Cross-ministerial Strategic Innovation Promotion Program

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

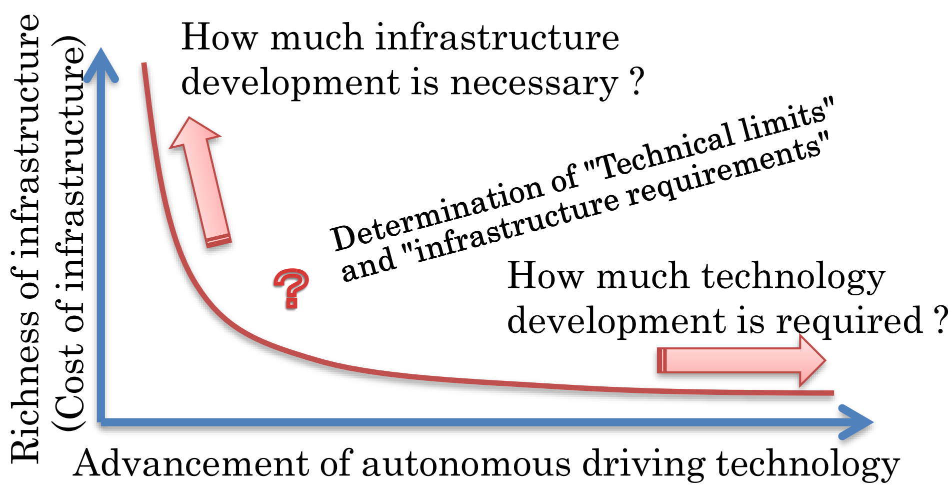
FY 2020 Report

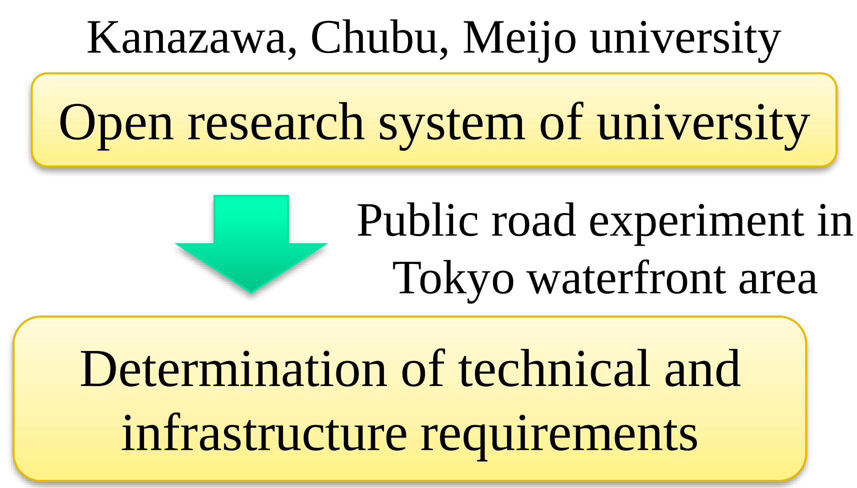
Kanazawa University
Chubu university
Meijo university

