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Simultaneous Localization, Mapping and Moving-Object Tracking Using Helmet-Mounted LiDAR for Micro-Mobility

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Presenter

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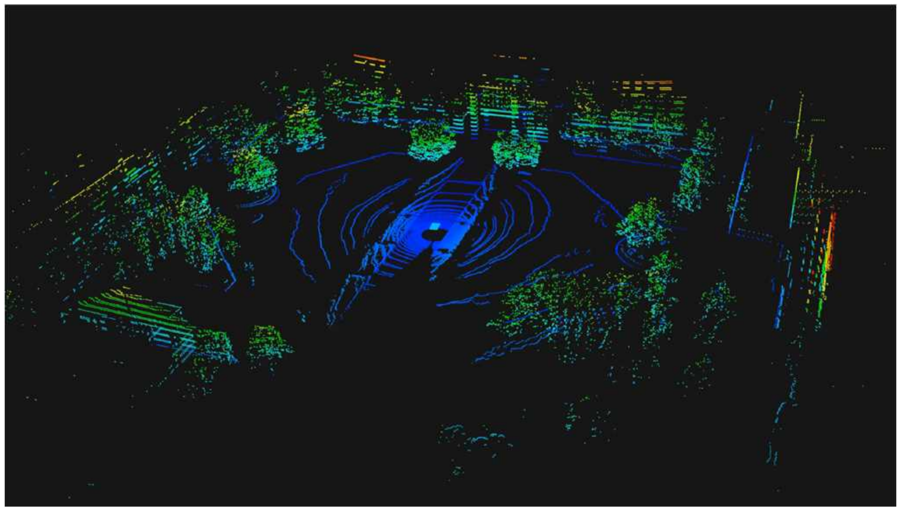
- **He received the M.Eng. and D.Eng. degrees in aeronautical engineering from University of Osaka Prefecture, Japan, in 1981 and 1988, respectively.**
- **He is currently working as a Professor with Department of Intelligent Information Engineering and Deputy Director of Mobility Research Center in Doshisha University, Kyoto, Japan.**
- **His research interests and expertise include LiDAR-based sensing, sensor fusion, and sensor network with applications in active safety and autonomous driving of vehicles and mobile robots.**

Agenda

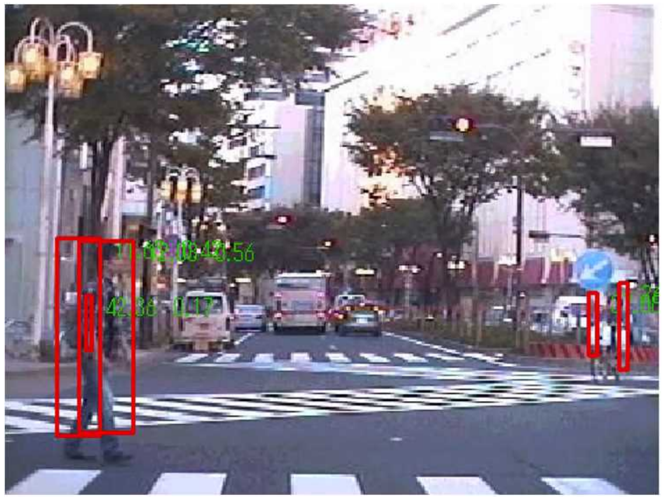
1. Motivation
2. Experimental System
3. Sequence of SLAMTMO
4. Distortion correction of LiDAR scan data
5. Classification of stationary and moving scan data
6. Experimental Results
7. Conclusions and future works

Motivation

- Environmental map building using **Simultaneous Localization And Mapping (SLAM)** and **Tracking of Moving Objects (TMO)**, such as cars, cyclists and pedestrians, are important issues for autonomous driving and active safety of vehicles and mobile robots.
- Many related studies have been presented using cameras, radars, and **Light Detection And Ranging (LiDAR) sensors**.
- LiDAR-based **SLAMTMO** is focused.



SLAM



TMO

Motivation

- Due to the impact of the novel coronavirus disease (COVID-19), many people are highly resistant to using conventional means of urban transportation, such as crowded trains and buses.
- To escape the three Cs' (closed spaces, crowded spaces, and close-contact settings), the use of single-seater "micro-mobility", such as bicycle, e-bike, e-scooter, and personal mobility, is on the increase for short-distance travel in urban cities.
- In the endemic society, the demand for micro-mobility will further increase.

Motivation

- **Although the frequency of traffic accidents involving micro-mobility increases, the R&D related to active safety for micro-mobility is far behind.**
- **For active safety of micro-mobility, a SLAMTMO method is presented in GNSS-denied environments using a LiDAR attached to the rider's helmet (Helmet-Mounted LiDAR) of micro-mobility.**

SLAMTMO: Simultaneous localization, Mapping, and tracking of moving objects

Experimental System

LiDAR (Ouster OS0-64)

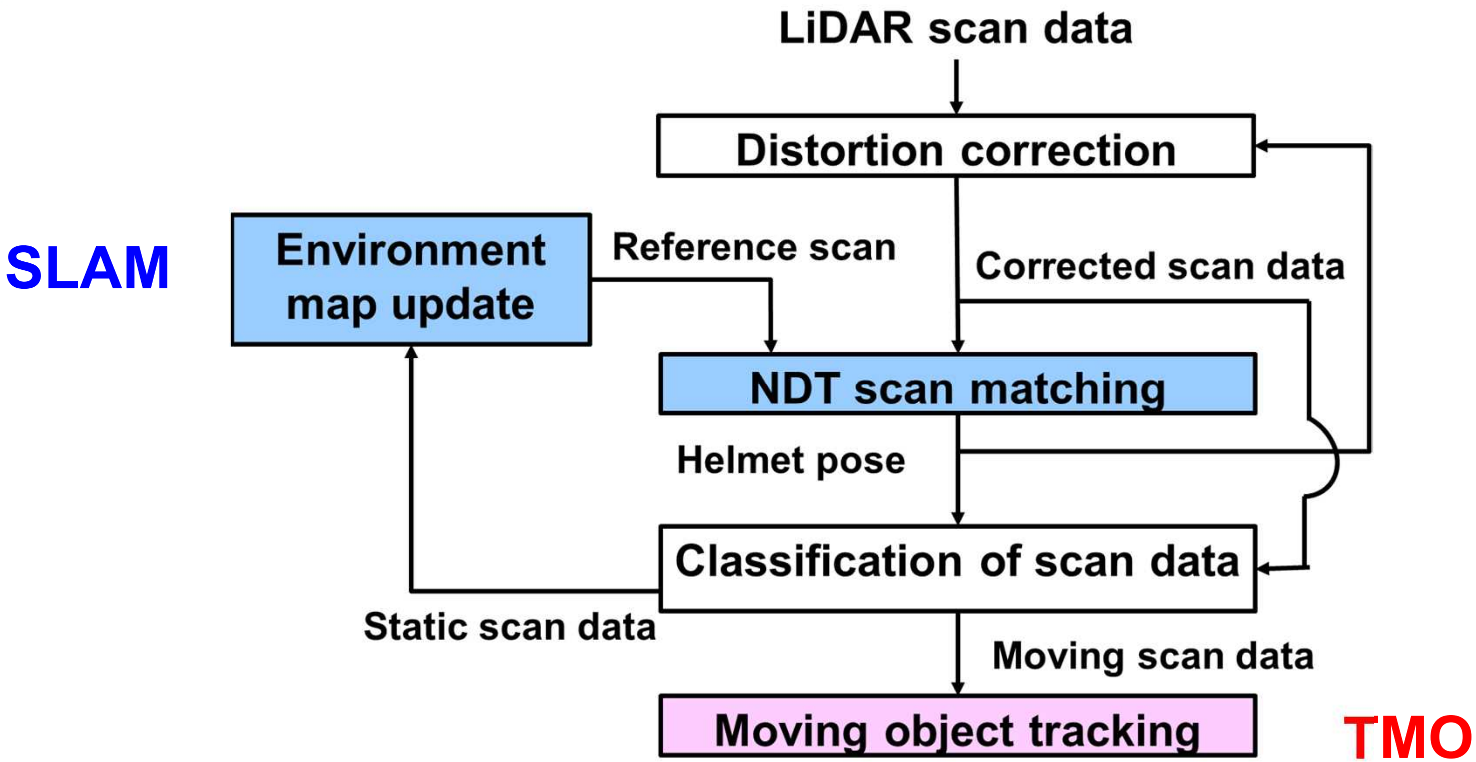
- **Layer : 64**
- **Scanning frequency : 10 Hz**
- **Maximum range : 50 m**
- **Horizontal view angle : 360°**
- **Vertical view angle : 90°**

