FY 2018 Report

Strategic Innovation Program (SIP) 2nd period
Autonomous driving (the scalability of systems and services)
Approach development for improving an autonomous driving validation environment in virtual space

<Project member>

Kanagawa Institute of Technology (Representative)

Ritsumeikan university
OTSL Inc.
Mitsubishi Precision Company, Limited
Nihon Unisys, Ltd.
Denso Corporation
Hitachi Automotive Systems, Ltd.
PIONEER CORPORATION
SOKEN, INC.
SOLIZE Engineering Corporation

March 29, 2019

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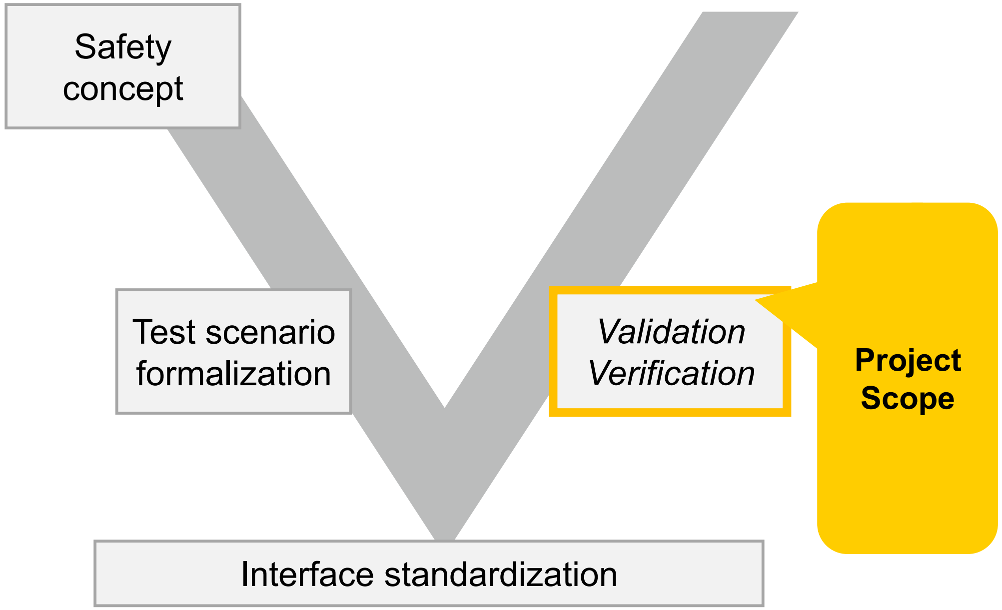
Project overview

Driving Intelligence Validation Platform (DIVP) is able to validate Sensor malfunction caused Performance limit, with standardized Interface

Project perspective

Standardized Validation platform

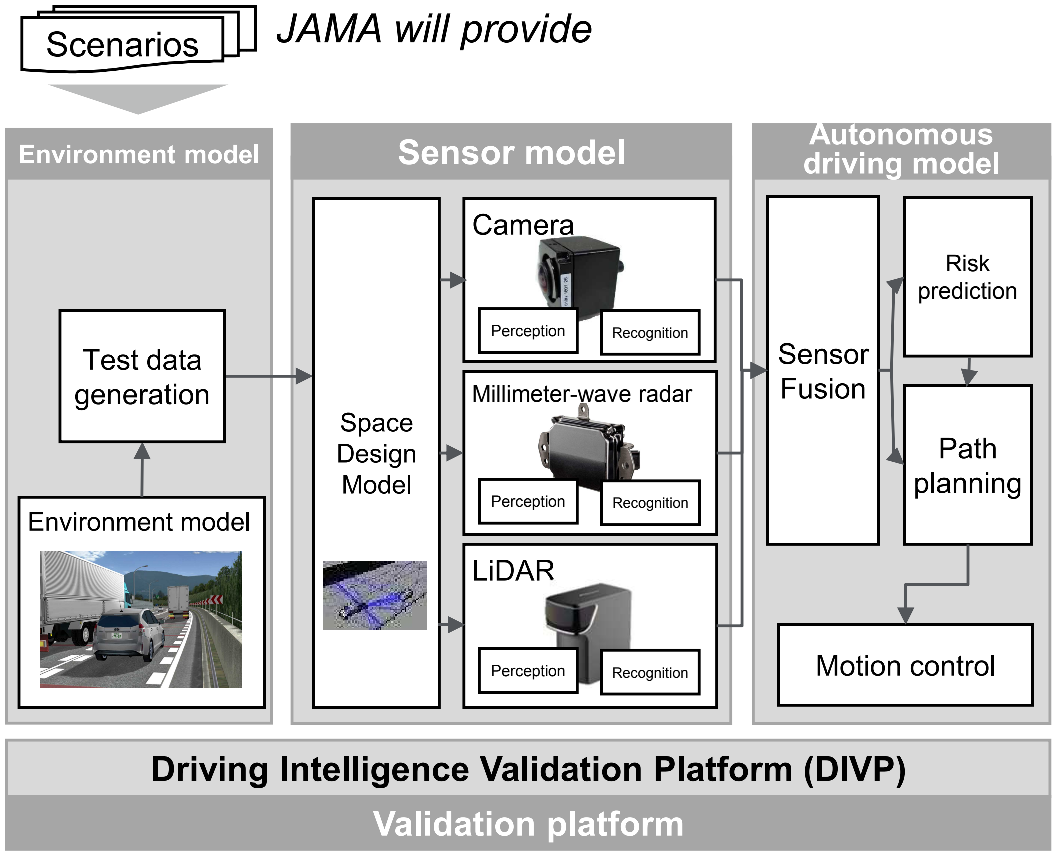
Safety assurance procedure for Autonomous



Standardized Platform
improve competitiveness of vendors and suppliers

Validation platform concept

Sensor Validation model



Enhancing capability for Sensor malfunction caused performance limit enables to increase the capability of Autonomous System's Safety Validation in virtually, ***contributes to Automotive industry including OEMs***

Source: Mitsubishi Precision Company, Limited, SOKEN. INC. Hitachi Automotive Systems, Ltd.DENSO CORPORATION, PIONEER CORPORATION

Although Autonomous driving system increasing complexity with AD-level, Higher-level safety must be secured in all potential driving situation

Conventional system design limits

Current System design

Design concept

- Individual Sensor malfunctions are screened thru Sensor's Recognition and/or Fusion in Autonomous system, not make Vehicle maneuver un-Safe

System architecture

Sensor		Autonomous driving control		Vehicle behavior
Perception	Recognition	Sensor fusion	Judgement, Planning	*Vehicle maneuver*
Perception	Recognition			
Perception	Recognition			

Vehicle maneuver

- *Intended performance*
- *Performance limits*
  - ✓ *Sensor malfunctions*
  - ✓ *Traffic disturbance*
  - ✓ *Human error*

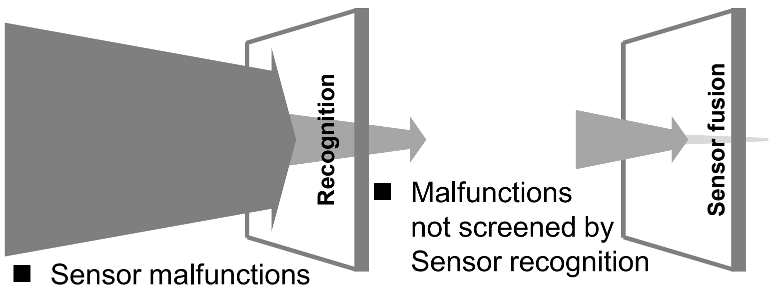
Intra-system processing

Recognition processing

- Screening sensing noises electric environmental ,etc. caused

Sensor fusion

- Compare, combine, adjust Sensor signals to screen as system level



- Sensor malfunctions
- Malfunctions not screened by Sensor recognition
- **Performance limits due to Sensor malfunctions** that the system cannot screened

Indicator of limit

Recent Car accident

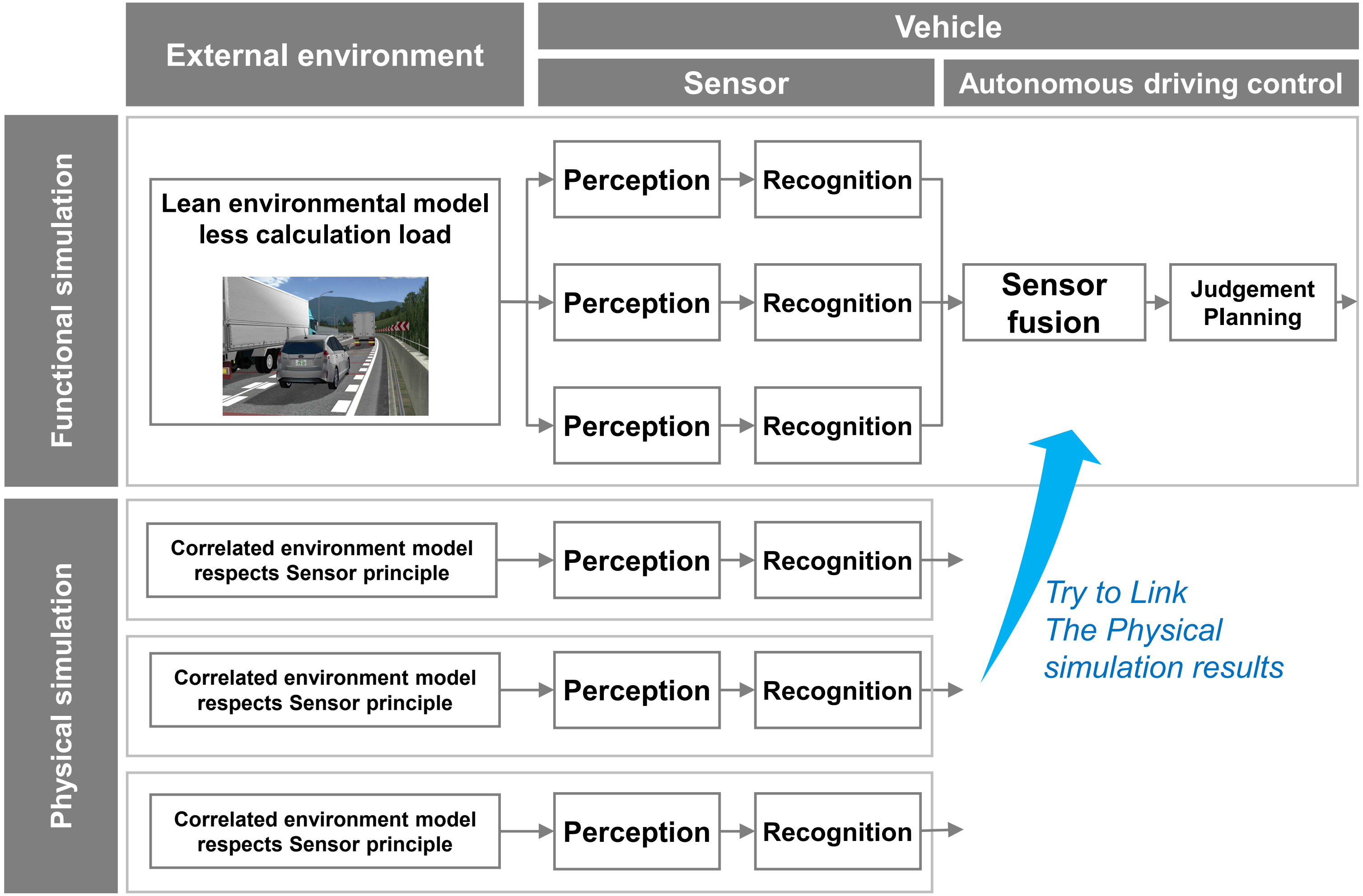
- One car failed to accurately detect a trailer and control itself due to the confluence of camera and radar malfunctions.
  - ✓ Camera failed to recognize the trailer due to the white side of the trailer under bright sky.
  - ✓ Signal processing of the car radar's recognition processing is designed not to recognize large-area reflection of an object as an obstacle.

Multiple Sensor malfunction cases combination was out of Validation and caused incident

Total System Design & Validation must screen & secure whole potential path of failure mode caused by Sensor malfunction as system

Define architecture & Interface in "Functional simulation", and then detail model implemented "Physical simulation" enables Sensor malfunctions

Strategy of DIVP



Target performance

- **Validate as total system**
- **Validate the Vehicle's intended performance**
- **Validate performance limits**

Functional simulation validating autonomous driving system functions
- ✓ *Real-time processing*

- **Validate performance limits due to Sensor malfunctions and other failures in a detailed manner**

Physical simulation validating Physical phenomena of Sensors
- ✓ *Heavy computational load, and less speed processing*
- ✓ *Limited connectivity to Sensor fusion*

Connection between real-time "Functional simulation" & precise but slow "Physical simulation" is further research theme

•Source: Mitsubishi Precision Company, Limited

The Project Target is verification & to define Validation Platform can Validate Performance limits due to Sensor malfunctions, etc.

Project Target & approach

	Target	Approach
Basic function	■ Validating intended autonomous driving performance in a virtual environment	■ Verify the consistency of Validation results between virtual and real environments
Advantage	■ Capable for validating performance limits in a virtual environment due to autonomous driving recognition failures	■ Research the connection the "Physical simulation" output into "Functional simulation"
	■ Able to check individual outputs in each Nodes after Sensor, after recognition, etc. ■ Able to investigate Plug&play of each Block bases	■ Define a standard Platform has standardized Interface in each Node

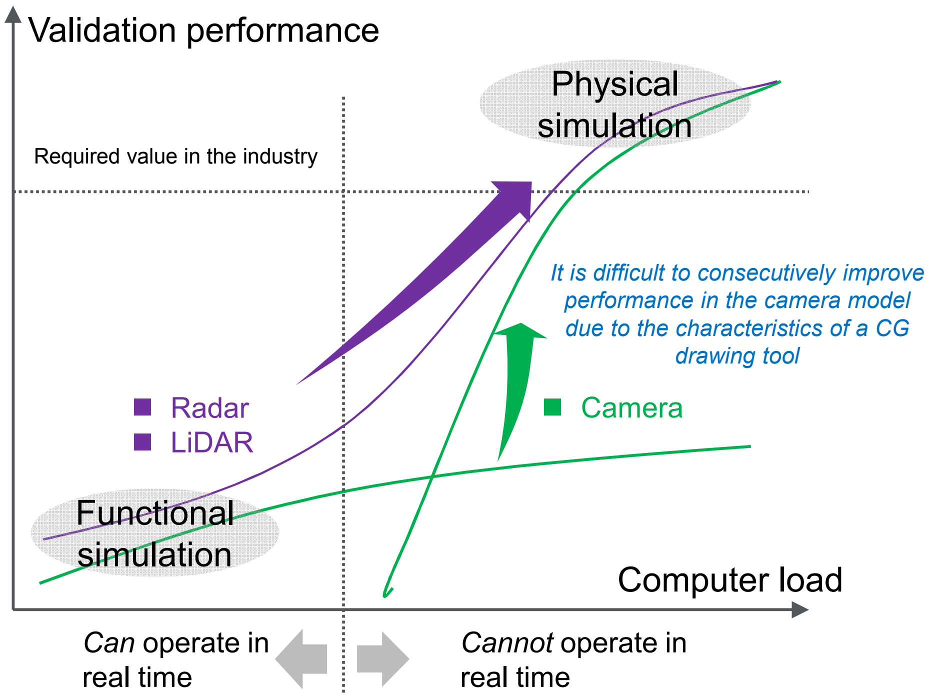
Outcome toward Target

Interface specification Document	■ Interface specifications that could be standard for the autonomous driving Validation environment ■ Build an environment consisting of the Functional simulation and the Physical simulation
Functional simulation	■ ***Real time validation capability*** ■ One & only verified simulator vs real world ■ Capable of simulating in typical scenes ■ Similar Performance limit's maneuver vs real world ■ Capable of Plug&Play each component
Physical simulation	■ ***Highly correlated Sensor model, can contributes industry with Validation possibility of Sensor malfunction caused Performance limit*** ■ One & only verified simulator vs real world ■ Capable of Plug&Play each component

Target is "Physical simulation" to validate sensor malfunction, through Continuous growth from real time "Functional simulation"

Direction Simulation growth

Growth chart from Functional simulation to Physical simulation



Step by step Target

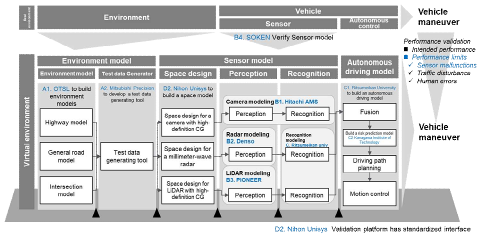
Step	Validation	Performance goal
Step 1	■ Joint check	■ Activate & simulates sample scenario
Step 2	■ Functional simulation Verification	■ Simulate basic driving scenes (Intended maneuver)
Step 3	■ Physical simulation Verification	■ Simulate Performance limit (Sensor malfunction caused system maneuver scenario)
Step 4	■ Potential Validation	■ Study of connectivity Physical simulation to Functional simulation ■ And expand various scenes

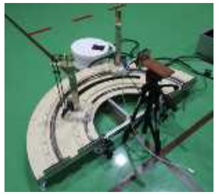
Using the Functional simulation and Physical simulation with same principle One-Architecture, consecutively increase the simulation accuracy with improving precise Models

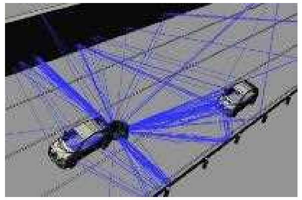
Through the step by step approach, Realtime "Functional simulation" 1st and Highly correrated "Physical simulation" 2nd

Project plan

	First half of FY 2019	Second half of FY 2019	First half of FY 2020	Second half of FY 2020
Step	Examine behavior of combined modules	Step 1 Joint check → Step 2 Functional simulation Verification	Step 3 Physical simulation Verification	Step 4 Potential Validation
Validation details	■ Implement the software of the function model based on defined Interface ■ Operational Check as component level	■ Joint & check overall behavior of combined modules including a test data generating tool ■ Validate simulations on the functional model	■ Implement the physics model based on measurements of actual Sensors ■ Build a model of factors of recognition failures ■ Validate consistency with actual measurements of a measuring car	■ Investigation for Linkage of Physics simulator to the Functional simulator ■ Examine Validation possibilities in driving environments including a local road
	Simulation Interface for standardization	***Functional simulation: Joint check & Verification with intended functionality***	***Physical simulation: Joint check & Verification with Performance limits***	***Expand the scope of scenes***







Source: SOKEN. INC, Mitsubishi Precision Company, Limited

Based on Sensor malfunction and measurement possibilities in a real environment, planned Validation scenes in each step

Validation scenes (under study)