March, 2021

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

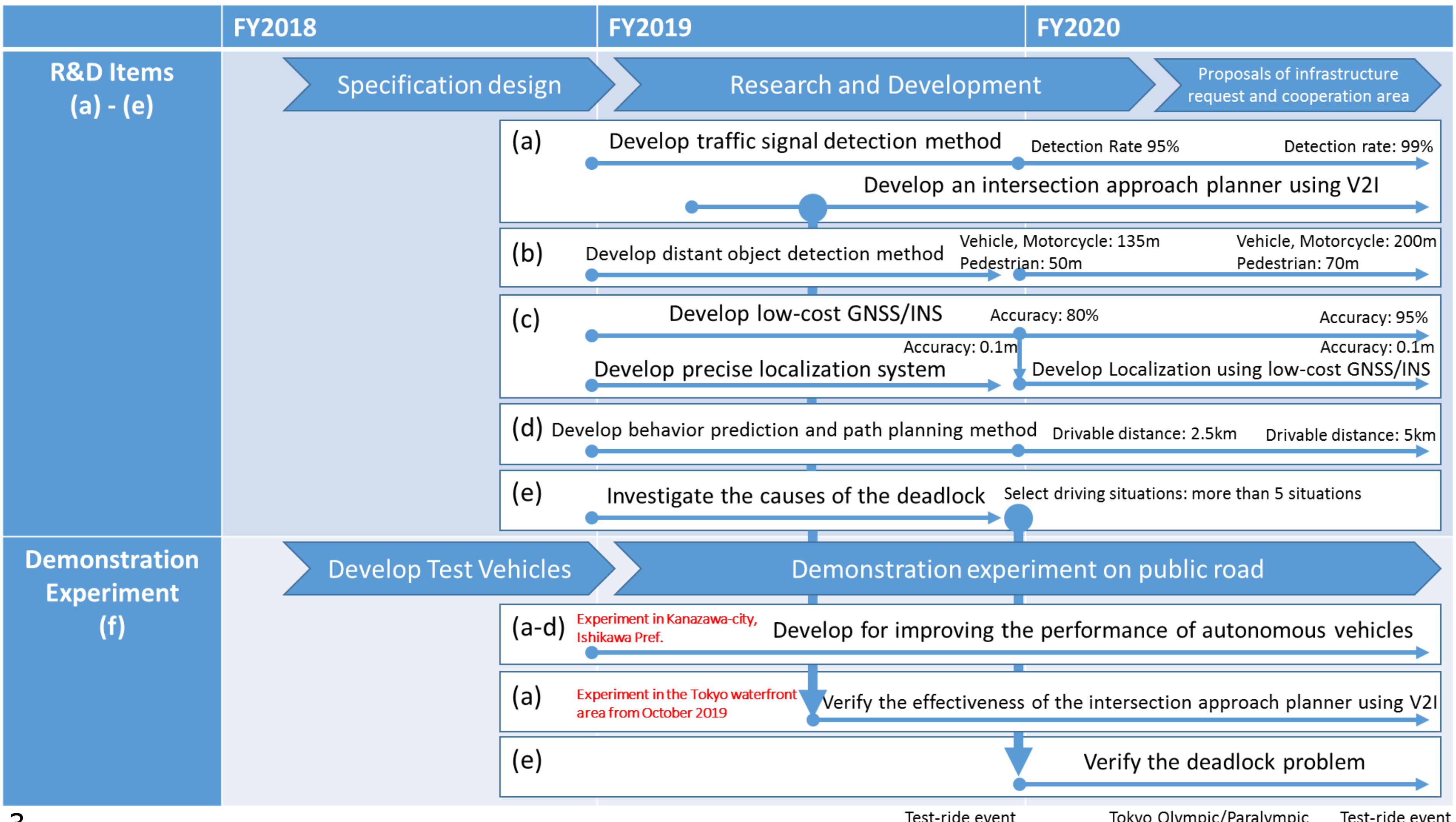




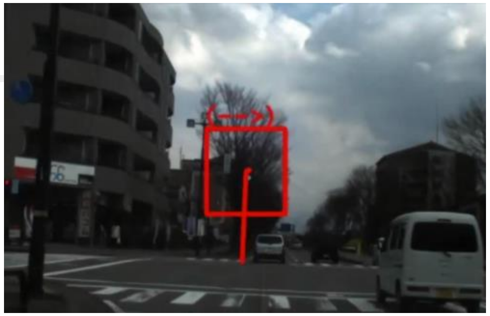
1.1.R&D items

- 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」
  - Distant objects recognition technology necessary for driving at urban area
- c.「Development of high precision self–localization technology」
  - Utilizing QZSS and map matching technology
  - Investigation on influence of lane line condition to autonomous vehicles
- d.「Development of behavior prediction technology of traffic participants and path planning algorithm」
  - Autonomous driving technology in high traffic volume urban area
- e.「Investigation of problem in the situation where multiple autonomous vehicle exist」
  - Investigation for deadlock problem that makes autonomous vehicle get stuck
- f.「Demonstration experiment」
  - Public road testing at Kanazawa city and Tokyo waterfront area

1.1.Schedule


FY2018
FY2019
FY2020
R&D Items
(a) - (e)
Specification design
Research and Development
Proposals of infrastructure request and cooperation area
(a)
Develop traffic signal detection method
Detection Rate 95%
Detection rate: 99%
Develop an intersection approach planner using V2I
(b)
Develop distant object detection method
Vehicle, Motorcycle: 135m
Pedestrian: 50m
Vehicle, Motorcycle: 200m
Pedestrian: 70m
(c)
Develop low-cost GNSS/INS
Accuracy: 80%
Accuracy: 95%
Accuracy: 0.1m
Develop precise localization system
Accuracy: 0.1m
Develop Localization using low-cost GNSS/INS
(d)
Develop behavior prediction and path planning method
Drivable distance: 2.5km
Drivable distance: 5km
(e)
Investigate the causes of the deadlock
Select driving situations: more than 5 situations
Demonstration
Experiment
(f)
Develop Test Vehicles
Demonstration experiment on public road
(a-d)
Experiment in Kanazawa-city, Ishikawa Pref.
Develop for improving the performance of autonomous vehicles
(a)
Experiment in the Tokyo waterfront area from October 2019
Verify the effectiveness of the intersection approach planner using V2I
(e)
Verify the deadlock problem
Test-ride event
Tokyo Olympic/Paralympic
Test-ride event

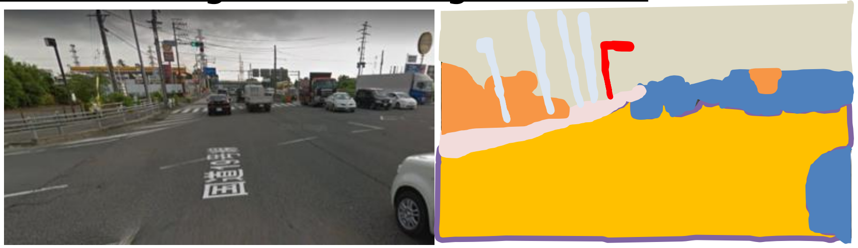
1.2. Development contents and goals
a.「Development of traffic signal recognition technology and investigation of difficult conditions」



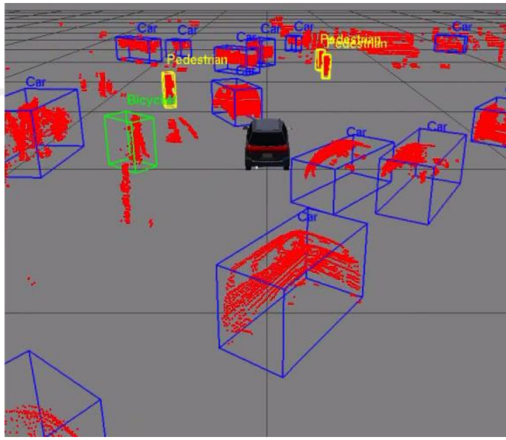
- Necessity for R&D
  - Autonomous driving on urban area
    - Need precise recognition of distant traffic signals
    - Exist situations that are difficult for human eyes to recognize (sunshine, occlusions)
  - It is necessary to maintain an infrastructure-supported traffic signal using V2I communication
    - 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 (Evaluate the effectiveness in Tokyo waterfront area)

    FY2020： Evaluate a far traffic / arrow light detection method, and verify a decision-making method using V2I for intersection approaching
  - ②「Development of the method based on semantic segmentation」
    - Solve situations that are difficult to recognize with conventional methods (degraded ramp traffic signal, occlusions)

    FY2020：Develop a traffic light recognition method using semantic segmentation
  - FY2020 Goal: 99% recognition rate of traffic lights (red and green) and arrow lights within 120m



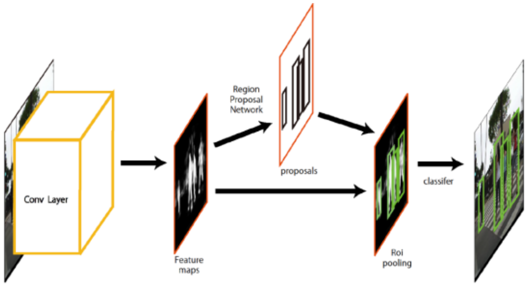
1.2. Development contents and goals
b.「Development of AI technology required to detect distant objects」



