# 「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) 」

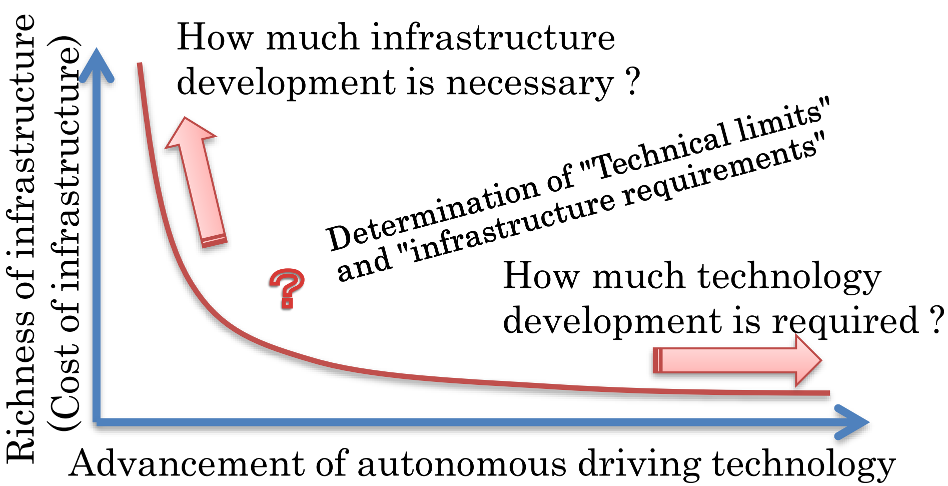
# FY 2019 Report

Kanazawa University
Chubu university
Meijo university

March, 2020

# 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




Kanazawa, Chubu, Meijo university

Open research system of university

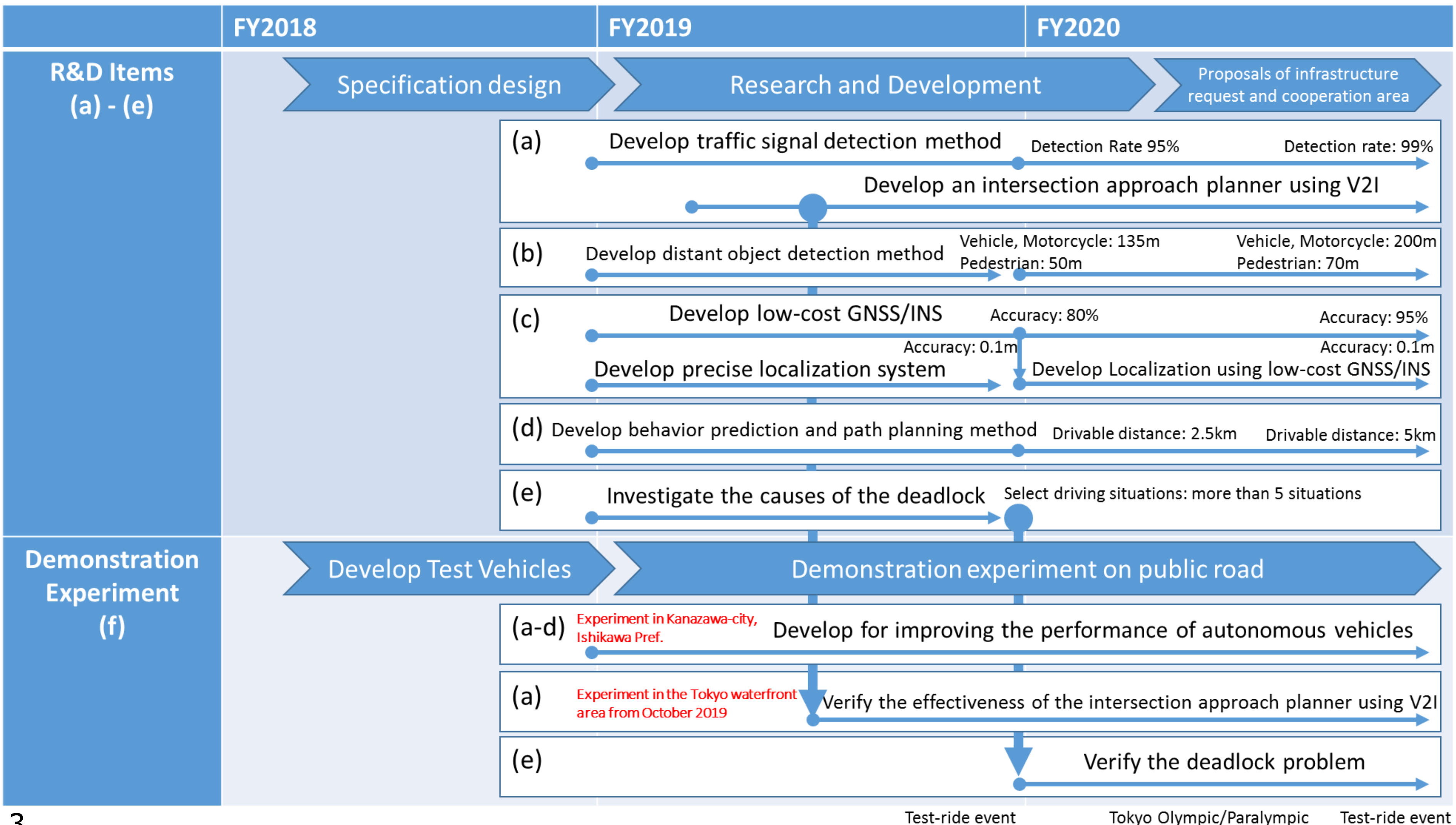
Public road experiment in Tokyo waterfront area

