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

DIVP™
Driving Intelligence Validation Platform

FY2019 Year-end report

Weather Forecast

AD safety Assurance*

For Validation & Verification Methodology

* AD : Automated Driving

Agenda

- Project Design
- FY2019 outcome
- Validation framework study

About the Cross-ministerial Strategic Innovation Promotion Program (SIP)
This is a program for achieving science, technology and innovation as a result of the Council for Science, Technology and Innovation exercising its headquarters function to accomplish its role in leading science, technology and innovation beyond the framework of government ministries and traditional disciplines.
The program strives to promote research and development in a seamless manner from the basic research stage to the final outcome by endeavoring to strengthen cooperation among industry, academia and government under the strong leadership of the Program Director (PD)

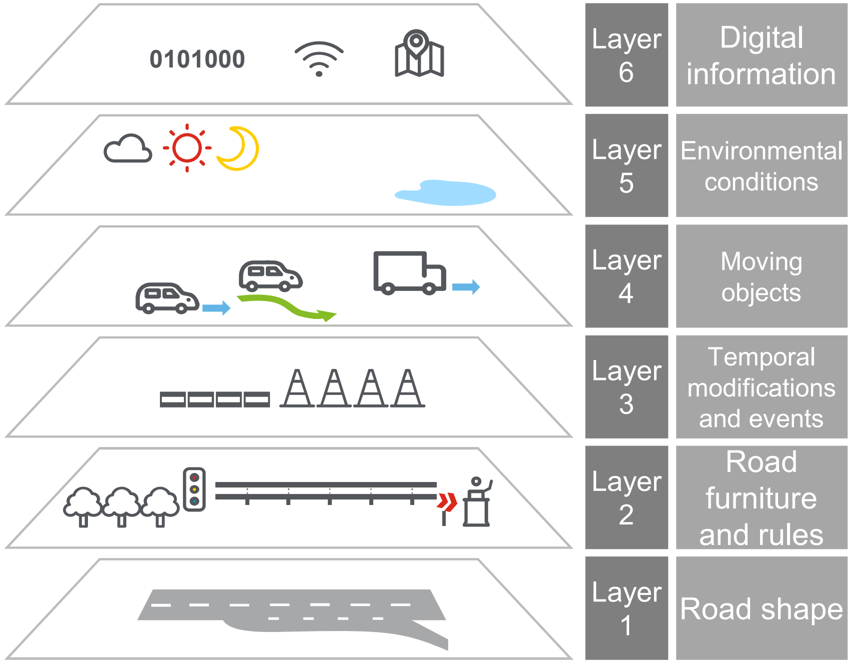
Project Design

Definition of AD safety evaluation system, multi test method combination for huge test scenario for safety assurance is important for the promotion for social acceptance

AD safety evaluation system

Evaluation conditions

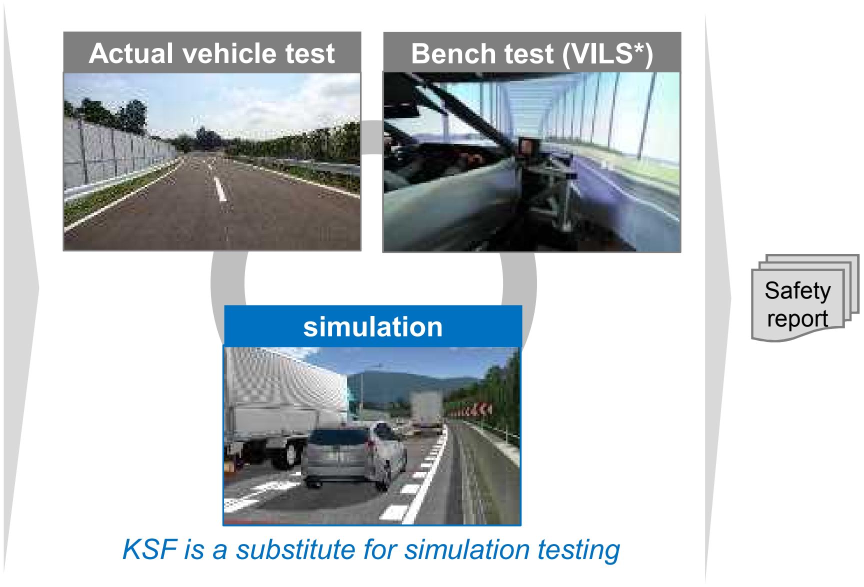
■ Generating evaluation conditions by combining various conditions



Layer 6	Digital information
Layer 5	Environmental conditions
Layer 4	Moving objects
Layer 3	Temporal modifications and events
Layer 2	Road furniture and rules
Layer 1	Road shape

Safety evaluation test

■ Test management combining various experimental methods



Actual vehicle test

Bench test (VILS*)

simulation

KSF is a substitute for simulation testing

Safety report

Expansion of test scenario availability & Test results consistency are required for methodology standardization

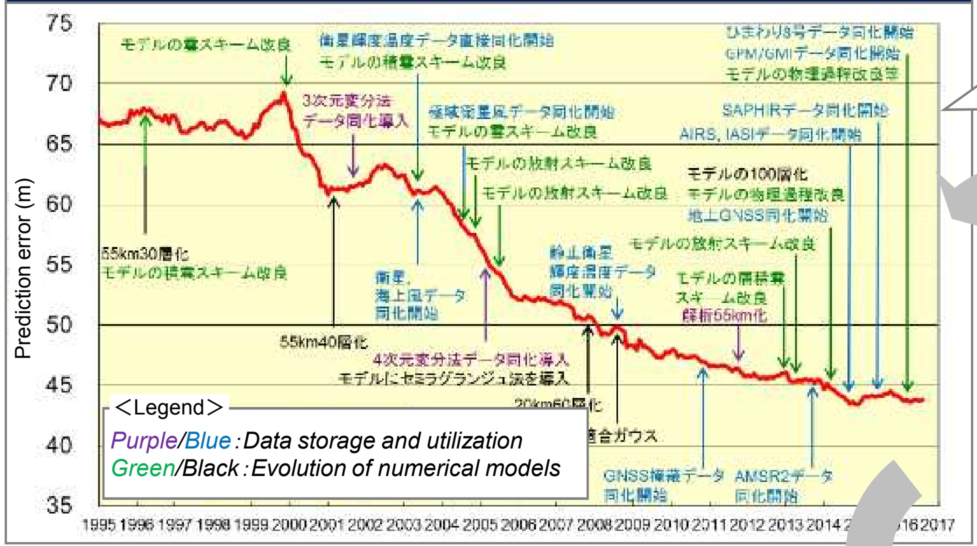
* VILS : Vehicle in the Loop

Source: Mitsubishi Precision Co. Ltd.

Referring Weather forecast, simulation based physics forecasting, Forecasting technology and computing performance improvements are mandatory required

History of weather forecasts

■ Forecasting technology improvement
(5 days Forecast of Northern Hemisphere 500hPa Altitude)



The prediction method is two-factor

- ***Data accumulation and utilization***
- ***Physical models***

improved by about 30% in 25 years

■ Computing performance has **increased 70 billion times in about 50 years**

■ Computing performance improvement

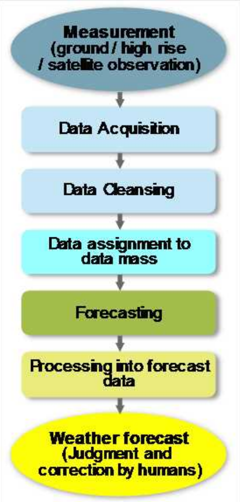
	1959	2015	Evolution over time
■ **Main memory capacity**	36KB	108TB	**3 billion times**
■ **Maximum computing performance**	12Kflops	847Tflops	**70 billion times**
■ **Model**	Northern hemisphere model	Global model	
■ **Horizontal resolution**	381km	20km	**About 20 times**
■ **Number of vertical layers**	1 layer	100 layers	**100 times**
■ **Forecast frequency**	1/day	4/day	

Trinitarian approach with “Data accumulation“, “Physical modeling“ and “Computing performance“ improvement has to be managed as long term based

Source: Created based on JMA website public information

【Reference】
Weather forecast has been enhanced over the long term through a Trinitarian approach

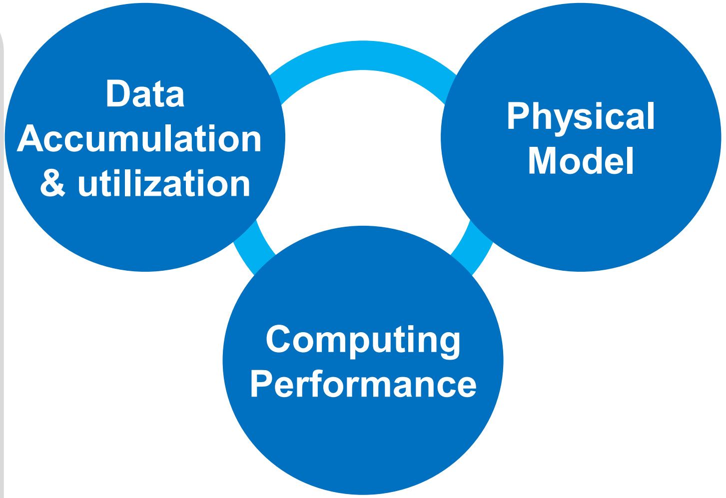
Trinitarian approach



Data management flow

■ Acquisition	■Data measurement
■ Processing	■Noise removal, etc.
■ Structuring	■Creating a database for use and purpose
■ Utilization	■Data selection and processing according to purpose

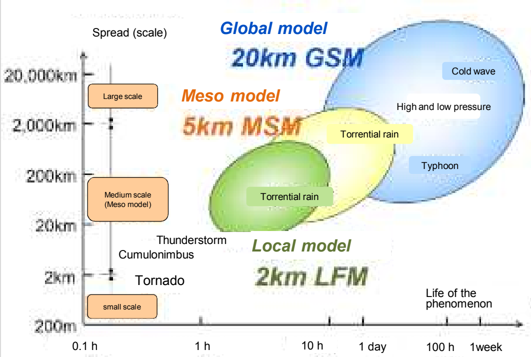
Data value chain



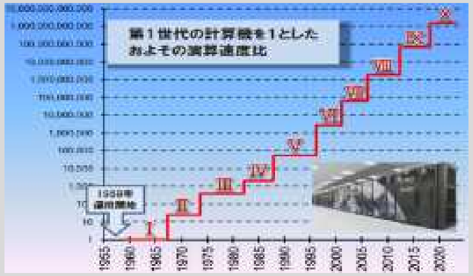
Data Accumulation & utilization

Physical Model

Computing Performance



Various physics Models for variety of usage



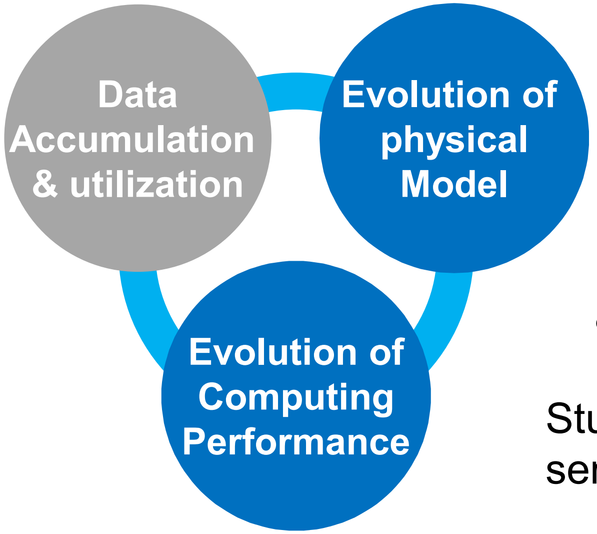
History of computer enhancement

DIVP™ scope covers "Physical Model" & "Computing Performance" in Trinitarian approach

DIVP™ scope & Objectives

DIVP™ scope

Trinitarian approach



Platform implementation

&

Study reasonable semiconductor spec

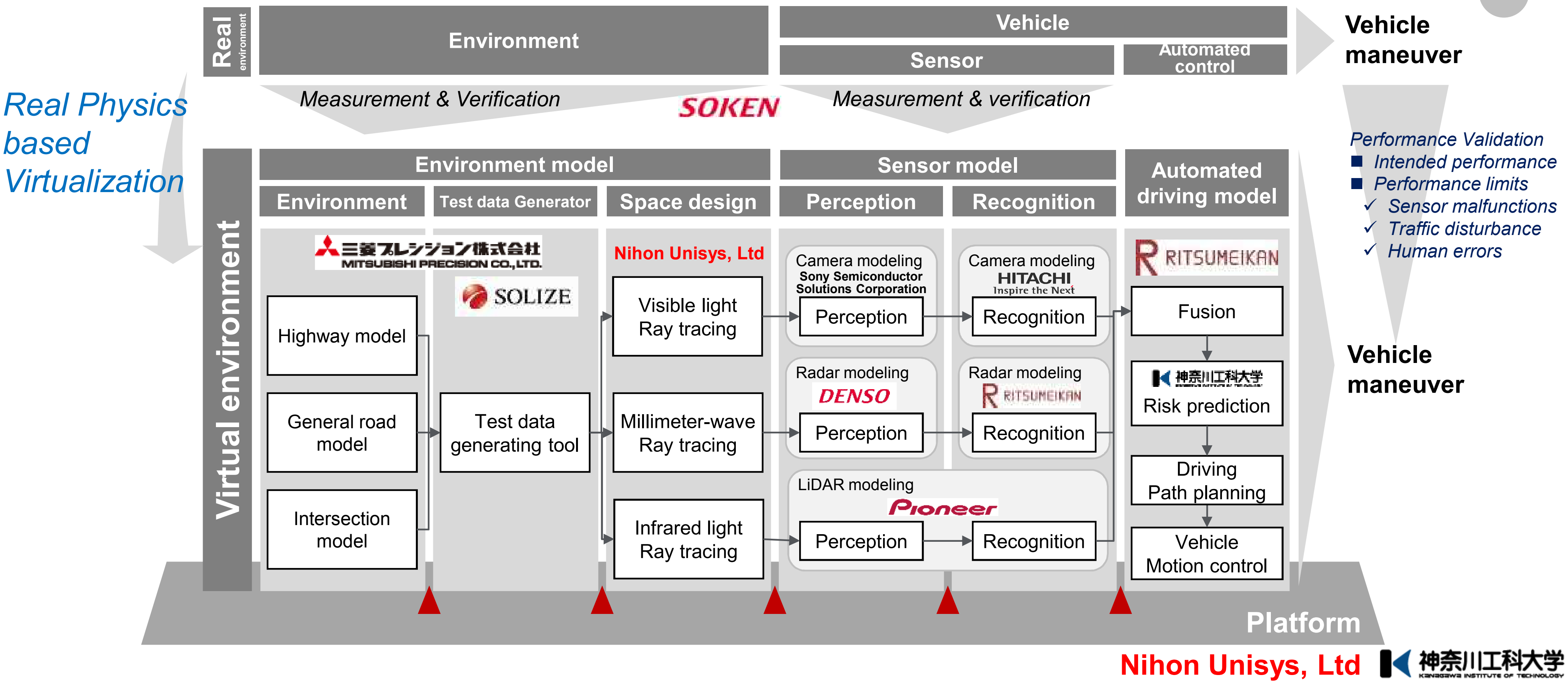
DIVP™ Objectives

- ***Open Standard Interface***
- ***Reference platform with reasonable verification level***
- ***E & S pair model based approach*** *(E : Environmental model, S : Sensor model)*

With project outcome DIVP™ is to Improve Simulation based AD Safety validation for Consumer acceptable Safety assurance

Designed research theme, Duplicate from Real to Virtual, and Verification of correlation level by 10-exparts as DIVP^{TM} Consortium

DIVP™ project design



Real Physics based Virtualization

Real environment

Environment

Vehicle

Sensor

Automated control

Vehicle maneuver

Measurement & Verification

SOKEN

Measurement & verification

Virtual environment

Environment model

Environment

Test data Generator

Space design

Sensor model

Perception

Recognition

Automated driving model

三菱プレシジョン株式会社 MITSUBISHI PRECISION CO.,LTD.

SOLIZE

Nihon Unisys, Ltd

Highway model

General road model

Intersection model

Test data generating tool

Visible light Ray tracing

Millimeter-wave Ray tracing

Infrared light Ray tracing

Camera modeling
Sony Semiconductor Solutions Corporation
Perception

Camera modeling
HITACHI Inspire the Next
Recognition

Radar modeling
DENSO
Perception

Radar modeling
RITSUMEIKAN
Recognition

LiDAR modeling
Pioneer
Perception
Recognition

RITSUMEIKAN

Fusion

神奈川工科大学
Risk prediction

Driving Path planning

Vehicle Motion control

Performance Validation

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

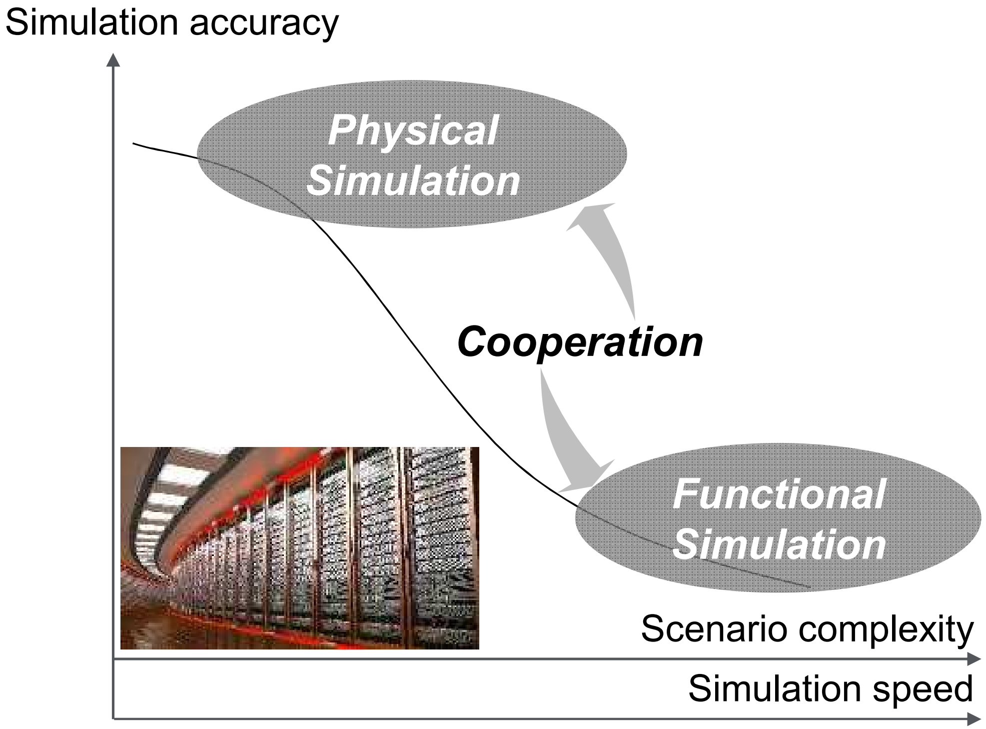
Vehicle maneuver

Platform

Nihon Unisys, Ltd 神奈川工科大学 KANAGAWA INSTITUTE OF TECHNOLOGY

Study Physical & Functional Simulation platform, and cooperate those for multiple user needs in various Industry player

DIVP™ focusing simulation structure



- ■Physical Simulation for *Accurate duplication of physics but not real-time*
- ■*Cooperate & Balance* accurate simulation results into real-time based system simulation
- ■Functional Simulation for *System evaluation in real time*

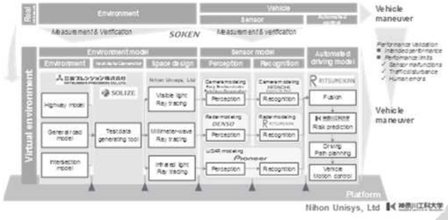
Leading global collaboration in AD safety verification using simulation

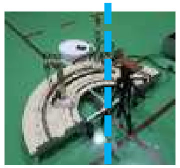
Through the step by step approach, develop Functional & Physical simulation and study for further opportunity

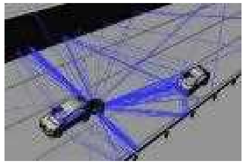
Project plan

Today

	FY 2019 1st half	FY2019 2nd half	FY2020 1st half	FY2020 2nd half
Step	**Combination operation check**	**Step 1 Joint check** **Step 2 Functional simulation Verification**	**Step 3 Basic scenario implementation**	**Step 4 Expansion study**
Target	■ Functional model software implementation based on formulated I / F ■ Verification of module connection operation	■ Verification of the whole combination including the test data generation tool ■ Evaluation of functional model Sim	■ Implementation of physical model based on actual sensor measurement results ■ Modeling cognitive upset factors ■ Evaluation of consistency with actual measurements on measuring vehicles	■ Link physical simulation results to functional simulation ■ Verification of evaluation potential in driving environment including general road
	Simulation I / F aiming for standardization	***Operation check using original performance of functional simulation***	***Verification of evaluability of physical simulation performance limit***	***Support scene expansion***





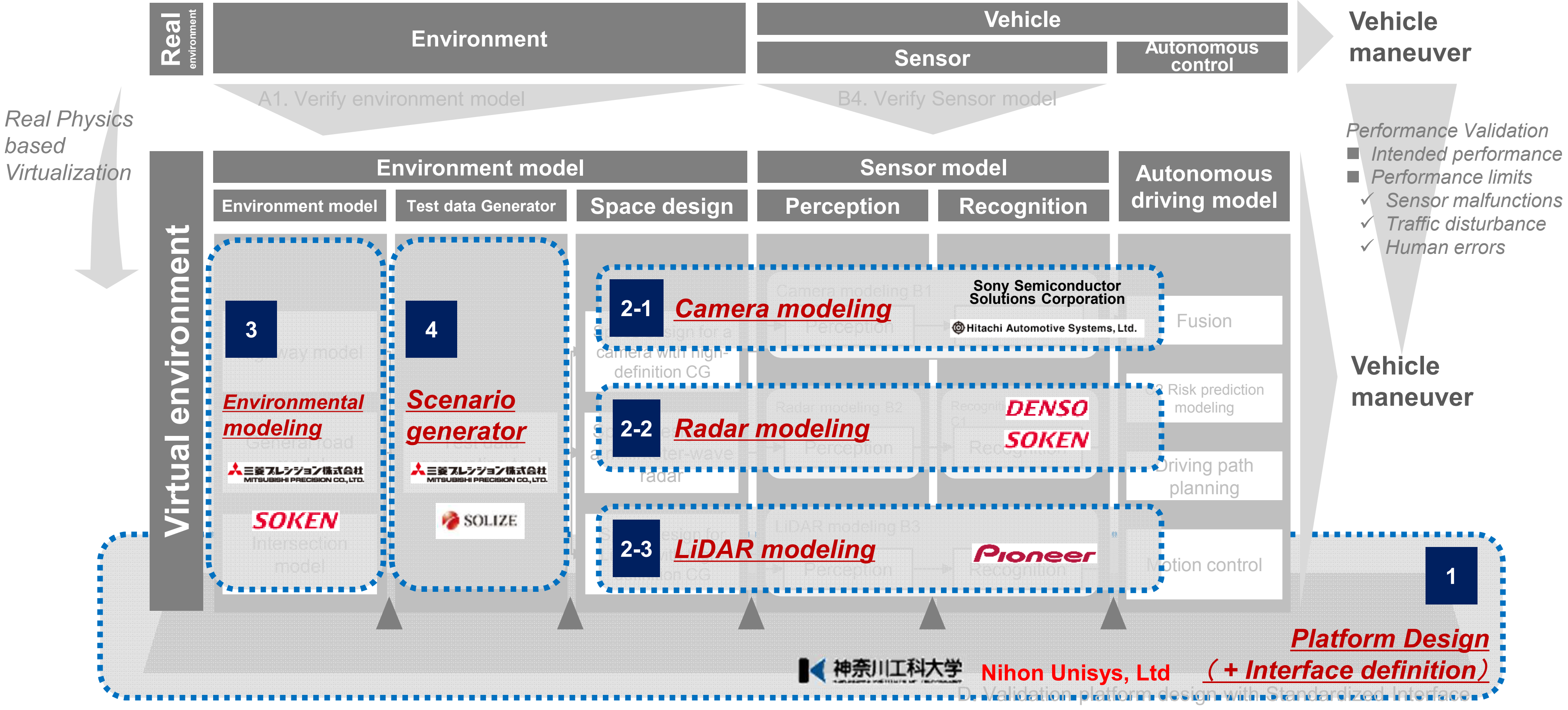


Source: SOKEN. INC, Mitsubishi Precision Co. Ltd.

FY 2019 outcome

In FY2019, 4-major research have been progressed,
Platform design, Sensor modeling, Environmental modeling and Scenario generator

Outcome overview



Real environment

Environment

Vehicle

Sensor

Autonomous control

Vehicle maneuver

A1. Verify environment model

B4. Verify Sensor model

Real Physics based Virtualization

Performance Validation

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

Virtual environment

Environment model

Sensor model

Autonomous driving model

Environment model

Test data Generator

Space design

Perception

Recognition

3 ***Environmental modeling***

MITSUBISHI PRECISION CO., LTD.

SOKEN

4 ***Scenario generator***

MITSUBISHI PRECISION CO., LTD.

SOLIZE

2-1 ***Camera modeling***

Sony Semiconductor Solutions Corporation

Hitachi Automotive Systems, Ltd.

2-2 ***Radar modeling***

DENSO

SOKEN

2-3 ***LiDAR modeling***

Pioneer

Fusion

Risk prediction modeling

Driving path planning

Motion control

Vehicle maneuver

1 ***Platform Design***
（+ Interface definition）

神奈川工科大学

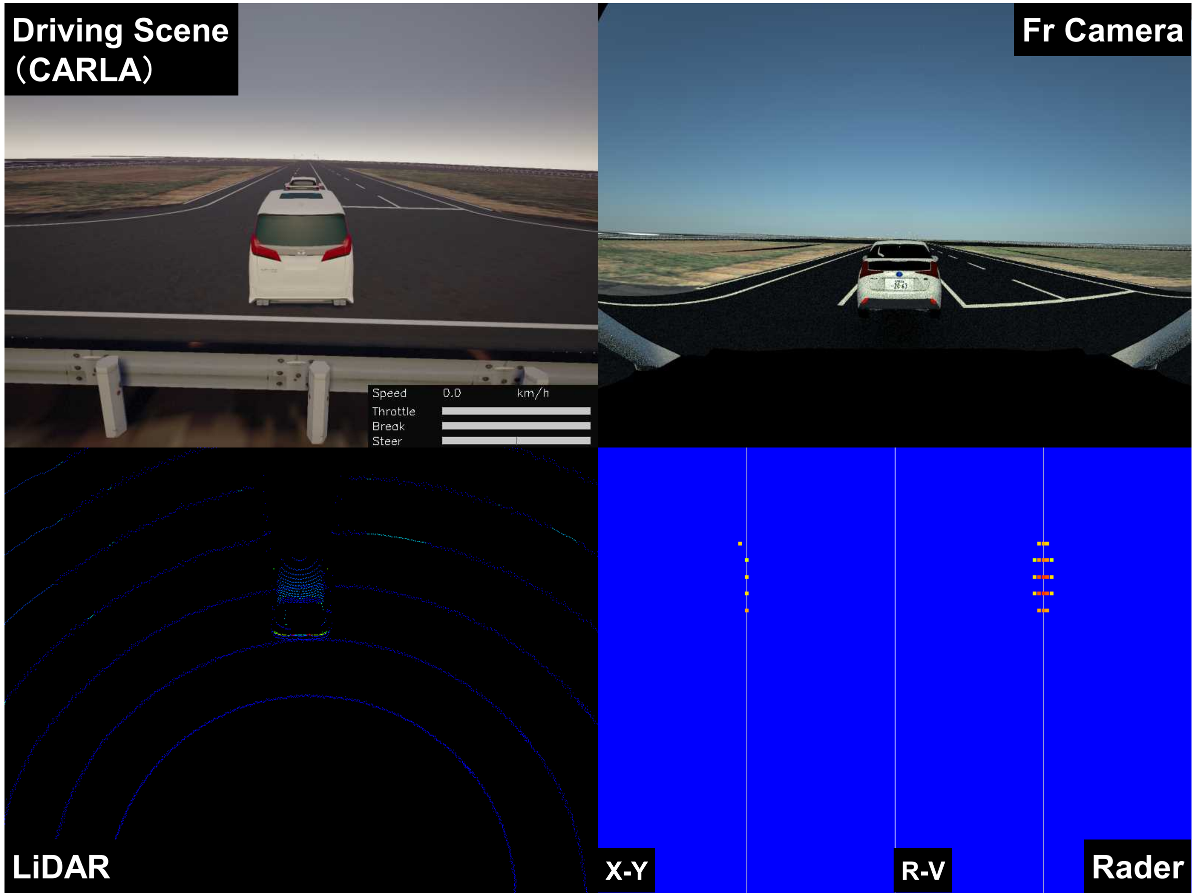
Nihon Unisys, Ltd

D. Validation platform design with Standardized Interface

Launched DIVP^{TM} simulator with jointing Environmental, Space design & sensor modeling for Camera, Radar & LiDAR sensors for consistency verification

Hitachi Automotive Systems, Ltd. DENSO Pioneer
神奈川工科大学 Nihon Unisys, Ltd

DIVP^{TM} perception output Sample



Source：Copyright © CARLA Team 2019.

Launched DIVP^{TM} simulator with jointing Environmental, Space design & sensor modeling for Camera, Radar & LiDAR sensors for consistency verification

DIVP™ Camera model output Sample

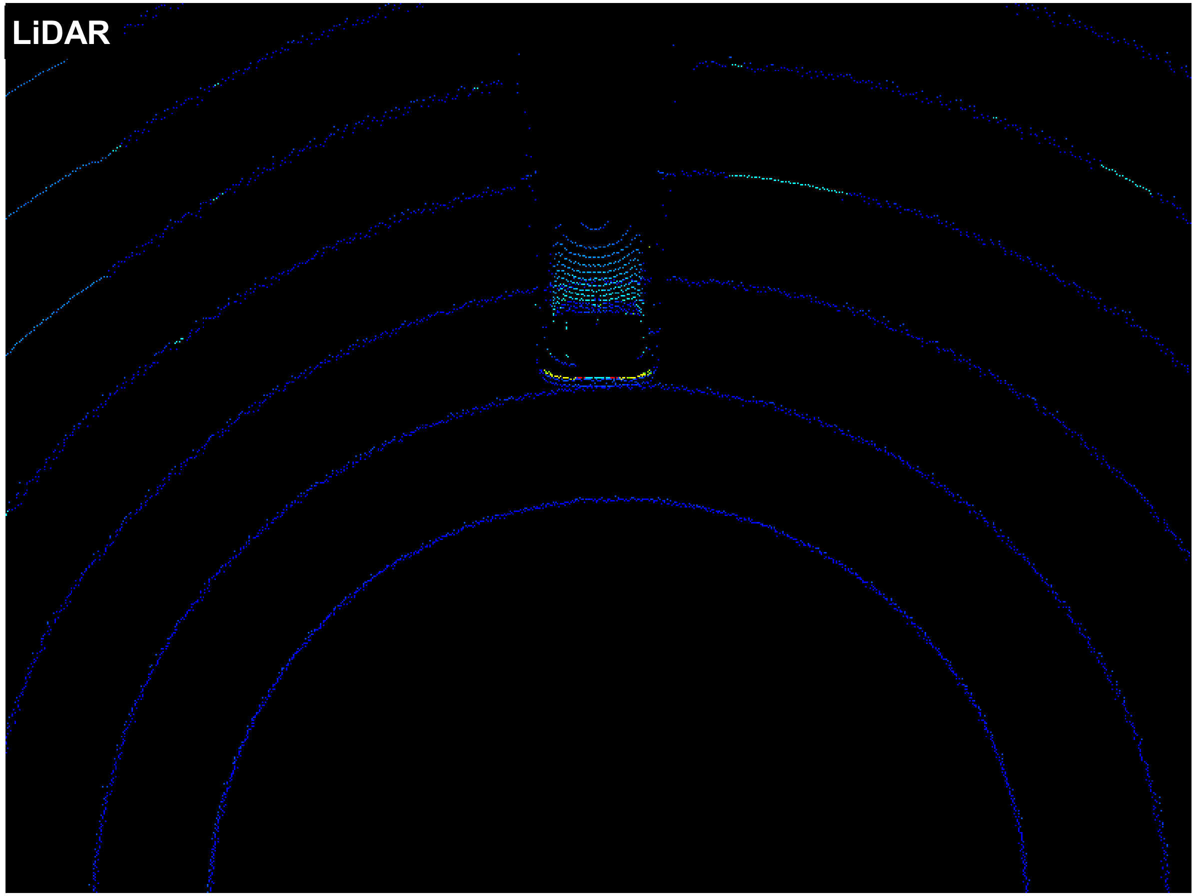
Hitachi Automotive Systems, Ltd. DENSO Pioneer
神奈川工科大学 Nihon Unisys, Ltd

Source: Copyright © CARLA Team 2019.

Launched DIVP^{TM} simulator with jointing Environmental, Space design & sensor modeling for Camera, Radar & LiDAR sensors for consistency verification

Nihon Unisys, Ltd

DIVP™ LiDAR model output Sample

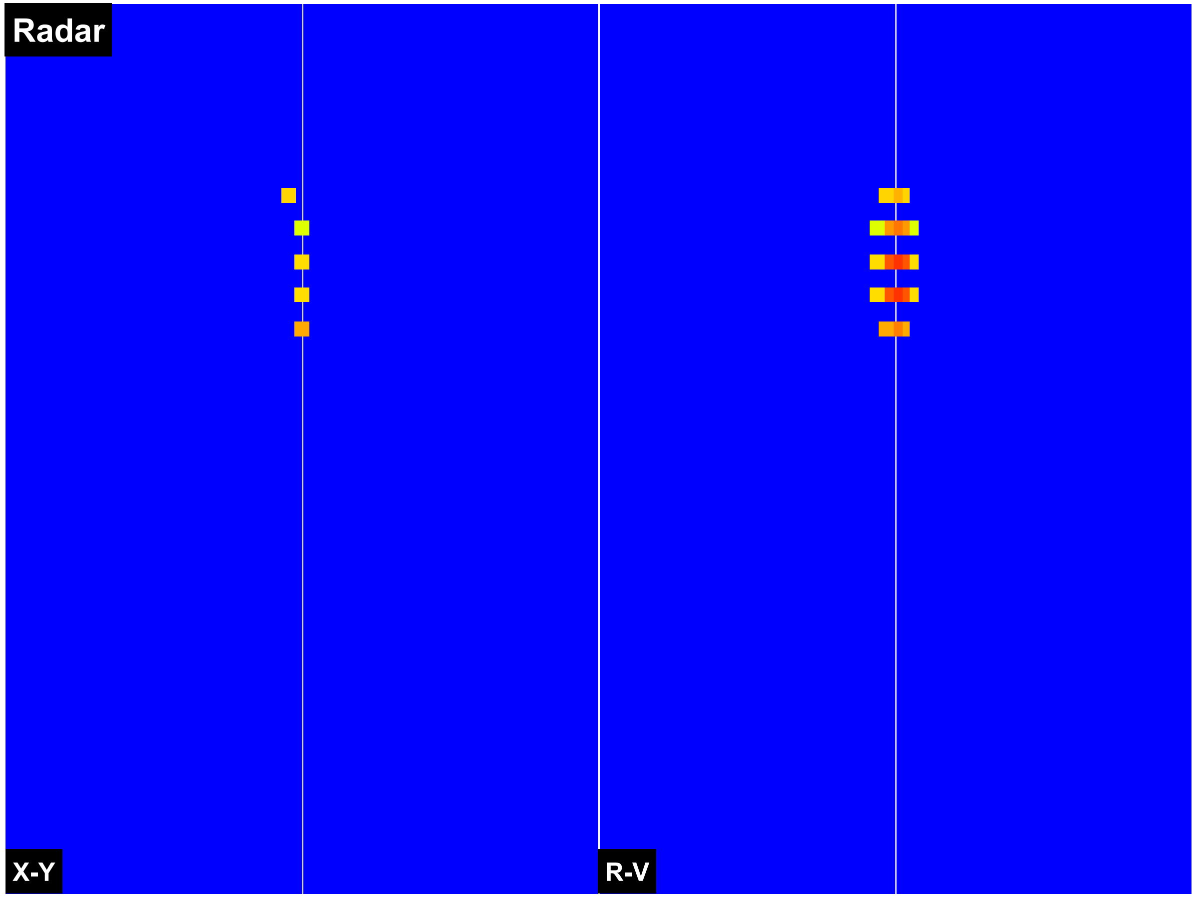


Source: Copyright © CARLA Team 2019.

Launched DIVP^{TM} simulator with jointing Environmental, Space design & sensor modeling for Camera, Radar & LiDAR sensors for consistency verification

Hitachi Automotive Systems, Ltd. DENSO Pioneer
神奈川工科大学 Nihon Unisys, Ltd

DIVP™ Radar model output Sample

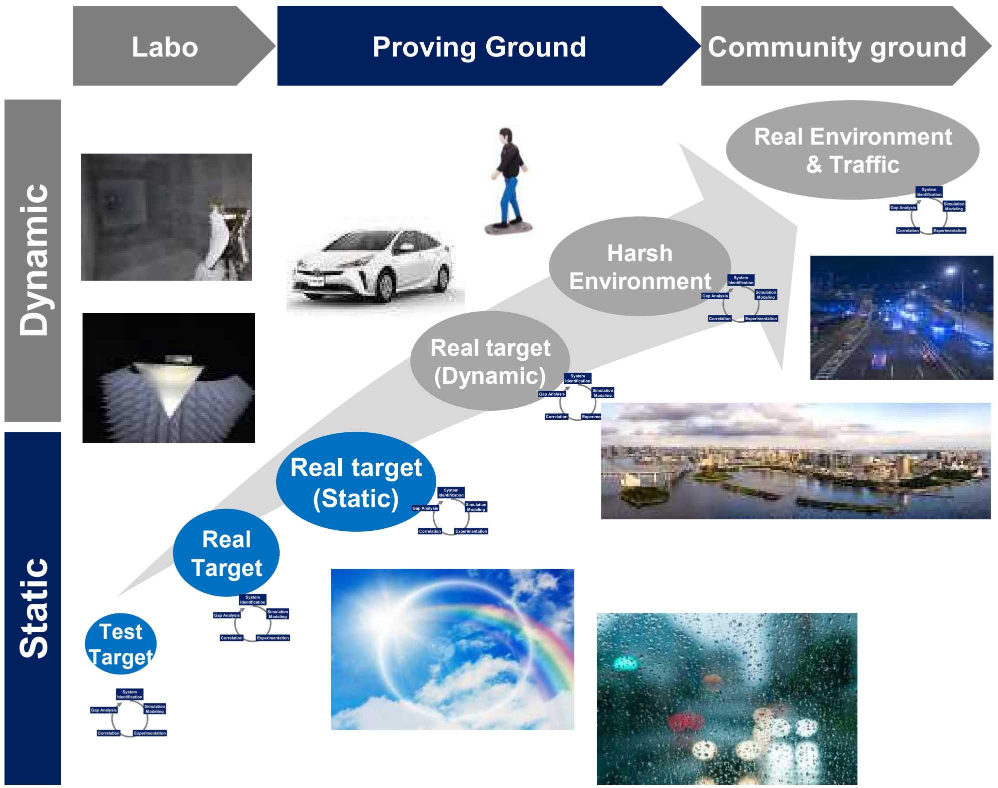


Source: Copyright © CARLA Team 2019.

