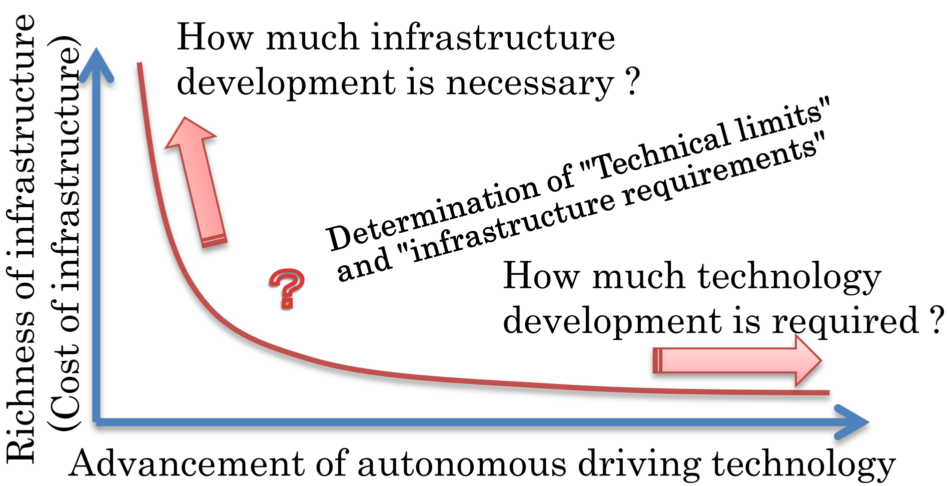
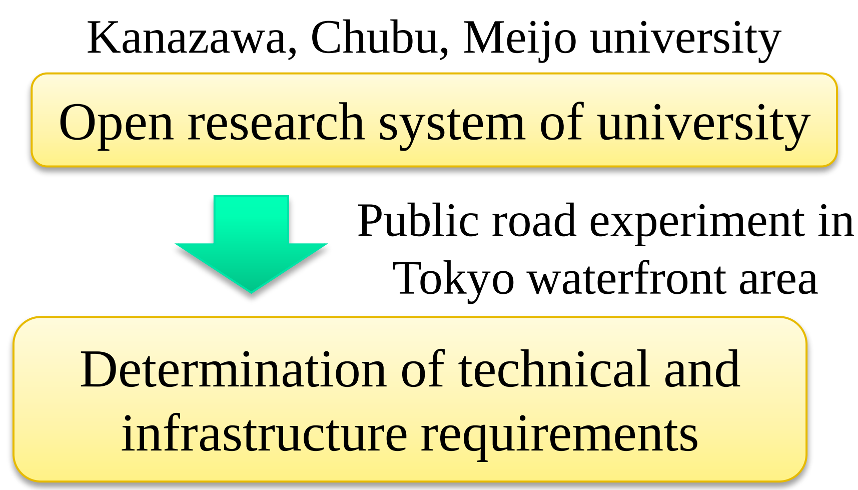
「Research on recognition technology etc. necessary for autonomous driving (Level 3, 4) 」

