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Benefits and Problems in Digital Map for Autonomous Driving: From Our Research Experiences

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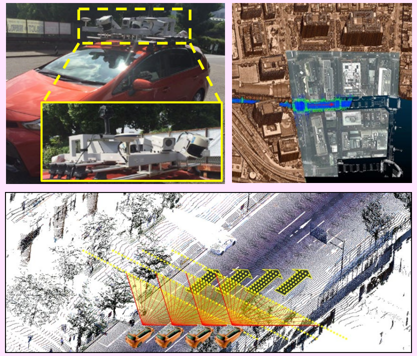
LiDAR-based vehicle localization

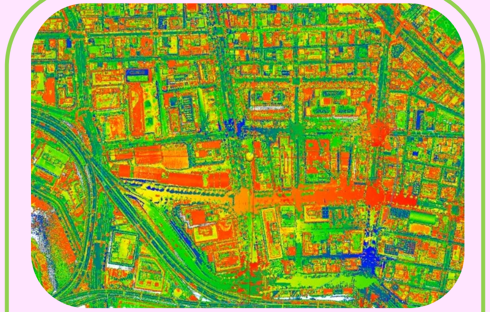
- LiDAR: One of the well-known sensor for localization
- LiDAR-based self-localization methods
  - SLAM (Simultaneous localization and mapping)
  - Map-based methods

3D Light Detection and Ranging (LiDAR) sensor

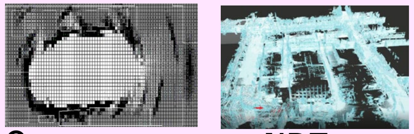
- ➢ 360 field of view
- ➢ Measuring error is less than 2cm in 100m
- ➢ Night condition without illumination
- ➢ Google, Toyota, Uber, Ford are using LiDAR



Collection data using Mobile Mapping System

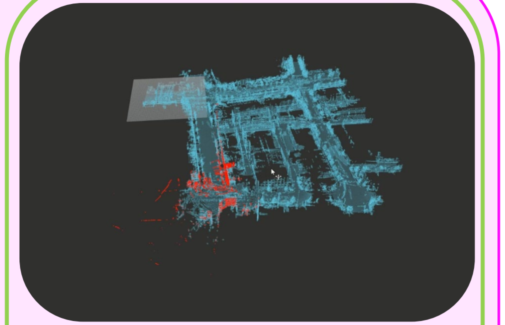


Generate point cloud map (HD map)



Occupancy map **NDT Map**

Based on the matching algorithm the point cloud is converted to other map formats



Input scan is matched to the map to get position

Benefits of Digital Map in Autonomous Vehicle Application

- Self-Localization referencing to point-cloud data.
- Static rules are annotated in the High-Definition map.
  - Buildings, road sided facilities, lanes, road markings, …
  - lane semantics, speed limitation, traffic sign, stop line, pedestrian crossing, direction guiadance, …
  - Those information are useful for motion planning.
- Dynamic information are attached on the HD map, and delivered through digital network to the autonomous vehicles.
  - Macroscopic events of road construction, traffic regulation, damaged road, …
  - Mesoscopic events as congestion, accident, …
  - Those information are useful for travel planning.
- Object detection aided by HD map
  - HD map might comprise information of traffic signals, traffic sings, variable message signs: 3D positions and bounding boxes.
  - Improve the detection accuracy of those facilities in adverse condition as rain, fog, night time, …

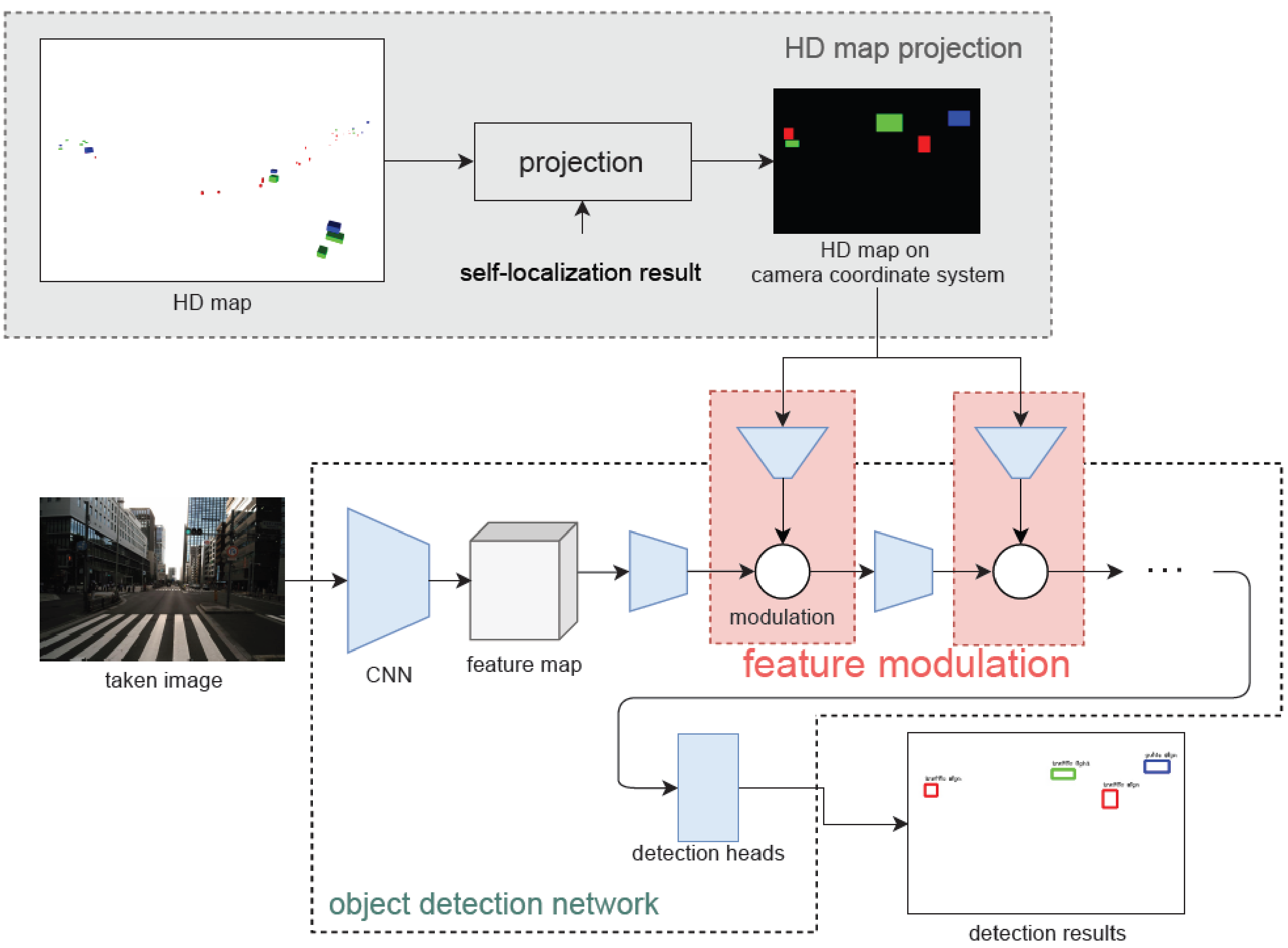
Problems of Digital Map in Autonomous Vehicle Application

- How the digital map can be updated?
  - Cloud sourcing or Tailor made?

- How the digital map should be standardized among countries, map providers, and OEMs?
  - What kind of format is available and suitable for the digital map?
    point cloud, vector, polygon, …
  - How the quality of the digital map should be defined, evaluated and secured?
    - and by whom?

- LiDAR is not reliable for localization in some scenarios.
  - Adverse weather conditions: heavy rain and fog
  - Occlusion effects: beams are interrupted by the surrounding tall vehicles
  - Passive sensor fusion mitigates the occlusion effects in conjunction with the digital map.