Step	Validation	Timing	Objective	Validation scenes	Malfunction conditions	Candidate real environment
1	Joint check	From Oct 2019	■ Examine consistency in a stationary condition	■ Stationary objects and in a stationary condition	■ N/A	JARI JTown
2	Functional simulation Validation	From Jan 2020	■ Examine consistency in basic driving scenes	■ Large Vehicles run side by side, etc. ■ NCAP (pedestrians and bicycle-riding persons)	■ N/A	JARI JTown
3	Physical simulation Validation	From Apr 2020	■ Examine consistency under the condition of recognition failures	■ Large Vehicles run side by side ■ NCAP (pedestrians and bicycle-riding persons)	■ Rain and fog ■ Backlight ■ Night	JARI JTown
4	Potential Validation	From Oct 2020	■ Check Validation possibilities various scenes on a local road	■ Intersection ■ Local road in a suburb	■ Rain and fog ■ Backlight ■ Night & others	N/A

Large Vehicles run side by side

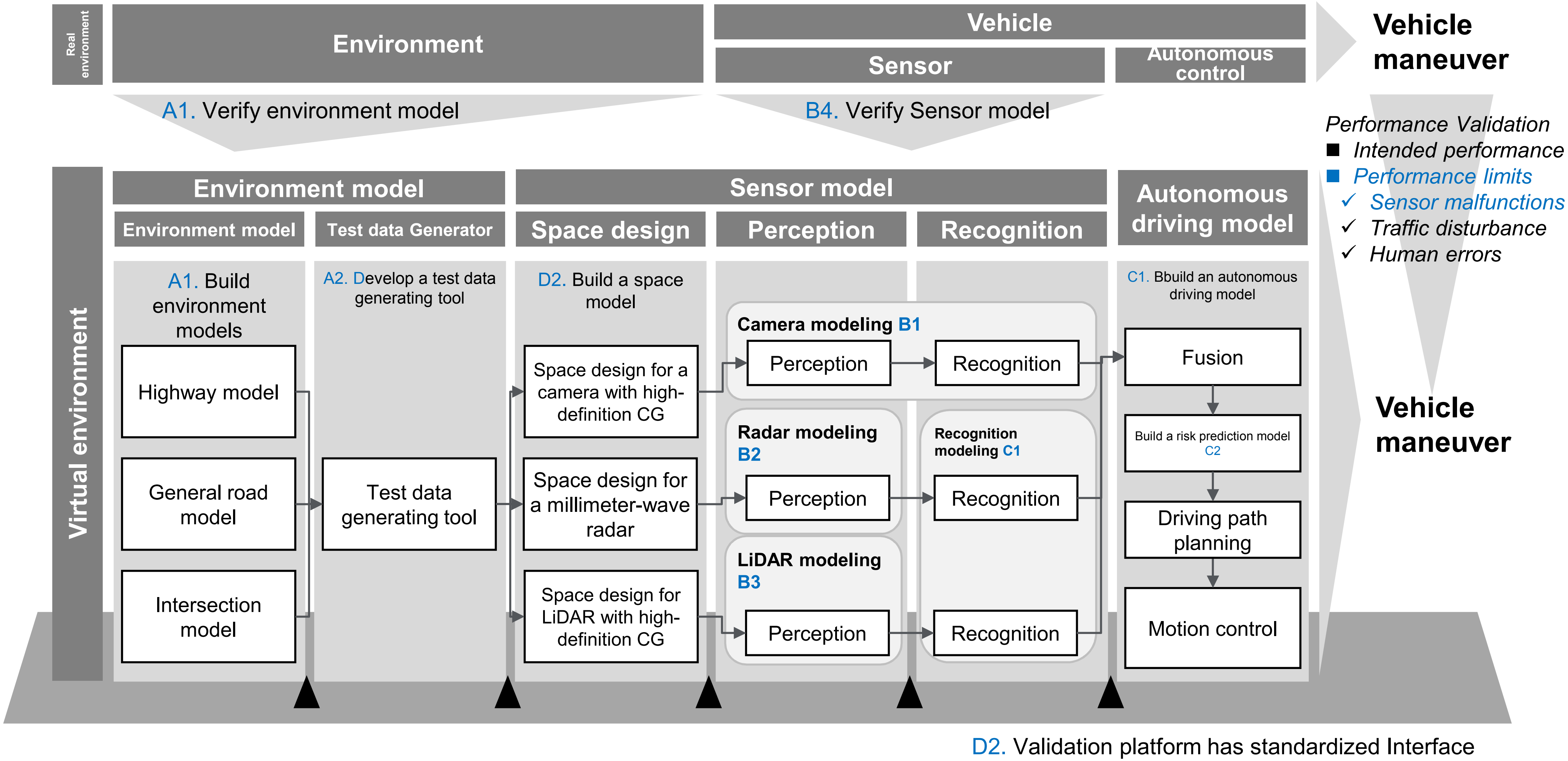
Environmental factor (Backlight)

Environmental factors (Rain and Fog)

•Source: Mitsubishi Precision Company, Limited

Designed research theme, Platform & Interface Design, each Model enhancement and Verification shared by 10-Experts

Responsibility assignment matrix



Total 10-experts(2-universities and 8-company) contributed as Consortium style progressing each research theme

Consortium formation

Participating organizations		Area of research	
	Kanagawa Institute of Technology	B0	■ Combine and validate Sensor simulation models
		C2	■ Implement Risk prediction model
	Ritsumeikan University	C1	■ Research the autonomous driving behavior model
	OTSL Inc.	A1	■ Build environment models
		D1	■ Research for Standardized Interface
	SOKEN, INC.	A1	■ Measure real world environmental data,
		B4	■ Verification of Sensor model's performance
	Mitsubishi Precision Company, Limited	A2	■ Develop a safety Validation test data generating tool
	SOLIZE Engineering Corporation	A2	■ Research of Validation scenarios format, etc.
Hitachi Automotive Systems	Hitachi Automotive Systems, Ltd.	B1	■ Research Camera model
	DENSO CORPORATION	B2	■ Research Millimeter-wave Radar model
	PIONEER CORPORATION	B3	■ Research LiDAR model
	Nihon Unisys, Ltd.	D2	■ Research of Validation platform

FY 2018 outcome

■ Project summary

(1) Virtual Validation platform research

(2) Models requirements & Interface research

(3) Measurement design research

FY 2018 outcome

■ Project summary

(1) Virtual Validation platform research

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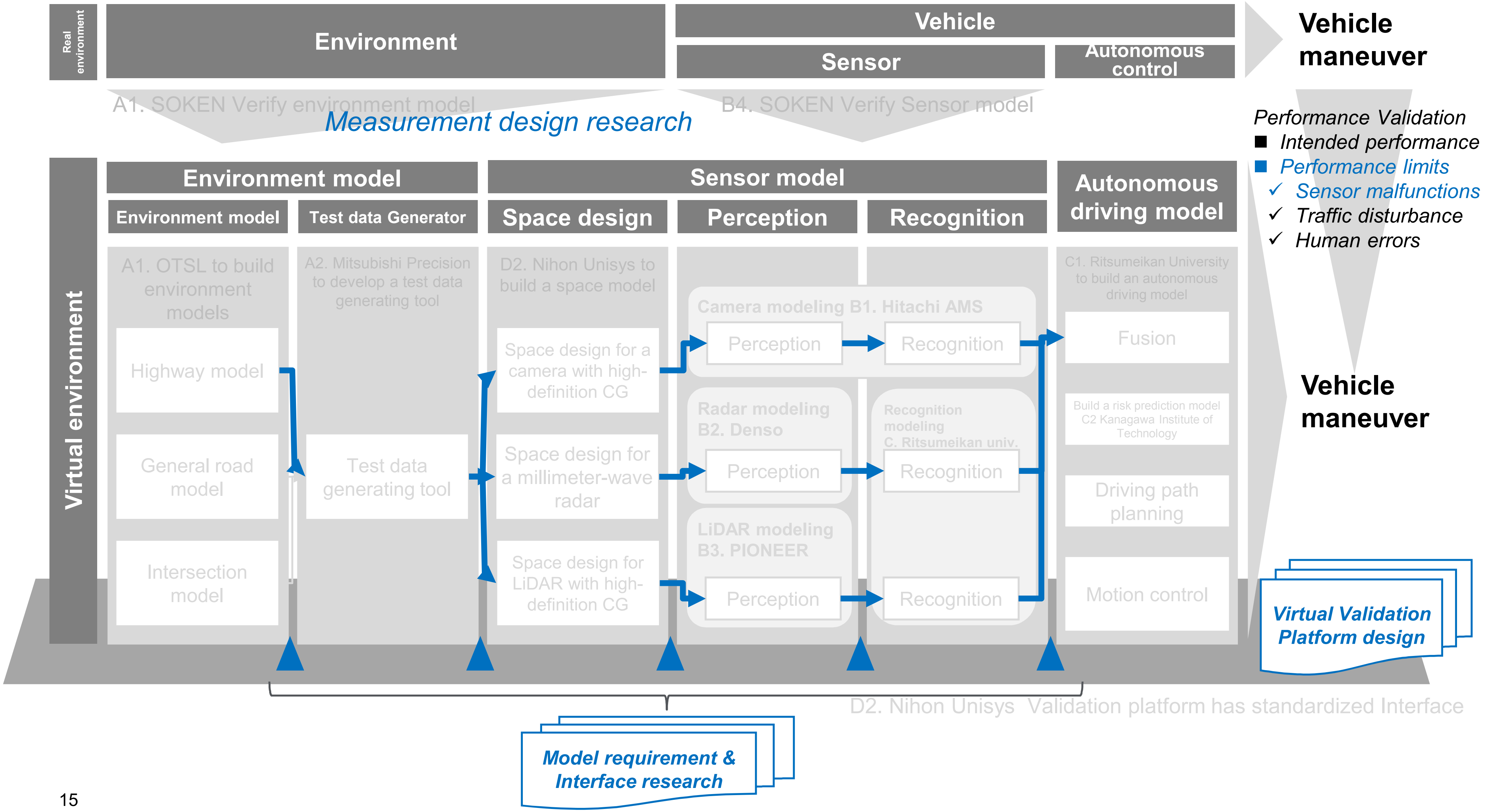
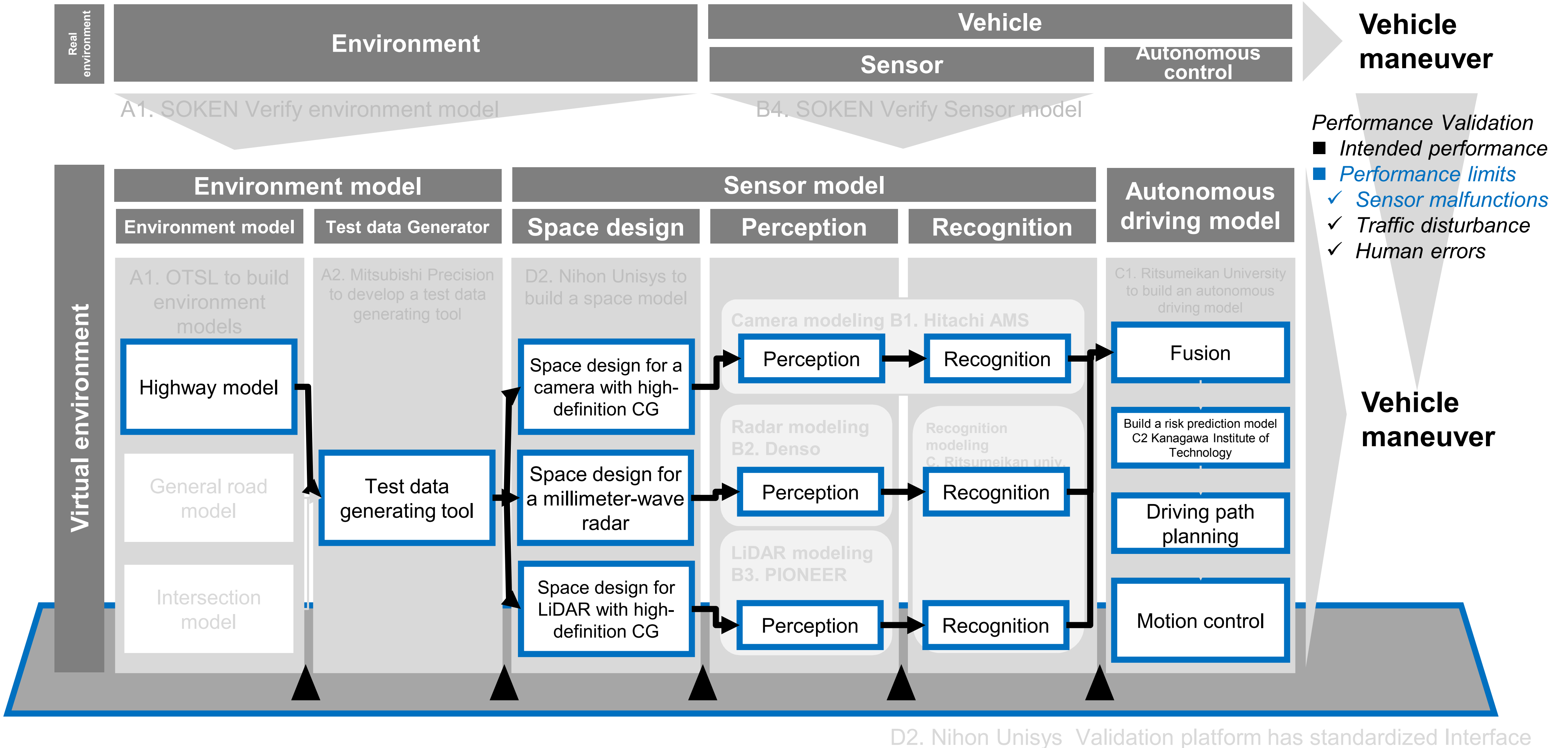
FY 2018 outcomes are Interface spec, Platform design, and measurement design for validity of simulation as an Architecture for Validation platform

Outcome during FY 2018



Based on FY2018 architecture design, modeling of each environmental, Sensor models and connect to check simulation operation check

Activities and expected outcome during FY 2019



FY 2018 outcome

- Project summary

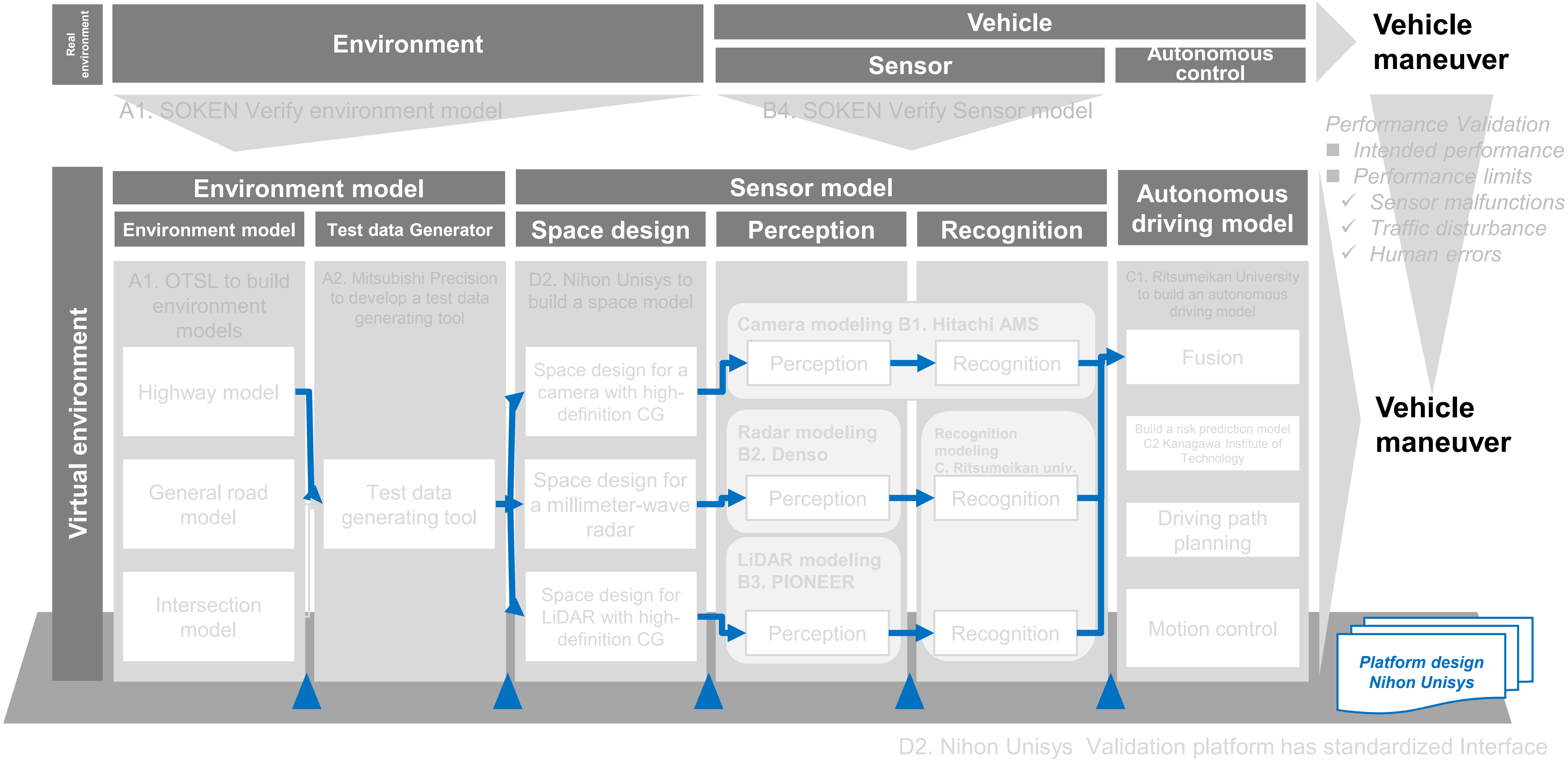
(1) Virtual Validation platform research

(2) Models requirements & Interface research

(3) Measurement design research

Researched Platform architecture for realize continuous growth of simulator from High-speed real time "Functional simulation" to high validity "Physical simulation"

Outcome during FY 2018



Made a direction to proceed Platform investigation using Carla+UE4 base, from current open source simulation research results

Carla vs AirSim comparison

Item	1st Category	2nd Category	3rd Category	CARLA	AirSim	Memo
Development base	PF	Unreal Engine 4	-	4.21	4.18	
		Unity	-	×	Experimental	
	OS	Windows	-	△	○	
		Linux	-	○	○	
	License	-	-	code：MIT License Asset：CC-BY License	MIT License	CC: creative commons license CC-BY: require Author print in case of copy, show demo, etc.
Environment model(PartA)	APIs	Scenario	-	○	×	
		Weather	-	○	○	
Sensor model (PartB)		Detection（Sensor）	Camera	○	○	
			Rader	0.9.9	×	
			LiDAR(ground truth)	○	○	
Autonomous model (PartC)		Judgement	-	○	×	
		Operation	-	○	×	
Out side connectivity		Support ROS	-	○	○	
		Support Autoware	-	○	×	
Space model (PartD2)	Arithmetic processing	Ray cast	-	○	○	
Driving environment model (PartA)	Asset	Vehicle	-	○	△	Asset of AirSim doesn't able to use on another tool scored △
		Human	-	○	△	
		Road side objects	-	○	△	
		Map	-	○	△	
Origin	Target	-	-	Autonomous	Drone, Autonomous	

Choose Carla as a investigation base

- *Higher diversion of Model, Assets, Map, etc.*
- *Support for Scenario function, Autonomous model*