Conducted Static Data measurement in Real-PG for Sensor consistency verification

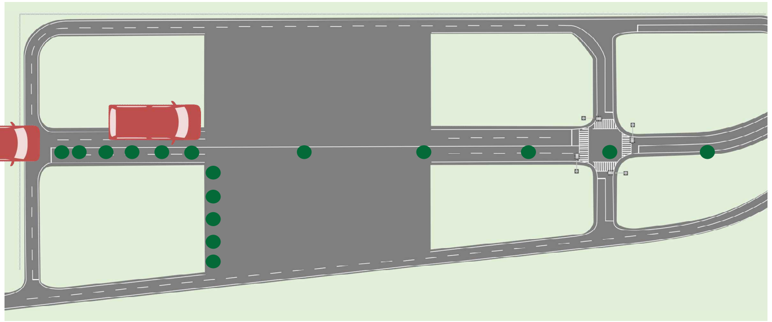
Verification framework

Enhancement roadmap



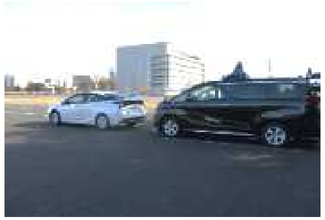
Static test

- ■Conduct measurement using some Targets statistically



Legend 🟥 Test car：Alphard ● Target：Prius NCAP Dummy human / bicycle

Test scene



Target

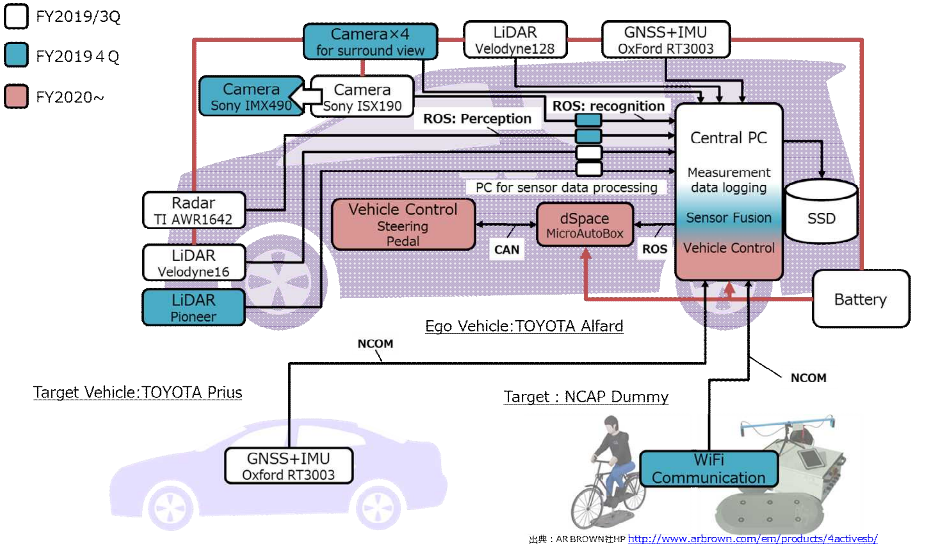
Measurement

Source：DENSO,INC

Constructed Data measurement vehicle, has accurate GNSS/IMU & WiFi system for accurate location management

Test Vehicle

Test vehicle configuration and construction plan

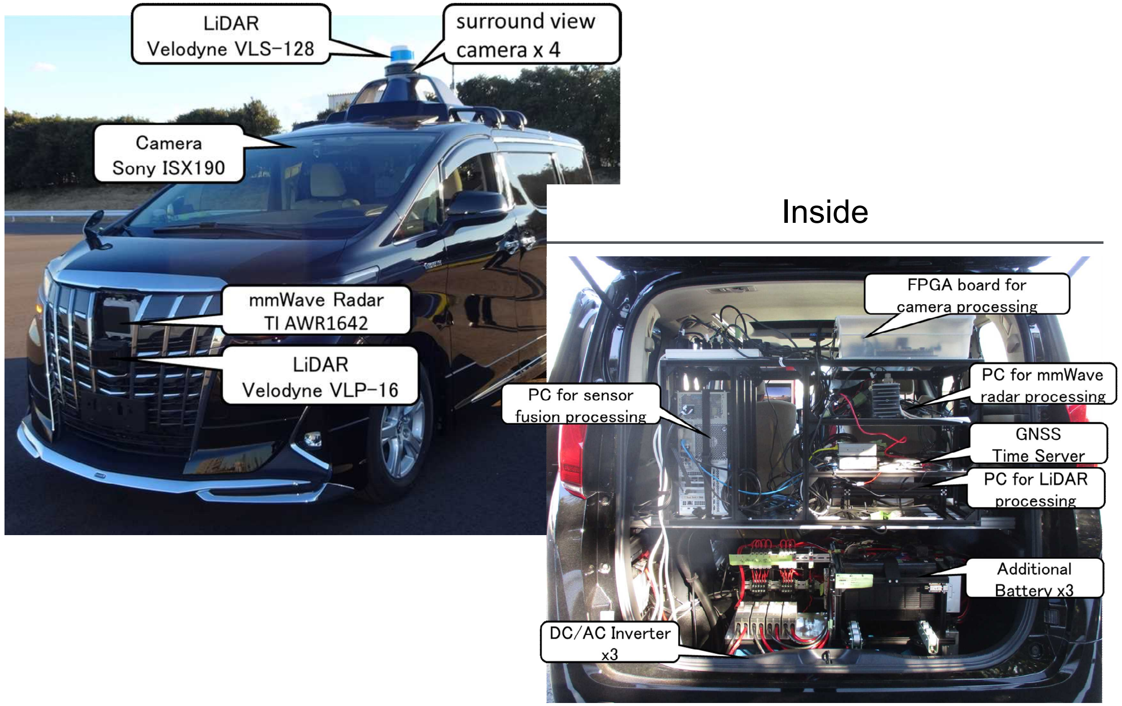


出典：AR BROWN社HP http://www.arbrown.com/em/products/4activesb/

Test Vehicle

Outside

Inside



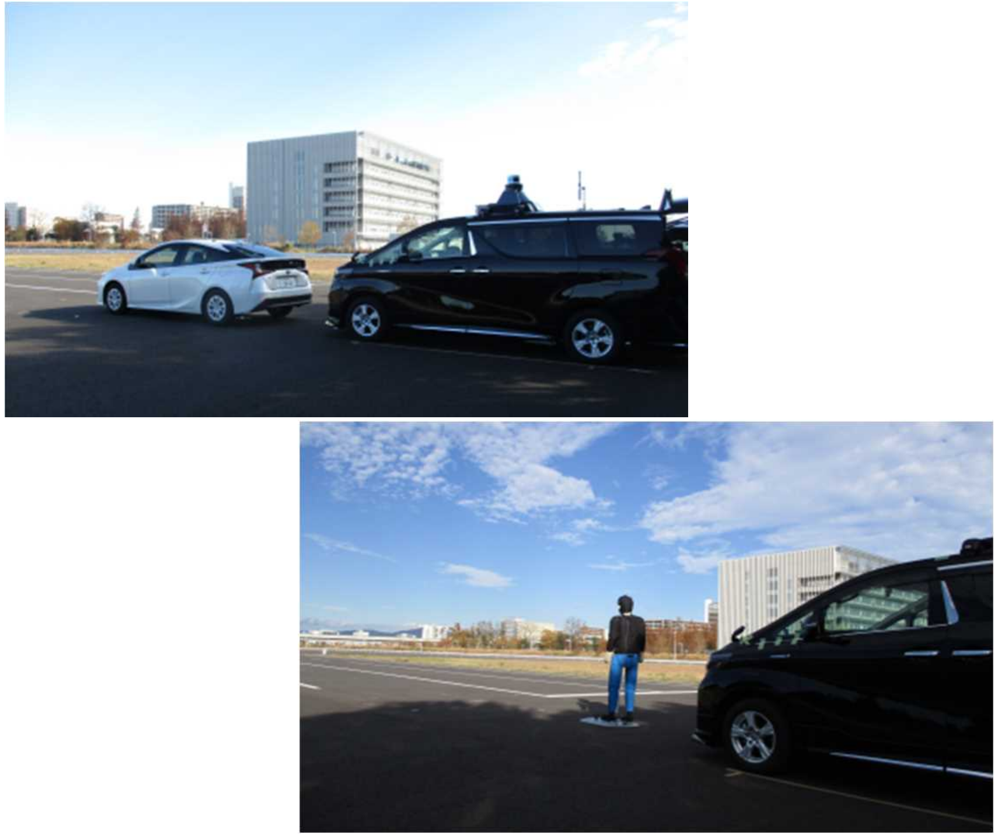
Source ：SOKEN, INC

Performs sensor data measurement in static test and driving test, and provided measurement data for verification with simulation results.

Sensor data measurement

SOKEN

Scene of sensor data measurement (Static test)



Scene of sensor data measurement (Driving test)

Source : SOKEN, INC

Verified sensor output based consistency in Real/Virtual-PG, results each Sensor topics, Environmental modeling & Verification procedure for next step

Static test results

Test environment

Camera (Recognition)

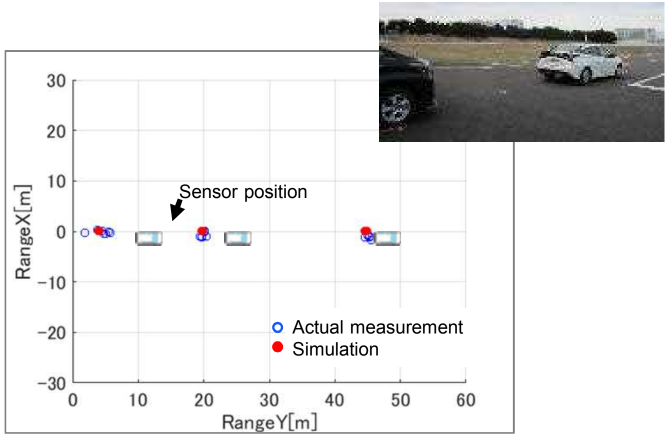
HITACHI Inspire the Next

Output from real camera

Output from camera model

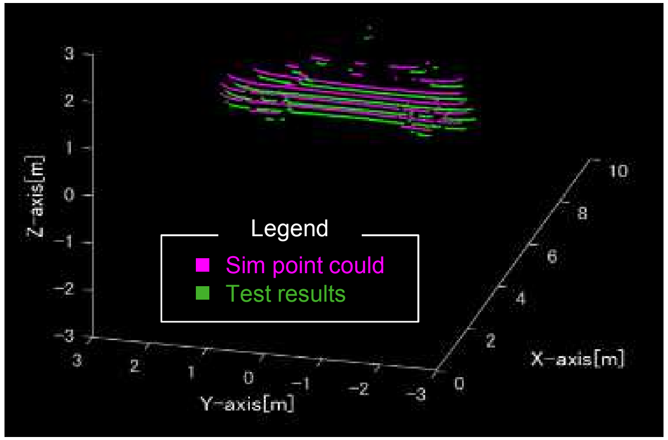
Rader (Perception)

DENSO



LiDAR (Perception)

Pioneer



Results

Evaluation index	inspection result
Target size	Nearly OK
Target distance	Nearly OK
Target type	OK

Checked recognition output based consistency
Next step is to duplicate environmental model could affecting consistency error

Evaluation index	inspection result
Distance	Nearly OK
Angle	Nearly OK
Intensity	***NG***

Computer road are counter measured
Next step is to more precise modeling millimeter-wave propagation physics

Evaluation index	inspection result
Distance	Sufficient consistency @ short range
Size(width)	Sufficient consistency @ short range
Number of points	Confirm errors caused by target reflectance and transparent characteristics

Verified Target distance and Size(width) are sufficient level in short range.
Next step is to reevaluate with proper target reflection characteristics.

Source: Hitachi Automotive Systems, DENSO,INC, PIONEER SMART SENSING INNOVATIONS CORPORATION

From existing simulation benchmarks, competitiveness is based on the possibility of precise sensor simulation based on verification by actual measurement.

Benchmark result of Camera

神奈川工科大学

Classification	Phenomena	DIVP^{TM}	CarMaker 8.1.0	PreScan 2019.3	VIRES VTD 2.2.0	
Source	General light source (vehicle lamp, etc.)	◎	○	○	○	
Source	Radiance of solar	◎	○	○	○	①
Source	Radiance of sky	◎	×	△	○	
Source	Indirect light	◎	○	×	×	
Optics	*Reflection, diffusion, transmission on the object surface*	◎	△	△	△	②
Optics	Aging of the object surface	◎(asphalt)	×	○	△	
Optics	Fouling	×	×	△	×	
Propagation	*Scattering（Participating medium）*	○(fog)	×	×	×	
Sensor	*Effect of vehicle dynamics*	◎	△	△	△	③
Sensor	Effect of temperature characteristic	×	×	×	×	
Sensor	Aging of the sensor	×	×	×	×	
Sensor	Lens distortion	○	○	○	○	
Sensor	Lens flare	×	×	×	×	
Sensor	Ghost	×	×	×	×	
Sensor	Fouling (windshield)	○ (raindrop）	△	×	×	

◎: supported（with actual verification）
○: supported（with no verification）
△: partially supported
×: unsupported

※ Limit the range that can be completed within 2020 by prioritizing DIVP^{TM} functions based on frequency and criticality

Items that shows the superiority of DIVP^{TM}

① Only DIVP^{TM} is to verify the actual machine.
② CarMaker only supports reflection and transmission,
Prescan only supports reflection,
VTD unsupports a moving objects.
③ Only DIVP^{TM} fully supports vehicle behavior.

From existing simulation benchmarks, competitiveness is based on the possibility of precise sensor simulation based on verification by actual measurement.

Benchmark result of Radar

神奈川工科大学

Classification	Phenomena	DIVP™	CarMaker 8.1.0	PreScan 2019.3	VIRES VTD 2.2.0	
Source	*Other vehicle light source (interference)*	◎	×	×	×	②
Optics	*Reflection, diffusion, transmission on the object surface*	◎	△	△	△	③
Optics	Aging of the object surface	○(asphalt)	×	×	×	
Optics	*Fouling*	◎(raindrop)	×	×	×	
Optics	*Phase / polarization change during reflection*	◎	×	×	×	④
Optics	Diffraction	×	×	×	×	
Propagation	*Multi reflection / transmission*	◎	△	△	×	⑤
Propagation	Scattering (attenuation), interference in space	◎	○	○	×	
Propagation	Doppler	◎	○	○	×	
Propagation	Micro-Doppler	◎	×	○	×	
Sensor	Own light source (reproduction of modulation method)	◎	○	○	×	
Sensor	*Effect of vehicle dynamics*	◎	△	△	△	⑥
Sensor	Effect of temperature characteristic	×	×	×	×	
Sensor	Aging of the sensor	×	×	×	×	
Sensor	Fouling	×	×	×	×	
Sensor	Internal reflection	×	×	×	×	

①

◎: supported（with actual verification）
○: supported（with no verification）
△: partially supported
×: unsupported

※ Limit the range that can be completed within 2020 by prioritizing DIVP™ functions based on frequency and criticality

Items that shows the superiority of DIVP™

① Only DIVP™ is to verify the actual machine.
② Only DIVP™ is to support interference.
③ Only DIVP™ supports reflection, scattering and transmission
④ Only DIVP™ responds to the effects of extraneous matter and phase / polarization changes during reflection
⑤ Only DIVP™ supports multiple reflection / transmission

From existing simulation benchmarks, competitiveness is based on the possibility of precise sensor simulation based on verification by actual measurement.

Benchmark result of LiDAR

神奈川工科大学

Classification	Phenomena	DIVP™	CarMaker 8.1.0	PreScan 2019.3	VIRES VTD 2.2.0	
Source	Other vehicle light source（interference）	×	×	×	×	
Source	Other source（halogen lamp）	×	×	×	×	①
Source	*Radiance of solar*	◎	×	×	×	
Source	*Radiance of sky*	◎	×	×	×	
Optics	*Reflection, diffusion, transmission on the object surface*	◎	△	△	△	②
Optics	*Aging of the object surface*	◎(asphalt)	×	×	×	
Optics	*Fouling*	◎(raindrop)	×	×	×	
Propagation	*Multi reflection/transmission*	◎	△	×	△	
Propagation	Scattering in space (attenuation)	◎	×	○	×	
Sensor	*Own light source*	◎	×	×	×	
Sensor	*scanning*	◎	×	×	×	③
Sensor	*Effect of vehicle dynamics*	◎	△	△	△	
Sensor	Effect of temperature characteristic	×	×	×	×	
Sensor	Aging of the sensor	×	×	×	×	
Sensor	*Fouling*	◎(raindrop)	×	×	×	④

◎: supported（with actual verification）
○: supported（with no verification）
△: partially supported
×: unsupported

※ Limit the range that can be completed within 2020 by prioritizing DIVP™ functions based on frequency and criticality

Items that shows the superiority of DIVP™

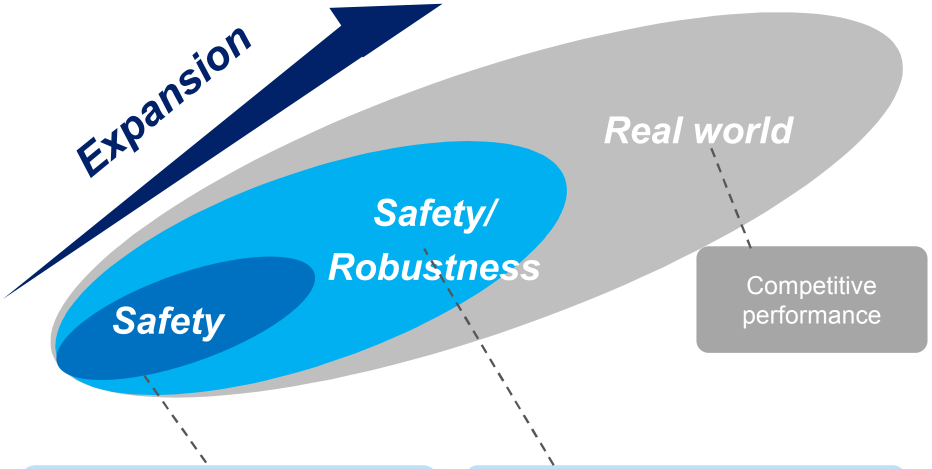
① Only DIVP™ is to verify the actual machine.
② Only DIVP™ supports the radiance of sunlight, radiance of sky light, reflection / scattering / transmission on the object surface, influence of deterioration, attached matter, multiple reflection / transmission
③ Only DIVP™ responds to the effects of its own light source, scanning and vehicle behavior
④ Only DIVP™ responds to the effects of sensor deposits

In FY2020 besides sensor simulation accuracy improvement, proceed Virtual-PG(Proving ground) construction and realize part of NCAP protocol in Simulation

Virtual-PG expansion strategy

Expansion roadmap

- Simulation based Safety validation as industrial cooperation area could aware DIVP^{TM} performance



Fundamental Safety must be secured to protect serious accidents

Basic performance for consumer safety not even in serious accidental scene

DIVP^{TM} scope

Construction with 2-piller Virtual-PG

1

<u>Safety validation for serious accident reduction</u>

- Define test protocol based on accident data base, and realize Safety validation in simulation
  - Actual Accident data driven (Fatal, public road)
  - Highway(AD) driving data driven

Prioritize asset construction with Referring Eur-NCAP

2

<u>Safety / Robustness validation</u>

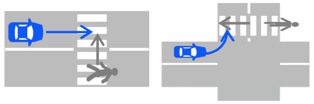
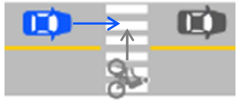
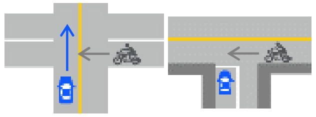
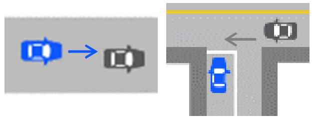
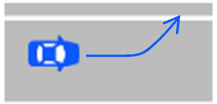
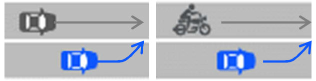
- Define Sensor sensing cons based environmental input for real world robustness validation in simulation
  - Sensor sensing physics & propagation characteristics driven

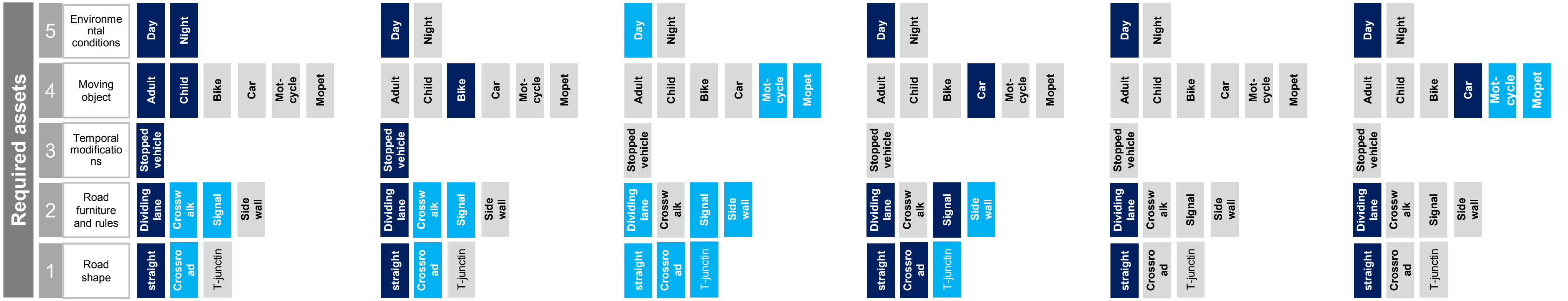
Prioritize asset construction with communion with OEM/Sensor suppliers

【1 Safety validation for serious accident reduction】
Structured assets based on Eur-NCAP, current & NCAP2025 for Virtual-PG construction

Required Assets for Eur-NCAP protocol

Legend
Current plan
NCAP2025 forecast
Out of scope

	AEB[*1]				LSS[*3]	
	Pedestrian	**Cyclist**	**PTW**	**Car**	**White Lane**	**Car/PTW**
Objective	Emergency braking with forward Pedestrian detection (with Night condition)	Emergency braking with forward Crossing bike	Emergency braking with forward PTW	Emergency braking with forward & crossing Car detection	Lane keeping control with warning alert	Driving assist with lane merging
NCAP2025 forecast	■ Crossing Pedestrian ■ Backward Pedestrian in reverse ■ AEB/AES[*2] cooperative control	■ AEB/AES[*2] cooperative control	■ PTW in cornering ■ Jumping out stuff in insufficient visibility	■ Head on collision ■ Jumping out stuff in insufficient visibility	–	■ Oncoming PTW ■ Passing PTW
Overview						



Required assets		Pedestrian	Cyclist	PTW	Car	White Lane	Car/PTW
5	Environmental conditions	Day Night	Day Night	Day Night	Day Night	Day Night	Day Night
4	Moving object	Adult Child Bike Car Mot-cycle Mopet	Adult Child Bike Car Mot-cycle Mopet	Adult Child Bike Car Mot-cycle Mopet	Adult Child Bike Car Mot-cycle Mopet	Adult Child Bike Car Mot-cycle Mopet	Adult Child Bike Car Mot-cycle Mopet
3	Temporal modifications	Stopped vehicle	Stopped vehicle	Stopped vehicle	Stopped vehicle	Stopped vehicle	Stopped vehicle
2	Road furniture and rules	Dividing lane Crosswalk Signal Side wall	Dividing lane Crosswalk Signal Side wall	Dividing lane Crosswalk Signal Side wall	Dividing lane Crosswalk Signal Side wall	Dividing lane Crosswalk Signal Side wall	Dividing lane Crosswalk Signal Side wall
1	Road shape	straight Crossroad T-junctin	straight Crossroad T-junctin	straight Crossroad T-junctin	straight Crossroad T-junctin	straight Crossroad T-junctin	straight Crossroad T-junctin

---

*1 AEB : Automatic Emergency Braking, *2 AES : Automatic Emergency Steering, *3 LSS : Lane Support System / PTW : Powered Two Wheeler

【2 Safety / Robustness validation】
Sensor sensing mechanism & Light / Millimeter wave propagation modeling in Virtual-PG

Example for Sensor sensing weakness

Difficult for Sensor detection

Black jacket

Group moving objects

Card board

Wet surface

Affects for light / millimeter wave propagation

Night

Millimeter wave Multi-path

Rain

Sun light, Backlit

Database Accumulates and Utilizes “Environmental & Space design models" and Test manager for Simulator usability are the Key for DIVP^{TM} successful implementation

DIVP^{TM} Ecosystem

Nihon Unisys, Ltd

Database

Environmental model | **Space design model** | **Sensor model** | **AD modl**

Scenario + **Environmental Model** | **Measured Data** | **Camera Visible light Ray tracing** | **Rader Millimeter wave propagation** | **LiDAR Infrared light Ray tracing** | **Camera model** | **Rader model** | **LiDAR model** | **AD model**

3D Map / 3D Object Model / Material Reflection Property

Generate input conditions based on evaluation scenarios

User

Test manager

Scenario generator

UI

Functional Scenario Composer

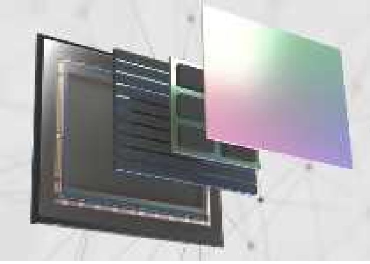
Scenario Authoring

Measured Data Importer

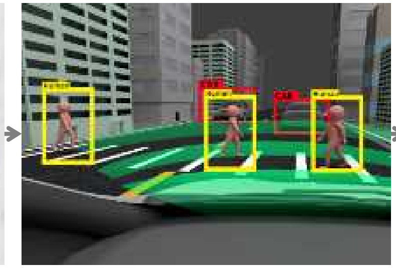
Input

Autonomous driving system simulation

Sensor perception model



Sensor recognition model



Autonomous driving model

Accelerate Data base structuring & Scenario generator design toward DIVP^{TM} ECO-system

Source : Sony Semiconductor Solutions Corporation

Industrial needs verification thru Workshop with 5-major domestic OEMs on January 23rd /24th

Work shop with OEMs

Agenda

- Introduction & DEMO
- Modeling strategy (Environment, Space, Camera, Rader, LiDAR)
- Interface
- Environmental assets & Scenario
- Industrial use-case for DIVP^{TM} implementation
- HILS effectiveness

Participating companies

2 ~ 6 persons
from 5 OEMs

Toyota Motor Corporation
Honda R&D Co., Ltd
Nissan Motor Co., Ltd.
Mazda Motor Corporation
Isuzu Motors Limited

Opinions received

- Exchange the DIVP^{TM} status and could received fare opinions from attendance

- ***No verified simulator,*** although various simulations in the world

  \- Domestic OEM Work Shop participants

- ***The Problem most OEM has is The sensor validation not available in simulation*** thru development phase

  \- Domestic OEM Work Shop participants

- OEM require ***the precise duplication with highly consistency physics base*** rather than Real Time simulator

  \- Domestic OEM Work Shop participants

- I think it is already competitive enough at the current level, so ***I want to use it ASAP***

  \- Domestic OEM Work Shop participants

FY 2019 outcome

1. Interface design
2. Sensor modeling
3. Environmental modeling
4. Scenario generator

Released 1st Draft I/F spec, Utilizing the feature of ROS for possibility to easily evaluation of communication specifications between models

DIVP™ Interface design

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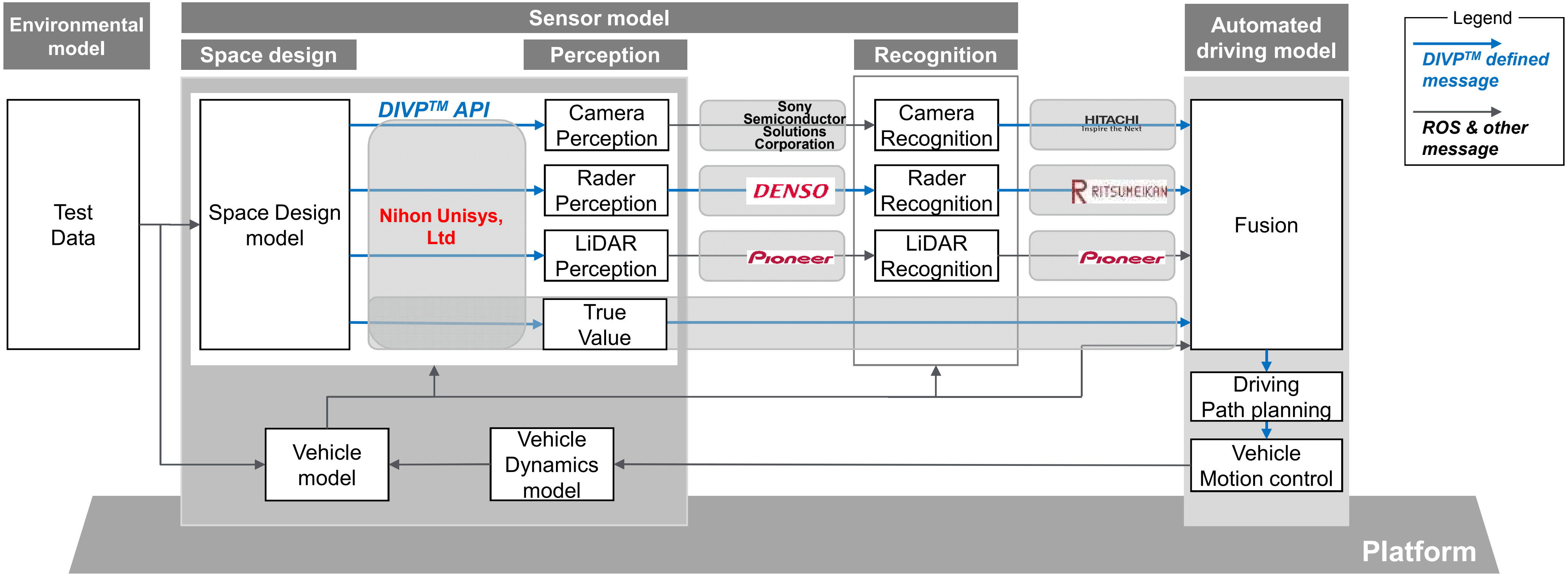

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* Johou Systems Kougaku (JSK) Laboratory The University of Tokyo

Assuming practical use, we consider the requirements for simulation platform.

Cooperation with existing simulation system

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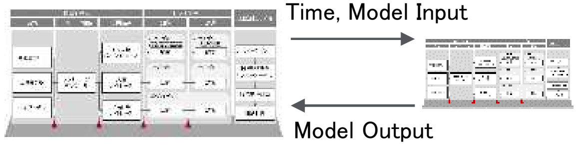
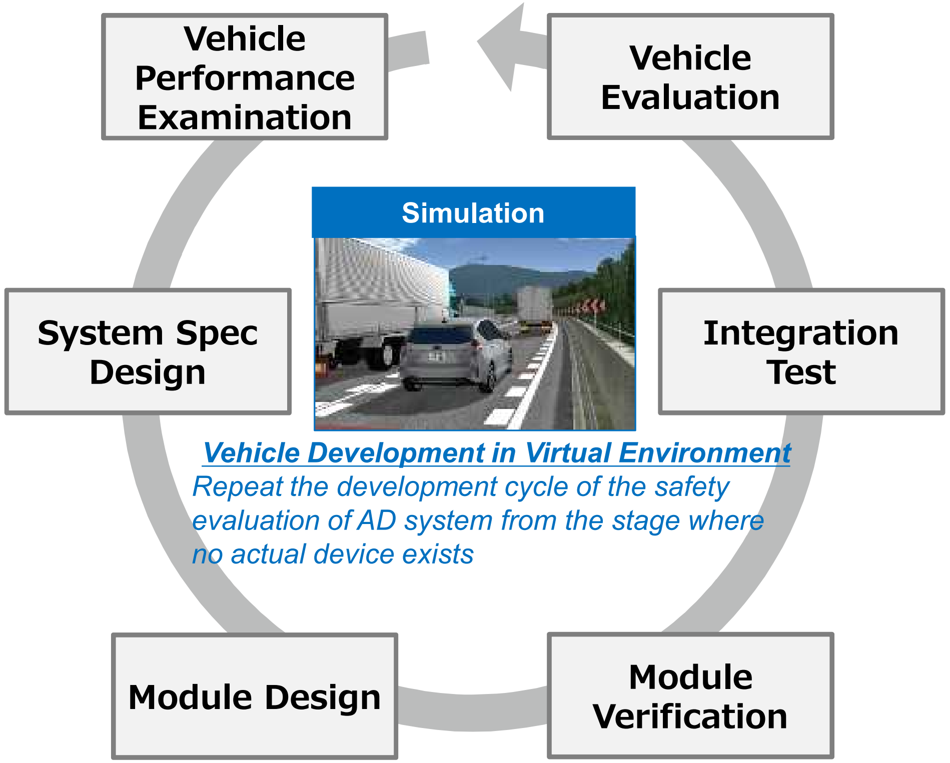
Cooperation with MIL/SIL

・Module development cooperating with existing MIL/SIL system.

ex) Communicate with other PF.



・*I/F can be defined with API*[*1]



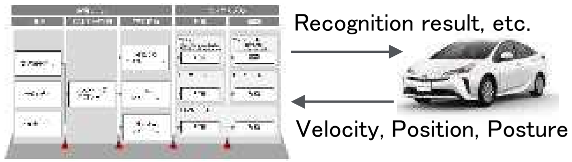
Vehicle Development in Virtual Environment

Repeat the development cycle of the safety evaluation of AD system from the stage where no actual device exists

Cooperation with HIL/VIL

・Verification/Evaluation with connecting to ECU/Vehicle.

ex) Communicate with Autonomous driving system



・***Require the Real-Time simulation***

・***Require the I/F considering for I/O required by ECU***

[*1] :API : Application Programing Interface.

Source : Mitsubishi Precision Company, Limited, SOKEN, INC

Assume the system configuration for each simulation system and consider the required I/F, Standardized and PF-independent I/F is required for Module/System compatibility

Simulation System

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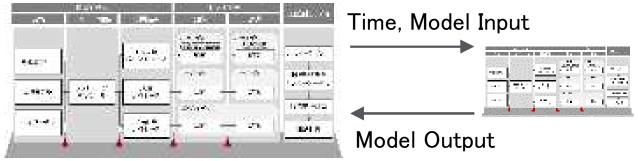
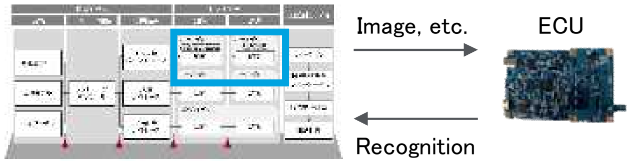
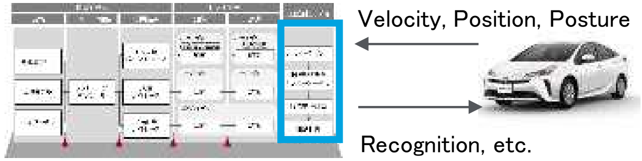
		I/F required for Module/System compatibility
MIL SIL	ex) Communicate with other PF.  Time, Model Input Model Output	■ **Require the inter-module I/F independent from PF.** ✓ The inter-module I/F independent from PF is required for module compatibility. ✓ When cooperating with other PFs, the I/F needs to negotiate which PF will lead the simulation (initialization processing, start / stop, time synchronization).
HIL	ex) Camera sensor injection  Image, etc. ECU Recognition	■ **Require the I/F to make the modules on PF and the ECU connectable.** ✓ In order for the PF to lead the simulation, real-time simulation and communication speed that can follow the processing speed of the ECU are required. ✓ The I/F which can convert the communication content of the PF according to the ECU is required
VIL	ex) Communicate with Autonomous driving system  Velocity, Position, Posture Recognition, etc.	■ **Require the I/F enables simulation starting from the actual vehicle.** ✓ Need to be able to receive notification of simulation start / stop and initial position / posture from actual vehicle. ✓ Real-time simulation is required. It is necessary to process in real time until the behavior of the vehicle is received from the actual vehicle and simulation results are returned to the actual vehicle. ✓ The I/F which can safely disconnect the PF from the actual vehicle when an error occurs (for example, when a safety device is activated) is required.

Source : Mitsubishi Precision Company, Limited, Kanagawa Institute of Technology

For future international standardization, we select base specifications according to the purpose of DIVP™ from existing standard I/F.

Functions and ranges provided by each standard I/F

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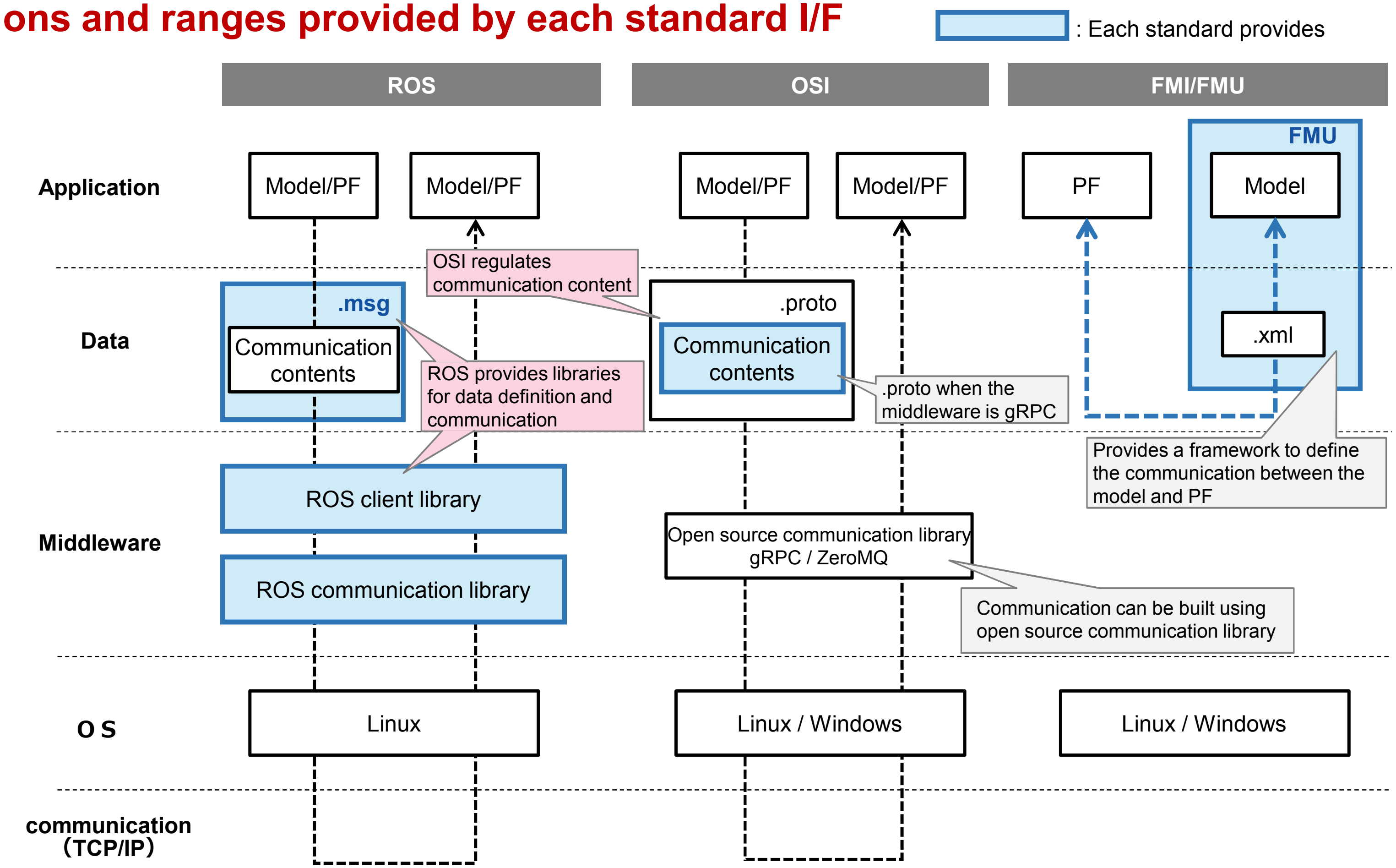

OSI regulates communication content

ROS provides libraries for data definition and communication

.proto when the middleware is gRPC

Provides a framework to define the communication between the model and PF

Communication can be built using open source communication library

Investigate and compare major simulation I / Fs with a view to future standardization, and select an architecture that will be the axis for studying communication contents and communication methods

Comparison of each standard I / F in sensor model

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Item	ROS	OSI [*1]	FMI/FMU
Communication content *Sensor perception, recognition, fusion	△	○	×
	■ Insufficient for AD system sensors (Originally for robots)	■ Sensor model and fusion communication contents are defined	Not defined
Communication method	○	×	○
	■ Provides middleware for communication using TCP / IP	■ Not stipulated ■ Communication is performed using an open source library such as ZeroMQ.	■ Define library API calls
Trend	■ TierIV, Apex.AI adopted. ■ It is easy to use and is used by various companies and universities.	■ Transferred from Pegasus, Germany to ASAM. ■ Adopted by a national pro near the German DIVP^{TM}	■ It is often used in multiple model simulations. ■ CarMaker also supports.

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*1:OSI https://opensimulationinterface.github.io/osi-documentation/

Compared with DIVP^{TM} and OSI sensor model I / F, confirmed correspondence and considered adding communication contents

Comparison of DIVP^{TM} and OSI sensor model I / F

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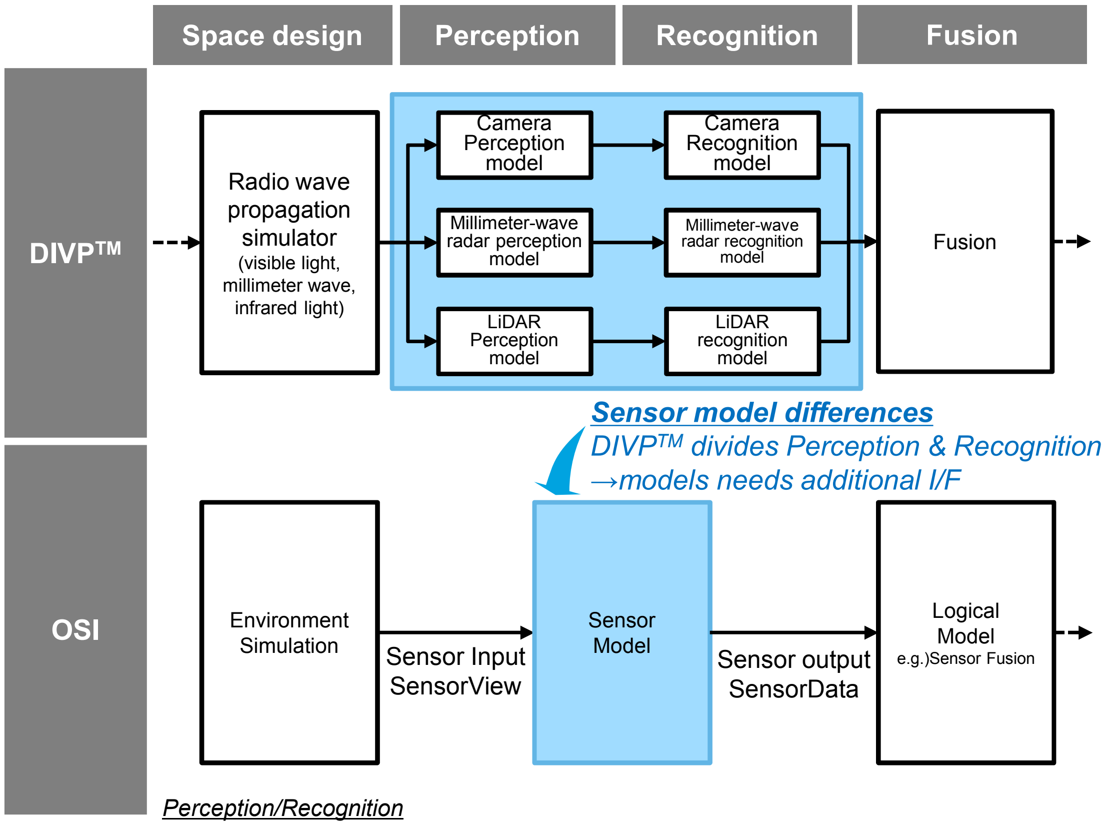


Space design

Perception

Recognition

Fusion

DIVP^{TM}

Radio wave propagation simulator (visible light, millimeter wave, infrared light)

Camera Perception model

Camera Recognition model

Millimeter-wave radar perception model

Millimeter-wave radar recognition model

LiDAR Perception model

LiDAR recognition model

Fusion

Sensor model differences

DIVP^{TM} divides Perception & Recognition →models needs additional I/F

OSI

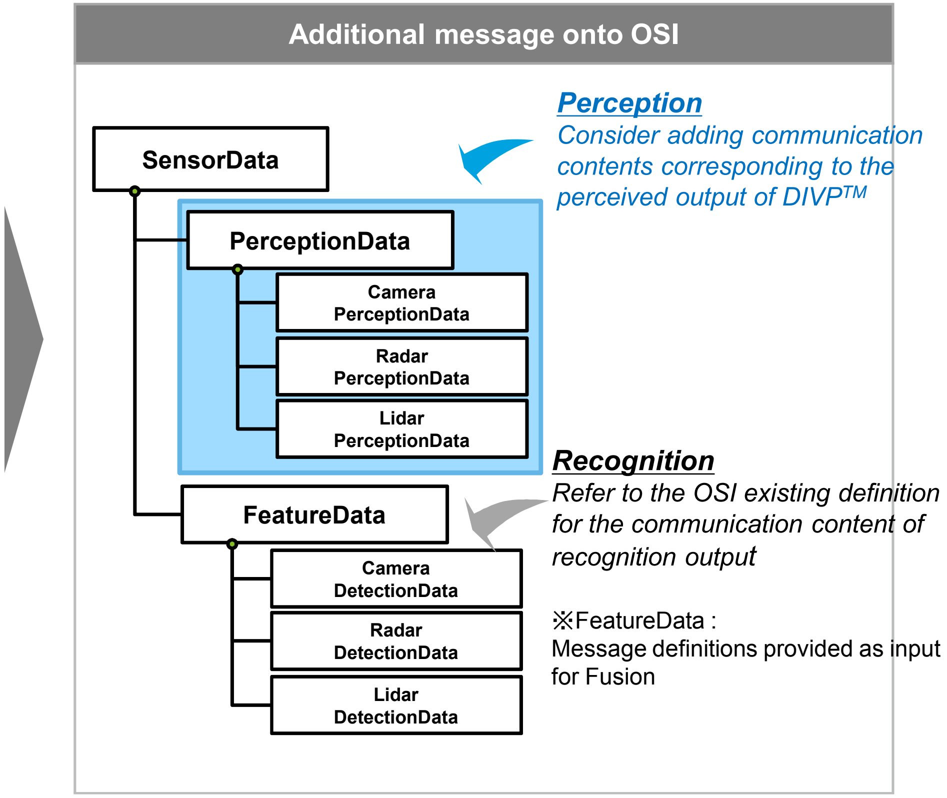
Environment Simulation

Sensor Input SensorView

Sensor Model

Sensor output SensorData

Logical Model e.g.)Sensor Fusion



Additional message onto OSI

SensorData

PerceptionData

Camera PerceptionData

Radar PerceptionData

Lidar PerceptionData

FeatureData

Camera DetectionData

Radar DetectionData

Lidar DetectionData

Perception

Consider adding communication contents corresponding to the perceived output of DIVP^{TM}

Recognition

Refer to the OSI existing definition for the communication content of recognition output

※FeatureData :
Message definitions provided as input for Fusion

Perception/Recognition

Since there are cases where the outputs of multiple perceptual models are input to one recognition model, and cases where the outputs of perceptual models are directly input to Fusion (RAW data Fusion), each sensor model is divided into perception and recognition.

