ALLSENSORS 2020

Normal Distributions Transform-based Mapping Using Scanning LiDAR Mounted on Motorcycle

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Resume

Akihiko Yoshida

Education

Doshisha University -Kyoto, Japan Apr. 2016 – Mar. 2020

- Major: Science and Engineering
- Dissertation title: “Point Cloud Mapping using Scanning LiDAR Mounted on Motorcycle in Dynamic Environments”

Graduate school of Doshisha University -Kyoto, Japan
Apr. 2020 - present

- Major: Science and Engineering

Skills

Technical skills

- Languages : C/C++, Java
- OS : Windows, Linux
- Tools : OpenCV, OpenGL, PCL

Agenda

1. Introduction
2. Experimental System
3. Map Generation
4. Experimental Result
5. Conclusions and Future Works

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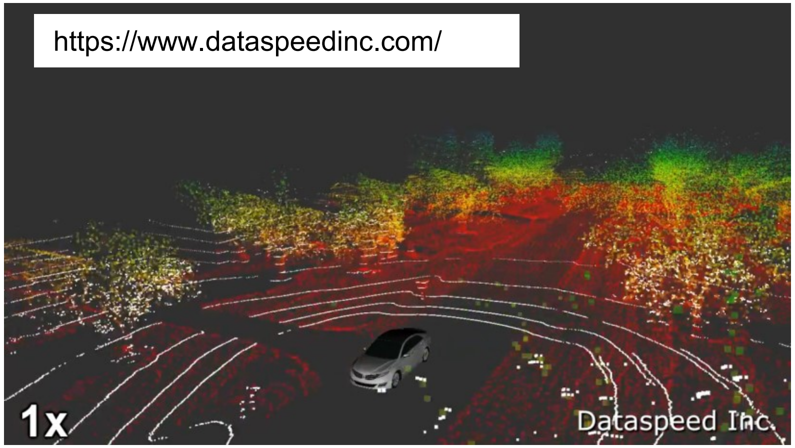
Introduction

- Environment recognition using vehicle-mounted LiDAR is an important issue in mobile robotics and vehicle automation domains.

- Several recognition methods using LiDAR have been proposed, such as simultaneous localization and mapping (SLAM) and moving-object tracking .

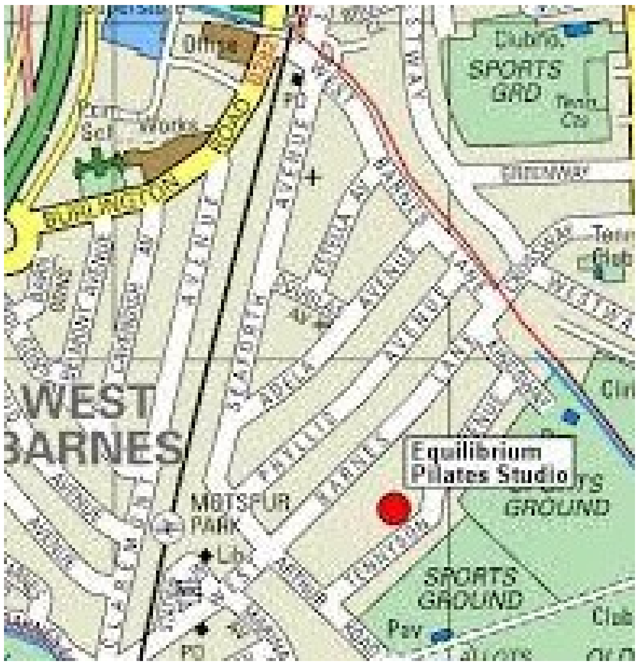


SLAM

Moving-object tracking

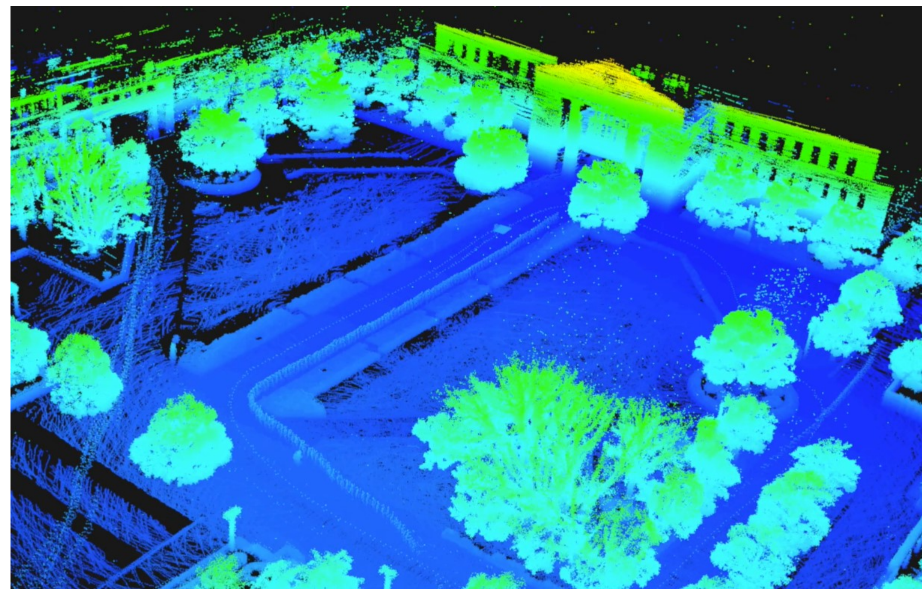
Introduction

- Automated vehicles require a 3D environmental map.



Conventional 2D map

cannot apply to automated vehicles



3D map (point cloud map)

Introduction

- There were few studies on 3D point cloud mapping with sensor mounted on two-wheeler.
- A method of 3D point cloud mapping using a LiDAR mounted on a motorcycle was presented.