UE4 vs Unity comparison

Item	Unity	Unreal Engine 4	Memo
Language	C#, JavaScript	C++	
Blue print	-	○	
License strategy & fee	Personal: free Plus: $25/month Pro: $125/month	Free 5% royalty on over $3,000 gross profit in quarterly basis	
Reference book (from amazon)	30,000 over	71	
Share	50%	25%	Unreal Engine4 share is growing
OS	Windows, Mac, Linux	Windows, Mac, Linux	
Asset store	○	○	
CARLA	×	○	

Choose UE4 as a investigation base

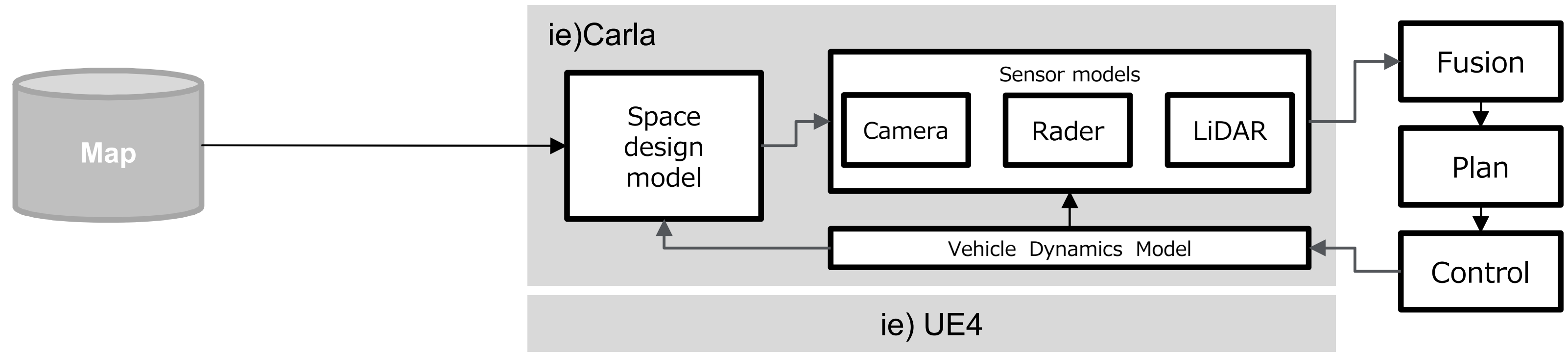
- *Easy development-ability with Visual Scripting system*

Utilize Carla+UE4, Interface standardization realizing Plug&Play of each models is 1st step, then improving simulation performance with Precise of each Models

Simulation Platform design

		Environmental model		Sensor model			Autonomous
		Environment	Test data generation tool	Space design	Perception	Detection	
Open Platform	Structure	(see diagram below)					
	Problem	■ Lo-Accurate model	■ Limited scenario	■ Limited Ray-trace function	■ Lo-Accurate model		■ Limited connectivity

Structure:



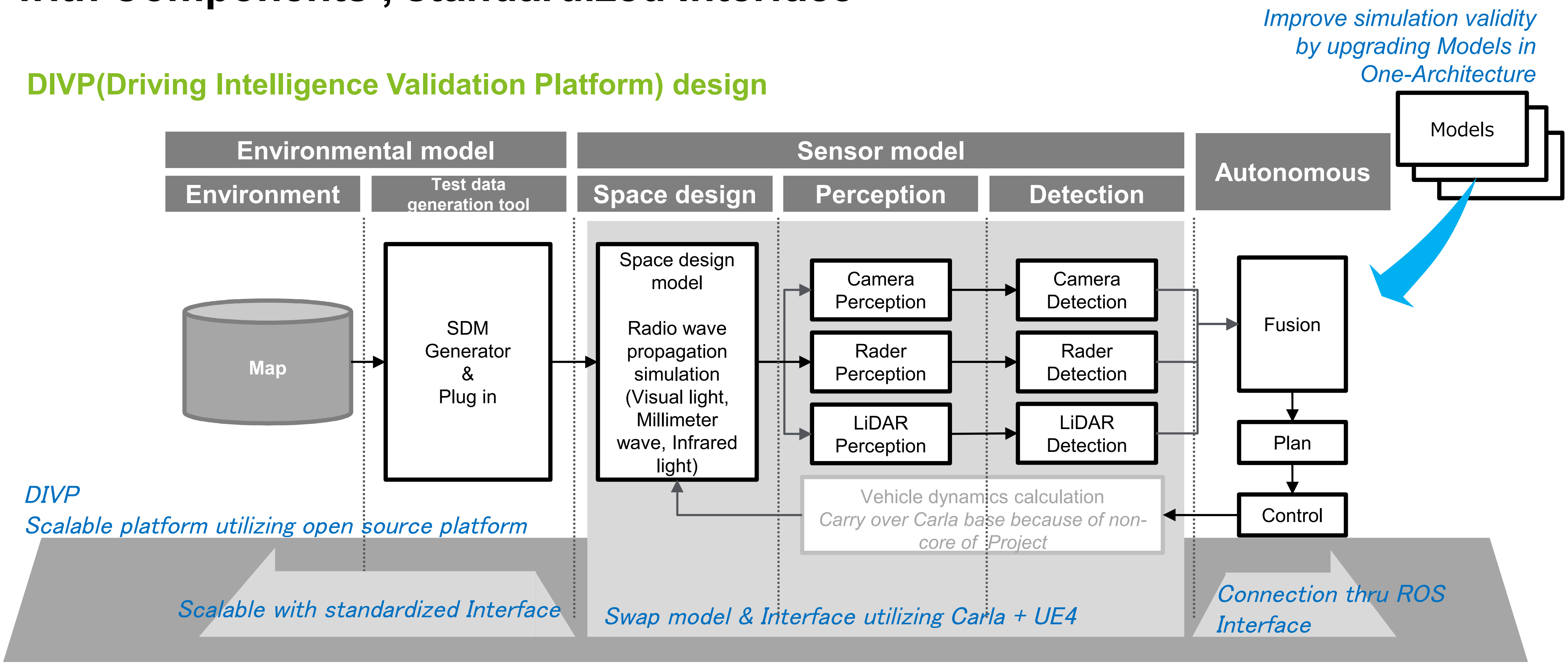
Making platform to solve those problems

Requirements

- ■ Maximus output with minimum resources
- ■ Able to standardize Interface on each node for realizing Plug&Play of each models
- ■ Able to Precise each models to realize higher correlation simulation

Utilize current open source simulation, and concentrate Project focus efficiently
1. ***Standardize Interface***
2. ***Precise models based on Sensor Principles***

Define DIVP(Driving Intelligence Validation Platform) Architecture with Components , standardized Interface



■ **Higher Refraction characteristics correlated model**	■ **SDM generator connection**	■ **Sensor specific Ray-trace function can be adopted**	■ **Scalability to switch models of higher correlated Sensor models**	■ **Autonomous models connection available**

Target is to indicate the direction of standardized Interface,
And Higher correlated simulation with Precise models

Space design model with one architecture can achieve the both Functional & Physical simulation

Space design model study

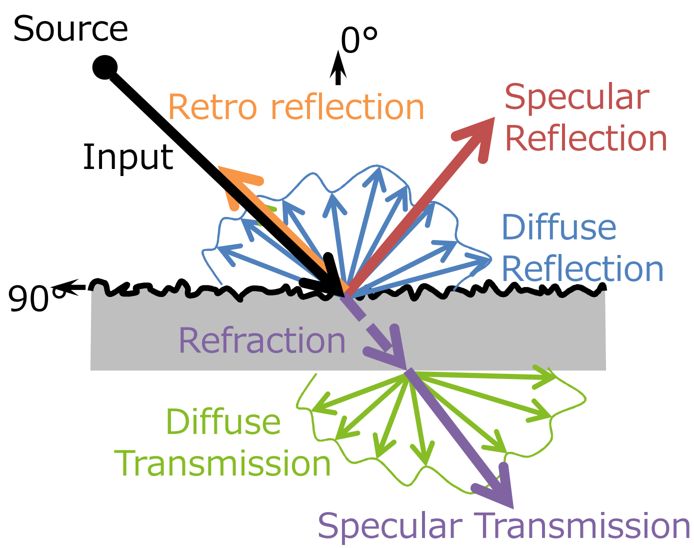
Direction

Simulation category	Space design model / Perception model		
	Camera	Rader	LiDAR
Functional simulation	■ Simple model can percept UE4 basic animation	■ Model for non-multi path Ray tracing	■ Model does not use foot print
Physical simulation	■ Model for Path tracing	■ Model for Multi path Ray tracing	■ Model with foot print

Continues improvement using one platform

Space design model Principle

Refection characteristics



Radio wave for each Sensor

Sensor	Radio wave	Wave length	Characteristics for calculation
Camera	■ Visible light	■ 380nm～770nm	
Rader	■ Millimeter wave	■ 3mm～5mm	■ Material's Electric characteristics(Dielectric constant)
LiDAR	■ Infrared light	■ 905nm	■ Material's Infrared refraction characteristics

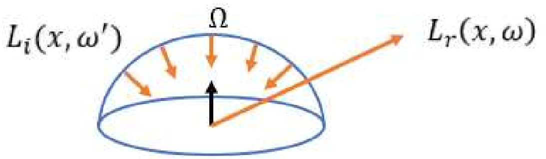
Space design model operates Ray tracing based on each Sensor & Radio wave principles

Space design method on each Sensor

Camera

Calculate refraction with Rendering equation

$$L_r(x,\omega) = \int_{\Omega} f_r(x,\omega,\omega')L_i(x,\omega')(\omega',n)d\omega'$$



Rader

Calculate receive electric power with Rader equation

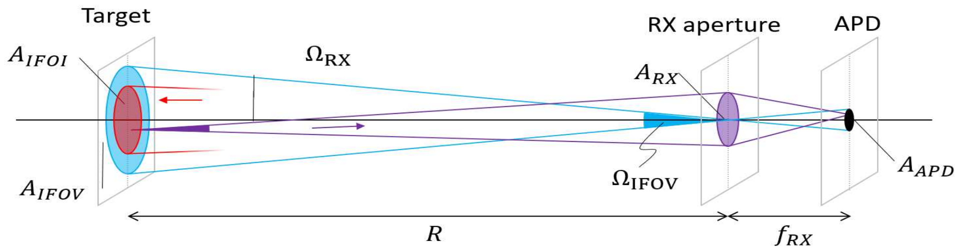
$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}$$

P_r: Recieve electirc power
P_t: Transmit electric power
G_t:Transmit antenna gain
G_r: Recieve antena gain
λ: Length
σ: RCS
R: Distance

LiDAR

Calculate Intersection point of pulse wave Power of receive wave

$$P_r = \frac{\rho}{\pi}\frac{A_{RX}}{R^2}P_t$$

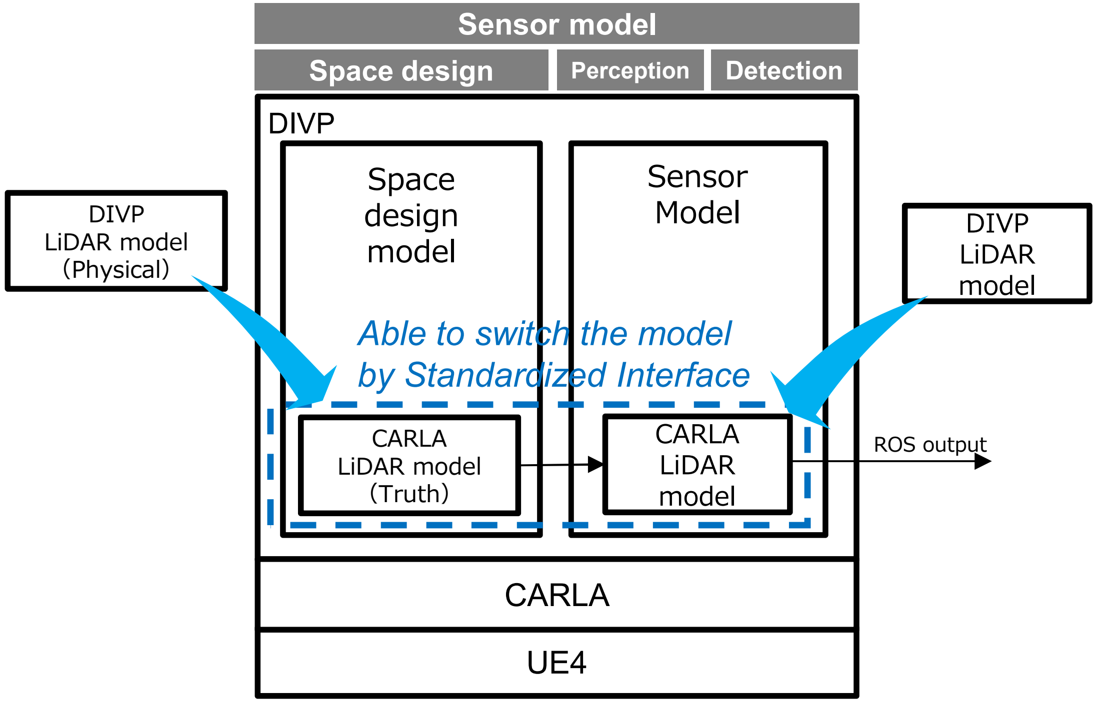


A_X : area of X [m²]
Ω_X : solid angle of X [sr]
R : range [m]
f_{RX} : focal length of RX optics [m]

Initial release of Functional simulation

1st release platform

LiDAR simulation under development

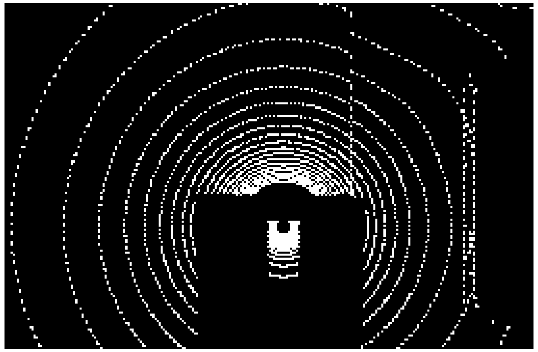


- Switch the Sensor model to DIVP origin from CARLA's base
- FY2018 implement LiDAR model, and expand Camera, Rader next Fiscal year

