Cross-ministerial Strategic Innovation Promotion Program

「The second phase of Cross-ministerial Strategic Innovation Promotion Program / Automated Driving for Universal Services / Research on the recognition technology required for automated driving technology (levels 3 and 4) 」

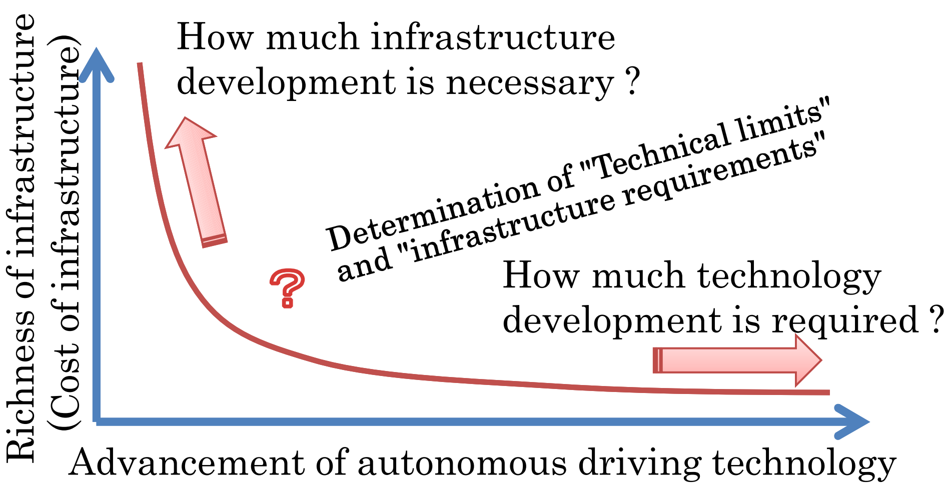
FY 2021 Report

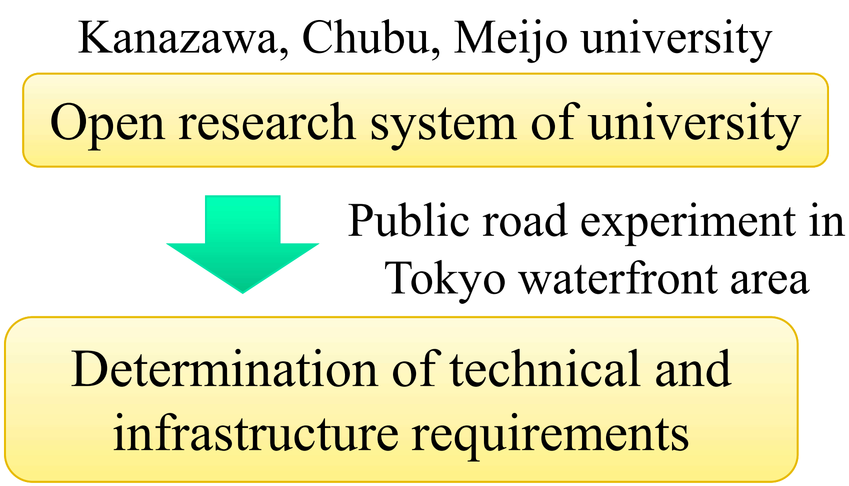
Kanazawa University
Chubu university
Meijo university

May, 2022

1.1.Overview of this research

- Level 4 equivalent autonomous driving at urban area
  - It is necessary to have advanced perception and decision-making system by onboard AI, as well as infrastructure such as road facilities and communication facilities to support it
- State-of-the-art autonomous vehicle technology
  - Competition area in the industry
  - Knowledge of academia is essential





1.1.R&D items

a.「Development of traffic signal recognition technology and investigation of difficult conditions」

Utilizing traffic light with communication facilities in Tokyo waterfront area

b.「Development of AI technology required to detect distant objects」

Comparative evaluation of simulator and demonstration experiment results

Improvement of recognition technology using simulation technology

c.「Development of high precision self-localization technology」

Utilizing QZSS and map matching technology

d.「Verification of simulators and scenarios in cooperation with SAKURA/DIVP」

Testing FOT algorithm under virtual environment

e.「Investigating problems when driving autonomous vehicle」

Emergency vehicle recognition and response to emergency vehicles

f.「Demonstration experiment」

Public road testing at Kanazawa city and Tokyo waterfront area

1.1.Schedule

Action item		FY2021	FY2022
a) Development of traffic signal recognition technology and investigation of difficult conditions	traffic signal detection method FOT using V2I	Summarization of traffic signal detection issues including blinking lights Comparison w/ and w/o V2I/V2N	
b) Development of AI technology required to detect distant objects	Cooperation w/ DIVP Prj. Safety evaluation of recognition technology using simulation	Improvement of recognition technology using simulation technology	
c) Development of high precision self-localization technology	Improve availability of Michibiki	INS error modeling Evaluation of effectiveness of map matching and Michibiki using simulation	
d) Verification of simulators and scenarios in cooperation with SAKURA/DIVP	Development of prediction and path planning technology under urban area Cooperation w/ SAKURA/DIVP	Build a test environment for simulation	Improvement using simulation Verification and improvement using simulation
e) Investigating problems when driving autonomous vehicle	Dead-lock issues	Evaluation of effectiveness of emergency vehicle information (V2N) Develop emergency vehicle recognition technology	Improvement using simulation
f) Demonstration experiment	FOT using V2I Collection of sensor data and providing data set	FOT using V2N	Reproduction of traffic environment to simulator

1.2. Development contents and goals
a.「Development of traffic signal recognition technology and investigation of difficult conditions」