IMU (Xsens MTi-300)

- **Output**
  Attitude angle (roll and pitch angles)
  Angular velocity (roll, pitch, and yaw velocities)
- **Measurement frequency : 100 Hz**

- In micro-mobility systems, it is difficult to mount a large number of sensors on the vehicle body, as is the case with cars, because of size and theft concerns.
- Thus, it is desirable to mount small and easily detachable sensors on the handlebar of the micro-mobility or on the helmet worn by the micro-mobility rider.

Sequence of SLAMTMO



- **Distortion correction: Distortion in LiDAR scan data, which is caused by motion of micro-mobility and rider is corrected.**
- **Normal distributions transform (NDT) scan matching: The self-pose of the helmet is obtained in GNSS-denied environments.**
- **Classification of LiDAR scan data: Scan data are classified into stationary scan data relating to stationary objects and moving scan data relating to moving objects.**

Simultaneous localization and mapping (SLAM)

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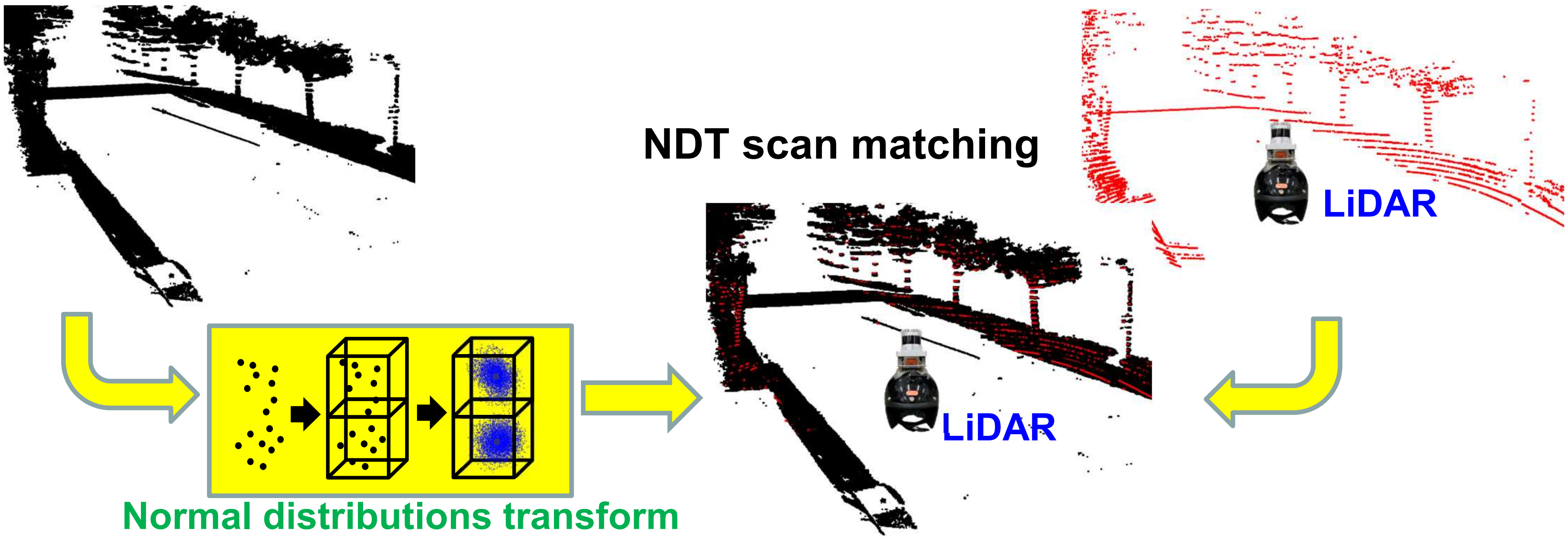
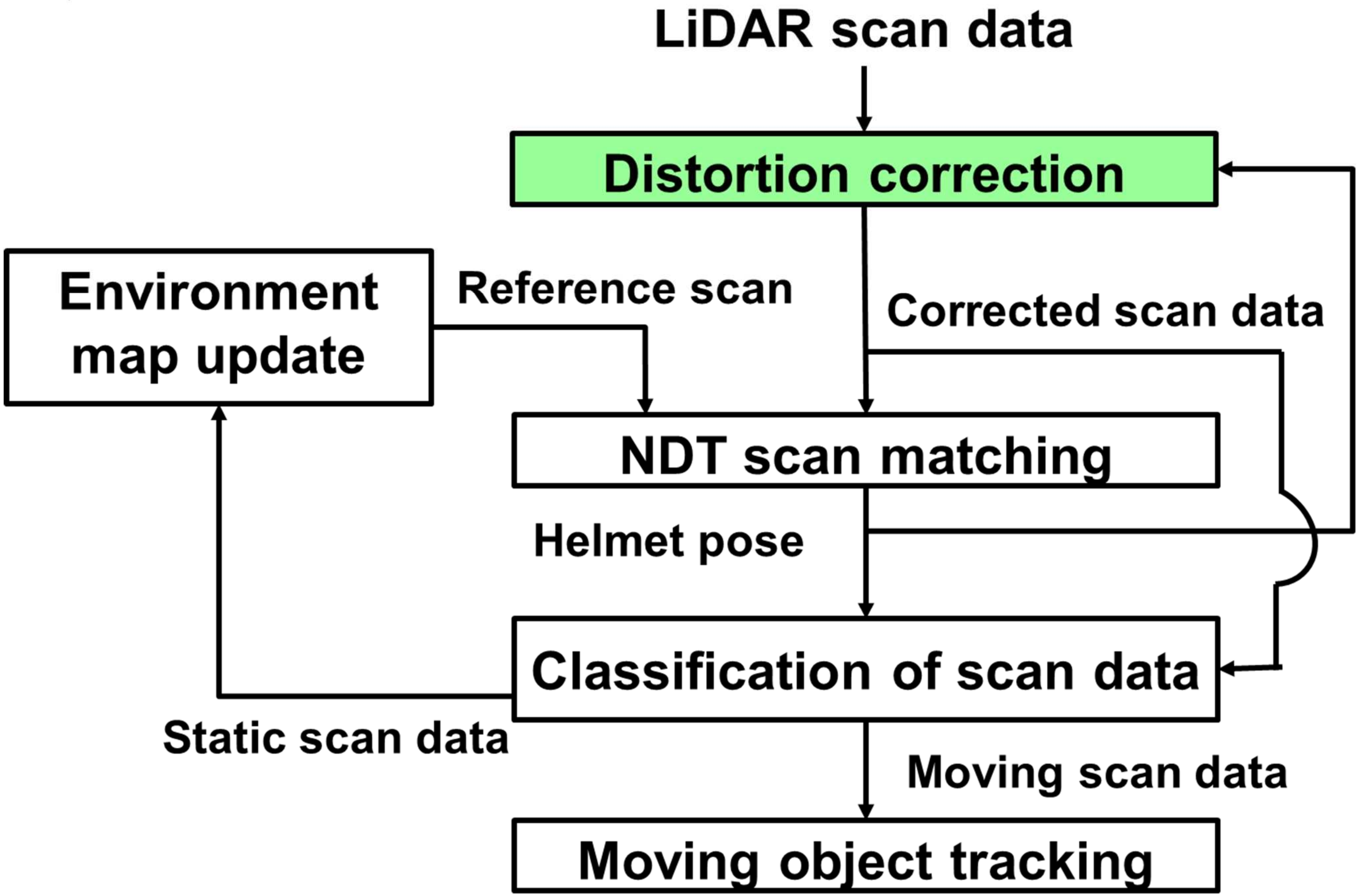
Reference scan (environmental map)
obtained before the current scan
(represented in the world coordinate frame)