Demo of LiDAR simulation

validate

LiDAR simulation（CARLA model）



- Output Point cloud

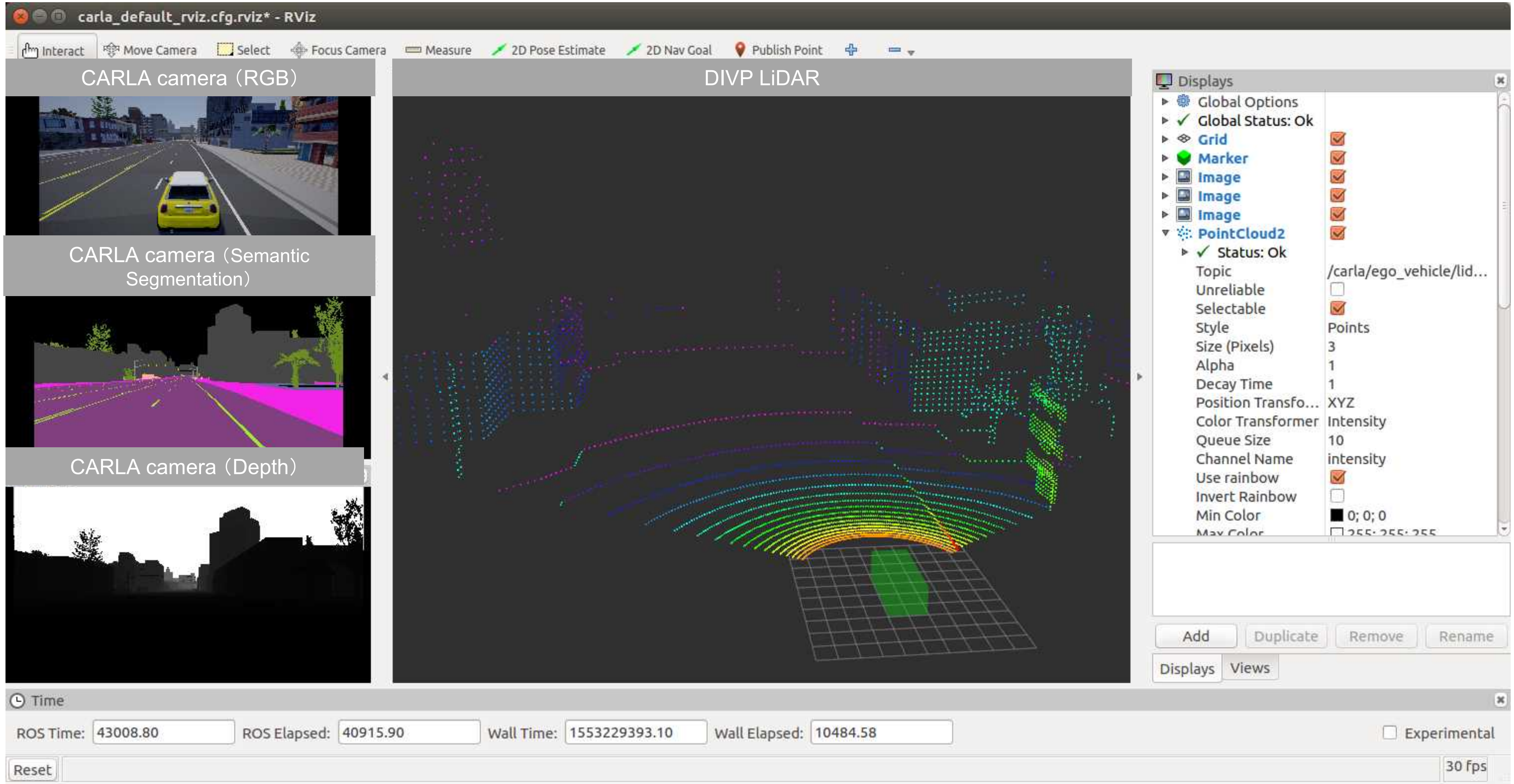
DIVP LiDAR simulation

- Output Point cloud *& Reflect intensity*

Initial release of Functional simulation

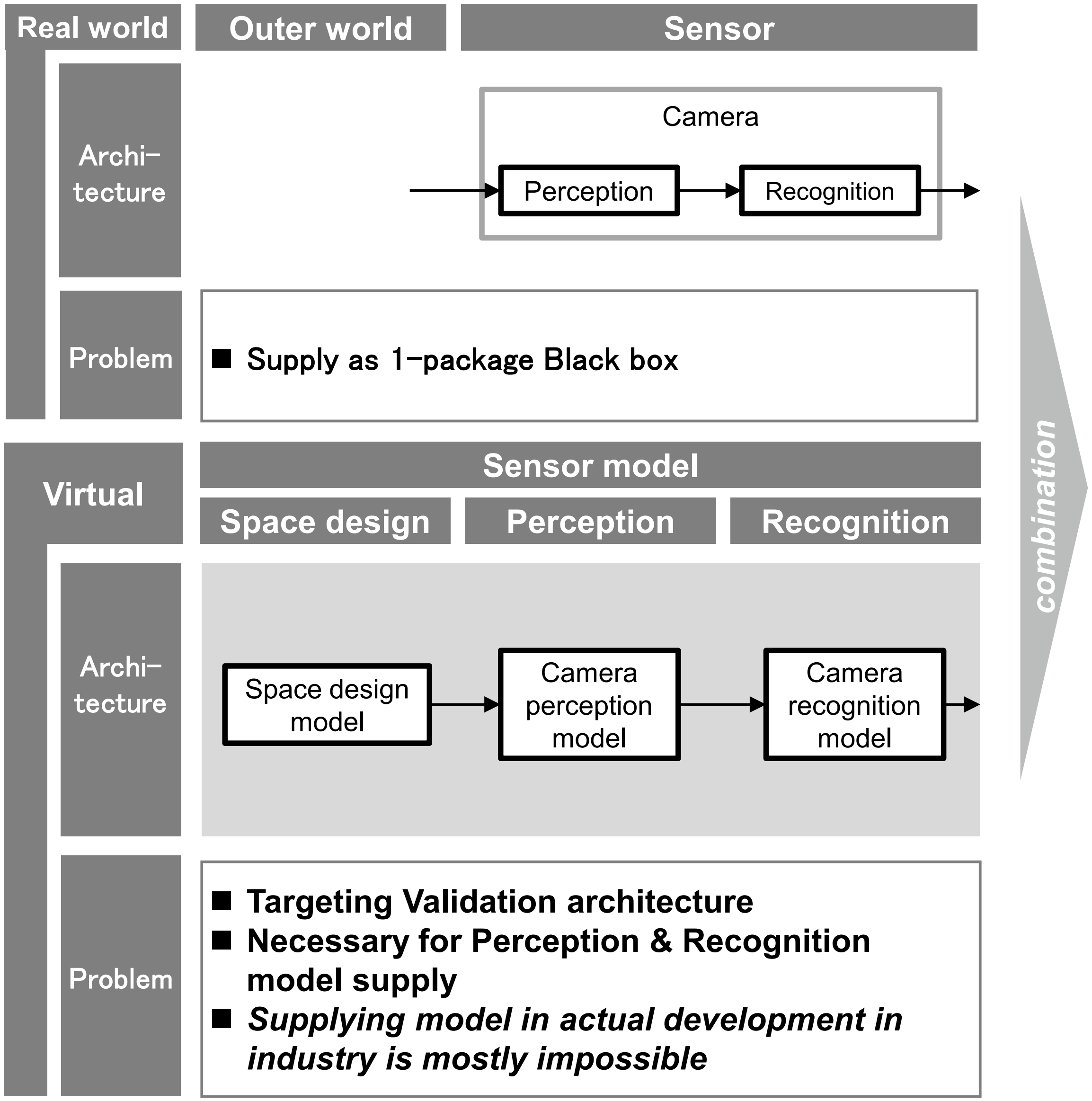
PF first edition

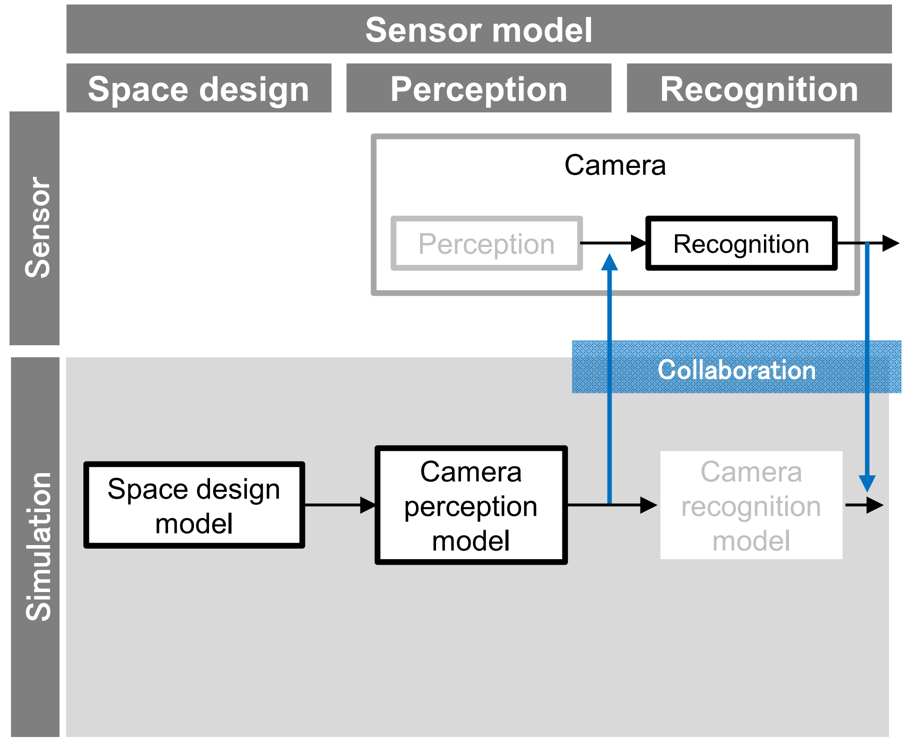
Display the result of ROS output from PF with rviz (ROS visualization tool)



Research of HILS architecture utility using Injection methodology

Challenge for Injection technology





■ *Enable to validate Black box models with using Injection technology, which can connect signal after perception as a input to recognition of actual Sensor and get output*

FY 2018 outcome

- Project summary

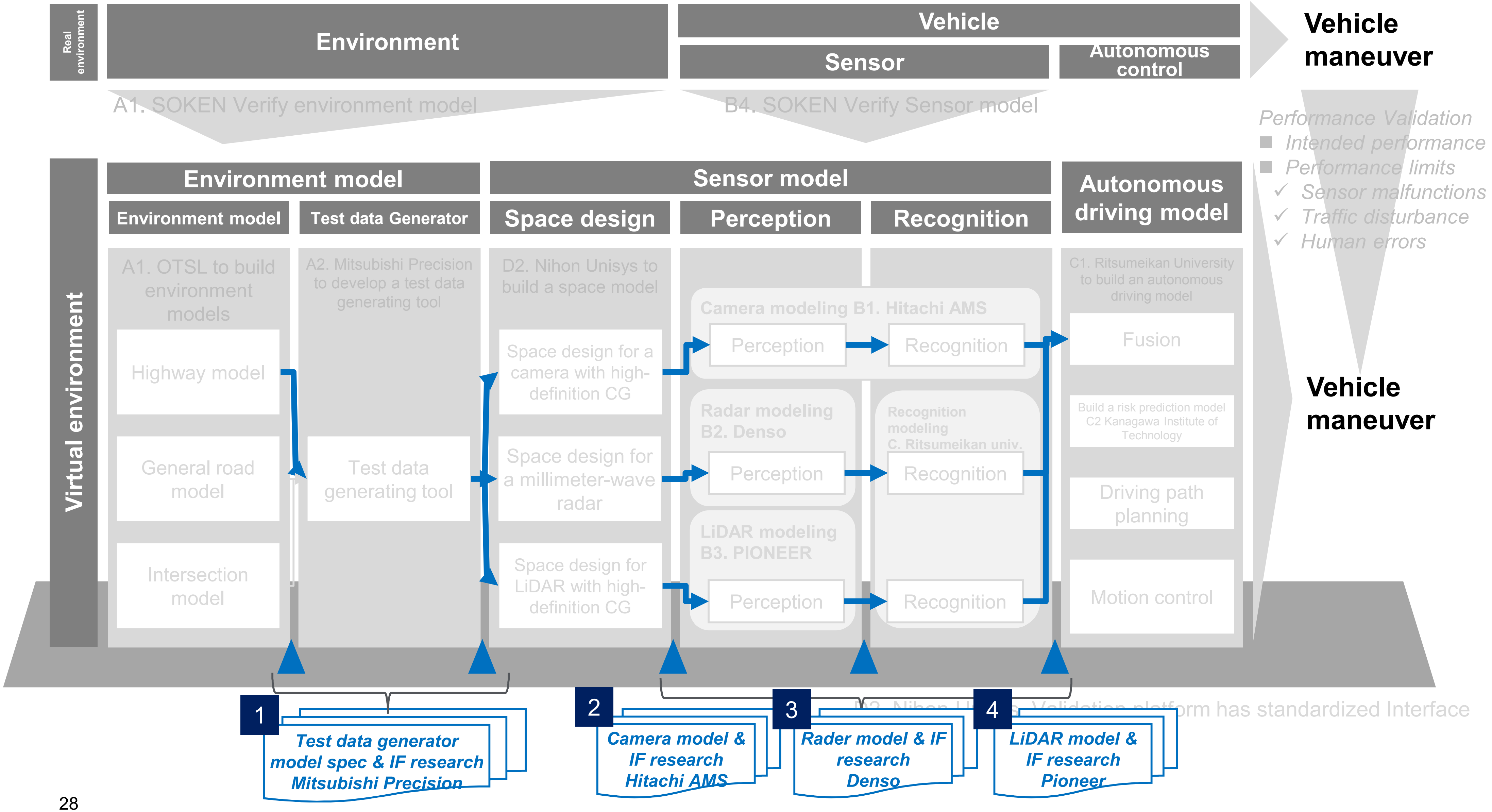
(1) Virtual Validation platform research

(2) Models requirements & Interface research

(3) Measurement design research

Studied & Defined each Modeling requirements & Interface spec for platform architecture design

FY2018 output

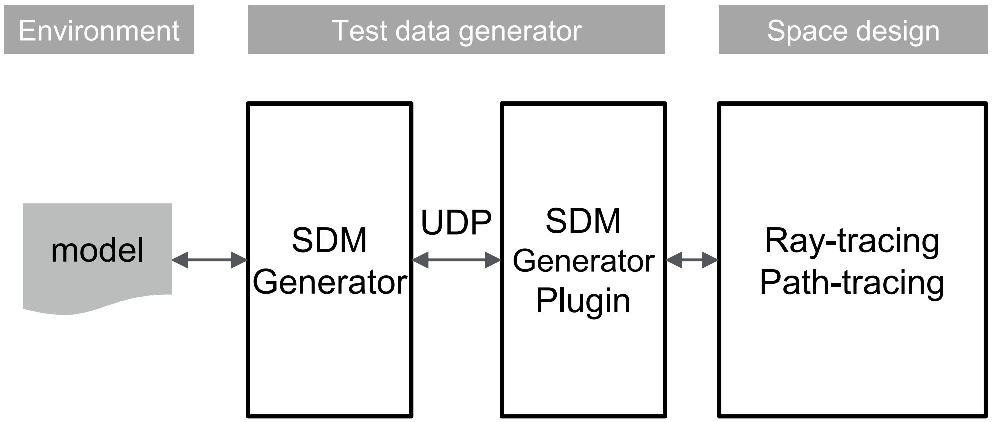


1 【Test data generator research】
Defined Interface Input/Output of Test data generator = SDM generator*1

Study of SDM generator

Platform sample for study

■ Definition of Test data generator structure for Interface study



Advantage

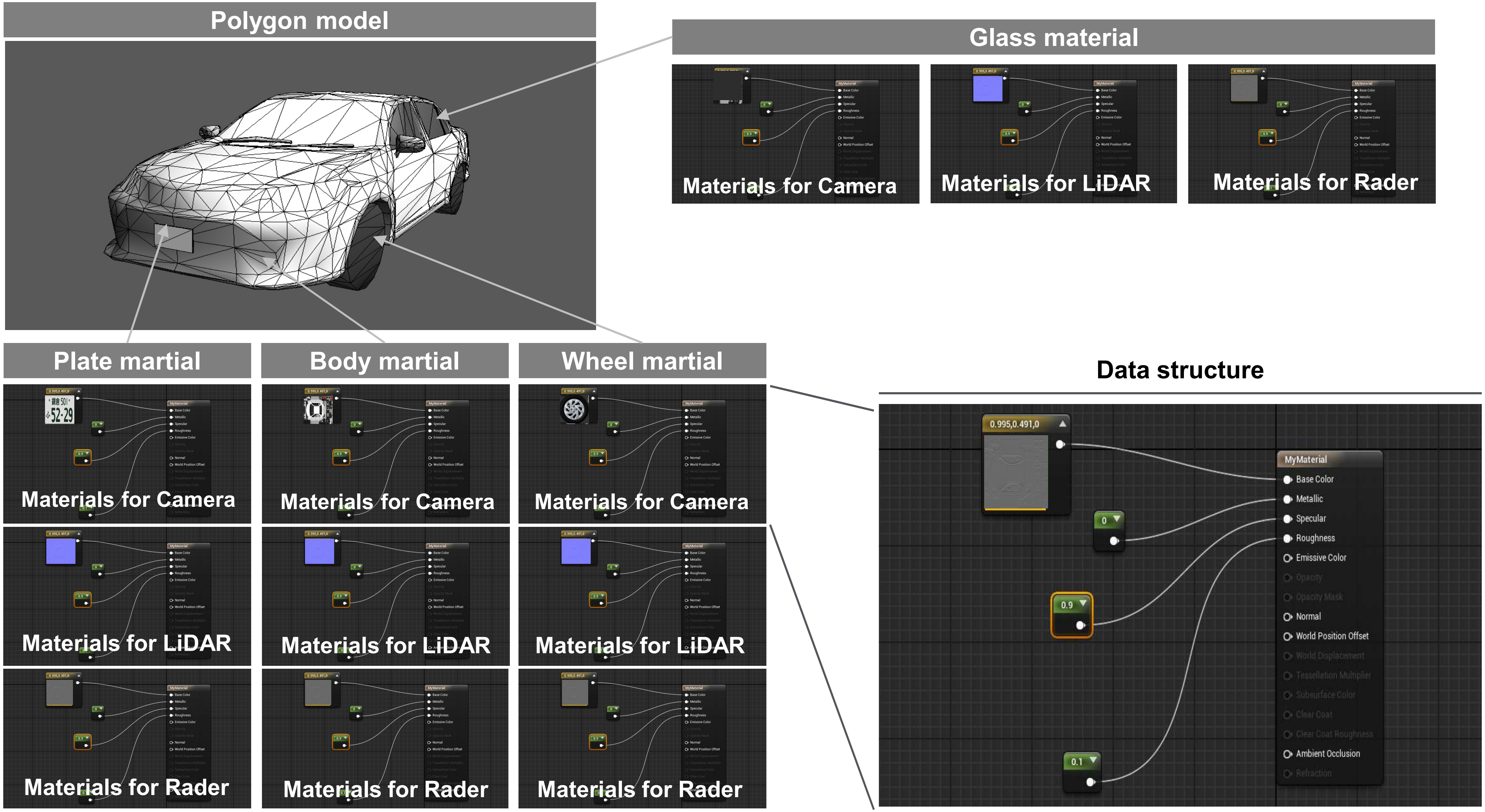
■ Able to absorb OS difference
■ Able to use CPU power with Distributed processing
■ Able to enhance thru put with pipe line processing

I/F	Name	Format	Contents
Model relates	Model (Asset)	umap	■ Translate fbx to umap ■ Refer of Material information
	Material	csv	■ Prepare ,material information with CSV
	Road network	Open DRIVE	■ Output OpenDRIVE format information for Autonomous model
Communication I/F	Communication	UDP	■ Internal communication done by Packet communication thru UDP ■ Outer communication use API thru SDM Generator Plugin

*1 SDM Generator : Space Design Model Generator

1 【Test data generator research】 Environment model has each Sensor's sensing characteristics base reflection data

Environmental model Sample

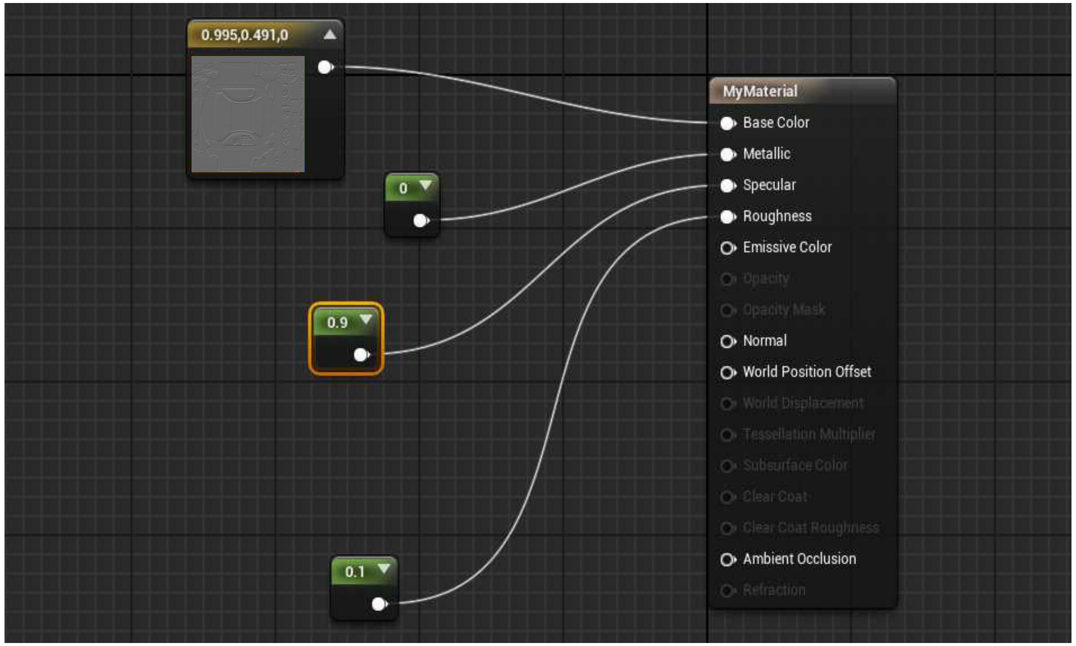


Source : Image from Mitsubishi Precision

1 【Test data generator research】 Environment model has actual measured characteristics realizes Accurate test data vs General simulator

Data structure sample

Data structure



Contents

Base Color	■ Definition of material color
Metallic	■ Parameter the material is Metal or not
Specular	■ Reflecting ratio
Roughness	■ Surface roughness parameter
Emissive Color	■ Definition of emissive color
Normal	■ Normal on surface
Ambient Occlusion	■ Definition of environmental light reduction ratio
BRDF	■ Definition of by-directional reflection ratio distribution
BTDF	■ Definition of by-directional transfer ratio distribution

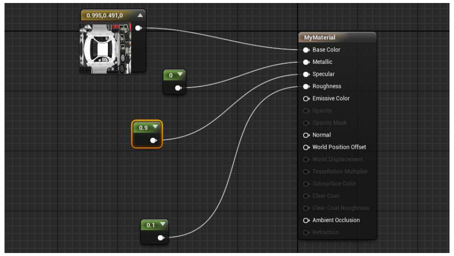
※Understudy of parameter value

Source : Image from Mitsubishi Precision

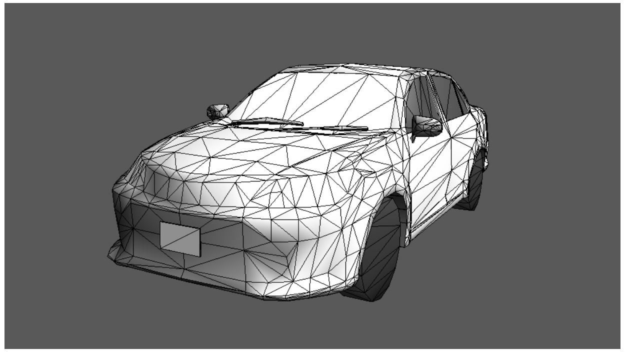
1 【Test data generator research】 Test data generator referring detailed materials onto Polygon so that realize Precise Test data