- 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)

- 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

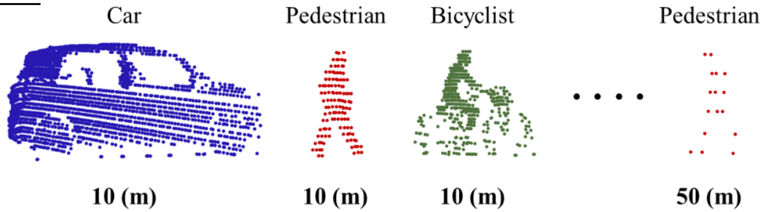
    <u>FY2020：Develop a fast object detection DNN for far object</u>



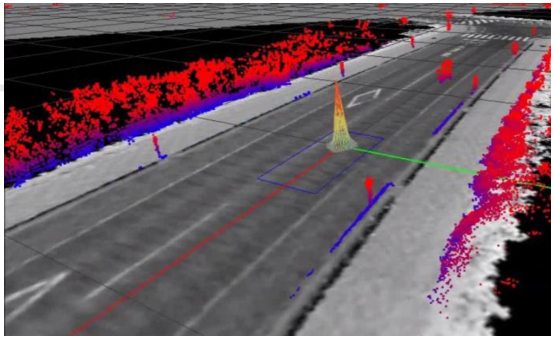
  - ②「Distant object detection by LiDAR and RADAR」
    - Improve detection distance by sensor fusion using LiDAR and Radar
    - Develop object detection method using machine learning
    - Design feature values specialized for distant objects

    <u>FY2020：Develop a camera-based object detection using digital map and an object recognition method using LiDAR-camera fusion</u>

  - <u>FY2020 Goal: 90% recognition rate of vehicle within 200m and pedestrian within 70m</u>

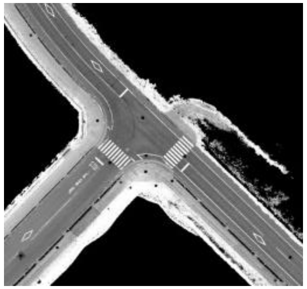


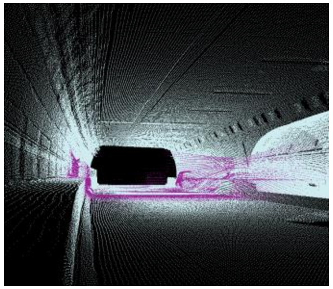
1.2. Development contents and goals c.「Development of high precision self-localization technology」



- 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>FY2020：</u>GNSS/INS reliability determination using MICHIBIKI





  - 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>FY2020：Development of position and heading angle estimation method for automotive-grade GNSS/INS</u>

  - ③「Investigation on influence of lane line condition to self-driving system」
    - Algorithm for extracting lane line using in-vehicle sensors
    - Methods to grasp the white line condition

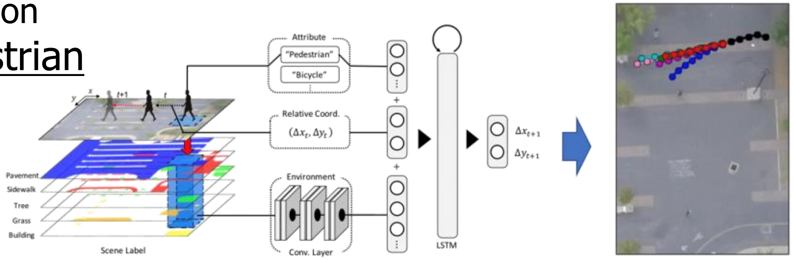
    <u>FY2020: Investigation on the lane line recognition and map matching of lane line abrasion and reflectance</u>

1.2. Development contents and goals
d.「Development of behavior prediction technology of traffic participants and path planning algorithm」

- 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

- 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

    FY2020：Evaluate behavior prediction of pedestrian using DNN



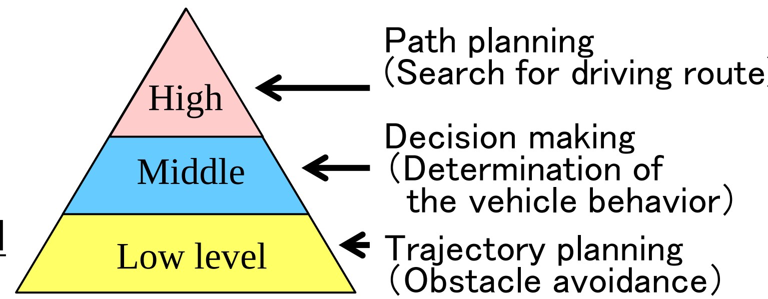
  - ②「Vehicle behavior prediction by tracking and path planning」
    - Estimate motion state and shape of dynamic objects, and develop behavior prediction using digital map
    - Develop an advanced trajectory planning method considering the predicted behavior (smooth and safe autonomous driving in a narrow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

    FY2020：Develop object tracking algorithm for surrounding moving objects and introduced to the experimental vehicle
  - FY2020 Goal: Average sustained driving distance exceeded 5km

1.2. Development contents and goals
e.「Investigation of problem in the situation where multiple autonomous vehicle exist」

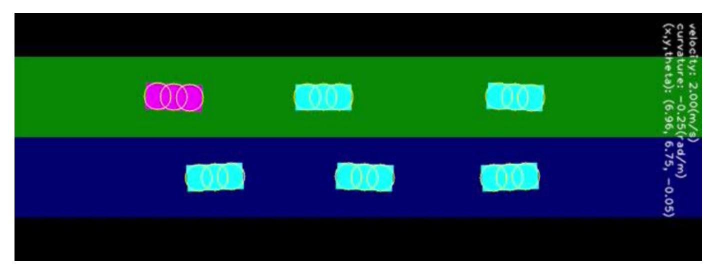
- Necessity for R&D
  - Future urban area:
    A mixture of many autonomous vehicles
  - Deadlock problem (Behavior that mutually gives over)
    - An encounter between autonomous vehicles with no inter-vehicle communication device.
    - Examples of intersections without traffic lights, entrances to commercial facilities, merging to highways, etc.
- 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>FY2020：Develop a deadlock avoidance method and evaluate it by real vehicle experiments</u>