New scan data
obtained at the current scan
(represented in the helmet coordinate frame)



- The helmet LiDAR obtains a new scan data every LiDAR-scan period.
- Using NDT scan matching, the helmet pose (3D positions and roll, pitch, and yaw angles) is calculated by matching the new scan data with the environmental map.
- The new scan data are merged to the environmental map using the calculated helmet's pose.
- By repeating this process every LiDAR scan period, the environmental map is built.

Distortion correction of LiDAR scan data



Distortion correction of LiDAR scan data

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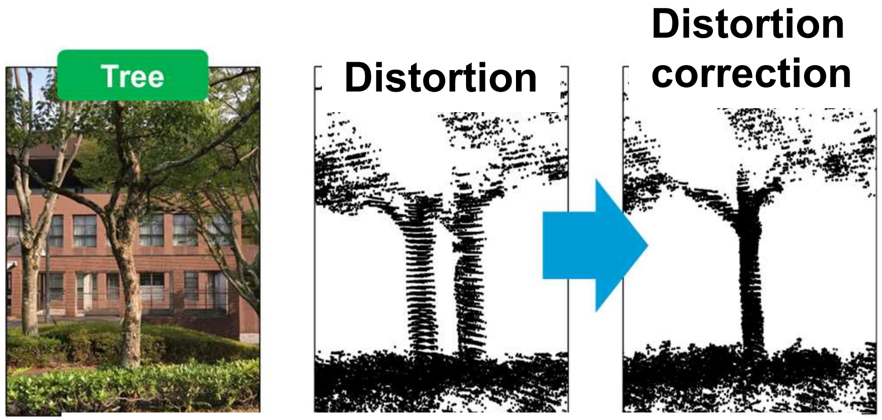
- It is usually assumed that all LiDAR scan data within a scan (one rotation of laser beams in the horizontal plane) are obtained at the same time; thus, all scan data are mapped onto the world coordinate frame using the same pose of a LiDAR.
- However, the LiDAR obtains range measurements by scanning laser beams; thus, when the helmet moves and shakes strongly, all LiDAR scan data within a scan cannot be obtained at the same pose of the LiDAR, and distortion appears in mapping results.
- To correct the distortion, the helmet's pose is estimated using Kalman-filter based method every LiDAR scan data are obtained within a scan.

