「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

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**Diagram Description:**
- **Vertical Axis:** Richness of infrastructure (Cost of infrastructure)
- **Horizontal Axis:** Advancement of autonomous driving technology
- **Questions:**
  - How much infrastructure development is necessary?
  - How much technology development is required?

**Key Points:**
- 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
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

<table>
<thead>
<tr>
<th>R&amp;D Items (a) - (e)</th>
<th>FY2018</th>
<th>FY2019</th>
<th>FY2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop traffic signal detection method</td>
<td>Detection Rate 95%</td>
<td>Detection Rate 99%</td>
<td></td>
</tr>
<tr>
<td>Develop an intersection approach planner using V2I</td>
<td></td>
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<tr>
<td>(b)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop distant object detection method</td>
<td>Vehicle, Motorcycle: 135m</td>
<td>Pedestrian: 50m</td>
<td></td>
</tr>
<tr>
<td>Vehicle, Motorcycle: 200m</td>
<td>Pedestrian: 70m</td>
<td></td>
<td></td>
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<tr>
<td>(c)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop low-cost GNSS/INS</td>
<td>Accuracy: 80%</td>
<td>Accuracy: 95%</td>
<td></td>
</tr>
<tr>
<td>Develop precise localization system</td>
<td>Accuracy: 0.1m</td>
<td>Accuracy: 0.1m</td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop behavior prediction and path planning method</td>
<td>Drivable distance: 2.5km</td>
<td></td>
<td></td>
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<tr>
<td>Drivable distance: 5km</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(e)</td>
<td></td>
<td></td>
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<tr>
<td>Investigate the causes of the deadlock</td>
<td>Select driving situations: more than 5 situations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demonstration Experiment (f)</th>
<th>FY2018</th>
<th>FY2019</th>
<th>FY2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a-d)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Develop for improving the performance of autonomous vehicles</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(a)</td>
<td></td>
<td></td>
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<tr>
<td>Experiment in Kanazawa city, Ichikawa Pref.</td>
<td></td>
<td></td>
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<tr>
<td>(a)</td>
<td></td>
<td></td>
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<tr>
<td>Experiment in the Tokyo waterfront area from October 2019</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(e)</td>
<td></td>
<td></td>
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<tr>
<td>Verify the deadlock problem</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(a)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Verify the effectiveness of the intersection approach planner using V2I</td>
<td></td>
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</tr>
</tbody>
</table>

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
    - FY2018: Evaluate camera specifications

  - 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
    - FY2018: Evaluation of observation distance for the latest LiDAR
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”
      FY2018: Arrangement of conventional technology, accuracy evaluation in urban areas
  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
      FY2018: Investigation of map matching methods
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
    - FY2018: Survey of decision making and trajectory planning technology
  
  - 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

**FY2018:** Preparation for construction of two test vehicles
2. R&D results

2.1. a. 「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

<table>
<thead>
<tr>
<th></th>
<th>Non HDR Camera</th>
<th>HDR Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Conditions</td>
<td>0.882</td>
<td>0.928</td>
</tr>
<tr>
<td>Normal</td>
<td>0.982</td>
<td>0.999</td>
</tr>
<tr>
<td>Back light</td>
<td>0.796</td>
<td>0.936</td>
</tr>
<tr>
<td>Rain(rainfall: 30mm/h)</td>
<td>0.927</td>
<td>0.950</td>
</tr>
<tr>
<td>Fog (visibility: 80m)</td>
<td>0.789</td>
<td>0.790</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th></th>
<th>PSPNet  (Dilated ResNet50)</th>
<th>DeepLabV3+ (ResNet101)</th>
<th>MNet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Val data</td>
<td>Train data</td>
<td>Val data</td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>0.675</td>
<td>0.807</td>
<td>0.611</td>
</tr>
<tr>
<td>Lane</td>
<td>0.918</td>
<td>0.967</td>
<td>0.842</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>0.328</td>
<td>0.445</td>
<td>0.3</td>
</tr>
</tbody>
</table>
| Signal        | 0.212    | 0.257      | 0.166    | 0.164      | 0.176    | 0.23
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

<table>
<thead>
<tr>
<th>method</th>
<th>Camera conditions</th>
<th>bike</th>
<th>car</th>
<th>person</th>
<th>traffic light</th>
</tr>
</thead>
<tbody>
<tr>
<td>YOLOv3</td>
<td>4K camera1</td>
<td>0.67</td>
<td>0.89</td>
<td>0.84</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>4K camera2</td>
<td>0.61</td>
<td>0.88</td>
<td>0.93</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>HD camera with HDR</td>
<td>0.38</td>
<td>0.86</td>
<td>0.80</td>
<td>0.79</td>
</tr>
</tbody>
</table>
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

Detection distance under adverse weather conditions

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Rain(rainfall: 30mm/h)</th>
<th>Fog(visibility: 80m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Vehicle</td>
<td>107m</td>
<td>90m</td>
<td>110m</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>100m</td>
<td>65m</td>
<td>105m</td>
</tr>
<tr>
<td>Cyclist</td>
<td>100m</td>
<td>65m</td>
<td>105m</td>
</tr>
</tbody>
</table>

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

**Results of the Odaiba/Tokyo**

- Conventional 1\(^1\) 1.5m@94%
- RTK\(^2\) 0.3m@55%
- Proposal\(^3\) 1.5m@90% 0.3m@77%

**Results of the Shinjuku/Tokyo**

- Conventional 1\(^1\) 1.5m@77%
- RTK\(^2\) 0.3m@30%
- Proposal\(^3\) 1.5m@92% 0.3m@57%

Future plan

- Robustness and accuracy improvement
- Development of the real time positioning system for the vehicle

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\(^1\) Tomoji Takasu, et. al., “Development of the low cost RTK-GPS receiver with an open source program 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—, ロボティクスマネジメント講演会2019, 2019(発表予定)
2. R&D results

2.3. 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 few roads, roads with few road patterns, and tunnels with a total length of more than 1 km.

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

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

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

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

[Zhao, 2015]
2. R&D results
2.6. 『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

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

Leader
Kanazawa Univ.
N. Suganuma

Cabinet office SIP
METI

Direction
Consultation

NEDO

Kanazawa Univ. (Autonomous driving)
N. Suganuma, K. Yoneda, et al.
R&D items: a, b, c, d, e, f

Chubu Univ. (AI)
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」