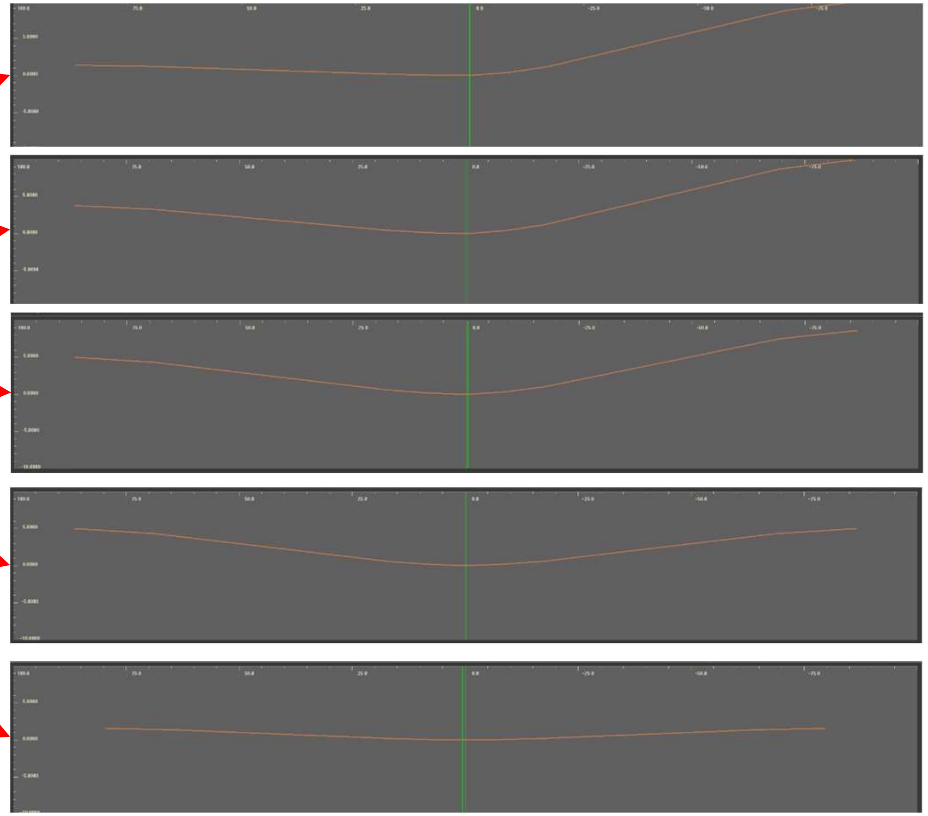


Virtual construction environment

Application2: Creating Virtual Environment Recognition Datasets

Motivation of actual construction site environment





Implementation of longitudinal/transverse gradient of construction site

Application2: Creating Virtual Environment Recognition Datasets

Scenario production based on ISO 21815

Scenario	Use Case			
	a	b	c	d
P1-Person (direct)	X	X	-	-
P3-Person (indirect)	X	X	-	-
P4-Access & Egress	-	-	-	-
L1-Head-on	X	X	X	X
L2-Reverse-on	X	X	X	X
L3-Backup	X	X	X	-
L4-Dovetailing	X	X	X	X
L5-Passing Head-on	X	X	X	X
L6-Passing Reverse-on	X	X	X	X
L7-Overtaking	X	X	X	-
L8-Blind Approach	X	X	X	-
C1-Curving Head-on	X	X	X	-
C2-Curving Dovetail	X	X	X	-
C3-Curving Reverse-on	X	X	X	-
T1-Merge	X	X	X	X
T2-Crossover	X	X	X	X
T3-Junction	X	X	X	X
T4-Intersection	X	X	X	X
R1-Swing	X	X	X	X
R2-Drop	X	X	-	-
O1-Obstacle	X	X	-	-
V1-Void	X	X	X	-
V4-Loss of Control	X	X	X	-
V6-Congested Area	X	X	-	-

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Application2: Creating Virtual Environment Recognition Datasets

Scenario production based on ISO 21815

ISO 21815 'Earth-moving machinery — Collision warning and avoidance'

- Considering the area and level of collision risk for machines using the detection system and avoidance techniques of construction machines
- Scenario Typical Examples : Take-off, Forward/Back, Definition of Turning Scenario
- Definition of stationary areas, expected routes, scheduled routes, and collision risk areas

ISO/TC 127/SC 2 'Safety, ergonomics and general requirements'

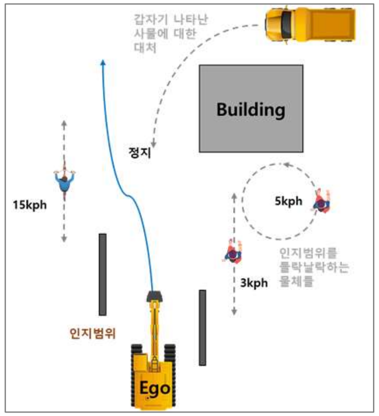
- WG28 : Earthwork machine safety, collision warning and avoidance
- Consideration of ISO 21815 general example scenarios and the test case of ISO/TC 127/SC 2