We examined the relationship between spatial rendering, sensor model, and fusion communication content when using OSI as the axis.

Association of communication contents

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Items to consider for OSI communication contents

Space design	■ Environmental condition ✓ Add sunlight (Reproduces backlight caused by sensor malfunction) ■ Camera ✓ Added lens and CMOS characteristics
Perception	■ Added perceptual output communication contents considered in DIVP^{TM}
Recognition	■ Added OSI existing + communication contents of recognition output considered in DIVP^{TM}
Fusion	■ Fusions under consideration by DIVP^{TM} are covered by OSI's existing communications

Convert and use communication contents from OSI format to ROS format to enable communication with ROS

Conversion of communication contents

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■From the viewpoint of standardization, communication contents are defined in OSI format
When using with DIVP^{TM}, convert to communication content in ROS format

OSI communication contents	*ROS communication contents*
osi_sensorview.proto	divp_sensorview.msg
osi_sensordata.proto	divp_sensordata.msg
osi_featuredata.proto	divp_featuredata.msg
….	….

Format conversion
Convert to a format that can be communicated with ROS

■Accuracy and speed

- In OSI, length, speed, acceleration, etc. are defined with double precision (double type)
  → Communication speed decreases, data volume increases **When compared with single precision (float type)*
- Consider single precision (float type) if it is considered sufficient
  → Convert from double precision to single precision when converting formats

1st Draft I / F spec utilizing general ROS I / F has been released, and operation evaluation will be promoted

DIVP™ Interface design

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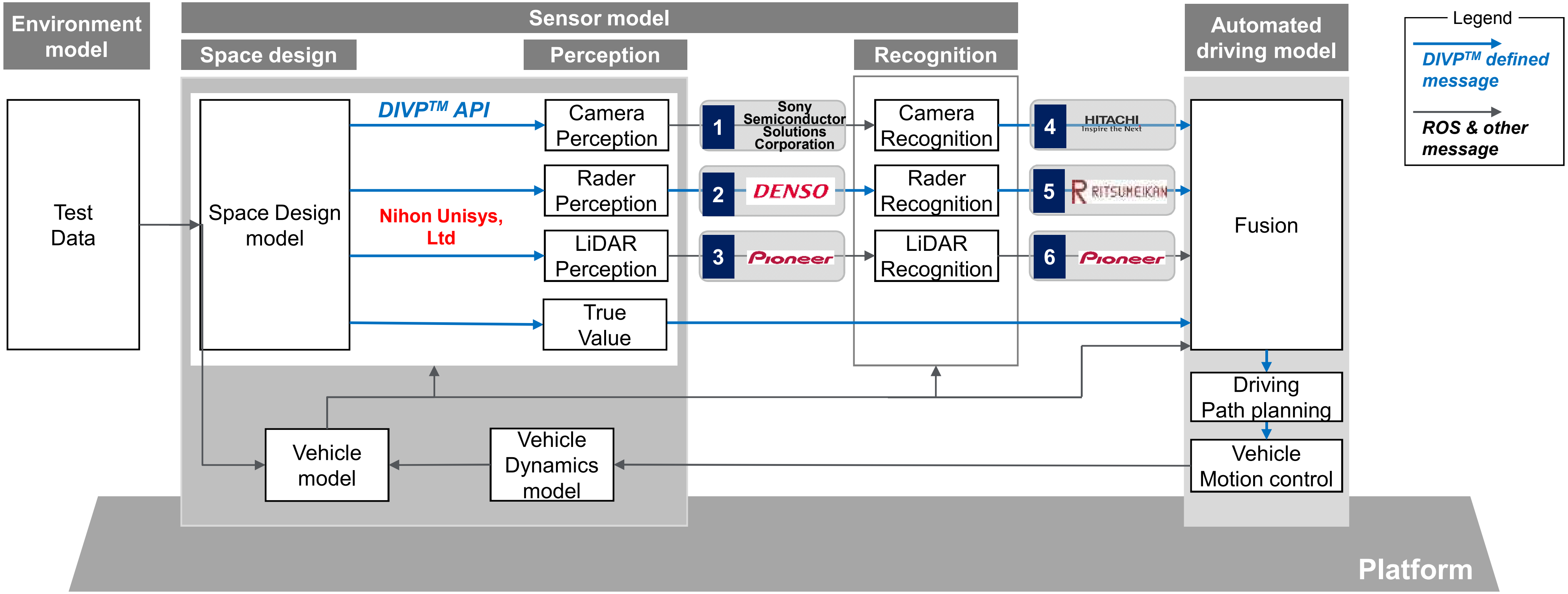

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* Johou Systems Kougaku (JSK) Laboratory The University of Tokyo

1

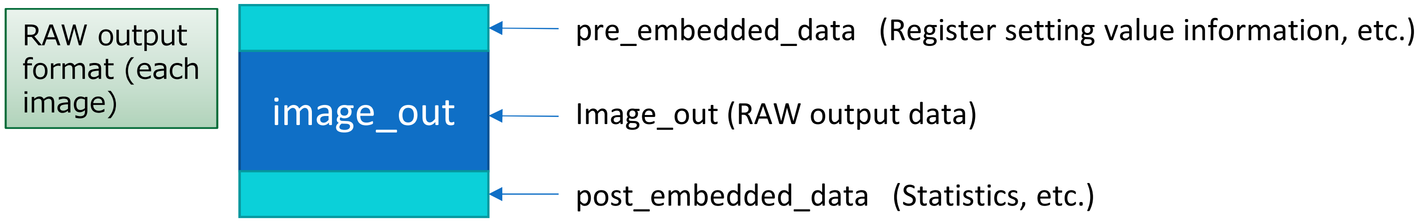
Camera perception output specification
HDR･Supports multiple output

RAW output CMOS image sensor

Sony Semiconductor Solutions Corporation

Corresponds to the trend of simultaneous output of multiple images (combination of (1) to(4) is possible. Image size may be different)
(1)HDR composition (compressed / uncompressed) *HDR compression 12~16bit, HDR uncompressed 16~24bit
(2)No HDR composition
(3)HDR partial composition (compressed / uncompressed)
(4)Metadata output

ROS message	Type	Description
image_out	float32[]	Processed RAW data (e.g. one HDR output, multiple exposure images, etc. Image size may be different among images)
pre_embedded_data	byte[]	Meta data 1 (vender specific: e.g. register values applied to image_out) per output image
post_embedded_data	byte[]	Meta data 2 (vendor specific: e.g. statistics such as histogram of output image) per output image


RAW output format (each image)

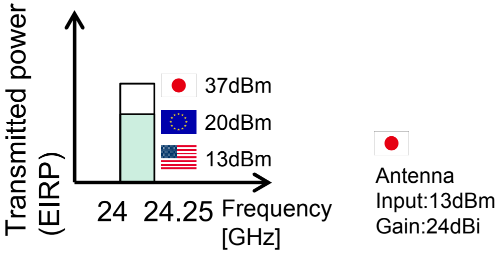
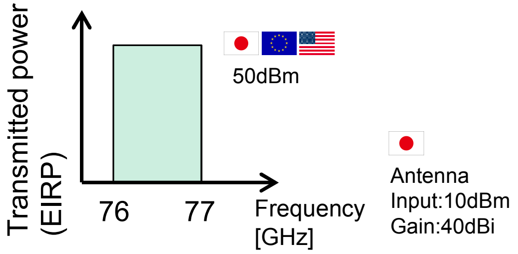
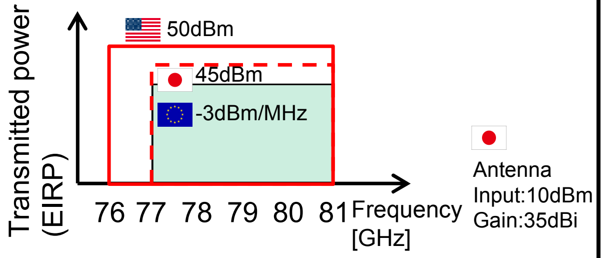
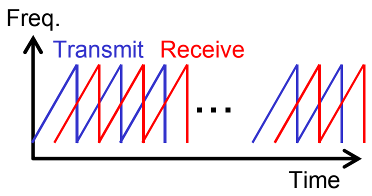
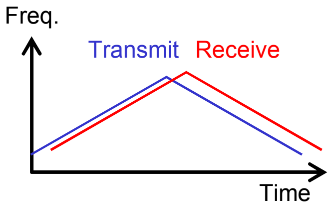
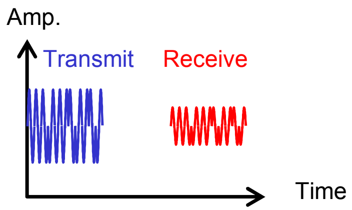
pre_embedded_data (Register setting value information, etc.)
Image_out (RAW output data)
post_embedded_data (Statistics, etc.)

HDR: High Dynamic Range

【Millimeter-wave Radar perception input】
2 Interface specifications compatible with various millimeter-wave radars based on industry trends

Millimeter-wave Radar perception input

DENSO

	24GHz	77GHz	79GHz
frequency			
modulation	FCM	FMCW	pulse
			

Compatible with all bands and modulation methods approved by the Radio Law of each country

2

【Millimeter-wave radar perception output】Current in-vehicle radar does not output perceptual output, but specifies perceptual output in view of Raw Data Fusion

Millimeter-wave radar output I/F

Output	Symbol	Unit	accuracy	Reason for decision
Target number	target_num	―	uinit32	■ Define a type that can handle the number of peaks handled by in-vehicle millimeter-wave radar
Distance	range	m	float32	■ Values handled by in-vehicle millimeter-wave radar are in range: 0 to several hundred meters resolution: 1um, and a type that can handle it is defined.
Velocity	velocity	m/s	float32	■ The values handled by the in-vehicle millimeter-wave radar are in range: ± 0 to 83.3 m / s (500 km / h) ■ resolution: 0.01 m / s (0.036 km / h), and a type that can handle them is defined.
Azimuth	theta	rad	float32	■ The values handled by the in-vehicle millimeter-wave radar are in range: ± 0 to 1.57 rad (90 deg) ■ resolution: 0.0000175 rad (0.01 deg), and a type that can handle it is defined.
Elevation	phi	rad	float32	■ Same as above
intensity	power	dB	float32	■ Defines a type that can handle the dynamic range handled by in-vehicle millimeter-wave radar

3

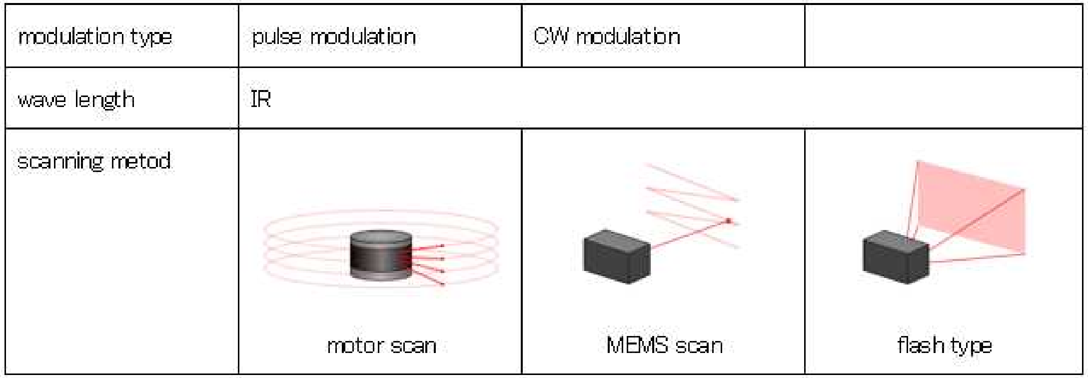
【LiDAR perception input】
Interface specifications compatible with various type of LiDARs based on industry trends

LiDAR perception input

Pioneer

Types of LiDAR optical system

Categorize LiDAR optical systems in terms of modulation scheme, laser wavelength, and scanning type



modulation type	pulse modulation	CW modulation	
wave length	IR		
scanning metod	motor scan	MEMS scan	flash type

Supported LiDAR types

- ***Pulse modulation method is supported.***
（CW modulation method is not supported）
- ***Laser wavelength supports near-infrared light including 900nm band and 1500nm band.***
- ***Scanning method supports motor method, MEMS method, flash method.***

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

3

【LiDAR perception model output 】
Interface specifications compatible with various LiDARs based on industry trends

LiDAR perception model output

Pioneer

- **Output 3D point cloud**
  Time stamp , intensity and position in the three-dimensional orthogonal coordinate system are defined as the elements of each point (angle and distance, which are general LiDAR output parameters, are expressed as positions).
- **Each LiDAR specific parameter is added as an option.**
- **Regarding the data size of each output parameter, a sufficient area for expressing the performance of the existing LiDAR is secured in both resolution and range.**

	Type	resolution	Maximum value
X [meter]	Float	6 significant digits (1mm from 1,000 meters can be expressed)	3.402823e+38
Y [meter]	Float	6 significant digits	3.402823e+38
Z [meter]	Float	6 significant digits	3.402823e+38
intensity	Float	6 significant digits	3.402823e+38
Time stamp [nsec]	int64	1nsec	About 580 years

【Camera recognition output】
Interface specifications based on industry trends

Camera recognition output

HITACHI
Inspire the Next

The configuration was studied with reference to the sensor interface discussed in the international standard ISO / TC22 SC31 WG9 (Sensor data interface for automated driving functions). Also refer to commercially available Sims (Carmaker, etc.)

Application：Camera sensor that detects visible light (camera sensors that detect or radiate components from objects, such as IR and TOF, are excluded)

Recognition result	Unit	Type	resolution	Remarks
Horizontal size on screen	pixel	uint16	1	
Vertical screen size	pixel	uint16	1	
Lateral position	m	float32	0.01	Right-handed side coordinate system
Vertical position	m	float32	0.01	Right-handed side coordinate system
Height position	m	float32	0.01	Right-handed side coordinate system
Horizontal center coordinates	pixel	uint16	1	
Vertical center coordinates	pixel	uint16	1	
Vertical relative distance	m	float32	0.01	Right-handed side coordinate system
Lateral relative distance	m	float32	0.01	Right-handed side coordinate system
Type	-	uint8	-	1: Mini car / 2: Ordinary car / 3: Truck / 4: Bus / 5: Motorcycle (including moped) / 6: Bicycle 7: Car (light distribution) / 8: Motorcycle (light distribution) / 9: Bicycle (light distribution) / 10: Other vehicles / 101: Adults / 102: Children / 103: Other pedestrians / 201: Signs / 202: Road structure / 203: Moving objects such as animals / 204: Other targets
…	…		…	…

5

【Millimeter-wave radar recognition output】
Filter perceptual output and output the result of clustering process

Millimeter-wave radar recognition output

◇Regarding the data size of the output parameters, a sufficient area for expressing the performance of the existing radar is secured in both resolution and range.

	Type	resolution	Maximum value
position [meter]	float32	Equivalent to perception	3.402823e+38
Bearing [degree]	float32	Equivalent to perception	3.402823e+38
Relative speed [meter/second]	float32	Equivalent to perception	3.402823e+38
Relative speed bearing [degree]	float32	Equivalent to perception	3.402823e+38
intensity [db]	float32	Equivalent to perception	3.402823e+38
width [meter]	float32	Equivalent to perception	3.402823e+38

6

【LiDAR recognition model output】
Interface specifications using multiple expressions based on industry trends

■ LiDAR recognition model output

- **Compatible with the following two methods**
  - **Detected objects are expressed as Bounding Box (3D position / azimuth / size) , its attribute label (car, pedestrian ...), and score.**
  - **An expression method that assigns an attribute label to each point of LiDAR perception model output**
- **Regarding the data size of the output parameters, a sufficient area for expressing the performance of the existing LiDAR is secured in both resolution and range.**

	Type		Maximum value
Bounding Box position [meter]	Float[3]	6 significant digits (1mm from 1,000 meters can be expressed)	3.402823e+38
Bounding Box Bearing [degree]	Float[4]	6 significant digits	3.402823e+38
Bounding Box Size [meter]	Float[3]	6 significant digits	3.402823e+38
Lavel	int32	—	—
Score	Float	6 significant digits	3.402823e+38

FY 2019 outcome

1. Interface design
2. **Sensor modeling**
3. Environmental modeling
4. Scenario generator

Simulation model based on mathematical model based on principles, and verification of consistency by comparison between experiment and simulation on sensor output

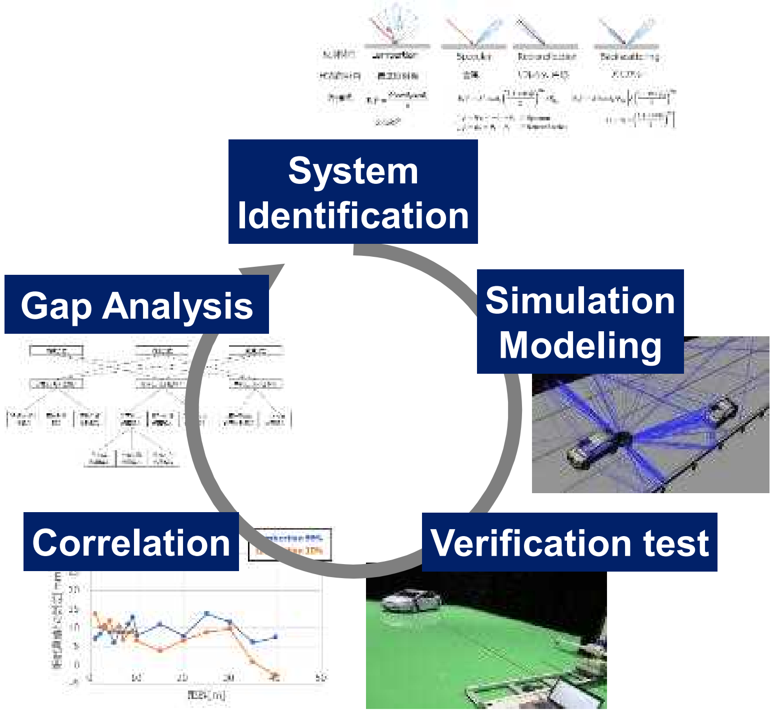
How to proceed with modeling

Steps	Implementation content	Implementation steps
Step1	■ Real physics modeling ✓ Mathematical modeling of physical phenomena in the real world ✓ Interface design	Understanding each sensor principle Function assignment of each part Interface design
Step2	■ Real physics based simulation model ✓ Simulation modeling of mathematical model ✓ Competitive advantage design	Simulation model design DIVP^{TM} superiority design
Step3	■ Verification & Validation ✓ Verification of consistency between Virtual vs Actual ✓ Verification of extrapolation possibility based on Verified modeling	Basic operation verification Extended operation verification

While expanding the PDCA cycle in modeling, expand the possibility of evaluating target objects from stationary objects to dynamic objects and from labs to test courses to general roads

Modeling Flame work

Real physics based approach



System Identification

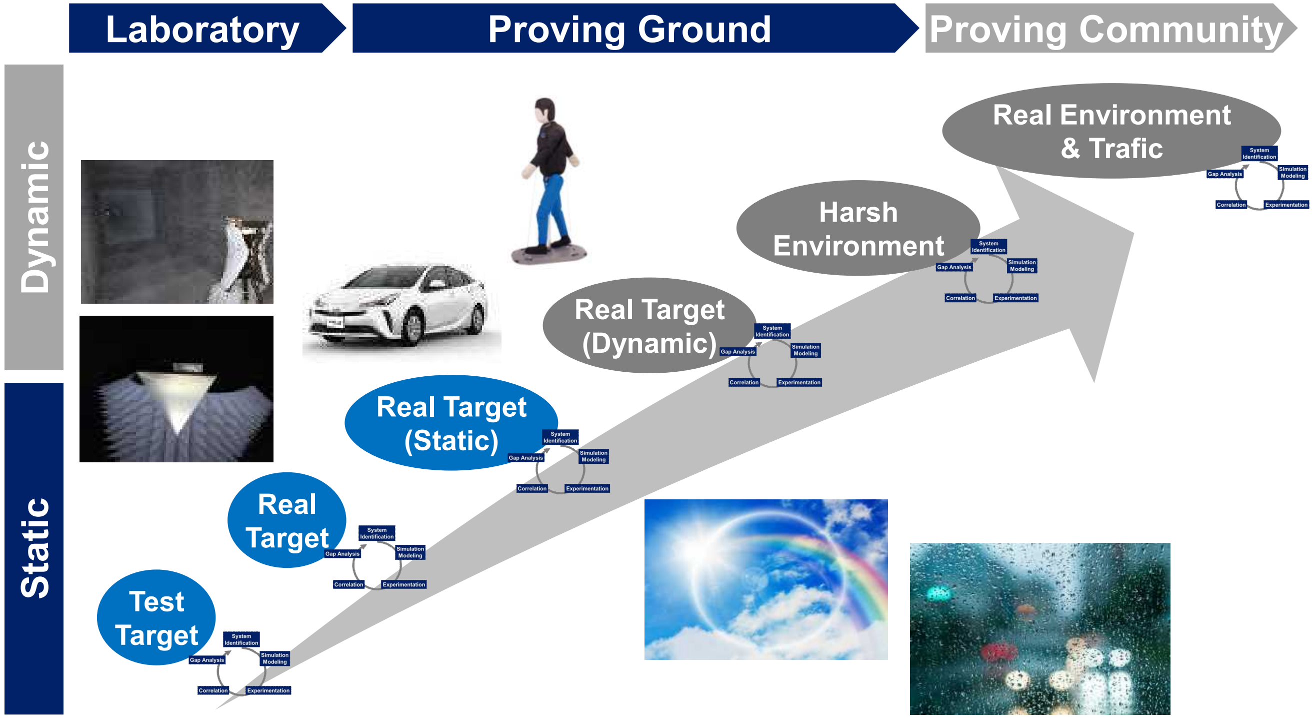
Simulation Modeling

Verification test

Correlation

Gap Analysis

Enhancement roadmap



Laboratory

Proving Ground

Proving Community

Dynamic

Static

Test Target

Real Target

Real Target (Static)

Real Target (Dynamic)

Harsh Environment

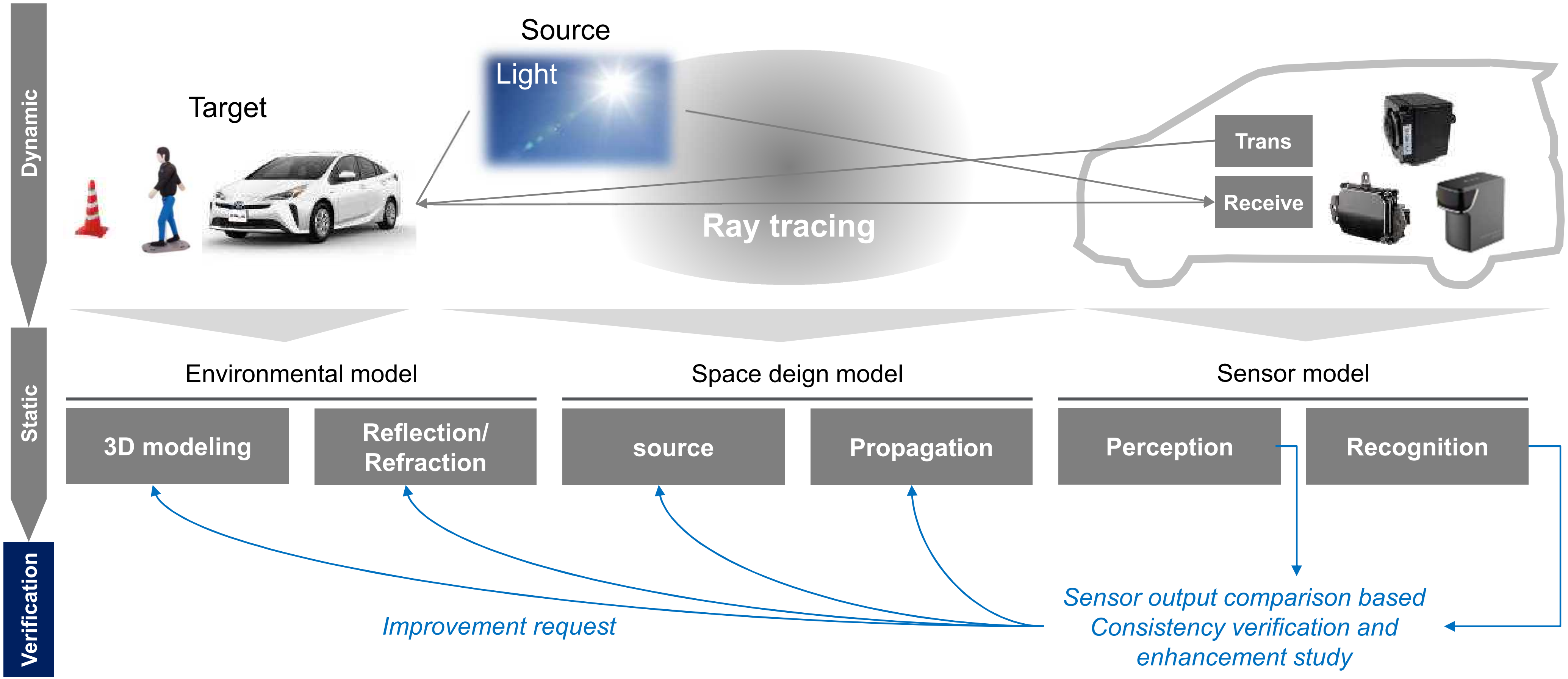
Real Environment & Trafic

Verification of PG x actual target (static) completed in the FY 2019

Modeling real Physics into Virtual modeling and verify of consistency

Verification approach

Sony Semiconductor Solutions Corporation HITACHI Inspire the Next DENSO SOKEN Pioneer



Dynamic

Target

Source

Light

Ray tracing

Trans

Receive

Static

Environmental model

- 3D modeling
- Reflection/ Refraction

Space deign model

- source
- Propagation

Sensor model

- Perception
- Recognition

Verification

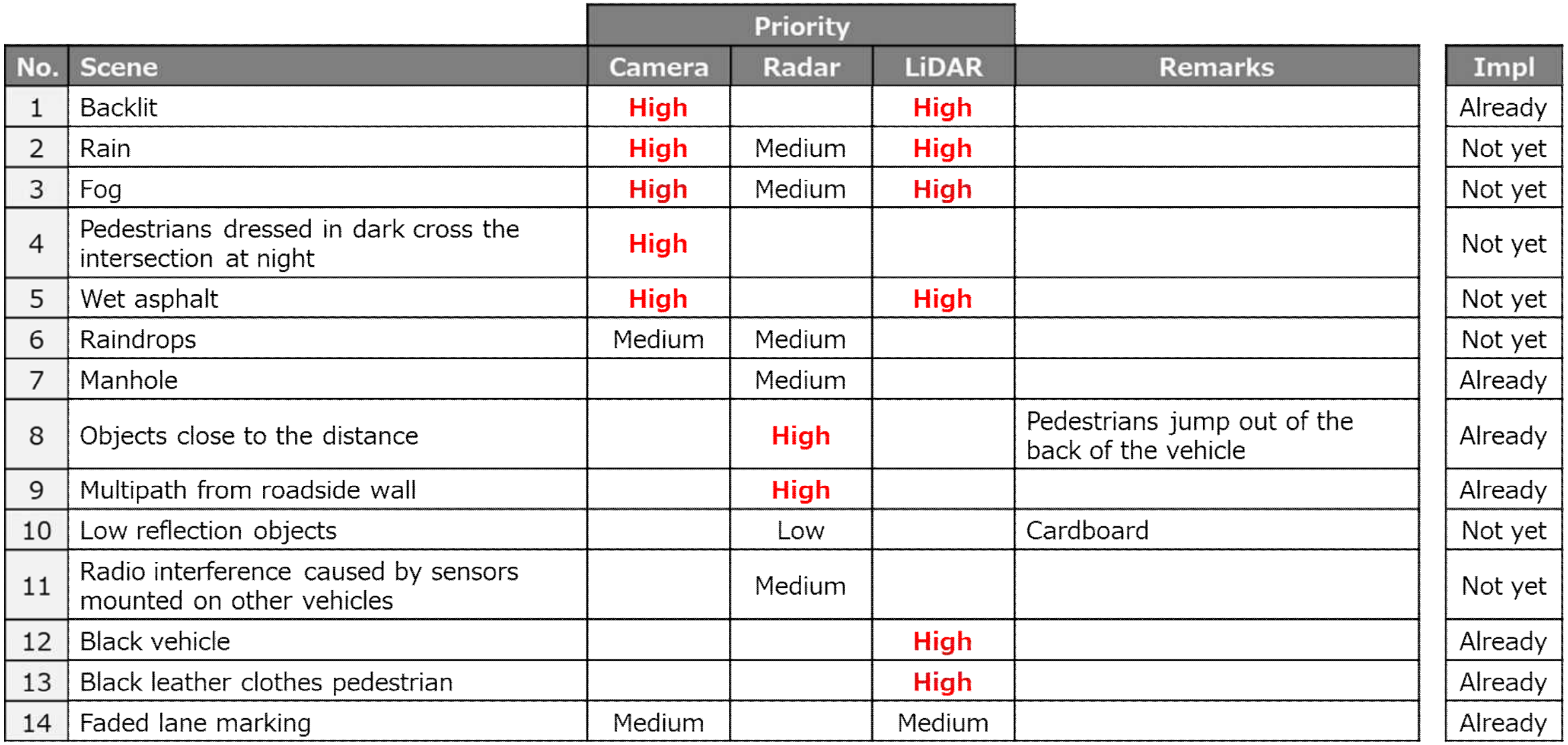
Improvement request

Sensor output comparison based Consistency verification and enhancement study

Highly consistent propagation modeling with Actual measured basis duplicate highly consistent sensor output

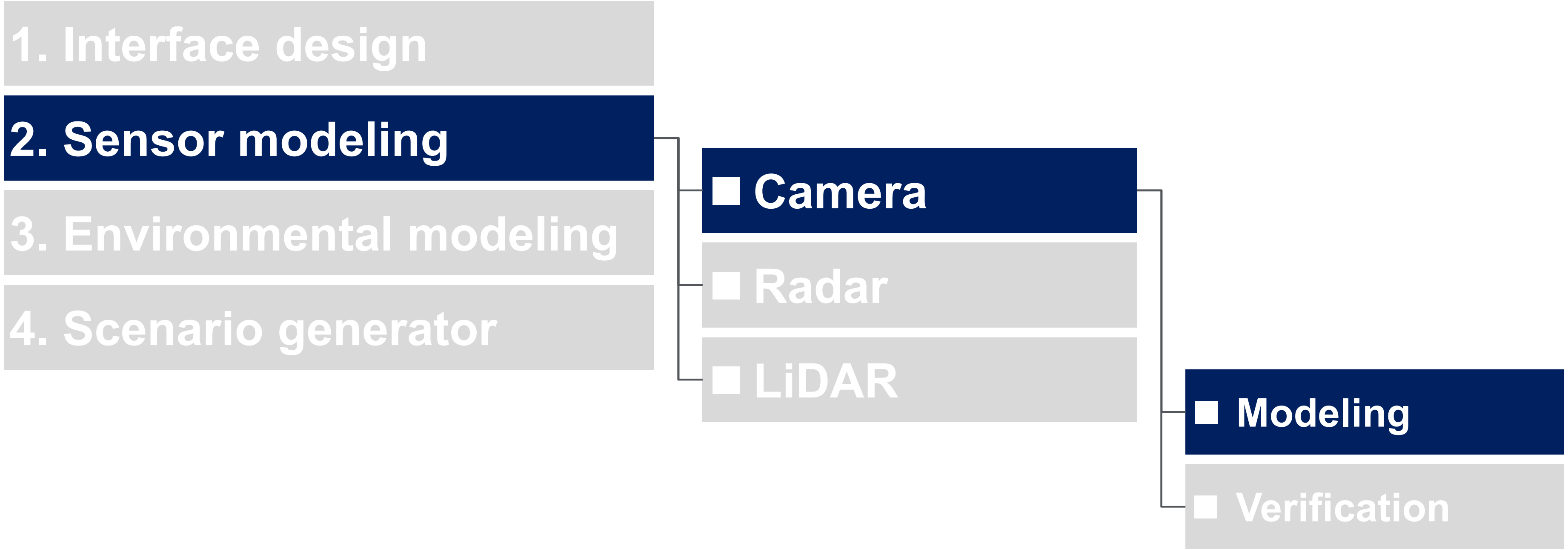
DIVP^{TM} sensor cons scene scope

Nihon Unisys, Ltd



		Priority				
No.	**Scene**	**Camera**	**Radar**	**LiDAR**	**Remarks**	**Impl**
1	Backlit	**High**		**High**		Already
2	Rain	**High**	Medium	**High**		Not yet
3	Fog	**High**	Medium	**High**		Not yet
4	Pedestrians dressed in dark cross the intersection at night	**High**				Not yet
5	Wet asphalt	**High**		**High**		Not yet
6	Raindrops	Medium	Medium			Not yet
7	Manhole		Medium			Already
8	Objects close to the distance		**High**		Pedestrians jump out of the back of the vehicle	Already
9	Multipath from roadside wall		**High**			Already
10	Low reflection objects		Low		Cardboard	Not yet
11	Radio interference caused by sensors mounted on other vehicles		Medium			Not yet
12	Black vehicle			**High**		Already
13	Black leather clothes pedestrian			**High**		Already
14	Faded lane marking	Medium		Medium		Already

FY 2019 outcome

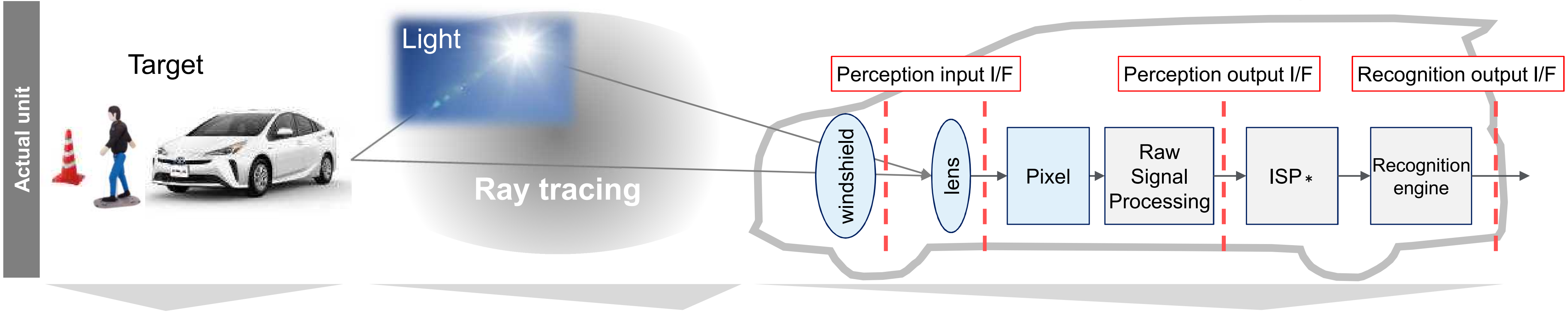


- 1. Interface design
- **2. Sensor modeling**
  - **Camera**
    - **Modeling**
    - Verification
  - Radar
  - LiDAR
- 3. Environmental modeling
- 4. Scenario generator

【Camera modeling】
Work on reproduction of visible light propagation and reflection between light source, target, and lens, and modeling of sensor internal structure for each part

The Key for camera modeling

Sony Semiconductor Solutions Corporation HITACHI Inspire the Next



The Key for modeling

Environmental model

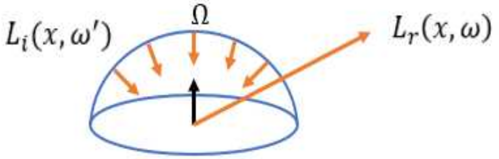
- Precise reproduction of object shape
- Reproduction of reflection characteristics of visible light spectrum

Space design

- Precisely reproduce propagation, reflection, etc. from the light source

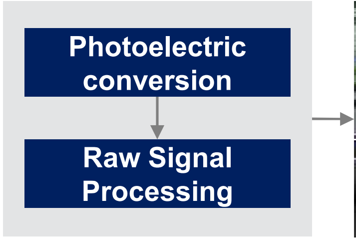
Calculate reflected waves using rendering equations

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



Sensor model

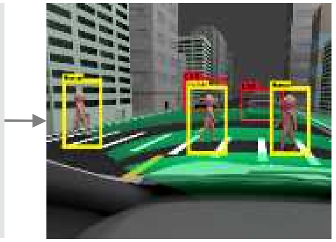
Camera perception model



Photoelectric conversion

Raw Signal Processing

Recognition model



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* Image Signal Processor

Source : SOKEN, INC, Sony Semiconductor Solutions Corporation

【Camera modeling】In order to generate an input that matches the sensor characteristics, the reflection characteristics of the light source and target surface are reproduced on an actual measurement basis. We challenge ray tracing using measured values.