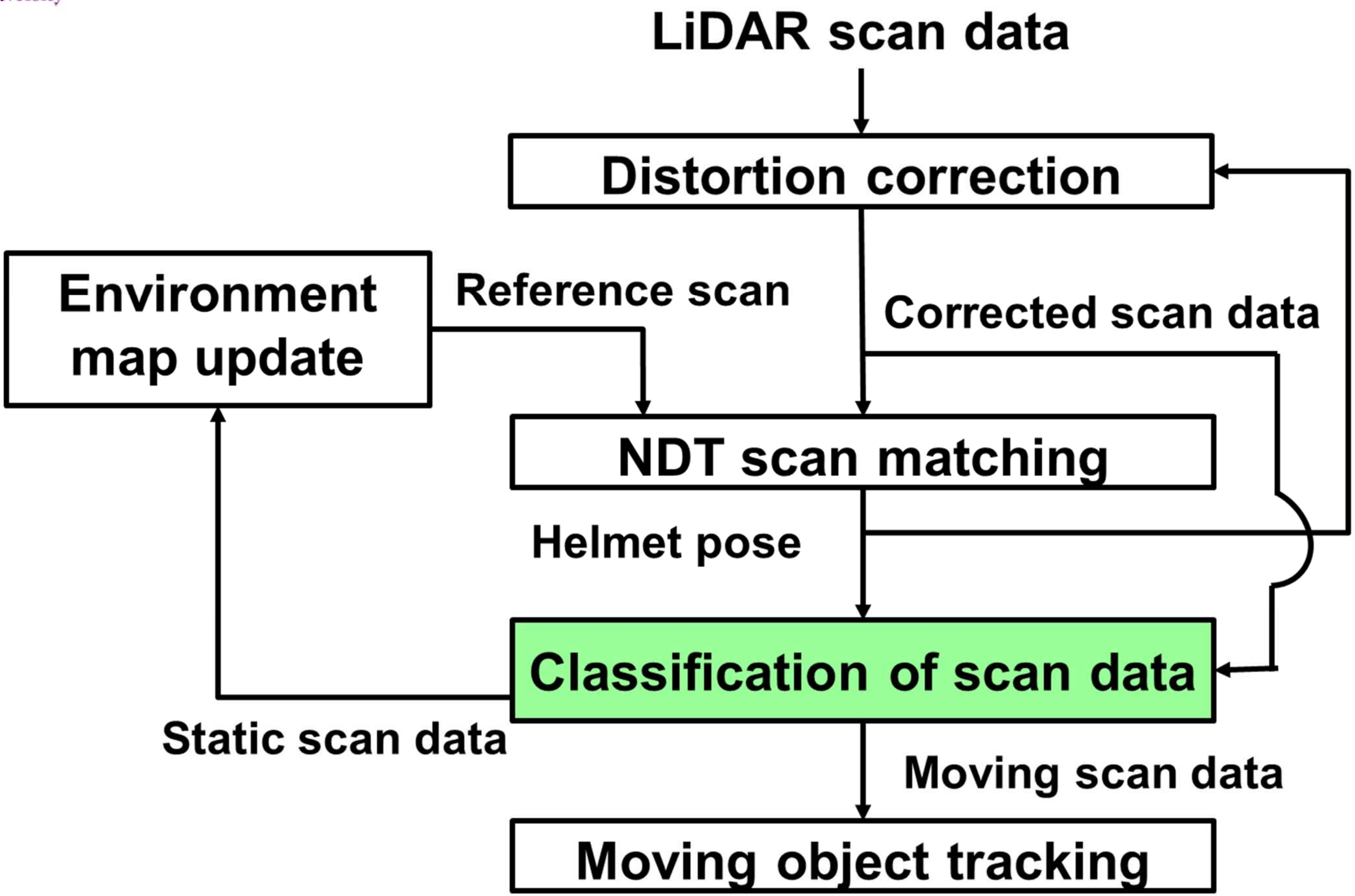
Laser scanning

View from helmet



Example of distortion correction
(LiDAR image of a tree)

Classification of LiDAR scan data



Classification of LiDAR scan data

- For SLAM, the scan data related to stationary objects (stationary scan data) have to be extracted from the entire scan data.
- For TMO, the scan data related to moving objects (moving scan data) have to be extracted from the entire scan data.
- Although the usual classification of LiDAR scan data is performed based on the occupancy grid method, LiDAR noises and outliers frequently cause misclassification.
- To classify the scan data as much correctly as possible from LiDAR scan data, environment map subtraction (EMS)-based classification method is presented.

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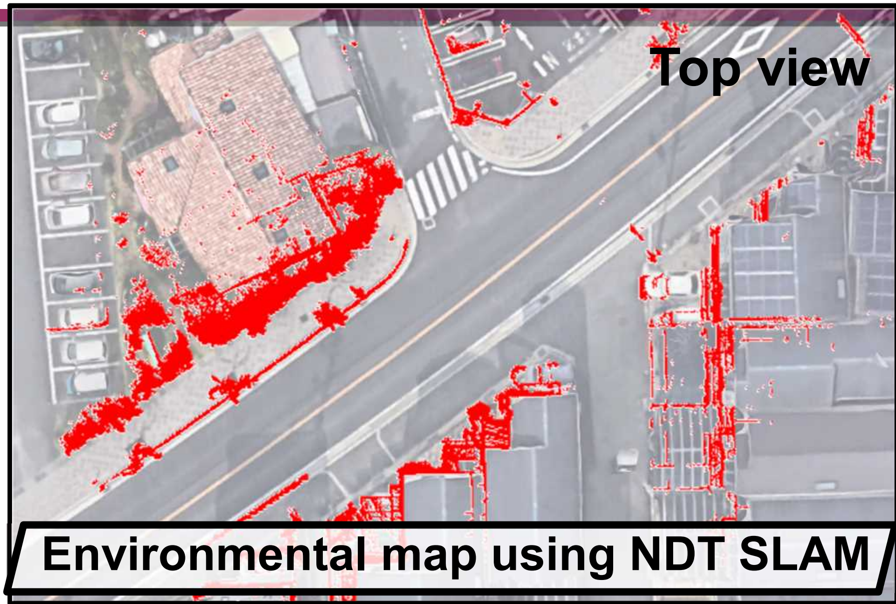
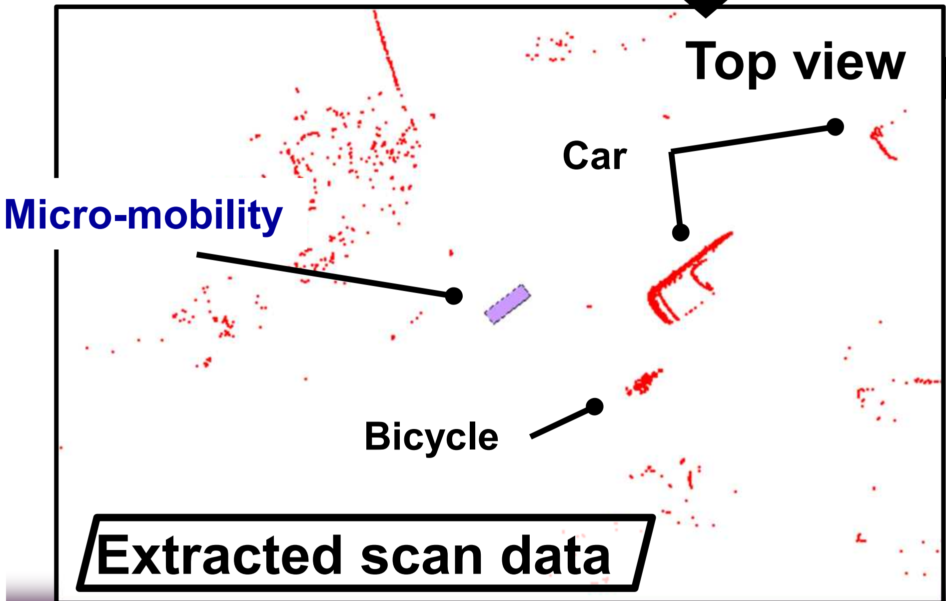
Environment map subtraction (EMS)-based classification method