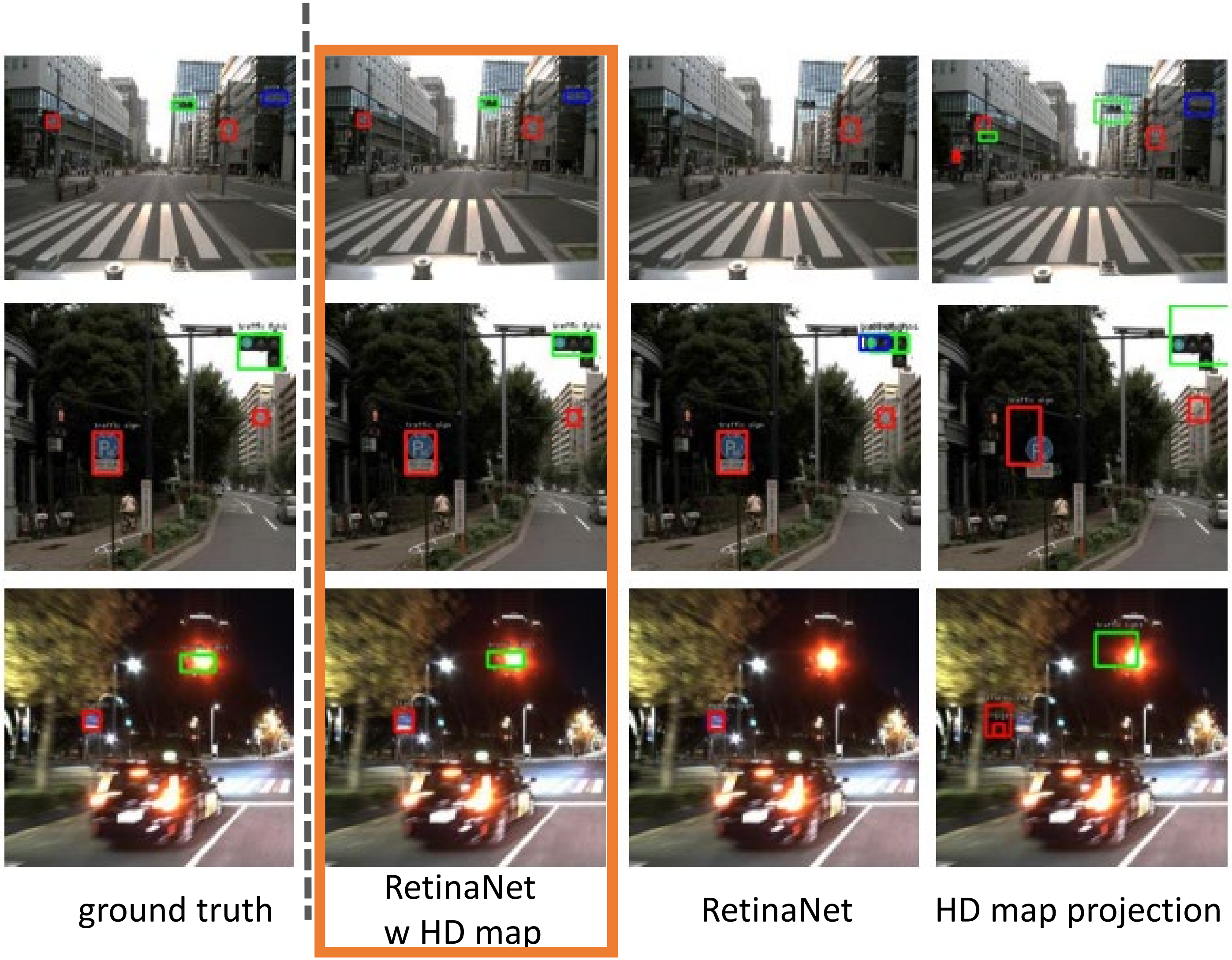
Algorithm Flow of the HD map aided Object Detection



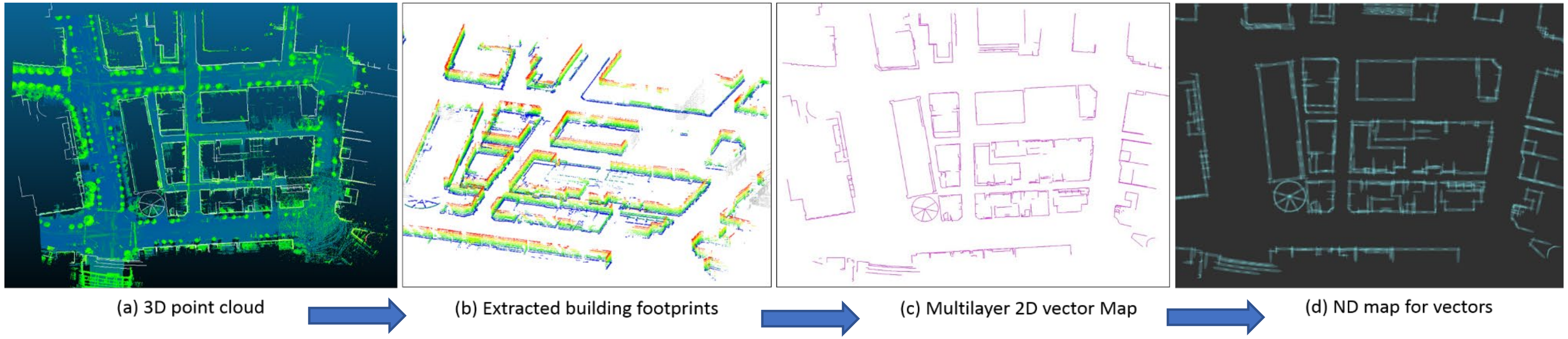
1. HD map projection as an image

2. Inference with HD map

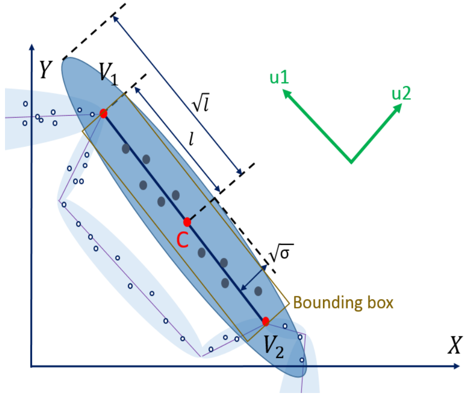
Evaluation of Object Detection in Night Image



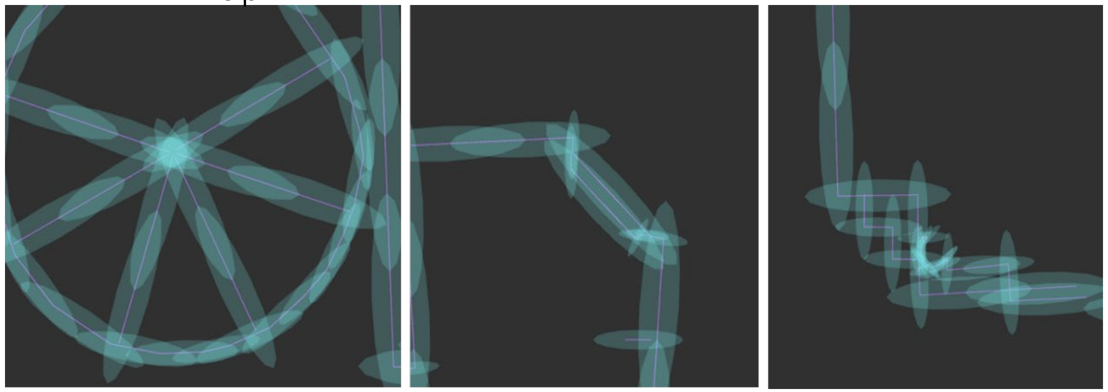
HD map comprising Vector Elements: Vector NDT



Points that made a vector form a normal distribution



Generated Normal distribution form vector map



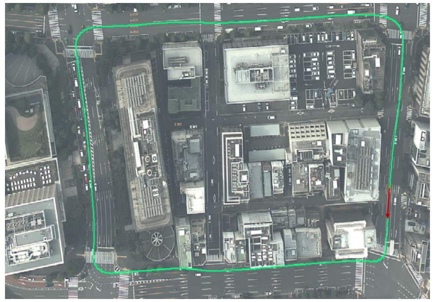
$$P(\vec{x}) = \frac{1}{2\pi\sqrt{|\Sigma|}}\exp\left(-\frac{(\vec{y}_k-\vec{\mu})^T\Sigma^{-1}(\vec{y}_k-\vec{\mu})}{2}\right)$$

$Y=\{\vec{y}_1, \ldots, \vec{y}_n\}$ Points that made a vector segment

$\vec{\mu}$ Mean of generated normal distribution

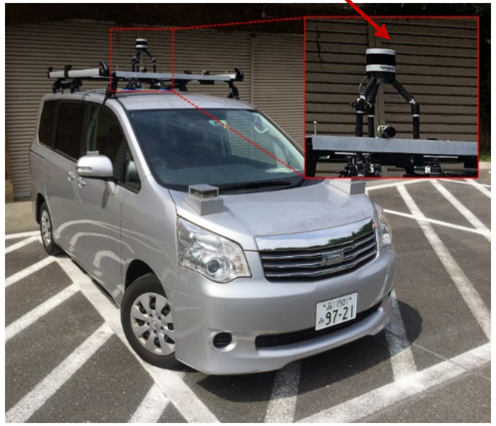
Σ Covariance of generated normal distribution