Nihon Unisys, Ltd

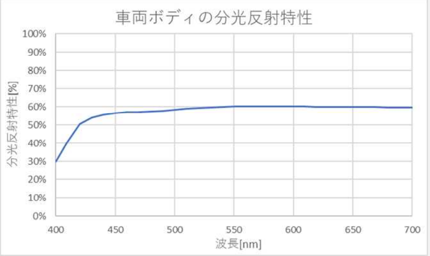
Space design modeling for Camera

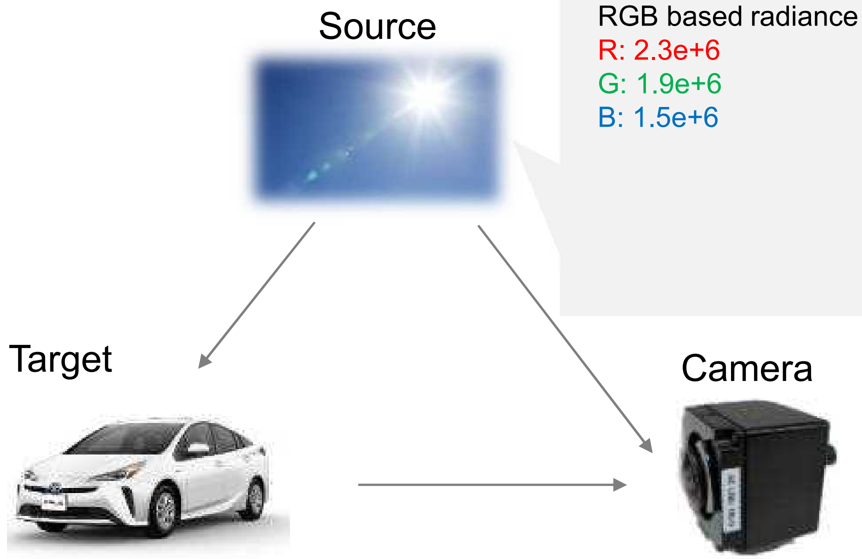
Usual simulator

RGB based modeling
R: 1.0
G: 1.0
B: 1.0

DIVP^{TM}’s

Measurement based modeling



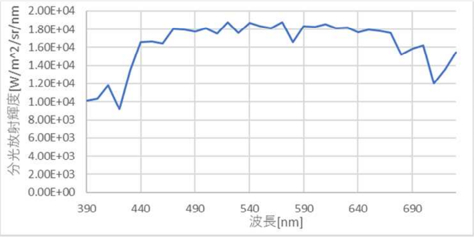


【Usual simulator】

RGB based radiance
R: 2.3e+6
G: 1.9e+6
B: 1.5e+6

【DIVP^{TM}】

Measurement based radiance



Point

- RGB is an expression based on the characteristics of the human eye, and is not appropriate as an input to an image sensor. ***We challenge ray tracing using measurement based data*** to generate an input that matches the characteristics of the sensor.
- The reflection characteristics of the light source and Target surface are also reproduced ***on an actual measurement basis.***

【Camera modeling】
For the light source, use the measured sky light radiance and the light distribution characteristics of the headlamp

Space design modeling for Camera

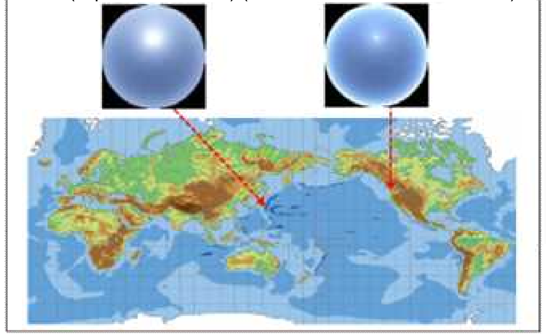
Nihon Unisys, Ltd

Sunlight / skylight simulation

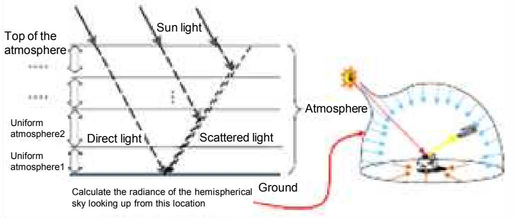
Expresses the brightness of visible and infrared light of the sun at any location and time (exact simulation based on actual measurements)

Location differences

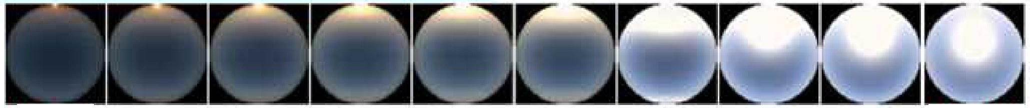
(Japanese summer) (Summer on the US West Coast)



Considering the scattering and absorption effects of the Earth's atmosphere



Time differences

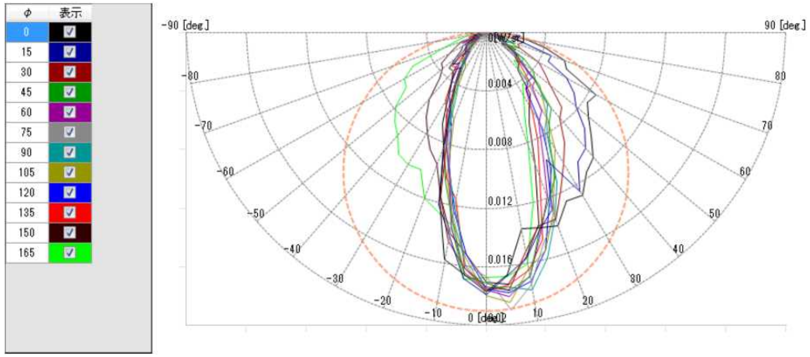


(Sunrise) (Mid-south)

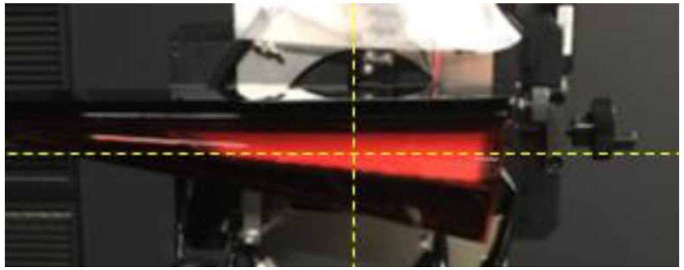
Measurement of lamp characteristics

Measures light distribution characteristics of vehicle headlamps and taillights

Light distribution characteristics data of Prius tail lamp



Prius tail lamp measured



Source : Nihon Unisys, Ltd.

【Space design model】 Compared to conventional conventional simulators that perform spatial rendering based on the three primary colors of RGB, it precisely reproduces the reflectance of visible light and the brightness of sunlight, and reproduces the perceptual output of a camera close to the real environment

DIVP^{TM} Space design

SOKEN **Nihon Unisys, Ltd**

DIVP™

Precise environment reproduction by sunlight and target reflectance

General simulator (CARLA)

Unrealistic space rendering due to limited (RGB3 primary color) reflection

Source: Copyright © CARLA Team 2019.

By simulating the spatial rendering based on the actual measurement, the malfunction scene is precisely reproduced

Reproduction of malfunction scene

Nihon Unisys, Ltd

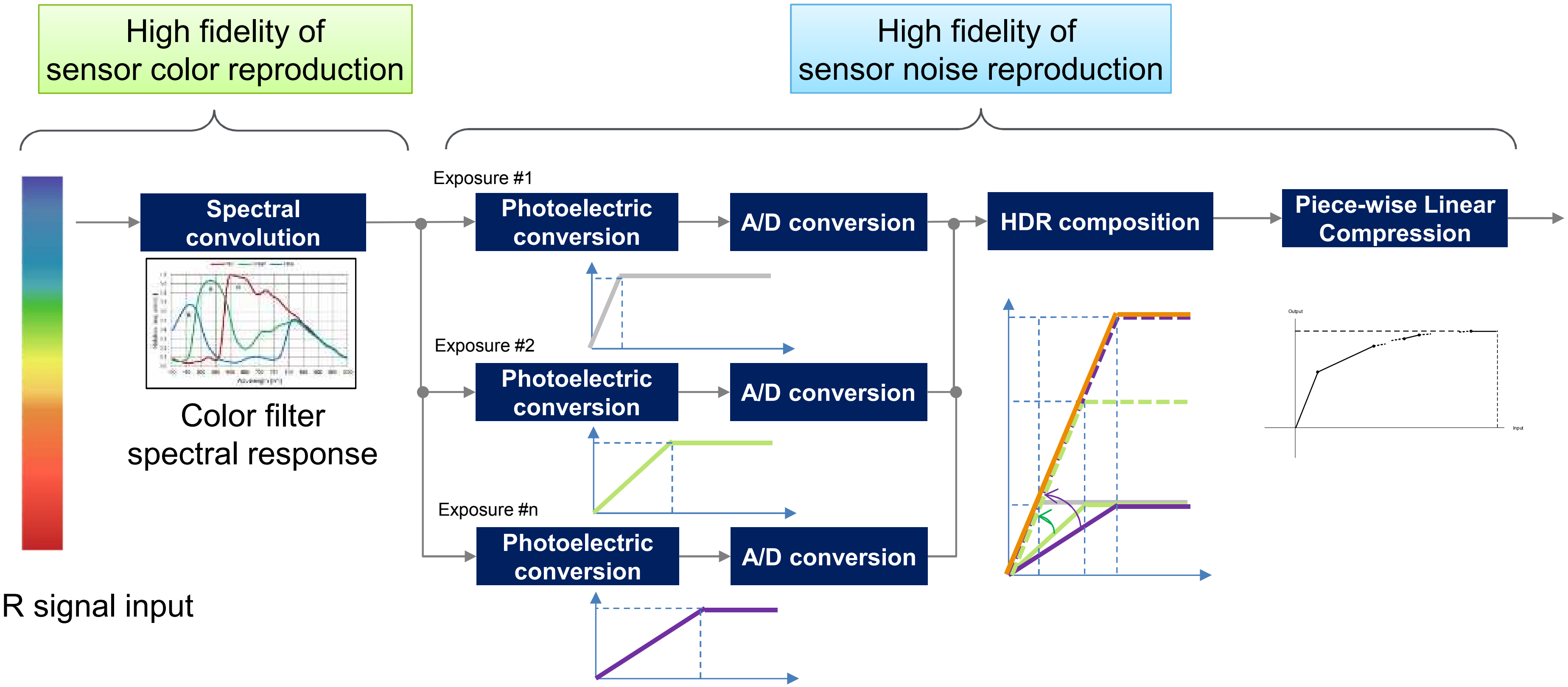
Sunset scene

Source：Copyright © CARLA Team 2019.

【Camera modeling】The camera sensor reproduces the CMOS device and circuit of the actual unit, and can precisely reproduce Photon shot noise (bright part) and floor noise (dark part)

Camera perception modeling

Sony Semiconductor Solutions Corporation



High fidelity of sensor color reproduction

High fidelity of sensor noise reproduction

Spectral convolution

Color filter spectral response

HDR signal input

Exposure #1

Exposure #2

Exposure #n

Photoelectric conversion

A/D conversion

HDR composition

Piece-wise Linear Compression

Photon shot noise (bright area) and floor noise (dark area) can be precisely reproduced

Source：Sony Semiconductor Solutions Corporation

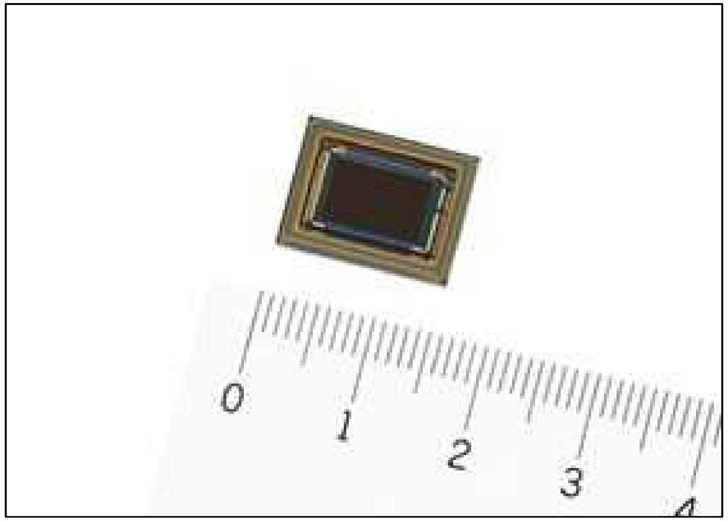
【Camera modeling】
Prepare the IMX490 sensor for the verification of consistency using camera perception output

Sensor specifications

Sony Semiconductor Solutions Corporation

IMX490

- Verification using IMX490 sensor for the pre-verification and the basic-verification



Actual unit used for the verification

	ISX019	IMX490
Number of pixels	1.2Mpix 1280(H)x960(V)	5.4Mpix 2880(H)x1860(V)
Picture size	1/3.8 type	1/1.55 type
Pixel size	2.9um × 2.9um	3.0um × 3.0um
Shutter method	Rolling shutter	Rolling shutter
HDR method	Digital Overlap（DOL）method (Synthesize Muti-exposure type)	Sub-pixel method (2pixSimultaneous exposure)
Flicker suppression function	None	Existence
Output	YCbCr	RAW (RGGB)
Sensor configuration	System On Chip (SOC) (Sensor + ISP)	Sensor only (Sensor + RAW Signal processing)
Remarks	ISP contents： ・HDR composition ・Tone mapping ・AE, AWB control ・Demosaic ・YC conversion etc.	RAW Signal processing contents： ・HDR composition ・Tone mapping（PWL） ・Shading correction etc.

Source：Sony Semiconductor Solutions Corporation

【Camera modeling 】

Further evolution of spatial rendering, lens model, and sensor model is required to reproduce malfunction factors

Camera malfunction event during reproduction plan

Sony Semiconductor Solutions Corporation

Item	malfunction	Reproduction (FY2020/2Q)
Dynamic range	■ Saturation of high-brightness subject when long shutter	Available
	■ Contrast loss due to tone mapping of HDR subjects	Available
Resolution	■ Resolution degradation when using a wide-angle lens	Available
Texture	■ Low illumination noise / dark area noise	Available
Motion blur	■ Blur during long shutter	N/A
	■ HDR composite artifact	N/A
	■ Rolling shutter	N/A
LED Flicker	■ Turn off LED light source during short shutter	N/A
	■ Banding artifact of the whole screen	N/A
Stray light	■ Low contrast, ghost	N/A (Difficulty obtaining lens specifications)

FY 2019 outcome

1. Interface design
2. **Sensor modeling**
    - **Camera**
        - Modeling
        - **Verification**
    - Radar
    - LiDAR
3. Environmental modeling
4. Scenario generator

【Camera consistency verification】 By comparing and verifying the perceptual output of the camera, the scenes and the areas where the difference appears are identified, and the causes are clarified to rotate the cycle from consistency verification to improvement

Overview of consistency verification

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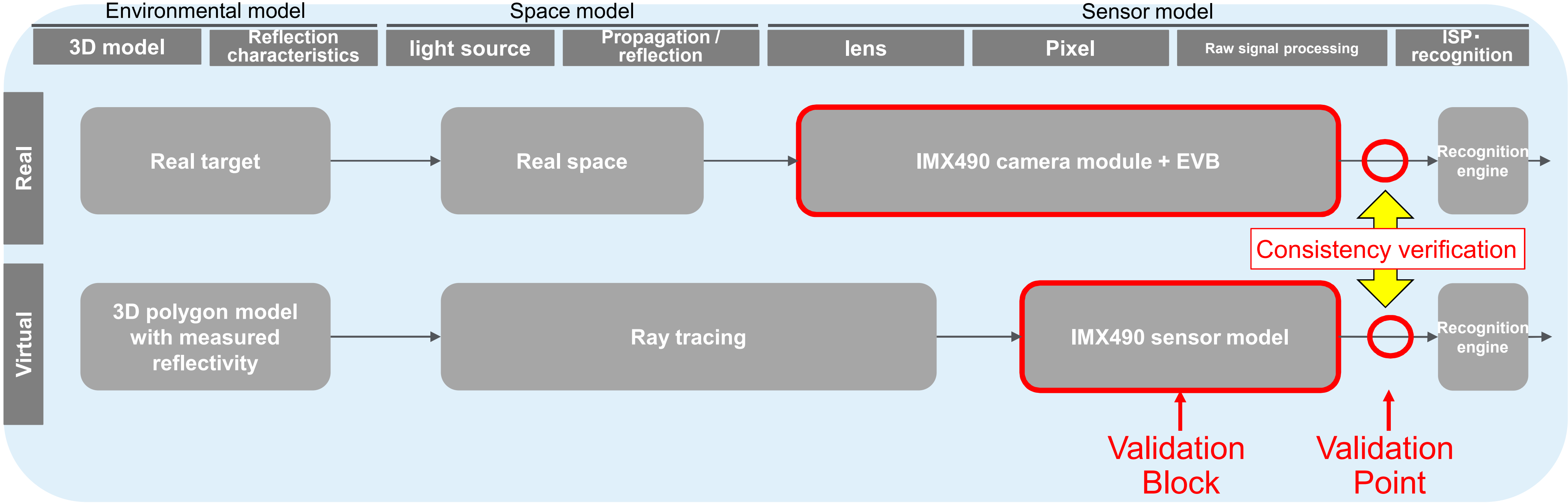
Solutions Corporation

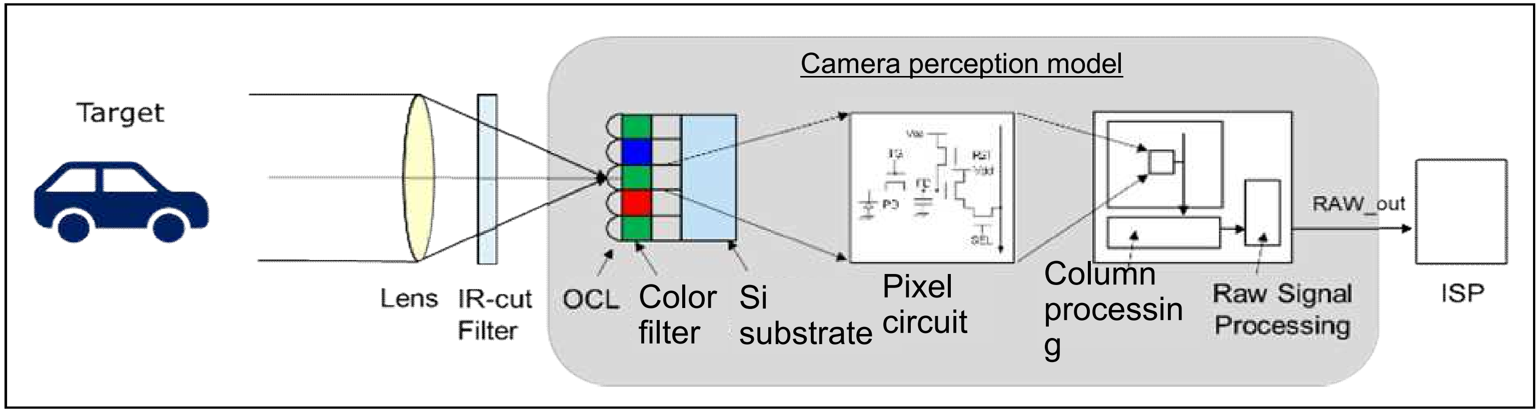
- Using the IMX490 sensor, compare the output result of the sensor model with the actual unit shooting data
- By comparing data, clarify the scenes and areas where differences appeare, and their causes



【Camera consistency verification】
Extract the factors that influence the consistency and proceed with the verification based on these.

Configuration of camera perception model and error factors

Sony Semiconductor Solutions Corporation



	Input	OCL (On Chip Lens)	Color filter	Si substrate	Pixel circuit	Column processing	RAW Signal Processing
Error factors	■ Illuminance ■ Projection data ■ shading	■ Focusing rate	■ Spectral characteristics	■ Quantum efficiency ■ Photon shot noise ■ Floor noise	■ Circuit in pixel	■ Analog gain	■ HDR composition ■ PWL compression
Influence point of error	■ Color reproduction ■ Pixel displacement ■ Brightness distribution	■ Brightness	■ Color reproduction	■ Brightness ■ Noise level	■ Signal level	■ Signal level	■ Tone expression
Error influence	**Large**	Little	**Large**	**Large**	Little	Little	**Large**

Source：Sony Semiconductor Solutions Corporation

【Camera consistency verification】
Designing a verification method that compares histograms starting from a known object

Consistency verification procedure

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- ■ Verification process
  - ① Indoor (studio) evaluation
    - Verification with white board
      - Confirmation with an in-plane uniform level subject
    - Verification by gray chart and color chart
      - Confirmation of contrast and color reproducibility
  - ② Outdoor evaluation
    - Real environment scene, malfunctioning scene

- ■ Verification method
  - ● Histogram comparison
    - Extracted by whole image or by area (image height, color, distance, subject)
    - Comparison of average value (Signal), variation (Noise) and distribution shape
  - ● Perform factor analysis and feedback from areas with large differences

【Camera consistency verification】
proceed with the consistency verification of both indoor and outdoor scene

Schedule of the consistency verification

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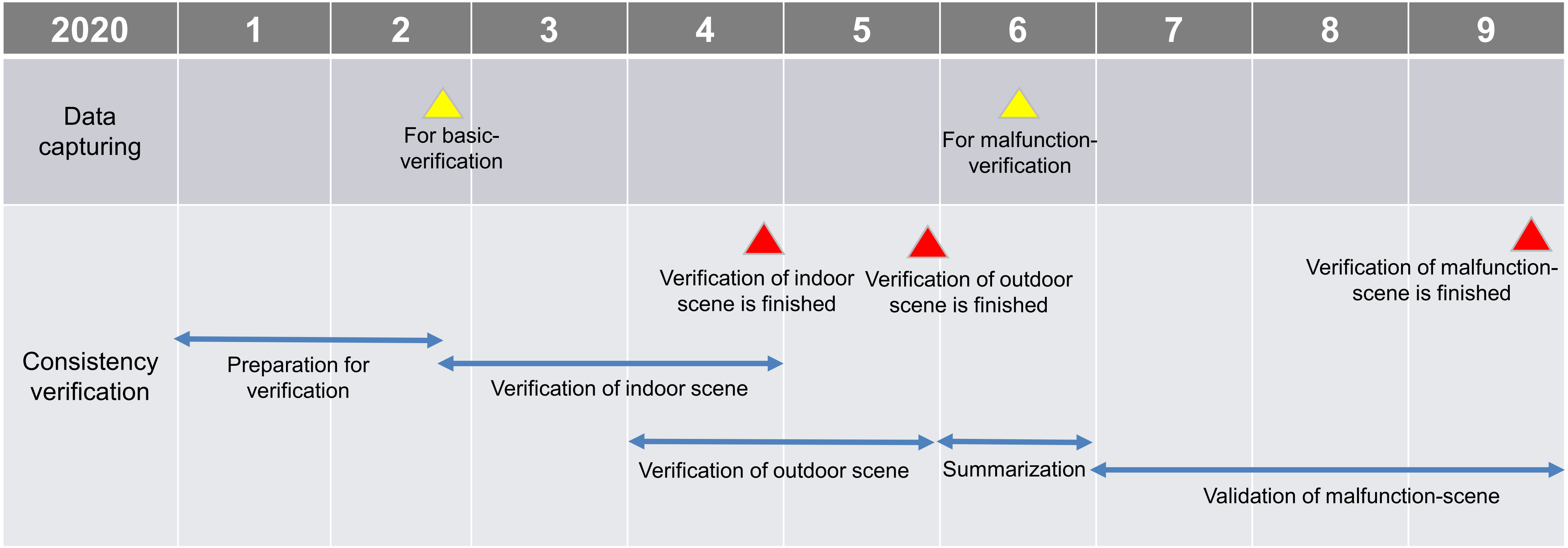


2020 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Data capturing

For basic-verification

For malfunction-verification

Consistency verification

Verification of indoor scene is finished

Verification of outdoor scene is finished

Verification of malfunction-scene is finished

Preparation for verification

Verification of indoor scene

Verification of outdoor scene

Summarization

Validation of malfunction-scene

【Camera modeling】To verify model consistency by perceptual output comparison, compare histograms for each subject area, create histograms of pixel outputs for each area in the scene, and evaluate the consistency between the average and variance

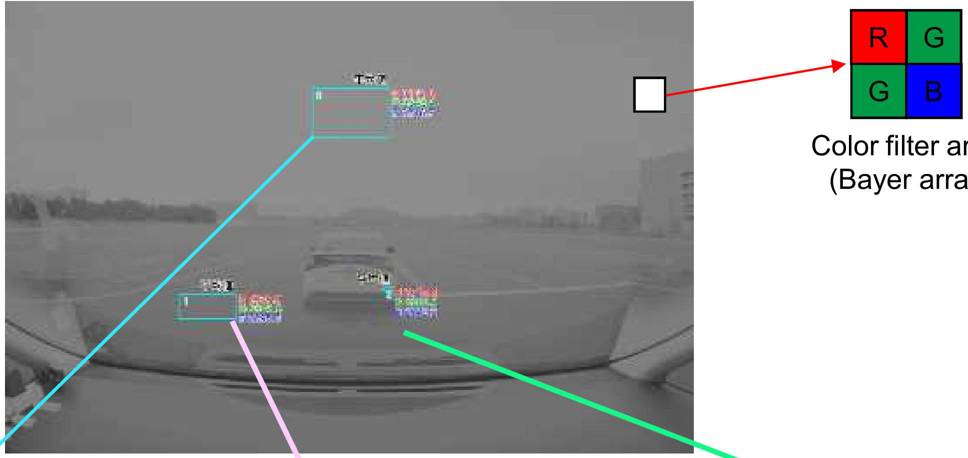
Sony Semiconductor
Solutions Corporation

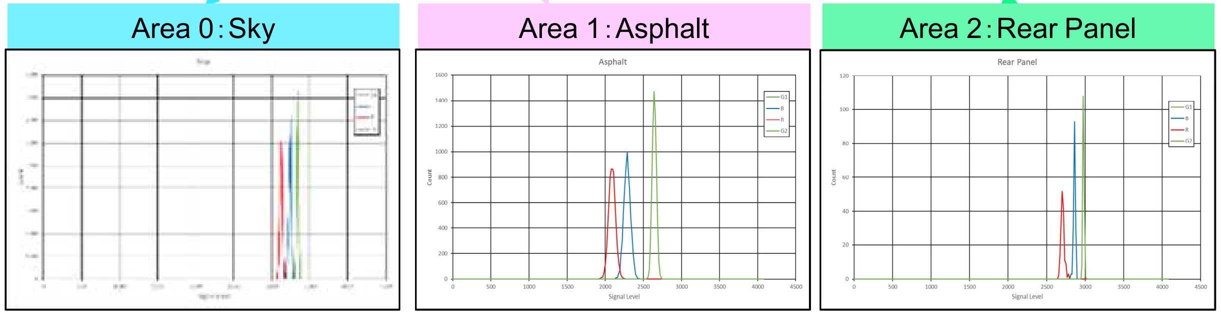
Consistency verification method by perceptual output comparison (example of histogram acquisition)

Reference: IMX490: Color image (simple development)

IMX490：
・Number of pixel：5.4Mpix（2896×1876）
・Pixel size: 3.0um×3.0um

IMX490：RAW data (8 bits out of 12 bits are displayed in monochrome)





Comparison with SIM result

Compare by area
- ■ Average value comparison
  - ➢ Signal level differences
- ■ Comparison of variance
  - ➢ Noise, texture differences

Source：Sony Semiconductor Solutions Corporation

【Camera consistency verification】
Confirmed that it is possible to verify the consistency between the recognition results of the actual unit and the simulation

Camera consistency verification

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Test data

①Video recording


DIVP^{TM} (SOKEN) Experimental video

②Video＋Recognition superimposed output: Object

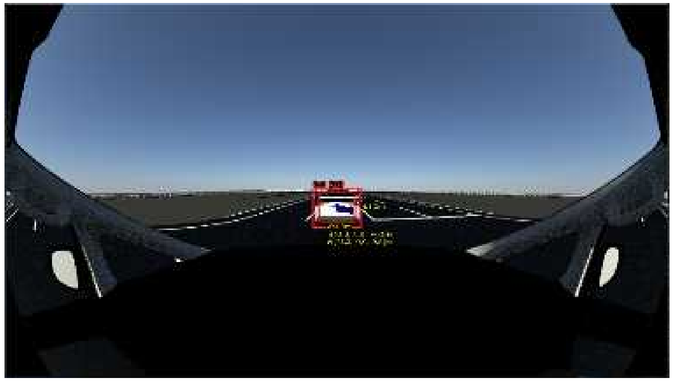
Verify

CG Data

①Video recording：data in rosbag


DIVP^{TM} CG video

②Video＋Recognition superimposed output: Object



Experimental scenery


© Hitachi Automotive Systems, Ltd.

*Camera sensor utilizes ISX019

ISX019：
- ・Number of pixel：1.2Mpix（1280×960）
- ・Pixel size: 2.9um×2.9um

Source : Hitachi Automotive Systems, Ltd.

【Camera consistency verification】
Confirmed that it is possible to verify the consistency between the recognition results of the actual unit and the simulation

Consistency verification method by comparing recognition output (this time)

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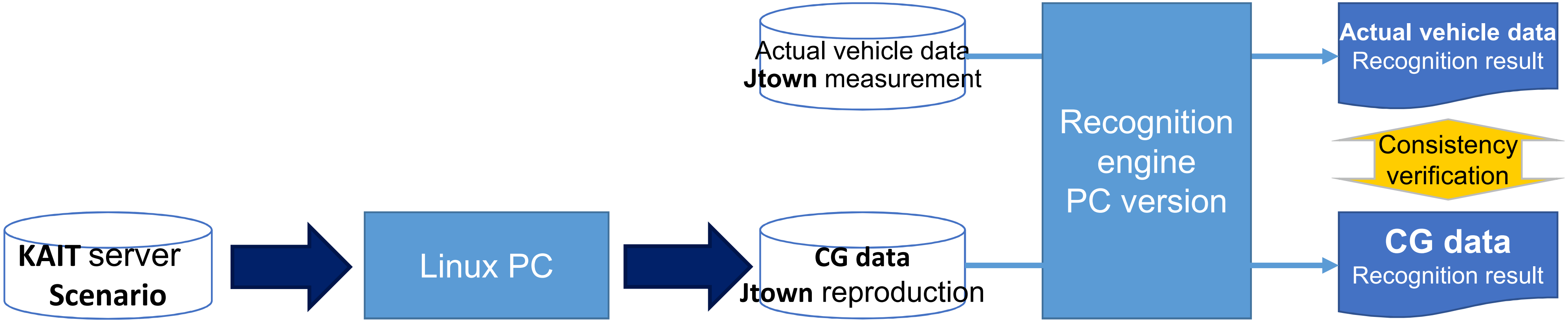

KAIT server
Scenario

Linux PC

CG data
Jtown reproduction

Actual vehicle data
Jtown measurement

Recognition engine
PC version

Actual vehicle data
Recognition result

Consistency verification

CG data
Recognition result

- The difference between the actual vehicle data and the CG data recognition result is verified for each item of the recognition output I / F.
- Since the same recognition engine is used, if the input data is the same, it is assumed that the recognition results will perfect consisutency in the stationary state.

Source : Hitachi Automotive Systems, Ltd.

【Camera consistency verification】 Confirmed that it is possible to verify the consistency between the recognition results of the actual unit and the simulation

[Input video] Difference between actual vehicle data and CG data

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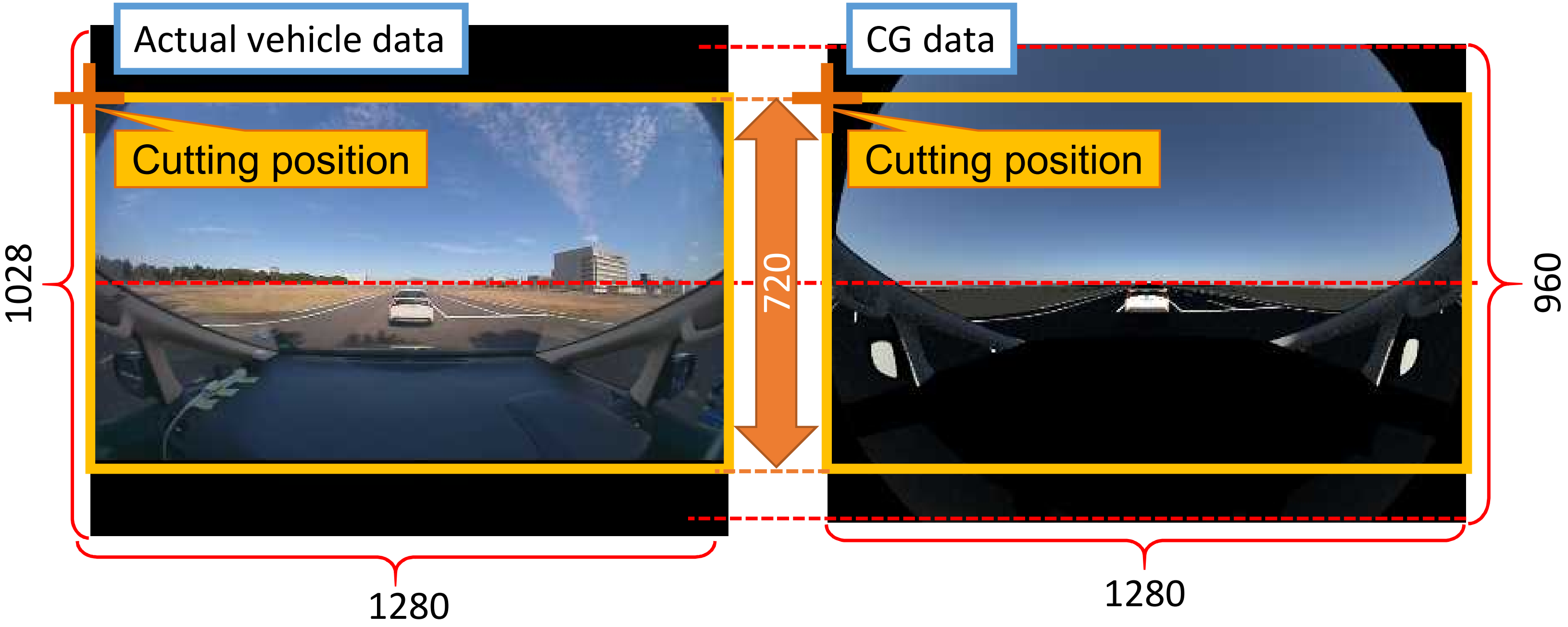
Inspire the Next

JTown1-1-1: Set distance 10m



■Difference of input video (future creation)

① Camera angle of view	② Camera height (depression angle)	③ roll angle
④ Positional relationship between vehicle and white line	⑤Dashboard reflectivity (material)	⑥Pillar reflection
⑦Road surface color	⑧Vehicle shadow	⑨Vanishing point

Source : Hitachi Automotive Systems, Ltd.

【Camera consistency verification】
Confirmed that it is possible to verify the consistency between the recognition results of the actual unit and the simulation

[Recognition result: Object]

CameraRecogInfo	unit	real world	CG	Absolute error	Note
Horizontal size on screen	pixel	90	93	3	
Vertical size on screen	pixel	75	76	1	
Horizontal position	m	0.00	0.00	0.00	
Vertical position	m	1.76	1.86	0.10	
Hight position	m	1.46	1.51	0.05	
Horizontal center coorinate	pixel	642	639	3	
Vertical center coorinate	pixel	413	395	18	
Vertical relative distance	m	22.94	23.25	0.31	
Horizontal relative distance	m	-0.04	0.01	0.05	
Hignt relative distance	m	-0.56	-0.54	0.02	
Type	-	2	2	-	passenger car
Target direction	-	1	1	-	object vehicle
Target angle	rad	0.00	0.00	0.00	
Reliability	%	99.00	99.00	0.00	

[Consideration of recognition results]

The recognition distance was 22.94m in the actual vehicle data and 23.25m in the CG data.
Because the same recognition engine is used, the difference between the input images appears to be the difference in the recognition due to the stationary object and the short distance.

*Recognition results are exactly the same in multiple experiments using CG and actual vehicle images (excluding time)

Source : Hitachi Automotive Systems, Ltd.

In this year‘s activities, build an environment to verify consistency and issues were confirmed. We’ll try to resolve issues in the first half of the fiscal year, before to verify difficult scene such as bad weather condition.

Summary of consistency verification and remaining issues

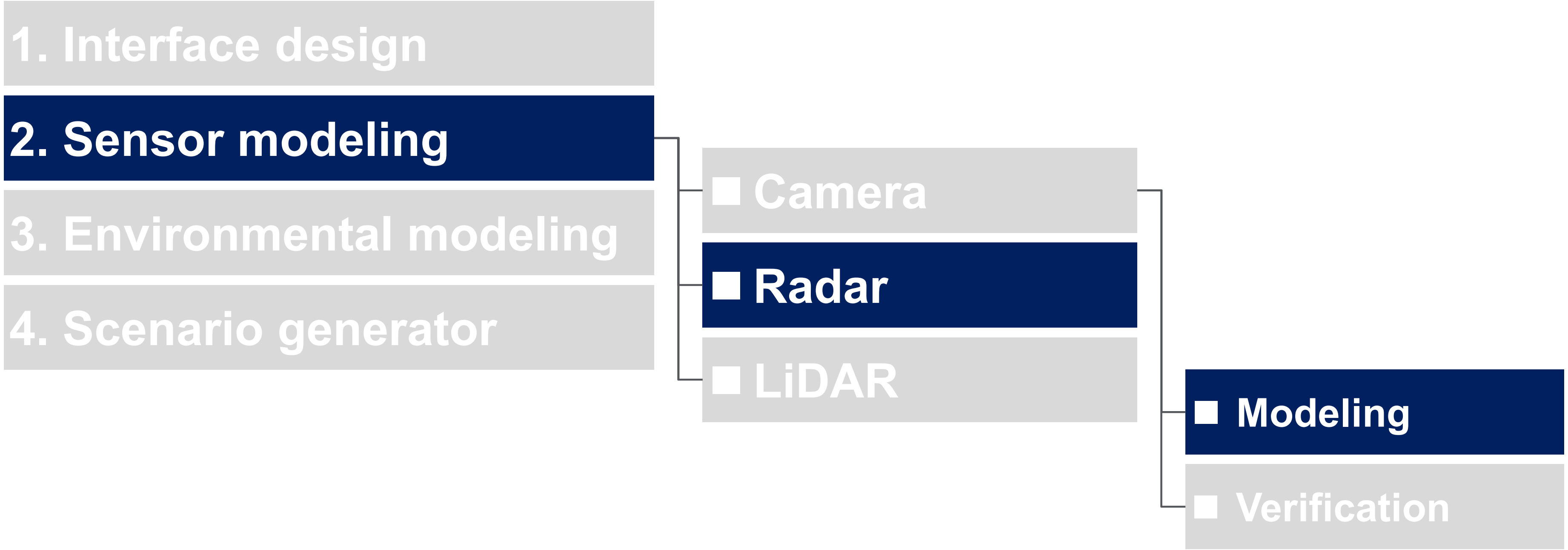
Verification type	target	Item			
		type	distance	size	angle
Pre verification	Prius	Consistent	Not consistent	Not consistent	Consistent (right in front)
Basic verification	Prius	Consistent	Not consistent	Not consistent	Consistent (right in front)

By reproducing the following with CG, it is expected that the recognition consistency between the real world and CG will be improved. However, because of the trade-off with the calculation time, the optimum value is derived while giving feedback to the recognition result.

⓪ Windshield **① Camera angle of view** **② Camera height (depression angle)**
③Roll angle **④Position relationship between vehicle and white line**
⑤Dashboard (reflectance / material) **⑥Pillar reflection**
⑦ Road color **⑧ Vehicle shadow** **⑨ vanishing point**

Source : Hitachi Automotive Systems, Ltd.

FY 2019 outcome

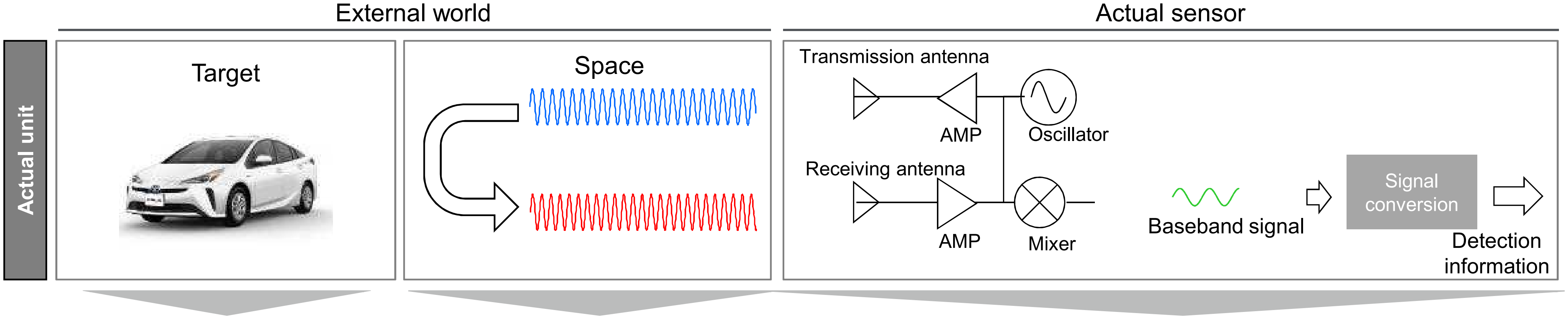


1. Interface design
2. **Sensor modeling**
   - ■ Camera
   - **■ Radar**
     - **■ Modeling**
     - ■ Verification
   - ■ LiDAR
3. Environmental modeling
4. Scenario generator

【Radar modeling】 Coordination with the external world model is the Key for sensor modeling, and a precise environmental model and a spatial model that reproduces the reflection and propagation of millimeter waves are the key to radar modeling

The key to radar modeling

DENSO



The Key for modeling

Environmental model

- Shape modeling
- Reproduction of millimeter wave material properties

Space model

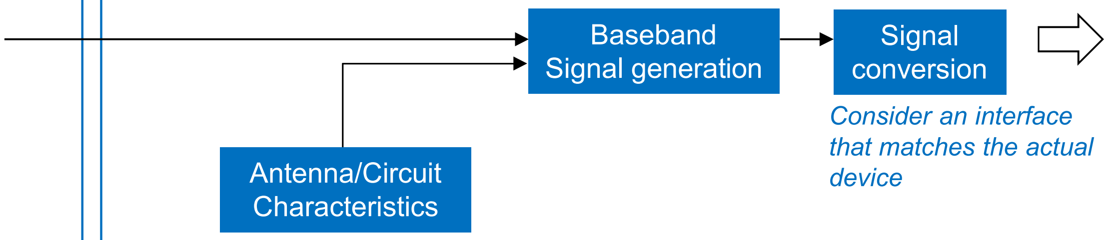
- ***Reproduction of radio wave source and space propagation based on millimeter wave propagation principle***

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

P_r: Reseived power
P_t: Transmitted power
G_t: Transmission antenna gain
G_r: Reseiving antenna gain
λ: wavelength
σ: RCS value
R: Distance between target and radar

Sensor perception model

- ***Reproduction of millimeter-wave antenna / circuit characteristics by baseband signal generation linked with ray trace***



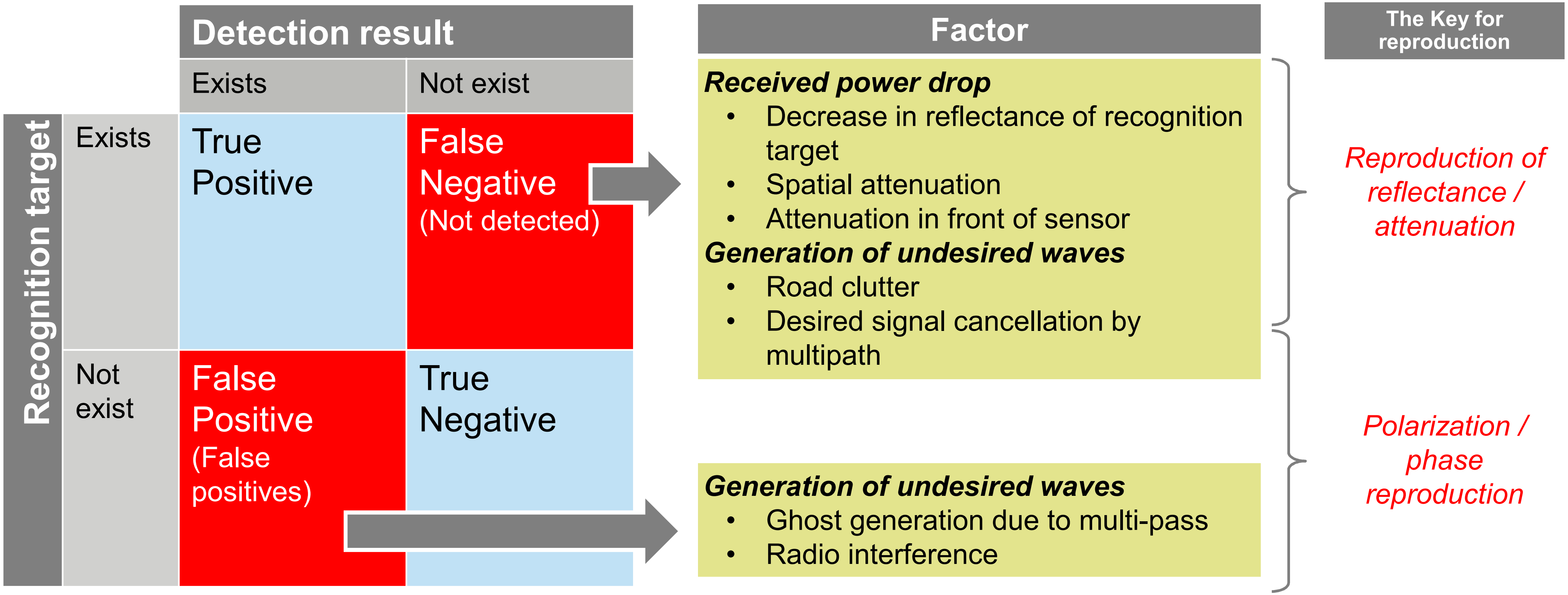
Consider an interface that matches the actual device

Source : DENSO,INC, SOKEN, INC

【Radar modeling】
For verification of malfunctioning factors, it is important to reproduce reflectance / attenuation and polarization / phase of radio waves.