Determination of technical and infrastructure requirements

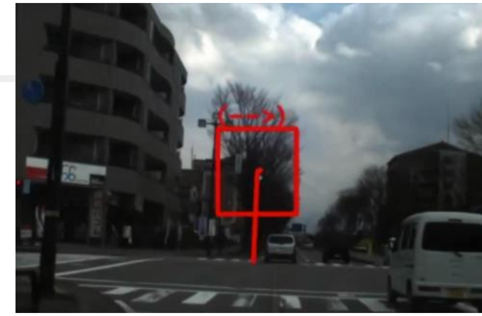
# 1.1.R&D items

- 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.Shedule


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
Accuracy: 0.1m
Develop precise localization system
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」



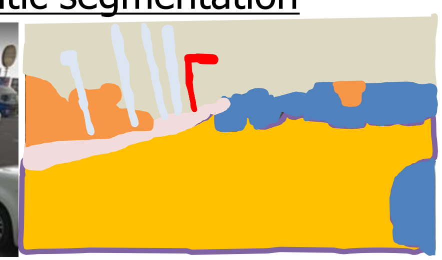
- Necessity for R&D
  - Autonomous driving on urban area
    - Need precise recognition of distant traffic signals
    - Exist situations that are difficult for human eyes to recognize (sunshine, occlusions)
  - It is necessary to maintain an infrastructure-supported traffic signal using V2I communication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

    <u>FY2019： Develop a far traffic / arrow light detection method, and a decision-making method using V2I for intersection approaching</u>

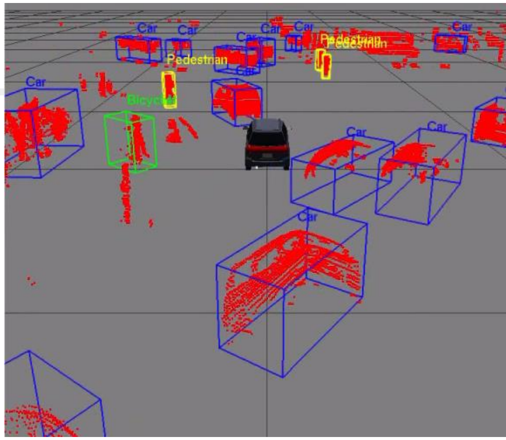
  - ②「Development of the method based on semantic segmentation」
    - Solve situations that are difficult to recognize with conventional methods (degraded ramp traffic signal, occlusions)

    <u>FY2019：Evaluate traffic signal recognition method based on semantic segmentation</u>

  - <u>FY2019 Goal: 95% recognition rate of traffic lights (red and green) and arrow lights within 120m</u>



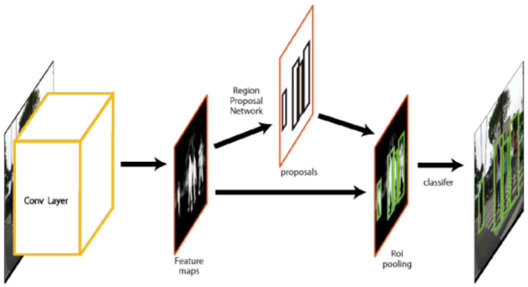
# 1.2. Development contents and goals
# b.「Development of AI technology required to detect distant objects」



- ## 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)

- ## 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

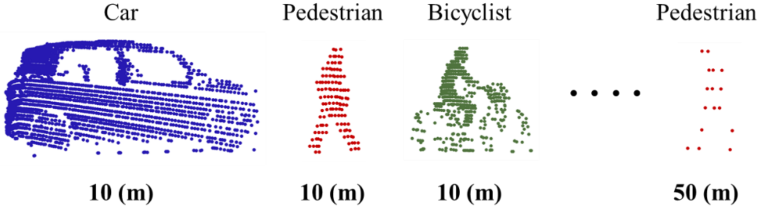
    <u>FY2019：Develop a fast object detection DNN for far object</u>



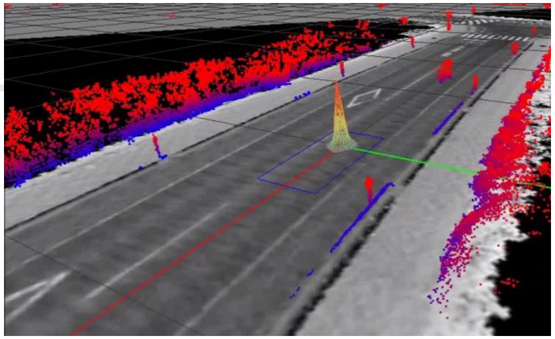

  - ②「Distant object detection by LiDAR and RADAR」
    - Improve detection distance by sensor fusion using LiDAR and Radar
    - Develop object detection method using machine learning
    - Design feature values specialized for distant objects