Experimental results



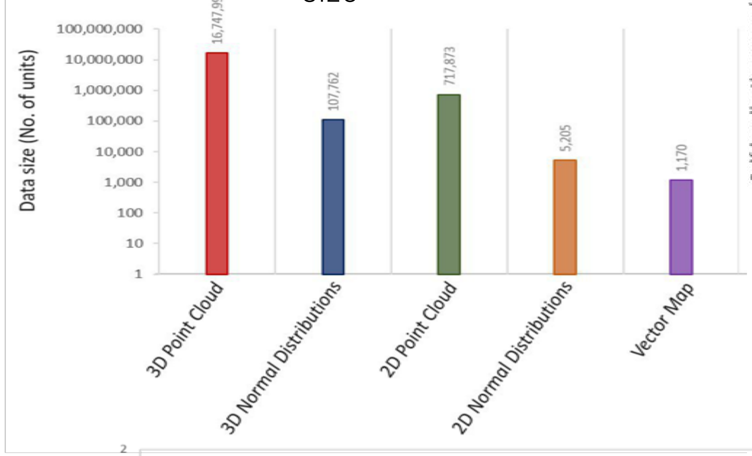
Route of experiments

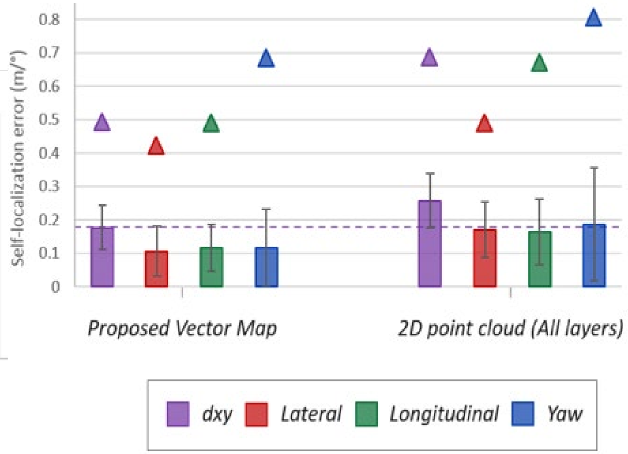
Velodyne's VLP-16 (16 chennel)



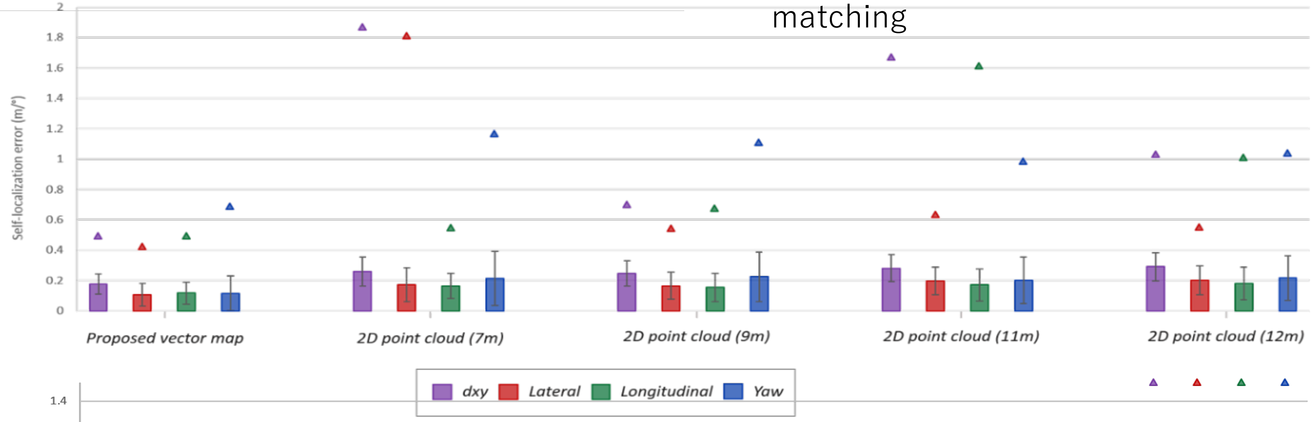
Our experimental vehicle

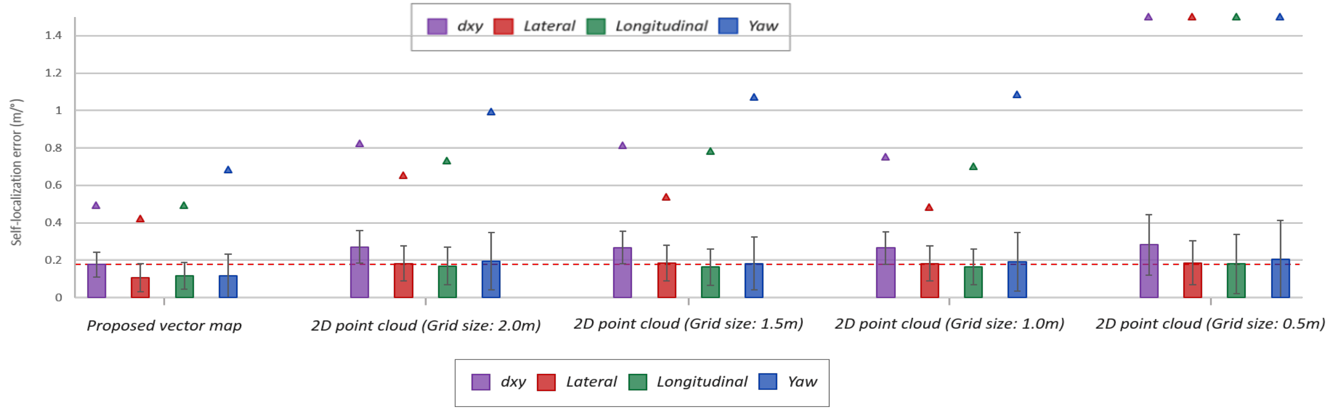
Evaluation of data size





Evaluation of vector ND map-matching

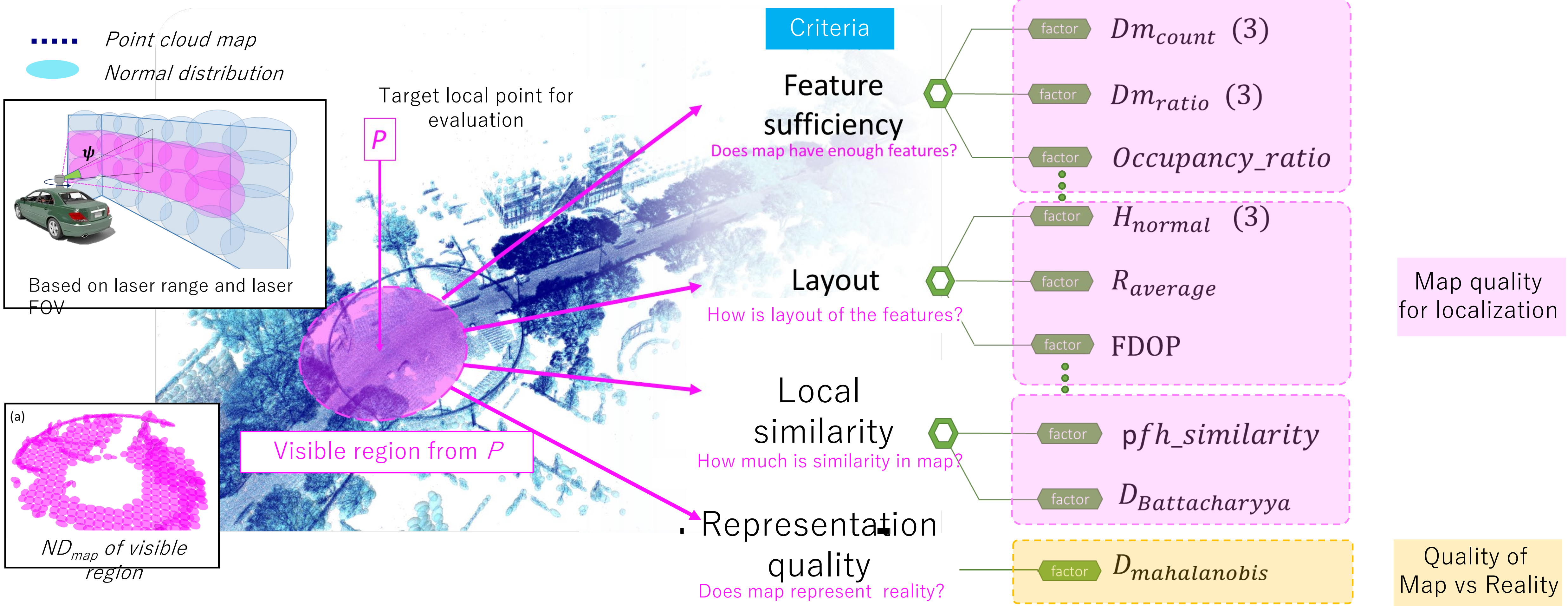




Evaluation of multilayer 2D vector structure (comparison with conventional 2D methods)