The Key for radar modeling

DENSO **Nihon Unisys, Ltd** **SOKEN**



		Detection result	
		Exists	Not exist
Recognition target	Exists	True Positive	False Negative (Not detected)
	Not exist	False Positive (False positives)	True Negative

Factor

Received power drop
- Decrease in reflectance of recognition target
- Spatial attenuation
- Attenuation in front of sensor

Generation of undesired waves
- Road clutter
- Desired signal cancellation by multipath

Generation of undesired waves
- Ghost generation due to multi-pass
- Radio interference

The Key for reproduction

Reproduction of reflectance / attenuation

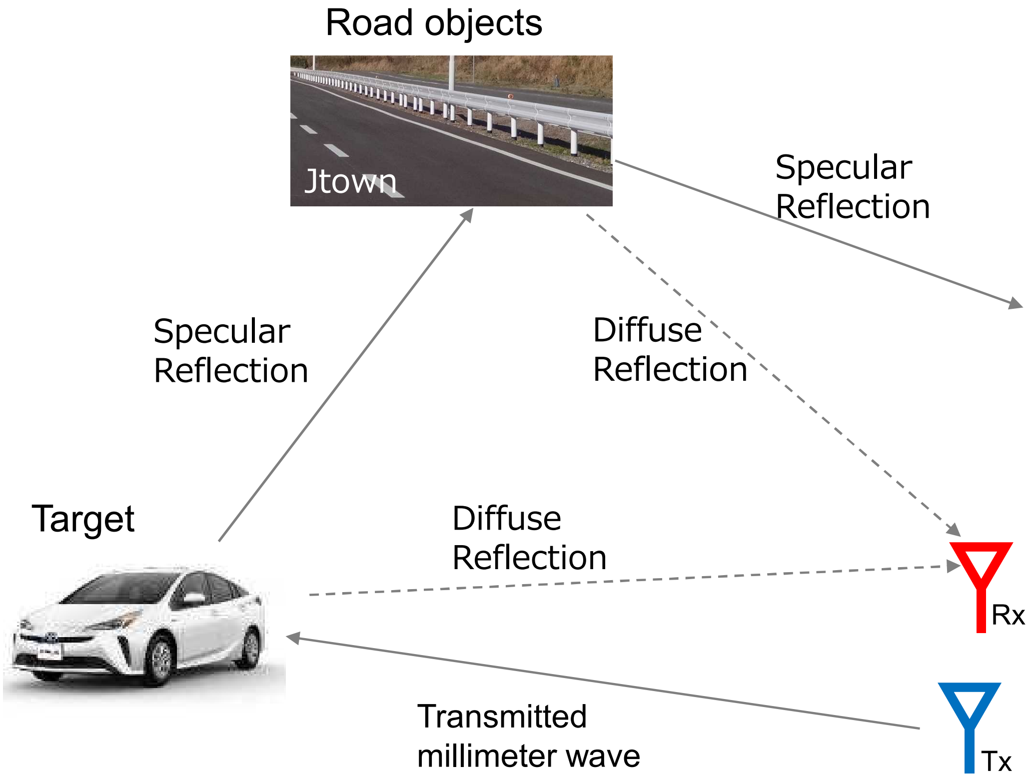
Polarization / phase reproduction

Source : DENSO,INC, SOKEN, INC

【Radar modeling】 Collaboration with environmental models is the Key for radar modeling. Accurate environmental models and spatial models that reproduce millimeter wave reflection and propagation are the Key for radar modeling.

Radar modeling

DENSO Nihon Unisys, Ltd SOKEN



Point for propagation & reflection modeling

- Using Raytracing to duplicate millimeter wave propagation
- Duplicate intensity using actual measured reflection characteristics
- In addition to duplicate Micro-Doppler physics as well

- Modeling millimeter wave source, propagation, reflection characteristics
- Calculate propagation based on Rader formula

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

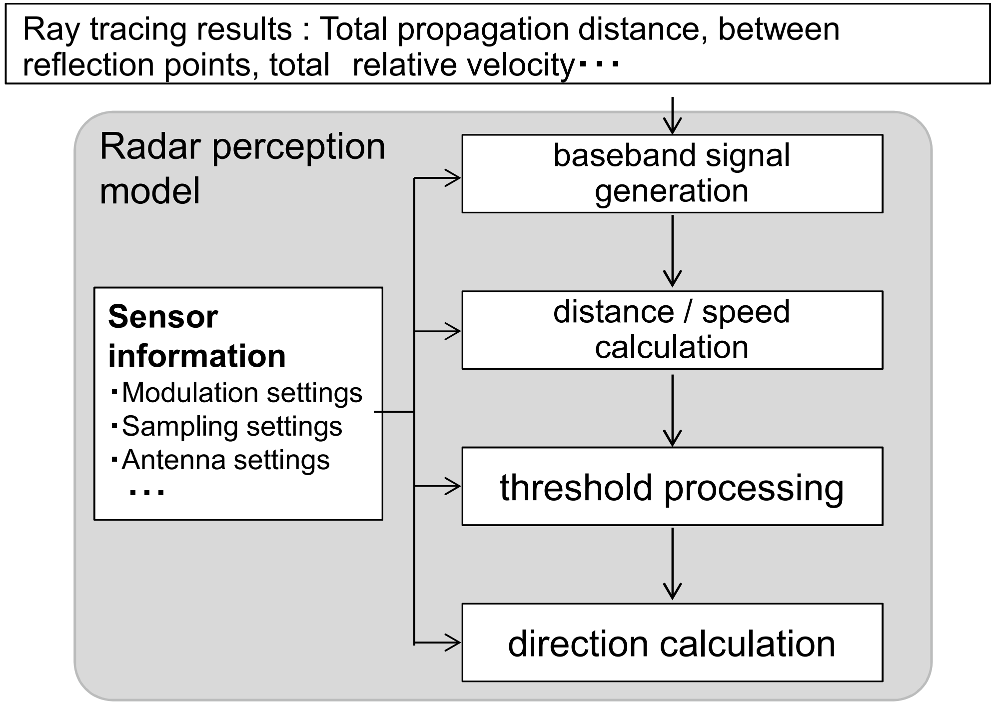
P_r: Recieved power
P_t: Transmitted power
G_t: Transmission antenna gain
G_r: Recieving antenna gain
λ: length
σ: RCS
R: Distance

Source：DENSO,INC, SOKEN, INC

【Radar modeling】 Developed a millimeter-wave radar perception model consisting of baseband signal generation, distance / speed calculation, threshold processing, and direction estimation

Radar processing flow

Nihon Unisys, Ltd DENSO



Ray tracing results : Total propagation distance, between reflection points, total relative velocity･･･

Radar perception model

Sensor information
- ･Modulation settings
- ･Sampling settings
- ･Antenna settings
- ･･･

baseband signal generation

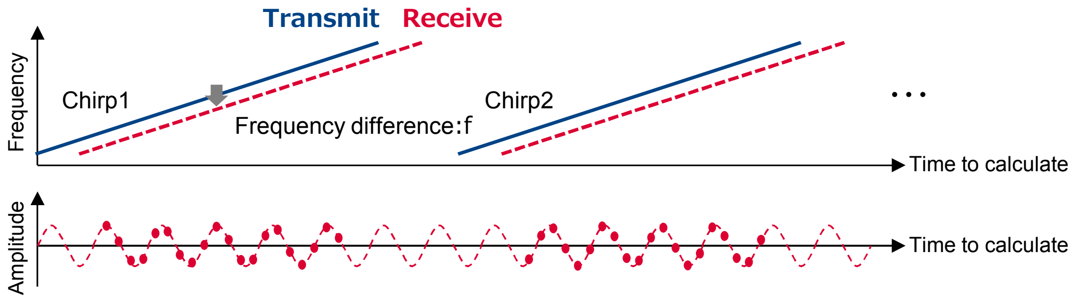
distance / speed calculation

threshold processing

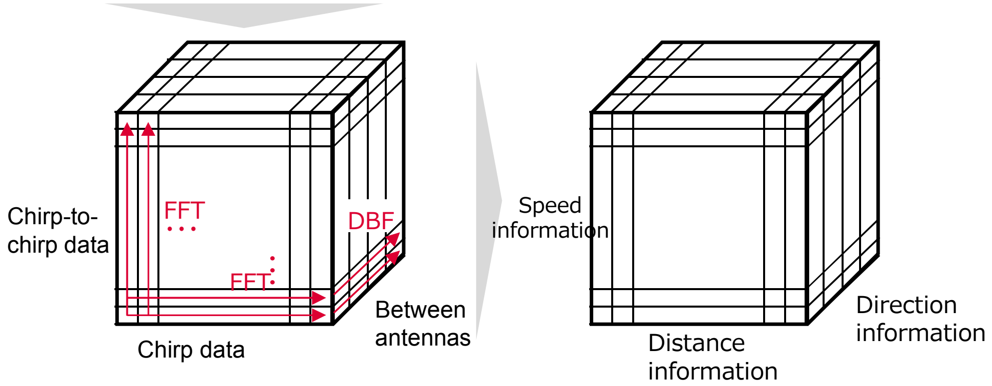
direction calculation

Perceptual output: distance / speed / direction / signal intensity

To recognition processing



Generate chirp and baseband signals according to specifications in sensor model from spatial model output



Calculate distance, speed and direction based on baseband signal

Source : DENSO,INC, SOKEN, INC

【Radar modeling】 Improve reflectivity / attenuation and reproducibility of radio wave polarization / phase using environment model considering polarization and spatial model considering object size

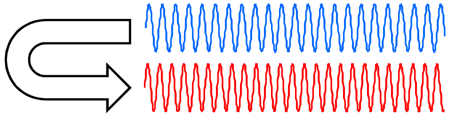
The Key for radar modeling

DENSO **Nihon Unisys, Ltd** **SOKEN**

Modeling of detection target

Modeling of millimeter wave propagation space

Actual unit



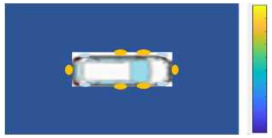
The Key for modeling

■Object Modeling Considering Operation Speed

Save reflection characteristics as DB

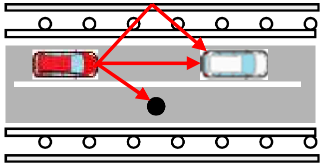
Real-time calculation of reflection characteristics by ray tracing

Finding reflection characteristics in advance



Express objects as polygons

Ray tracing only for the positional relationship of the object and the multipath route



Apply reflection approximation formula for each polygon

Physical Optics approximation

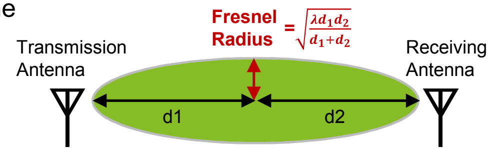
$$E_s(r,\theta,\phi) = -\frac{jkZ_0}{4\pi r}\underbrace{e^{-jkr}(J_x^{"}\hat{x}^{"}+J_y^{"}\hat{y}^{"})}_{\text{Material properties (polarization)}}\underbrace{\iint_A e^{jk(g+h)}ds_p}_{\text{Shape}}$$

Small ⟷ Computational complexity ⟷ Large

■Realization of propagation characteristics considering object size

- ■ Objects smaller than the Fresnel zone

$$P_r \propto \frac{1}{R^4}$$



Fresnel Radius $= \sqrt{\frac{\lambda d_1 d_2}{d_1+d_2}}$

- ■ Objects larger than the Fresnel zone

$$P_r \propto \frac{1}{R^2}$$

- ■ Fresnel zone
  Area representing the spread of radio waves traveling straight
- ■ Fresnel radius 31cm
  (Frequency: 77GHz, distance between antennas: 100m)

Objects are expressed as polygons. The consistency of the reflection intensity will be improved by Physical Optics.

Source : DENSO,INC, SOKEN, INC , Mitsubishi Precision Co. Ltd.

FY 2019 outcome

1. Interface design
2. Sensor modeling
    - Camera
        - Modeling
        - Verification
    - Radar
    - LiDAR
3. Environmental modeling
4. Scenario generator

【Radar consistency verification】 Step-by-step verification of error factors

Millimeter-wave radar coincidence error factors

Item	Confirmation contents	Target	Location	Verification error factors		
				Target	Space	Sensor
Evaluation of joint operation	• Operation verification • Accuracy of metal reflection and space propagation	Corner reflector	Anechoic chamber	• Metal reflection error (amplitude / phase) • Area calculation error	Propagation attenuation error	Amplification error
Preliminary evaluation (still object)	• Effect of polygon accuracy • Precision of dielectric such as glass / bumper • Multipass accuracy	• Prius • NCAP dummy	Jtown	• Shape error • Dielectric reflection / transmission error	• Multipath path search error • Road surface reflection error	• Noise error • Antenna directivity error
Basic evaluation (moving object)	• Relative speed generation accuracy	• Prius • NCAP dummy	Jtown	• Same as above • Micro Doppler error	Same as above	—
Malfunction evaluation	• Influence of various malfunction factors on accuracy	Rain	Rain test track	—	Spatial attenuation modeling error	—
		Wall	—	Wall reflection error	—	
		Radio interference	—	—	—	Antenna polarization characteristics error

Source : DENSO, INC

【Radar modeling】The distance / velocity / azimuth / signal intensity that can be detected by the radar principle is used as an index for consistency verification.

Target value

Item	Target value (Difference from actual unit)	Grounds
distance	30cm	Equivalent to 500MHz distance resolution
Vehicle	0.3km/h	Performance of actual verification unit
Azimuth	10deg	Performance of actual verification unit
intensity	±5dB	Performance of actual verification unit

【Radar consistency verification】Rader intensity is not consistent, further study for duplication various Targets(Figure, Size, materials, etc) needs to be discussed

Rader consistency verification

Static test in Labo

Test environment

Corner Reflector

Anechoic Chamber

Millimeter wave radar

Static test in PG

Test environment

Results	Static test in Labo	Static test in PG
Distance	OK	Under verification
Azimuth	OK	Under verification
Intensity	NG	Under Model enhancement

Source : DENSO,INC

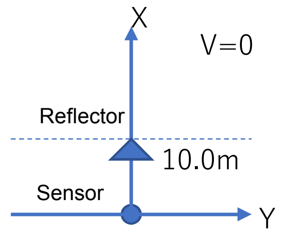
【Radar consistency verification】
Under basic conditions using corner reflectors, the consistency of distance and angle was confirmed

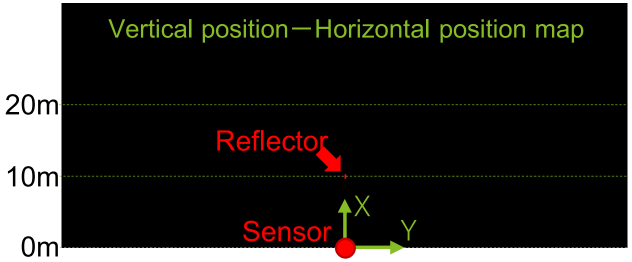
Combination verification results using corner reflectors

Corner reflector position

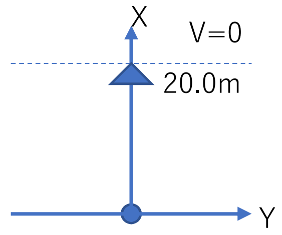
simulation result

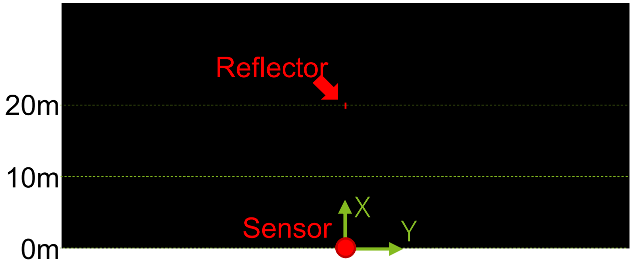
Result judgment



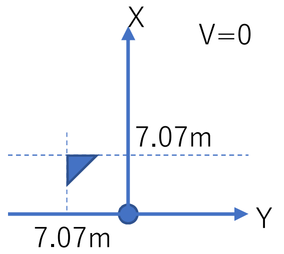


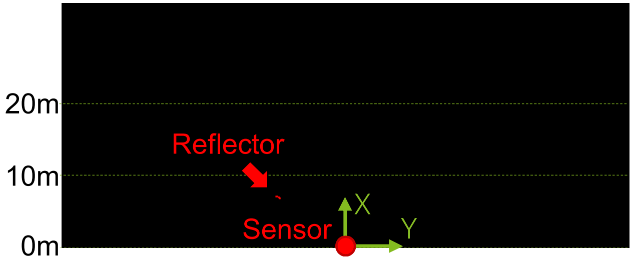
	Set value	Perception output	difference	Target value	Pass or fail
Distance	10.00 m	10.08 m	0.08 m	0.30 m	Pass
Azimuth	0.0 deg	1.8e-15 deg	1.8e-15 deg	10 deg	Pass





	Set value	Perception output	difference	Target value	Pass or fail
Distance	20.00 m	20.01 m	0.01 m	0.30 m	Pass
Azimuth	0.0 deg	1.8e-15 deg	1.8e-15 deg	10 deg	Pass





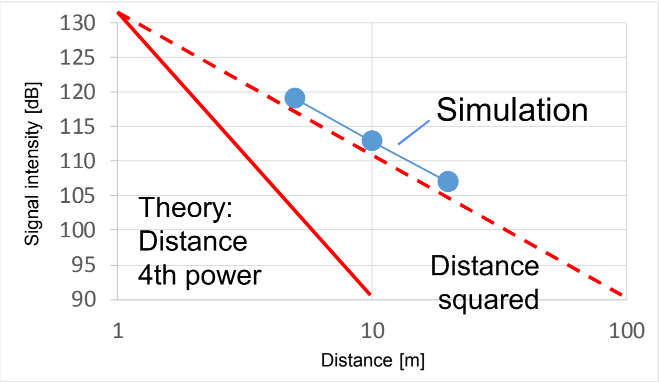
	Set value	Perception output	difference	Target value	Pass or fail
Distance	10.00 m	10.08 m	0.01 m	0.30 m	Pass
Azimuth	45.0 deg	45.0 deg	0 deg	10 deg	Pass

Source : DENSO, INC, Data by Nihon Unisys, Ltd.

【Radar consistency verification】
For the intensity, it is necessary to obtain the area that contributes to reflection and consider distance attenuation.

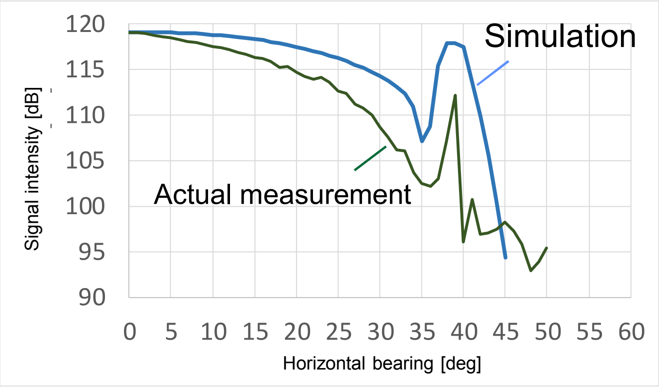
Reflectivity consistency

■Distance dependence of signal intensity



Distance attenuation different from the theoretical value

■Dependence of signal Intensity on direction of corner reflector



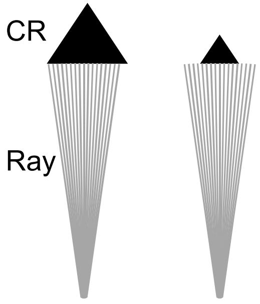
Signal intensity different from actual measurement

■Consideration

	Theory	Current status
Receive power	$\propto (area)^2$ * $\propto (distance)^4$	$\propto (area)^1$ $\propto (distance)^2$

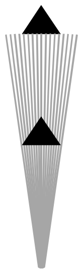
* For corner reflector

Cause proportional to $(area)^1$



Target area is determined by the number of reflected rays → reflected power is proportional to $(area)^1$

Cause proportional to $(Distance)^2$



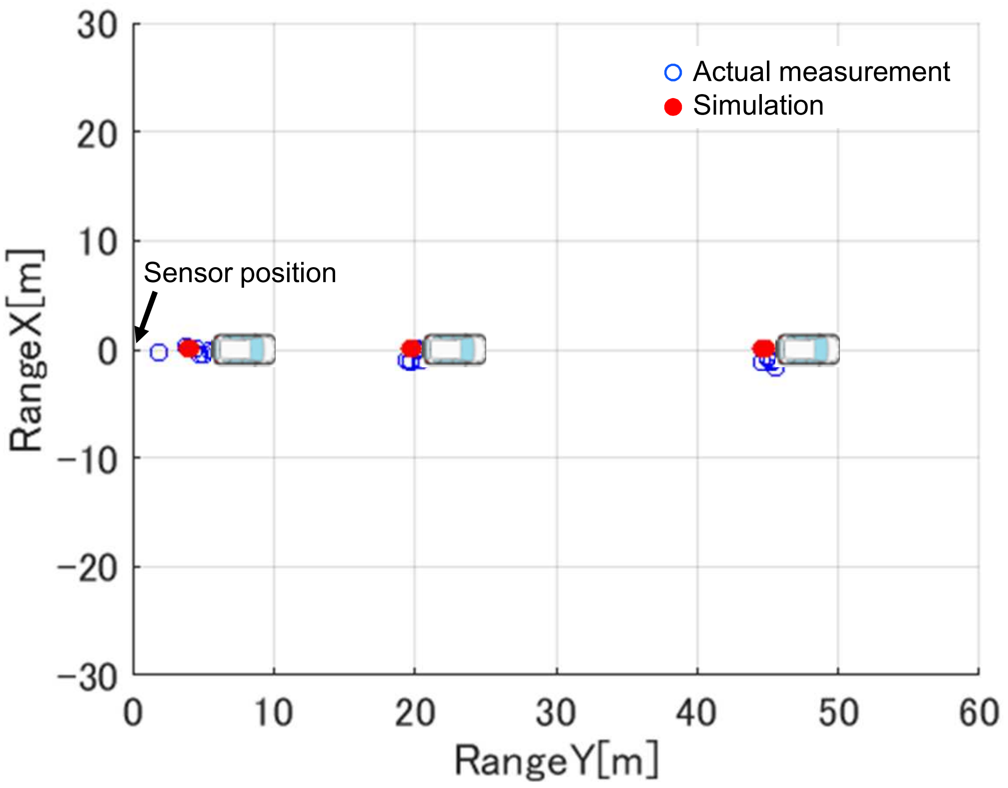
Proportion to outbound only $(distance)^2$ → Return distance attenuation is not considered

Source : DENSO, INC

【Radar consistency verification】 We are verifying the consistency with the Prius at Jtown. It was confirmed that the distance / azimuth / velocity (0 km / h) was almost the same. Verify the consistency in detail, including the signal Intensity.

Pre-verification (still object)

DENSO



Test

Simulation

Source : DENSO, INC, Data by Nihon Unisys, Ltd

It was confirmed that the distance / azimuth / velocity (0 km/h) was almost the same. Inconsistency of Intensity will be improved by space model refinement.

Summary of consistency evaluation and remaining issues

Evaluation	Target	Items			
		Distance	Azimuth	Velocity	Intensity
Evaluation of joint operation	Corner Reflector	Consistent	Consistent	Consistent (0km/h)	Inconsistent
Preliminary evaluation	Prius	Almost Consistent	Almost Consistent	Almost Consistent	—

To improve the consistency of signal intensity, the following items are required.

- Reflection characteristics considering the shape of the object
- Improvement of multipath calculation accuracy

FY 2019 outcome

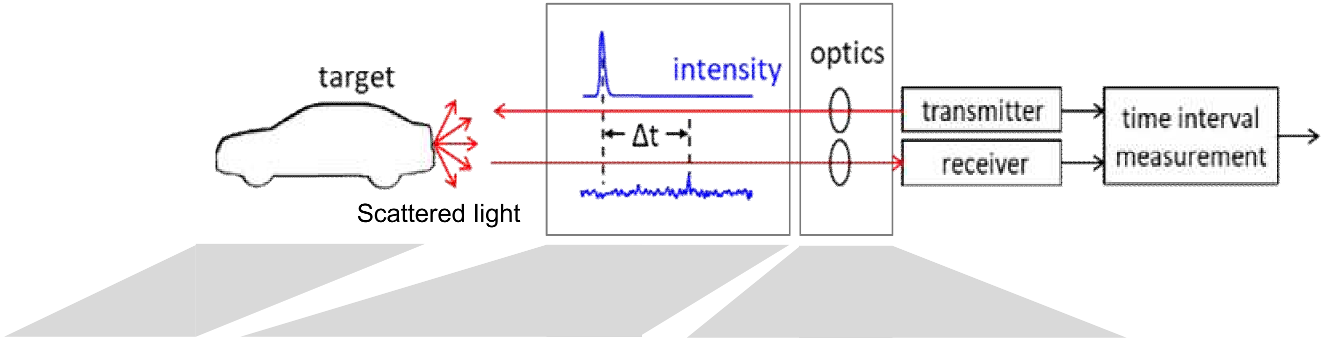
1. Interface design
2. **Sensor modeling**
    - Camera
    - Radar
    - **LiDAR**
        - **Modeling**
        - Verification
3. Environmental modeling
4. Scenario generator

【LiDAR modeling】 Examining the requirements to be modeled in LiDAR simulation, modeling of signal propagation, LiDAR scanning, optical system / ranging method is the Key

The Key for LiDAR modeling

Sensor structure, detection principle

- LiDAR is a sensor that calculates the distance R to the target from the time distance between the time when light is transmitted and the time when the light is received.
- Separate LiDAR into functional moduls and models each functional module.

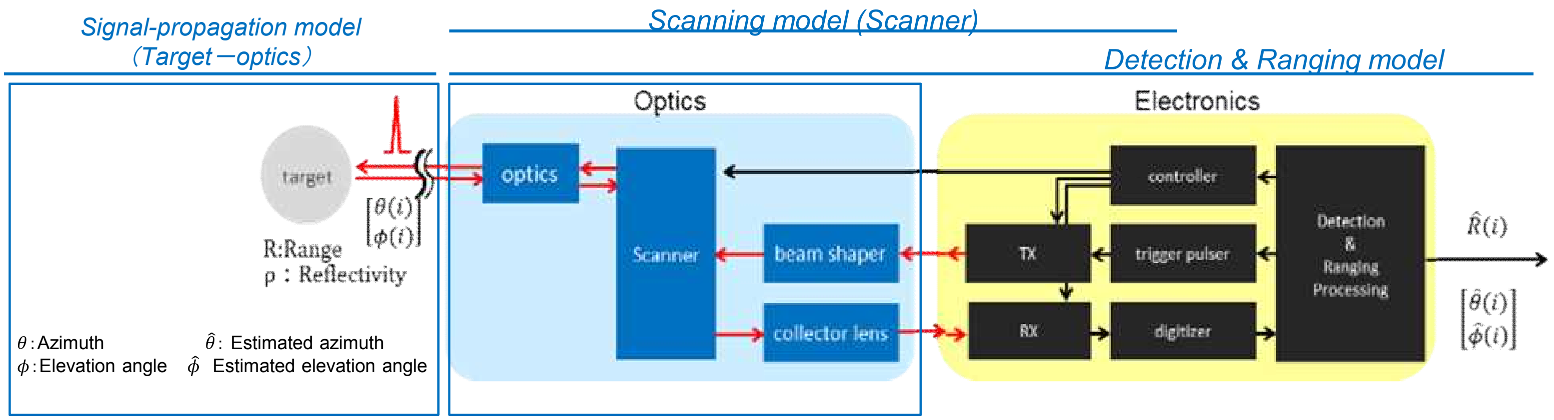


Target	■ Target
Scattered light	■ Scattered light (reflected light)
Transmitter	■ Transmitter
Receiver	■ receiver
Time interval measurement	■ Time interval measurement

Modeling requirements

Environmental model

- Precise reproduction of object shape
- Reproduction of infrared light reflection characteristics



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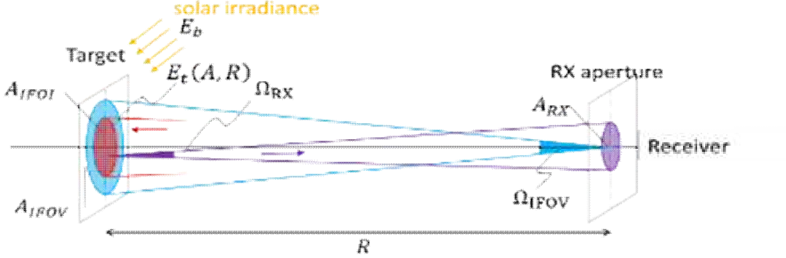
* TOF:TimeOfFlight

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

【LiDAR modeling】
Considered the signal propagation model (optical model) and clarified the factors to be modeled

Signal propagation model (optical model)



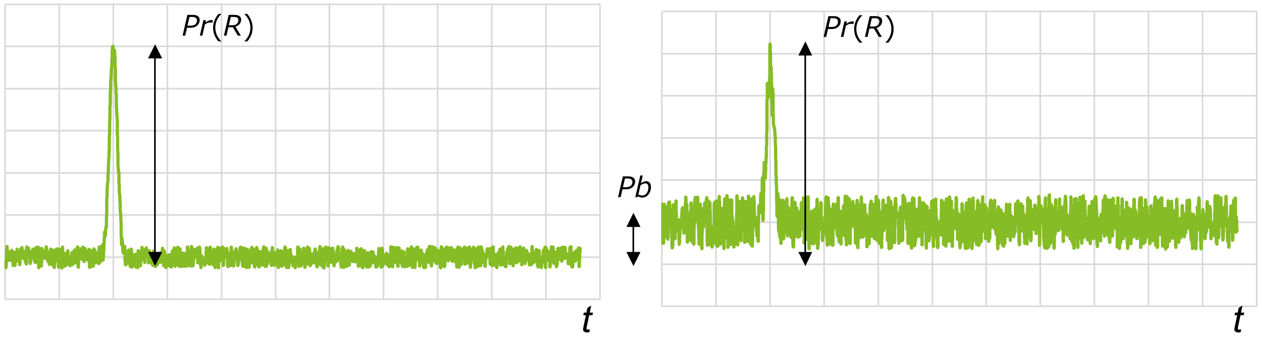
A_{IFOI}	Area onto which transmitted light is irradiated・Footprint [m^2]
A_{IFOV}	Area from which reflected light can be received [m^2]
Ω_{RX}	Reception solid angle of receiving lens aperture [sr]
Ω_{IFOV}	Instantaneous field of view (solid angle) [sr]
A_{RX}	Reception aperture area [m^2]
R	Distance between the target surface and the Sensor [m]
$E_t(A,R)$	Illuminance on the target surface [W/m^2]

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

$$Pb \ = \frac{\rho}{\pi}\int_{A_{IFOV(R)}}\int_{\Omega_{RX(R)}} E_b dAd\Omega = \frac{\rho}{\pi}A_{RX}\Omega_{IFOV}E_b$$

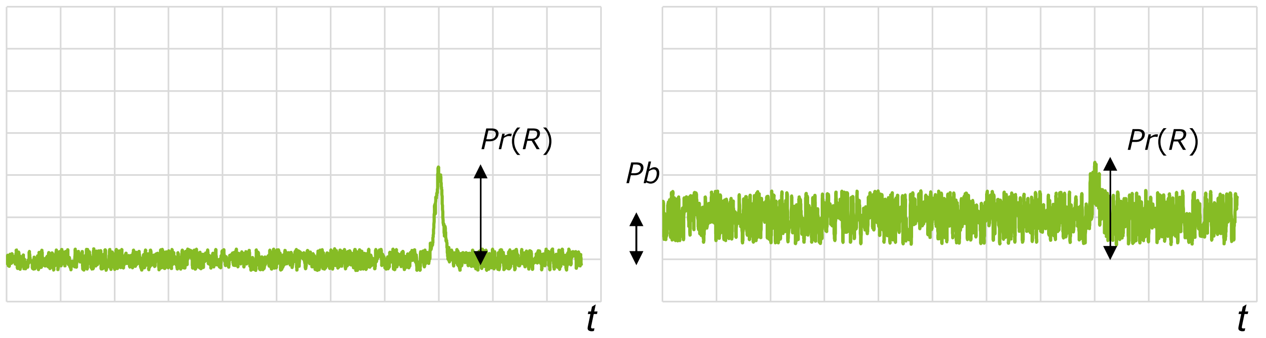
ρ: Target emissivity, where the reflection characteristic is the Lambertian reflector
Pt: Transmitting light power
E_b: Irradiance from the sun

- Received waveform when the target is close


No background noise

Background noise

- Received waveform when the target is far away


No background noise

Background noise

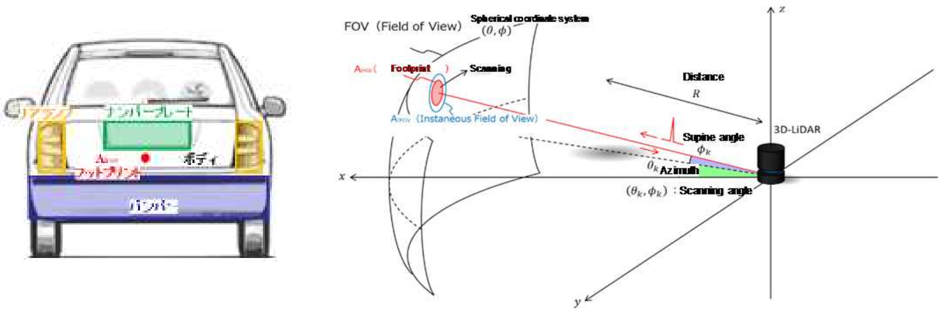
LiDAR model requires modeling of target reflection characteristics, propagation attenuation, and background light power that affect Pr and Pb

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

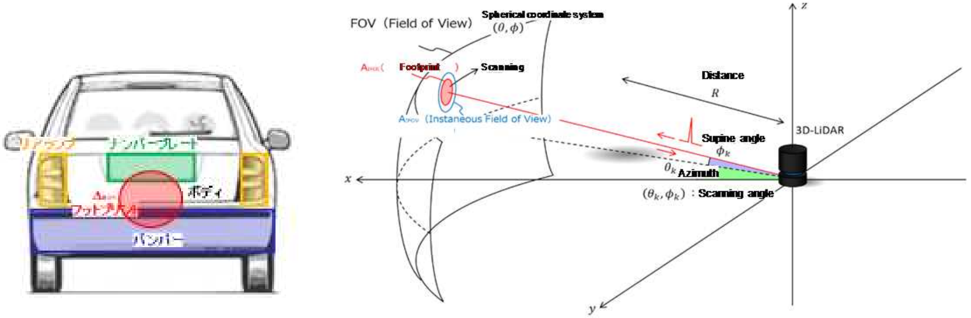
【LiDAR modeling】
Computation amount of scan model is scalable by handling of footprint (point to surface)

Scan model

Do not consider diffusion, with rays as points



Elaborately simulate the real environment, taking into account the diffusion and reflection of light rays



- Footprint from point to surface (beam divergence is represented by multiple rays, taking into account the angle of incidence)
- Because it expresses beam divergence, it is possible to handle cases where beams are irradiated on multiple targets
- High resolution beam emission timing (nsec order)

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

【LiDAR modeling】Environmental model for LiDAR includes quantified reflection characteristics of target for LiDAR signal wavelength.