Test data generation sample

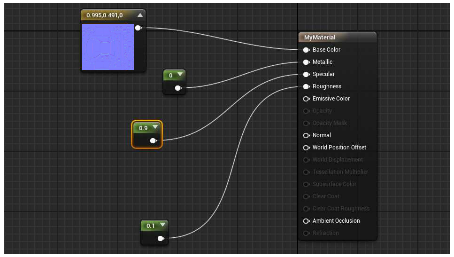
Materials for Camera



Polygon model

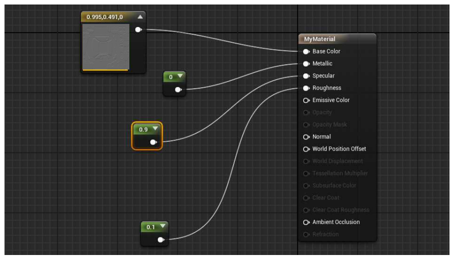


Materials for LiDAR



Output test data

Materials for Rader



Source : Image from Mitsubishi Precision

1 【 Test data generator research 】
Example of test data by SDM Generator

Example of SDM Generator

※SDM Generator generate
Test data from Assets & Scenario input

Source : CG image from Mitsubishi Precision

1 【 Test data generator research 】
Example of test data by SDM Generator

Example of SDM Generator

※SDM Generator generate
Test data from Assets & Scenario input

Source : CG image from Mitsubishi Precision

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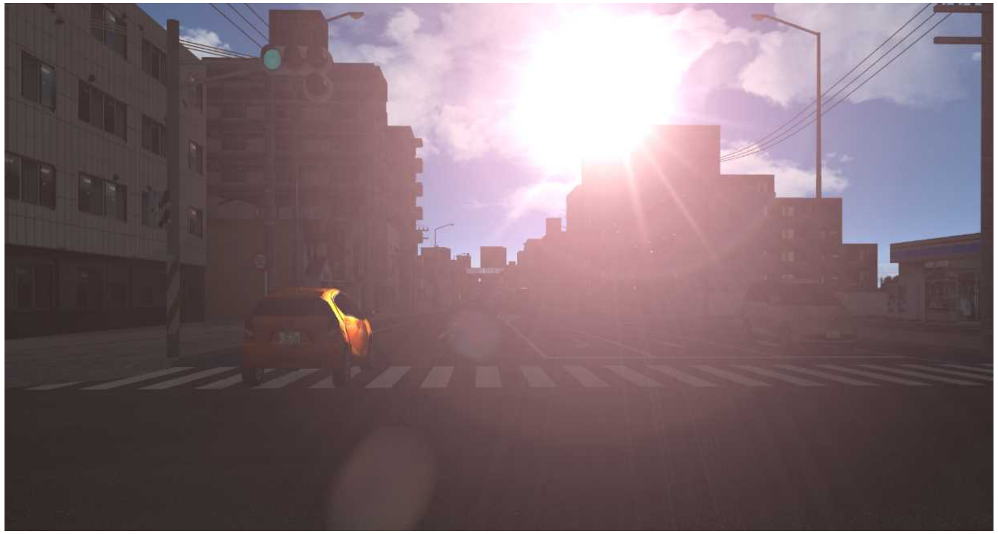
Example of test data by SDM Generator

Example of SDM Generator



※SDM Generator generate
Test data from Assets & Scenario input

Source : CG image from Mitsubishi Precision

1 【 Test data generator research 】 Researched test data formats for validating recognition in Autonomous

Research results of OpenDRIVE and OpenSCENARIO standard formats related to recognition

Research abroad	■ **We participated in OpenDRIVE and OpenSCENARIO workshops held by Association for Standardization of Automation and Measuring Systems (ASAM) in Germany for 4 days from January 15.** ■ With the current versions of OpenDRIVE and OpenSCENARIO, recognition-related functions in autonomous Vehicles have not been completed. ■ ASAM expects to refer to the definitions of other standard for properties of materials which are key for OpenDRIVE Sensor simulations. ■ Participants in the OpenSCENARIO workshop proposed adding information on the mounting positions of Sensors such as cameras. ■ For OpenSCENARIO, there was a movement toward adding environmental conditions that impact on Sensors, such as precipitation, fog, wind, and lighting.
Research in Japan	■ **ASAM Japan plays the central role in encouraging the standardization** of OpenDRIVE and OpenSCENARIO based on **Japan's specifications**. ■ We participated in the OpenDRIVE Concept Project for its next version 2.0. ■ We will incorporate Japan's specifications into OpenDRIVE, and describe properties of materials which are key for Sensor simulations.

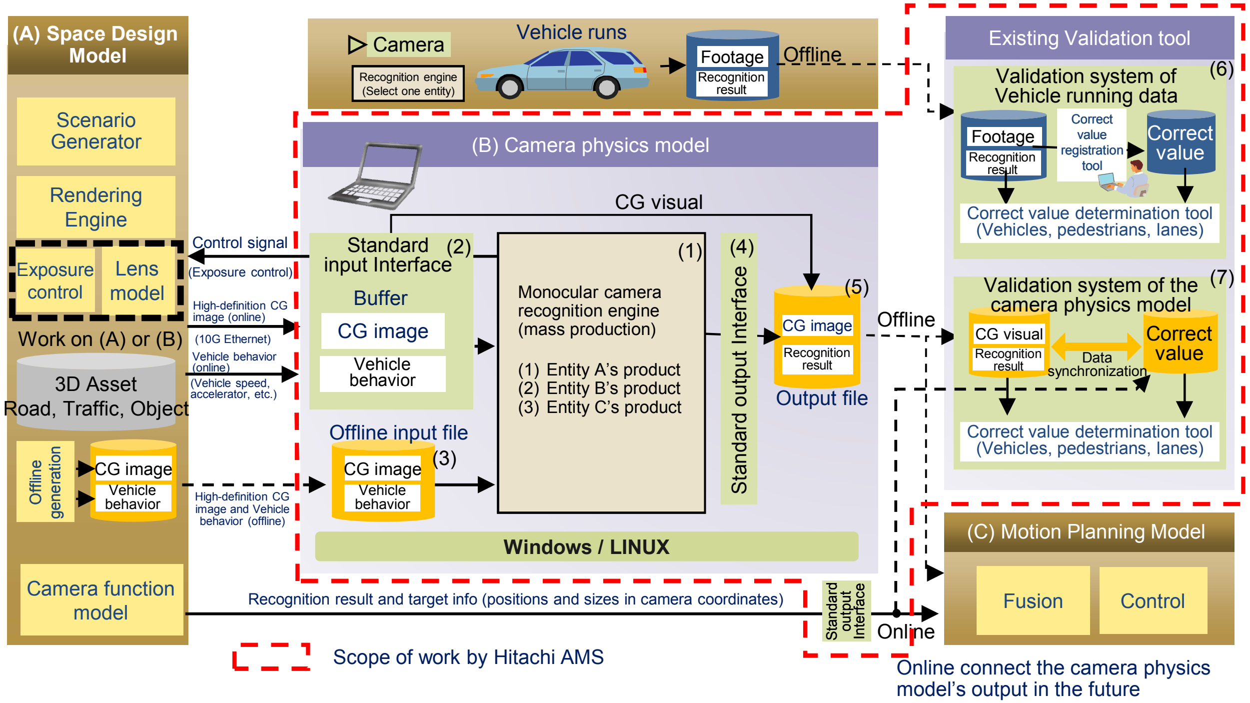
Conclusion
OpenDRIVE can be used in the DIVP. However, it is necessary to incorporate Japan's unique specifications, and properties of materials used in roads and facilities into OpenDRIVE.
→ By working together with ASAM Japan, incorporate the DIVP specifications into OpenDRIVE next version 2.0.
It is difficult to use the current version of OpenSCENARIO in the DIVP, and it is also uncertain at this moment when the next version of OpenSCENARIO will be developed.
→ Draw up DIVP scenario format specifications by referring to the current version of OpenSCENARIO and harmonizing with a scenario format to be developed by JAMA.

Project title	Timing	Participation	Purpose
OpenDRIVE Transfer Project	Apr 2019 to Sep 2019	No	Project to update the current version 1.4, and move toward standardization
OpenDRIVE Concept Project	Apr 2019 to Aug 2020	Yes	Concept Project for the next version 2.0
OpenSCENARIO Transfer Project	Apr 2019 to Dec 2019	No	Project to update the current version 0.91, and move toward standardization
OpenSCENARIO Concept Project	TBD	Yes	Concept Project for the next version 2.0

2 【Camera model & IF research】
Consider requirements that should be modelled for camera simulations

Configuration of the camera model and related peripheral functions

Configuration of the camera model



Components

No	Function	Outline
(1)	Camera recognition engine	It is a camera Sensor function (commercially available recognition engine) that recognizes Vehicles, pedestrians, and others with input from high-definition CG images.
(2)	Standard input Interface	It receives, sends, and buffers exposure control signals, high-definition CG data, and Vehicle behavior data.
(3)	Offline input file	Data received in a file from the environment model includes high-definition CG images and Vehicle behavior data.
(4)	Standard output Interface	It determines coordinate axes of location information including one on recognized 3D objects
(5)	Output file	It includes output data of the camera's recognition results, and high-definition CG images that the camera recognition engines receives.
(6)	Validation system of real Vehicle data	It compares the camera's recognition results collected from a running Vehicle with correct values[1], and validates recognition performance. ([1] Calculated by human based on collected footage)
(7)	Validation system of the camera physics model	It compares results that the camera recognition engine recognizes with the environment model's true values, and validates recognition performance.

2 【 Camera model & IF research 】
Defined the camera model's Input Interfaces

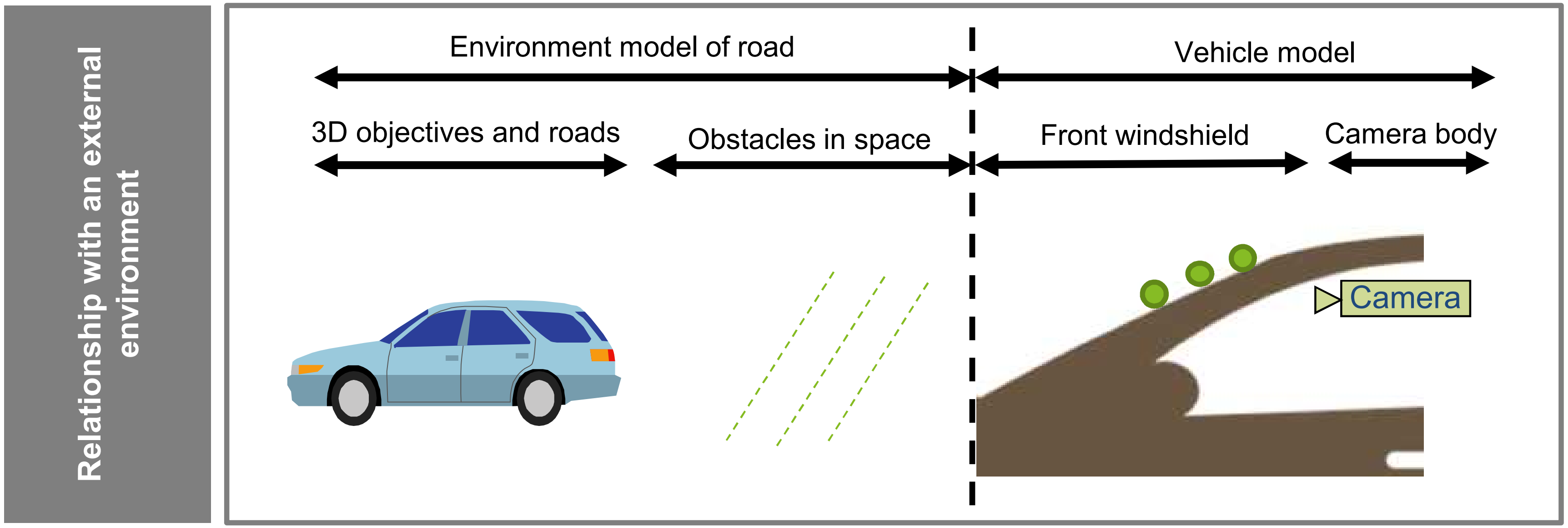
The camera model's input Interfaces

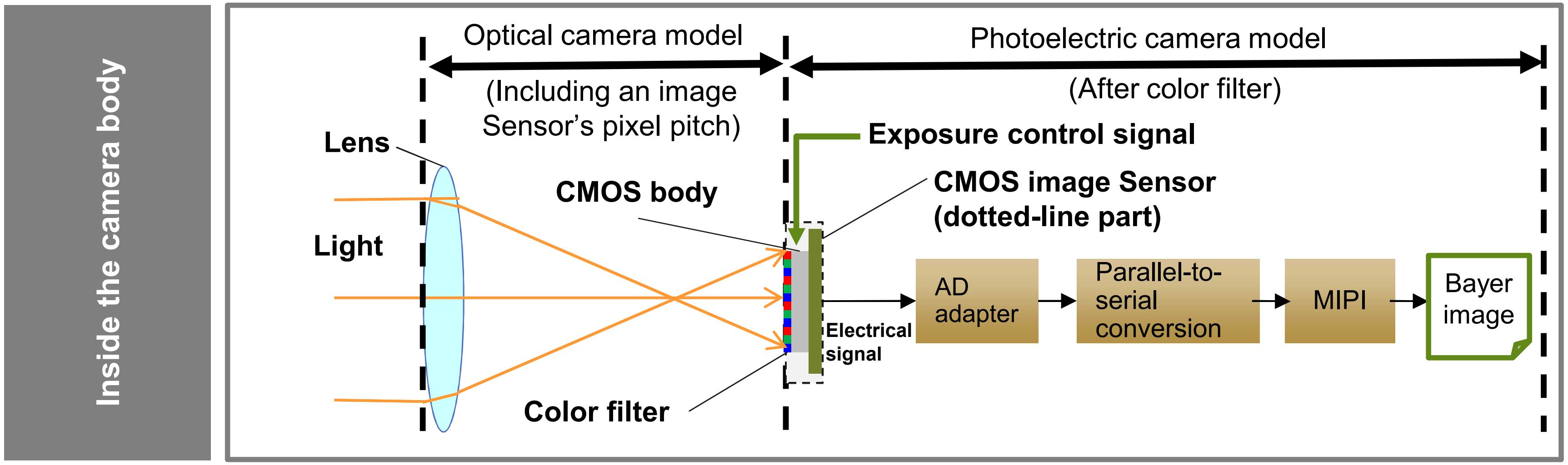
No	Communications	Type	Send	Receive	Outline
1	Online	High-definition CG data	High-definition CG tool	Camera model	■ One-frame CG data ■ Data includes Bayer images and timestamped data
2		Vehicle behavior data			■ Data on Vehicle behavior in a virtual space ■ Data includes Vehicle speed, steering angle, accelerator position, brake pressure, gear position, engine speed, and timestamped data
3	Offline	High-definition CG data file			■ High-definition CG data made up of several sequential frames ■ Data is stored in a BMP file per frame, and its file name contains timestamped information
4		Vehicle behavior data file			■ Data on Vehicle behavior in a virtual space ■ Data includes Vehicle speed, steering angle, accelerator position, brake pressure, gear position, and engine speed ■ Data is stored in a file per frame, and contains timestamped information
5		Camera function model's recognition results		Validation tool	■ The camera function model's recognition results ■ Results show the location information and type of 3D objectives (Vehicles and pedestrians), road markings, etc.
6	Offline Running Vehicle data	Running Vehicle footage	Vehicle	Validation tool	■ Camera footage obtained from a running Vehicle
7		File of recognition results			■ Tool outputs several 3D objectives (Vehicles and pedestrians) simultaneously, including the location information and type of 3D objectives and road markings that the camera recognizes while the Vehicle is running.

Further, consider high-definition CG requirements in detail

2 【 Camera model & IF research 】
Defined high-definition CG requirements and overall configuration

Elements that should be reproduced in high-definition CG





2 【 Camera model & IF research 】

Implemented the requirements definition of high-definition CG and defined the whole configuration

High-definition CG overall configuration and requirements

Environmental information
- Road (shape, white line, curb, guardrail, tunnel)
- Traffic lights, signs, and information boards
- Three-dimensional object (Vehicle, pedestrian)
- Streetlight
- Solar altitude (time specified)
- Weather (rain, snow, dirt etc.)

Own Vehicle information
- Mounting position (x, y, z, depression angle, azimuth angle)
- Window glass(distance, slope, curvature, Physical property)
- Fender, Instrument panel shape
- Wiper condition
- Light source： own Vehicle HL （HI/LO)

Camera information
- Color filter :RGGB
- Number of pixels:1 Mpix or 2 Mpix (maximum 10Mpix)
- Pixel pitch: 3.0μm
- Shutter type: Global
- Frame rate: 30fps
- Angle of view (focal length): 120°
- Distortion: Barrel type 30%
- resolution (Concentric circles)：MTF

Recognition result
- Exposure control: Shutter time (msec) gain (dB)

High-definition CG generation tool

Road environment model
- Placement (position and orientation)
- shape
- Optical reflection characteristics
- Light source (HL / TL, streetlight, sunlight)
- Weather (rain, snow, dirt etc.)

Own Vehicle model
- Camera placement (position and direction)
- Characteristics of window glass
- Fender, Instrument panel shape
- Wiper operation
- Light source：own Vehicle HL （HI/LO) Light distribution pattern

Camera model（optics）
- Filter characteristic
- CMOS characteristic (number of pixels, pixel pitch)
- Lens characteristics (focal length, distortion factor）

Camera model （Photoelectric）
- AD characteristics (20bit）
- Exposure characteristics

High-definition CG image
- Image format: RAW
- Data width: 12bit (maximum16bit)
- file format: BMP

2 【 Camera model & IF research 】
Defined the output Interface of the camera model

Interface of the camera model

No	Communications	Type	Send	Receive	Outline
1	Online	Exposure control:	Camera model	High-definition CG tool	■ Signal to instruct exposure control to definition CG tool ■ Exposure control includes shutter time (msec) and gain (dB). The high-definition CG tool determines the exposure (brightness) of CG data to be generated based on this signal.
2		Camera information	Camera model	High-definition CG tool	■ Camera model information ■ It includes information such as color filter, number of pixels, pixel pitch, shutter type, frame rate, angle of view (focal length, distortion, resolution (concentric circle) and the like.
3		Recognition result	Camera model	Fusion	■ Position information and classification of solid objects (Vehicles and pedestrians) and white lines recognized by the camera model. ■ Output multiple solid objects at the same time. Also includes reliability information.
4	Offline	Recognition result file	Camera model	Evaluation tool	■ Position information, type, etc. of solid objects (Vehicles and pedestrians) and white lines recognized by the camera model ■ Output multiple solid objects at the same time. Also includes reliability information.
5		High-definition CG data file	Camera model	Evaluation tool	■ CG data generated by high-definition CG tool ■ It is composed of a plurality of consecutive frames, and one frame is stored in one BMP file. File name includes timestamp information.