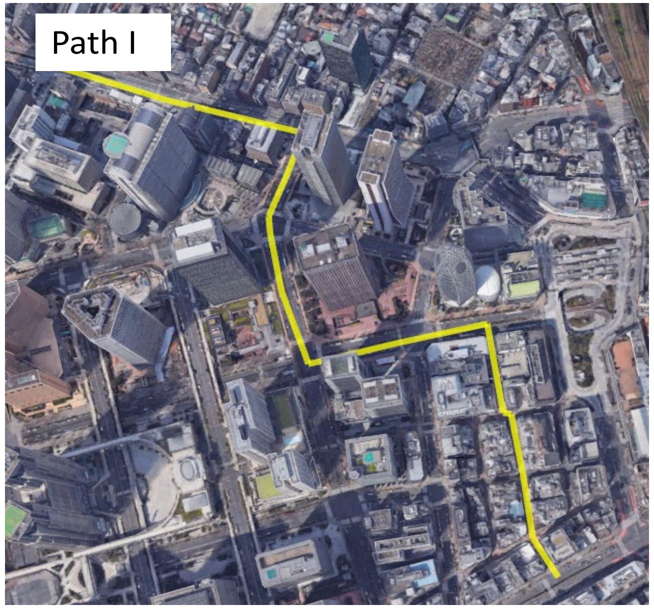
Map evaluation criteria to formulate the Localization accuracy

- For each local point P on the map, a visible region is extracted
- To evaluate the map ability for localization for point P 4 criteria are introduced



Test-bed and Setups for the Experiments

Experimental Path



Experimental Path in
Shinjuku, Tokyo
1.2 km path

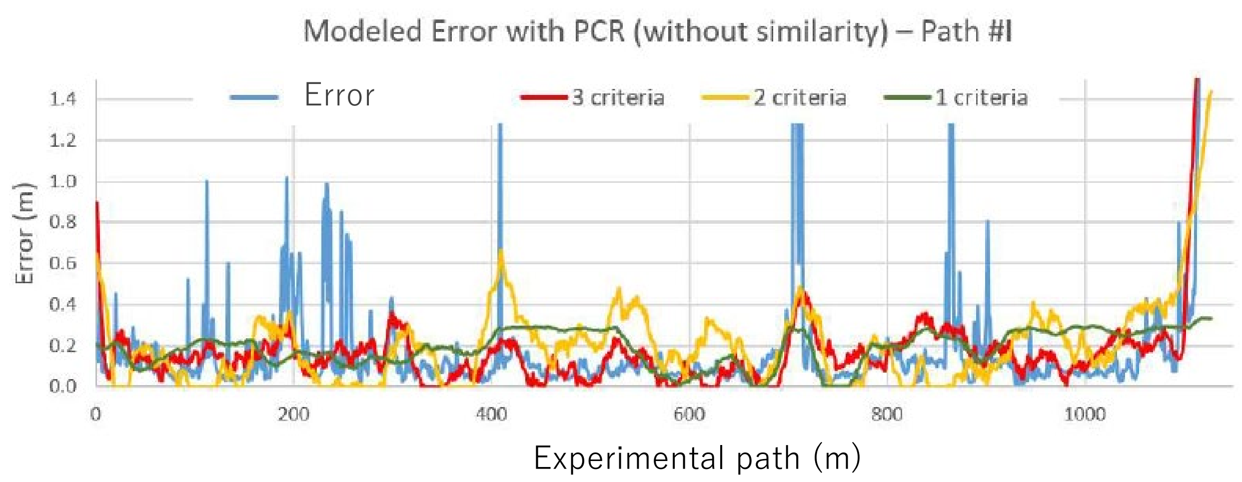
Point cloud map of experimental path

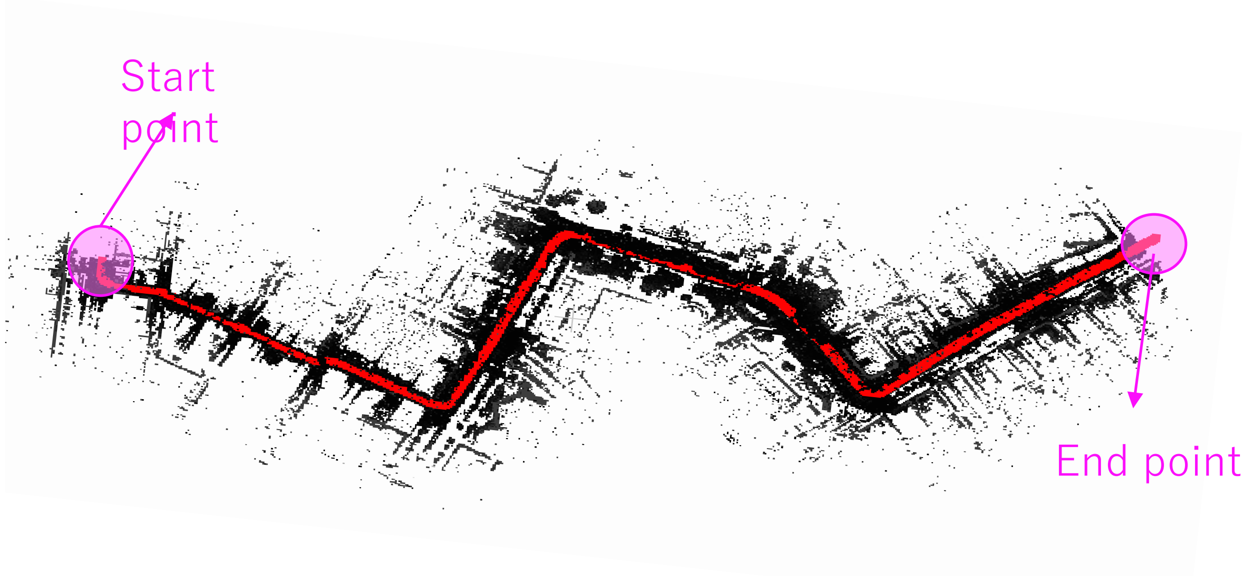
Our experimental vehicle

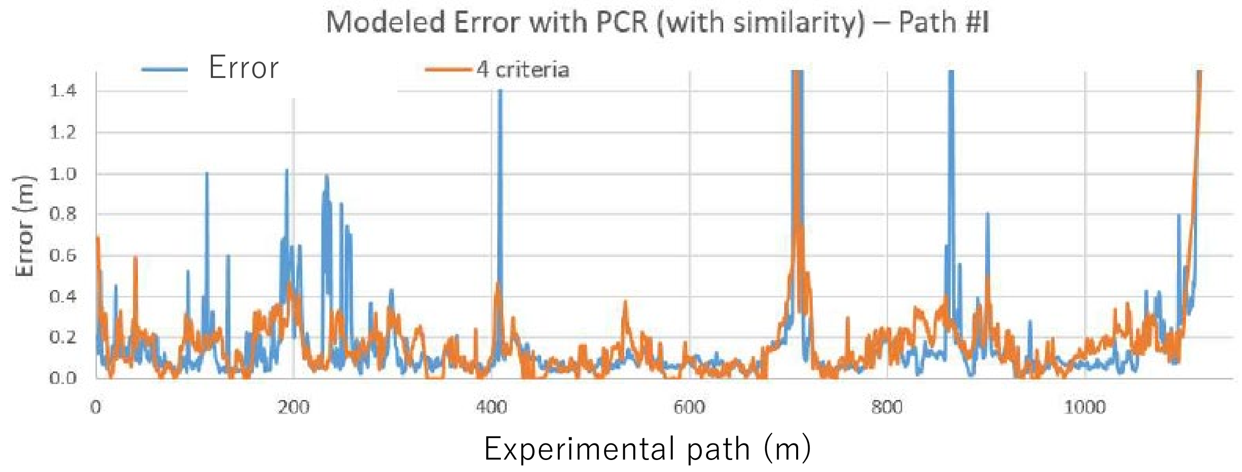
- Laser scanner range : 20m
- Frequency : 20Hz
- Driving speed : 10km/h
- (distortion is less than 7cm in each scan)