- Necessity for R&D
  - Autonomous driving on urban area
    - Need precise recognition of distant traffic signals
    - Exist situations that are difficult for human eyes to recognize (sunshine, occlusions)
  - It is necessary to maintain an infrastructure-supported traffic signal using V2I communication
    - Need to estimate the number of installations required due to the huge installation costs
- R&D Contents
  - ①「Traffic signal recognition by pattern recognition and decision making for intersection entering」
    - Evaluate camera with functions such as HDR (High Dynamic Range) and LFM (LED Flicker Mitigation)
    - Develop traffic signal detection using pattern recognition method
    - Develop an intersection approach planner using V2I/V2N

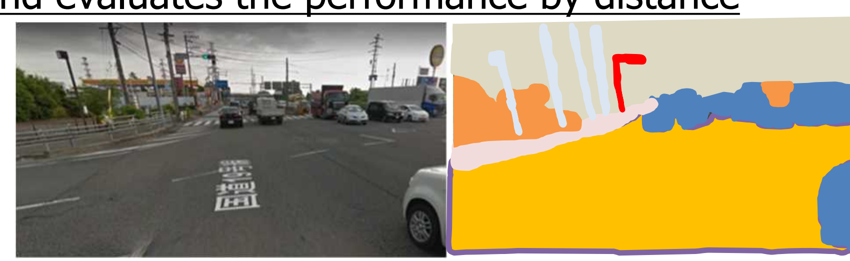
    (Evaluate the effectiveness in Tokyo waterfront area)

    <u>FY2021： Develop a blinking light detection method, evaluate the recognition performance, and acquire V2N information data when approaching intersection</u>

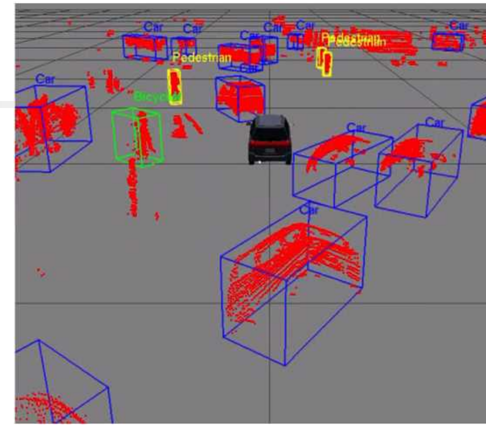
  - ②「Development of the method based on semantic segmentation」
    - Solve situations that are difficult to recognize with conventional methods (degraded ramp traffic signal, occlusions, blinking light)

    <u>FY2021： Create a dataset of blinking light and evaluates the performance by distance</u>

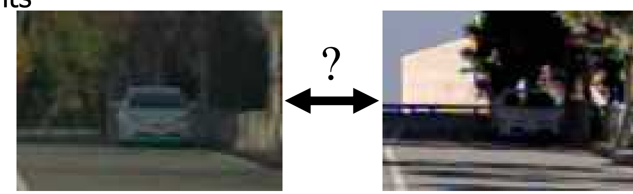
  - <u>FY2021 Goal: Create a dataset of blinking lights and develop a blinking light detection method</u>



1.2. Development contents and goals
b.「Development of AI technology required to detect distant objects」



- Necessity for R&D
  - Safety and smooth autonomous driving on urban area
    - Precise detection for traffic participants
      (e.g. Vehicle, Pedestrian, Cyclist)
  - Need to detect distant dynamic objects
    (e.g. Oncoming vehicles at intersections or crossing pedestrians)
  - Simulation environment is important for reproducible evaluations
    - Differences in detection accuracy between real and simulated environments



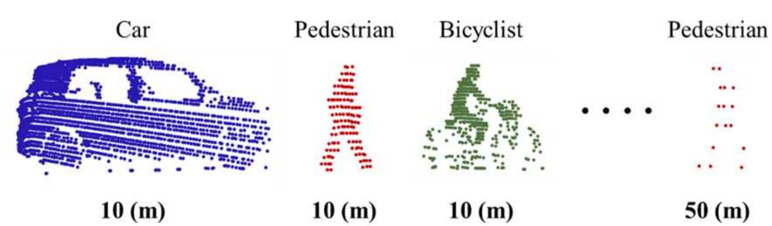
- R&D Contents
  - ①「Distant object detection and camera selection」
    - Evaluate appropriate cameras
    - Develop distant object detection using Deep Neural Network
    - Improve detection accuracy for a small size of objects
    - Investigate the consistency with the real environment for the utilization of the simulation environment

    <u>FY2021： Investigate differences between environments in vehicle detection</u>

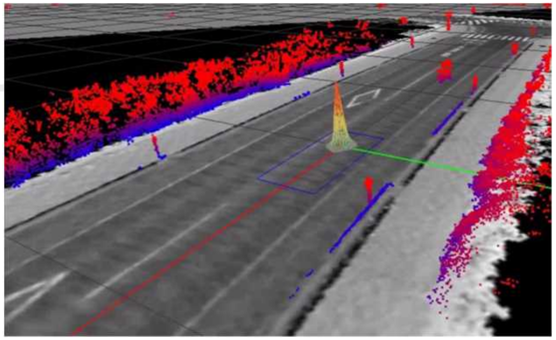
  - ②「Distant object detection by LiDAR and RADAR」
    - Improve detection distance by sensor fusion using LiDAR, Radar, and Camera
    - Develop object detection method using machine learning
    - Design feature values specialized for distant objects
    - Investigate the consistency with the real environment for the utilization of the simulation environment

    <u>FY2021： Construct simulation environments for LiDAR and evaluate the consistency for object detection</u>

  - <u>FY2021 Goal: Identify differences between</u>
  - <u>real and simulated environments</u>