Environmental model

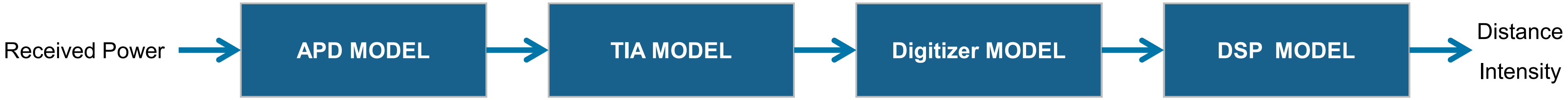
Diffuse reflection characteristics	Reproduce measured target reflection characteristics
Transmission characteristics	
Specular reflection characteristics	
Retroreflective characteristics	
Multiple reflection characteristics	Reproduce measured target reflection characteristics * If there is a scene to be reproduced
Propagation attenuation	Consider for each irradiation beam
Background light	Consider each iFov of scanning point

Source : SOKEN, INC

【LiDAR modeling 】
Detection & Ranging Model is modeled on a design or analysis basis

■ Design base

- **When the design specification is known ⇒ Modeling from design specification**

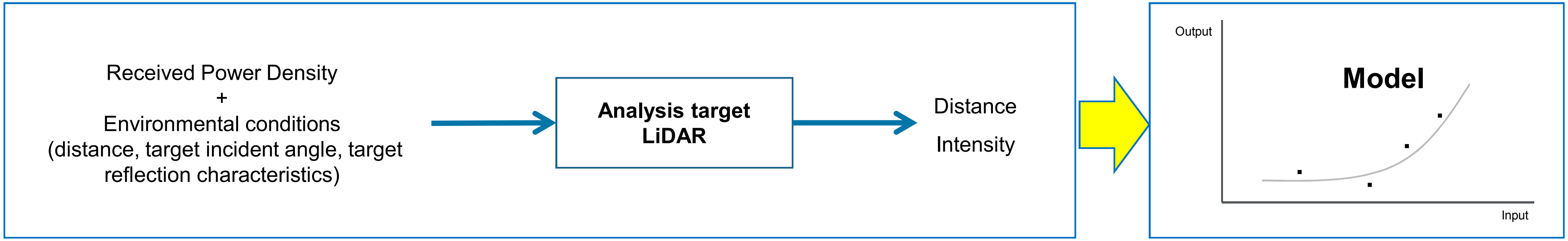


Received Power → APD MODEL → TIA MODEL → Digitizer MODEL → DSP MODEL → Distance
Intensity

Model each element based on design specification

■ Analysis base

- **When the design specification is unknown ⇒ Modeling from measurement values (analysis base)**



Received Power Density
+
Environmental conditions
(distance, target incident angle, target reflection characteristics)

→ **Analysis target LiDAR** → Distance
Intensity

Measures output for known inputs (environmental conditions) and models the relationship

【LiDAR modeling】
Prioritize LiDAR detection error cases

LiDAR error cases example

Pioneer

Difficult to detect from LiDAR

Reflection Measurement base

Black leather jacket

Wet asphalt

Propagation in Rain, Fog condition

Propagation calculation base

Rain

Fog

Sun light condition

Study with Back ground light

Sun light, Backlit, etc

【LiDAR modeling】
We will work on reproducing the thermal barrier paint seen in Tokyo (Odaiba) as a scene where white lines are difficult to detect

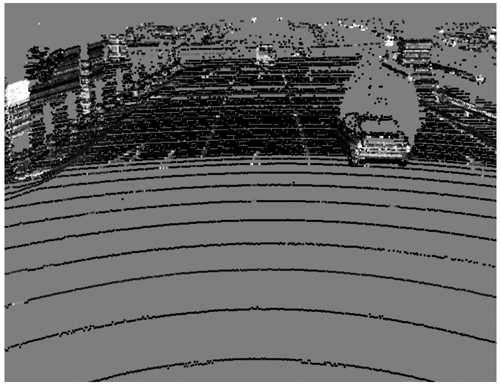
Reproduction of LiDAR malfunction event (white line detection)

Pioneer

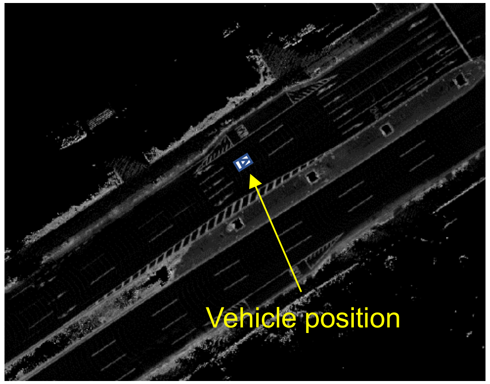
Normal asphalt (near Big Sight)

- **White line can be detected due to the difference in reflectance between asphalt and white line**

LiDAR point cloud

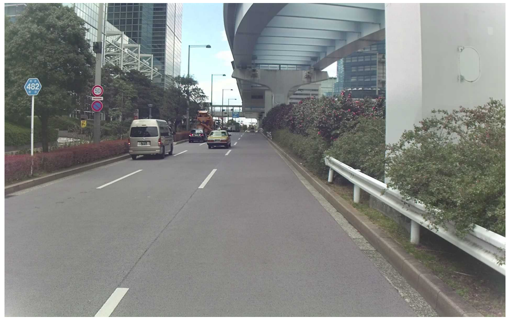


LiDAR Ortho Map

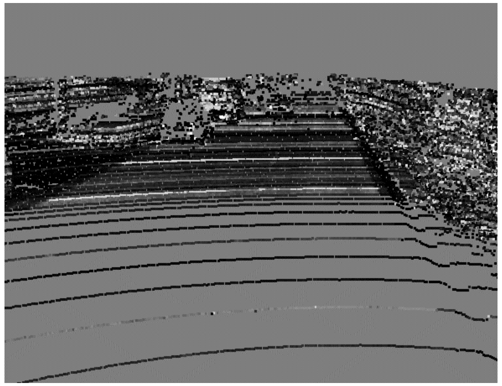


Thermal barrier coating (in front of Telecom Center)

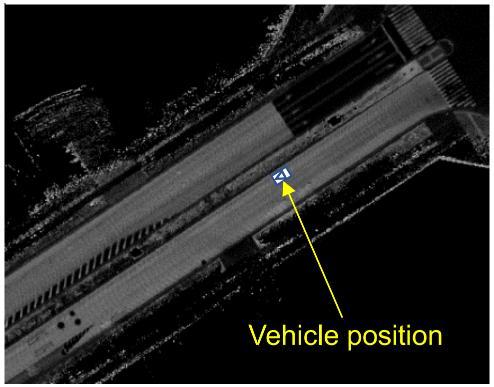
- **Difficult to detect white line because of the same reflectance of asphalt and white line**



LiDAR point cloud



LiDAR Ortho Map



Source：金沢大学、SIP第2期 自動運転（システムとサービスの拡張）「自動運転技術（レベル3, 4）に必要な認識技術等に関する研究」計測データ
Kanazawa University, SIP Phase 2 Autonomous Driving (Expansion of systems and services) “Research on recognition technology required for autonomous driving technology (levels 3 and 4)” Measurement data

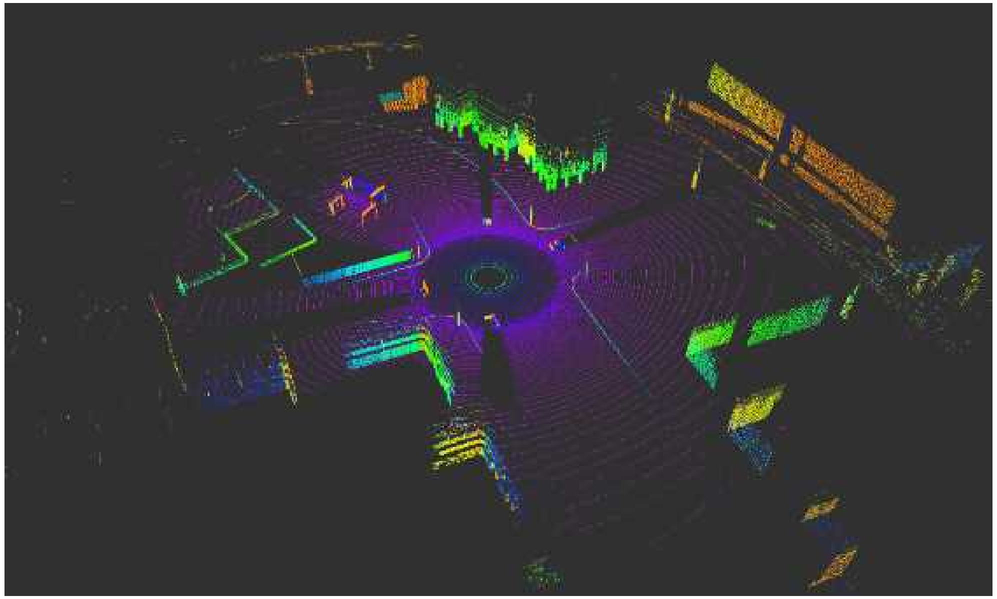
【LiDAR modeling】
Evaluation using LiDAR model

Use of LiDAR model

Nihon Unisys, Ltd

Spatial rendering performance improvement

- **Examination of improvement by using Optix, confirmed about 3000 times faster**



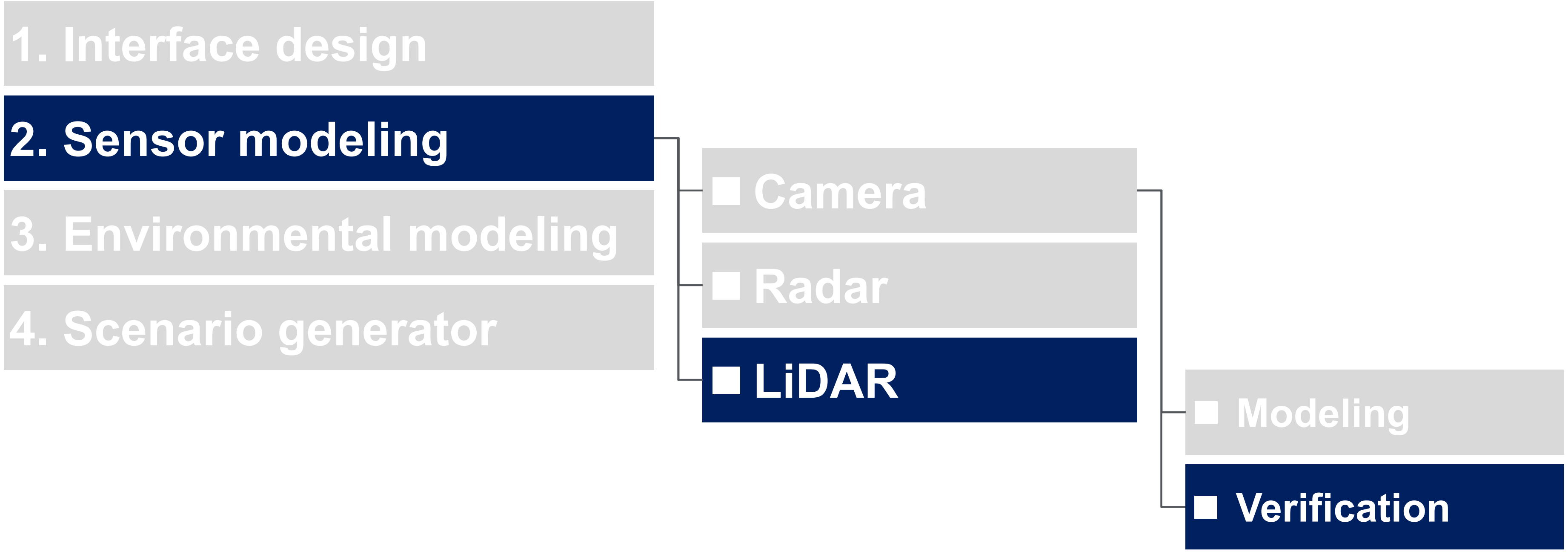
processing	Ray number	processing time [msec]	Processing time per ray [µsec]
Conventional	240,152	1004.458	4.1826
OptixJ version	1,080,000	1.4	0.0013

Status of sensor modeling

- **Modeling 2 different LiDARs with different spacial resolution, verifying consistency**
- **Once the measurement of the reflection characteristics of the target and embedment to the environmental model are completed, a point cloud close to the actual measurement can be simulated (required target model, reflection characteristics data, scenario)**

ex) The phenomenon that the road surface on the previous page is indistinguishable from the white line can be reproduced because a simulation that reflects the reflection characteristics of the road surface is possible.

FY 2019 outcome



1. Interface design
2. Sensor modeling
3. Environmental modeling
4. Scenario generator

- Camera
- Radar
- LiDAR

- Modeling
- Verification

【LiDAR modeling 】
Performs effective consistency verification by eliminating error factors other than the evaluation target as much as possible at each step

consistency verification (joining operation check, preliminary verification)

Step	Purpose of verification	Evaluation parameters	Evaluation indicator
Combined operation check (IT)	■ Evaluate the consistency of LiDAR perception model(scanning model and detection & ranging model) by eliminating errors caused by environmental model, spatial propagation model and scenarios as much as possible.	■ Angle	■ Consistency of vertical resolution (elevation angle between adjacent lines) ■ Consistency of horizontal resolution (azimuth between adjacent points in the horizontal direction)
		■ Distance ■ Intensity	■ Consistency of angle and accuracy at each distance of a target whose shape and reflection characteristics are known
Pre-verification (PV)	■ Evaluate the consistency of environmental model and LiDAR perception model(scanning model and detection & ranging model) by eliminating errors caused by spatial propagation model and scenarios as much as possible.	■ Shortest distance to measured object (Prius)	■ Consistency of distance accuracy and precision
		■ Number of target points (points detected on object)	■ Consistency of accuracy and precision of number of target points
		■ Object size (width)	■ Consistency of accuracy and precision of object size (width)
		■ Intensity distribution of target points	■ Intensity distribution consistency
		■ Recognition model output result	■ Consistency of recognition model output results
Malfunction reproduction verification	*Implementation of ongoing verification*		
Extensibility verification			

【LiDAR consistency verification (joint operation check) 】
Error factors in joint operation check and model to be evaluated

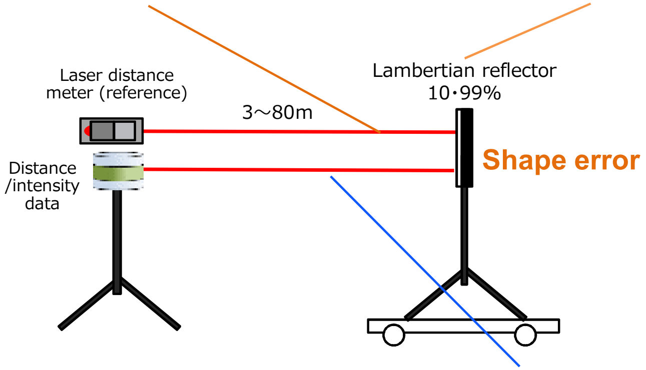
■ consistency verification (joint operation check)

Evaluate the consistency of, scanning model, and detection & ranging model by eliminating errors caused by environmental model, spatial propagation model and scenarios as much as possible.

Distance / intensity measurement

Position and orientation error between measured object and LiDAR

Reflection characteristic error



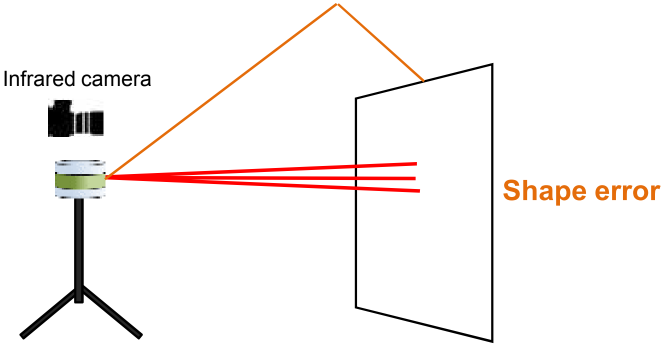
Distance / intensity error of detection & ranging model

Attenuation rate error of space propagation model

Measurement by changing the distance between LiDAR and Lambertian reflector

Angle measurement

Position and orientation error between measured object and LiDAR



Angular error of scan model

Project the LiDAR beam on to a plane and measure the resolution with an infrared camera

Legend
Not evaluated
Evaluation target

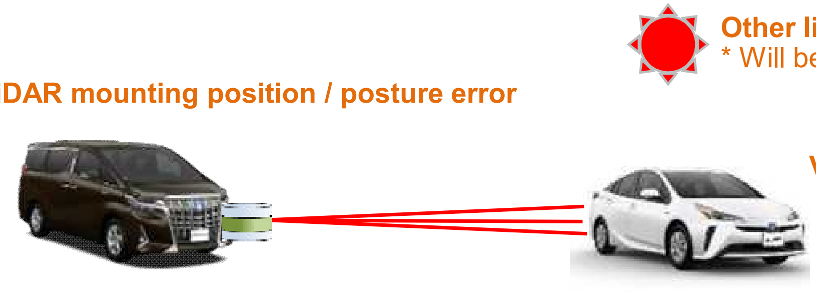
Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

【LiDAR consistency verification (pre-verification)】
Error factors in pre-verification and the model to be evaluated

■ Consistency verification (pre-verification)

Errors due to the LiDAR mounted position / posture, ego vehicle position / posture, and target vehicle position / posture are eliminated as much as possible, and the scanning model / detection & ranging model and environment model (shape and reflection characteristics of the target object) are evaluated together.

The shortest distance to the target object (Prius), the number of points in the target point cloud (the number of points detected on the object), the object size (width), the intensity distribution of the target point cloud, and the output results of the recognition model



Other light source effect (background light effect)
* Will be evaluated in malfunction evaluation

LiDAR mounting position / posture error

Ego vehicle position / posture error

Vehicle position and posture error

Target vehicle 3D model shape error
Target vehicle reflection characteristic error

Scan model angular error
* Evaluated in joint operation check

Distance / intensity error of detection & ranging model
* Evaluated in joint operation check

Legend
Not evaluated
Evaluation target

Source : SOKEN, INC

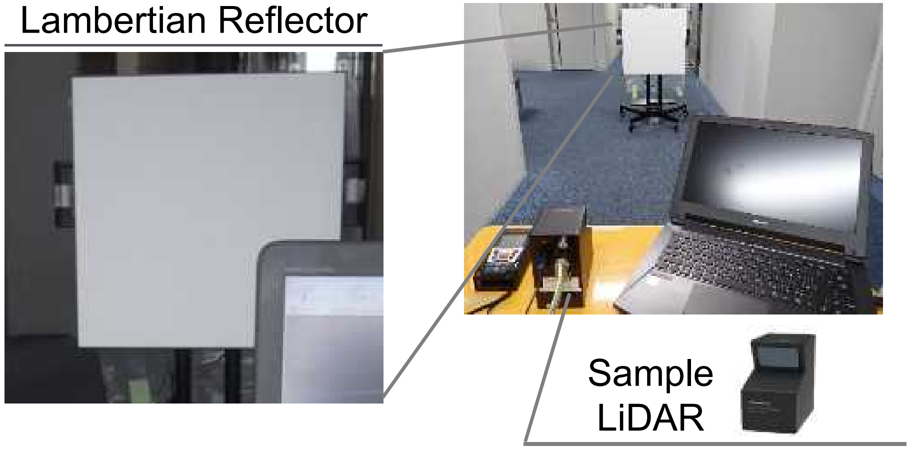
【LiDAR consistency verification】 In the joint operation check, verify sufficient consistency for distance and angle, and in the preliminary verification, verify the shortest distance, size (width), and total number of points

LiDAR consistency verification

Joint operation check (Labo)

Test environment

Test in Labo



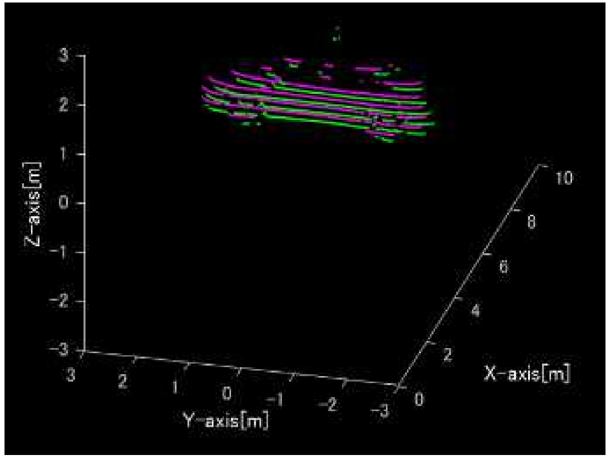
Results	**Distance**	**Confirm sufficient consistency**
	Angle	**Confirm sufficient consistency**
	Intensity	**Unmodeled irregular intensity fluctuations remains @ short range**

Pre-verification (Jtown)

Test environment

Test in Jtown

LiDAR Output



Legend
- 🟪 Simulation
- 🟩 Actual measurement

Results	**Distance**	**sufficient consistency @ short range**
	Size (width)	**sufficient consistency @ short range**
	Number of points	**Confirm errors caused by target reflectance and transparent characteristics**

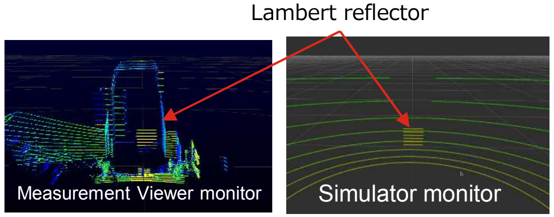
※Plan to continue verification after embedding target reflection characteristics.

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

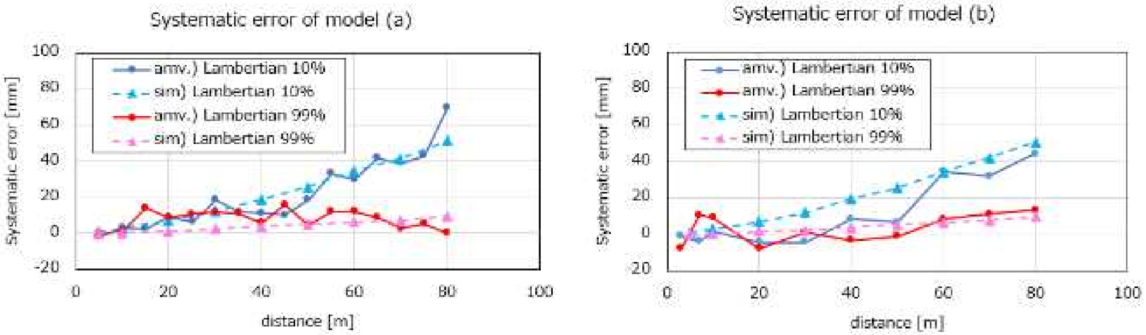
【LiDAR consistency verification (joint operation check)】
Confirmation of a certain degree of coincidence of accuracy and accuracy of distance and intensity, sufficient confirmation of angle

Lab verification results

Distance / intensity measurement scenery

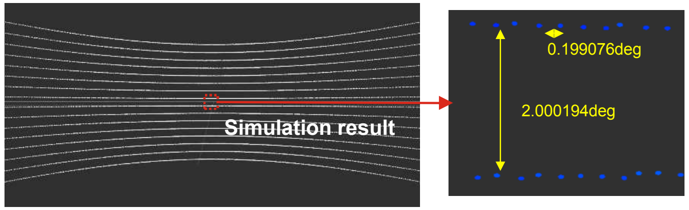


●Distance data consistency result



Regarding the distance, confirm sufficient consistency between actual measurement and simulation output.

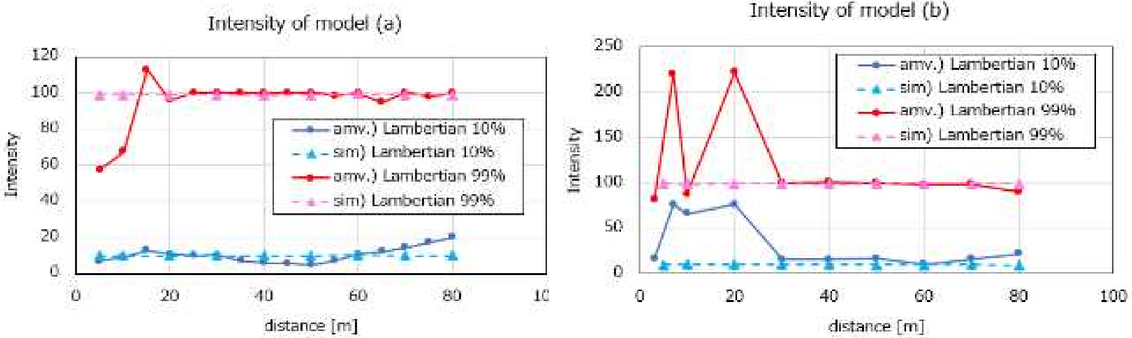
●Angle consistency test result



Confirmation of sufficient consistency of scan model output for angle data (horizontal / vertical resolution)

	Measurement result	Sim result
Horizontal resolution	0.20deg	0.20deg
Vertical resolution	2.01deg	2.00deg

●Intensity data consistency result



Regarding the intensity , confirm sufficient consistency between actual measurement and simulation output over 50m range.

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

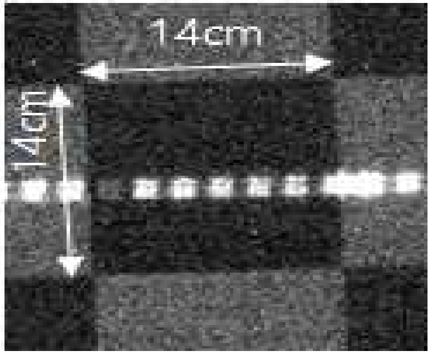
In the joint operation check in the laboratory, four issues were confirmed, and countermeasures continued to be studied

Issues found in the joint operation check (1/2)

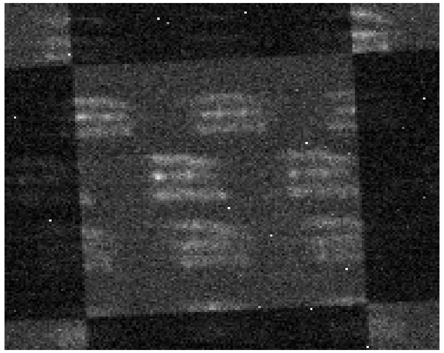
Vertical beam divergence mismatch due to the effect of the lens.

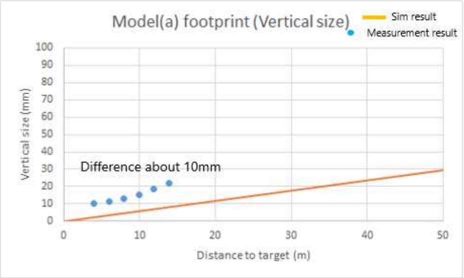
- At vertical direction about 10mm error occurs because the scanning model does not consider the effect of the lens

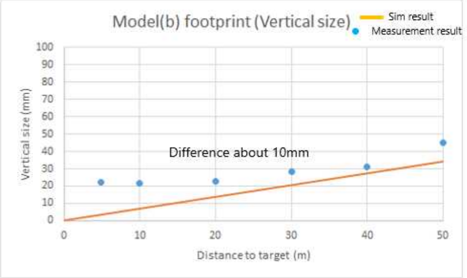
Model(a) put print Infrared image



Model(b) put print Infrared image

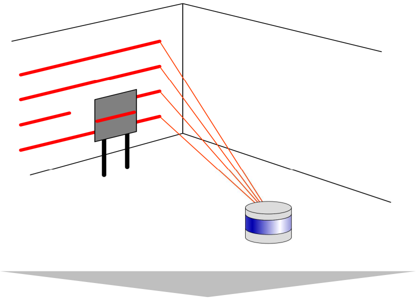




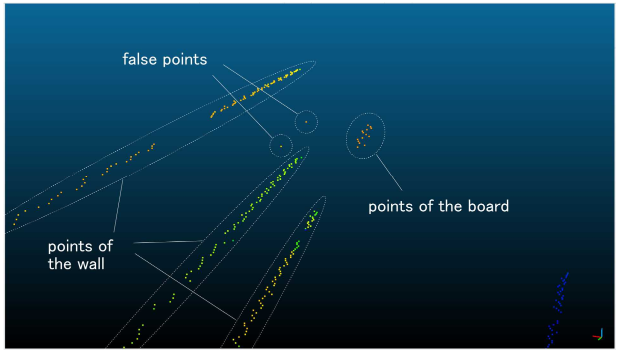


Noise generated between adjacent objects (false points)

- In case there are two adjacent objects with a short distance difference, false point occurs between the two objects.



For example, when a wall and a board are close, false points occur between the wall and the board.



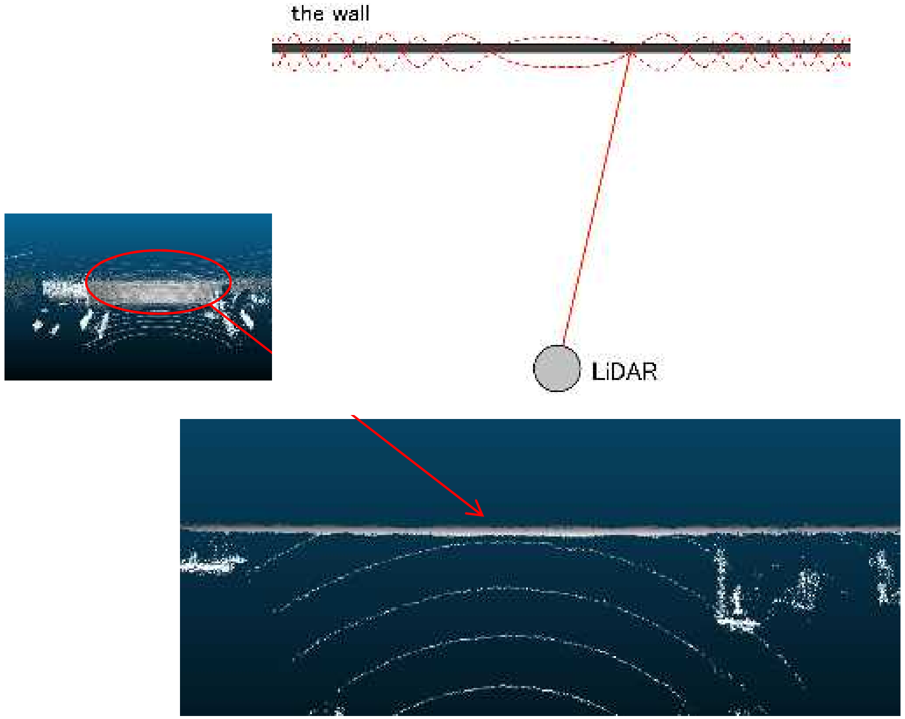
Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

Confirm the four issues in the joint operation check, and continue to consider countermeasures

Issues revealed by the joint operation check (2/2)

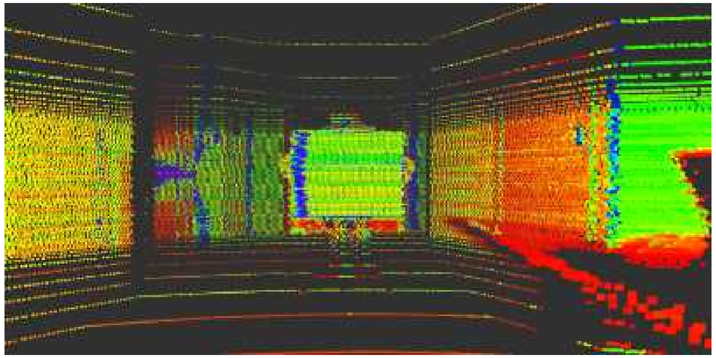
The phenomenon that the plane is distorted

- Since the error changes depending on the measured distance, the plane is observed to be distorted.

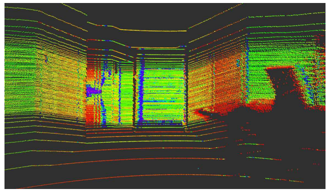
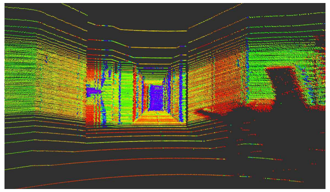
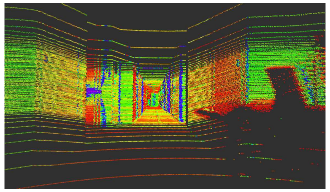


Phenomenon of different intensity on the same material

- Even though the plane is made of the same material, variations of intensity are observed.(blue line in left sideband and variation of each horizontal line from the plate with the same material)



- Irregular intensity fluctuations are depend on the distance.

Distance 5m	Distance 15m	Distance 30m
Intensity about 70	*Intensity about 220*	*Intensity about 95*
		

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

【LiDAR consistency verification (pre-verification)】Joint test with Jtown data
At long distances, there are errors due to the position and orientation of the sensor, but both the distance and the size (width) evaluation are sufficiently consistent as a LiDAR model.

Jtown verification result:

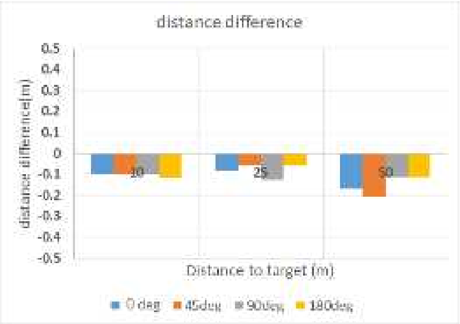
Test in Jtown


Target：10m, 90deg

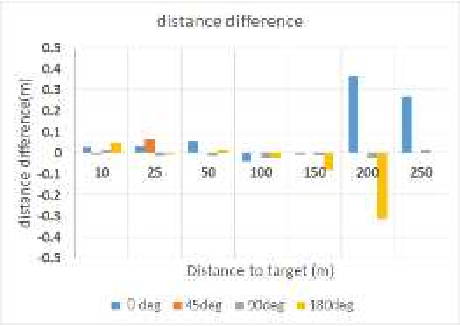
・distance evaluation

★Short range : Confirmation of sufficient consistency
※Model (a) has systematic error due to LiDAR mounting position.
★Long range : Model (a)/(b) have error due to the position and orientation of the object, target reflection characteristics, and the LiDAR Detection & Ranging model.

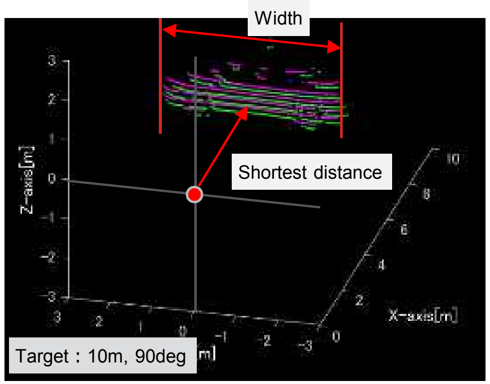
Model(a)



Model(b)



Point cloud comparison



Target：10m, 90deg

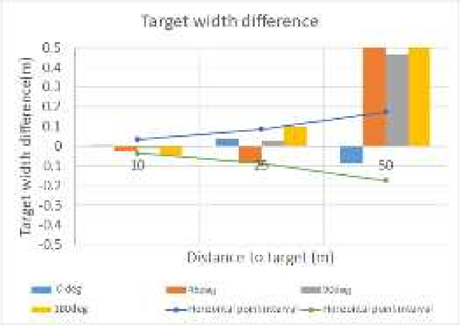
Sim point cloud : Magenta

Actual measurement point cloud : Green

・Size(width) evaluation

★Short range : Confirmation of sufficient consistency
★Long range : Model (a)/(b) have error due to the position and orientation of the object, target reflection characteristics, and the LiDAR Detection & Ranging model.

Model(a)



Model(b)

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

【LiDAR consistency verification (pre-verification)】Joint test with Jtown data
Confirmation of error occurrences due to target reflection / transmission characteristics in numbers of point evaluation

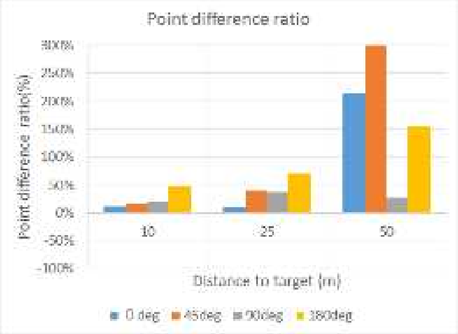
Jtown verification result

Test in Jtown

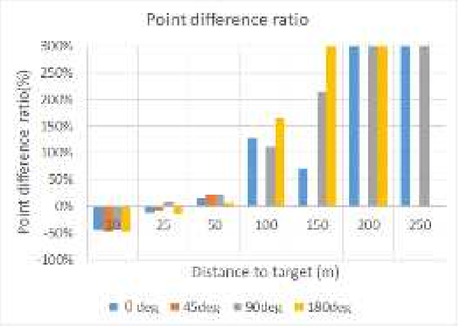
・Numbers of point evaluation

★Short range : Model (a)/(b) have error due to target reflection / transmission characteristics.
★ Long range : Model (a)/(b) have error due to the position and orientation of the object, target reflection characteristics, and the LiDAR Detection & Ranging model.

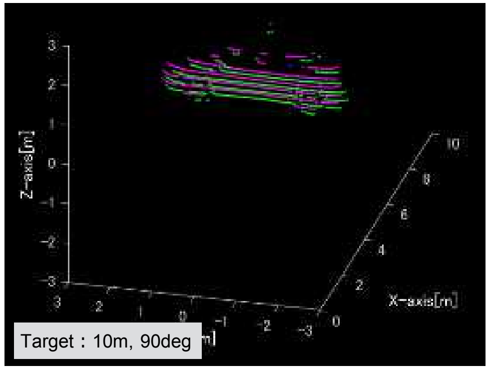
Model(a)



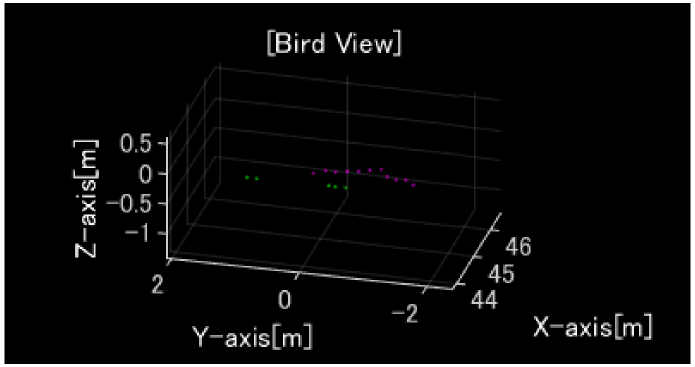
Model(b)



Point cloud comparison (10m)



Point cloud comparison (50m)



Sim point cloud : Magenta

Actual measurement point cloud : Green

Source : PIONEER SMART SENSING INNOVATIONS CORPORATION

In this year's activities, certain degree of consistency and issues were confirmed. We’ll try to resolve issues in next year's activities

Summary of consistency verification and remaining issues

■Results of consistency verification in joint operation check（Summary and issues）

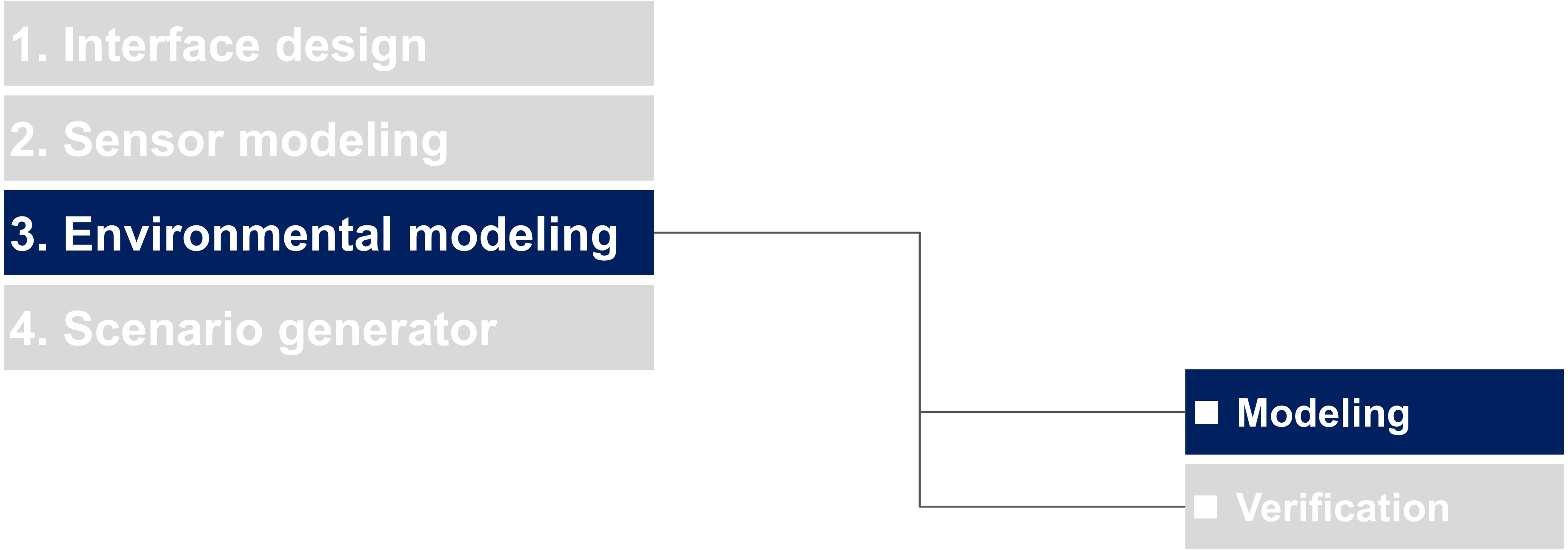
Model	Evaluation items	Result of consistency verification
Scan Model	angle（horizontal & vertical resolutions)	Confirmed sufficient consistency
	beam divergence(footprint size)	In the vertical direction, errors remain due to the effect of the lens. In the horizontal direction confirmed sufficient consistency
Detection & Ranging Model	distance	Confirmed sufficient consistency
	intensity	In short range, there are irregular intensity fluctuations depending on the distance. In long range, confirmed sufficient consistency

■Results of consistency verification in preliminarily verification（Summary and issues）

Evaluation items	Short range consistency	Long range consistency
Target size(Width)	Confirmed sufficient consistency	Error remains due to the position and orientation of the object, target reflection characteristics, and the LiDAR Detection & Ranging model.
Distance to the target	Confirmed sufficient consistency	
Number of points on the target	Error remains due to target reflection / transmission characteristics.	

※After the reflection characteristics of the target are embedded, the remaining issues will be re-evaluated. After the re-evaluation, the LiDAR model is ready to be evaluated as an automatic driving simulator.

FY 2019 outcome

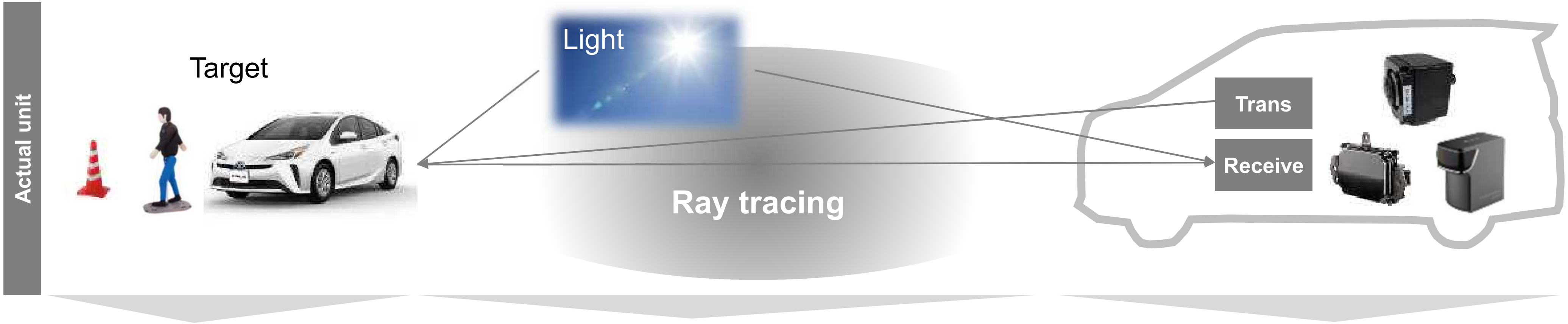


1. Interface design
2. Sensor modeling
3. Environmental modeling
4. Scenario generator

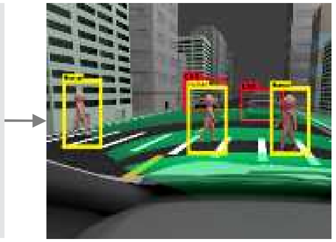
- Modeling
- Verification

Precise Environmental & Space design modeling & accumulation into Database as Real-PG are important Key for Highly consistent input data generation for sensor simulation

Environmental model / space design



The Key for modeling

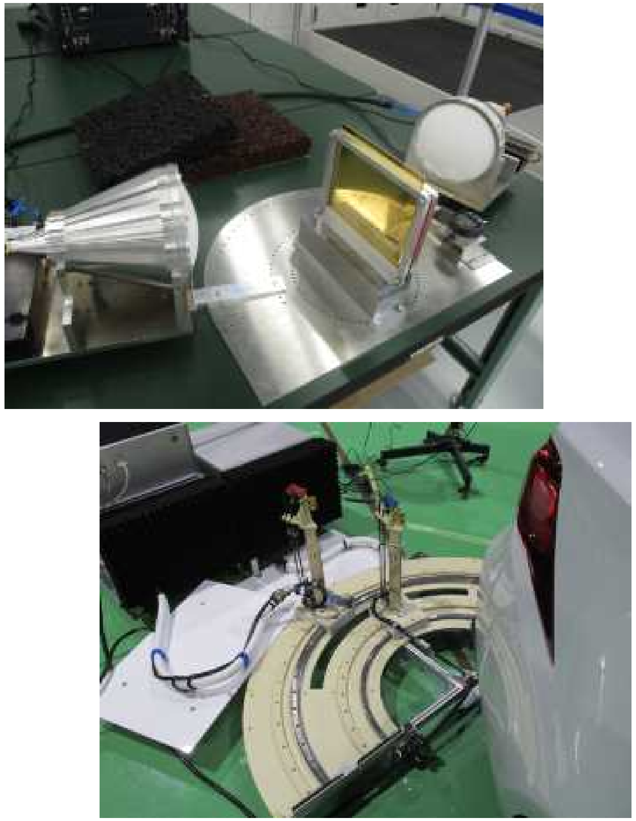
Environmental model	Space design	Sensor model (Camera example)
■ *Precise reproduction of object shape* ■ *Reproduction of reflection characteristics of visible light spectrum*	■ Based on the characteristics of electromagnetic waves used by each sensor, the propagation, attenuation, reflection, etc. from the light source / radio wave source are reproduced using the ray tracing method	Camera perception model: **Photoelectric conversion** → **Raw Signal Processing** → Recognition model 

Sensor principle based measurement & modeling for Asset catalog

Measurement facility example

SOKEN 三菱プレシジョン株式会社 MITSUBISHI PRECISION CO.,LTD.