Learn more about the Online Interface

2 【 Camera model & IF research 】
Defined the output Interface of the camera model

Exposure control Interface

Correction of the brightness of high-definition CG image is necessary to realize the optimum recognition performance. Exposure control information for brightness correction of an image is defined for a high-definition CG generation tool.

Classification	Name	Description	Unit
Exposure control	Exposure time	■ Output exposure time per line	μsec
	Gain information	■ Output gain value of camera output	-
Degree of reliability	Detection reliability	■ Output the detection reliability of the target	%

Camera information Interface

Model-based optical correction is required to achieve optimal recognition performance.
The camera function / Physical model specifications are defined as a camera information Interface.

Classification	Name	Description	Unit
Sensor specification	Horizontal pixel count	■ Output the number of horizontal pixels of the Sensor	pixel
	Vertical pixel count	■ Output the number of vertical pixels of the Sensor	pixel
	pixel pitch	■ Output the pixel pitch of the Sensor	Um
	Bit width	■ Outputs the bit width of Sensor data	Bit
	Color filter	■ Output Sensor color filter	-
	Shutter type	■ Output the shutter type of the Sensor	-
Lens specification	Focal length	■ Output lens focal length	mm
	Polarized filter	■ Output the presence or absence of a polarization filter	-
Recognition specification	Recognition delay amount	■ Output the amount of delay for imaging frame and recognition frame	frame
	Longest recognition distance	■ Output the longest recognizable distance	m
	Shortest recognition distance	■ Output the shortest recognizable distance	m
	Maximum recognition angle (left and right)	■ Output maximum recognizable left and right angle	deg
	Maximum recognition angle (up and down)	■ Output maximum recognizable upper and lower angles	deg

2 【 Camera model & IF research 】
Defined the output Interface of the camera model

Recognition result Interface

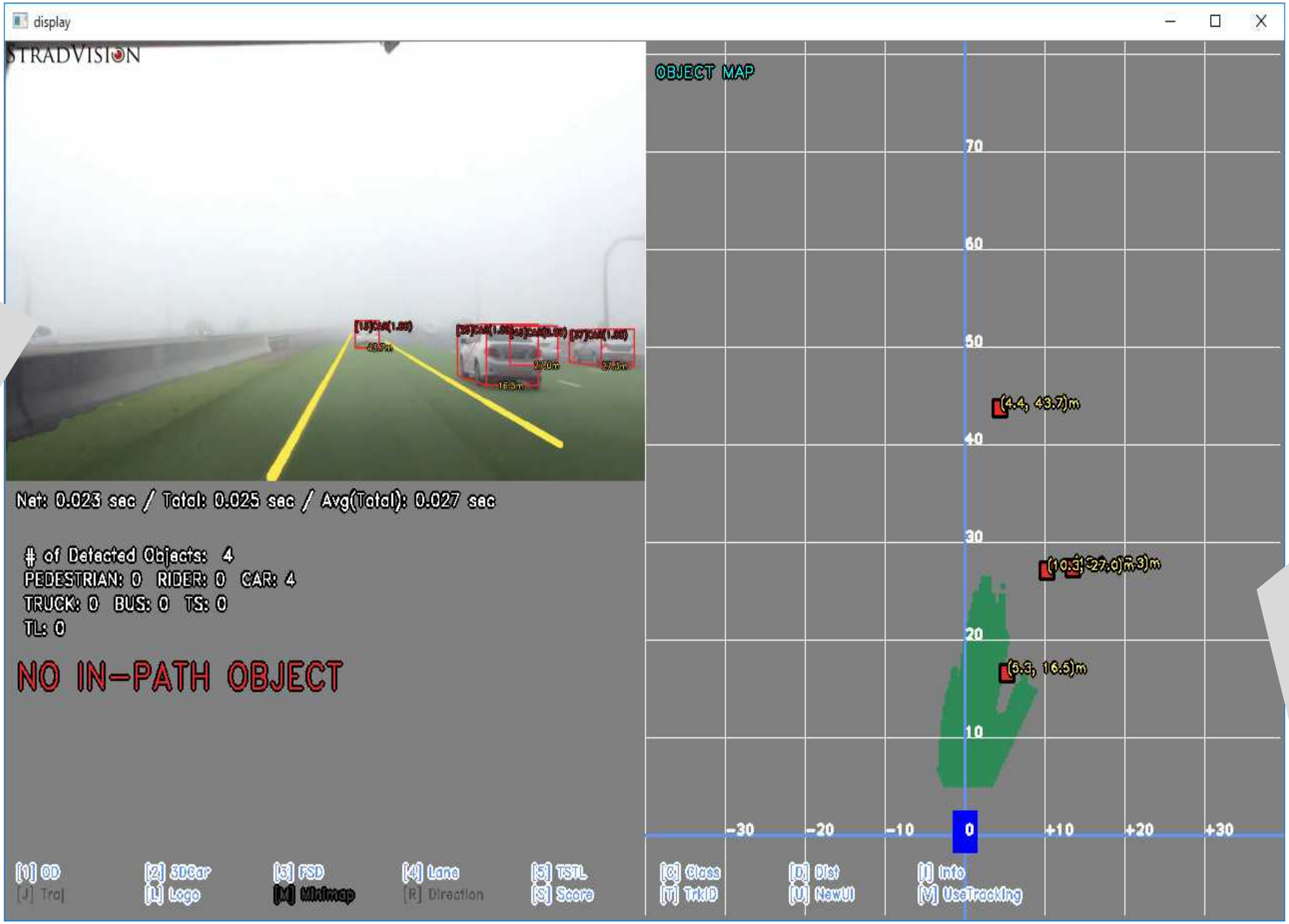
Classification	Name	Description	Unit
Time information	Imaging time	Output camera imaging time	μsec
	Recognition time	Output camera recognition time	μsec
Diagnostic information	HALT information	Output whether the camera is working properly	-
Exposure control	Exposure time	Output exposure time per line	μsec
	Gain information	Output gain value of camera output	-
Target information (Sensor standard)	Screen coordinates (X,Y)	Output target center coordinates on camera image	pixel
	World coordinates (X,Y,Z)	Output target center and facing center coordinates based on lens focal position	m
	Size (X,Y,Z)	Output target size	m
	Speed (X,Y,Z)	Output the moving speed of the target	km/h
Target information (Vehicle standard)	World coordinates (X,Y)	Output target center and facing center coordinates based on center of front wheel axle	m
	World coordinates (Z)	Output target coordinates based on tire contact area	m
	Size (X,Y,Z)	Output target size	m
	Speed (X,Y,Z)	Output the moving speed of the target	km/h
Target identification information	Vehicle recognition number	Output recognition number of Vehicle objects	-
	Pedestrian recognition number	Output recognition number of pedestrian object	-
	Other target recognition number	Output number of recognition of other objects	-
	Vehicle, Vehicle type	Output Vehicle type of recognition target	-
	Vehicle angle	Output the angle with the Vehicle to be recognized	deg
	Pedestrian orientation	Output the direction of the pedestrian's front	-
	Pedestrian type	Output pedestrian type to be recognized	-
	Other type	Output object type of other recognition target	-

Classification	Name	Description	Unit
Own lane information	Own lane recognition information	Output white line recognition status	-
	Left and right lane@ 10,20,30m	Outputs the lateral distance of the left and right lanes 10, 20 and 30 m from the center position of the host Vehicle	m
	Road radius of left and right lane	Output road radius of left lane	m
	Yaw angle to left and right lane	Output the yaw angle of the Vehicle relative to the left lane	deg
	Distance to the left and right lanes	Output distance between left lane and own Vehicle center	m
Own lane type information	Left and right lane type	Output left lane type	-
Next lane information	Next lane recognition information	Output white line recognition status	-
	Left and right adjacent lanes@10,20,30m	Outputs the lateral distance of the left and right lanes 10, 20 and 30 m from the center position of the host Vehicle	m
	Road radius of left and right adjacent lanes	Output road radius of left lane	m
	Yaw angle to left and right adjacent lanes角	Output the yaw angle of the Vehicle relative to the left lane	deg
	Distance to left and right adjacent lanes	Output distance between left lane and own Vehicle center	m
Next lane type information	Left and right adjacent lane type	Output left lane type	-
Degree of reliability	Target detection reliability	Output the detection reliability of the target	%
	White line detection reliability	Output white line detection reliability	%

2 【 Camera model & IF research 】
Stradvision selected as camera model evaluation engine

Environment construction by Stradvision

Sample image with tool



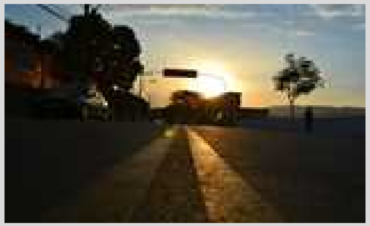
Confirm that the camera model is recognized

Source: Stradvision SVNet

2 【 Camera model & IF research 】

Defined an evaluation scenario for camera model Verification.

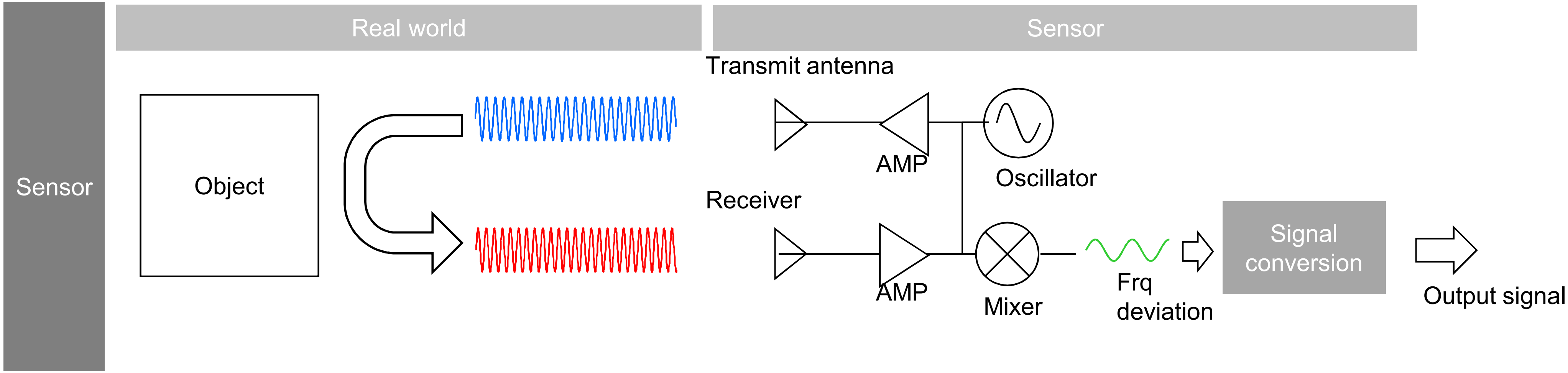
Camera model evaluation scenario example

No	Implementation period	Item	Image	Outline
1	First half of 2019	■ Basic scenario Leading Vehicle approaching		■ Approaching the Leading Vehicle while stopped（equivalent to E-NCAP2018 CCRs） ■ Straight and curved road
2		■ Basic scenario Leading Vehicle separation		■ Leading Vehicle separation ■ Straight and curved road
3	Second half of 2019	■ Middle obstacle (rain and wiper) Leading Vehicle approaching		■ Approaching the Leading Vehicle while stopped（equivalent to E-NCAP2018 CCRs） ■ Activate the wiper when it rains ■ Recognition disorder occurs due to image disturbance by wiper
4		■ Middle obstacle (rain and wiper) Leading Vehicle separation		■ Leading Vehicle separation under the same conditions as above
5		■ Light source failure (backlight) Leading Vehicle approaching		■ Approaching the Leading Vehicle while stopped（equivalent to E-NCAP2018 CCRs） ■ While driving toward the west sun, whiteout occurs and we lose sight of the target Vehicle traveling ahead.
6		■ Light source failure (backlight) Leading Vehicle separation		■ Leading Vehicle separation under the same conditions as above
7	2020	■ Road obstacle Night, pedestrian		■ At night, people who came in dark clothes cross the sidewalk (equivalent to E-NCAP2018 CPAF ＋night)
8		■ Recognition disorder expansion（Determined in coordination with JAMA requirements）		■ Night driving, oncoming high beam, step, tunnel exit, wet road surface, traffic light, dropped objects, construction lane reduction, etc.

source：https://pxhere.com/

3 【Rader model & IF research】
Rader modeling space design model collaboration is important

Modeling design



Model

Space design model | Sensor model

- Collaboration space design model signal processing & input signal processing is important for Ray-trace output conversion to baseband signal generation

Input

- Ray-trace
- Radio wave propagation
- Radio wave reduction ratio

Input → Baseband Signal generation → Signal conversion

Antenna/Circuit Characteristics → Baseband Signal generation

Higher correlated signal output Interfaces are under consideration

3 【Rader model & IF research】
Higher correlated model by Pre-processing in Space design model

In/Out signal

Sensor model

Space design

- Preprocessing by space design model

Input
- ✓ Relative distance
- ✓ Relative angle (azimuth/elevation)
- ✓ Relative speed
- ✓ Object's Annotation

Perception

- Calculate signal strength by distance reduction
- Calculate noise level by circuit spec
- Output object's signal above noise level

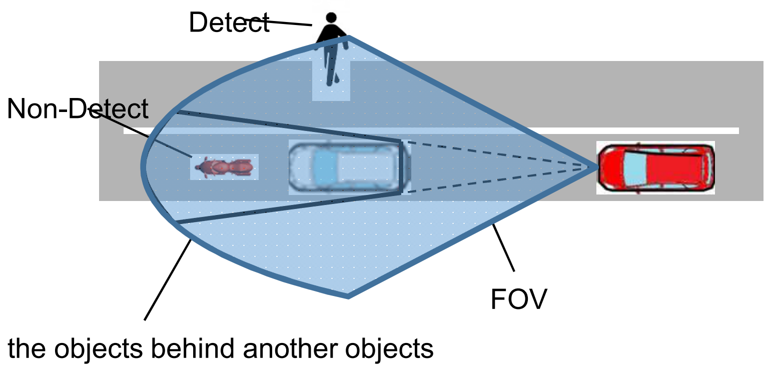
Output
- ✓ Relative distance
- ✓ Relative angle Relative speed
- ✓ Received power

Detection

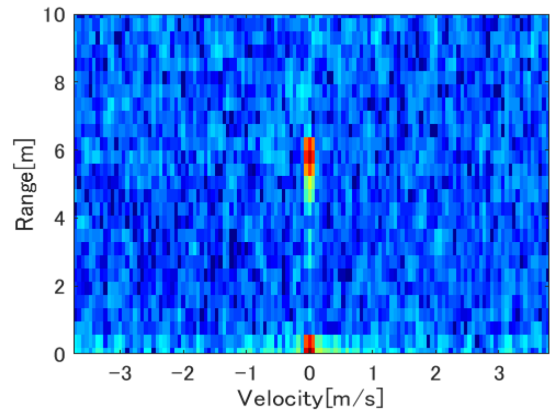
- Data processed in Autonomous model

preprocessor

- **Ignore the objects behind another objects, by pre-processing in space design model by communicating FOV data**



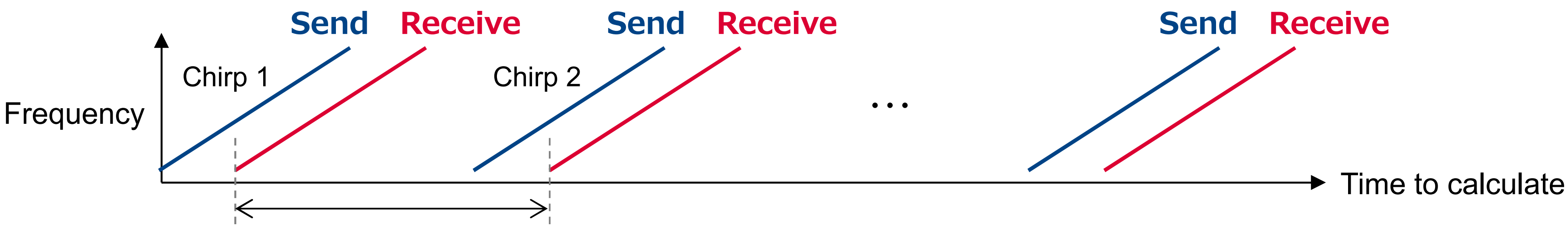
Sensor output sample



* FOV Field of View

3 【Rader model & IF research】
Research subject in the generation of relative velocity signal for modeling

Radar modeling requirements



Chirp interval (number ＋ us) = Raytrace execution interval

In the case of reproducing a method of repeating high-speed chirp, it is necessary to execute ray tracing for each chirp, which requires a large amount of calculation.

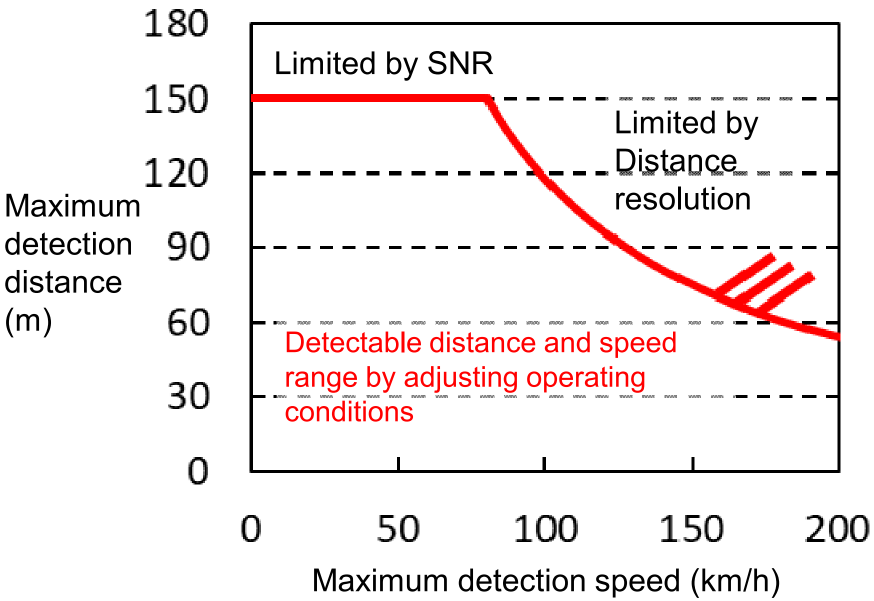
The relative velocity of the target is received from the system to generate a Doppler signal.

For multipath, it is necessary to study the method of calculating from the relative velocity between multiple reflection points.