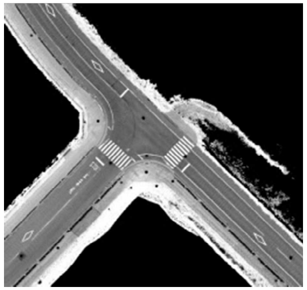
1.2. Development contents and goals
c.「Development of high precision self-localization technology」

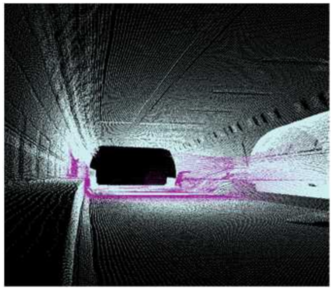


- Necessity for R&D
  - High precision self-localization is necessary for using high precision map
    - It is difficult to estimate self-location only in GNSS (ex. Tunnel)
    - Accurate self-localization by map matching
  - Importance of GNSS/INS
    - Advancement of both GNSS/INS and map matching is important.
    - Initial position estimation and validation of map matching, complement of map matching
- R&D Contents
  - ①「Development of GNSS/INS」
    - Robustization of lane level position estimation (1.5m accuracy) by in-vehicle grade GNSS/INS
    - Reliability estimation of RTK-GNSS (0.3m accuracy) by in-vehicle grade GNSS/INS
    - Utilization of QZSS "MICHIBIKI"

    <u>FY2021：Dead reckoning error factors analysis and its accuracy improvement</u>

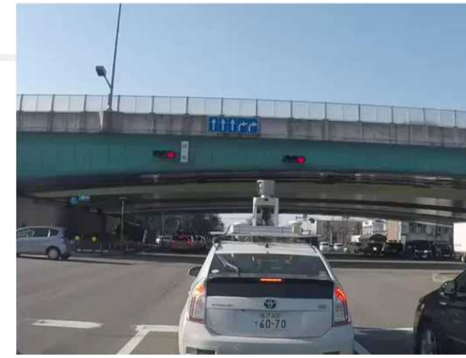
  - ②「Development of map matching technology」
    - Evaluation of map matching algorithms
    - Modeling of reliability in map matching
    - High-accuracy position and attitude estimation using in-vehicle grade GNSS / INS



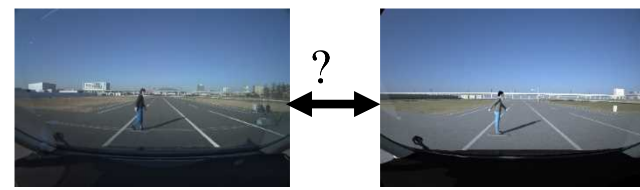


<u>FY2021: Development of a map matching method using high-precision GNSS/INS under rainy conditions</u>

1.2. Development contents and goals
d.「Verification of simulators and scenarios in cooperation with SAKURA/DIVP」



- Necessity for R&D
  - Autonomous driving on urban area
    - High-speed dynamic objects (e.g. vehicle, motorcycle)
    - Low-speed dynamic objects(e.g. pedestrian, cyclist)
  - Smooth and safety autonomous driving
    - Predict future behaviors of dynamic objects in addition to velocity vectors (especially for low-speed objects)
    - Smooth trajectory planning in relatively narrow spaces due to high traffic
  - Simulation environment is important for reproducible evaluation
    - Accuracy must be consistent between real and simulated environments



- R&D Contents
  - ①「Path prediction of pedestrian based on AI」
    - Estimate pedestrian’s orientation and attribute information using Recurrent Neural Network
    - Develop behavior prediction using attribute information
    - Investigate the consistency with the real environment for the utilization of the simulation environment

    <u>FY2021：</u> Investigate differences between real and simulated environments for pedestrian detection

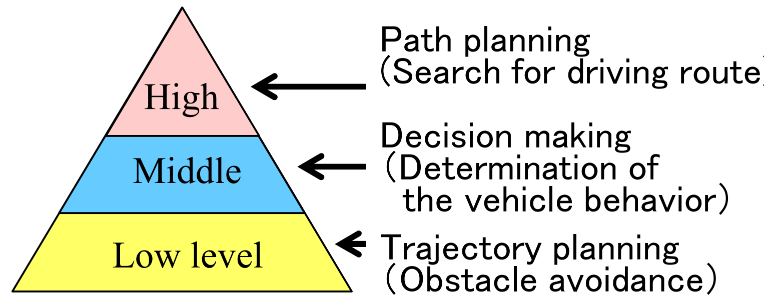
  - ②「Vehicle behavior prediction by tracking and path planning」
    - Estimate motion state and shape of dynamic objects, and develop behavior prediction using digital map
    - Develop an advanced trajectory planning method considering the predicted behavior (smooth and safe autonomous driving in a narrow space)

    <u>FY2021：Construct simulation environments for the generation of recognition failure scenes</u>

  - <u>FY2021 Goal: Construct simulation environments for the generation of recognition failure scenes that occurs in the real scenes</u>

1.2. Development contents and goals
e.「Investigating problems when driving autonomous vehicle」

- Necessity for R&D
  - Future urban area:
    A mixture of many autonomous vehicles
  - Deadlock problem (Behavior that mutually gives over)
    - An encounter between autonomous vehicles with no inter-vehicle communication device.
    - Examples of intersections without traffic lights, entrances to commercial facilities, merging to highways, etc.
    - Approaching an emergency vehicle



- R&D Contents
  - ①「Deadlock avoidance by robotics technology」
    - Modeling of deadlock patterns (traffic scene)
    - Trajectory generation for deadlock avoidance
    - Scene extraction based on simulation software

    <u>FY2021： Develop recognition algorithm for emergency vehicles by sensor fusion, extract a dead lock scenes from actual driving data, and acquire approaching information via V2N</u>