Subtraction



Occupancy grid method

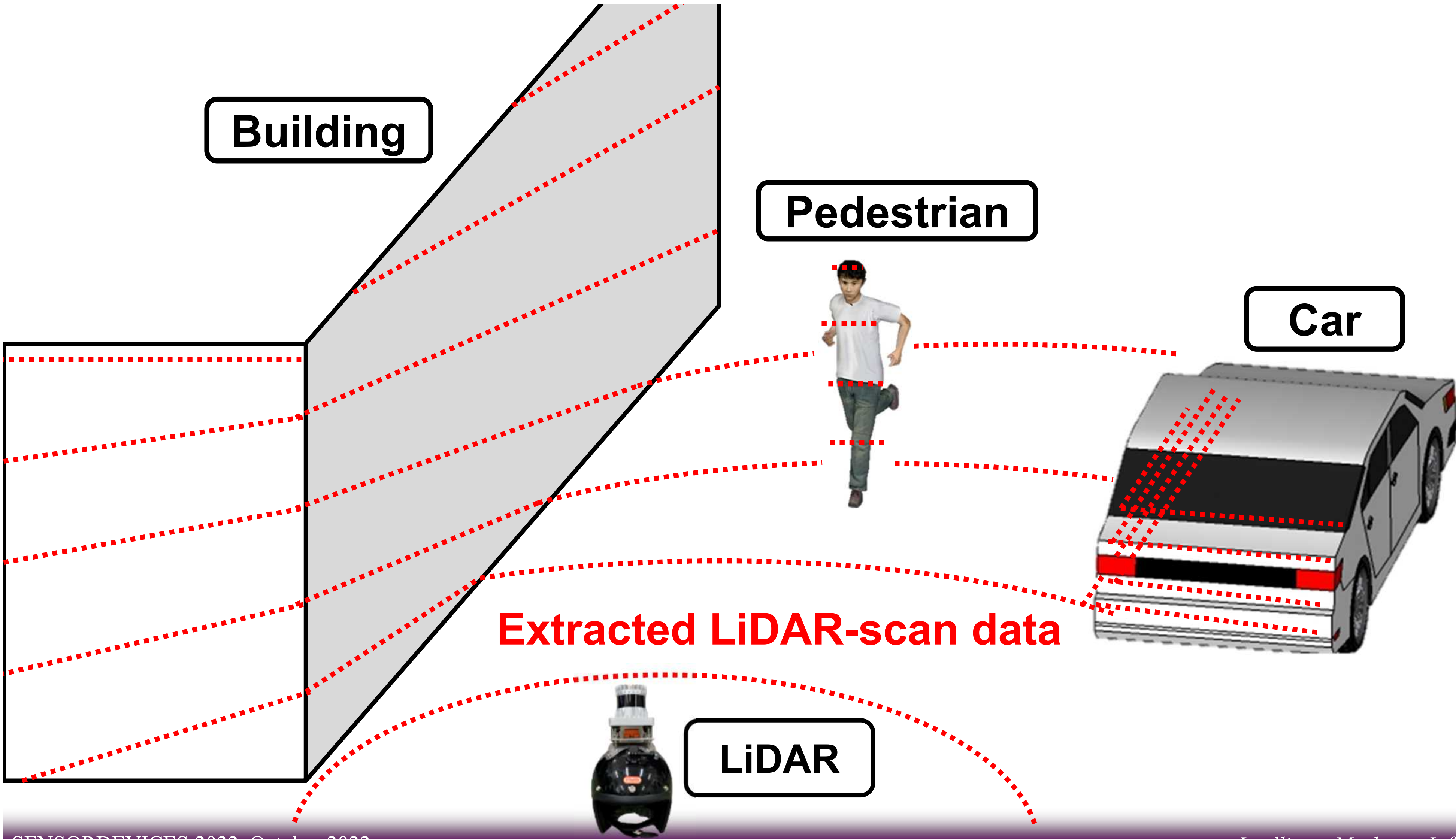
Stationary scan data

Moving scan data

- The environment map is subtracted from the current scan data.
- Based on the occupancy grid method, stationary and moving scan data are classified from the extracted scan data.

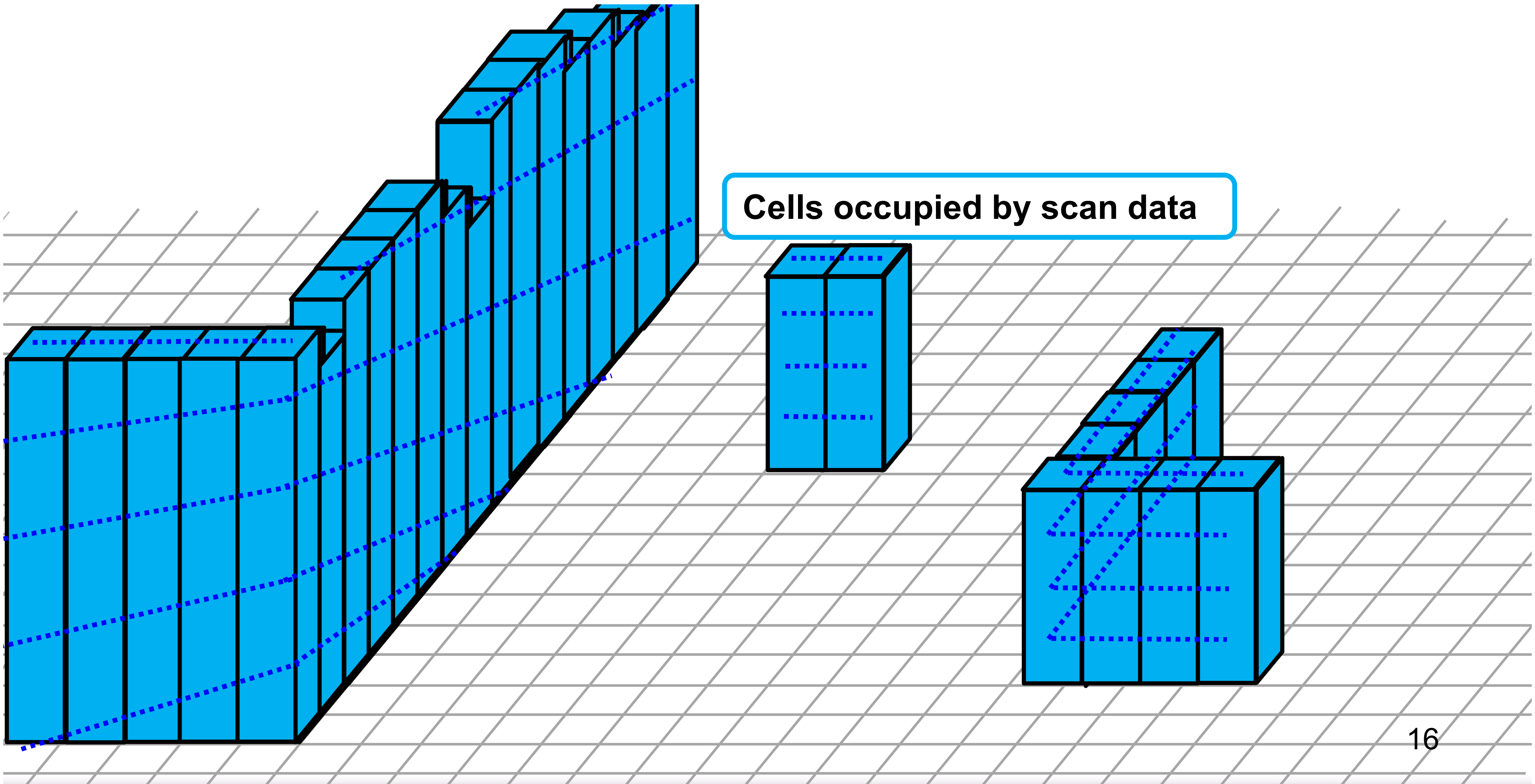
Occupancy grind method

LiDAR-scan data are extracted based on EMS-based classification method.