Car → Motorcycle

Small attitude change

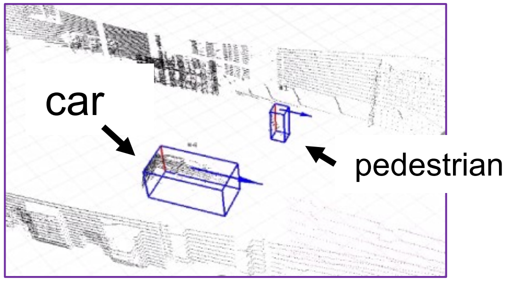
Large attitude change

Introduction

Our previous mapping method assumed the use in in static environments without moving objects such as cars and pedestrians.

However in real world …

In environments, many moving objects exist.
When our previous mapping method is used in such dynamic environments, moving scan data originating from moving objects remain in maps.



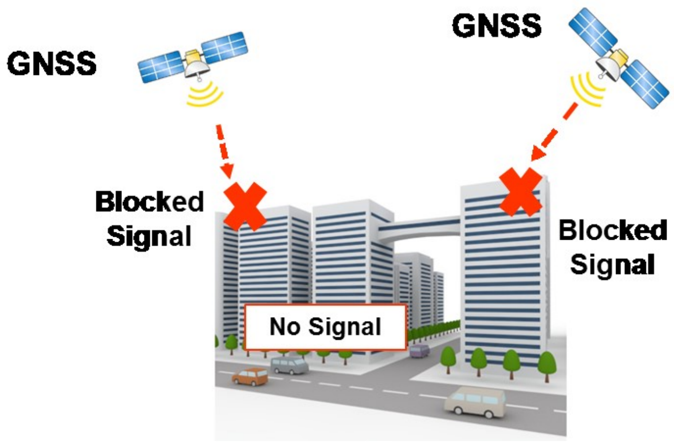
Moving-object detection

LiDAR-based moving-object detection

Moving scan data will be removed from maps in dynamic environments.

Topic

- Use of a scanning LiDAR mounted on motorcycle
- 3D point cloud mapping using LiDAR in GNSS-denied and dynamic environments
- Distortion correction of LiDAR-scan data
- Removal of moving scan data, and mapping using only static scan data (originating from static scan data)



GNSS-denied and dynamic environments


LiDAR mounted on motorcycle

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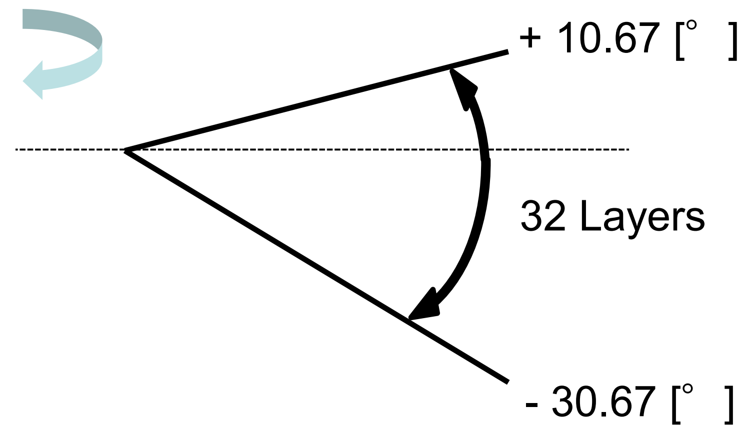
Experimental System

Motorcycle
(Honda Gyro Canopy)

LiDAR (Velodyne HDL-32E)



Spec.

Range	0.05～70 [m]
Horizontal viewing angle (Res.)	360(0.16) [°]
Vertical viewing angle (Res.)	41.3(1.33) [°]
Scan period	100 [ms]
LiDAR scan data period	0.55 [ms]

Experimental System

IMU (Xsens MTi-300)

Output

- Attitude angle (roll and pitch angles)
- Angular velocity (roll, pitch, and yaw velocities)

Spec.

Error of attitude angle	± 0.3 [°] (typ.)
Error of angular velocity	± 0.2 [° /s] (typ.)
Observation period	10 [ms]