Contents for Scenarios

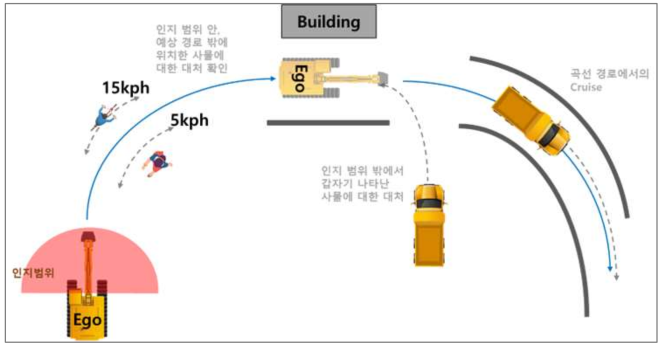
1. **Straight Cruise**
2. **Curve Cruise**
3. **Crossing**
4. **Take off**
5. **Straight passing**
6. **Curve passing**
7. **Rotating**
8. **Junction & Intersection**

Application2: Creating Virtual Environment Recognition Datasets

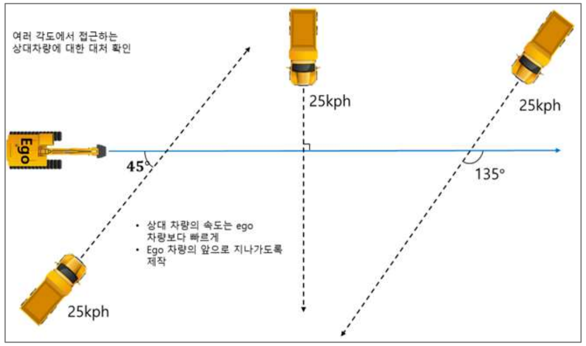
Scenario configuration based on ISO 21815