＜Kanazawa university, Chubu university, Meijo university＞

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

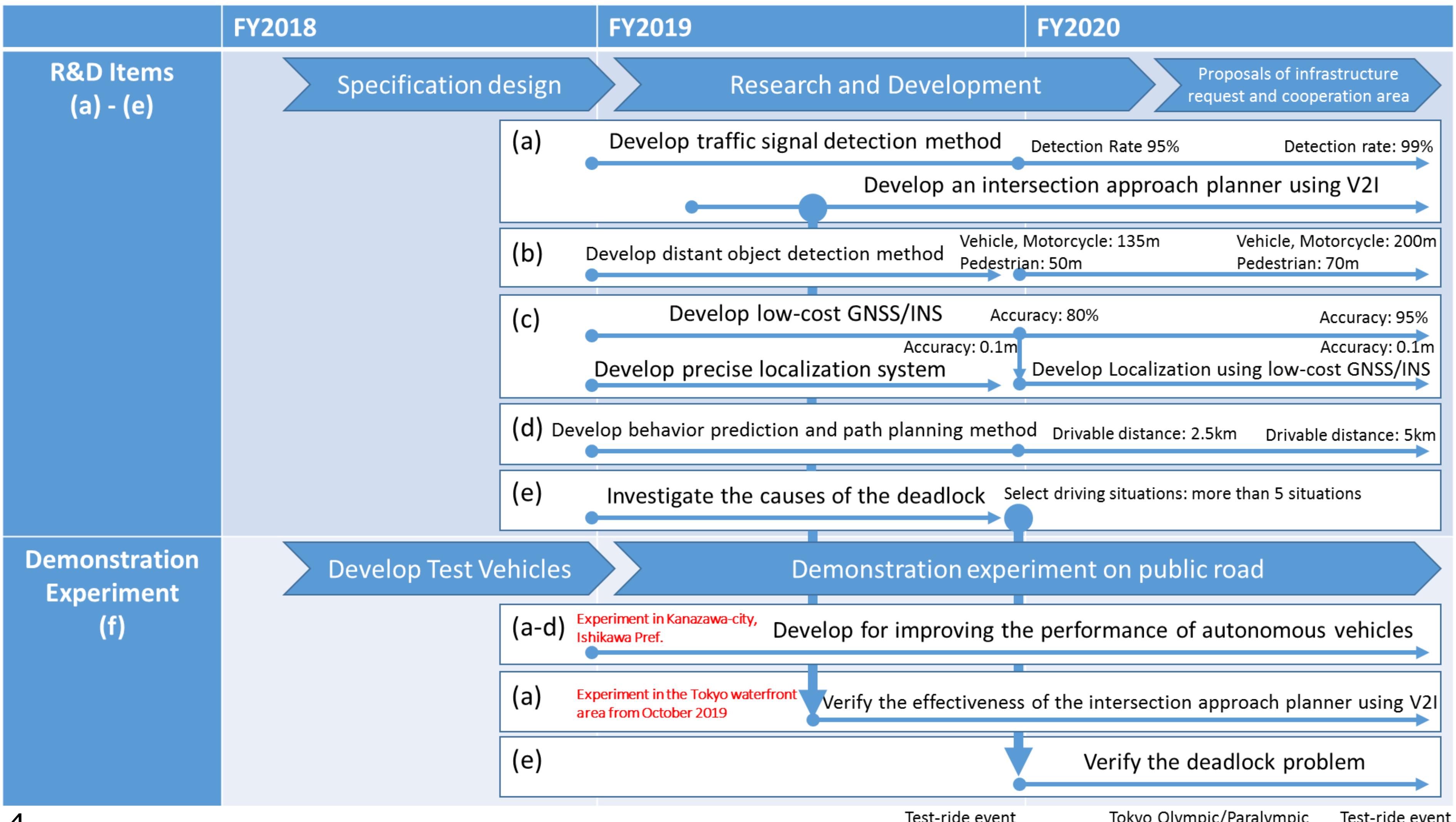




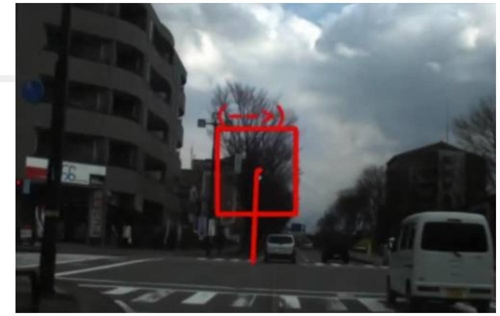
1.1.R&D items

- 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
- 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」

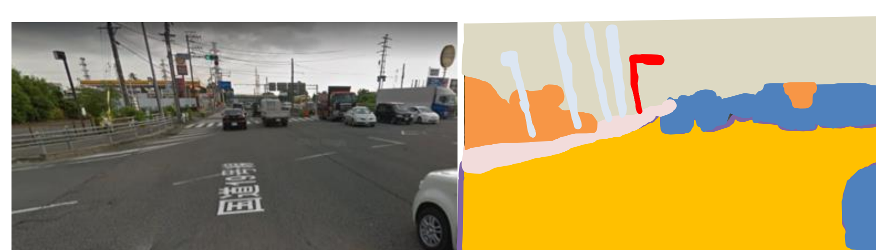


- Necessity for R&D
  - Autonomous driving on urban area
    - Need precise recognition of distant traffic signals
    - Exist situations that are difficult for human eyes to recognize (sunshine, occlusions)
  - It is necessary to maintain an infrastructure-supported traffic signal using V2I communication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

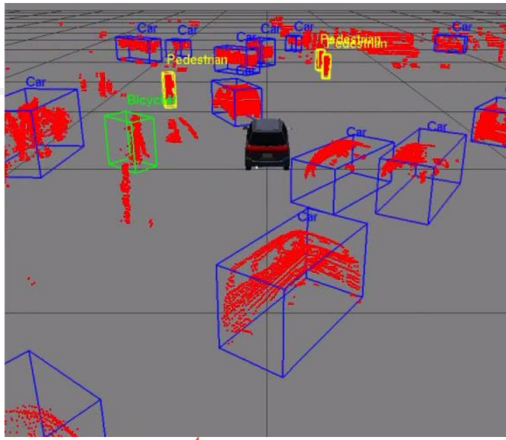
    FY2018: Evaluate Camera Specification

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

    FY2018: Evaluate state-of-the-art semantic segmentation methods



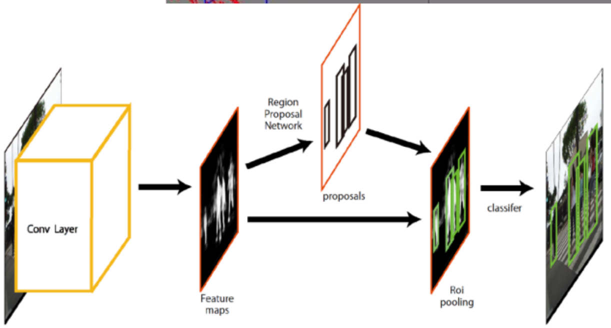
1.2. Development contents and goals
b.「Development of AI technology required to detect distant objects」