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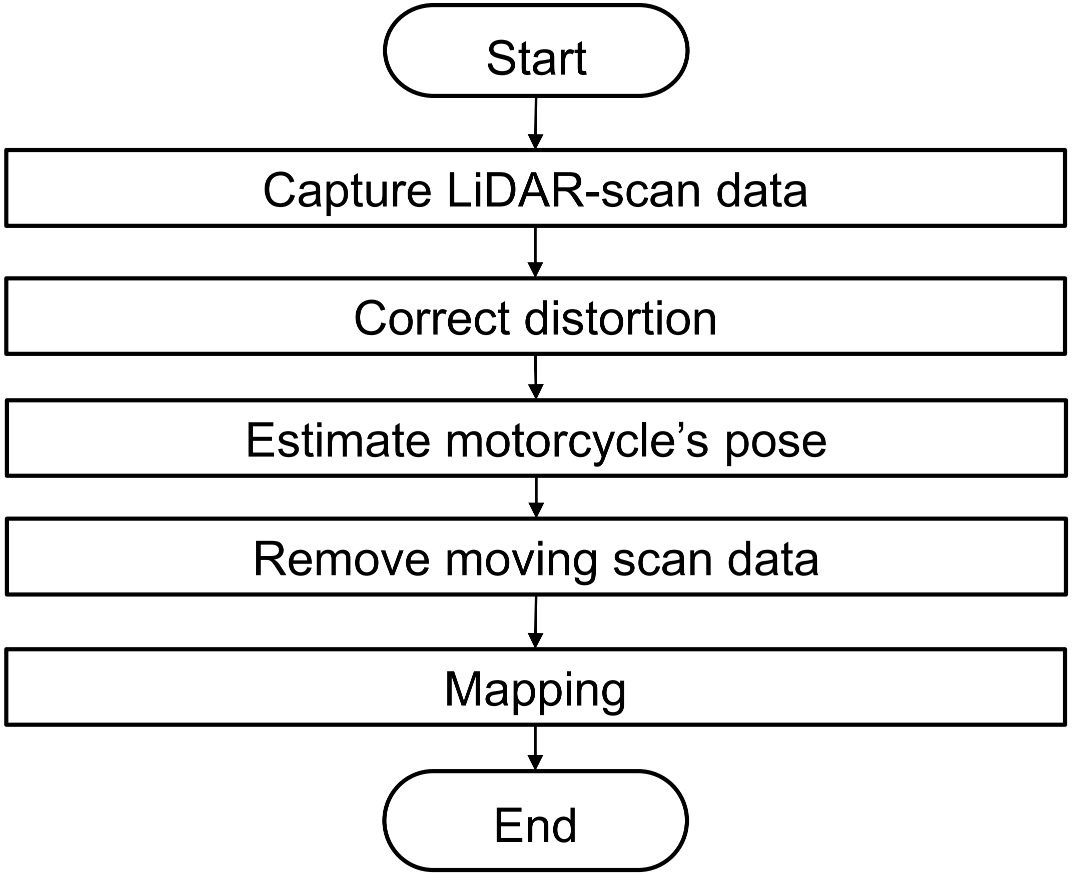
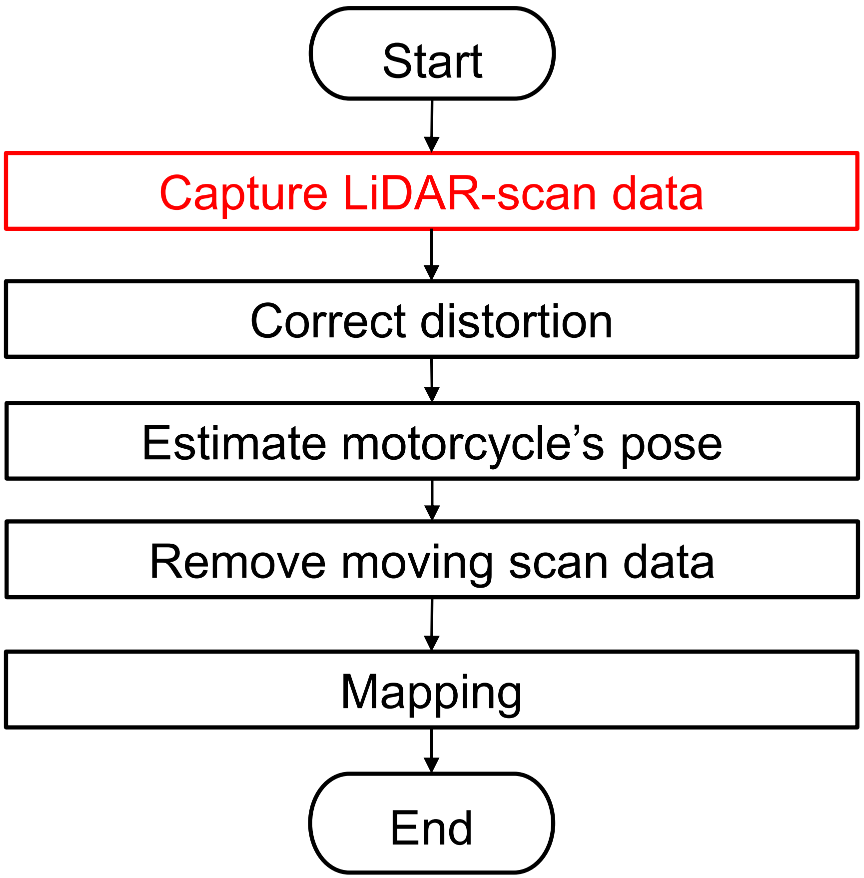
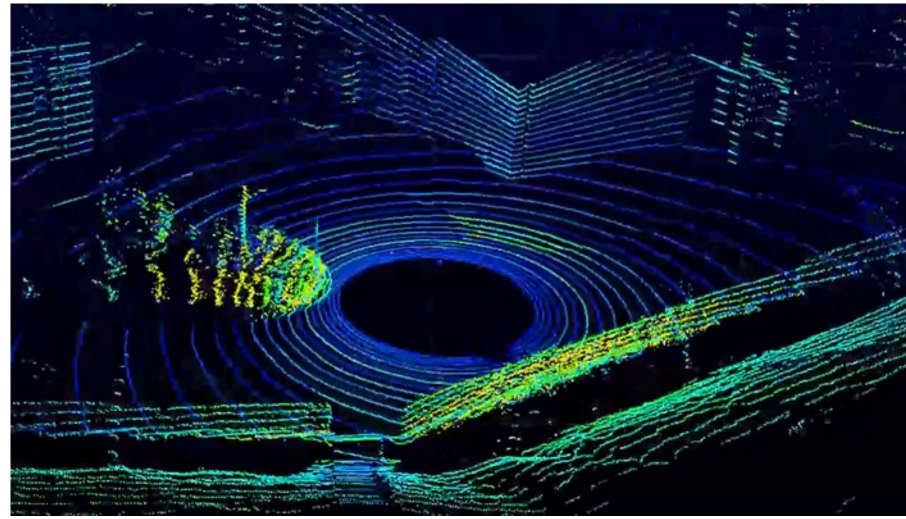
Flow of Mapping Using NDT SLAM