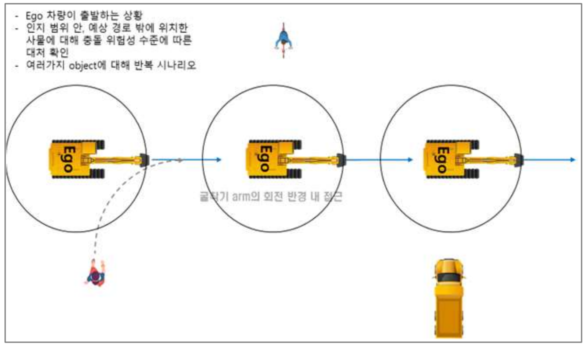
1. Straight Cruise



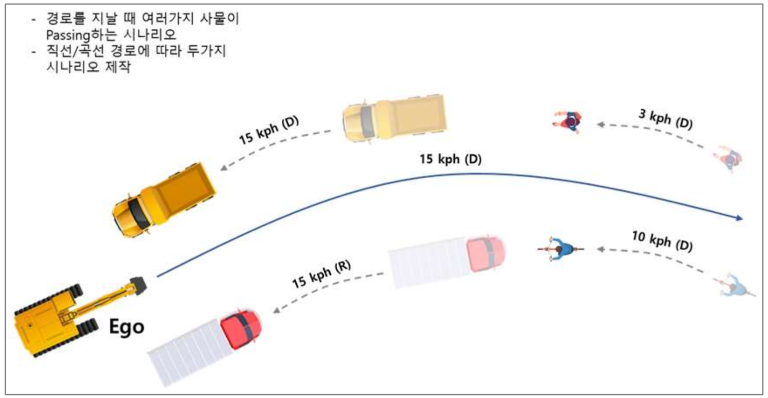
2. Curve Cruise



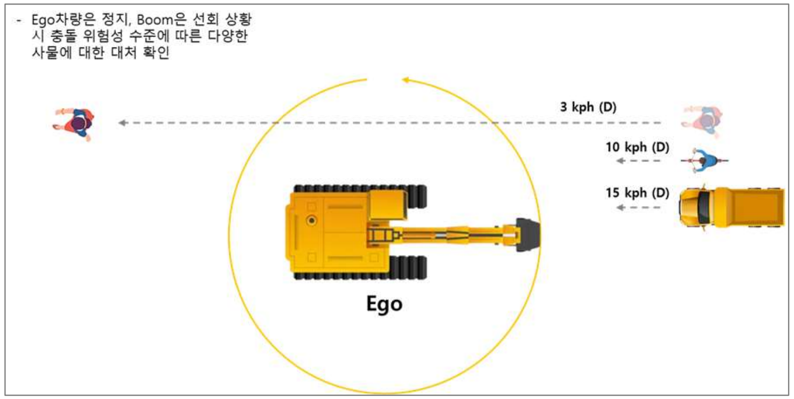
3. Crossing



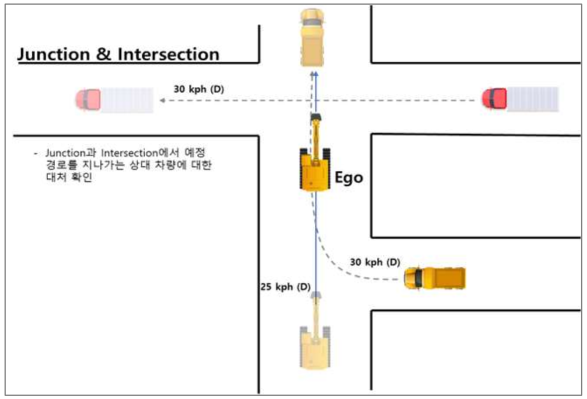
4. Take Off



5,6. Straight/Curve Passing



7. Rotate



8. Junction & Intersection

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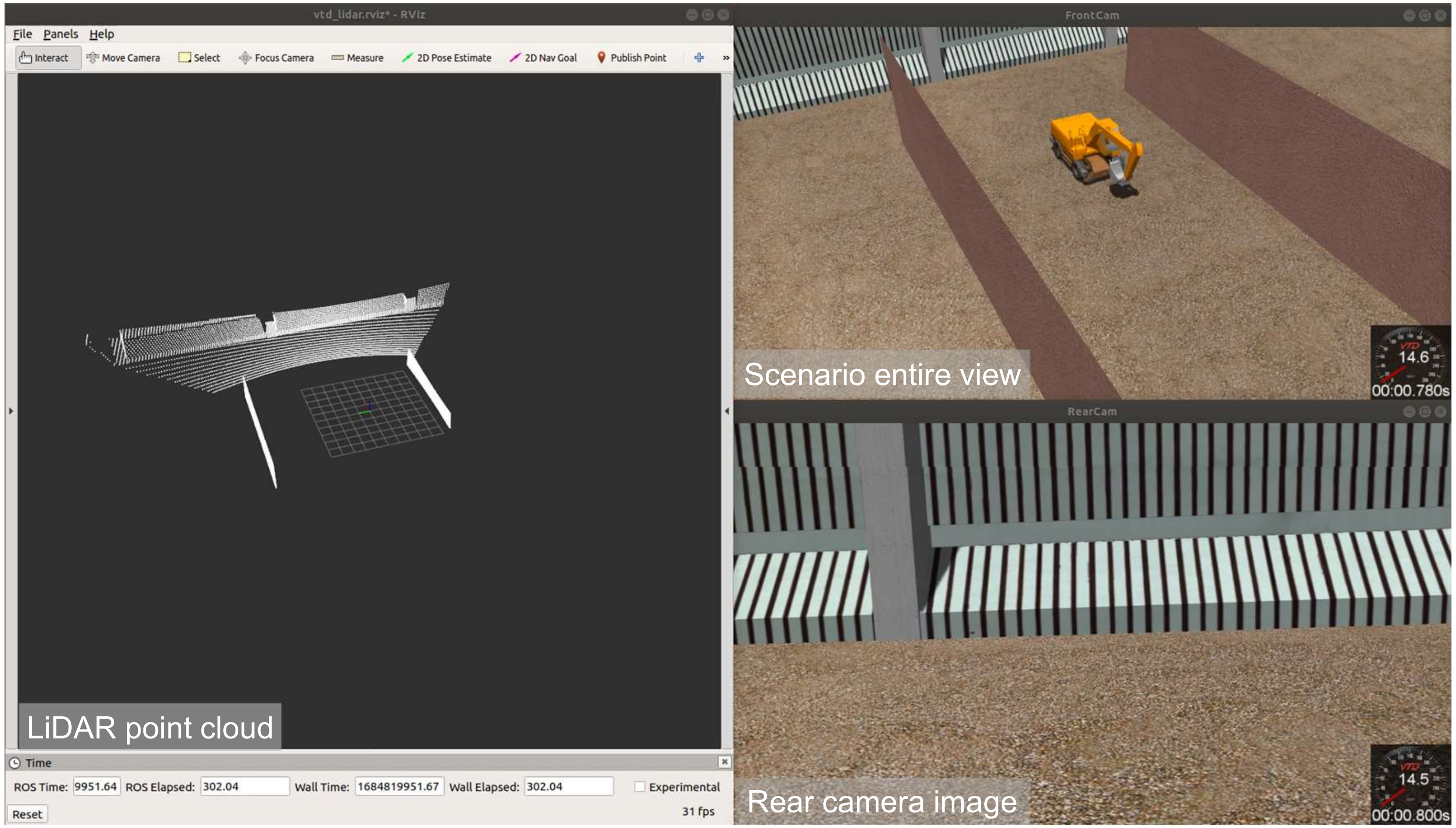
Application2: Creating Virtual Environment Recognition Datasets