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

    <u>FY2020: Develop a deadlock avoidance method using Deep reinforcement learning</u>



  - <u>FY2020 Goal: Verify effectiveness of a deadlock avoidance method</u>

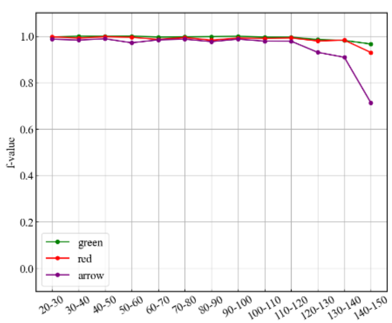
1.2. Development contents and goals f.「Demonstration experiment」

- 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, ITS communication, etc.

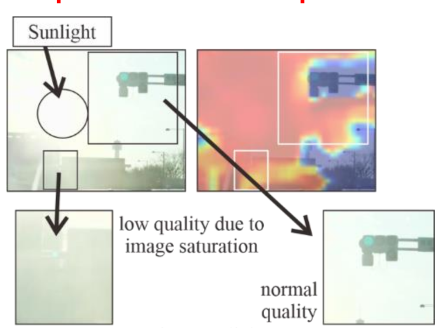
FY2020: Conducting continuous public road testing of autonomous driving and providing test driving opportunities for improving social acceptability.

2. R&D results
2.1. a.① 「Traffic signal recognition by pattern recognition and decision making for intersection entering」

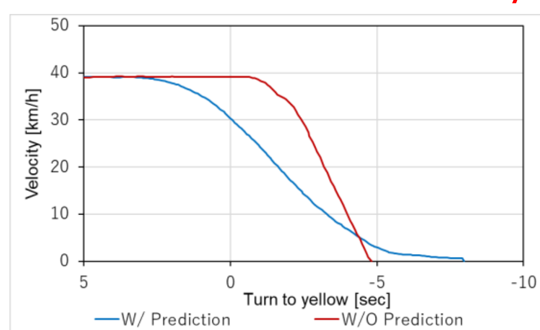
- Evaluate a recognition method for traffic/arrow lights using digital map
  - Evaluated data: Recorded at Tokyo water front area (day, night, night, sunshine)
    - F-value：99.0% (green, red, arrow lights within 120m)
      - Environmental upset scenes: occlusion, background assimilation, night, sunshine
  - Situations affecting intersection approaching
    - Unable to determine entry in case of unrecognizable situation continues (no problem with evaluated data)
    - Unable to start in case of the front traffic lights cannot be recognized due to sunshine
- Evaluate of the influence range of sunshine
  - Back light: The range of influence is limited. Develop a method of recognizing glare-region by DNN
  - Forward light: it is difficult to distinguish the lighting color for the lamp type traffic lights
- Evaluate intersection approaching using V2I
  - Verify effectiveness of reducing deceleration in dilemma zone
    - Conducting experiments on public roads in consideration of safety



Evaluated results of traffic light recognition



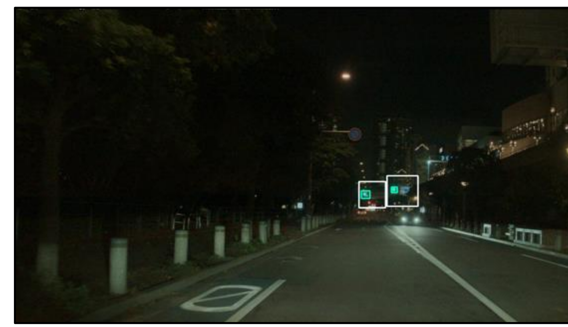
Recognize Sun-glare region

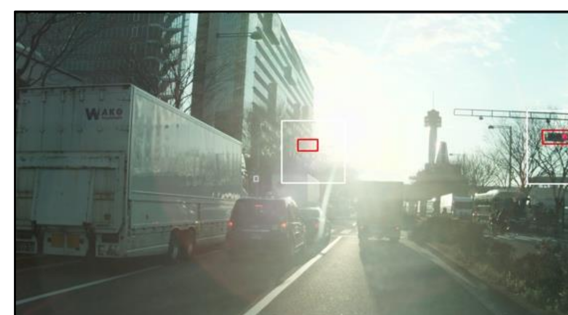


Reduction of rapid dec. using V2I (Left: velocity, Right: experimental area.)

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

- Development of 2 stages algorithm
  - 1^{st} stage : semantic segmentation based on HRNet
  - 2^{nd} stage : status recognition based on mobilenet v2
- Evaluation data: Tokyo bay front
- accuracy without time series processing : 97.28%
- accuracy with time series processing : 98.96 %





recognition accuracy[%](without time series processing)

	All	＞20 pixel
daytime	89.63	99.28
night	96.15	97.14
All time	95.65	97.28

recognition accuracy[%](with time series processing)

	All	＞20 pixel
daytime	98.35	99.49
night	98.55	98.84
All time	98.51	98.96

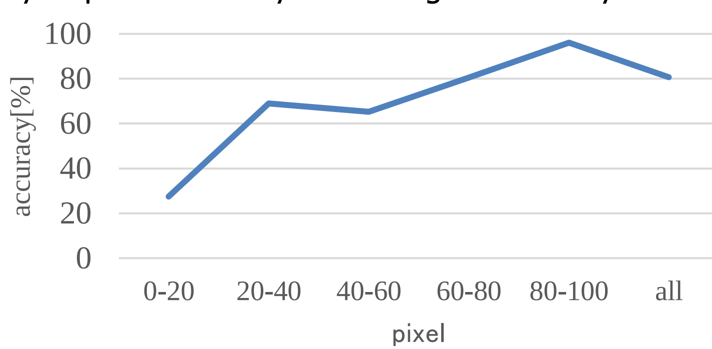
2. R&D results
2.2. b.① 「Distant object detection and camera selection」