    <u>FY2019：Develop an object recognition method using LiDAR-camera fusion</u>

  - <u>FY2019 Goal: 90% recognition rate of vehicle within 135m and pedestrian within 50m</u>

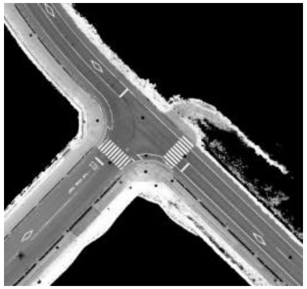


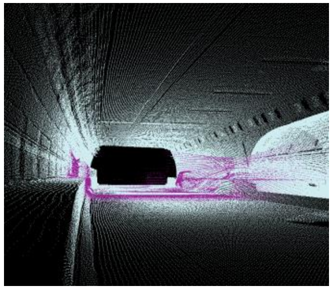
# 1.2. Development contents and goals c.「Development of high precision self-localization technology」



- 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"

    FY2019： FY2019:Realization of high-precision (0.3 m) position/confidence estimation





  - 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

    FY2019：Implementation and Evaluation of map matching methods
  - 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

    FY2019: Initial investigation of lane line extraction and methods to grasp lane line condition

# 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 (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

    <u>FY2019：Evaluate pedestrian attributes recognition for path prediction</u>

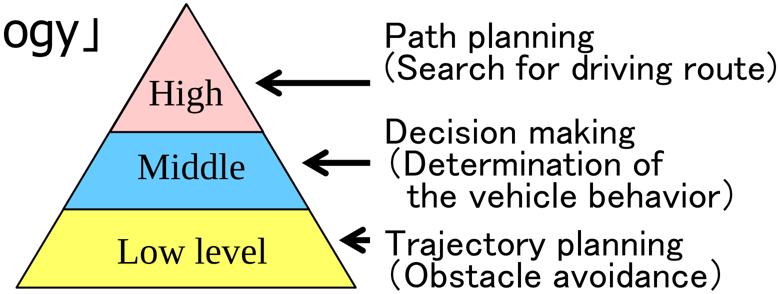
  - ②「Vehicle behavior prediction by tracking and path planning」
    - Estimate motion state and shape of moving objects, and develop behavior prediction using digital map
    - Develop an advanced trajectory planning method considering the predicted behavior (smooth and safe autonomous driving in a narrow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

    <u>FY2019： Achievement of average sustained autonomous driving distance above 2.5km</u>

# 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>FY2019：Clarification of situations where deadlock can occurs</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>FY2019：Evaluate deadlock avoidance based on reinforcement learning</u>

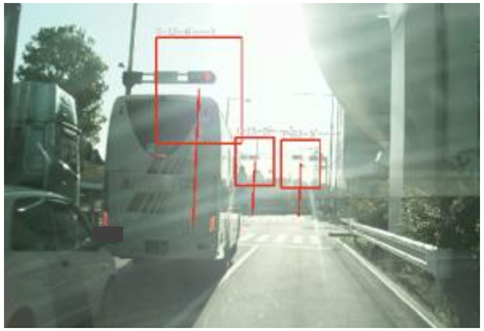
# 1.2. Development contents and goals
# f.「Demonstration experiment」

- 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.

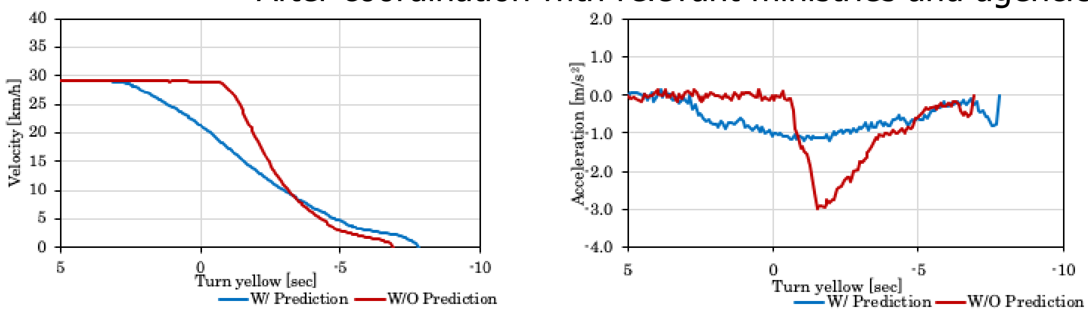
<u>FY2019: Development of two test vehicles, and start of public road testing at both Tokyo waterfront area, and Kanazawa city</u>

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

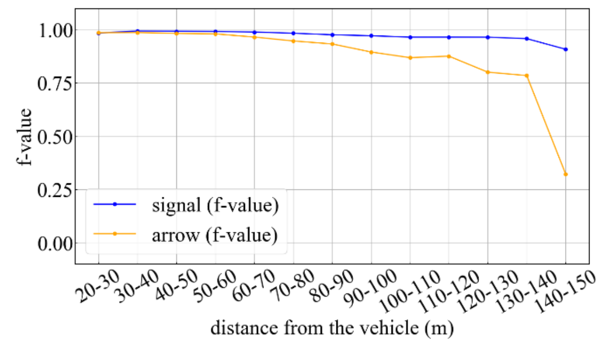
- Development of a recognition method for distant traffic/arrow lights
  - Using the relative position of traffic/arrow lights
    - The arrow lights of 10px can be recognized
- Evaluation of recognition rate
  - Driving data was recorded at Tokyo waterfront area
    - Condition: daytime, nighttime, rainy
    - F-value: 95.5% (traffic/arrow lights within 120m)
- Development of intersection approaching method
  - Reduction of rapid deceleration in a dilemma zone
    - Verify the effectiveness in non-public road (Kanazawa university)
- Future works
  - 99% recognition rate of traffic lights and arrow lights within 120m
    - List difficult conditions from both hardware and software
  - Verify the effectiveness of the improvement of the dilemma zone
    - After coordination with relevant ministries and agencies