NDT : Normal distributions transform



Capturing LiDAR-Scan Data

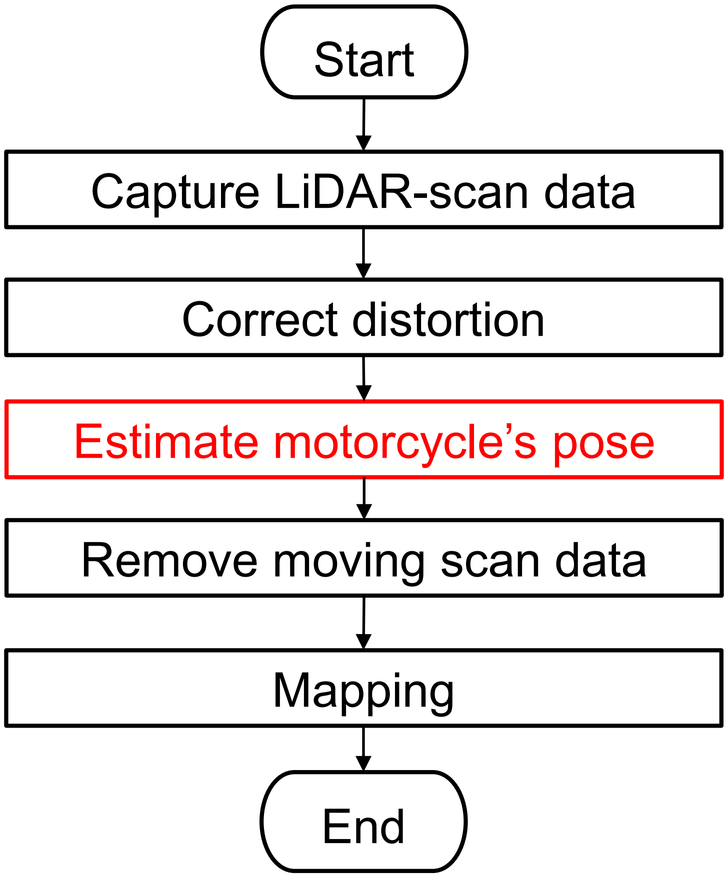




LiDAR-scan data (Bird's-eye view)

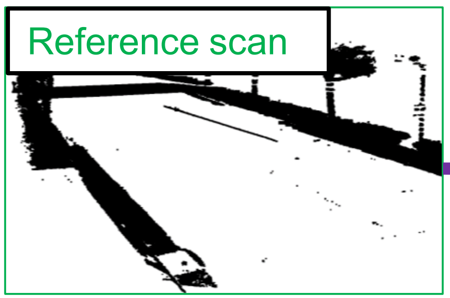
LiDAR obtains measurements by scanning laser beams; thus, when motorcycle moves, all the scan data within one scan cannot be obtained at the same position of the motorcycle.

NDT Scan Matching

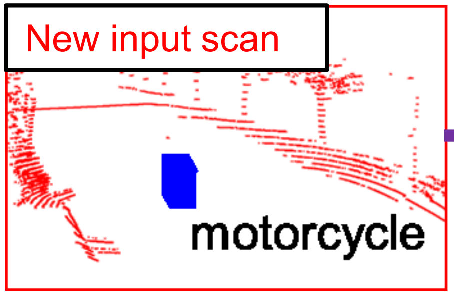


- The motorcycle's pose (3D positions and roll, pitch, and yaw angles) in the world coordinate frame is calculated by matching the new input scan with the reference scan.

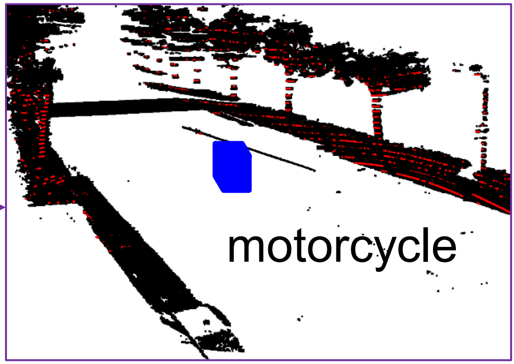
Obtained before the current scan
(represented in the world coordinate flame)



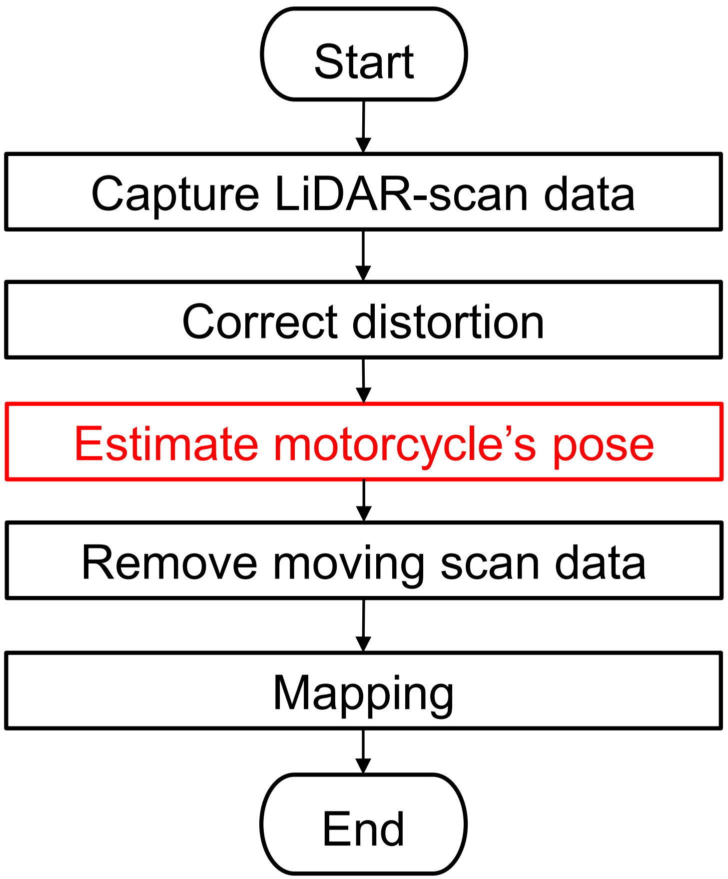
Obtained at the current scan
(represented in the sensor coordinate flame)