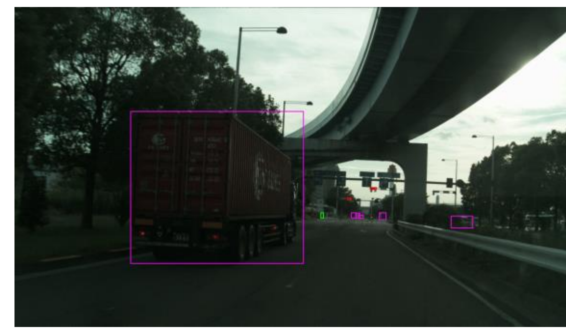
- Development of detection based on YOLO v4
  - improve input image size and internal of network
- Evaluate dataset : Tokyo bay front
  - pedestrian (70m) : enable
  - vehicle (200m) : enable

Accuracy of each size(mAP)

size	0–25	25–35	35–50	50–70	all
car	0.231	0.375	0.498	0.548	0.768
pedstrian	0.008	0.084	0.134	0.238	0.590
bike	0.010	0.033	0.138	0.371	0.456

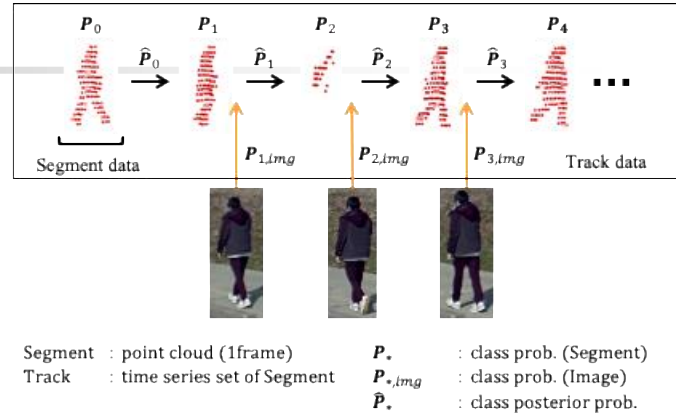
Accuracy of pedestrians by size in a good visibility environment





70m for a pedestrian is equivalent to 48 pixels
200m for a car is equivalent to 25 pixels

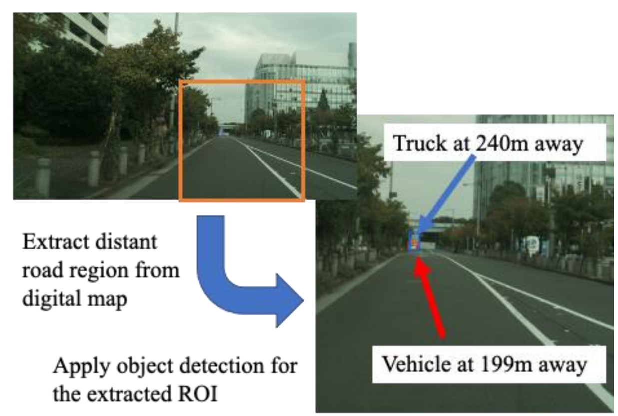
2. R&D results
2.2. b.② 「Distant object detection by LiDAR and RADAR」



- Development of an object recognition using LiDAR-Camera fusion
  - Object：Vehicle, Bicyclist, Pedestrian
    - LiDAR recognition: classify object point cloud
    - Camera recognition: detect object bounding box
    - Correspondence of both results with time series tracking
- Develop a far object detection method using digital map
  - Extract distant road regions from the map and determine region-of-interest (ROI)
    - Achieve object detection specialized for distant area
- Evaluation of recognition performance
  - Test data was recorded on a straight road of Kanazawa univ.
  - F-value: 96.2%(Veh. within 200m), 91.8%(Bicyc. Within 100m), 90%(Ped. Within 100m)
    - Time series tracking, and sensor fusion improve recog. rate

Evaluated results using LiDAR-camera fusion at the straight road

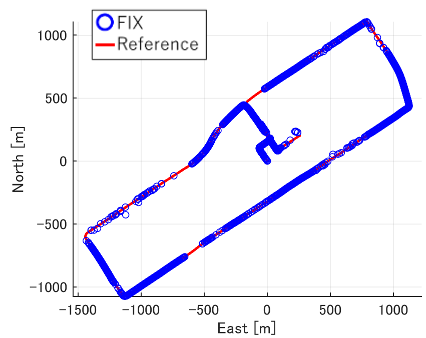
	Vehicle	Bicyclist	Pedestrian
Evaluation Range	20m-200m	20m-100m	20m-100m
Segment	0.853	0.573	0.710
Tracking (LiDAR)	0.973	0.904	0.868
Tracking (LiDAR w/ Image)	0.973	0.918	0.920
Tracking (LiDAR w/ Image + ROI)	0.977	0.922	0.933



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

- GNSS/INS reliability determination using MICHIBIKI
  - GNSS positioning improved on the CLAS LIB
  - GNSS/INS using the reliability determination by utilizing the height variation
  - Confirmed the effect of increasing the number of CLAS-enabled satellites to 17

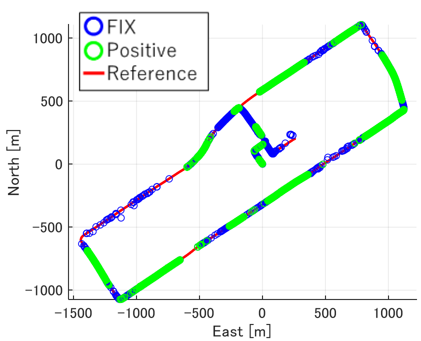
Evaluation course in Odaiba



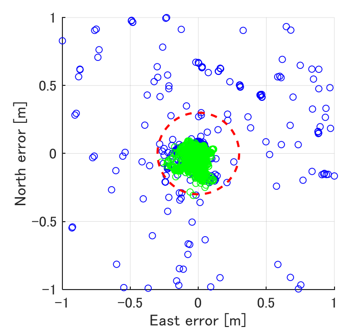
CLAS positioning results

Target positional accuracy achieved on evaluation course in Odaiba

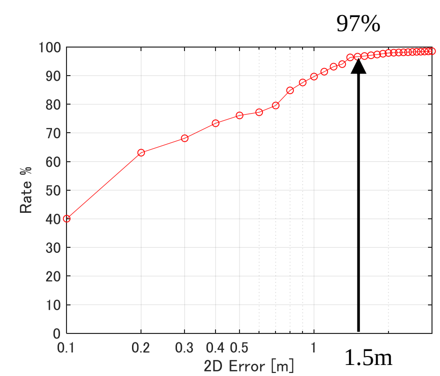
- 1.5 m position accuracy 97%
- 0.3m reliability 99%