- 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)

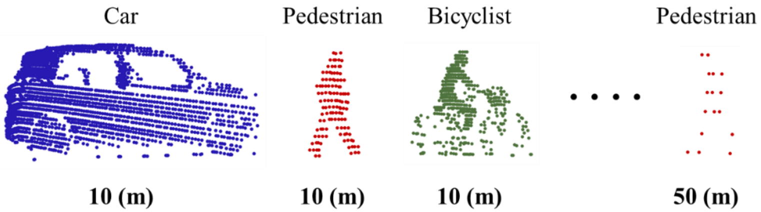
- R&D Contents
  - ①「Distant object detection and camera selection」
    - Evaluate appropriate cameras
    - Develop distant object detection using Deep Neural Network
    - Improve detection accuracy for a small size of objects

    <u>FY2018：Evaluate camera specifications</u>



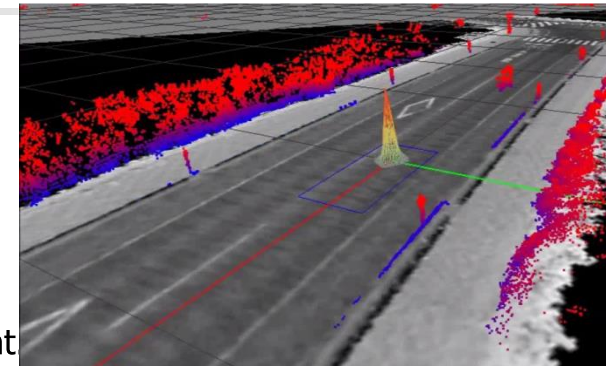
  - ②「Distant object detection by LiDAR and RADAR」
    - Improve detection distance by sensor fusion using LiDAR and Radar
    - Develop object detection method using machine learning
    - Design feature values specialized for distant objects

    <u>FY2018：Evaluation of observation distance for the latest LiDAR</u>



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

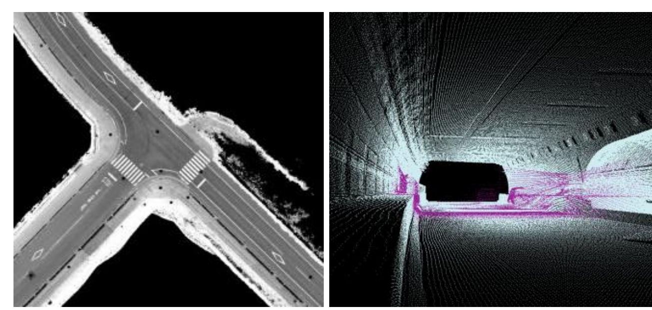
- Necessity for R&D
  - High precision self-localization is necessary for using high precision map
    - It is difficult to estimate self-location only in GNSS (ex. Tunnel)
    - Accurate self-localization by map matching
  - Importance of GNSS/INS
    - Advancement of both GNSS/INS and map matching 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>FY2018：Arrangement of conventional technology, Accuracy evaluation in urban areas</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

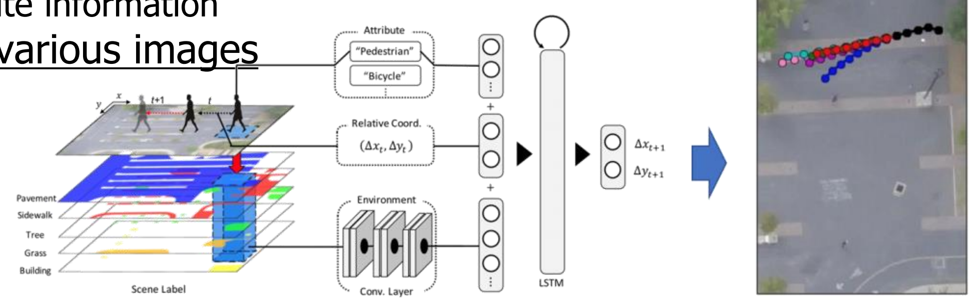
    <u>FY2018：Investigation of map matching methods</u>



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

    FY2018：Selection of area to collect various images



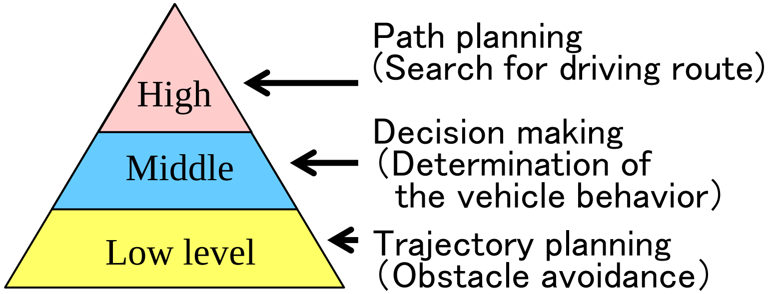
  - ②「Vehicle behavior prediction by tracking and path planning」
    - Estimate motion state and shape of dynamic objects, and develop behavior prediction using digital map
    - Develop an advanced trajectory planning method considering the predicted behavior (smooth and safe autonomous driving in a narrow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