Scenario configuration

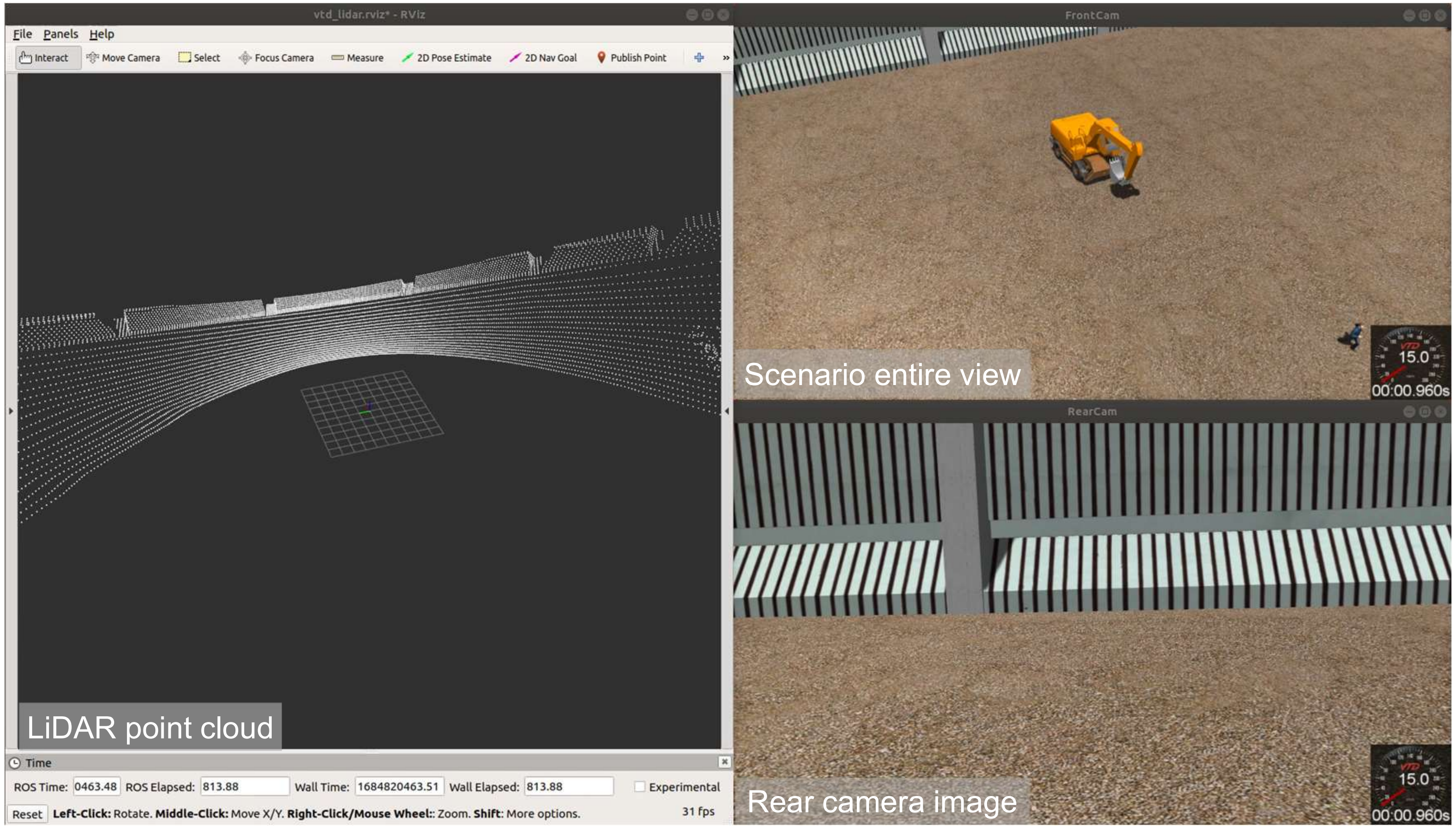
2. Curve Cruise



Application2: Creating Virtual Environment Recognition Datasets

Scenario configuration

5. Straight Passing



Application2: Creating Virtual Environment Recognition Datasets

Scenario configuration

Automatic simulation of scenarios

- Eight defined test cases are automatically executed through the SCP(Simulation Control Protocol) Generator.
- “SCP” is an integrated two-way network interface for the set value of the test case, the sequence of instructions.
- When a scenario ends using the SCP Generator, the phrase "End of Test" appears and then the next scenario is automatically execute.

```
#
   +1 "<SimCtrl> <Stop/> <LoadScenario filename="ksw/Excavator/Crossing.xml" /> <Init mode="operation"/> </SimCtrl>"
wait "<SimCtrl> <InitDone place="checkInitConfirmation"/> </SimCtrl>"
  +1 "<SimCtrl> <Start/> </SimCtrl>"
#  +1 "<Camera name="camlidar"><PosRelative player="cabin" dx="1.0" dy="0.0" dz="0.0"/><Set channel="0x1"/></Camera><Camera name="camOrigin"><PosRelative player="cabin" dx="1.0" dy="0.0" dz="0.0"/><Set channel="0x4"/></Camera><Camera name="camRear"><PosRelative player="cabin" dx="1.0" dy="0.0" dz="0.0"/><Set channel="0x2"/></Camera><Camera name="camlidar" showOwner="true"/><Camera name="camOrigin" showOwner="true"/><Camera name="camRear" showOwner="true"/>"
#  +1 "<Set entity="player" id="1" name="Ego"><Speed value="3"/></Set>"
#  +1 "<Traffic><ActionSpeedChange rate="4.0" target="3" force="true" delayTime="0.0" activateOnExit="false" pivot="" actor="Ego"/></Traffic>"
 +30s "<Symbol name="expl01" > <Text data="End of Test" colorRGB="0xffff00" size="50.0" /> <PosScreen x="0.01" y="0.05" /></Symbol>"
 +1s  "<SimCtrl> <Stop/> </SimCtrl>"
#
   +1 "<SimCtrl> <Stop/> <LoadScenario filename="ksw/Excavator/Rotate.xml" /> <Init mode="operation"/> </SimCtrl>"
wait "<SimCtrl> <InitDone place="checkInitConfirmation"/> </SimCtrl>"
  +1 "<SimCtrl> <Start/> </SimCtrl>"
#  +1 "<Camera name="camlidar"><PosRelative player="cabin" dx="1.0" dy="0.0" dz="0.0"/><Set channel="0x1"/></Camera><Camera name="camOrigin"><PosRelative player="cabin" dx="1.0" dy="0.0" dz="0.0"/><Set channel="0x4"/></Camera><Camera name="camRear"><PosRelative player="cabin" dx="1.0" dy="0.0" dz="0.0"/><Set channel="0x2"/></Camera><Camera name="camlidar" showOwner="true"/><Camera name="camOrigin" showOwner="true"/><Camera name="camRear" showOwner="true"/>"
#  +1 "<Set entity="player" id="1" name="Ego"><Speed value="3"/></Set>"
#  +1 "<Traffic><ActionSpeedChange rate="4.0" target="3" force="true" delayTime="0.0" activateOnExit="false" pivot="" actor="Ego"/></Traffic>"
 +30s "<Symbol name="expl01" > <Text data="End of Test" colorRGB="0xffff00" size="50.0" /> <PosScreen x="0.01" y="0.05" /></Symbol>"
 +1s  "<SimCtrl> <Stop/> </SimCtrl>"
```

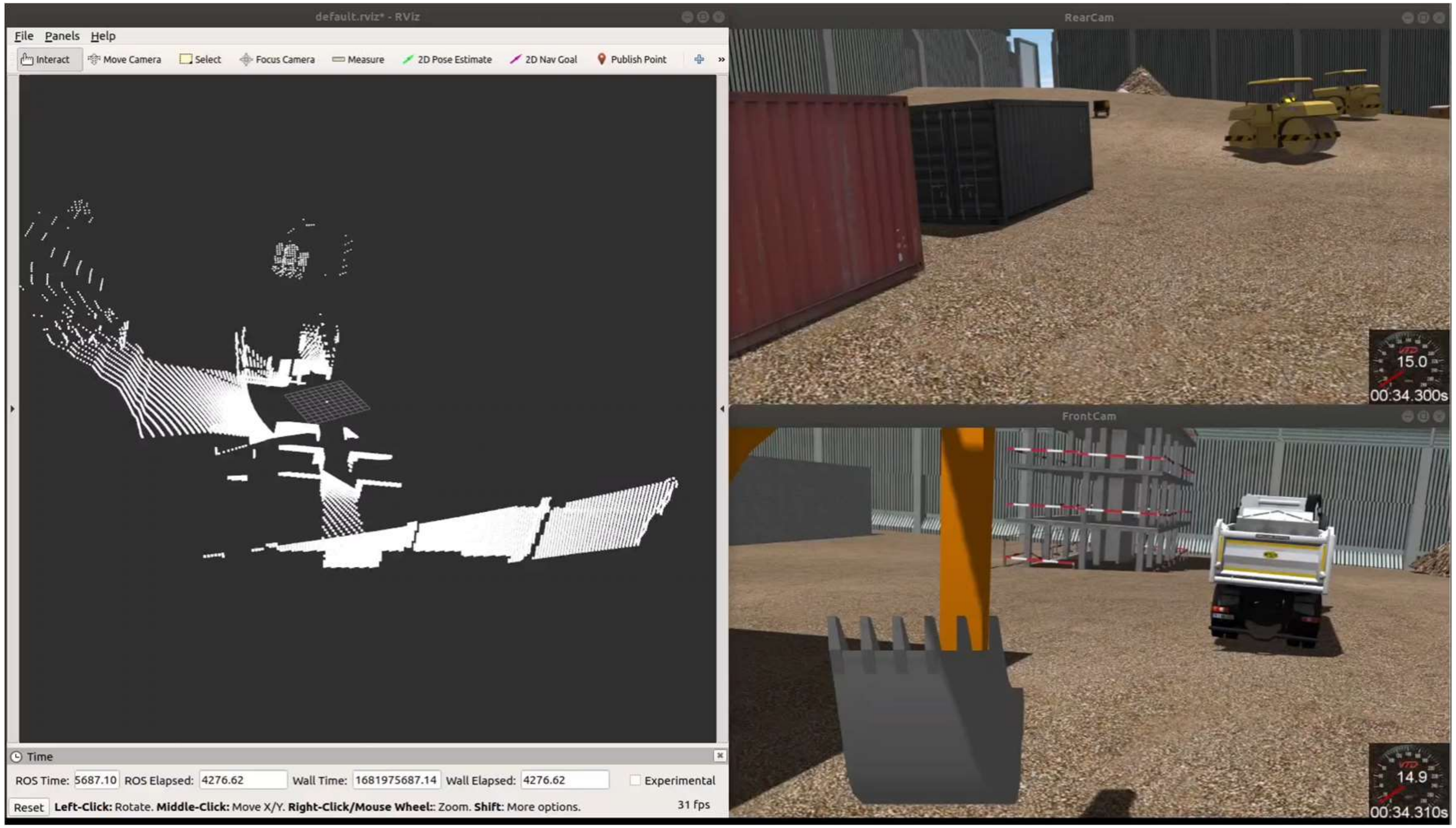
An example of SCP Generator scripts by XML format