Results of reliability judgment



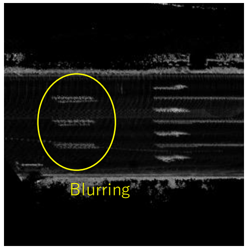
Positional accuracy after reliability determination



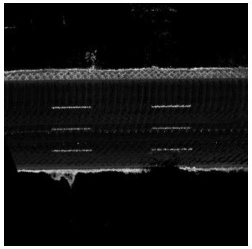
Position accuracy ratio of GNSS/INS utilizing CLAS

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

LiDAR image with low precision heading angle

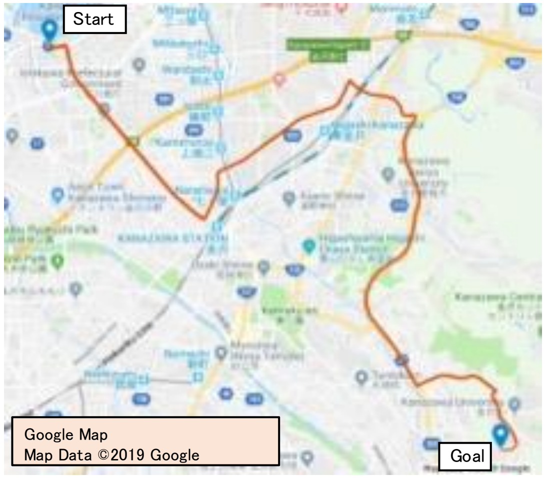


LiDAR image with accurate heading angle



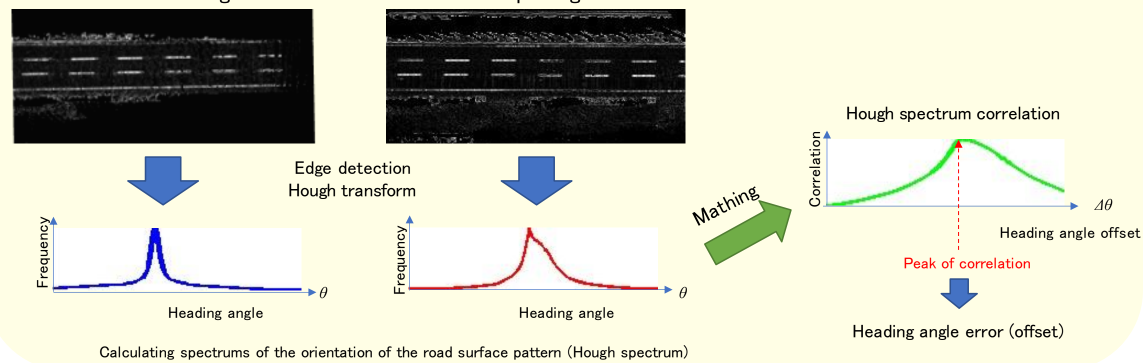
A blurring occurs in the LiDAR image due to low heading angle accuracy
→ Decreasing position accuracy

- Development of position and heading angle estimation method for automotive-grade GNSS/INS
  - Automotive-grade GNSS/INS:
    - Equipped with an inexpensive gyro sensor. Heading angle is less accurate than high precision GNSS/INS.
    - Blurring occurs when sensor data is mapped using heading angle of the GNSS/INS.
  - Development of heading angle estimation method
    - Heading angle estimation based on Hough transform
    - Focus on the orientation of the road surface pattern in the image. Estimate the heading error from the angle difference between the map image and the LiDAR image.
  - Accuracy evaluation
    - Evaluation using driving data in Kanazawa city: Achievement of target position estimation accuracy 0.1 m.



Route for evaluation in Kanazawa city

Heading angle estimation method

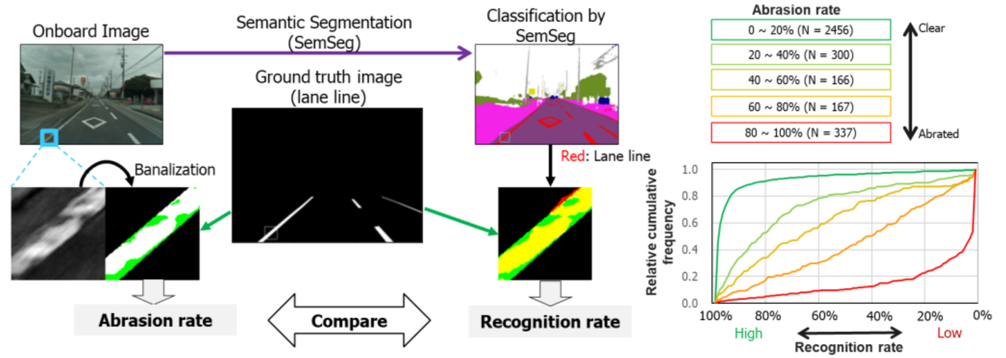


Estimation RMS Error

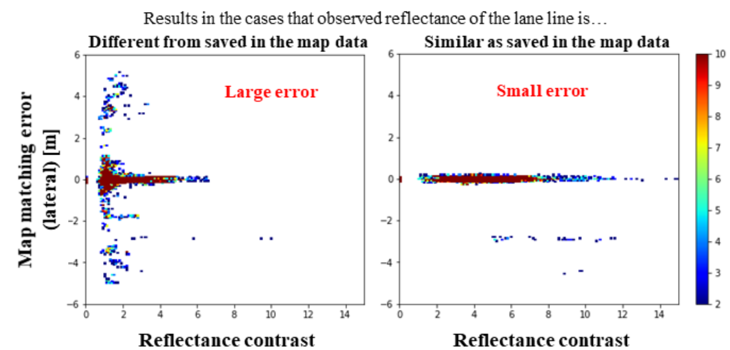
Longitudinal RMSE [m]	Lateral RMSE [m]	2-D position RMSE [m]	Heading angle RMSE [deg]
0.12	0.06	0.08	0.12