  - ②「 Deadlock avoidance using artificial intelligence (AI)」
    - Deadlock avoidance based on Deep Reinforcement Learning
    - Examination of optimal input/output information for deep learning
    - Detects emergency vehicles and reflects deadlock avoidance

    <u>FY2021: Develop recognition algorithm for emergency vehicles</u>

  - <u>FY2021 Goal: Develop recognition algorithm for emergency vehicles</u>

1.2. Development contents and goals
f.「Demonstration experiment」

- Necessity for R&D
  - Evaluation of R&D items form a. to e.
    - Accelerating development through actual vehicle tests
  - Study on infrastructure equipment
    - Conditions where infrastructure-assisted traffic signals is required
    - Investigation on influence of lane line condition to autonomous vehicles
- Development of test vehicles
  - Development of two test vehicles
    - Public road testing in central Kanazawa city.
    - Public road testing around Tokyo waterfront area
  - LiDAR, RADAR, Camera, GNSS/INS, V2X communication, etc.

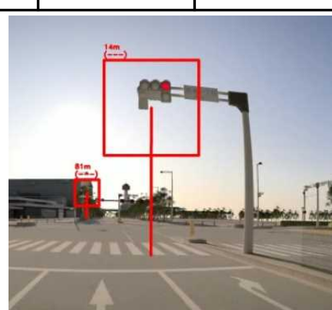
<u>FY2021: Start of public road testing of autonomous driving using V2N and providing test driving opportunities for improving social acceptability.</u>

2. R&D results
2.1. a.① 「Development of the method based on semantic segmentation」

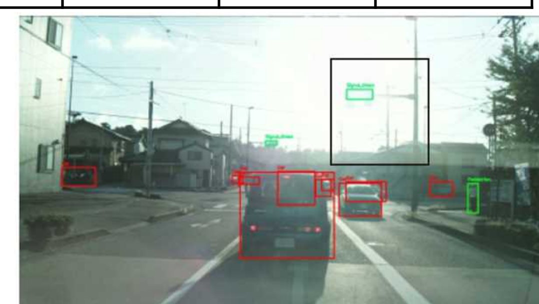
- Develop a blinking light detection and evaluate the performance
  - Compute a blinking freq. based on recog. states for each frames of traffic lights
  - F-value: 97% for normal condition
    - However, the performance was deteriorated depending on sunlight condition.
- Consistency verification between real and simulated data for traffic light
  - Verify the consistency for normal conditions and the influences for rare scenes such as heavy rainy
- Create open driving image dataset including adverse conditions for traffic light detection

	Normal Condition			Back light Condition			Following light Condition		
	Prec.	Recall	F-value	Prec.	Recall	F-value	Prec.	Recall	F-value
Lighting state（Indiv.）	0.946	0.933	0.936	0.874	0.791	0.800	0.777	0.598	0.520
Lighting state（Intersec.）	0.958	0.939	0.946	0.915	0.859	0.874	0.777	0.581	0.495
Blinking state（Indiv. ）	0.965	0.987	0.976	0.976	0.551	0.705	1.000	0.276	0.432
Blinking state（Intersec.）	0.962	0.992	0.977	0.975	0.686	0.805	1.000	0.308	0.471

Consistency verification
L: Normal scene
R: Heavy rainy scene



Example:
AD-URBAN
Open Image
Dataset v1.0



2. R&D results
2.1. a.② 「Development of the method based on semantic segmentation」

- Create a dataset of blinking light
  - Data was collected and annotated by driving through the city of Kanazawa
  - 55 scenes,108 signals (including 63 blinking light, 13,420 images)
- Evaluates the performance by distance
  - Detectable distance : 67m
    - If the background is difficult to distinguish from a traffic light (background change (forest to sky)), the distance becomes shorter
  - Recognition : blinking light recognition accuracy is higher with map information than without map information (using traffic light tracking)

Detectable distance[m]

Scene	furthest distance	Distance (light on)	Distance (light off)
uniform background (building or sky)	142	137	117
background change (forest to sky)	123	107	67
background change (building to sky)	138	133	102
background change (sign to sky)	136	129	112

Recognition accuracy[%]

state	without map	with map
blue	100	100
red	100	100
flashing	57.1	60.3

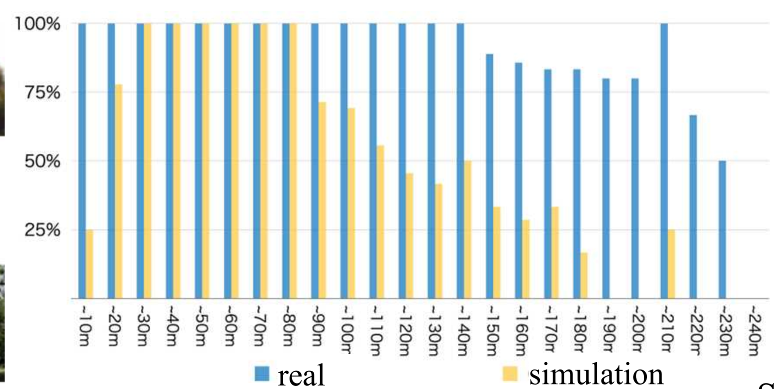
2. R&D results
2.2. b.① 「Distant object detection and camera selection」

- Consistency verification between real and simulated environments for vehicle detection
  - Public dataset: over-detects distant objects=>object contours are clear
  - DIVP simulator: Detection trend similar to real environment => False color on outlines
- Differences between real and simulated environments
  - Differences occur in the way shadows are expressed