    FY2018：Selection of driving area assuming urban areas and development of basic object tracking algorithm

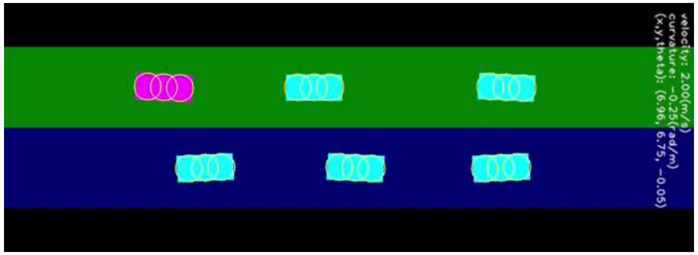
1.2. Development contents and goals
e.「Investigation of problem in the situation where multiple autonomous vehicle exist」

- 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>FY2018：Survey of decision making and trajectory planning technology</u>



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



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

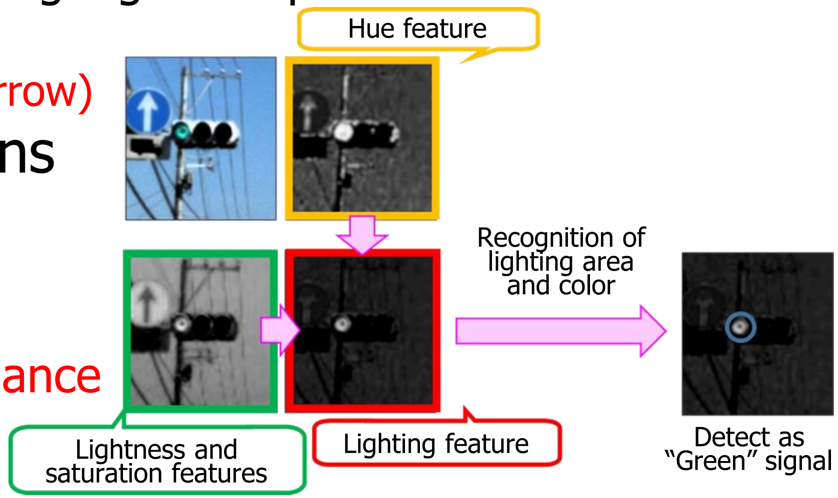
- Construction of test vehicle
  - Two test vehicles
    - Public road demonstration experiment in central area of Kanazawa city
    - Public road demonstration experiment in Tokyo waterfront area
  - Installation of LiDAR, Millimeter wave radar, Camera, GNSS/INS, V2X, etc.
- Safety measure
  - Comply with National Police Agency guidelines
  - Proprietary additional safety measures (Based on existing knowledge of Kanazawa University)
    - ① Pre-verification in test course.
    - ② Structural change inspection by Ministry of Land, Transport and Tourism.
    - ③ Test driver requirements.
    - ④ Emergency contact network,
    - ⑤ Insurance
- Third party certification
  - Japan Automobile Research Institute（JARI）
    Utilization of advance test service

<u>FY2018：Preparation for construction of two test vehicles</u>

2. R&D results

2.1. a.① 「Traffic signal recognition by pattern recognition and decision making for intersection entering」

- Basic development of traffic signal recognition method
  - Method: Extracting of lighting areas using digital map
  - Preliminary evaluations
    - F-value: 94.6%(Traffic light), 57.3%(Arrow)
- Evaluations under adverse conditions
  - Conditions: back light, rain and fog
    - Evaluate recognition rate for Non-HDR/HDR Cameras
  - HDR camera can contribute to performance improvement in adverse conditions
- Future works
  - Recognition of distant arrow lights (>70m)
  - V2I Communications for traffic lights



F-values under adverse weather conditions

	Non HDR Camera	HDR Camera
All Conditions	0.882	**0.928**
Normal	0.982	**0.999**
Back light	0.796	**0.936**
Rain(rainfall: 30mm/h)	0.927	**0.950**
Fog(visibility: 80m)	0.789	**0.790**

Typical captured image taken in Kanazawa city

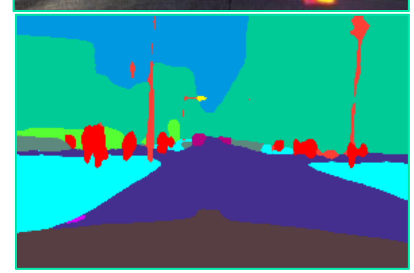
2. R&D results
2.1. a.② 「Development of the method based on semantic segmentation」

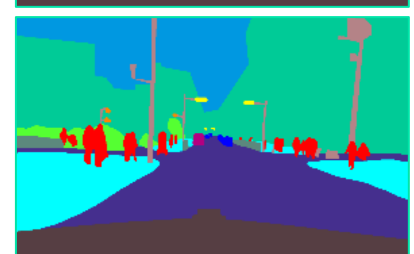
- Comparison with these three algorithms
  - PSPNet (winner of ISLVRC segmentation task in 2017)
  - DeepLabV3+(state-of-the-art method in 2018)
  - MNet(our method which is ranked in 3rd place of Cityscapes in 2016)
- Evaluation data: AI Edge Contest
- PSPNet achieves best performance for Signal