Traffic light detection at sun glare




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




Evaluated results of traffic light recognition

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

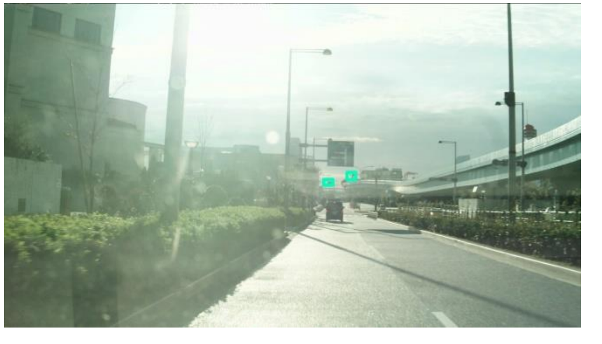
- Development of 2 stages algorithm
  - 1st stage : traffic signal detection based on DeepLab V3+
  - 2nd stage : status recognition based on ResNet
- Evaluation data: Tokyo bay front
- Detection accuracy : 96.4%
- Recognition accuracy : 91.7% (incl. detection)

Detection accuracy

| Width of signal[pixel] | Detection rate |
|---|---|
| all | 74.58% |
| > 20 pixel | 96.42% |
| > 10 pixel | 90.09% |

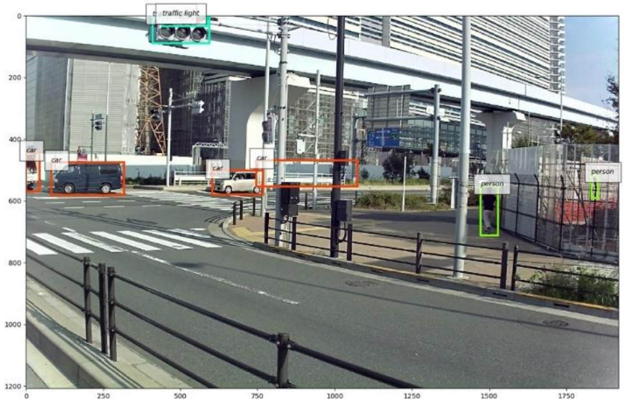
Recognition accuracy

| Width of signal[pixel] | recall | precision | F-score |
|---|---|---|---|
| all | 67.33% | 88.09% | 0.763 |
| > 20 pixel | 91.78% | 92.16% | 0.920 |
| > 10 pixel | 83.84% | 89.53% | 0.866 |



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

- Development of object detection based on Feature Pyramid Network
- Development of network architecture search for fast processing
- Evaluate dataset : Tokyo bay front
  - Pedestrian (50m) : enable
  - Vehicle (135m) : enable



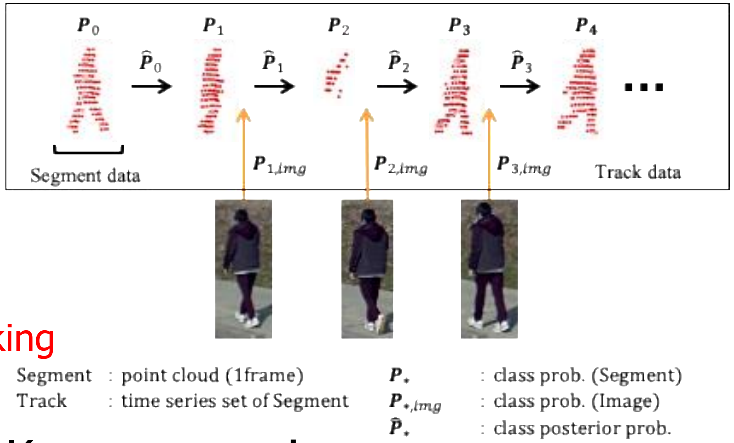


Accuracy of each size on several datasets (AP)

| Object size | 0–25 | 25–35 | 35– |
|---|---|---|---|
| Cityscapes | 0.140 | 0.228 | 0.708 |
| BDD100k | 0.382 | 0.355 | 0.738 |
| SIP(specific env.) | 0.550 | 0.368 | 0.765 |
| Tokyo bay front | 0.206 | 0.294 | 0.627 |

size of pedestrian (50m) and vehicle (135m) are 35 pixel

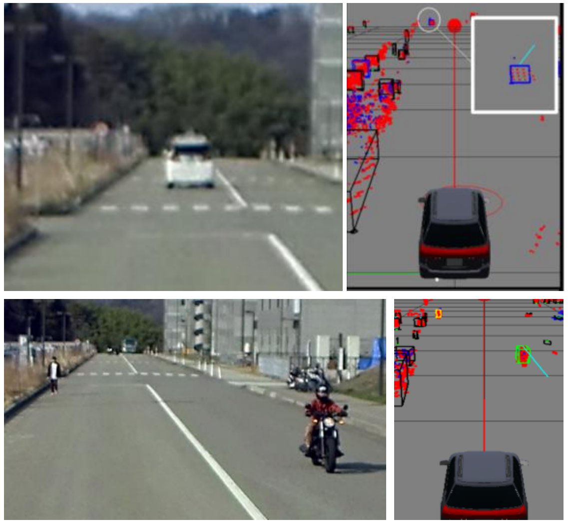
# 2. R&D results
## 2.2. b.② 「Distant object detection by LiDAR and RADAR」