Real environment

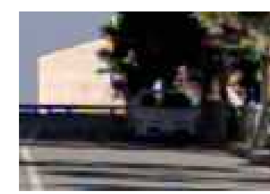
Simulation environment

Detection examples on public dataset



detection accuracy by distance

Real environment

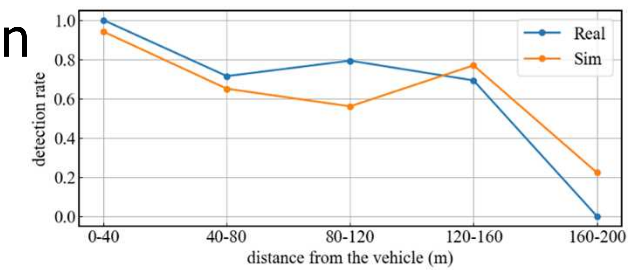


Simulation environment

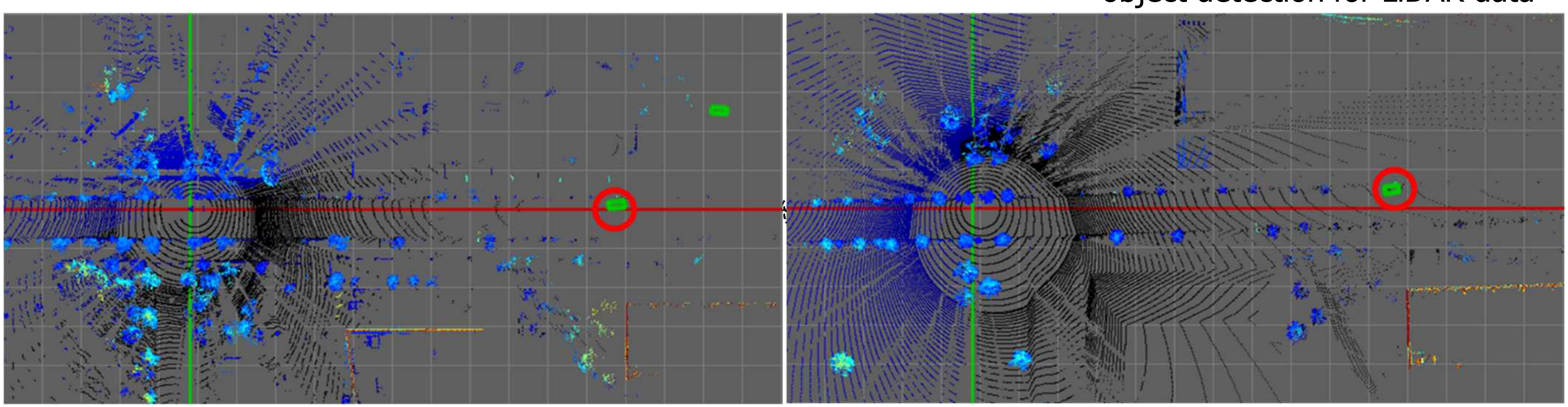
differences examples

2. R&D results
2.2. b.② 「Distant object detection by LiDAR and RADAR」

- Sensor-fusion based traffic participant recognition
  - (FY2020) Develop the recognition method based on LiDAR-Camera fusion
    - Difficult scenes: Occlusion, Adverse weather/sunlight condition
  - Investigate the performance improvement using simulated data
- Consistency verification for LiDAR object detection
  - Sensor data collection and generate simulated scenarios for distant target vehicle
  - Evaluate detection performance for both real and simulated LiDAR data
    - A similar tendency for the recognition performance in different distance was confirmed



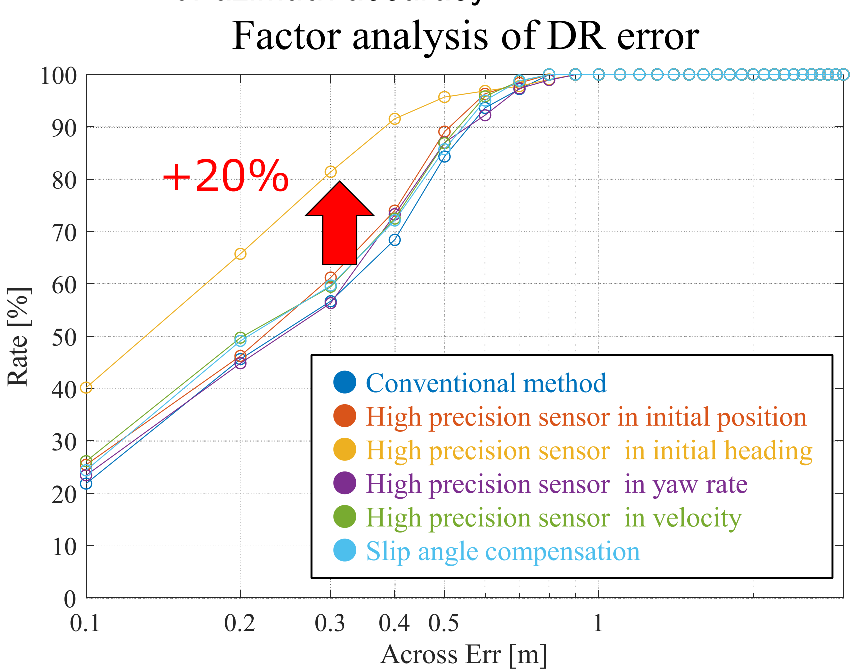
Evaluated results for distant object detection for LiDAR data