Accuracy of comparison methods (metrics is IoU)

	PSPNet (Dilated ResNet50)		DeepLabV3+ (ResNet101)		MNet	
	Val data	Train data	Val data	Train data	Val data	Train data
average	0.638	0.744	0.573	0.587	0.394	0.459
Car	0.675	0.807	0.611	0.638	0.452	0.553
Lane	0.918	0.967	0.842	0.85	0.552	0.565
Pedestrian	0.328	0.445	0.3	0.301	0.27	0.347
Signal	0.212	0.257	0.166	0.164	0.176	0.23


input image


predict result


ground truth

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

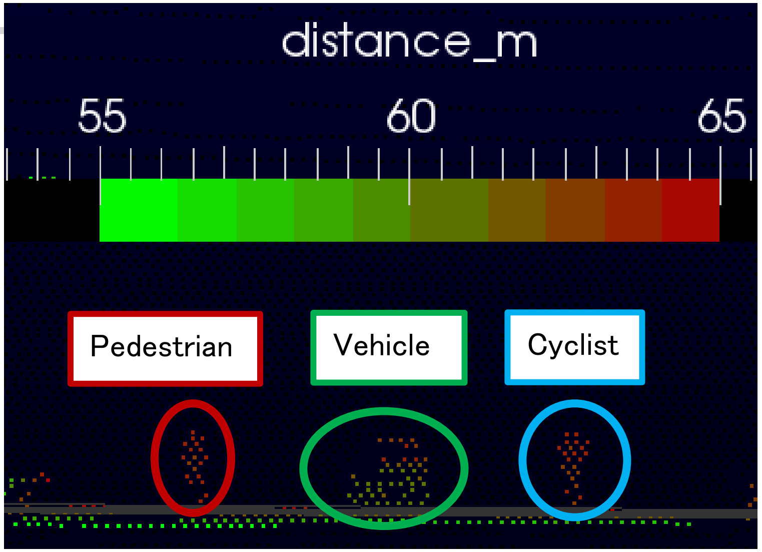
- For distant object (pedestrian:70m, car:200m) , evaluate following camera conditions.
  - 1)FLIR GS3-U3-123S6C-C＋LM16FC(KOWA optical)
    resolution：4096x3000, angle：H-47.6[deg], V-36.7[deg]
  - 2)FLIR GS3-U3-123S6C-C＋LM25FC (KOWA optical)
    resolution：4096x3000, angle：H-31.5[deg], V-23.9[deg]
  - 3)HDR＋LFM camera(prototype)
    resolution：1920x1080, angle：H-51[deg], V-30[deg]
- 4K camera is necessary to detect distant objects

Accuracy of camera conditions (metrics: AP)

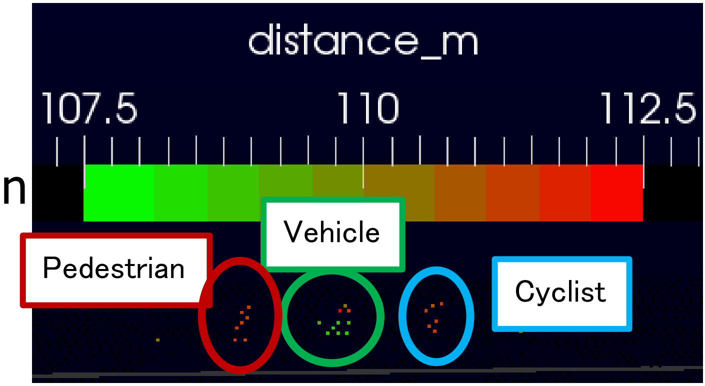
method	Camera conditions	bike	car	person	traffic light
YOLOv3	4K camera1	**0.67**	**0.89**	0.84	0.73
	4K camera2	0.61	0.88	**0.93**	0.64
	HD camera with HDR	0.38	0.86	0.80	**0.79**

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

- Evaluation of observation distance for the latest LiDAR
  - Sensor: Velodyne VLS-128
  - Target Objects: Vehicle, Pedestrian, Cyclist
  - Evaluation of detection distance by visual observation
  - The results of distinguishable distances
    - Vehicle: about 90m
    - Pedestrian or Cyclist: about 70m
- Future works
  - Improving recognition distance by sensor fusion



Distance: 60m(Normal Condition)



Distance: 110m(Normal Condition)

Detection distance under adverse weather conditions

	Normal		Rain(rainfall: 30mm/h)		Fog(visibility: 80m)	
	A	B	A	B	A	B
Vehicle	107m	90m	110m	92m	55m	45m
Pedestrian	100m	65m	105m	75m	65m	55m
Cyclist	100m	65m	105m	75m	65m	55m

A: Distinguishable dist. (>10 observation points)
B: Recognizable dist. (>20 observation points)