Reflection measurement



Environmental Assets Catalog

Source: SOKEN, INC

Measured Real-PG^{*1} using MMS^{*2} for Sensor simulation Virtual-PG

Measurement scene

SOKEN 三菱プレシジョン株式会社 MITSUBISHI PRECISION CO.,LTD.

Specific Environment Area

Rain

Road construction

Versatile Urban Area

Backlight

Under Path

Junction with poor visibility

Snow

---

*1 PG : Proving ground、*2 MMS : Mitsubishi Mobil Map System
Source : JARI home page, SOKEN, INC, Mitsubishi Precision Co. Ltd., NIED Homepage

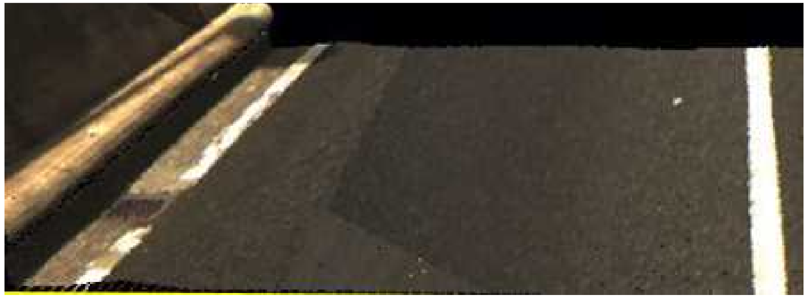
Implement 1cm base Environmental model with accurate measurement

Required data spec for accurate simulation

三菱プレシジョン株式会社
MITSUBISHI PRECISION CO., LTD.

	Item	DIVP™ requirement		Data from other SIP project
3D point cloud data	Reflection brightness information	○		○
	Color information	○		○
	Resolution	***Horizontal 1cm***	>	***Horizontal 6cm***
Camera image data	Resolution	2400x2000x3@24bits		2400x2000x3@24bits
	Number and location	3-cameras		3-cameras
	Location information	***Contains***	>	***None***

Data from DIVP™



>

Data from other SIP project

Source： Mitsubishi Precision Co, Ltd.

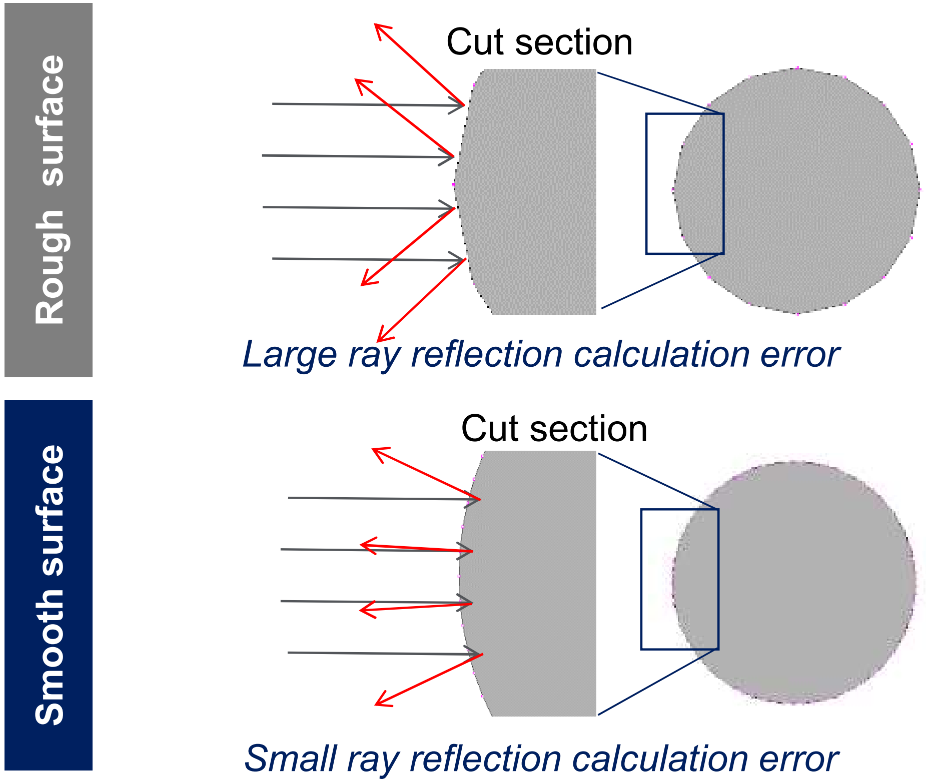
In order to improve simulation accuracy, it is essential to build a high-definition environmental model divided for each material with different characteristics

Relation environmental model definition vs Evaluation accuracy

三菱プレシジョン株式会社
MITSUBISHI PRECISION CO.,LTD.

Material deference based model division

Reflection model



Rough surface

Cut section

Large ray reflection calculation error

Smooth surface

Cut section

Small ray reflection calculation error

Source： Mitsubishi Precision Co. Ltd.

Create polygon models with different LOD (Level of Detail) to verify the effect on sensor output accuracy

Creating high-precision polygons (targets)

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MITSUBISHI PRECISION CO., LTD.

Laser measurement

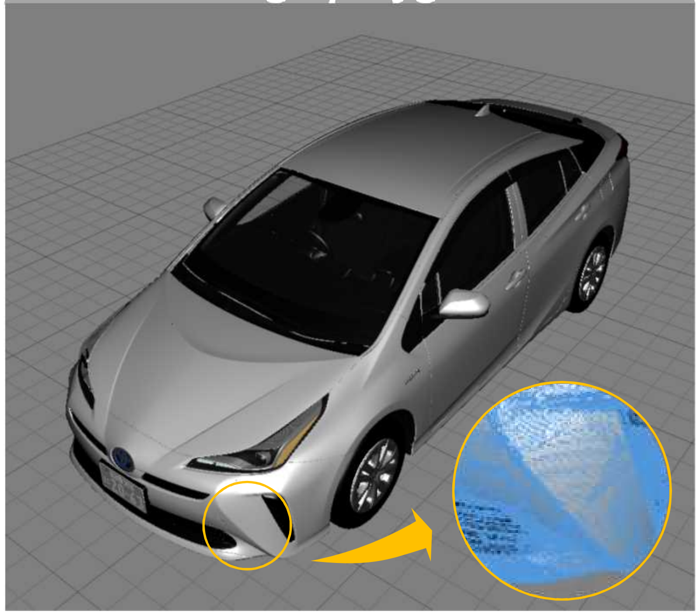
Measured with an accuracy of 1 mm or less

Polygon modeling

Creating models with different LODs

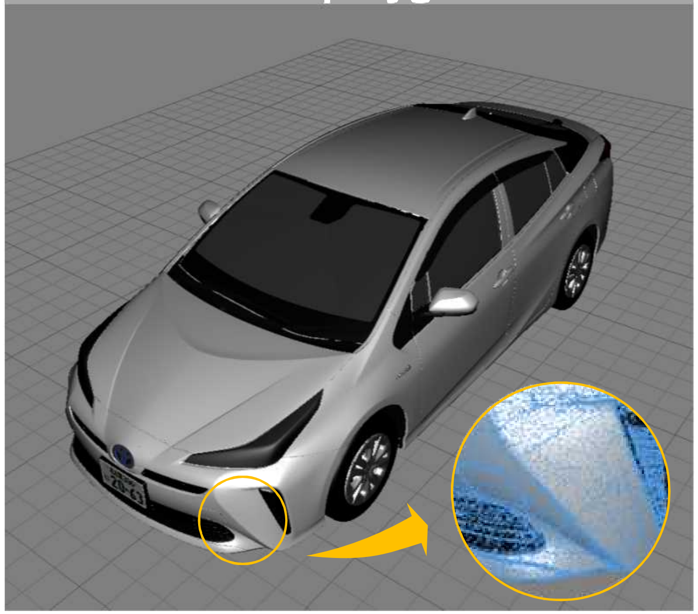
High *Low*

High polygon



…

Low polygon

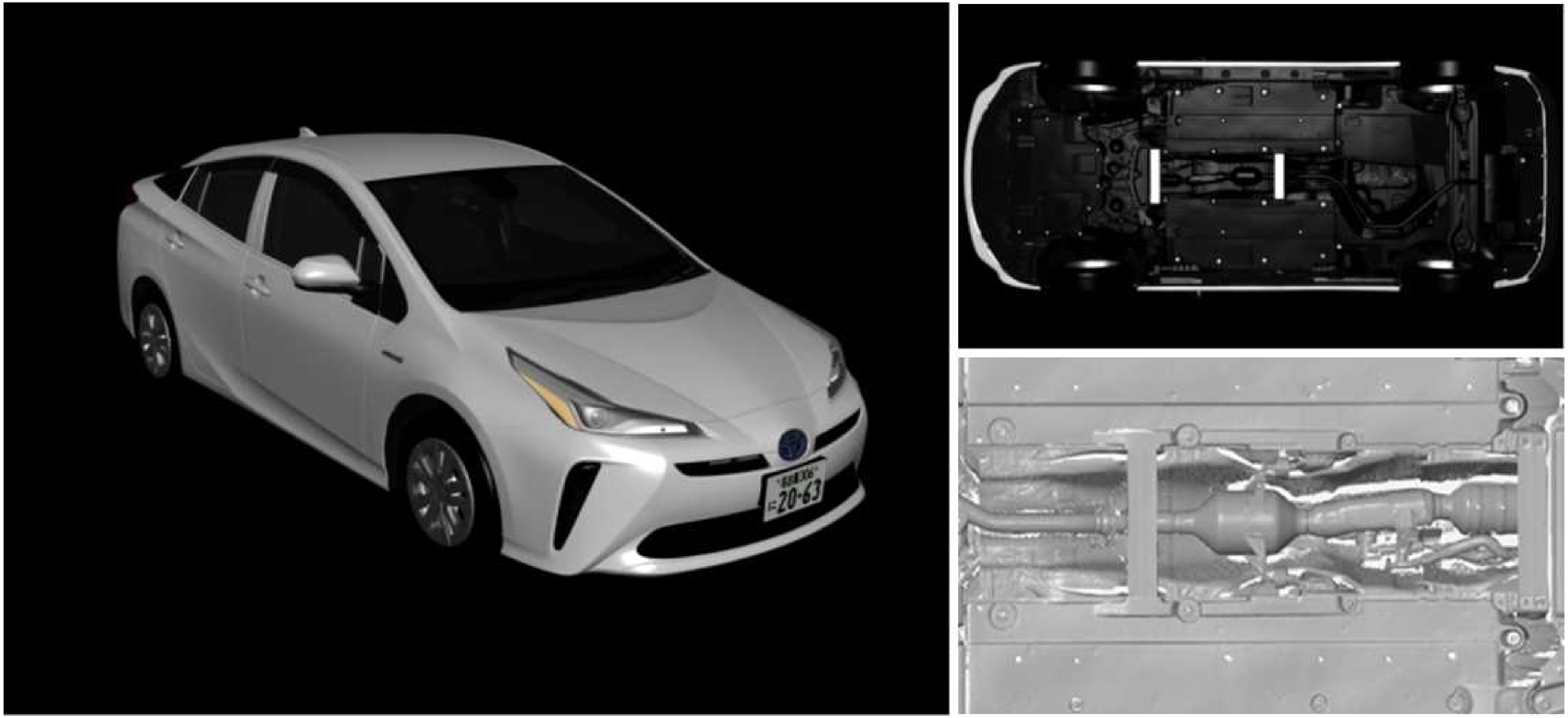


Source : Mitsubishi Precision Co. Ltd.

Create models precisely down to the bottom, aiming to reproduce millimeter wave multipath

Creating high-precision polygons (targets)

三菱プレシジョン株式会社
MITSUBISHI PRECISION CO., LTD.



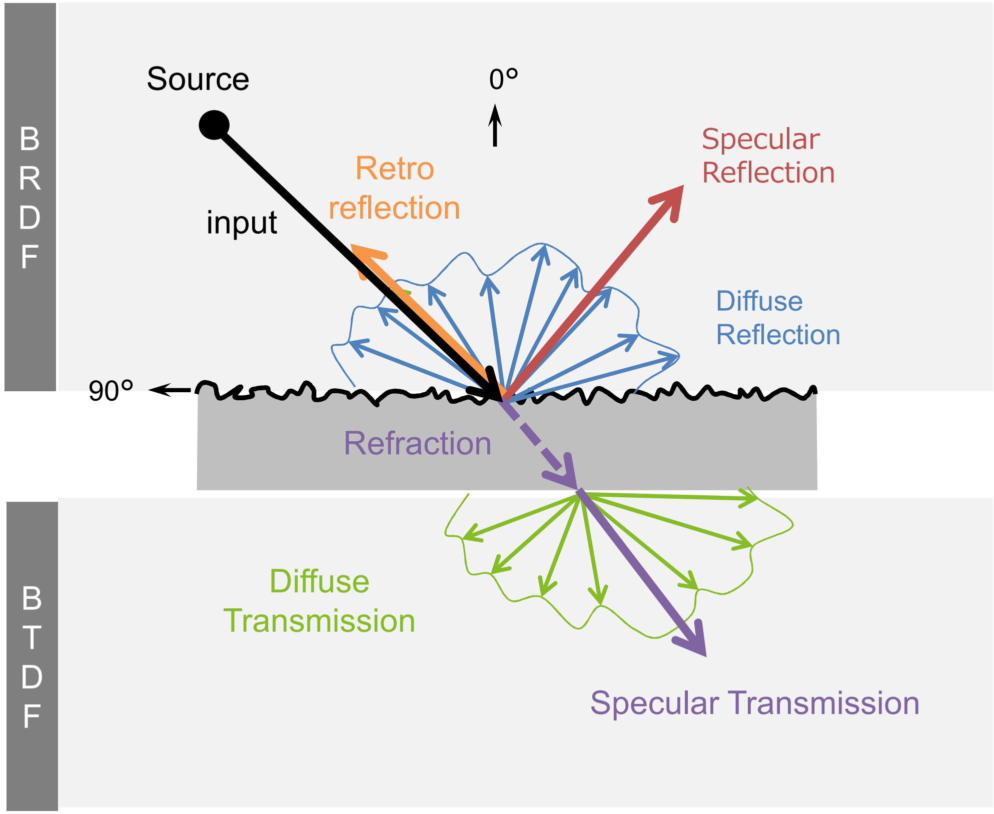
Source : Mitsubishi Precision Co. Ltd.

Detail characteristics Measurement based Environmental & Space deign modeling

Real based Measurement for modeling

Nihon Unisys, Ltd SOKEN

Reflection / Refraction characteristics



Step by step growth

Measurement based Modeling	■ Reflection and transmission characteristics important for each sensor function are measured for each material and reflected in the simulator.
Extrapolation	■ Generalize models and reproduce unmeasured materials

Highly affected Factor in each sensors

Camera	■ Visible light’s Diffuse Reflection
Rader	■ Millimeter wave Diffuse Reflection
LiDAR	■ Infrared light’s Retro reflection

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

Designs and prototypes a measurement system and performs measurements to achieve sufficient measurement accuracy for sensor consistency verification

Millimeter wave measurement system

SOKEN

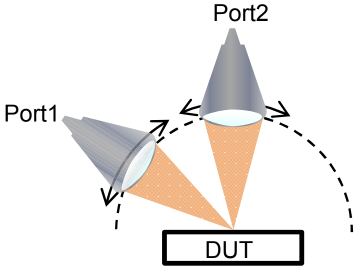
Measurement condition

- Measurement frequency：75-82GHz 0.1GHz Step
- Measurement angle：
  Transmit antenna 0 degrees～75 degrees 5 degree resolution
- Receiving antenna 0 degrees ～±75 degrees 5 degree resolution
- Angle between antennas >=45 degrees

Measurement method

Retro reflection

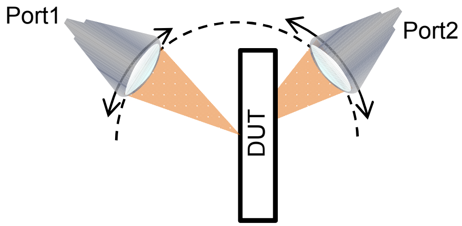
- Measures retroreflection from incident / reflected wave ratio at port 1



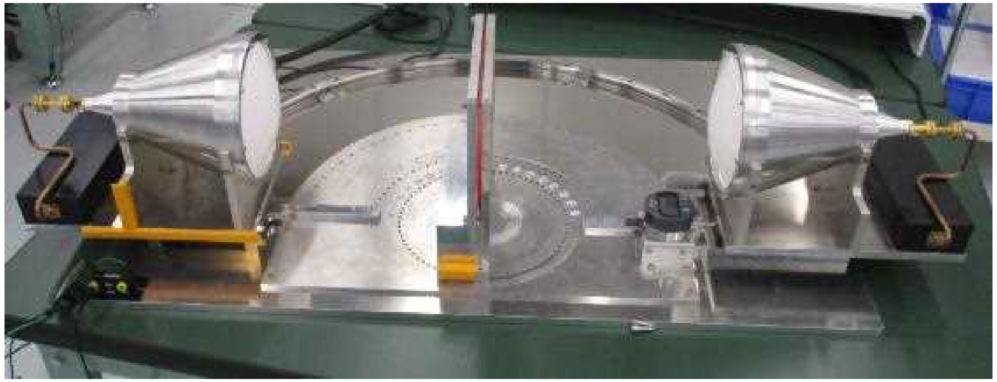
Diffuse reflection

Diffuse transmission

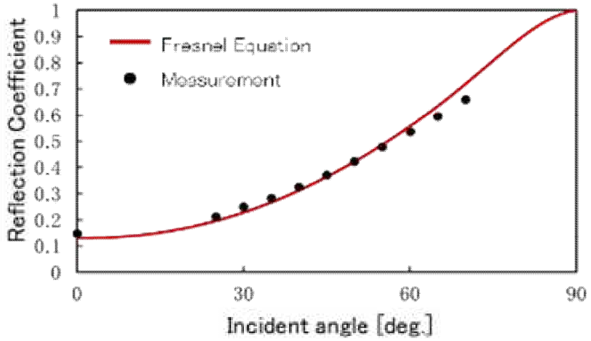
- Measures diffuse reflection and transmission characteristics by entering from port 1 and receiving at port 2



Measurement system



Measurement results



The difference between the theoretical formula (Fresnel equation) and the measured value is 0.5 dB or less

Sufficient accuracy achieved for radar target value ± 5 dB

Source：SOKEN, INC

Designs and prototypes a measurement system and performs measurements to achieve sufficient measurement accuracy for sensor consistency verification

Visible light / infrared light measurement system

SOKEN

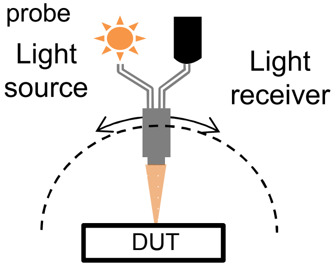
Measurement condition

- Measurement wavelength : 360-1000nm
- Measurement angle : light source 0 degrees ～90 degrees
- Light reception 0 degrees ～±180 degrees
- Light source /Light reception angle ＞10degrees

Measurement method

Retro reflection

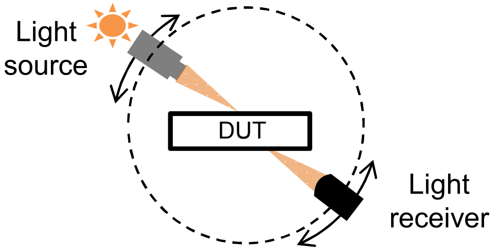
- Direct measurement of retro reflection with light source/ light receiving optical probe



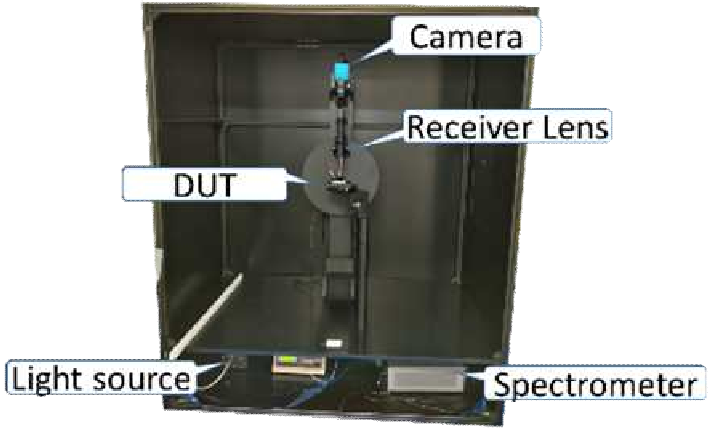
Diffuse reflection

Diffuse transmission

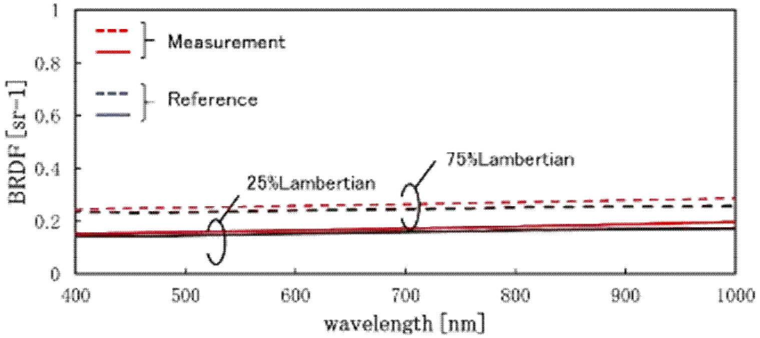
- Rotate the light source and light receiver to measure diffuse reflection / transmission



Measurement system



Measurement results



± 5% or less from reference data

Achieved ± 5% or less of required measurement accuracy for reflection characteristics

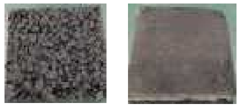
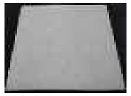
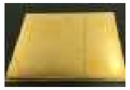
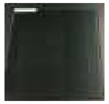
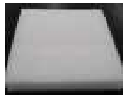
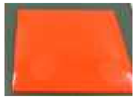
Source : SOKEN, INC

Sample plates of sensor target constituent material was prepared for comparison between simulation and experiment on multi-purpose urban test course in JARI J-town

DUT list and reflection characteristics measurement status

Legend

✔ Measured ✓ Measured(low accuracy) ✗ Not yet measured

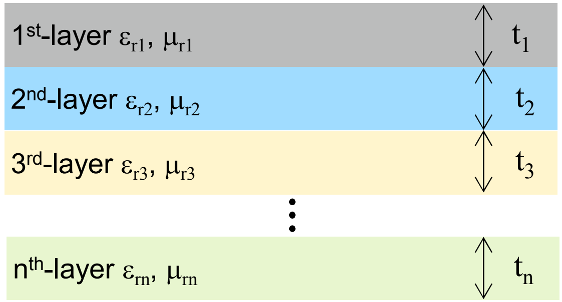
		Road surface		Vehicle					NCAP Dummy		Roadside Objects	
		Asphalt (Roughness different)	White Line	Metal	ABS	Body color		Windshield glass	Close	Body	Guardrail	Road pole
Picture												
BRDF	Radar	✔	–	✔	✔	–	–	✔	–	✔	–	✔
	LiDAR	✓	✓	–	–	✓	✗	✓	✗	–	✗	✗
	Camera			–	–		✗		✗	–	✗	✗

Source : SOKEN, INC

【Environmental modeling】 While designing an extrapolation formula so that unmeasured materials can be reproduced, correlation has been confirmed for targets with smooth surfaces, and research on targets with rough surfaces is ongoing.

Multi-layer model (smooth surface target)

- Reproducing reflection characteristics from material thickness and complex permittivity



1st-layer ε_{r1}, μ_{r1} t_1

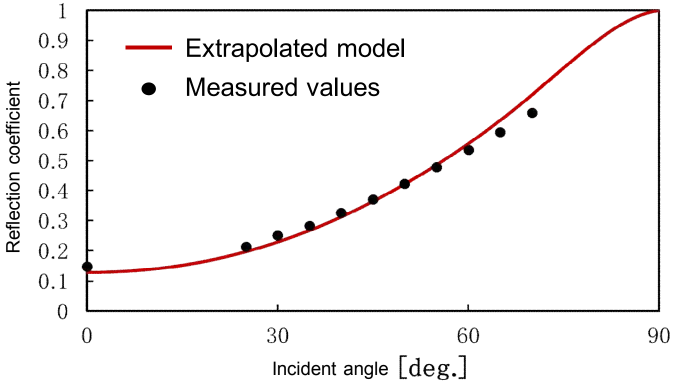
2nd-layer ε_{r2}, μ_{r2} t_2

3rd-layer ε_{r3}, μ_{r3} t_3

⋮

nth-layer ε_{rn}, μ_{rn} t_n

- Verify consistency between extrapolated model and actual measurement values

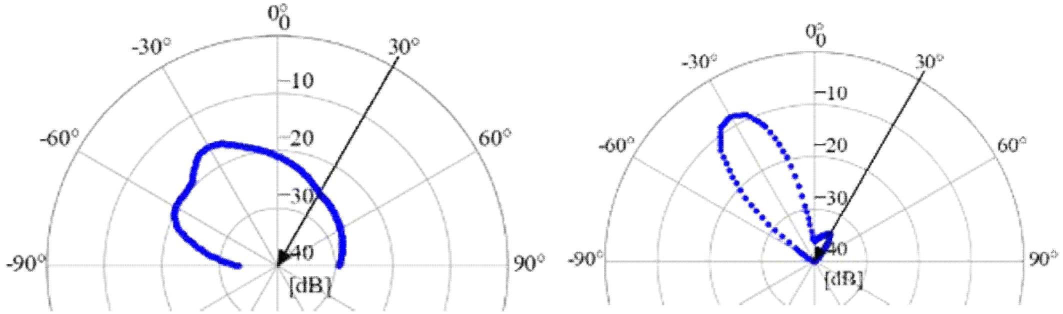


Surface roughness model

- Under consideration of extrapolation model of rough surface material (ex. Asphalt road surface)
- Plan to build theoretical formula from actual measurement results of samples with different surface roughness

Water permeable

Non water permeable



Actual measurement results of asphalt road surfaces with different roughness

Source : SOKEN, INC

【Generate Virtual-PG】 For rain and snow, we plan to model the reflection characteristics change due to spatial attenuation and surface adhesion from experiments at the test site, and conduct data measurement and verification necessary for modeling using experimental facilities unique to Japan

Measurement of sensor malfunction event based on actual measurement

Large rainfall experiment facility

World's largest

- Guerrilla rain (300mm / h) is possible for a long time over a wide area
- Wide building width prevents millimeter wave multipath

Snow and ice disaster prevention experiment building

The only in the world

- Reproduce dendritic crystals close to natural snow crystals
- Snowfall above average in heavy snowfall areas (~ 3.0cm / h)

Source：National Research Institute for Earth Science and Disaster Resilience（NIED）

【Virtual-PG implementation for sensor】
Implemented Hi-definition 1cm-order 3D-data for sensor consistency enhancement

JARI Jtown MMS measurement results

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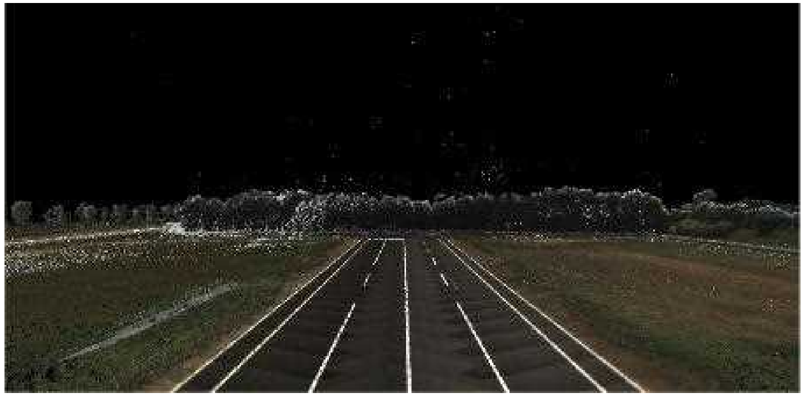
Multipurpose urban area



Multipurpose area

Unusual environmental testing center

V2X testing center

Source, Mitsubishi Precision Co. Ltd.

【Generate Virtual-PG】
Consider the priority of the model to be produced, aiming to reproduce the NCAP test at the end of FY 2020

Proposed environmental model roadmap

三菱プレシジョン株式会社 MITSUBISHI PRECISION CO.,LTD. SOLIZE

	Environmental model	
	FY 2019	FY 2020
Map model	■ Jtown Multipurpose urban area 	■ Tokyo (Odaiba) ■ Metropolitan Expressway C1 ■ Shirosato Test Center 
Target model	■ Other vehicles: Prius ■ Own vehicle: Alphard ■ Road pole, color cone ■ NCAP dummy doll ■ NCAP dummy bicycle	■ NCAP dummy vehicle ■ NCAP dummy motorcycle ■ NCAP dummy children ■ NCAP dummy animal

Source, Mitsubishi Precision Co. Ltd.

DIVP™ now structuring asset catalog with referring PEGASUS & OpenX stricture, however found some struggle for sensor simulation assets

Data base strutting study

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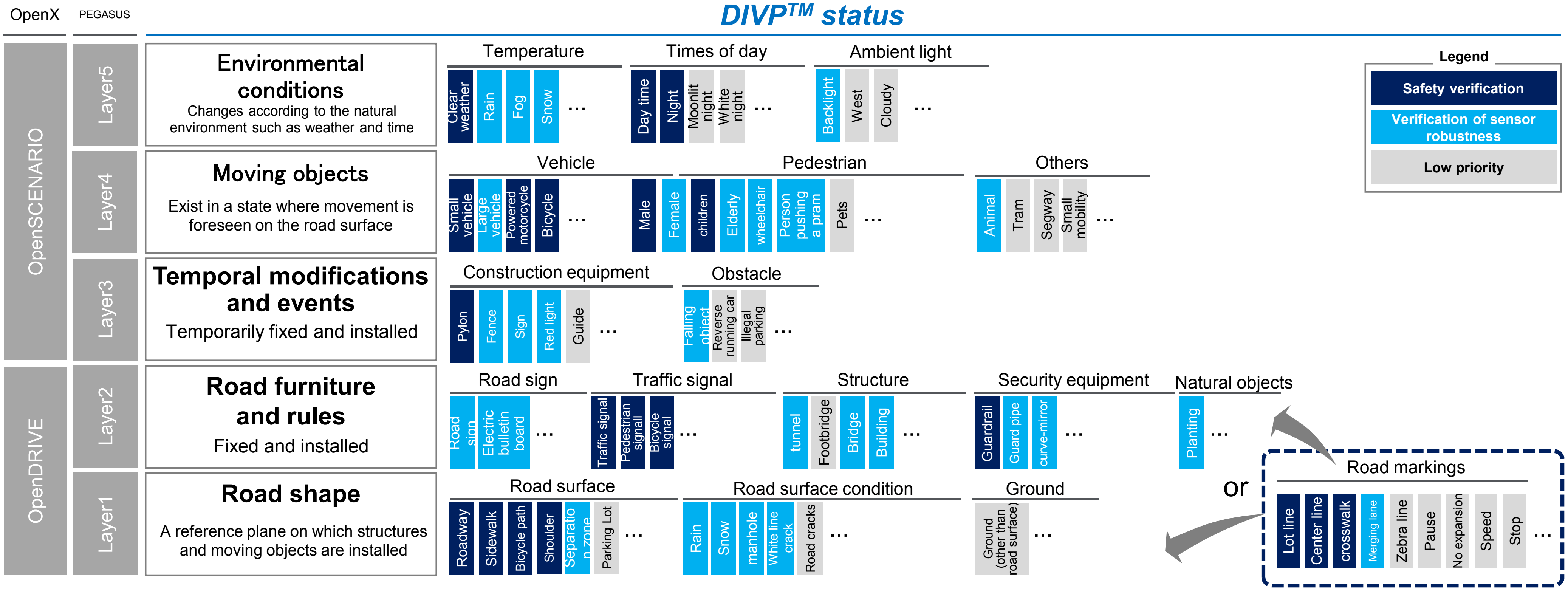
MITSUBISHI PRECISION CO.,LTD.



OpenX PEGASUS

DIVP™ status

Legend
- Safety verification
- Verification of sensor robustness
- Low priority

OpenSCENARIO

Layer5 — **Environmental conditions**
Changes according to the natural environment such as weather and time
- Temperature: Clear weather, Rain, Fog, Snow, …
- Times of day: Day time, Night, Moonlit night, White night, …
- Ambient light: Backlight, West, Cloudy, …

Layer4 — **Moving objects**
Exist in a state where movement is foreseen on the road surface
- Vehicle: Small vehicle, Large vehicle, Powered motorcycle, Bicycle, …
- Pedestrian: Male, Female, children, Elderly, wheelchair, Person pushing a pram, Pets, …
- Others: Animal, Tram, Segway, Small mobility, …

Layer3 — **Temporal modifications and events**
Temporarily fixed and installed
- Construction equipment: Pylon, Fence, Sign, Red light, Guide, …
- Obstacle: Falling object, Reverse running car, Illegal parking, …

OpenDRIVE

Layer2 — **Road furniture and rules**
Fixed and installed
- Road sign: Road sign, Electric bulletin board, …
- Traffic signal: Traffic signal, Pedestrian signall, Bicycle signal, …
- Structure: tunnel, Footbridge, Bridge, Building, …
- Security equipment: Guardrail, Guard pipe, curve-mirror, …
- Natural objects: Planting, …

Layer1 — **Road shape**
A reference plane on which structures and moving objects are installed
- Road surface: Roadway, Sidewalk, Bicycle path, Shoulder, Separation zone, Parking Lot, …
- Road surface condition: Rain, Snow, manhole, White line crack, Road cracks, …
- Ground: Ground (other than road surface), …

or

Road markings: Lot line, Center line, crosswalk, Merging lane, Zebra line, Pause, No expansion, Speed, Stop, …

FY 2019 outcome

1. Interface design
2. Sensor modeling
3. Environmental modeling
   - Modeling
   - Verification
4. Scenario generator

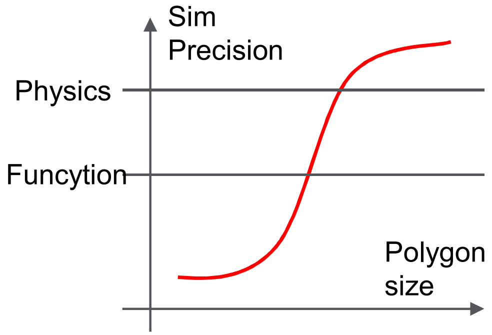
【Environmental modeling】
Challenges in creating high-precision environmental models using measurement data due to data capacity issues

Creating high precision polygons

Items	Target specifications / performance	Current status	Future initiatives
Target (Prius)	■ Created with a mesh size of 1 mm accuracy based on laser scanner measurement data ■ Expand to 5 levels of LOD (Level of Detail)	■ 1mm accuracy model is used in Optix. However, the model with the interior removed. ■ Create a reduced model for loading UE4	■ Improvement of gap removal method when creating LowLOD model ■ Quantitative evaluation of mesh accuracy and simulation accuracy
Map（Jtown multipurpose urban area）	■ Created with a mesh size of 1cm based on MMS measurement data	■ Multi-purpose city area is under construction with 10m square ■ 2cm precision etc. were manufactured, but cannot be operated with PF ■ Currently provided maps are simple maps	■ Modeling in a wide area ■ Accuracy evaluation in mesh and texture representation

Analyze the effect of asset accuracy on sensor consistency using the current method
⇒ Clarify the requirements of environmental models for each sensor

∗ 2cm-accurate map cannot be read with Workstation-grade GPU (24GB memory)



【Environmental modeling】 Since the data was heavy in the high precision model and the efficiency of editing and material addition work after meshing was reduced, the work flow was divided into parts and meshed.

Creating high precision polygons (targets)

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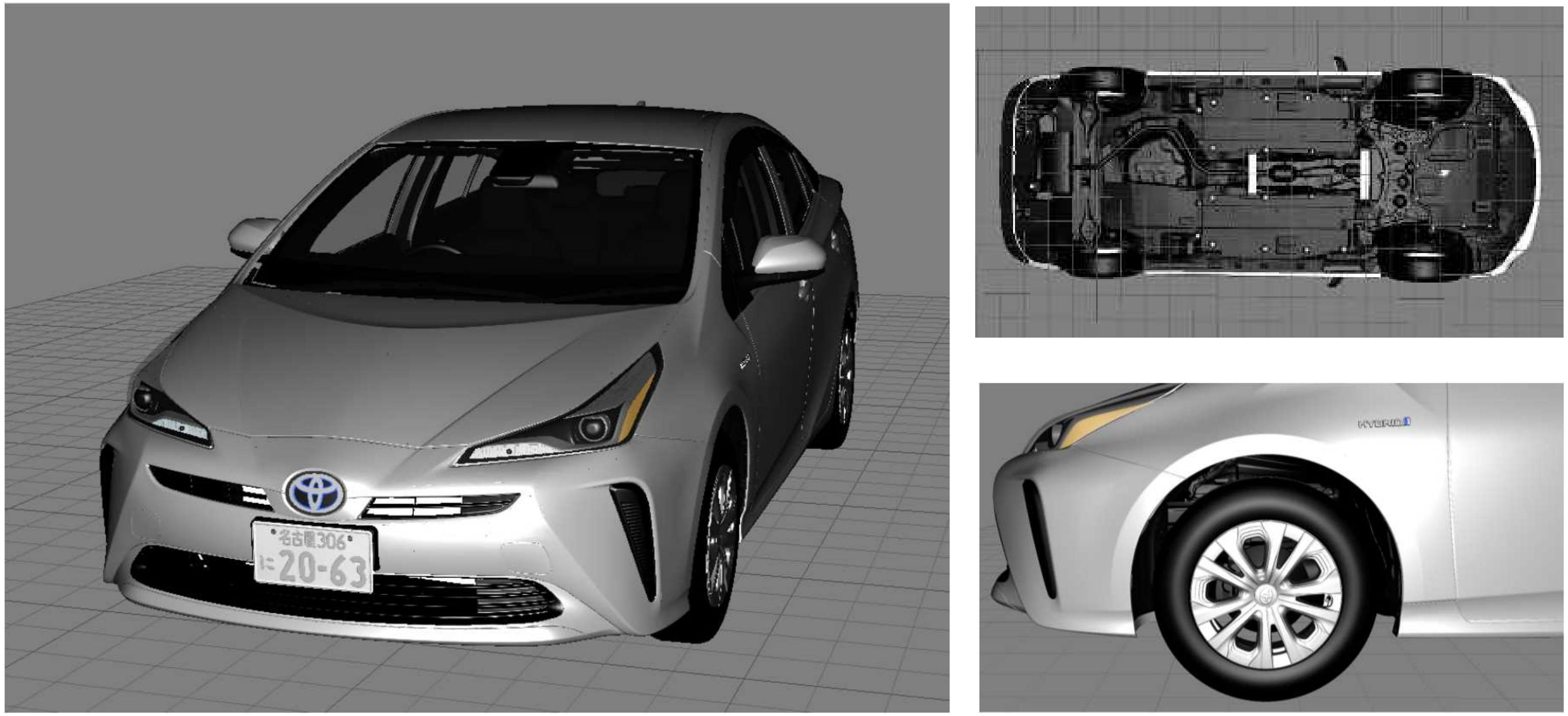


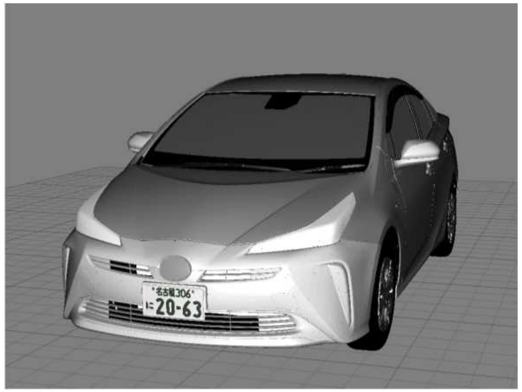
■ Task	■ Content
■ High precision modeling	■ Since the data was heavy in the high precision model and the efficiency of editing and material addition work after meshing was reduced, the work flow was divided into parts and meshed.

Source : Mitsubishi Precision Co. Ltd.

【Environmental modeling】 When the reduction was performed, a gap occurred between the parts, so the reduction with the vertices shared between the parts was performed

Creating high precision polygons (targets)

三菱プレシジョン株式会社
MITSUBISHI PRECISION CO., LTD.



NO IMAGE

	HiLOD Prius	LowLOD Prius	Competitor model
Number of polygons	48,570,890	4,874,194	35,774
File size	1,382MB(1.35 GB)	165MB	9.76 MB

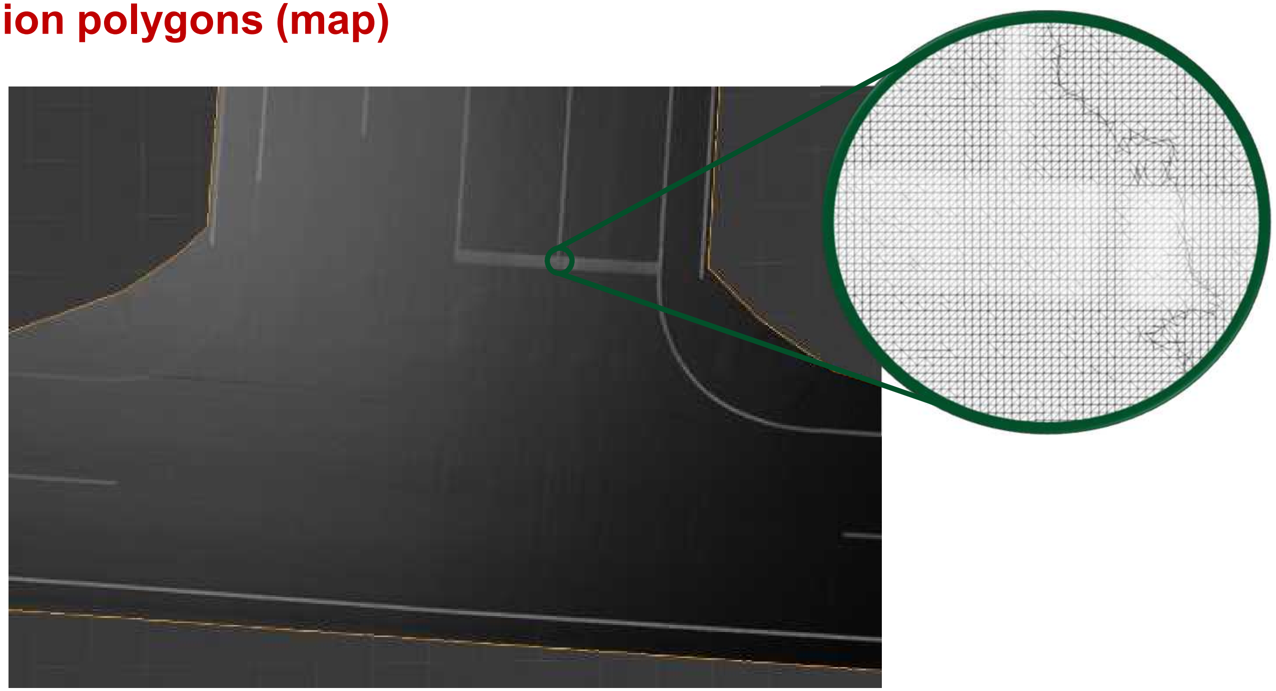
■ **Task**	■ **Content**
■ Improvement of gap removal method when creating LOD model	■ When a reduction was performed, a gap was created between the parts, so a reduction method was implemented that retained the vertices shared between the parts

Plan for future evaluation of the trade-off between model mesh accuracy and simulation accuracy for simulation result accuracy

Source : Mitsubishi Precision Co. Ltd.