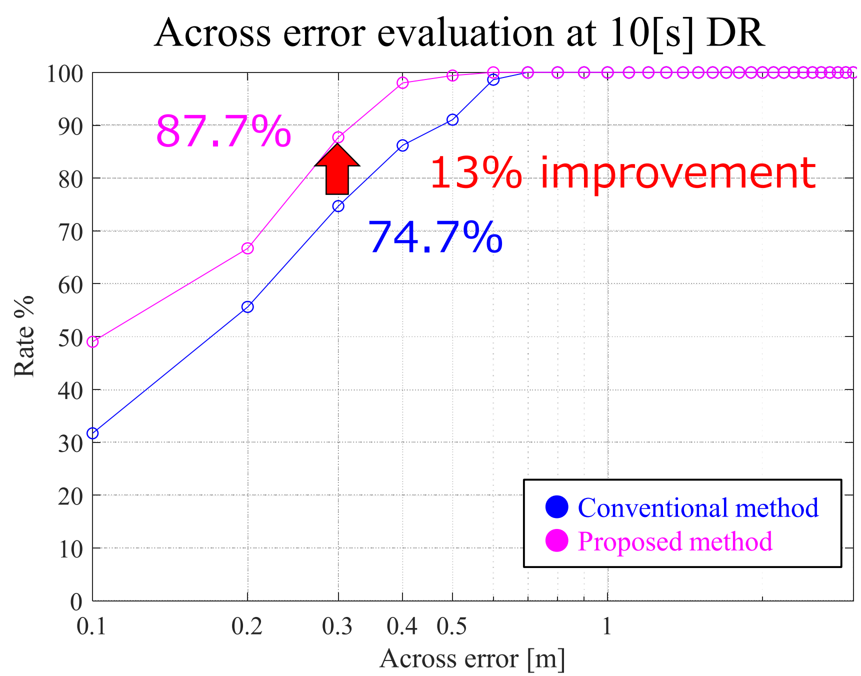


Typical detection results（distance: 110m, red: target, green: detected obj., L: real, R: simulated data）

2. R&D results
2.3. c.① 「Development of GNSS/INS」

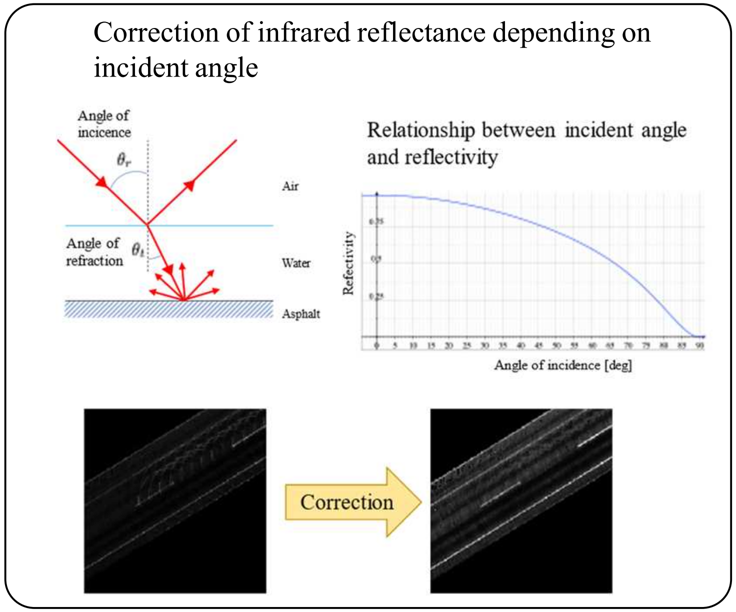
- Achievement of 0.3m positional accuracy for 10 seconds after CLAS receiving failure, and investigation of the conditions for achieving the accuracy.
- Analysis of Error Factors in Dead Reckoning and Improvement of the accuracy
  - Dead Reckoning Errors and Factor Analysis Utilizing Conventional Techniques
- Focusing on azimuth error, a method to improve azimuth and dead reckoning error by utilizing FIX solution is proposed.
  - Confirmation that the target value (30 cm/70%) for FY2021 has been achieved through improvement of azimuth accuracy.