Results of error modeling

Localization error for 3.0m grid size NDT map



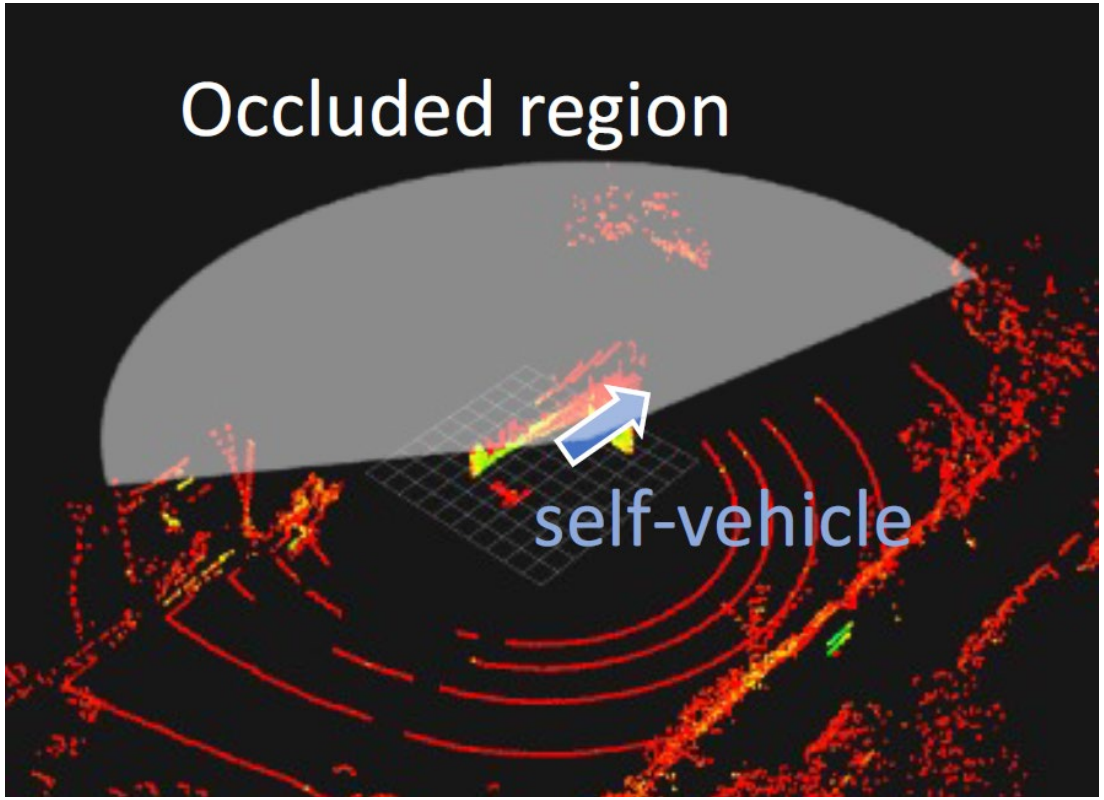




	R^2	RMSE	predErr < 10cm	predErr < 15cm	predErr < 20cm
Represent Quality	0.046	0.399	47.6%	65.2%	79.9%
+Feature Criteria	0.269	0.350	40.9%	60.2%	72.5%
+Layout Criteria	0.664	0.238	66.2%	83.3%	89.7%
+Local Similarity	**0.747**	**0.207**	**70.7%**	**83.2%**	**88.9%**

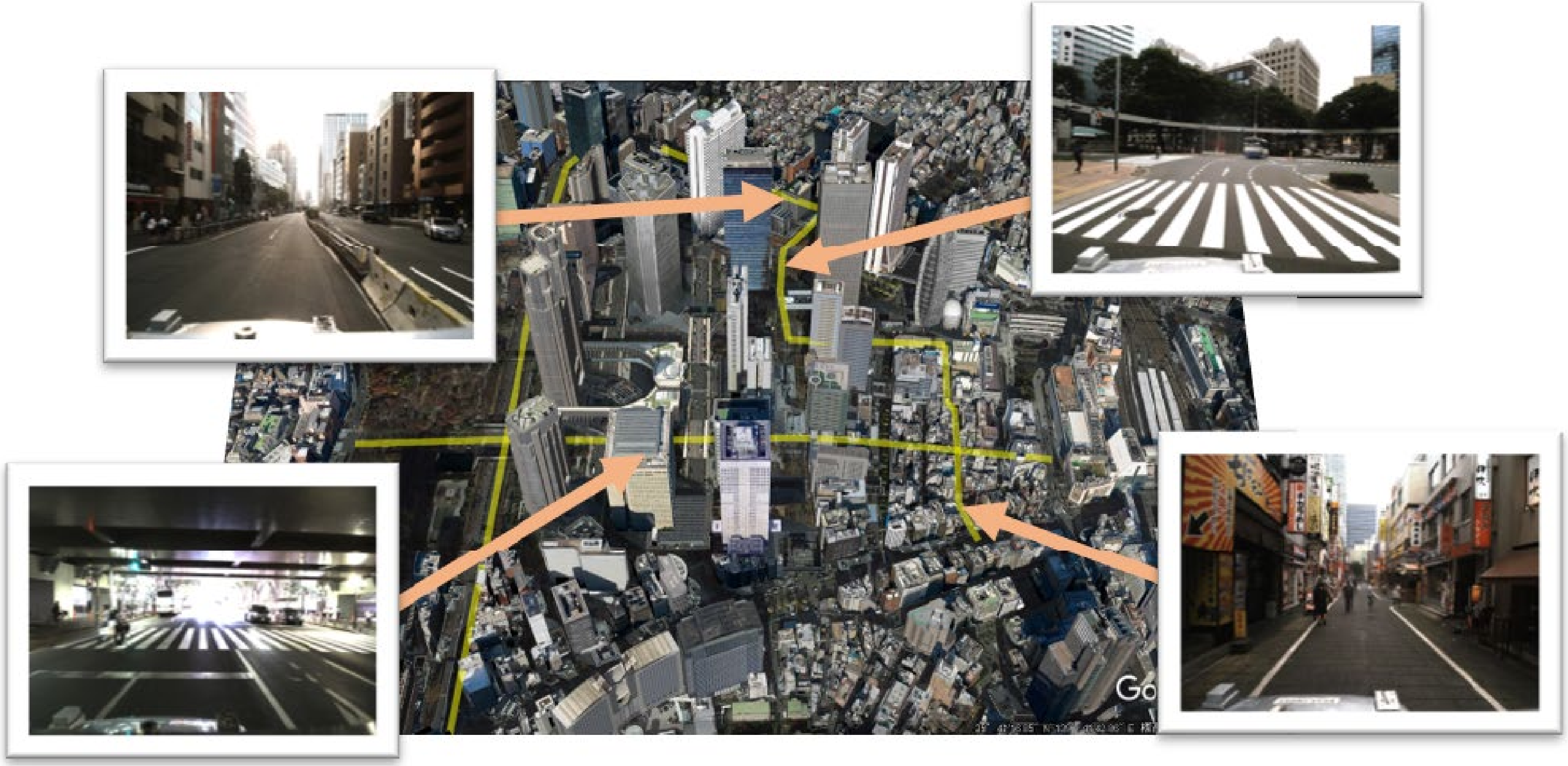
Occlusion Effects for Localization in Urban Scenario

- LiDAR beams are interrupted by tall vehicles in heavy traffics, and could not reach the reference infrastructures for the localization.
- The accuracy of the localization degenerates due to occlusion effects