An example of automatic simulation using SCP Generator

Application2: Creating Virtual Environment Recognition Datasets

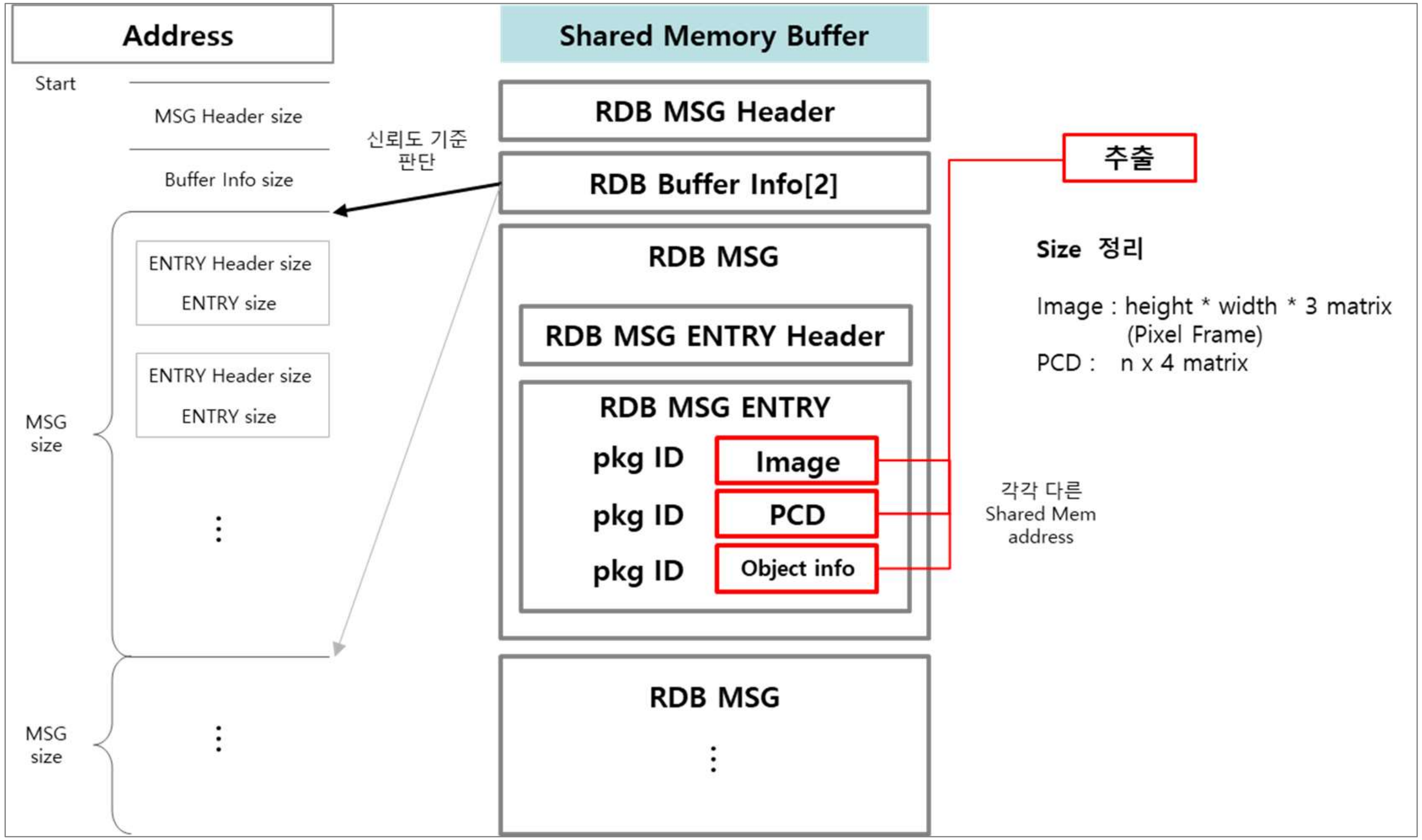
Scenario configuration

Task Automation



Application2: Creating Virtual Environment Recognition Datasets

RDB Msg & Shared memory

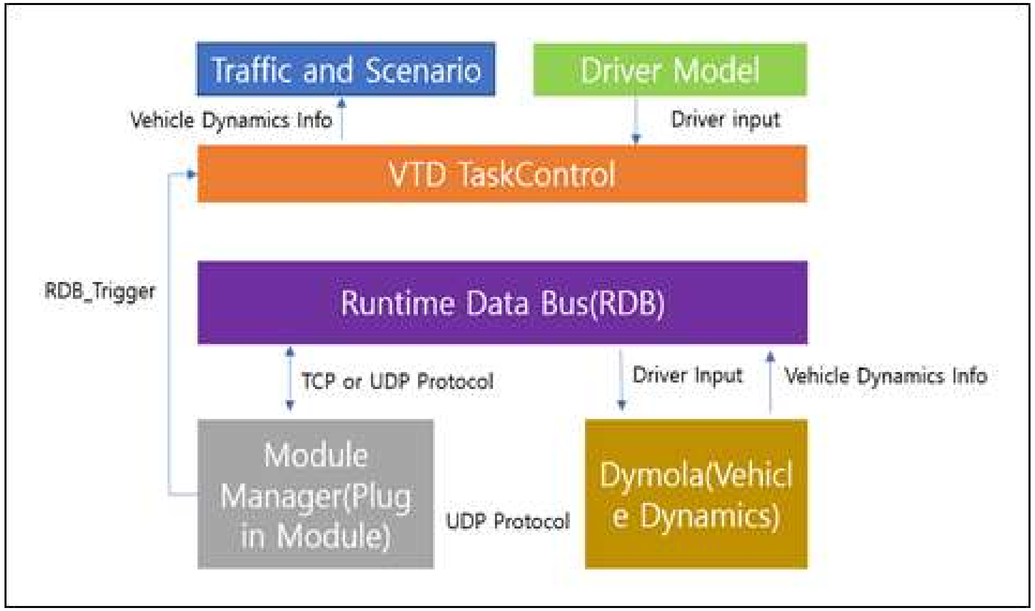


Data Extraction

- Using Runtime Data Bus(RDB) structures in the VTD simulator & Shared memory