Estimate motorcycle's pose
(represented in the world coordinate flame)



Mapping of LiDAR-Scan Data



- A new input scan captured in the sensor coordinate frame is transformed to the reference scan in the world coordinate frame using the homogeneous transformation form:

$$\begin{pmatrix} P_i \\ 1 \end{pmatrix} = T(X) \begin{pmatrix} P_{s_i} \\ 1 \end{pmatrix} \qquad (i = 1, 2, \dots, n)$$

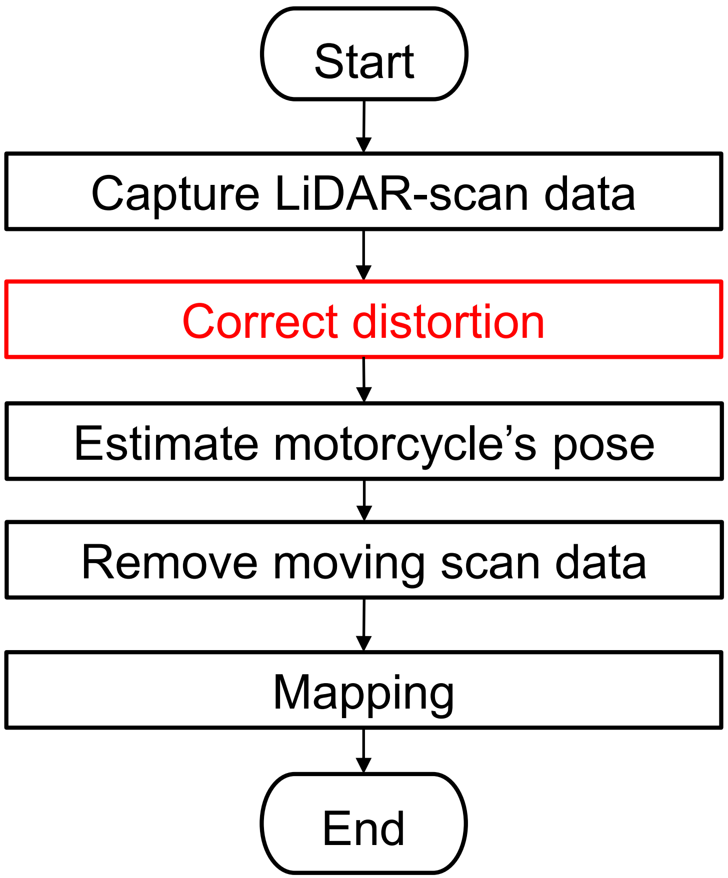
$$T(\boldsymbol{X}) = \begin{pmatrix} \cos\theta\cos\psi & \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi & x \\ \cos\theta\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi & y \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta & z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$P_i = (x_i, y_i, z_i)^T$: Scan data in the world coordinate frame

$P_{s_i} = (x_{s_i}, y_{s}, z_{s_i})^T$: Scan data in the sensor coordinate frame

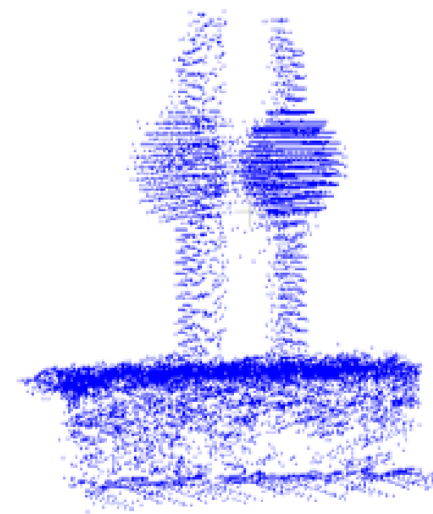
$X = (x, y, z, \phi, \theta, \psi)^T$: Motorcycle's pose

Distortion in LiDAR-Scan Data



- When the LiDAR-scan data are mapped using the motorcycle's pose by NDT scan matching, distortion appears in the environmental map.