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

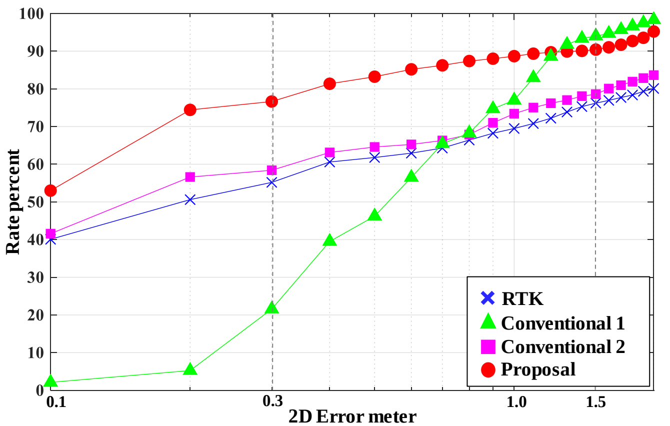
- Data was collected with low-cost GNSS and MEMS-IMIU
- Odaiba and Shinjuku were selected for the evaluation field of urban area

<u>Results of the Odaiba/Tokyo</u>

Conventional 1[1] 1.5m@94%

RTK[2] 0.3m@55%

Proposal[3] 1.5m@90% 0.3m@77%

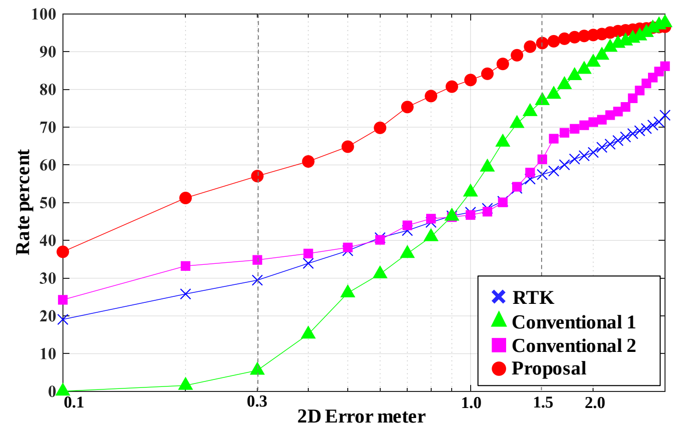


<u>Results of the Shinjuku/Tokyo</u>

Conventional 1[1] 1.5m@77%

RTK[2] 0.3m@30%

Proposal[3] 1.5m@92% 0.3m@57%



[1]Tomoji Takasu, et. al., , “Development of the low cost RTK-GPS receiver with an open source prgram package RTKLIB. In Proceeding of the International Symposium on GPS/GNSS”, Jeju, Korea, 4-6 November 2009.
[2]Junichi Meguro, Takuya Arakawa, Syunsuke Mizutani and Aoki Takanose, “Low-cost Lane-level positioning in Urban Area Using Optimized Long Time Series GNSS and IMU Data”, IEEE ITSC,2018
[3]高野瀬，荒川，滝川，目黒，都市部における車両軌跡を活用した高精度測位　—初期条件の最適化による精密測位の改善—，ロボティクスメカトロニクス講演会2019，2019.6(発表予定)

<u>Future plan</u>

･Robustness and accuracy improvement

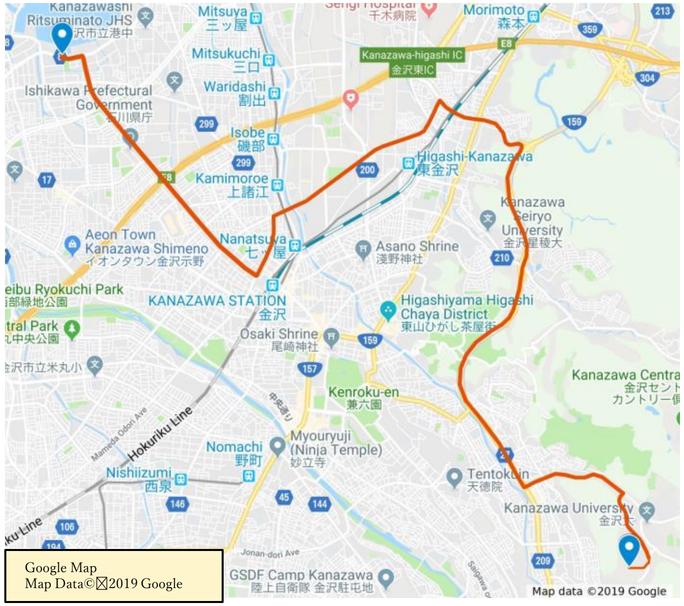
･Development of the real time positioning system for the vehicle

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

- Survey of methods for map matching
- Route selection for algorithm development and examination for the next fiscal year
  - Kanazawa city (about 20km)
  - Including situations such as three-dimensional structures with / with few roads, roads with / with few road patterns, and tunnels with a total length of more than 1 km.

Features used for matching	**Three-dimensional structure**	**Road surface pattern**
Map structure	Three-dimensional point cloud	Two-dimensional image/ line segments
Matching method	･ICP algorithm ･NDT scan matching	･Image matching ･Line segment matching
Advantage	Various objects such as curbs and poles can be used as landmarks.	High environmental resistance Small map data size
Disadvantage	Low environmental resistance Large map data size	Difficulty in places with few road patterns.