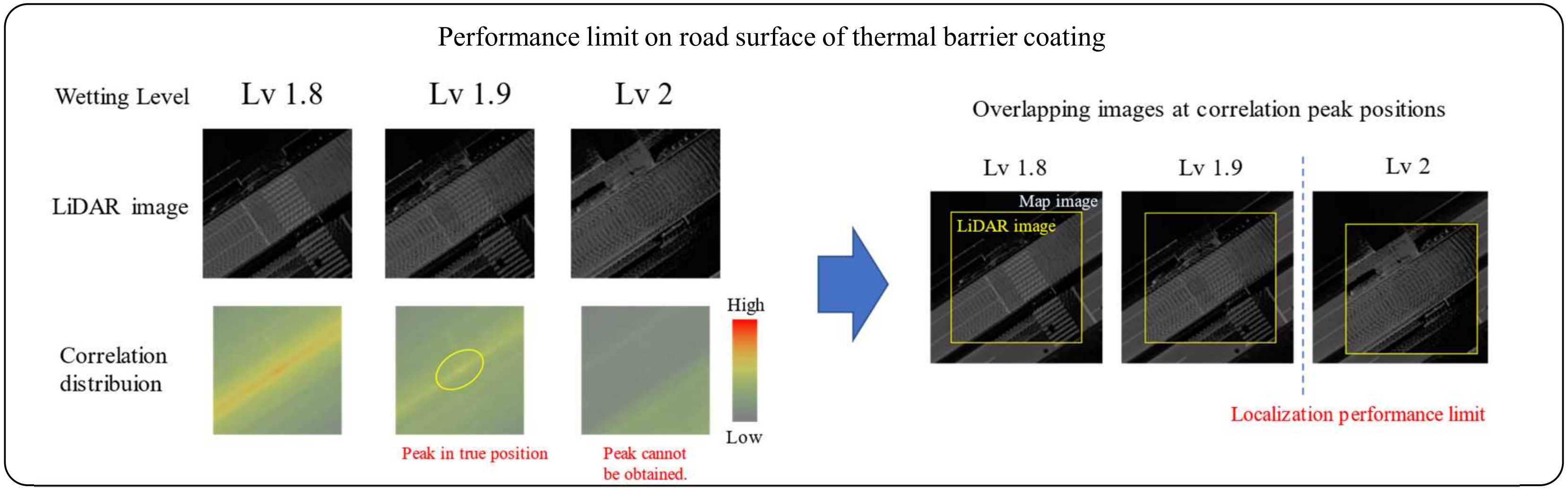




2. R&D results
2.3. c.② 「Development of Map Matching Technology」

- Improvement of localization accuracy under rainy conditions
  - Strategies: Correction of infrared reflectance depending on incident angle and image contrast correction.
  - Target estimation accuracy of 0.1m was achieved.
- Investigation of performance limits of localization estimation by cooperating DIVP project
  - Simulation of sensor malfunction scene: road surface material (asphalt/thermal barrier coating), road surface wetting level
  - The performance limits can be evaluated by comparing the correlation distribution and the position estimation results.
  - In real data, there are deviations in the decrease in reflectance.
    - Simulation is required for more detailed verification.





2.R&D results
2.4. d.① 「Path prediction of pedestrian based on AI」

- Consistency verification between real and simulated environments for pedestrian detection
  - Investigate the causes of differences by changing the conditions reproduced in the simulator
    - conditions: time (influence of sunlight), specular (object reflectance), assets (object resolution and texture), background complexity, trimming of own vehicle’s interior
  - Asset resolution and texture have a significant impact on consistency

conditions	influence	
specular	×	
asset	◎	Higher resolution is more accurate
texture	◎	texture is as accurate as in a real environment
background complexity	○	Accuracy equivalent to real environment by placing buildings
trimming of interior	○	Significantly improved (due to larger pedestrian size)

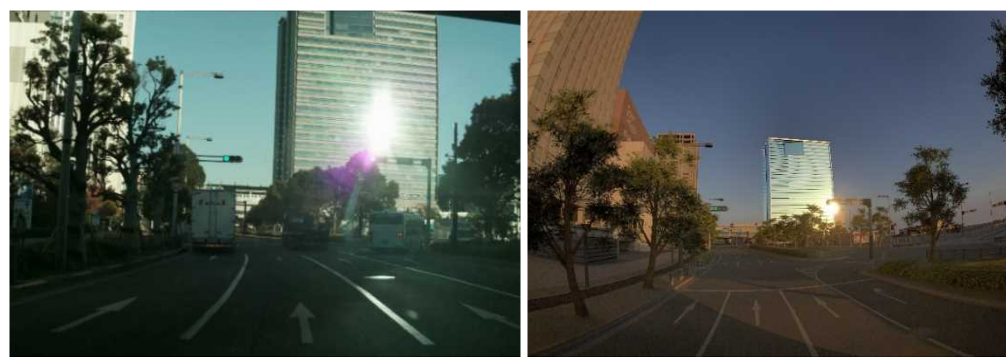

Real environment


Simulation environment (high resolution asset)


Simulation environment (with texture)

2. R&D results
2.4. d.②「Vehicle behavior prediction by tracking and path planning」

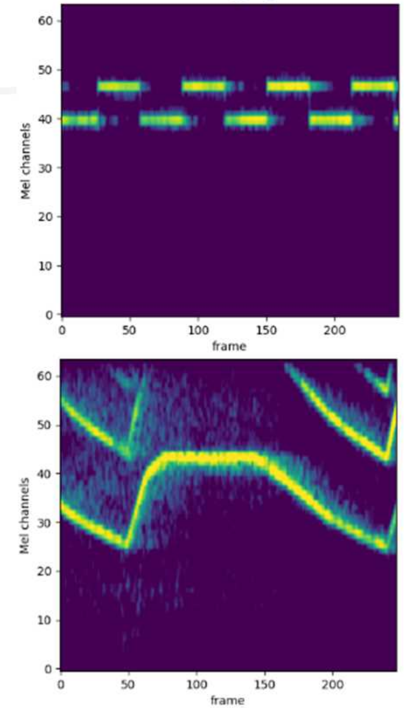
- Collaboration with DIVP Project
  - DIVP: Driving Intelligence Validation Platform (Other SIP Project)
    - Develop simulation platform to evaluate safety of automated driving under various traffic environmental conditions
- Implement interfaces between our system and simulator
  - Consistency verification for various recognition technologies between real and simulated data
    - Implement basic driving scenes with different weather or sunlight conditions
    - Generate sensor data of LiDAR and camera for designed scenarios
  - Improve recognition performance using simulator
    - Implement failure scenes of surrounding recognitions for LiDAR or Camera data
  - Camera recognition
    - Traffic light
    - Object detection
  - LiDAR recognition
    - Object detection
    - Self-localization



Example of verification for failure scene of traffic light detection under backlight of reflected sunlight
（Left: real, Right: simulated image）