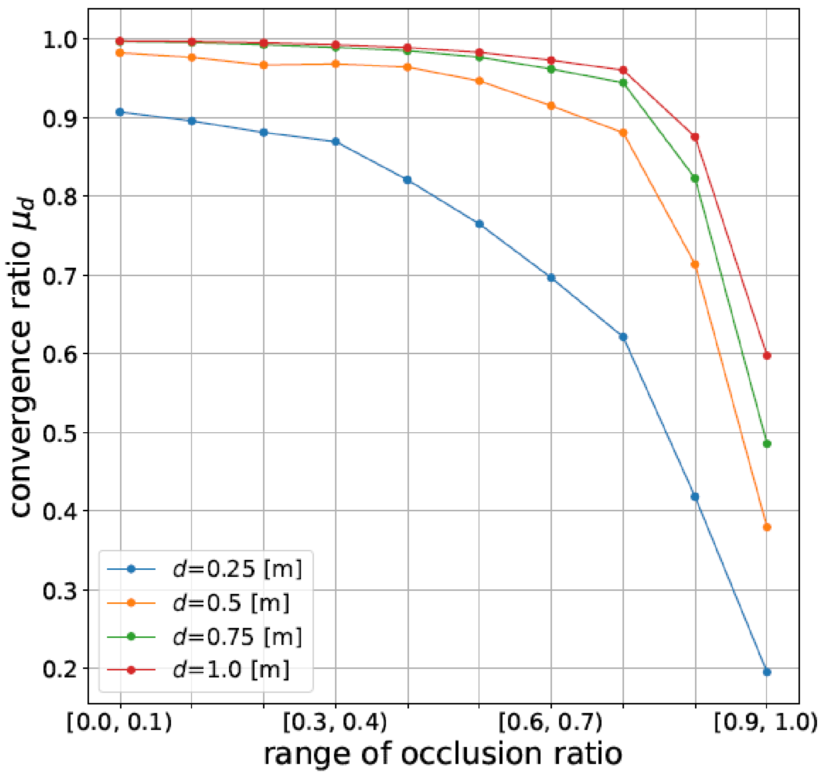


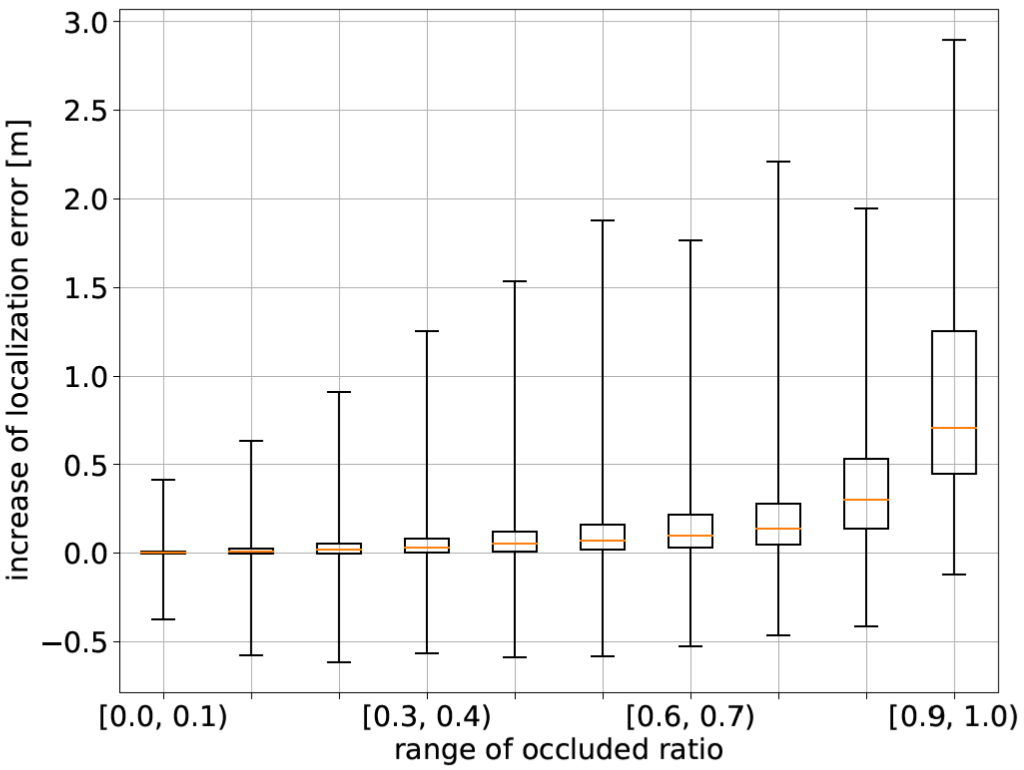
Test-bed to evaluate Occlusion effects in Urban Canyon

- The evaluations were performed in Shinjuku, Tokyo.
- Total length of the trajectory is 7.0km.



Evaluation of Occlusion effects: Convergence and Error

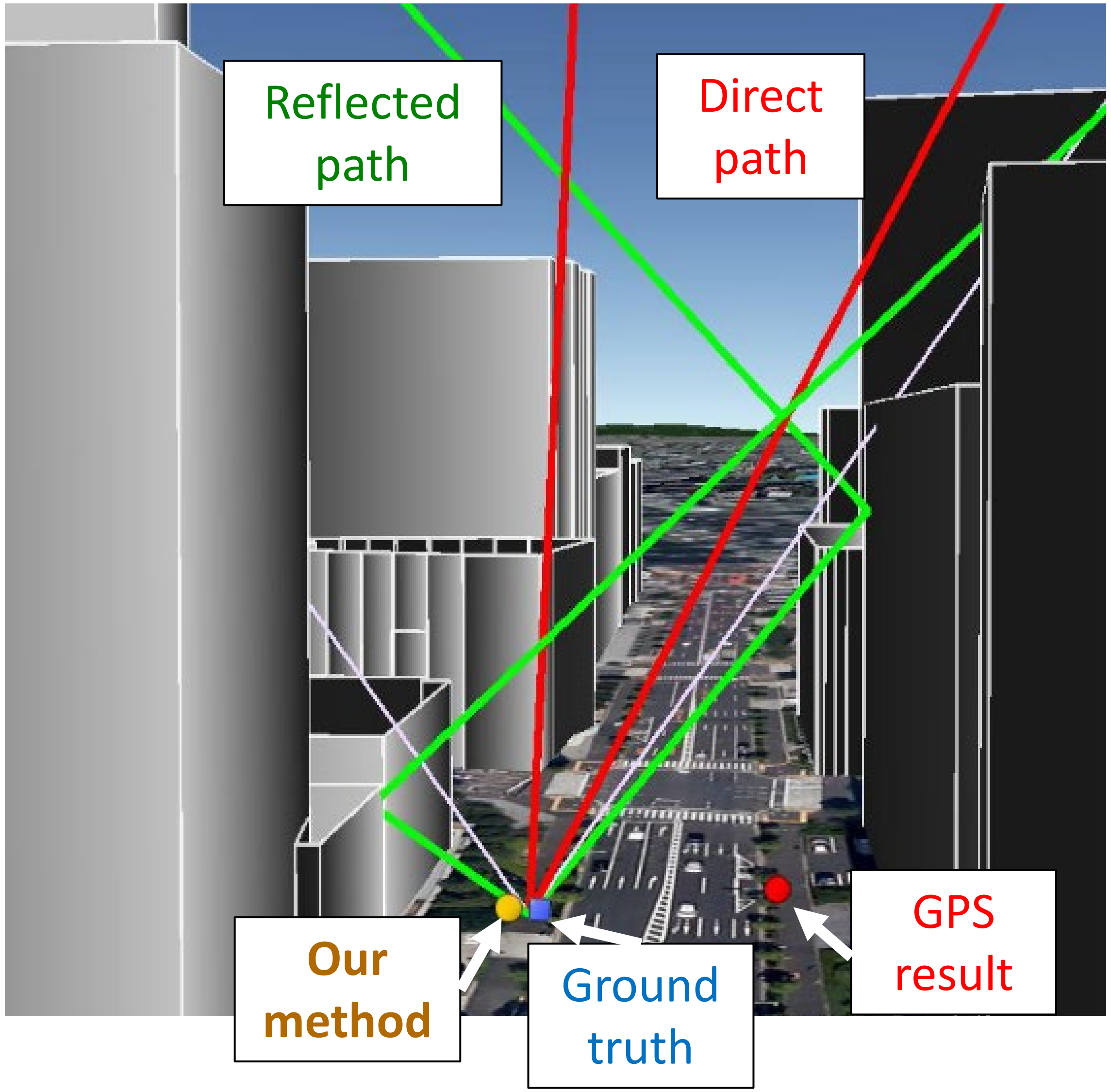




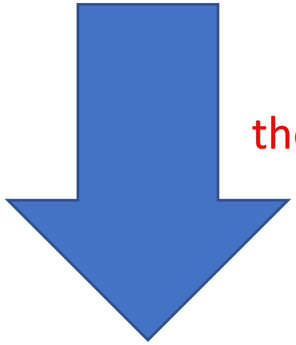
In the case which occlusion ratio is high:

- convergence ratio becomes lower for the localization algorithm
- localization error becomes larger even in the converged case.