Traffic sign



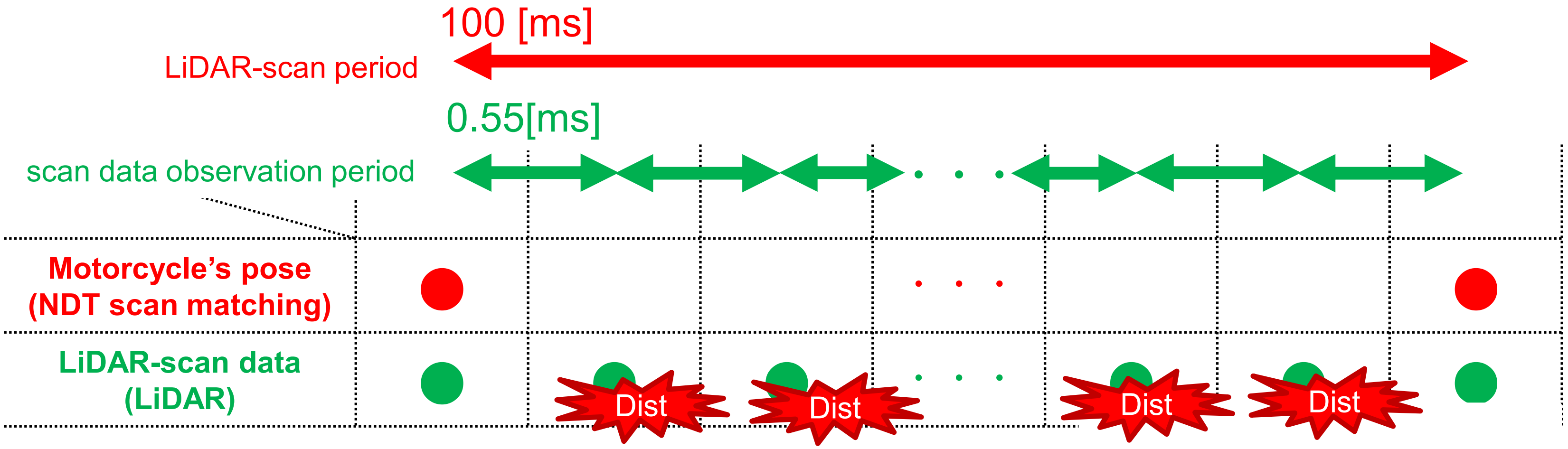
Mapping result

Example of LiDAR-scan data distortion

Distortion Correction

- The motorcycle's pose is calculated by NDT scan matching every 100[ms] (LiDAR-scan period: LiDAR beam rotation of 360° in a horizontal plane).
- LiDAR-scan data are captured every 0.55[ms] (scan data observation period).

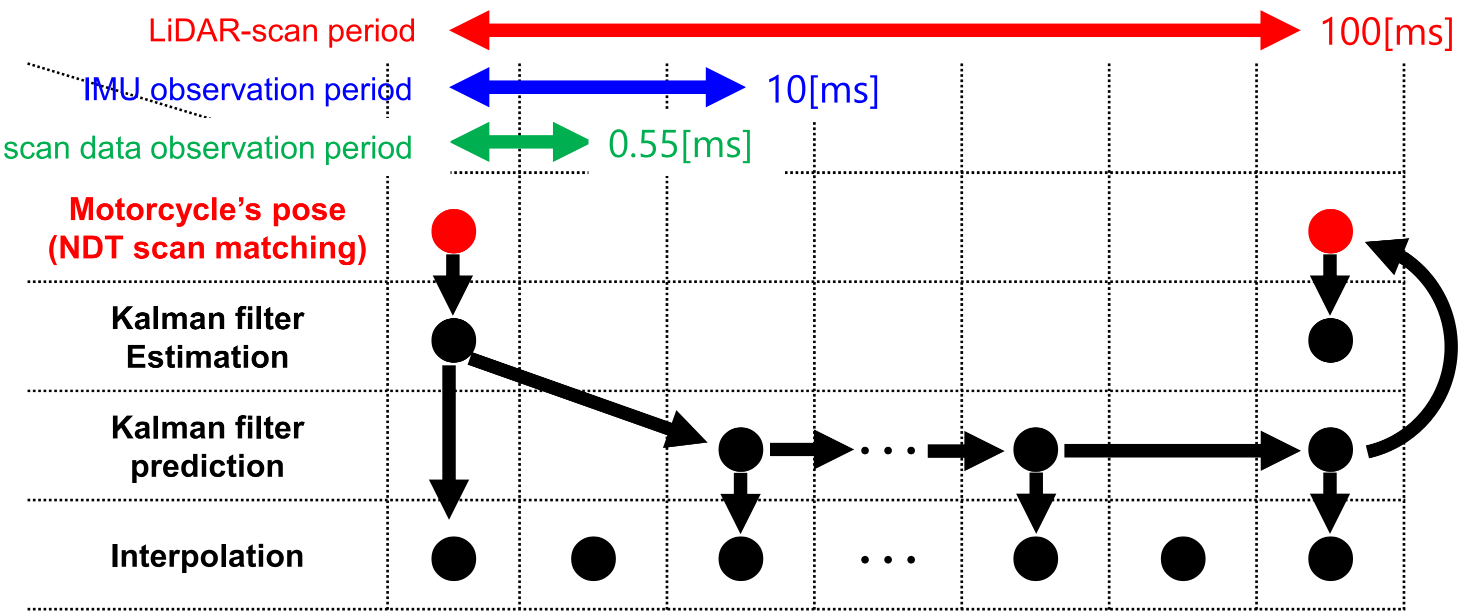
→ If the entire scan data obtained within 100[ms] are mapped onto the world coordinate frame using the motorcycle's pose information, distortion arises in environmental maps.