Driving route in Kanazawa city



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

- Select the area to collect various image
  - collection area : Kanazawa city
  - To develop the path prediction method, we collect the data in similar environment
    - Future plan : collect various scenarios
- Investigate of existing methods

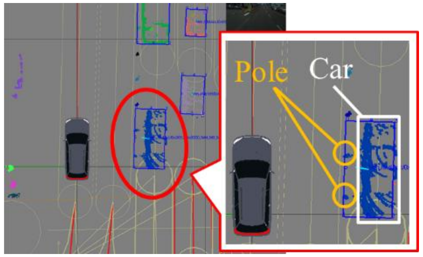
Algorithms	year	object	
Social LSTM	2016	pedestrian	Consider the interaction between near pedestrians using LSTM
Convolutional Social Pooling	2018	car	Propose Convolutional Social Pooling to predict car motion in highway
Social Attention	2018	pedestrian	Consider the interaction between far pedestrians by spatial – temporal graph
Social GAN	2018	pedestrian	Generate several paths based on GAN and select optimized path
SoPhie	2019	pedestrian	Consider static environment such as road and sidewalk
SR-LSTM	2019	pedestrian	Consider future path of each pedestrian after interaction

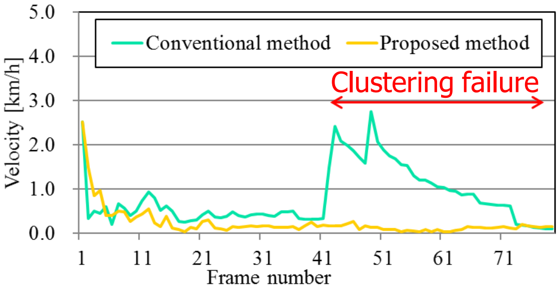
Collection area：Kanazawa city

data for early algorithm development : Chubu university

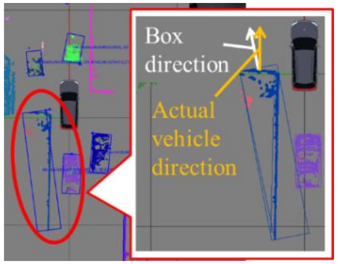
2. R&D results
2.4. d.② 「Vehicle behavior prediction by tracking and path planning」

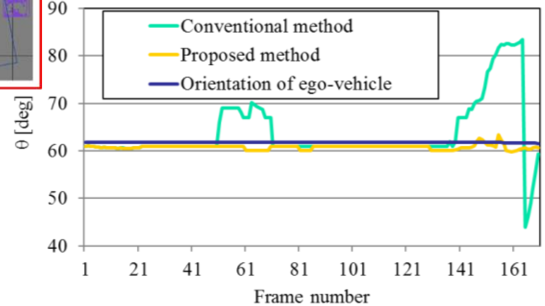
- Selecting a driving area assuming urban areas
  - Roads with lots of bus traffic or lots of parked vehicles
    - The road width becomes relatively narrow
  - Selected area
    - Kanazawa city, Ishikawa Pref. (2.5km)
    - Tokyo Waterfront Area (about 5km)
- Basic development of object tracking method in consideration of the shape
  - Method
    - Velocity estimation using point cloud matching
    - Attitude angle estimation considering the dead area of objects
  - Stable tracking in a dense traffic environment
- Future works
  - Real-time verification of the developed algorithm
  - Actual vehicle test in the selected areas





Stable velocity estimation during the clustering failure of vehicles with low velocity



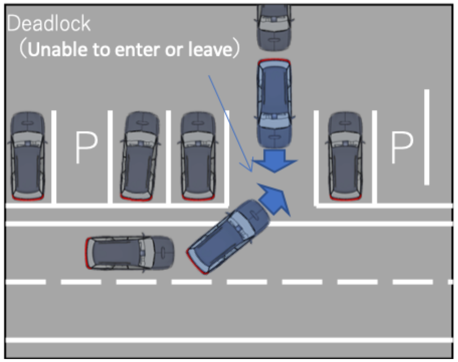


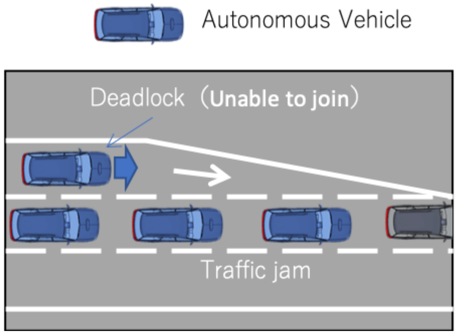
Stable heading estimation for vehicles with low velocity during occlusion

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

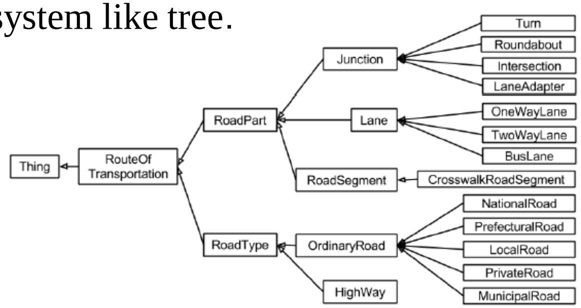
- Survey of decision making and trajectory planning techniques in consideration of deadlock avoidance
  - DARPA Urban Challenge
    - Avoid deadlocks in advance by adjusting the trajectory at places where deadlocks can occur, such as intersections [Kammel, 2009].
    - Avoid by changing the target position when a deadlock occurs [Urmson, 2009].
  - Ontology-based decision making
    - The ontology classifies the current situation based on various factors, and performs avoidance behavior according to the situation [Zhao, 2015].