3D-GNSS Positioning in Urban Canyon

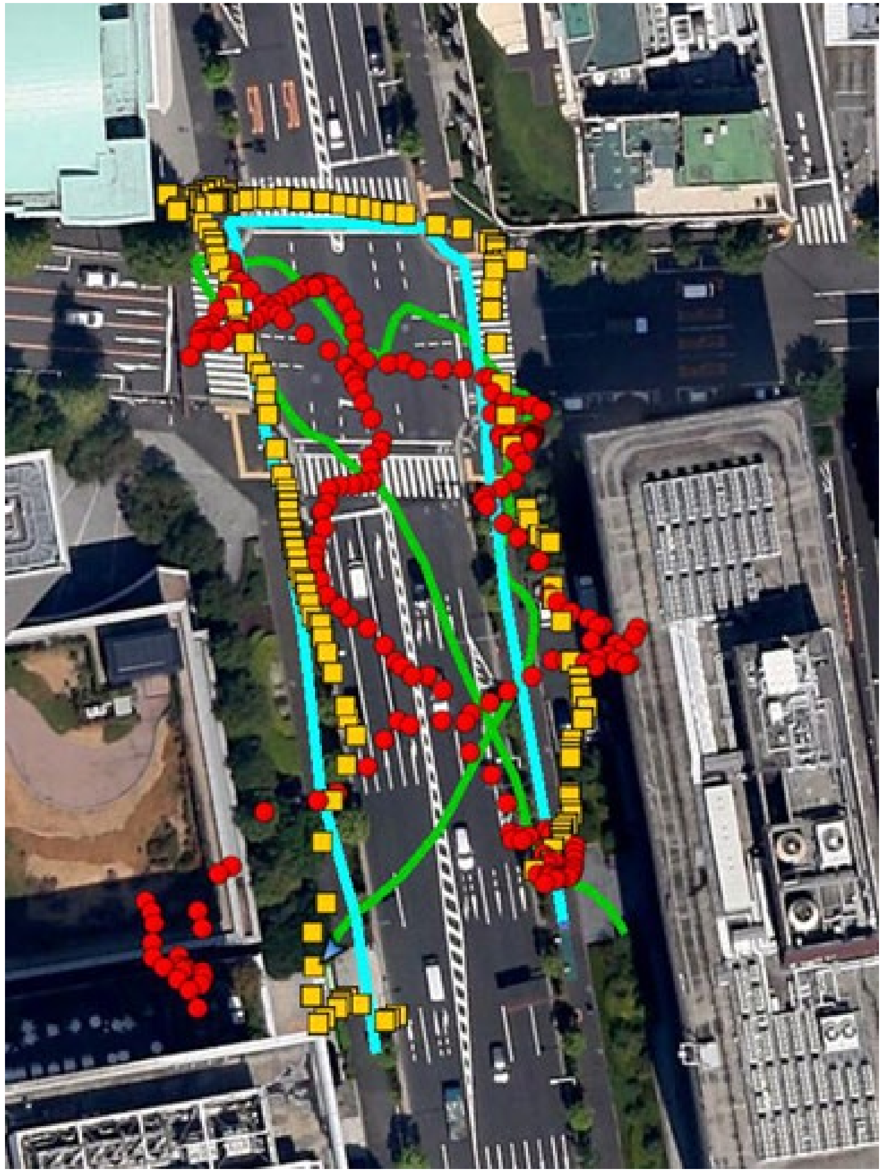


Signal Observation:
- Pseudorange
- RSSI (Received Signal Strength Indicator)
- Deceived positioning results



Position Assumptions:
Estimated by ray tracing
- Pseudorange
- RSSI (Received Signal Strength Indicator)
- Deceived positioning resuts

Evaluations applying 3D method to GPS signals



Shunsuke Miura, Shoma Hisaka, and Shunsuke Kamijo, "GPS Multipath Detection and Rectification using 3D Maps", IEEE ITSC2013, pp.1528-1534, The Hague, The Netherlands, Oct.6-9, 2013

Experimental result: GPS

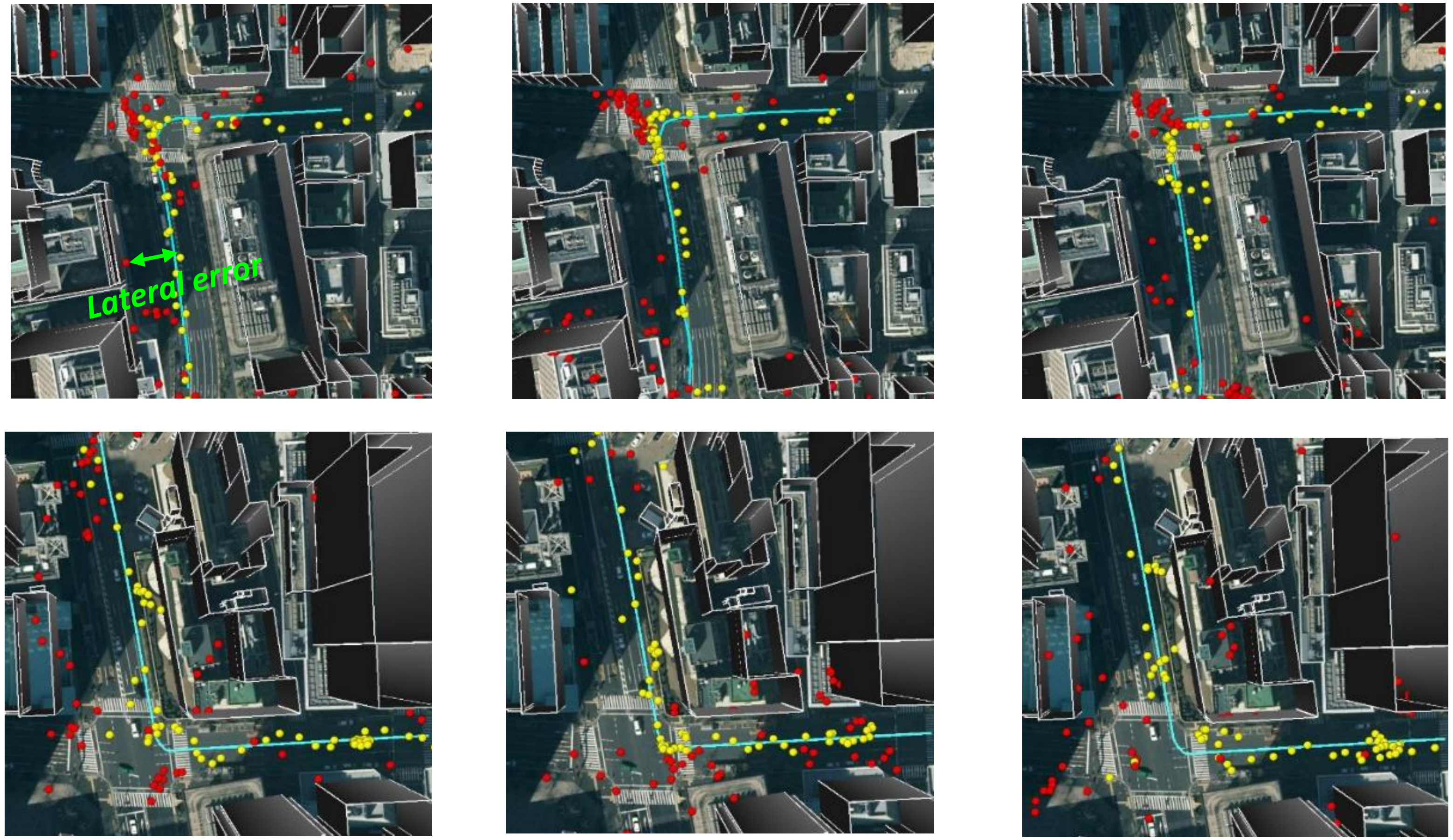
Weighted least square (WLS) GPS

Ground truth

3D map based GPS

Right turning

Left turning



	Mean error (m)	Standard Deviation (m)	Maximum error (m)
WLS GPS	17.8	11.8	82.9
3D map based GPS	3.1	3.2	24.1