- 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
- Evaluation of recognition performance
  - Test data was recorded on a straight road of Kanazawa univ.
  - F-value: 96.2%(Veh.), 91.8%(Bicyc.), 90%(Ped.)
    - Time series tracking, and sensor fusion improve recog. rate
- Future works
  - 90% recognition rate of vehicle within 200m and pedestrian within 70m
    - Evaluate driving data on public road
    - List the difficult conditions for recognition

Evaluated results using LiDAR-camera fusion at the straight road

| | Vehicle | Bicyclist | Pedestrian |
|---|---|---|---|
| Evaluation Range | 20m-140m | 20m-100m | 20m-110m |
| Segment | 0.810 | 0.573 | 0.699 |
| Tracking (LiDAR) | 0.962 | 0.904 | 0.854 |
| Tracking (LiDAR w/ Image) | 0.962 | 0.918 | 0.900 |

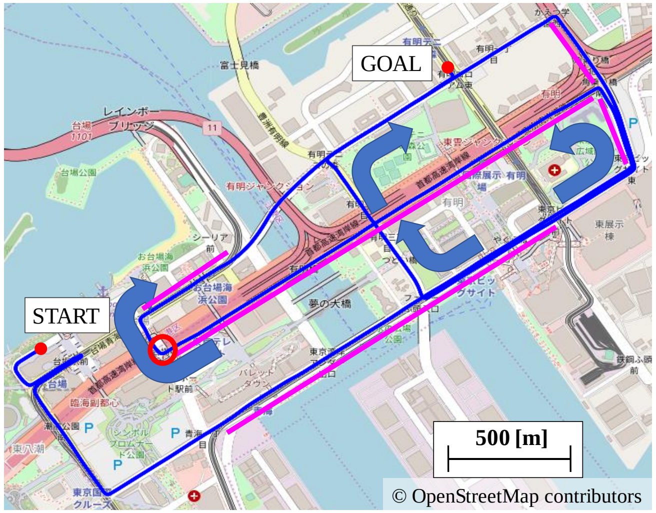


Recognized results (Top: Veh., Bottom: Ped., Bicyc.)

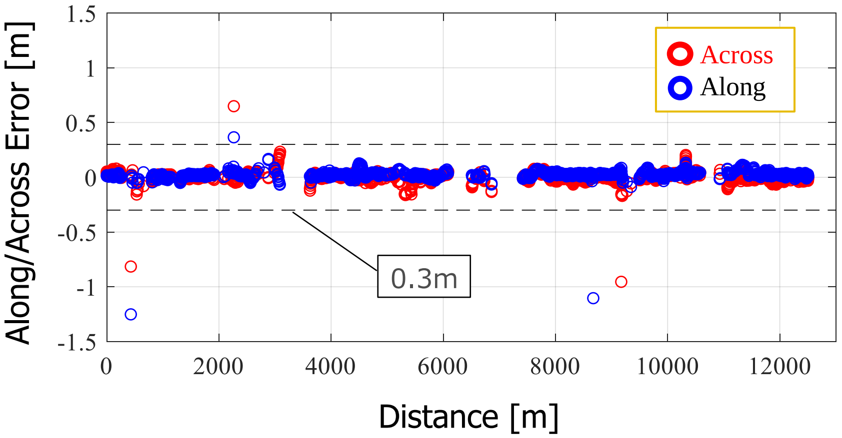
# 2. R&D results
# 2.3. c.① 「Development of GNSS/INS」

Realization of high-precision (0.3 m) position/confidence estimation

⇨ Estimation of absolute positional confidence using height movement




Evaluation Course: Odaiba




99% of solutions with high confidence (0.3m or less) are judged

Future works：

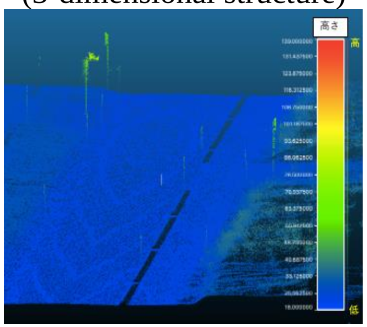
Improvement of FIX rate of RTK-GNSS by selecting GNSS raw data

Reliability judgment in GNSS/INS with error model construction of INS

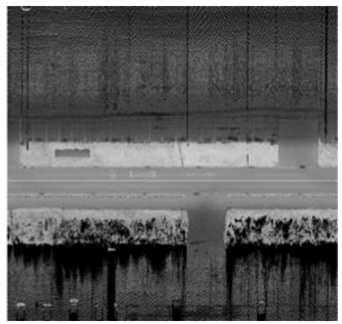
# 2. R&D results
# 2.3. c.② 「Development of map matching technology」