- LiDAR point cloud data
- Camera image data
- Information of objects (x, y, z, width, height, length, yaw)

Application2: Creating Virtual Environment Recognition Datasets

RDB Msg & Shared memory



Modelling UDP Communication Module for Virtual Driving Environment

- Module Manager

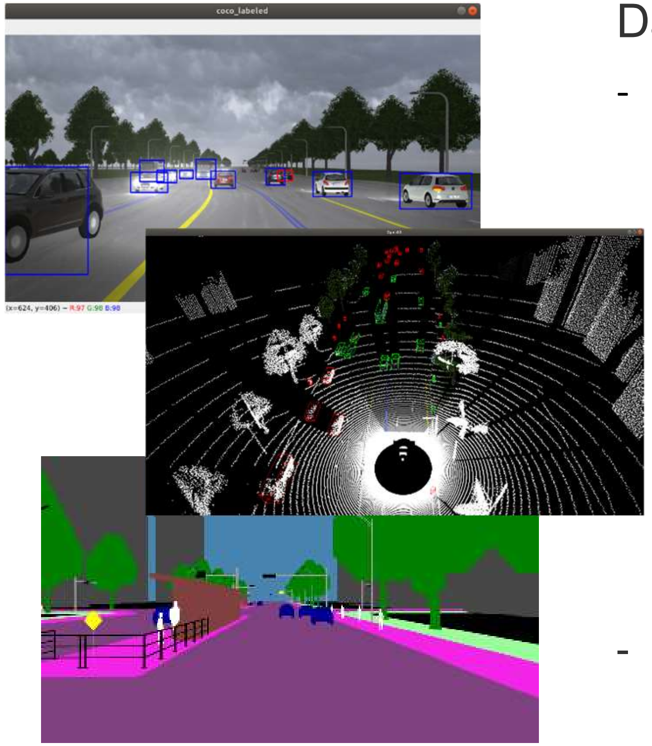
  Plug-in module that automatically executes