2. R&D results
2.3. c.③「Investigation on influence of lane line condition to self-driving system」

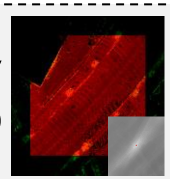
- Relationship between the abrasion rate and the recognition rate of a lane line
  - The higher the abrasion rate, the lower the recognition rate tends to be.



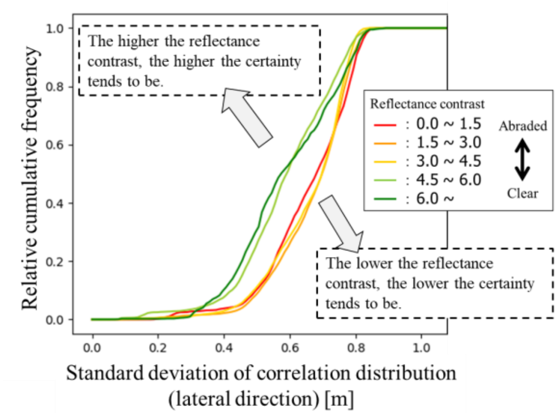
- Effect of lane line reflectance on map matching error and its certainty
  - If the reflectance data of the lane line saved in the map data is different from the actual one, the error tends to be large.
  - Even if the matching error is small, the higher the reflectance contrast between the white line and the pavement, the higher the certainty of map matching tends to be.



The matching position is correct, but the correlation distribution (shown in the lower right figure) is not sharp ⇒ low confidence

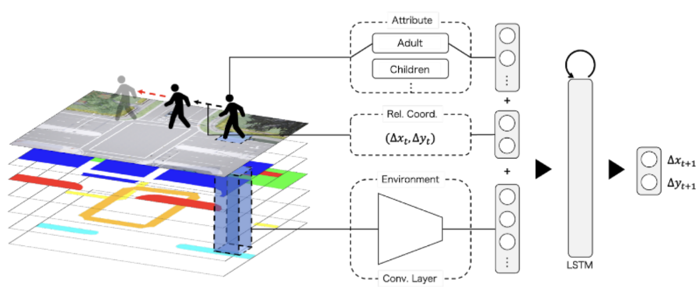


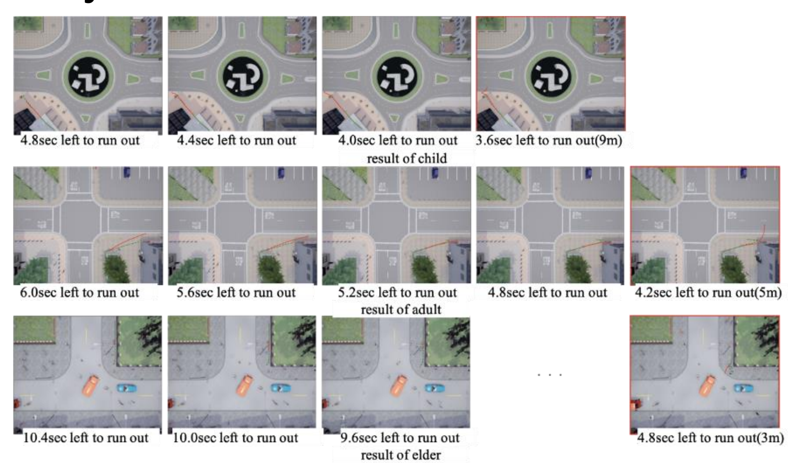
Matching position is correct, and sharp correlation distribution ⇒ high confidence



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

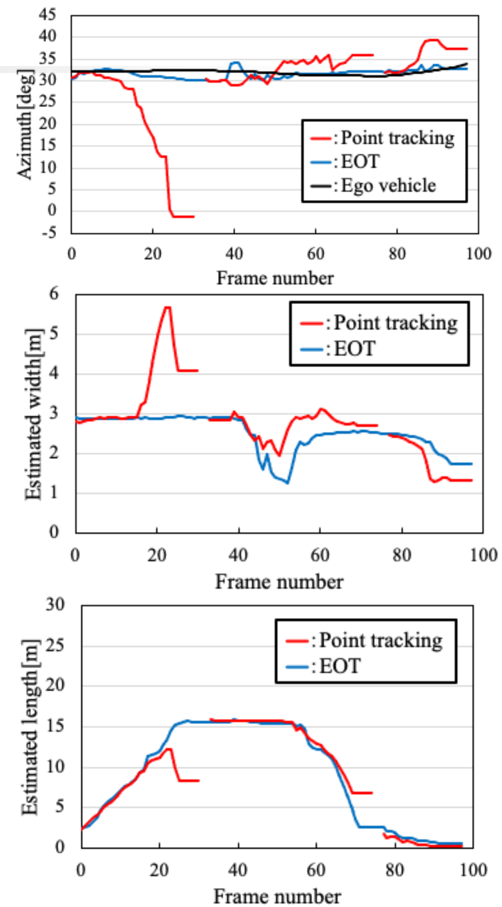
- Development and analysis of path prediction
  - From the car's point of view: Difficult
    (due to the amount of movement of the car)
  - From an bird's eye view: Predictable
    (regardless of the amount of movement of the car)
- Analysis of prediction of ejection route by pedestrian attributes
  - Elderly/adults: 3m/5m away from the road is predictable
  - Children: Must be at least 9 meters away from the road