- Implementation and evaluation of multiple map matching method
  - Achievement of the estimation accuracy of 0.1 m
  - Investigation of the influence of plants on the estimation accuracy

NDT scan matching
3D point cloud
(3-dimensional structure)



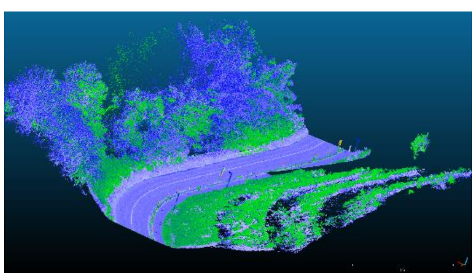
Template matching
2D ortho image (road pattern)



| | NDT scan matching (Used LiDAR points: 3000) | Template matching (LiDAR image size :48m × 48m) |
|---|---|---|
| Longitudinal RMSE [m] | 0.082 | 0.085 |
| Lateral RMSE [m] | 0.066 | 0.056 |
| Average matching time [ms] | 74 | 36 |

The target accuracy of 0.1m was achieved.
Each method can be processed in real-time.

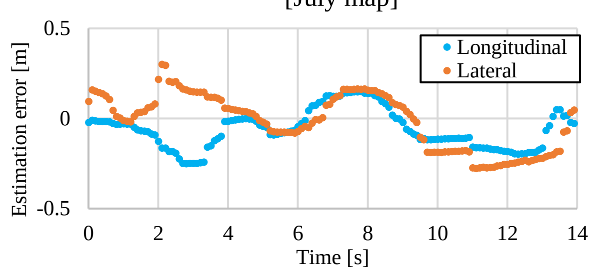
It was confirmed that changes in plants affect the estimation accuracy of NDT scan matching.



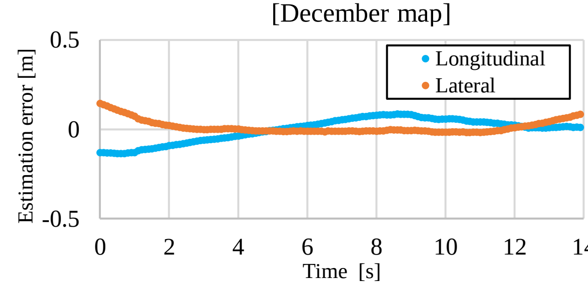
Green: July map,
Blue: December map

It is verified with the driving data of March.
The estimation accuracy becomes unstable when using the July map where the conditions of plants are very different.

[July map]




[December map]




※ Continued investigation is required on the influence of changes in road surface pattern on the estimation accuracy.

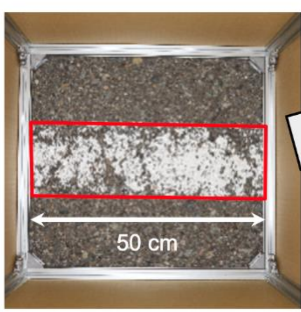
# 2. R&D results
# 2.3. c.③「Investigation on influence of lane line condition to self-driving system」

- Extraction of lane line
  - semantic segmentation technique is utilized to recognize lane lines from on-board camera images.

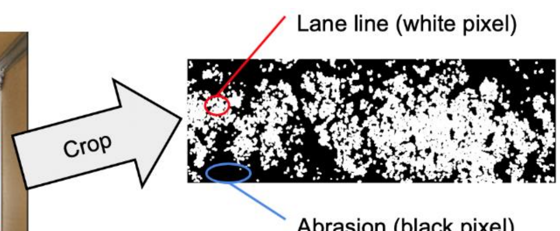
※ Red: lane line

- Methods to grasp lane line condition
  - Three kinds of perspectives: intensity level, contrast, and blurriness of lane line.
  - An original instrument with a digital camera has been manufactured as a reference, and abrasion rate is considered as a standard of blurriness.

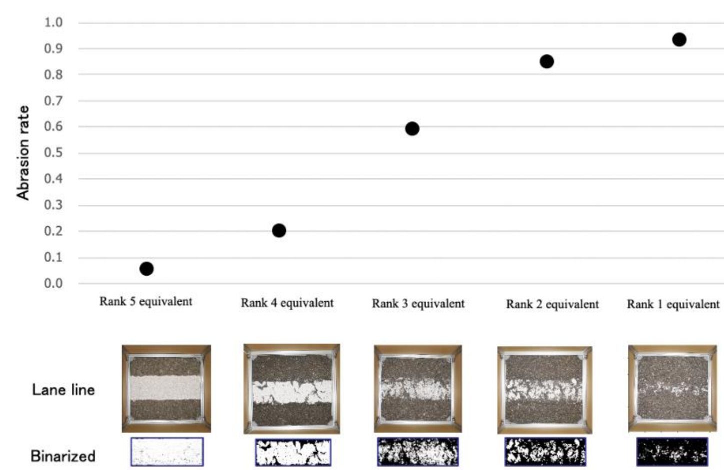
Take picture




Picture of lane line




$$\text{Abrasion rate} = \frac{\text{Num. of abrasion pixels}}{\text{Num. of whole pixels}}$$