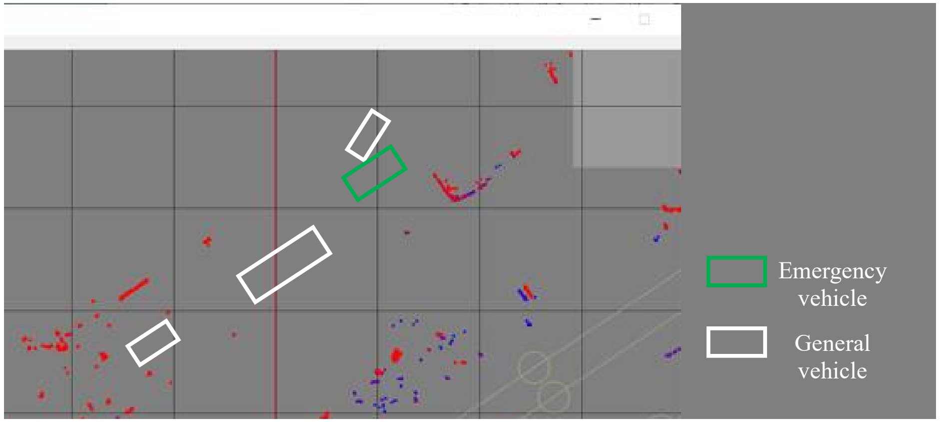
2. R&D results
2.5. e.① 「Deadlock avoidance by robotics technology」

- Typical deadlock scenes under actual traffic situations
  - （~FY2020）Deadlocks of automated vehicles are likely to occur when there are general vehicles with ambiguous traffic rules
  - (FY2021~) Avoidance behavior when encountering an emergency vehicle
- Develop emergency vehicle recognition system
  - Long range: Acquire emergency vehicle information via V2I
  - Middle range: Recognize siren of emergency vehicles
  - Short range: Recognize emergency vehicles using camera/range sensors
- Develop recognition system of siren using onboard microphone
  - Sensor data collection
  - Develop recognition method using machine learning
- Design deadlock scenario of emergency vehicles based on actual driving data



Siren feature for emergency vehicles （top：ambulance, bottom: police car）

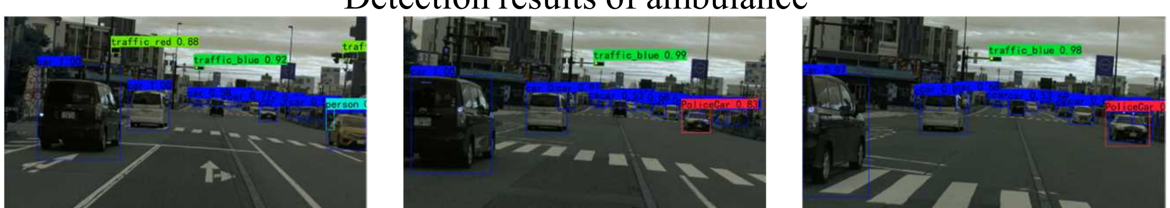
Driving scene of an emergency vehicle encountered in a demonstration experiment in the Tokyo waterfront area



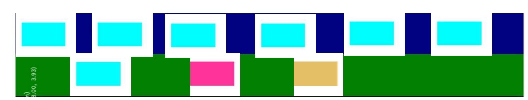
2. R&D results
2.5. e.② 「Deadlock avoidance by AI」

- Create a dataset of emergency vehicles
  - Data was collected and annotated by driving through the city of Kanazawa
  - 9 scenes, 2958 images (including 253 emergency vehicle images)
- Detection of emergency vehicles
  - The emergency vehicle is detected by the feature that the lamp is lit
- Building a Simulation Environment
  - Reproduce a scene in which a route is planned so as not to impede the travel of emergency vehicles in a traffic jam scene

Detection results of ambulance



Detection results of police car

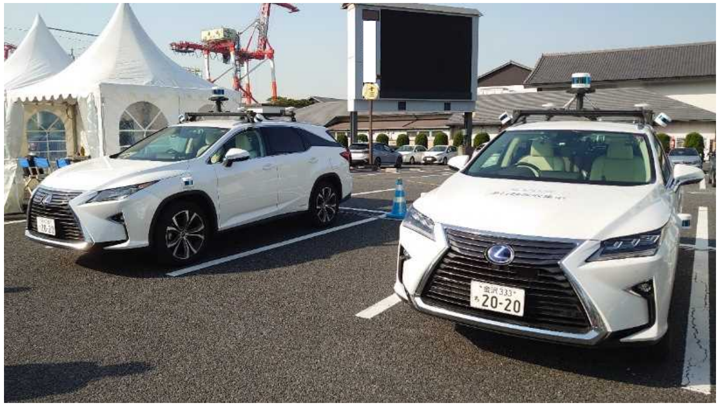


emergency vehicle
own vehicle
other vehicle

Simulation environment that reproduces traffic jam scenes

2. R&D results
2.6. f.「Demonstration experiment」

- Conducting continuous public road testing
  - Center area of Kanazawa city
  - Tokyo waterfront area
    - Odaiba area
    - Haneda area
- Start of FOT using V2N



Test drive event for the media

- Improving social acceptability
  - Test drive event for the media（April 2021）
    - Vehicle exhibition, providing test drive opportunities
- Driving record
  - 61 days of public road testing at Tokyo waterfront area
  - Totally 1,075.4km of autonomous driving

3.Project structure

Cabinet office SIP
METI

NEDO

Leader
Kanazawa Univ.
N.Suganuma

Direction
Consultation

Direction

Kanazawa Univ.
(Autonomous driving)


N.Suganuma, K. Yoneda, et al.
R&D items: a,b,c,d,e,f

Chubu Univ.
(AI)


T.Yamashita, H.Fujiyoshi, et al.
R&D items: a,b,d,e

Meijo Univ.
(GNSS)

J.Meguro, et al.
R&D items: c

R&D items

a.「Development of traffic signal recognition technology and investigation of difficult conditions」
b.「Development of AI technology required to detect distant objects」
c.「Development of high precision self-localization technology」
d.「Verification of simulators and scenarios in cooperation with SAKURA/DIVP 」
e.「Investigating problems when driving autonomous vehicle」
f. 「Demonstration experiment」

This report documents the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.