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

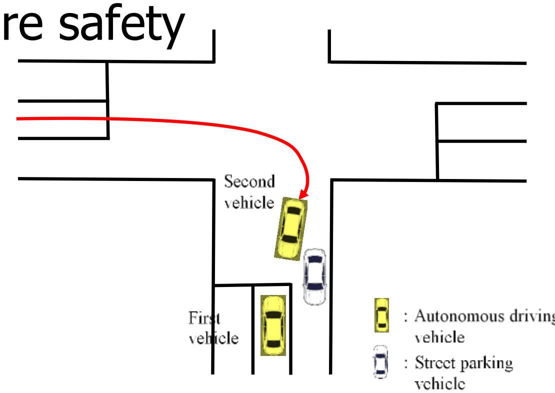
- Implement Extended object tracking algorithm
  - Modeling the contour of object
  - Representing object shape using B-spline curve
  - Evaluate tracking stability for actual driving data
  - Real-time implementation of developed method to introduce to experimental vehicle
- Performance Evaluation of Autonomous Vehicle on Public Roads
  - Evaluate of average sustained driving distance in demonstration experiments in Kanazawa city
    - Average sustained driving distance: 5.860km
  - Investigate cases of failure factors of overriding autonomous driving from demonstration experiments in the Tokyo water front area
    - Turn right at an intersection when a blind area occurs due to the presence of road structures or other vehicles
    - Turn right at an intersection where the lighting time of the arrow light is short
    - Sudden deceleration when the traffic light turns yellow while approaching an intersection (dilemma zone)



Evaluated results of object tracking
Developed method: EOT

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

- Clarification of situations where deadlock can occurs
  - Post-processing type: Tackle using robotics technology
  - Pre-prevention type: Tackle using AI technology
- Develop a deadlock avoidance algorithm by robotics technology
  - Develop a route planning algorithm to deviate from the lane and bypasses the space available for driving
- Verify effectiveness of deadlock avoidance for real vehicle
  - Conducted experiments on nonpublic road to ensure safety
  - Appropriate maneuver is verified when there is enough avoidance space



Deadlock is occurred | Update available route | Avoid deadlock

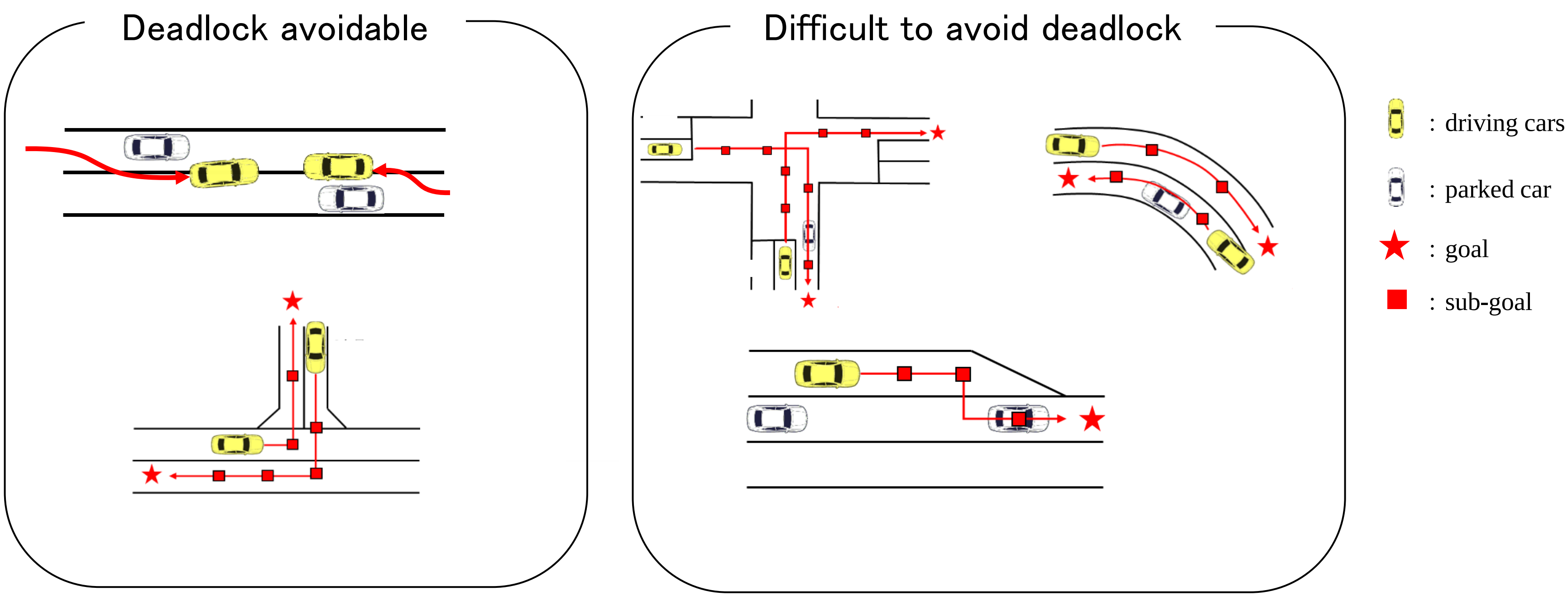
Develop deadlock avoidance method

Deadlock is occurred | Update available route | Avoid deadlock

Verify effectiveness of deadlock avoidance

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

- Feasibility Study on Avoiding Deadlock Condition by Deep Reinforcement Learning
  - Build a simulation environment for the five scenes extracted from the demonstration experiment
  - Design reward and learning in each scene
  - Deadlock avoidance is possible in two 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
- Improving social acceptability
  - Guided tour for the media.
    - September, 2020
  - SIP-adus interim results briefing session
    - March, 2021
- Driving record
  - 54 days of public road testing at Tokyo waterfront area
  - Totally 1,287.2km of autonomous driving

SIP-adus interim results briefing session

3.Project structure

Cabinet office SIP
METI

NEDO

Leader
Kanazawa Univ.
N.Suganuma

Direction / Consultation (between Leader and NEDO)

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.「Development of behavior prediction technology of traffic participants and path planning algorithm」
e.「Investigation of problem in the situation where multiple autonomous vehicle exist」
f. 「Demonstration experiment」