【Environmental modeling】 Since it was a large area, the meshing work required more time than expected, so we considered a process that could divide the area into blocks and perform parallel processing.

Creating high precision polygons (map)



■ Task	■ Content
■ Modeling in a wide area	■ Since it was a large area, the meshing work required more time than expected, so we examined and implemented a process that divided the area into blocks and performed parallel processing.

Since the capacity of the model after meshing becomes large, consider a data creation method utilizing textures, OpenCRG, etc.

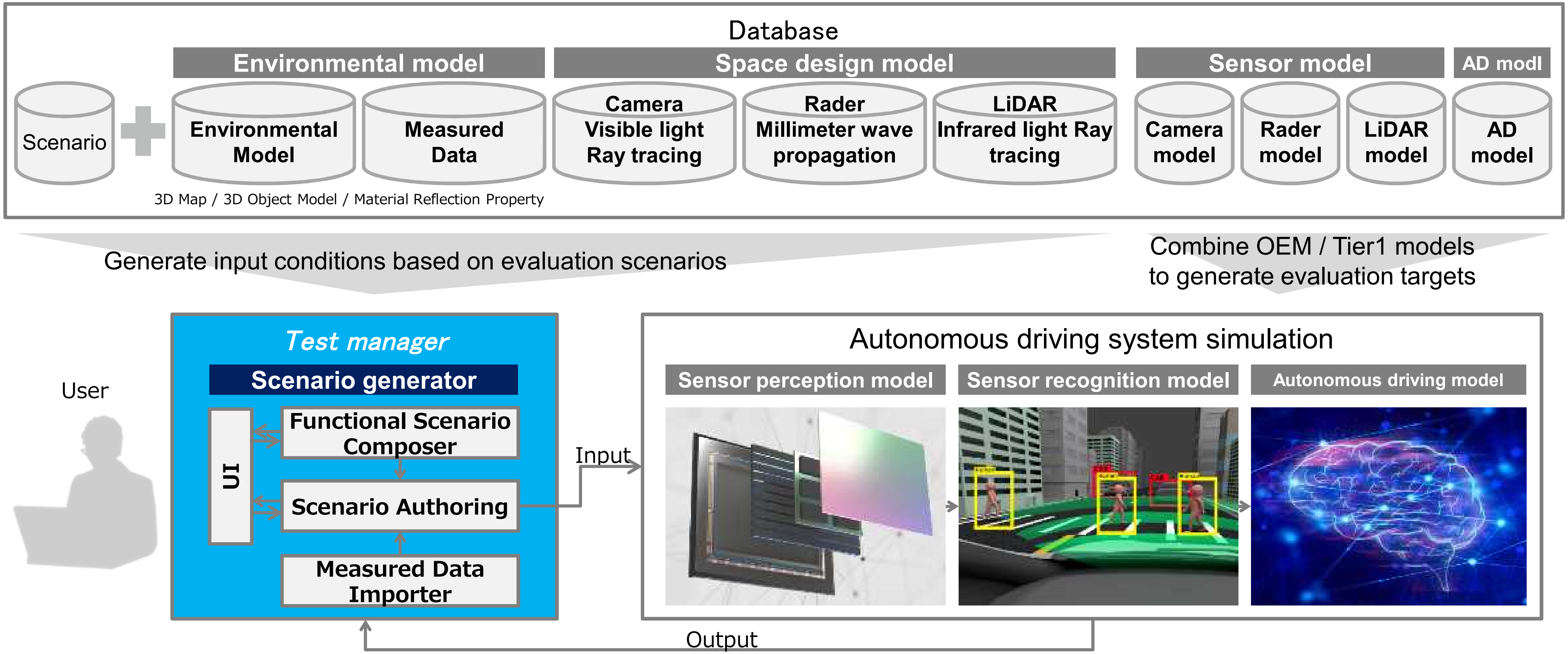
Source : Mitsubishi Precision Co. Ltd.

FY 2019 outcome

1. Interface design
2. Sensor modeling
3. Environmental modeling
4. **Scenario generator**

Scenario generator, which refers to a database that stores various assets and generates input data for simulation execution, determines the success or failure of DIVP™ usability

DIVP™ ECO-system



Database

Environmental model / **Space design model** / **Sensor model** / **AD modl**

Scenario + **Environmental Model** / **Measured Data** / **Camera Visible light Ray tracing** / **Rader Millimeter wave propagation** / **LiDAR Infrared light Ray tracing** / **Camera model** / **Rader model** / **LiDAR model** / **AD model**

3D Map / 3D Object Model / Material Reflection Property

Generate input conditions based on evaluation scenarios

Combine OEM / Tier1 models to generate evaluation targets

User

Test manager

Scenario generator

UI

Functional Scenario Composer

Scenario Authoring

Measured Data Importer

Input

Autonomous driving system simulation

Sensor perception model / **Sensor recognition model** / **Autonomous driving model**

Output

Source : Sony Semiconductor Solutions Corporation

DIVP^{TM} has developed an SDM Generator that can easily set conditions for sensor malfunctions, with extensible framework that ensures module independence

Scenario Generator concept

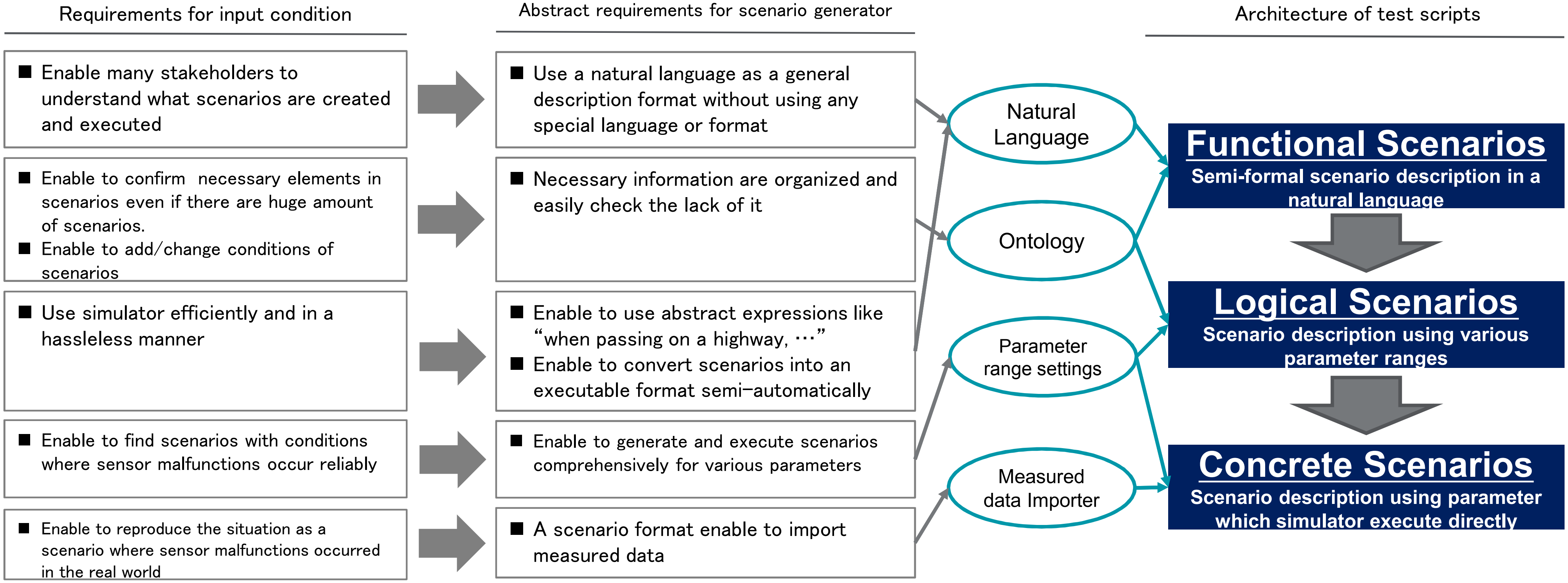
SOLIZE 三菱プレシジョン株式会社 MITSUBISHI PRECISION CO.,LTD.

Requirements	Contents	Module
■ **Flexible and easy to understand scenario system**	■ Scenario system in natural language that can easily understand and process easily ■ Achieve deployment from functional scenarios to specific scenarios according to the PEGASUS scenario system ■ Support importing data measured in the real world	**Functional Scenario Composer / Measured Data Importer**
■ **Operability**	■ *Simple yet flexible UI for scenario editing* ■ Enables data editing in 3D space, enabling intuitive data creation / confirmation Setting viewpoint information Specification of actual data path and attitude information Setting onboard sensor information Specifying events and user interactionsUsability is improved by Undo and Redo o ■ perations ■ Create a software structure that can be processed in parallel to enhance real-time performance	**UI/ Scenario Authoring Tool**
■ **Reproduction of malfunction**	■ Reproduction scene of sensor malfunction factor : A function to calculate the sun position, which is backlit from the sensor position and the object position ■ Display / non-display of assets that cause sensor malfunction : Display of obstacles, etc. ■ Change of asset that causes sensor malfunction : Change guardrails to road side walls, etc. ■ Detailed conditions of events related to malfunction can be set: time condition, asset proximity condition	
■ **Standardization**	■ *Standardization of input data*	

【Functional Scenario Composer 】Develop a system to make functional scenarios concrete with flexible and semi-automatic method using ontologies and NLP

Requirements for generate scenarios, input conditions, and assess conditions

SOLIZE



Requirements for input condition

- Enable many stakeholders to understand what scenarios are created and executed
- Enable to confirm necessary elements in scenarios even if there are huge amount of scenarios.
- Enable to add/change conditions of scenarios
- Use simulator efficiently and in a hassleless manner
- Enable to find scenarios with conditions where sensor malfunctions occur reliably
- Enable to reproduce the situation as a scenario where sensor malfunctions occurred in the real world

Abstract requirements for scenario generator

- Use a natural language as a general description format without using any special language or format
- Necessary information are organized and easily check the lack of it
- Enable to use abstract expressions like "when passing on a highway, …"
- Enable to convert scenarios into an executable format semi–automatically
- Enable to generate and execute scenarios comprehensively for various parameters
- A scenario format enable to import measured data

Architecture of test scripts

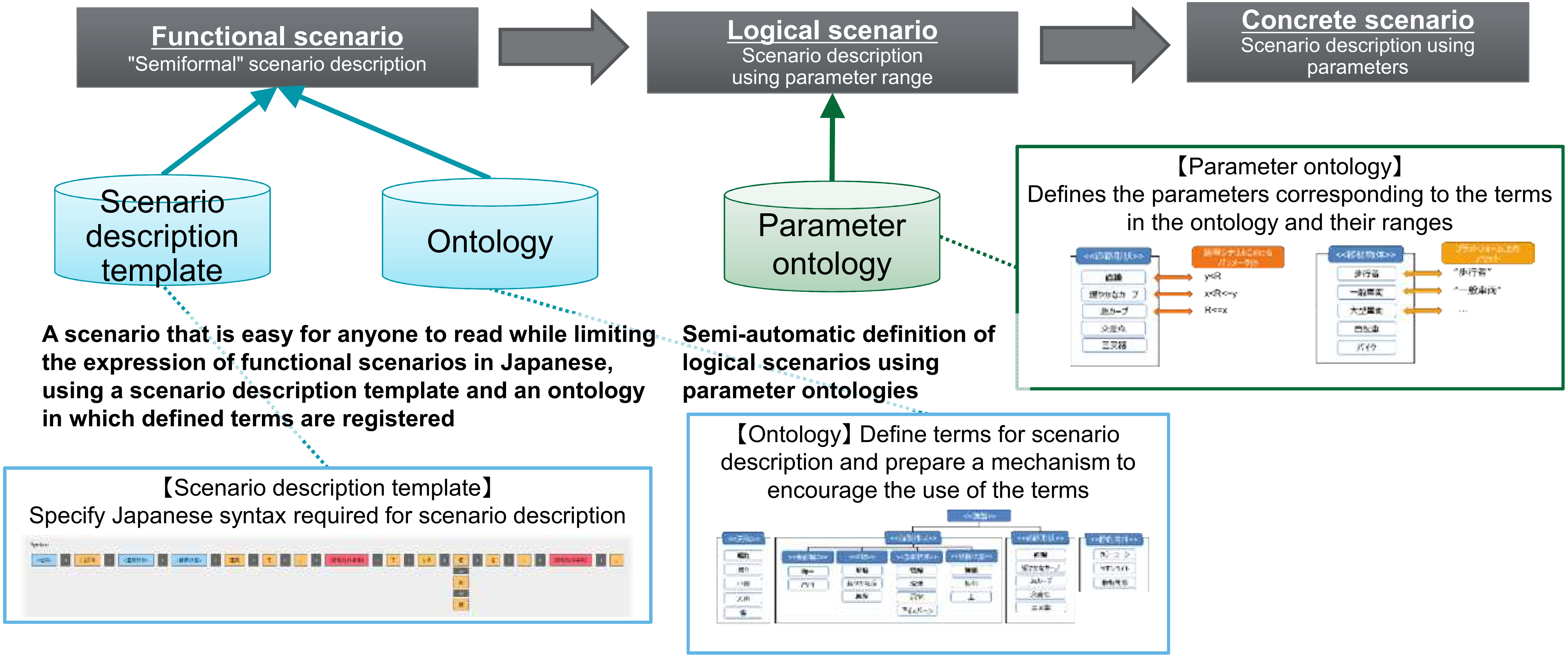
Functional Scenarios
Semi-formal scenario description in a natural language

Logical Scenarios
Scenario description using various parameter ranges

Concrete Scenarios
Scenario description using parameter which simulator execute directly

【Functional Scenario Composer 】Achieving a smooth step-by-step implementation by restricting the description of functional scenarios with ontology and syntax patterns

Overview of the step-by-step process



Functional scenario
"Semiformal" scenario description

Logical scenario
Scenario description
using parameter range

Concrete scenario
Scenario description using
parameters

A scenario that is easy for anyone to read while limiting the expression of functional scenarios in Japanese, using a scenario description template and an ontology in which defined terms are registered

Semi-automatic definition of logical scenarios using parameter ontologies

【Parameter ontology】
Defines the parameters corresponding to the terms in the ontology and their ranges

【Ontology】Define terms for scenario description and prepare a mechanism to encourage the use of the terms

【Scenario description template】
Specify Japanese syntax required for scenario description

【UI/Scenario Authoring Tool】
Build a simple SDM generator for display and editing with a simple UI

Test data display / editing example using scenario generator

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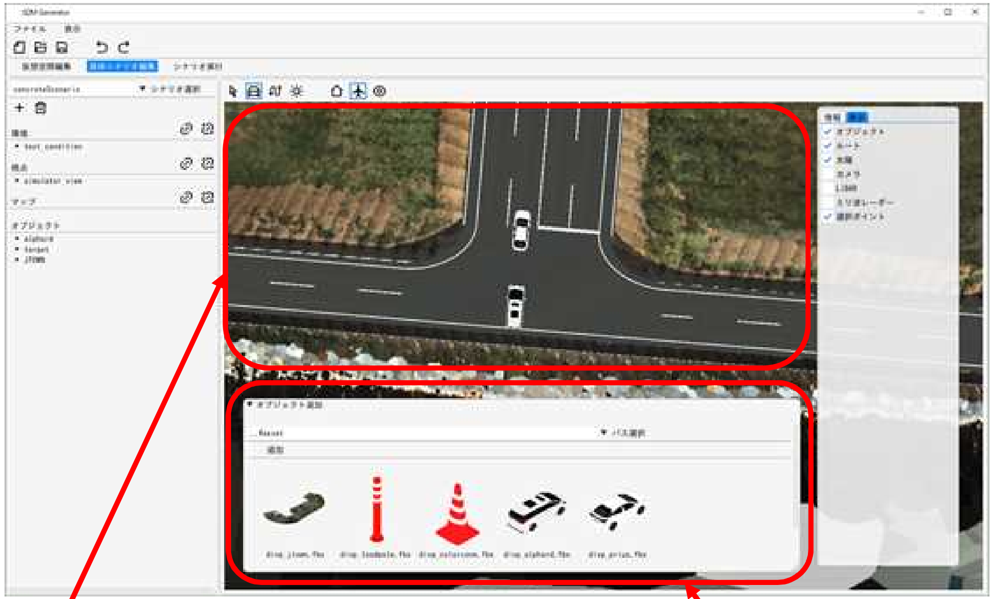
Change of each model

Select and arrange assets required for testing from the asset library

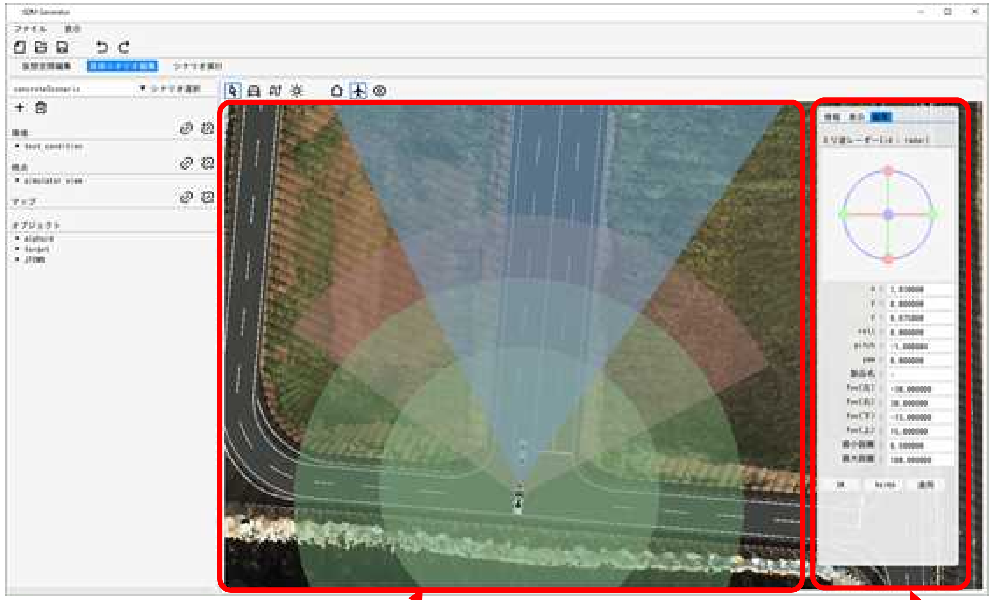


Displaying test editing status

Asset Library

Change of sensor model loading

Installing sensors on the vehicle, changing the sensor range



Sensor range display

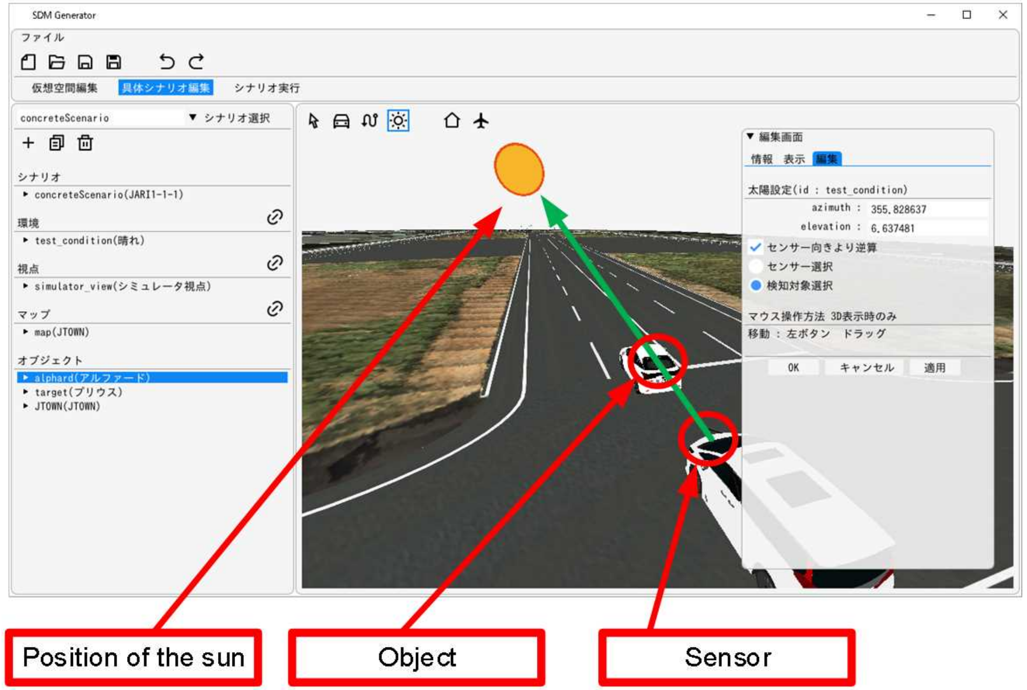
Editing sensors

【UI/Scenario Authoring Tool】
Easily create and set scene scenarios to reproduce sensor malfunctions

Scene creation/editing example of sensor malfunction cause using scenario generator

Calculating the position of the sun that is backlight

- Calculates the position of the sun as backlight from the positional relationship between the sensor and the object



concreteScenario

シナリオ
- concreteScenario(JARI1-1-1)

環境
- test_condition(晴れ)

視点
- simulator_view(シミュレータ視点)

マップ
- map(JTOWN)

オブジェクト
- alphard(アルファード)
- target(プリウス)
- JTOWN(JTOWN)

太陽設定(id : test_condition)

azimuth : 355.828637
elevation : 6.637481

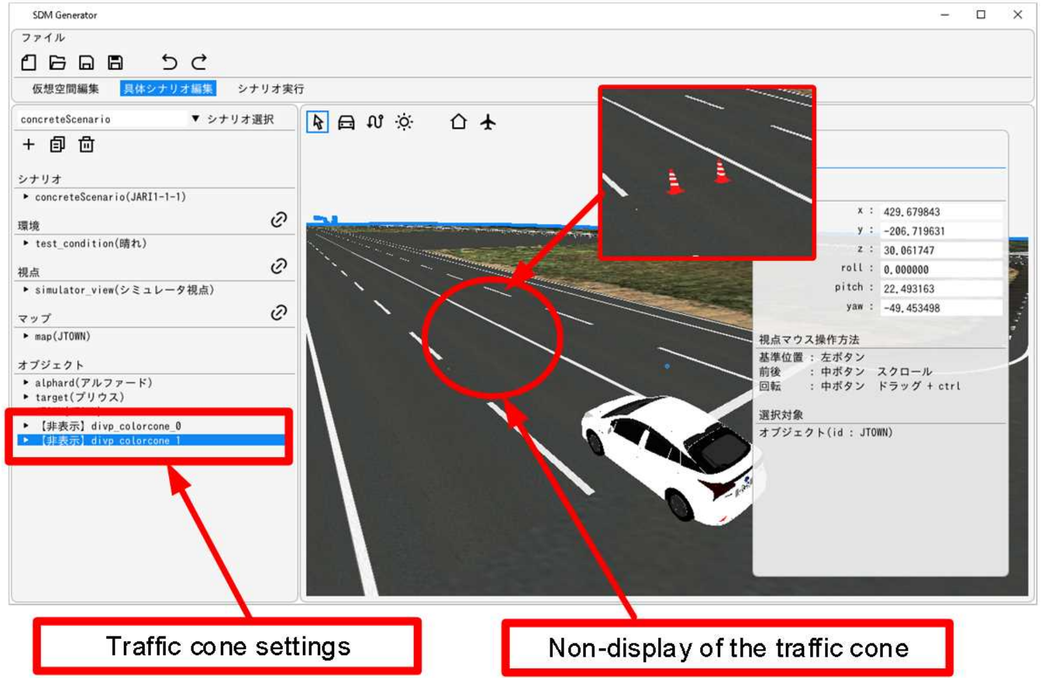
☑ センサー向きより逆算
○ センサー選択
● 検知対象選択

マウス操作方法 3D表示時のみ

移動 : 左ボタン ドラッグ

Show/hide assets

- Display / non-display of assets that cause sensor malfunction



concreteScenario

シナリオ
- concreteScenario(JARI1-1-1)

環境
- test_condition(晴れ)

視点
- simulator_view(シミュレータ視点)

マップ
- map(JTOWN)

オブジェクト
- alphard(アルファード)
- target(プリウス)
- 【非表示】divp_colorcone_0
- 【非表示】divp_colorcone_1

x : 429.679843
y : -206.719631
z : 30.061747
roll : 0.000000
pitch : 22.493163
yaw : -49.453498

視点マウス操作方法

基準位置 : 左ボタン
前後 : 中ボタン スクロール
回転 : 中ボタン ドラッグ + ctrl

選択対象

オブジェクト(id : JTOWN)

Source : MitsubishiPrecision Co.,LTD.

【Benchmark】from BM, there is a competitive advantage of the scenario generator in the environment model setting in the logical scenario

Benchmark result of Scenario Generator

functions	setting	SDM-G (2020年度)	VTD 2.2.0	CarMaker 8.1	Vissim 2020
Environment	*Roads and roadside objects (Layer 1)*	C L	C	C	C
	Signs, signals, guardrails and buildings (Layer 2)	C L	C	C	C
	Construction and traffic regulation (Layer 3)	C L	C	C	C△
	Weather, temperature, humidity, road conditions, backlight (Layer 5)	C L	C	C L	×
Control target (open loop)	Ego vehicle	M C L	M C	M C L	C
	Other vehicle	M C L	M C	M C L	C
	Pedestrian	C	C	C	C
	Cyclist	C	C	C	C
	NCAP dummy	Under review	C	×	×
	Other (animal etc.)	C	C	C	×
Control target (closed loop)	Ego vehicle	M C L	C	C L	C
	Other vehicle	M C L	C	C L	C
	Pedestrian	C	C	×	C
	Cyclist	C	C	×	C
	NCAP dummy	Under review	※	×	×
	Other (animal etc.)	C	C	×	×

①

M	getting from measurement data
D	Getting from data-base
F	Able to describe a functional scenario
L	Able to describe a logical scenario
C	Able to describe a concrete scenario
○	Supported
△	Partially supported
×	Unsupported
※	Investigating

Item that shows the superiority of Scenario Generator

① Only Scenario Generator can be set in logical scenario for layer Lv. 1, 2 and 3 of environment model.

【Benchmark】from BM, “Test evaluations” & “Change target of imported environment models” would be an advantage vs competitor’s

Benchmark result of Scenario Generator

functions	setting	SDM-G (2020年度)	VTD	CarMaker 8.1	Vissim 2020
Cooperation with other tools	OpenDRIVE (importing)	○	○	△	△
	OpenDRIVE (exporting)	○	○	×	×
	OpenCRG (importing)	Future consideration	○	×	×
	OpenCRG (exporting)	Future consideration	※	×	×
	OpenSCENARIO (importing)	Future consideration	○	×	×
	ISO (importing)	Under review	※	×	×
Test evaluations	*Automation*	Future consideration	※	○	×
	Recording	Future consideration	※	○	×
Evaluation loop of test data generation	Automated reconfiguration of Logical scenario parameters based on evaluation results	Future consideration	※	×	×
	Environment for checking the execution status	Future consideration	※	×	×
	Record of execution contents	×	※	×	×
Simple simulation (with no sensors)	Executing	○	○	×	○
	Recording / playing	○	○	×	×
Change target of imported environment models	*Roads and roadside objects*	Under review	○	△	△
	Signs, signals, guardrails and buildings	Under review	○	△	△
	Construction and traffic regulation	Under review	※	×	×
	Vehicle, pedestrian, cyclist, animal, NCAP dummy	Under review	※	×	×
	Weather, temperature, humidity, road conditions, backlight	Under review	※	×	×

②

③

○	Supported
△	Partially supported
×	Unsupported
※	Investigating

<u>Items that support only existing soft ware</u>

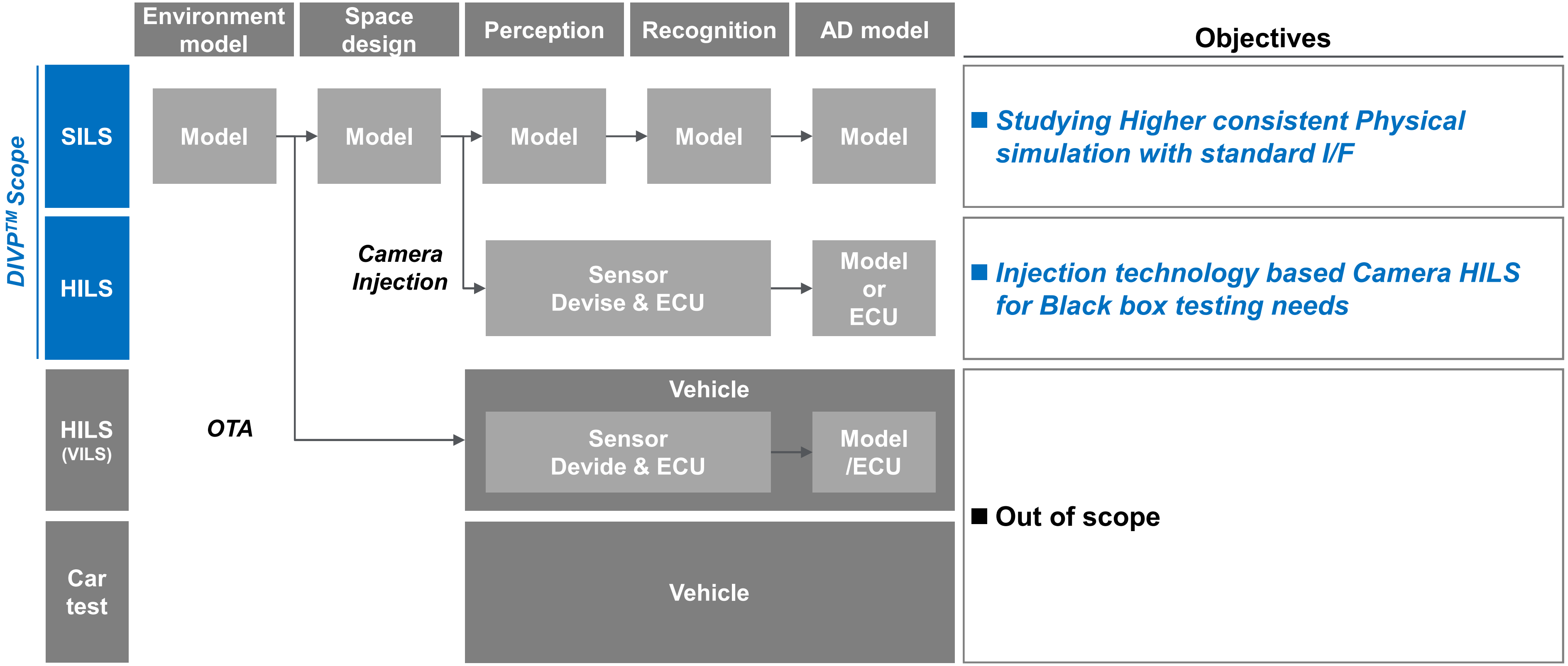
② CarMaker has been supported the function to evaluate test

③ The function to change setting after import is partially supported by other tools for Layer Lv. 1 and 2 (VTD is supported).

Validation framework study

DIVP™ scoping HILS method as for Validation robustness even in Black box operation in industrial needs

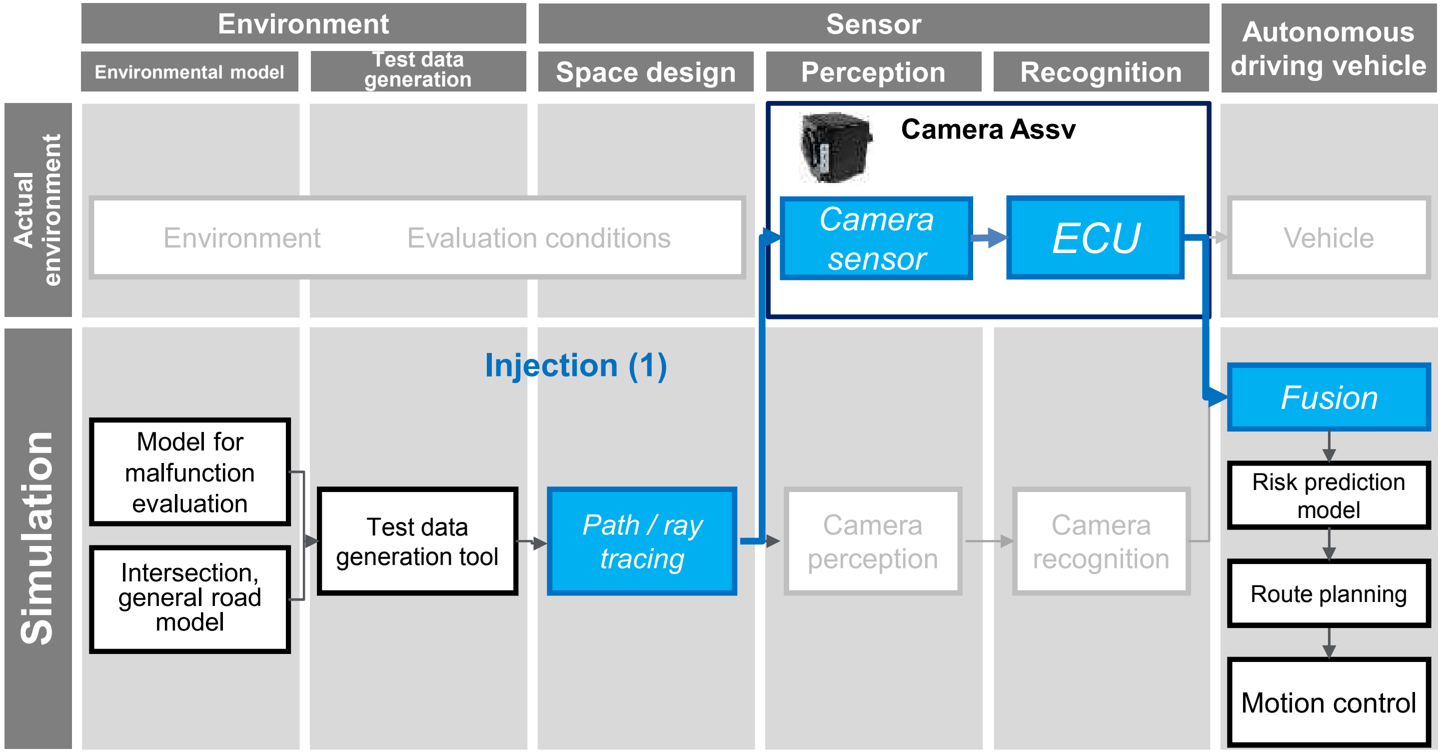
V&V total framework



- *Studying Higher consistent Physical simulation with standard I/F*
- *Injection technology based Camera HILS for Black box testing needs*
- Out of scope

【Camera HILS*】Construct HILS using injection technology for future black box evaluations, and study evaluation possibilities

Injection evaluation environment concept



Environment

Environmental model

Test data generation

Sensor

Space design

Perception

Recognition

Autonomous driving vehicle

Actual environment

Camera Assv

Environment

Evaluation conditions

Camera sensor

ECU

Vehicle

Simulation

Injection (1)

Model for malfunction evaluation

Intersection, general road model

Test data generation tool

Path / ray tracing

Camera perception

Camera recognition

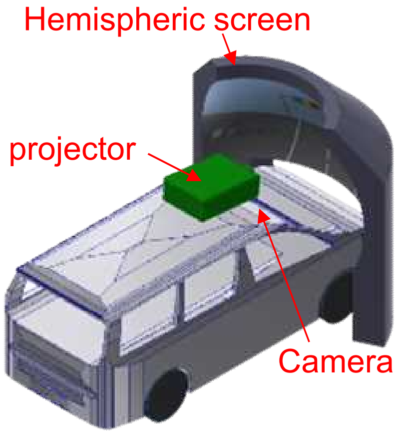
Fusion

Risk prediction model

Route planning

Motion control

Configuration image



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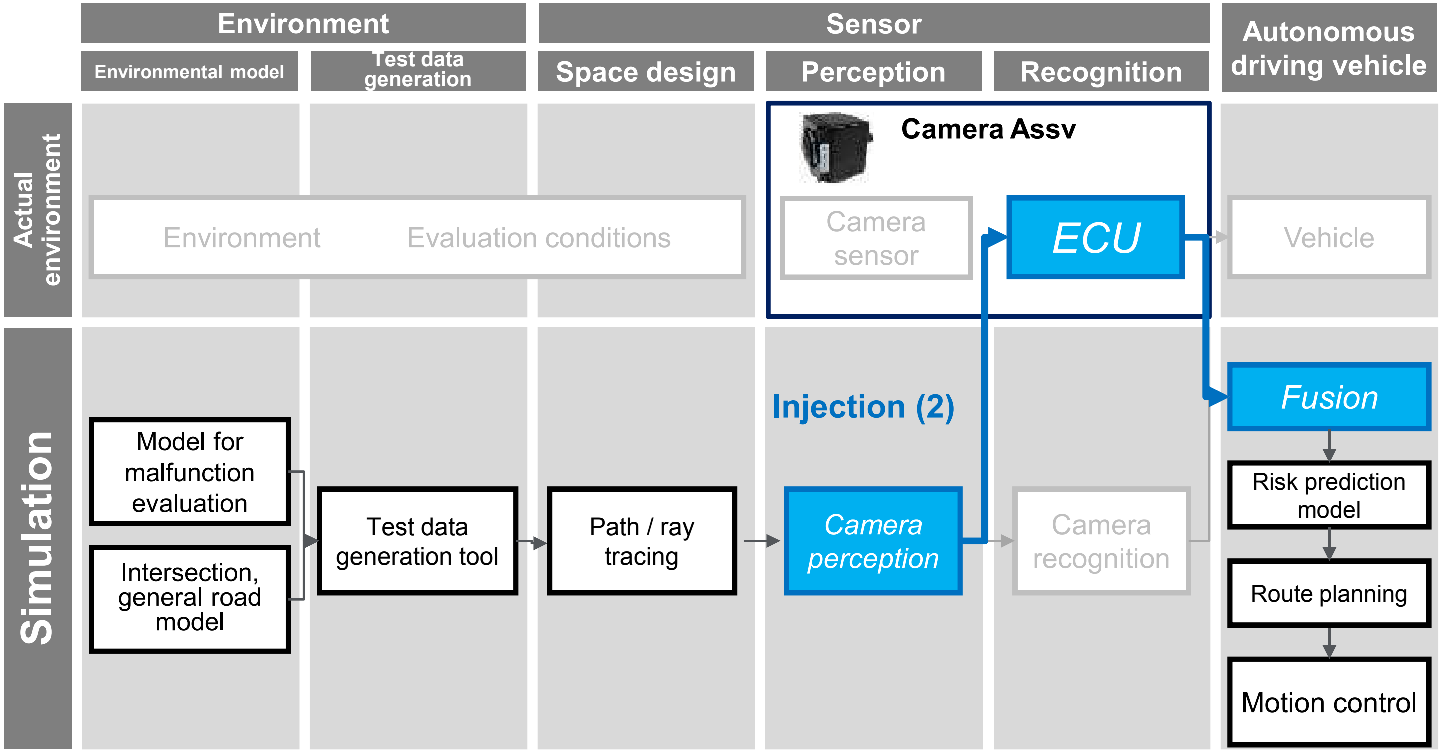
*HILS ; Hardware in the loop, Source: Hitachi Automotive Systems, Ltd.

【Camera HILS*】Construct HILS using injection technology for future black box evaluations, and study evaluation possibilities

Injection evaluation environment concept



Environment | Sensor | Autonomous driving vehicle

Environmental model | Test data generation | Space design | Perception | Recognition

Actual environment

Environment — Evaluation conditions

Camera Assv

Camera sensor → ECU → Vehicle

Simulation

Model for malfunction evaluation

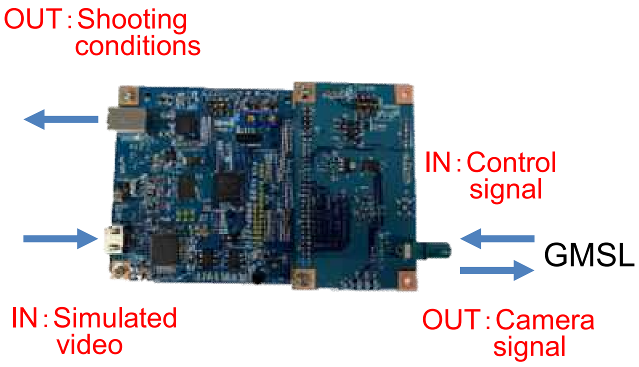
Intersection, general road model

Test data generation tool → Path / ray tracing → *Camera perception* → Camera recognition

Injection (2)

Fusion → Risk prediction model → Route planning → Motion control

Injection board



OUT : Shooting conditions

IN : Control signal

GMSL

IN : Simulated video

OUT : Camera signal

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*HILS ; Hardware in the loop, Source: Hitachi Automotive Systems, Ltd.

END

Tokyo Odaiba FOT area → Virtual Community Ground