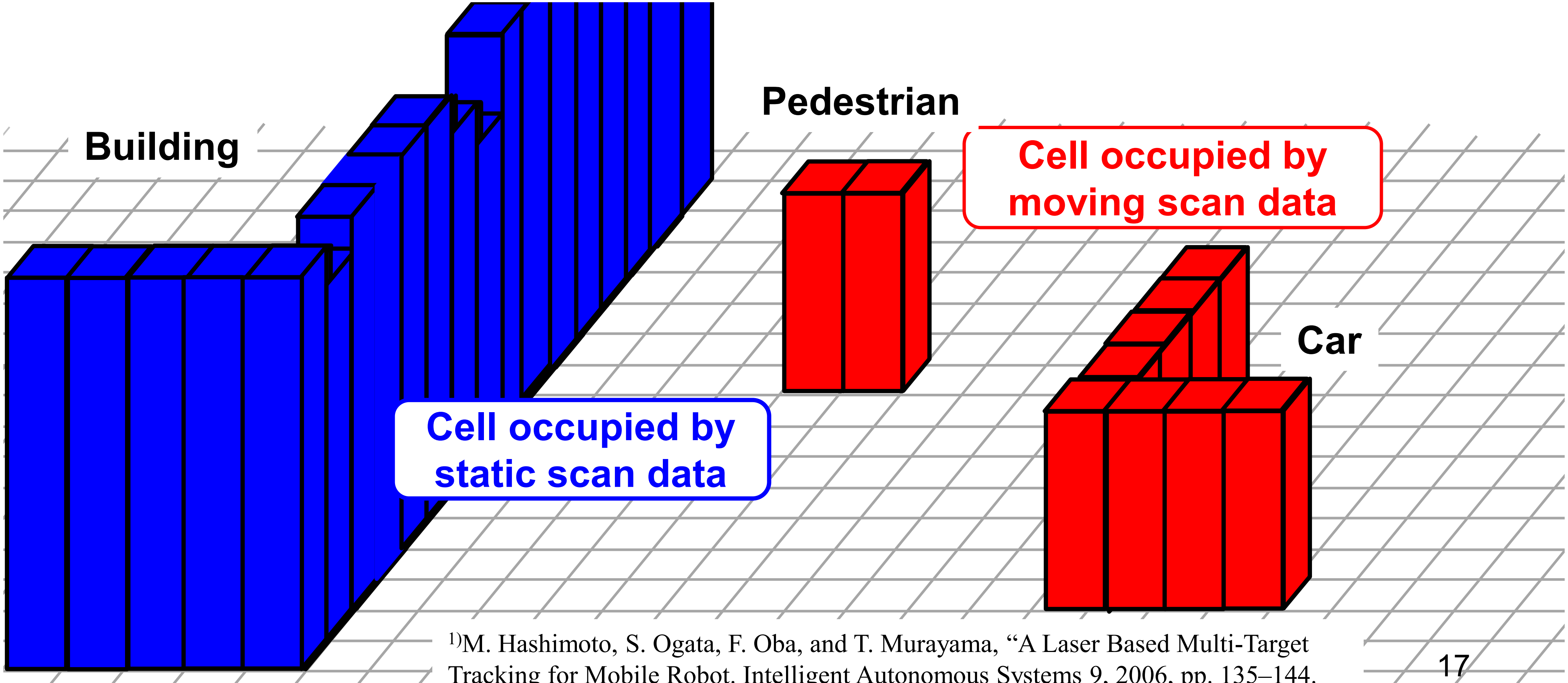
Mapping of scan data

Extracted scan data are mapped onto the **elevation map** which is represented in **the world coordinate frame**.



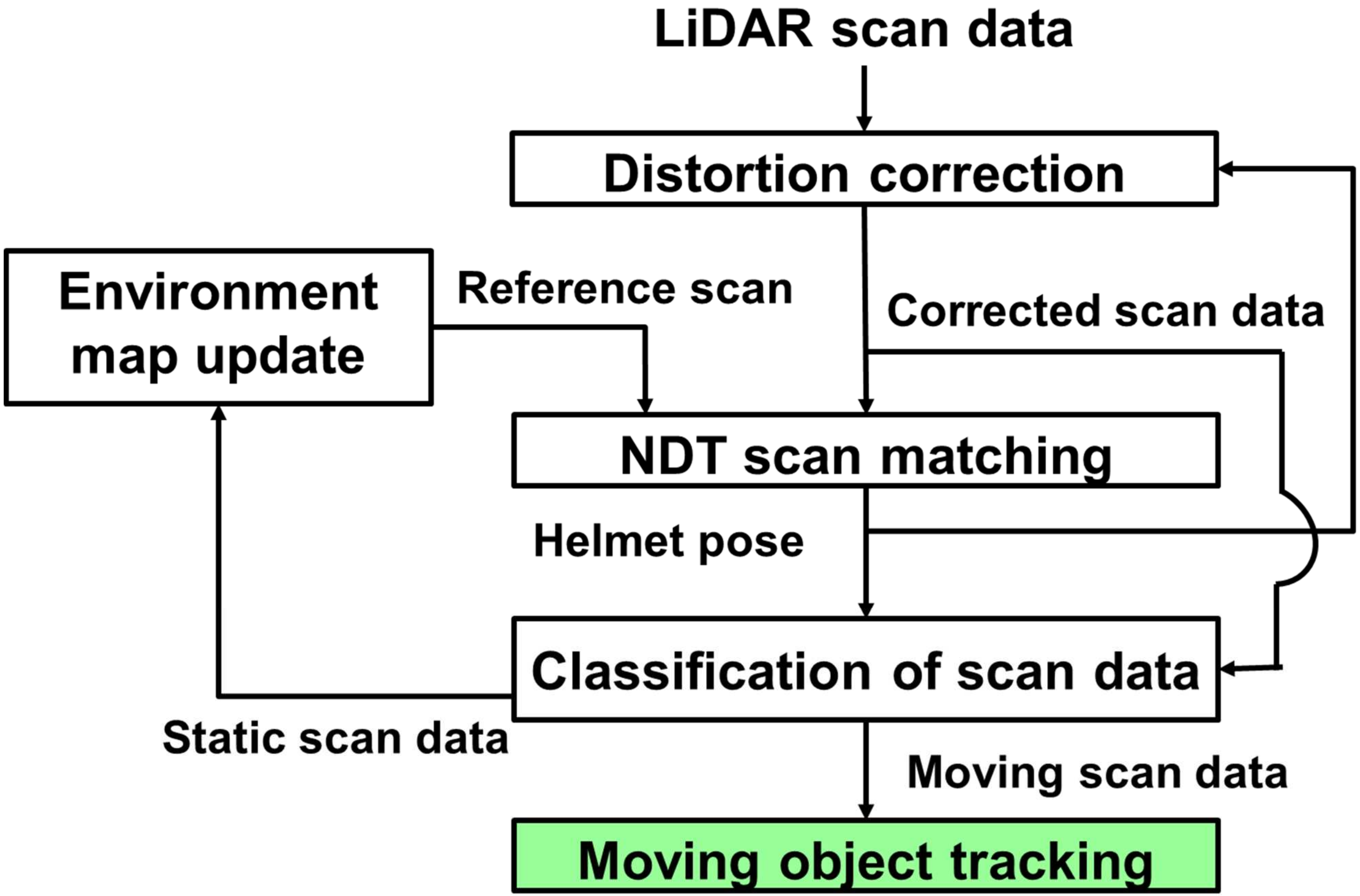
Classification of stationary and moving scan data

- For the **stationary scan data**, the time to occupy the same cell is **long**.
- For the **moving scan data**, the time to occupy the same cell is **short**.
- Based on the occupancy time, stationary and moving scan data are classified.