3 【 Rader model & IF research 】Select actual Sensor specifications from calculation of detection distance and speed by actual measurement

Examination of specifications of radar implementation

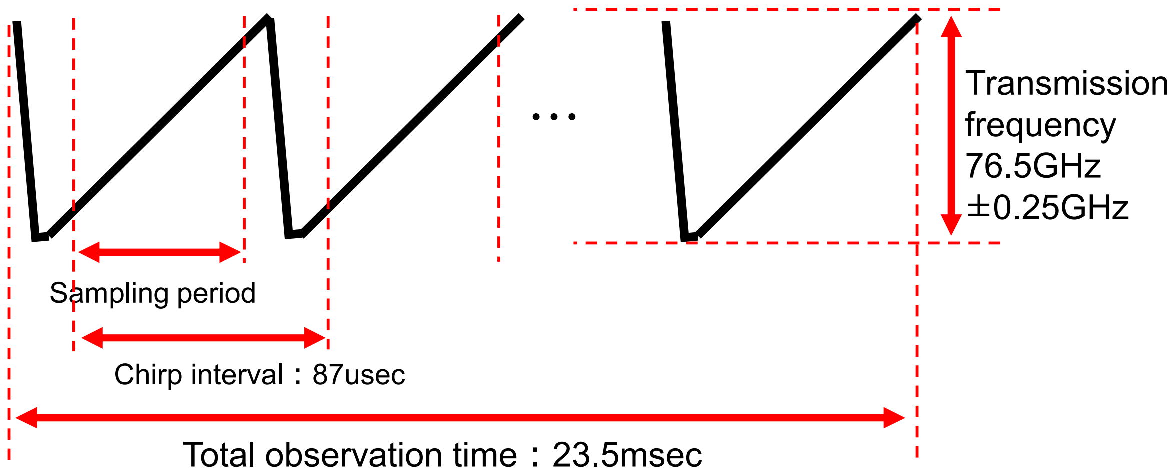
Select the condition that can ensure the largest detection distance
- Limited by modulation condition
- Limited by SNR



Sensor specifications after selection

Maximum detection distance	: 150m	Distance resolution	: 30cm
Maximum detection speed	: ±80km/h	Speed resolution	: 0.3km/h

Modulation waveform



* SNR: Signal to Noise Ratio

3 【 Rader model & IF research 】
Defined an evaluation scenario for radar model Verification

Evaluation scenario example of radar model

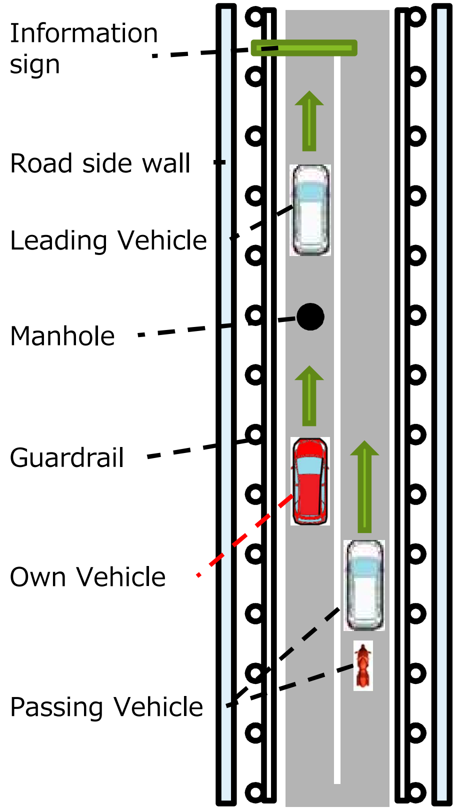
■ Extraction of evaluation object

Extract factors that should be preferentially evaluated based on the situation that becomes an issue in radar sensing

Situation that becomes problem	Selected malfunction factor
■ Object with low reception strength, or dropout situation	Bike, rain, snow
■ Situation where ghosting occurs due to multipath	Road side wall
■ Misrecognition occurs due to low resolution	Information sign, manhole
■ Situation in which a Doppler signal detection error occurs	Tire

[1] US Patent, US 6,661,370
[2] https://www.jsae.or.jp/~dat1/mr/motor36/06.pdf
[3] Victor C. Chen et al., "Radar Micro-Doppler Signature," The Institution of Engineering and Technology

■ Examination of sample evaluation scene



Scenario
A scene where another Vehicle overtakes while following the leading Vehicle on a dedicated road

Asset
- Own Vehicle (Radar mounted forward)
- Leading Vehicle, Following Vehicle (Including bikes)
- Guardrail
- Road surface
- Road side wall
- Information sign
- Rain, snow

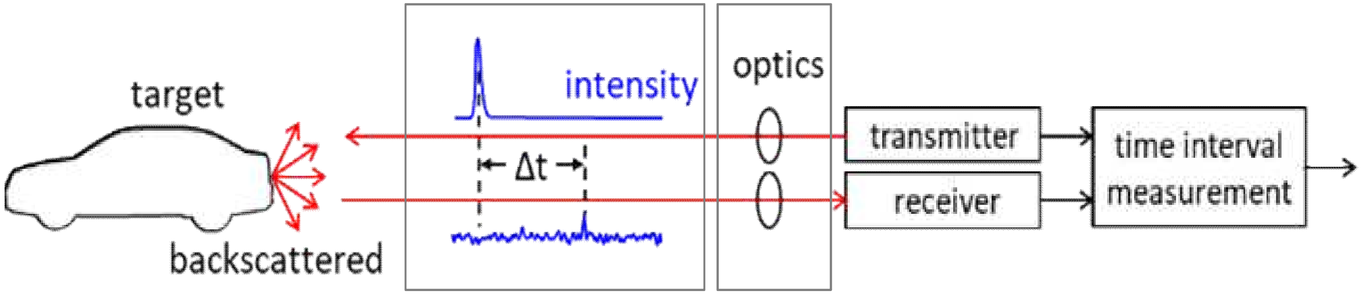
Evaluation items
- Reflections from leading and passing Vehicles
- Doppler signal by tire rotation
- Reflection by guardrail pole
- Multipath from the road side wall
- Reflection by information sign
- Attenuation due to rain and snow

4 【 LiDAR model & IF research 】
Study of modeling requirements for LiDAR simulation

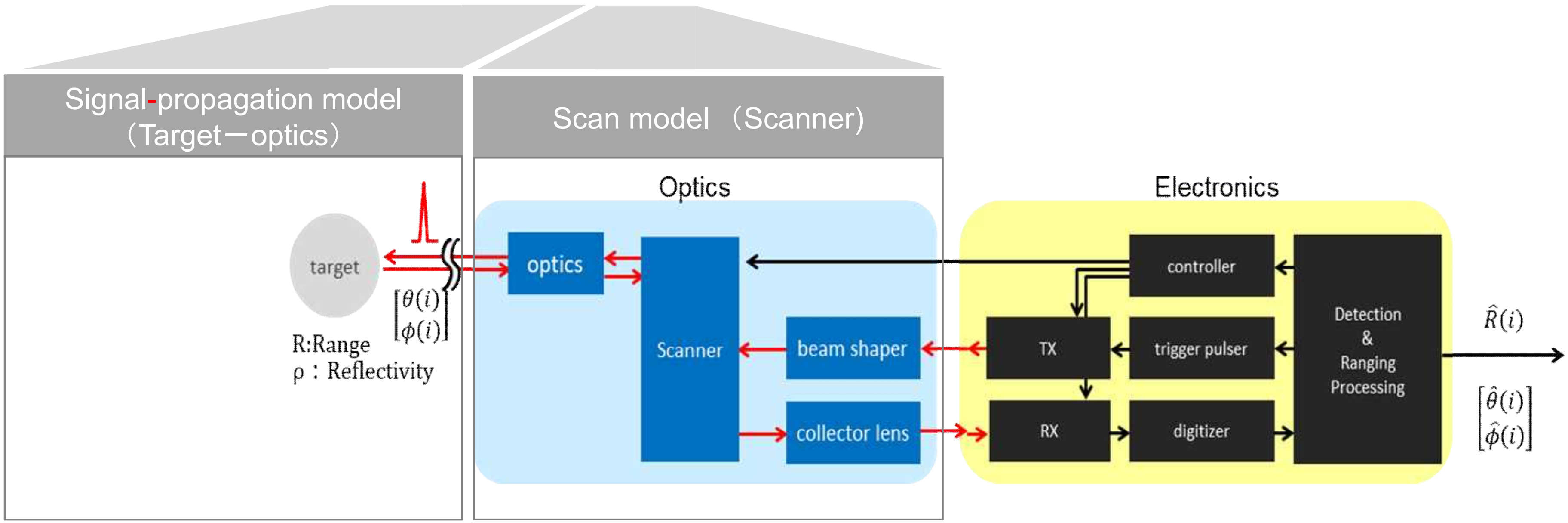
Modeling

Sensor structure, detection principle

- A Sensor which outputs the detecting target-position by the distance R derived from the transmitting-beam angle（θk, φk）and the time interval between transmitting and receiving beams



Modeling requirements



θ : Azimuth
ϕ : Supine angle

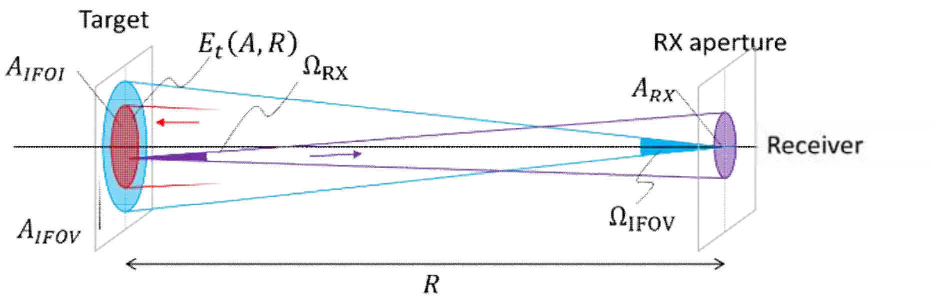
$\hat{\theta}$: Estimated azimuth
$\hat{\phi}$: Estimated supine angle

TOF: Time Of Flight

4【 LiDAR model & IF research 】Clarification of the modeling factors by examination of signal propagation model (optical model)

Signal propagation model (optical model)

Optical model

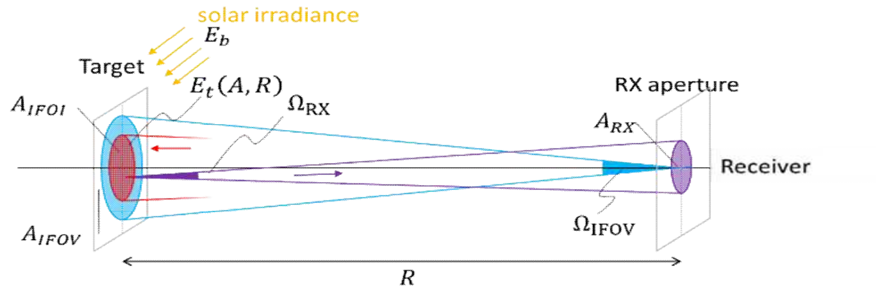


A_{IFOI}	Area onto which transmitted light is irradiated・Footprint [m²]
A_{IFOV}	Area from which reflected light can be received [m²]
Ω_{RX}	Reception solid angle of receiving lens aperture [sr]
Ω_{IFOV}	Instantaneous field of view (solid angle) [sr]
A_{RX}	Reception aperture area [m²]
R	Distance between the target surface and the Sensor [m]
$E_t(A,R)$	Irradiance distribution on the target surface [W/m²]

$$P_r(R) = \frac{\rho}{\pi}\int_{A_{IFOV}(R)}\int_{\Omega_{RX}(R)} E_t(A,R)\,dA\,d\Omega$$
$$= \frac{\rho}{\pi}\frac{A_{RX}}{R^2}P_t$$

ρ: Target emissivity, where the reflection characteristic is the Rambert reflector
Pt: Transmitting light power

Optical model including sunlight



$$P_b = \frac{\rho}{\pi}\int_{A_{IFOV}(R)}\int_{\Omega_{RX}(R)} E_b\,dA\,d\Omega$$
$$= \frac{\rho}{\pi}\frac{A_{RX}}{R^2}R^2\Omega_{IFOV}E_b$$
$$= \frac{\rho}{\pi}A_{RX}\Omega_{IFOV}E_b$$

E_b Irradiance from the sun

$$S/N \propto \frac{P_r^2}{P_b}$$

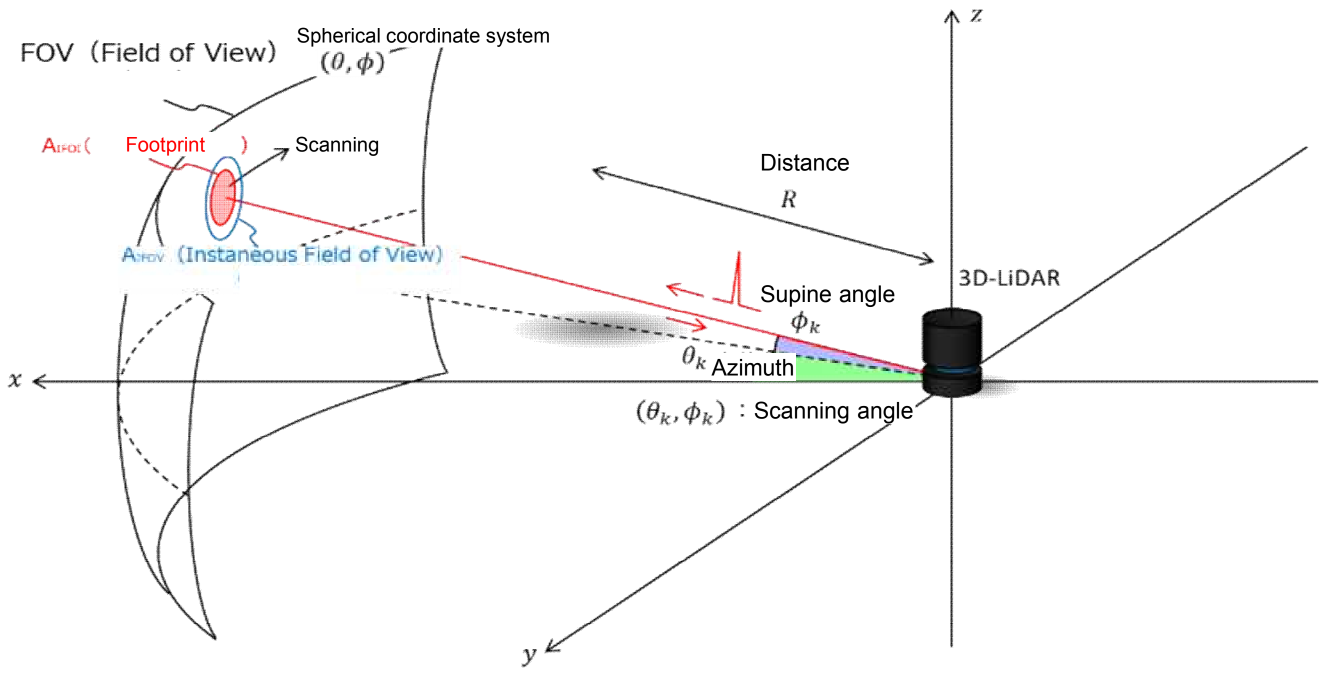
* LiDAR performance improves as S/N becomes higher.
* For S/N, there is a relationship between Pr and Pb as shown on the left formula, where Pr is the receiving reflected-light power from the target which is the signal component, and Pb is the background sunlight power which is the main noise component.

For Accurate LiDAR modeling, Target reflection characteristics, Propagation-decay property and Background lights power should be essential factors which affects to Pb and Pr.

4 【 LiDAR model & IF research 】Clarification of the modeling factors by examination of Scan model requirements

Scan model

Model image



Modeling requirements

- Optical model simulating optical transmission and reception at each scanning angle (θk, φk)
- Since a transmitted light spreads at a solid angle as shown in the optical model, a target surface is taken into account for modeling.
- Calculation procedure of a spread light is based on the concept of Ray tracing
- The parameters affect to detection rate and ranging accuracy are Target reflectivity, Distance, Solid angle of light reception, and Reflected light intensity from other light sources represented by the sun (background light)

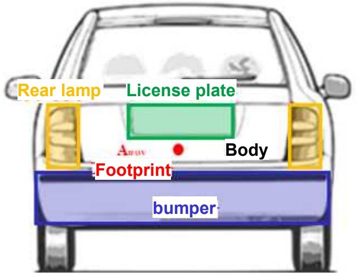
4 【 LiDAR model & IF research 】

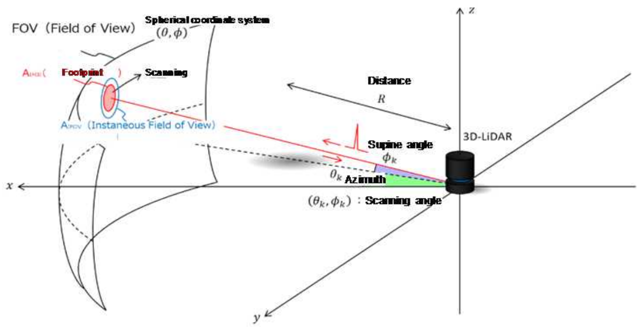
Speeding up of Scan modeling - can be controlled by "Footprint"

Scan model

Functional model

- **Light spread is not taken into account, but just a point at a target surface without "Footprint"**

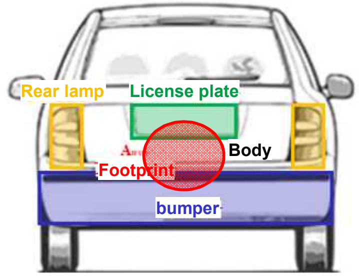


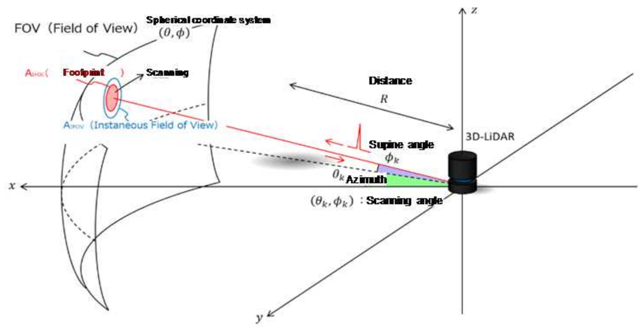


AIFOV (Foot print)	Point
Area	Point（Footprint）reflection ratio
Transmission	No refraction considered
Specular Reflection	Zero-deg only
Multi reflection	No consideration
Propagation reduction	uniformly affected in a frame
Background light	uniformly affected in a frame

Physical model

- **Light spread and reflection is taken into account with "Footprint" calculated at a target surface**





AIFOV (Foot print)	Area
Area	Footprint calculated
Transmission	Use target characteristics
Specular Reflection	Use target characteristics
Multi reflection	considered
Propagation reduction	consider in each beam transmission
Background light	consider in each Footprint