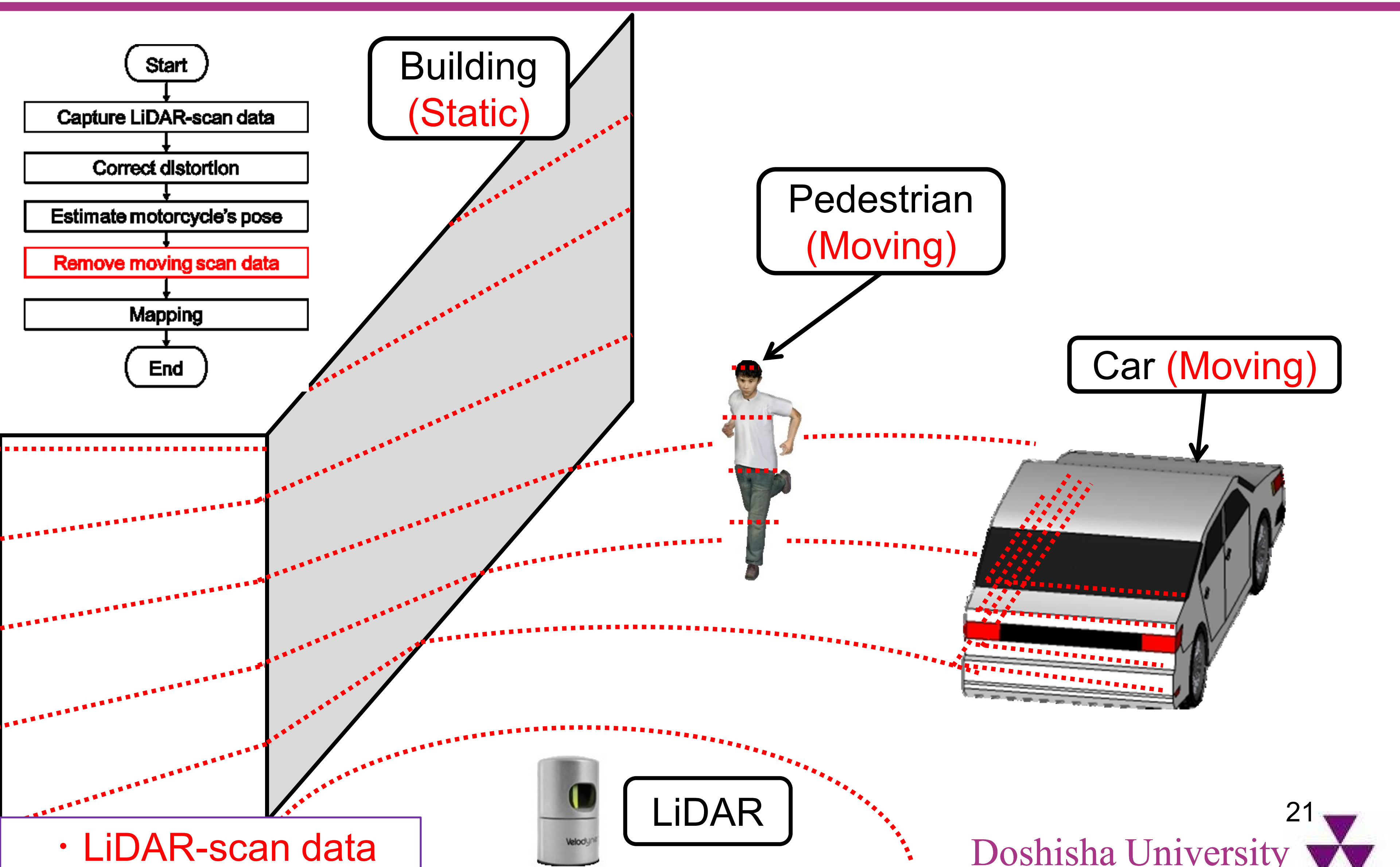
Distortion Correction

- To correct the distortion, the motorcycle's pose is determined every 0.55[ms].
- Extended Kalman filter predicts the motorcycle's pose every 10[ms] from the IMU.
- The pose prediction is interpolated every 0.55[ms].