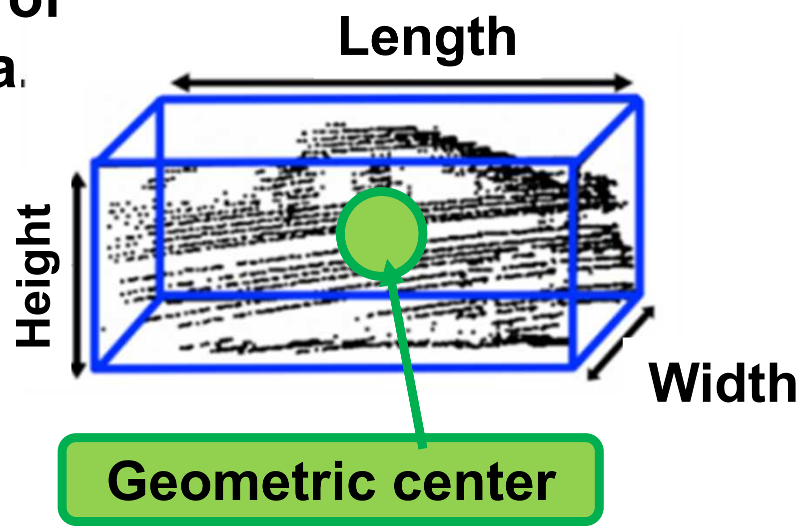
[1]M. Hashimoto, S. Ogata, F. Oba, and T. Murayama, "A Laser Based Multi-Target Tracking for Mobile Robot. Intelligent Autonomous Systems 9, 2006, pp. 135–144.

Moving-object tracking (TMO)



Moving-object tracking (TMO)

1. Obtain the width (W_{meas}) and length (L_{meas}) of the moving object from the moving scan data.



2. Estimate the size of moving object by

Width / Length

$$\begin{cases} W(t) = W(t-1) + G(W_{meas} - W(t-1)) \\ L(t) = L(t-1) + G(L_{meas} - L(t-1)) \end{cases}$$

where G is a filter gain.

The height estimate *H* of the moving object is directly obtained from the height measurements of the moving scan data.

3. Obtain the position of the geometric center of estimated cuboid.

4. Estimate the position (*x*, *y*) and velocity (*Vx*, *Vy*) of the moving object based on the position of the geometric center via Kalman filter.

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Experimental environment

- A micro-mobility was moved on our university-campus road
- Traveled distance：500 m
- Maximum speed：30 km/h

TMO results


Start/goal position
Area 1
2021 Google 20 [m]


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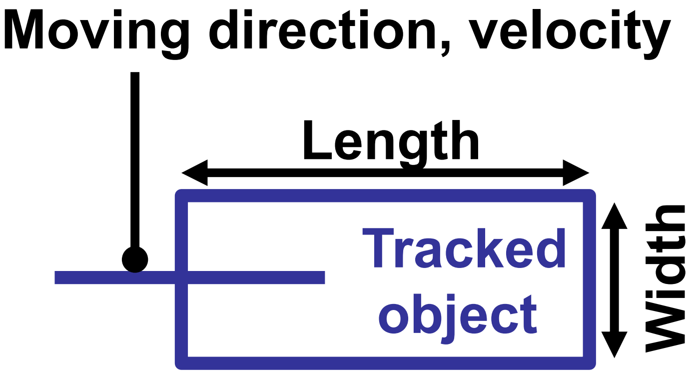
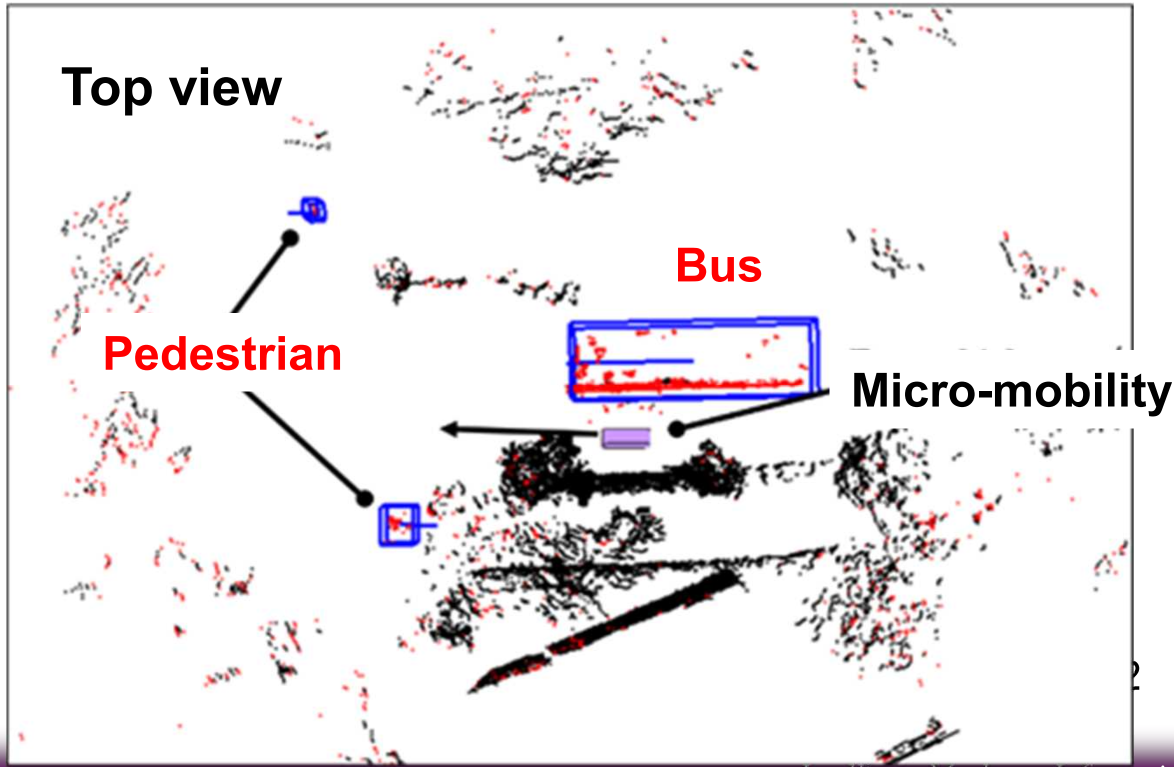
Top view