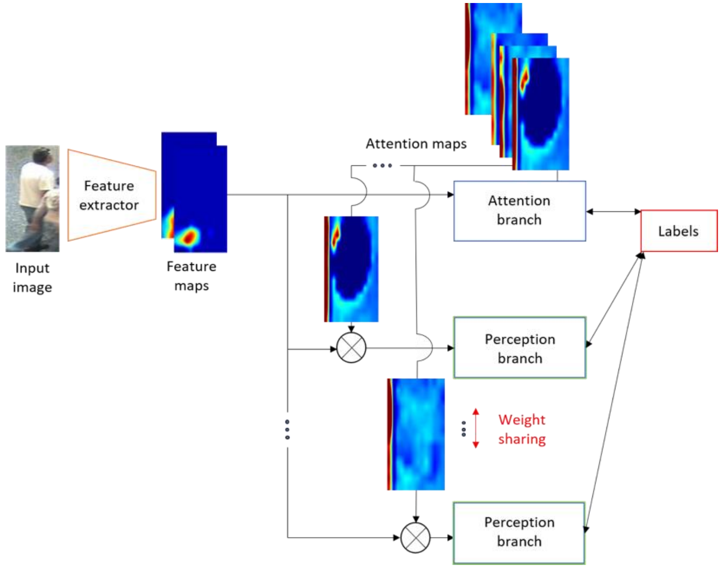
# 2.R&D results
# 2.4. d.① 「Path prediction of pedestrian based on AI」

- Development of pedestrian attribute recognition
  - Recognition of detail information such as gender, age, bring bag, for path prediction

- Better performance than conventional methods on public dataset.

Accuracy of attribute recognition(AP)

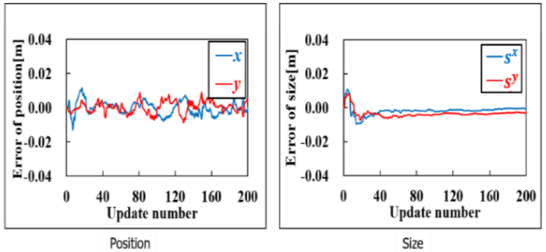
| Attribute | DeepSAR | DeepMAR | ours |
|---|---|---|---|
| Age16-30 | 82.9 | 85.8 | 80.6 |
| Age31-45 | 79.4 | 81.8 | 77.6 |
| Age46-60 | 83.3 | 86.3 | 94.1 |
| AgeAbove61 | 92.0 | 94.8 | 97.3 |
| Backpack | 78.8 | 82.6 | 76.3 |
| CarryingOther | 73.0 | 77.3 | 84.1 |
| Male | 85.1 | 89.9 | 79.2 |
| MessengerBag | 77.4 | 82.0 | 79.7 |
| average | 81.3 | 82.6 | 84.6 |



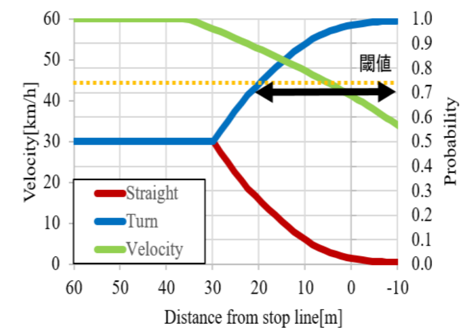

Architecture of proposed method

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

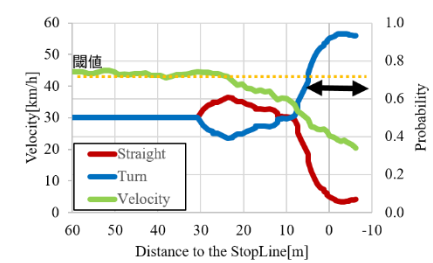
- Simultaneous estimation of motion and shape of moving objects
  - Implementation of extended object tracking (EOT) technology
    - Representing object shape using B-spline curve
    - Evaluation by simulation and actual data
  - Future work
    - Implementing in autonomous driving system and evaluating the performance of overall system
- Predicting trajectory of moving objects based on map data
  - Generating all-possible routes for surrounding vehicles, and probabilistic representation of future trajectory
    - Evaluation by simulation and actual data
  - Future work
    - Validating the proposed method in various conditions, environments and tasks
- Performance evaluation on public road
  - Evaluation in Tokyo waterfront area
  - <u>Average sustained autonomous driving distance in 7 days: 2.82km, achieved FY 2019's goal 2.5km</u>