Situations where deadlock can occur





※ Structure of knowledge representation based on a hierarchical classification system like tree.



[Zhao, 2015]

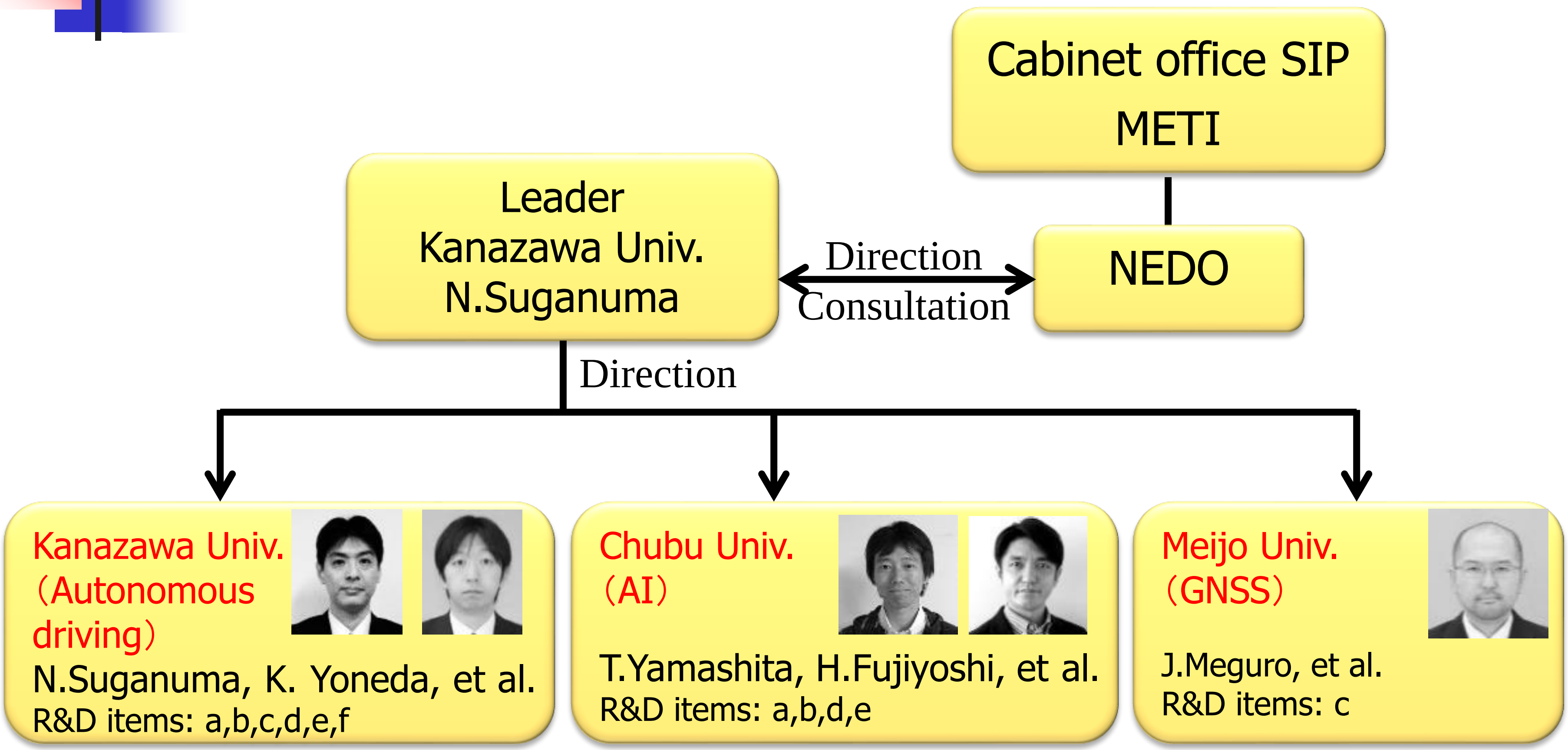
2. R&D results
2.6. f. 「Demonstration experiment」

- Conducted contents in FY2018
  - Preparation of test vehicle for public road experiment
- Test vehicles
  - Chosen from commercial vehicle
    - Safety and Efficiency：
      - Models which have already been modified by automobile manufactures
  - LEXUS RX450hL
    - Capacity：7 people
    - Minimum turning radius:5.9m

LEXUS RX450hL
（https://lexus.jp/models/rx/gallery/）

- Sensors
  - LiDARs，RADARs，Cameras，GNSS
    - Chosen from knowledge of demonstration experiment by Kanazawa Univ.

3.Project structure



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」