  user-generated code

- TCP/UDP protocol
- RDB Trigger

Application2: Creating Virtual Environment Recognition Datasets

RDB Msg & Shared memory



Dataset format

- YOLO(2D Object Detection)
  - class, center coordinates(x, y), width, height
- KITTI(3D Object Detection)
  - velodyne : LiDAR raw data
  - Image_2 : camera image data
  - calib : camera calibration parameters

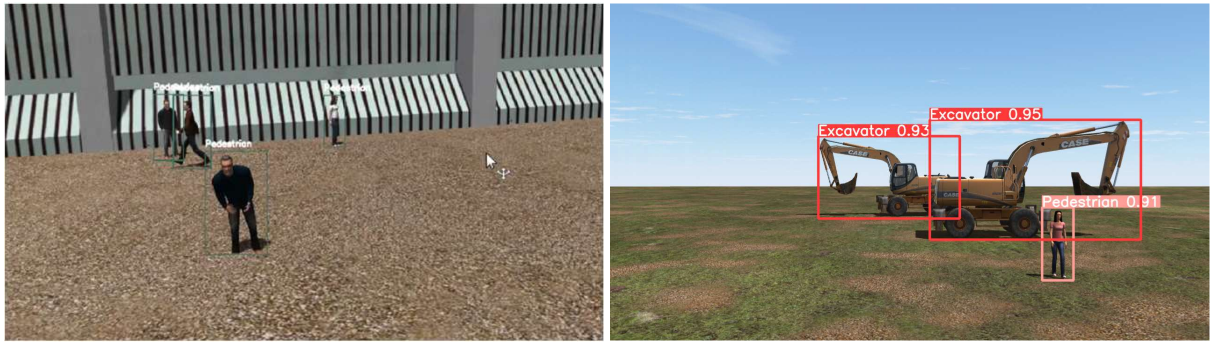
    (internal parameters, vehicle to camera/LiDAR to camera rotation matrix)
  - label : bounding box labeling data
- Cityscapes(Semantic Segmentation)
  - image, ground truth images masked by class

Application2: Creating Virtual Environment Recognition Datasets

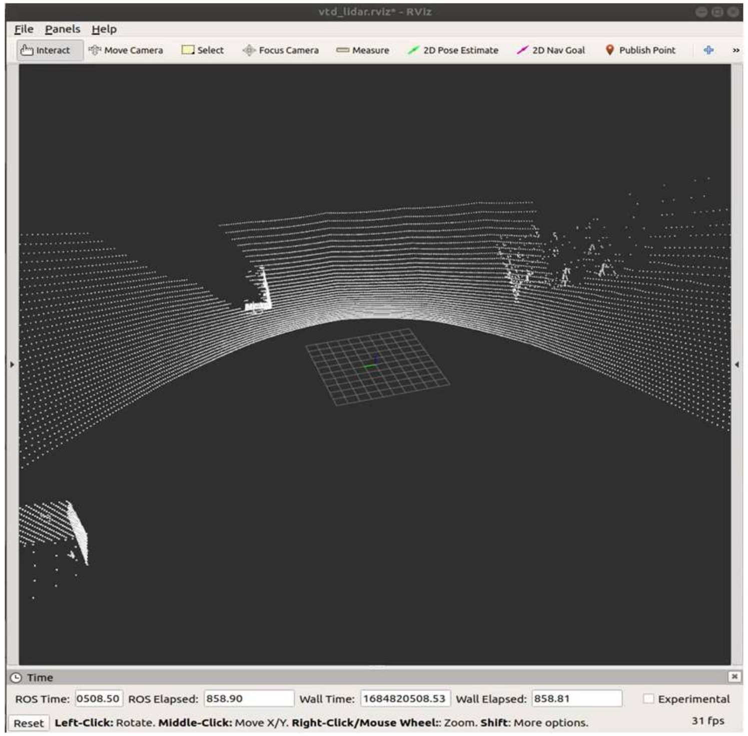
RDB Msg & Shared memory

Configuration of the real-time interface

- Simulation PC – Logic board real-time communication interface
- ROS melodic(ROS1)/noetic(ROS2) Master-Slave communication
    - Image : Data from shared memory -> CompressedImage msg publish
    - PointCloud : Data from shared memory -> PointCloud2 msg publish



An example recognized by the board after receiving the message(YOLO)



LiDAR PointCloud msg visualization

Thank you for your attention!

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e-mail: h2ejsong@naver.com