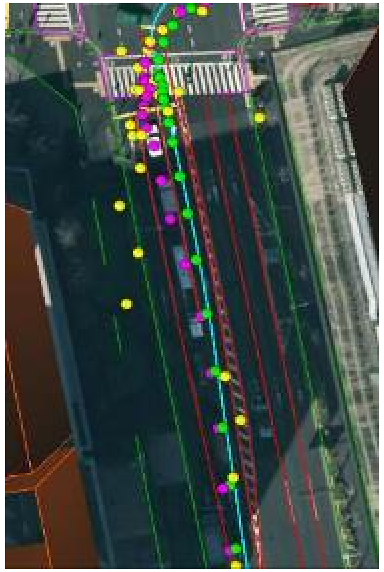
Experimental result for localization

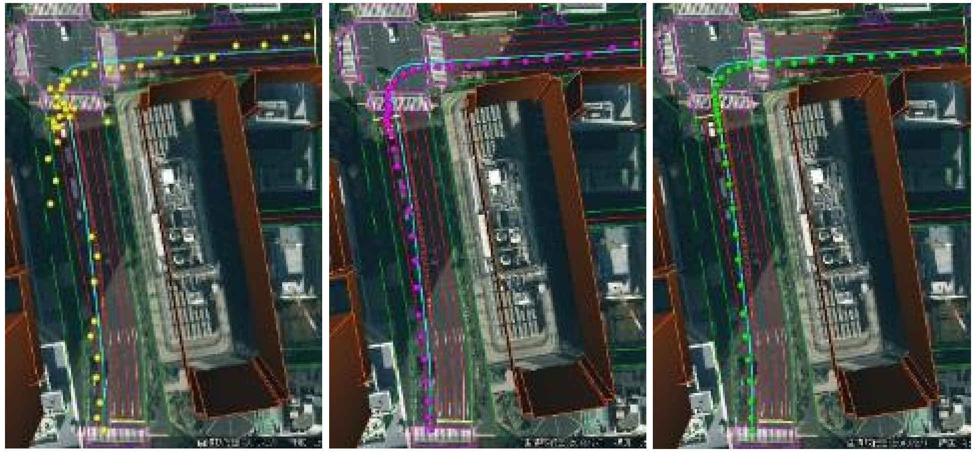
GNSS

GNSS/INS

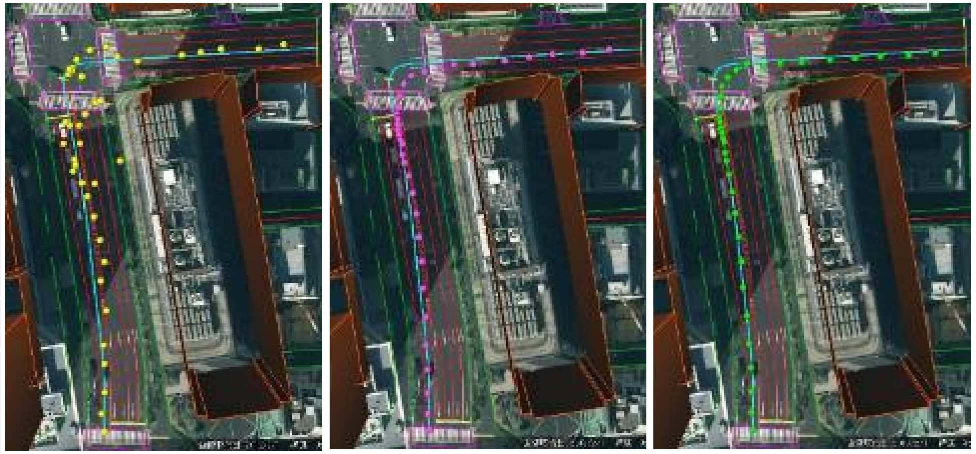
GNSS/INS/lane detection

Ground truth





(a) First right turning experiment



(b) Second right turning experiment

Ex.	*Evaluation method*	*GNSS*	*GNSS/ INS*	*GNSS/INS/ Lane Det.*
1	Positioning Error mean (meter)	3.44	1.79	0.73
	Correct lane rate	43.2%	59.1%	93.2%
2	Positioning Error mean (meter)	2.41	1.29	0.71
	Correct lane rate	55.0%	82.5%	95.0%

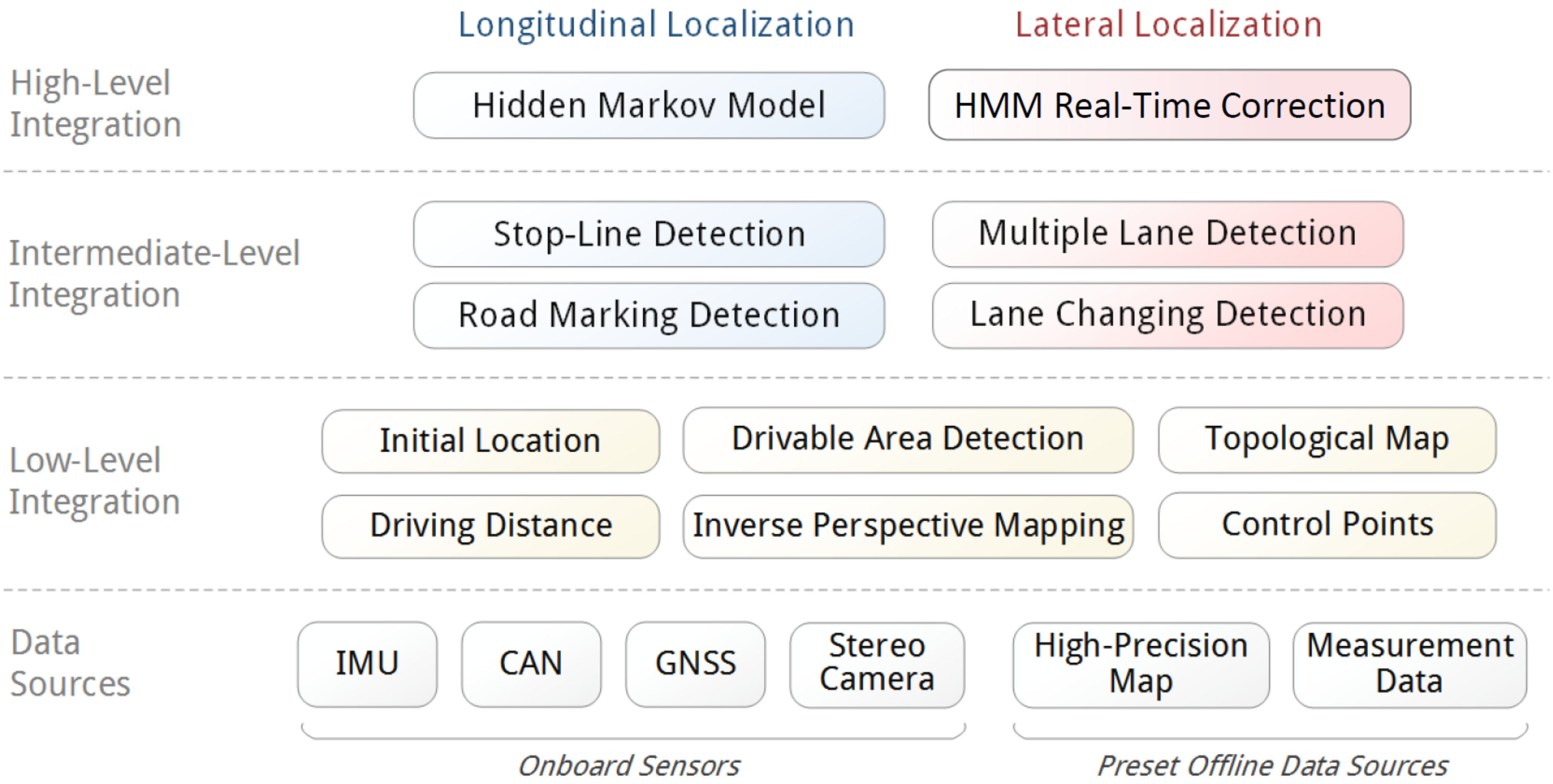
Case Study of Under the Bridge Environment

Experimental environment

Experimental equipment

Proposed Vehicle Localization System

- Topological map & stereo camera & IMU/CAN → HMM → Position



Conclusions

- Benefits and problems of the digital map for autonomous vehicle application were discussed in this presentation.
- Problems and their solutions were exemplified from our research experiences with the evidence of experimental data.

- Need to slimulate the discussions on the digital map solutions for the successful cross bordered delivery and usage of autonomous vehicles.