Moving direction, velocity
Length
Tracked object
Width


Top view
Bus
Pedestrian
Micro-mobility

TMO performance (Number of moving objects tracked)

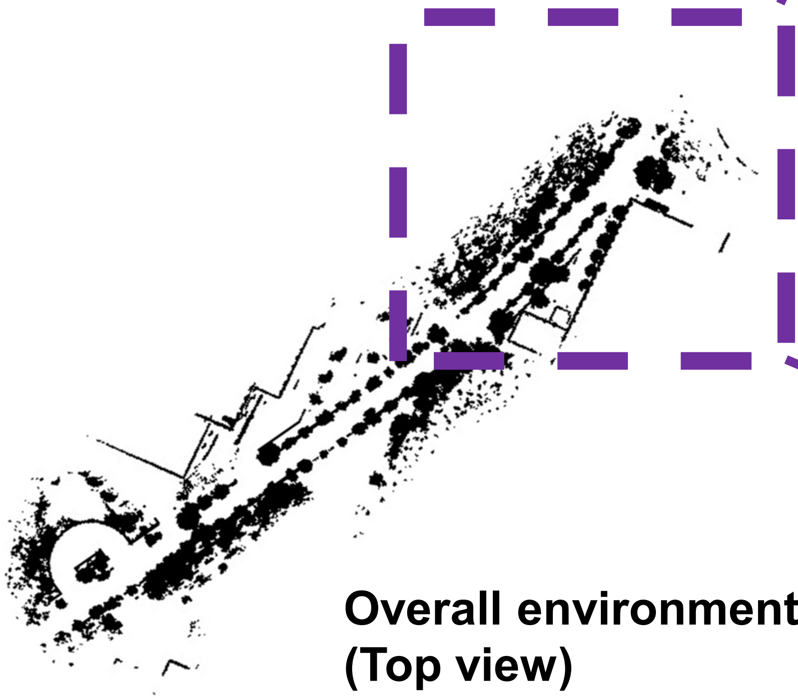
- In the environment, the number of moving objects is 111 (106 pedestrians and 5 cars).
- Experiments are conducted in two cases:
  Case 1: SLAMMTO with distortion correction of LiDAR scan data and EMS-based classification method (proposed method)
  Case 2: SLAMMTO without using either method.
- The proposed method (case 1) gives better TMO accuracy.

Erroneously tracking stationary objects

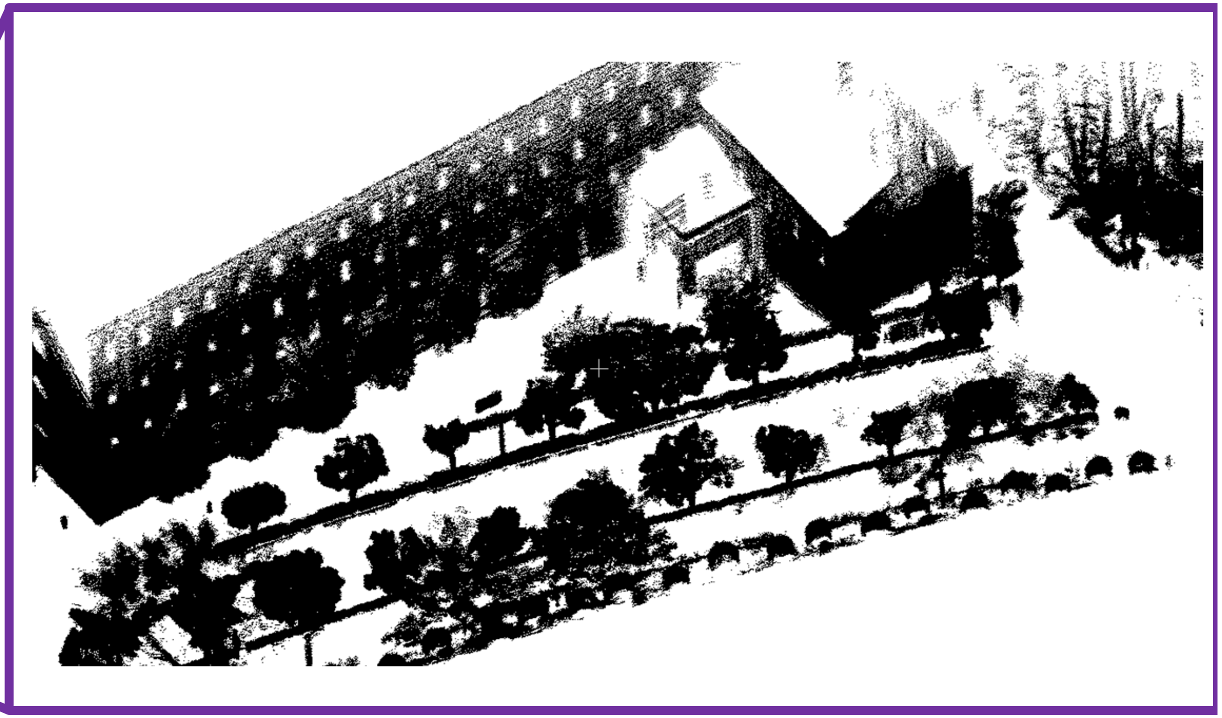
Moving objects that cannot be tracked

	Correct tracking	False tracking	Untracking
Case 1	109	0	2 (pedestrians)
Case 2	103	0	8 (pedestrians)

SLAM result



Overall environmental map
(Top view)



Enlarged map (Bird's-eye view)

SLAM performance (Error of position estimate)

- In the SLAM, the mapping accuracy can be evaluated by the pose accuracy. Therefore, the error of position estimate of the helmet at the goal position is obtained.
- Experiments are conducted in two cases:
  Case 1: SLAMMTO with distortion correction of LiDAR scan data and EMS-based classification method (proposed method)
  Case 2: SLAMMTO without using either method.
- The proposed method (case 1) gives better SLAM accuracy.

Error of position estimate at the goal position

	Case 1	Case 2
Run 1	0.23 m	5.91 m
Run 2	1.93 m	15.10 m
Run 3	0.71 m	6.03 m

Conclusions

- **A SLAMTMO method in GNSS-denied environments using LiDAR attached to a rider helmet of micro-mobility (helmet-mounted LiDAR) was presented.**
- **To accurately perform SLAMTMO, the distortion of scanning LiDAR data was corrected using the self-pose information by NDT scan matching and IMU information via extended Kalman filter.**
- **Stationary and moving scan data were classified by the EMS-based classification and occupancy grid-based methods.**
- **The performance of the presented SLAMTMO was examined through experiments in a road environment of our university campus.**

Future works

- **Obstacles on road surfaces, such as curbs, gutters, and steps, using LiDAR and accelerometer will be detected to reduce the falling risk of micro-mobility, and the obstacle information will be included in the environment map.**

- **Since the current helmet-mounted mechanical LiDAR is heavy and large, there are issues in terms of practicality and usability.**
  Therefore, instead of a mechanical LiDAR, a small size and light-weight solid-state LiDAR will be mounted on a rider helmet.