Simulation result of EOT



Simulation result of probabilistic model for trajectory prediction

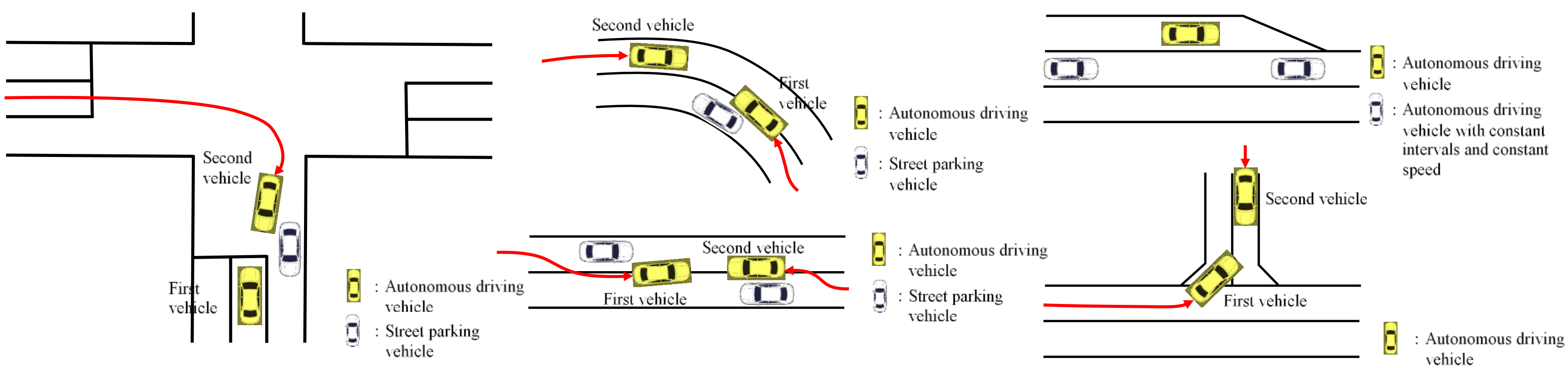


Experiment result of probabilistic model for trajectory prediction on real data

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

- Clarification of situations where deadlock can occurs
  - Development of simulation software
    - We have developed simulation software that can reproduce the behavior of multiple autonomous vehicles.
  - Reproduction of scenes where deadlock is likely to occur
    - Based on the scenes and topography encountered in the demonstration experiment, some simulations were conducted.
    - We ran multiple self-driving cars on simulation software and confirmed the scene where deadlock occurred.

Situations where deadlock can occur



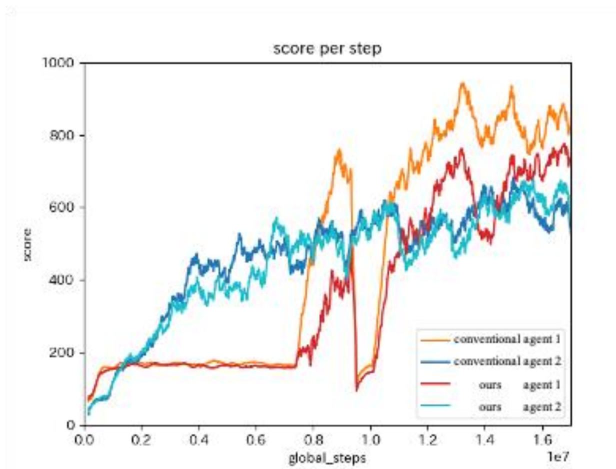
# 2. R&D results
# 2.5. e.① 「Deadlock avoidance by AI」

- Applying to difficult scene for rule-based methods
  - Survey deadlock scene in Tokyo bay front
    - A scene in which there is a parked vehicle in the driving lane and the driver avoids an oncoming vehicle
    - A scene in which there is a parked vehicle in the opposite lane while waiting for a signal and a right-turn vehicle arrives
  - Development of the algorithm based on reinforcement learning

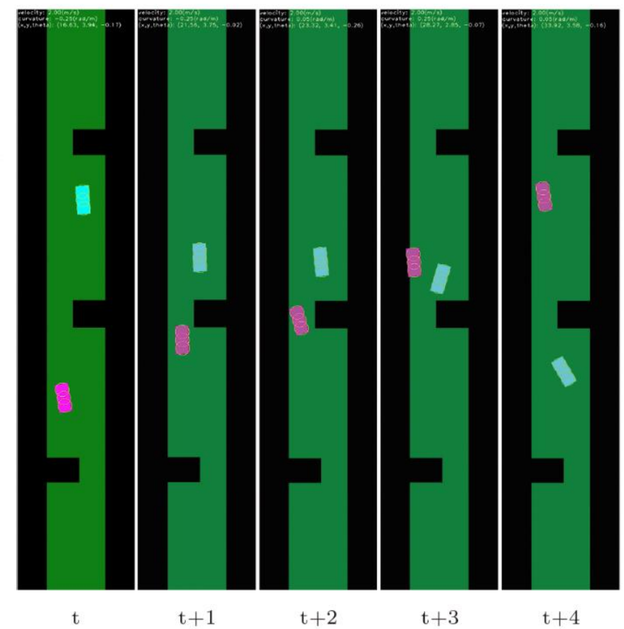
Accuracy of deadlock avoidance

| | # of Successes |
|---|---|
| Conventional | 3 |
| Ours | 398 |

# of trial : 1000




Score of each step during training




Example of deadlock avoidance

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

- Development of test vehicles
  - Two test vehicles
    - Manual override functions
    - Installation of onboard sensors
  - Preparation for public road testing
    - Safety evaluation by third party, etc.
- Start of public road testing
  - In kanazawa city from 29th July.
  - In Tokyo waterfront from 2nd September.
- Driving record
  - 67 days of public road testing at Tokyo waterfront area
  - Totally 850.6km of autonomous driving

Autonomous driving
in the Tokyo waterfront

# 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.「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」