4【 LiDAR model & IF research 】
Study & defined LiDAR model In/Out Interface

LiDAR Interface

Class	Method	Input	Output	Return	Processing
Sensor Component	GetPosition	■ -	■ Place	■ -	■ Sensor position
	GetOrientation	■ -	■ Angle	■ -	■ Sensor angle
	AdjustPosition	■ Current time	■ -	■ -	■ Sensor point correction
	AdjustOrientation	■ Current time	■ -	■ -	■ Sensor angle correction
	Tick	■ Progress time	■ -	■ -	■ Common processing
LiDAR Component	InitLiDAR	■ Spec file name	■ -	■ -	■ LiDAR model initialization
	OutputSensorData	■ Point cloud ■ Power	■ -	■ -	■ Sensor data output
LiDAR Model	GetShootList	■ Current time ■ Simulate time in a flame	■ Shot number ■ Time stamp ■ Transmit angle	■ -	■ Shot angle
	SetReceiveInfo	■ Shot number ■ Time stamp ■ Shot angle ■ distance ■ Return light ■ Back ground light density	■ -	■ -	■ Receive info
	DoSensorProc	■ -	■ -	■ -	■ Internal Processing
	GetSensorData	■ -	■ Point cloud ■ Power	■ -	■ Sensor data
Time Keeper	GetSimTimePerFrame	■ -	■ Simulate time in flame	■ -	■ Simulate time in flame
	GetCurrentTime	■ -	■ Current time on simulator	■ -	■ Current time on simulator
Env Model	CalcInfraredPropagation	■ Shot point ■ Shot angle	■ Distance ■ Reflect light ■ Back ground light density	■ -	■ Infrared light propagation calculation

4【 LiDAR model & IF research 】
Defined objects for LiDAR model Verification

Defined high-way objects from LiDAR point of view

- The minimum number of objects are defined for high-way scene only, for those of the other scenes will be defined later on.
- Priority of object selection
    1. Minimum required objects in high-way
    2. Passenger Vehicle
    3. Infra objects（easy to detect for LiDAR ）
    4. Large Vehicle, Motor cycle

1. Minimum required object in high-way

Priority	Objects	memo
1	Road（Asphalt）	City
1	White line	Major lane
1		Side lane
2		Splitter
2		Guide(text)
2		Guide（arrow）
3	Yellow line	No overtake

2. Passenger Vehicle

Priority	Objects	memo
1	White	
2	Silver	
2	Blue	
2	Red	
※	Black	Reason of miss-detection（difficult to detect）

3. Infra objects（easy to detect for LiDAR）

Priority	Objects	memo
1	Curb	
1	Guard rail	
1	Delineator	Round
1	Wall	Insulation wall
2		Use Retro reflection
1	Splitter post	
2	Splitter corn	
2	Road（Asphalt）	Other than No1
2	Road（concrete）	Tunnel
2	Road	Red paint
2	dots butts	Cat'sEye
2	Guard rail	Use Retro reflection
3	Guard wire	Potential risk for Reason of miss-detection

4. Large Vehicle, Motor cycle

Priority	Objects	memo
1	Motor cycle	
1	Truck	Modeling 4t
	Dump	
	Trailer	
	Cargo	
	Tank role	
1	bus	

FY 2018 outcome

- Project summary

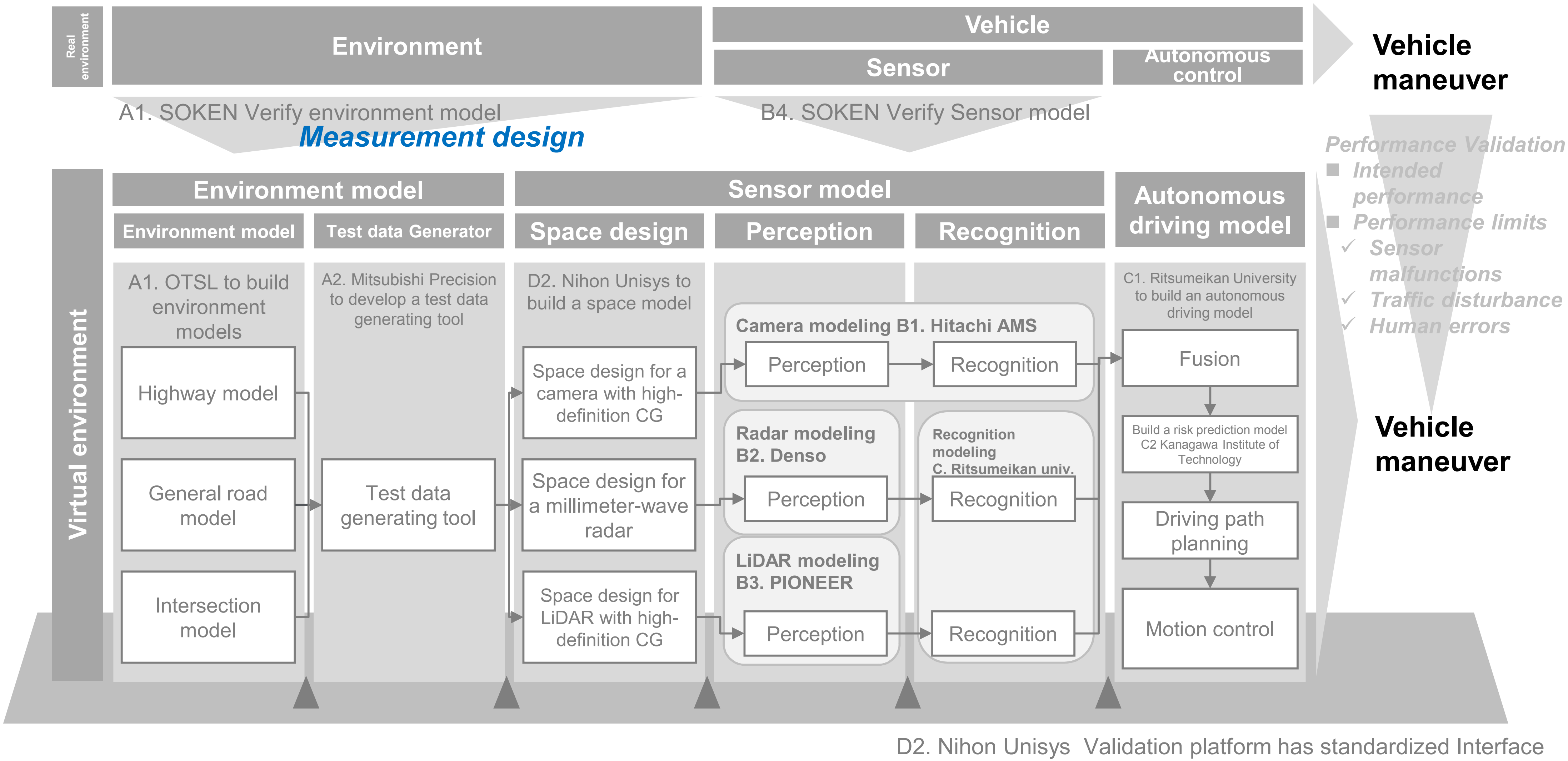
(1) Virtual Validation platform research

(2) Models requirements & Interface research

(3) Measurement design research

Defined Measurement method & measuring objects for Highly correlated Environment model

FY2018 outcome



Measuring specific characteristics defining BRDF &BTDF* for Highly correlated Environment model

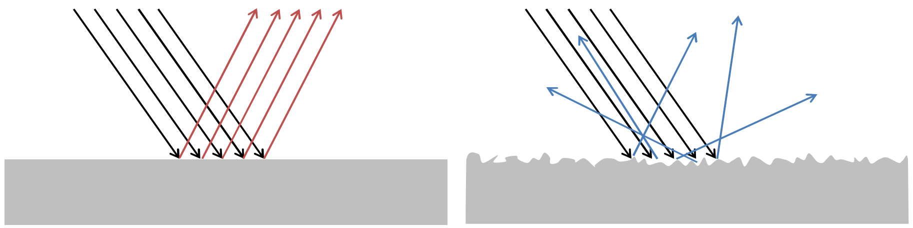
Measurement method reasonability

Back ground

- Using Ray-tracing is the reasonable solution
- Realize accurate simulation, needs accurate modeling with using Reflection / Refraction / Transmission characteristics

Affects of roughness

- In reality, reflection from object is not ideal because of roughness on surface and the roughness is important factor for accurate simulation



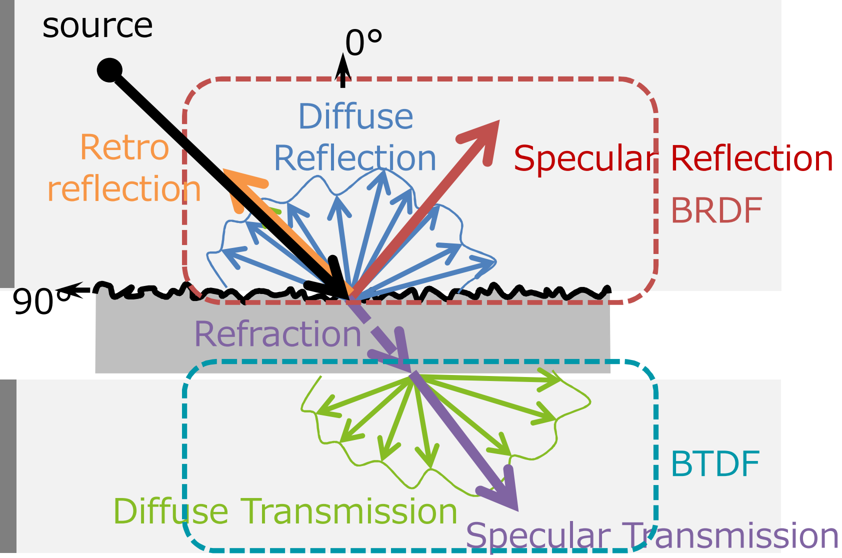
Necessary of BRDF･BTDF measurement

- *Able to realizing affect for Sensor detection by object's roughness, color etc.*
- *Able to realize Sensor Miss-detection due by Multi-path and/or background light, etc.*

Measurement method

Method

BRDF	
BRDF	



Measuring items

Retro reflection	Use distance calculation, signal tends to be most powerful signal
Specular Reflection	Need for realize multi-path reflection in virtual
Diffuse Reflection	Risk for sensing error of Rader by surface roughness Important for LiDAR background light from Sun
Diffuse Transmission	Needs for Grass, Bumper etc., has transparent material

* BRDF: Bidirectional Reflectance Distribution Function,
BTDF: Bidirectional Transmittance Distribution Function

Defined measuring objects from Sensor physics

Measurement items

Category	object	Memo	LiDAR	Radar
Road surface	Asphalt		○	○
	Asphalt（RED）		○	
	Concrete		○	○
	White line		○	
	Yellow line		○	
Road besides objects	Side wall		○	○
	Guard rail	Retro reflection Yes / No	○	○
	Road Pole		○	
	Curb		○	
	Botts Dots		○	
	Delineator		○	
	Guard wire		○	
	Road sign			○
Vehicle parts	Grass		○	○
	Bumper		○	○
	Tire / Wheel		○	○
	Miller		○	
	Reflector		○	
	Front / Rear lamp		○	
	Number plate		○	
	Paint	White peal, Silver, Blue, Red, Black	○	
Moving objects	Passenger Vehicle		○	○
	Motor cycle		○	○
	Truck		○	
	Dump		○	
	Trailer		○	
	Cargo		○	
	Tank role		○	
	Bus		○	

Designed measurement facility so that needed characteristics measurement

Millimeter wave measurement for Rader

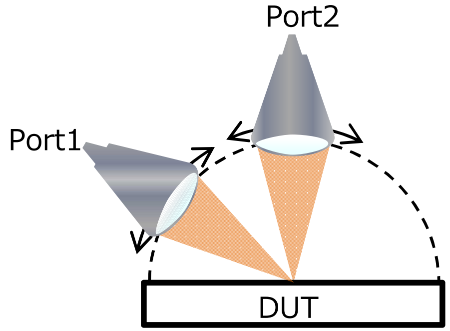
Measurement Condition

- Freq：76-81GHz 0.1GHz Step
- Range：Transmit antenna 0〜60deg 5deg resolution
- Range : Receive antenna 0〜±deg 5deg resolution
- Distance between antenna＞30 deg.

Method

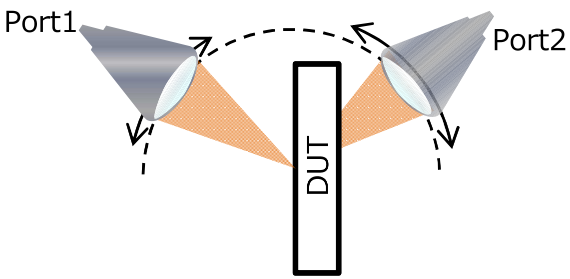
Retro reflection

- Measure Retro reflection use Pot1



Diffuse Transmission / Diffuse Reflection

- Measure Diffuse Transmission & Diffuse reflection Transmit Port1 and receive Port2



Infrared wave measurement for LiDAR

Measurement Condition

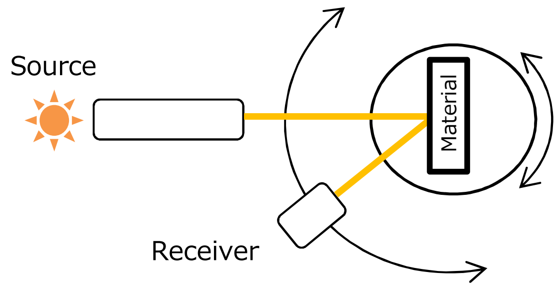
- Wavelength：905nm
- Range：Light source 0〜90deg
- Range : Receiver 0〜±180deg
- Source to Receiver angle : TBD

* Measurement range resolution TBD

Method

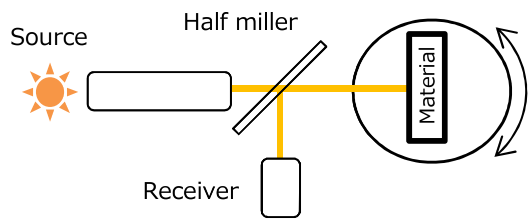
Retro reflection

- Measure Retro reflection use Combination with Half miller & Splitter etc.



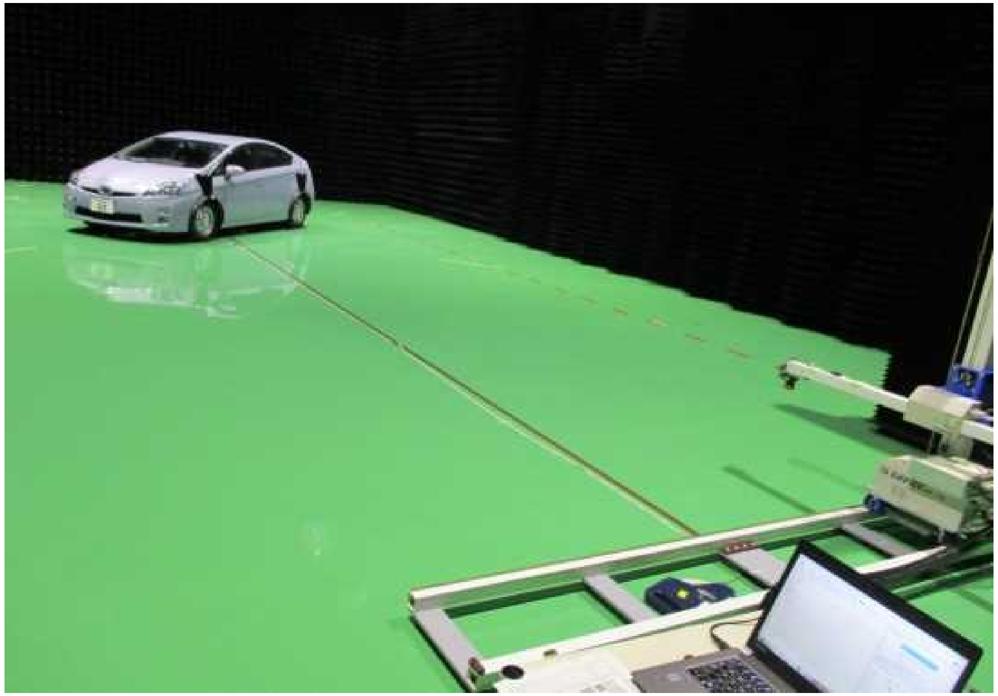
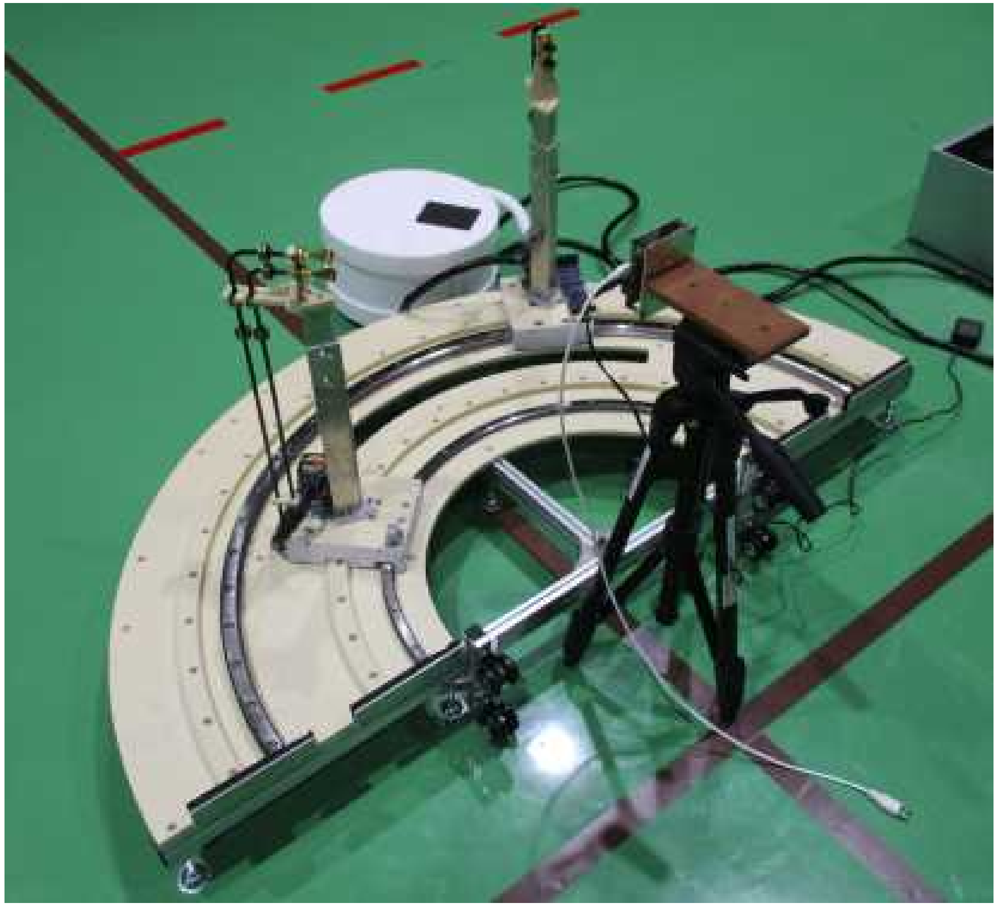
Diffuse Transmission / Diffuse Reflection

- Measure Diffuse Transmission & Diffuse reflection with Rolling of material



【Example】Measurement facility

Measurement facility example

Millimeter wave measurement Room	Millimeter wave measurement lane
	

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