IMU

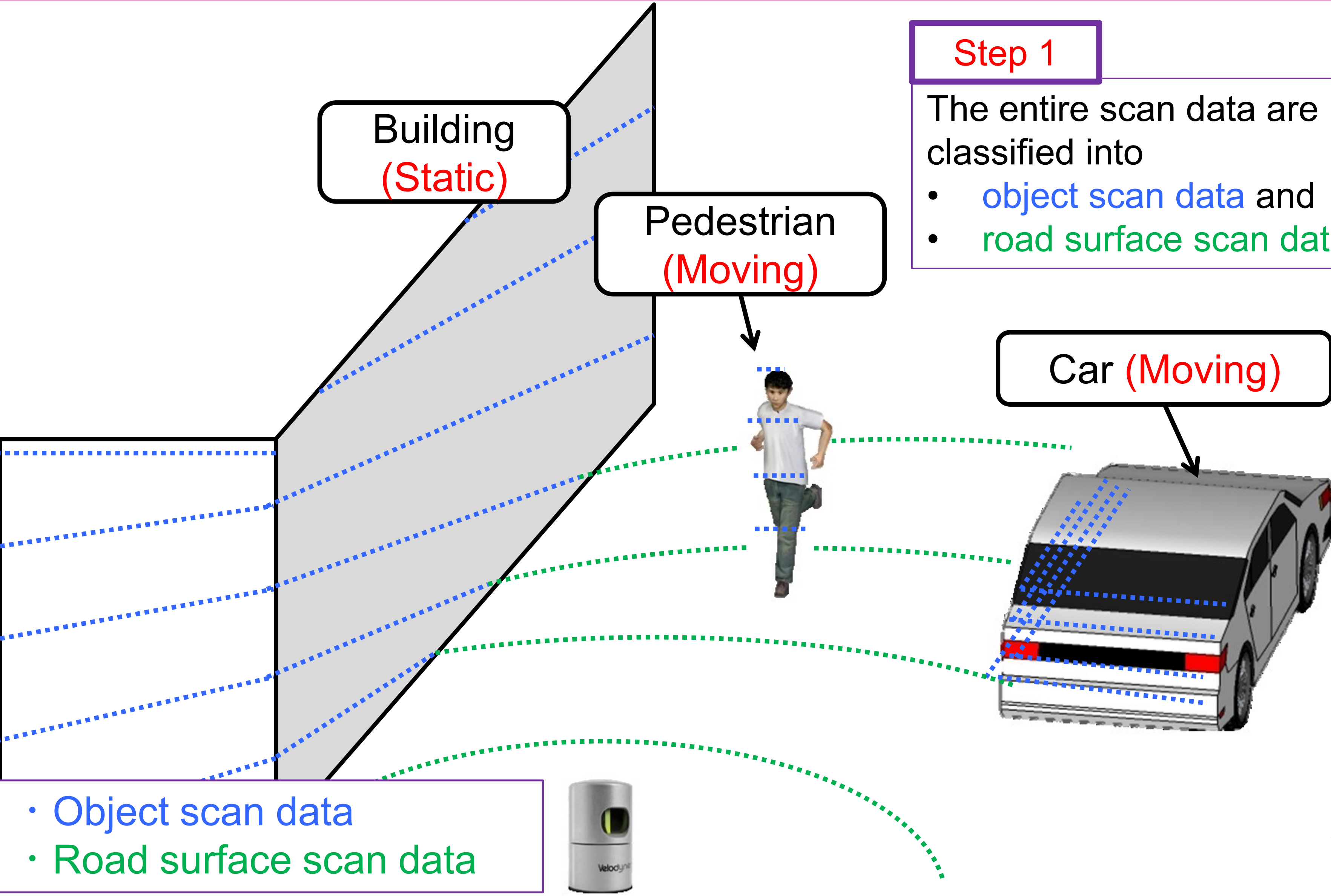


Removal of Moving Scan Data from LiDAR-scan Data



- LiDAR-scan data

Removal of Moving Scan Data from LiDAR-scan Data



Step 1

The entire scan data are classified into

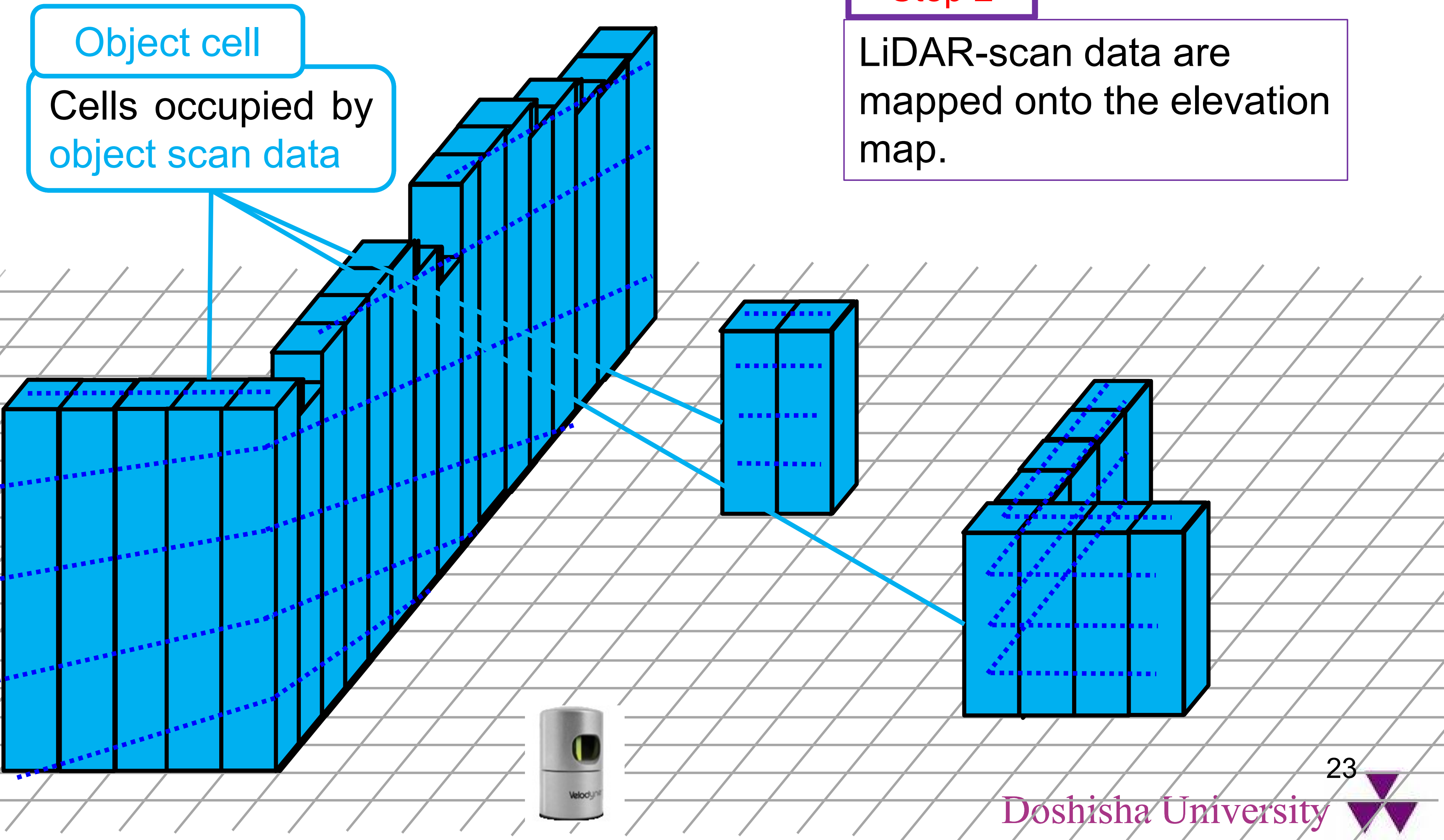
- object scan data and
- road surface scan data.

・Object scan data
・Road surface scan data

Mapping of Object Scan Data

Step 2

LiDAR-scan data are mapped onto the elevation map.



Classification of Static and Moving Cells

Step 3

Two kinds of cells are classified.

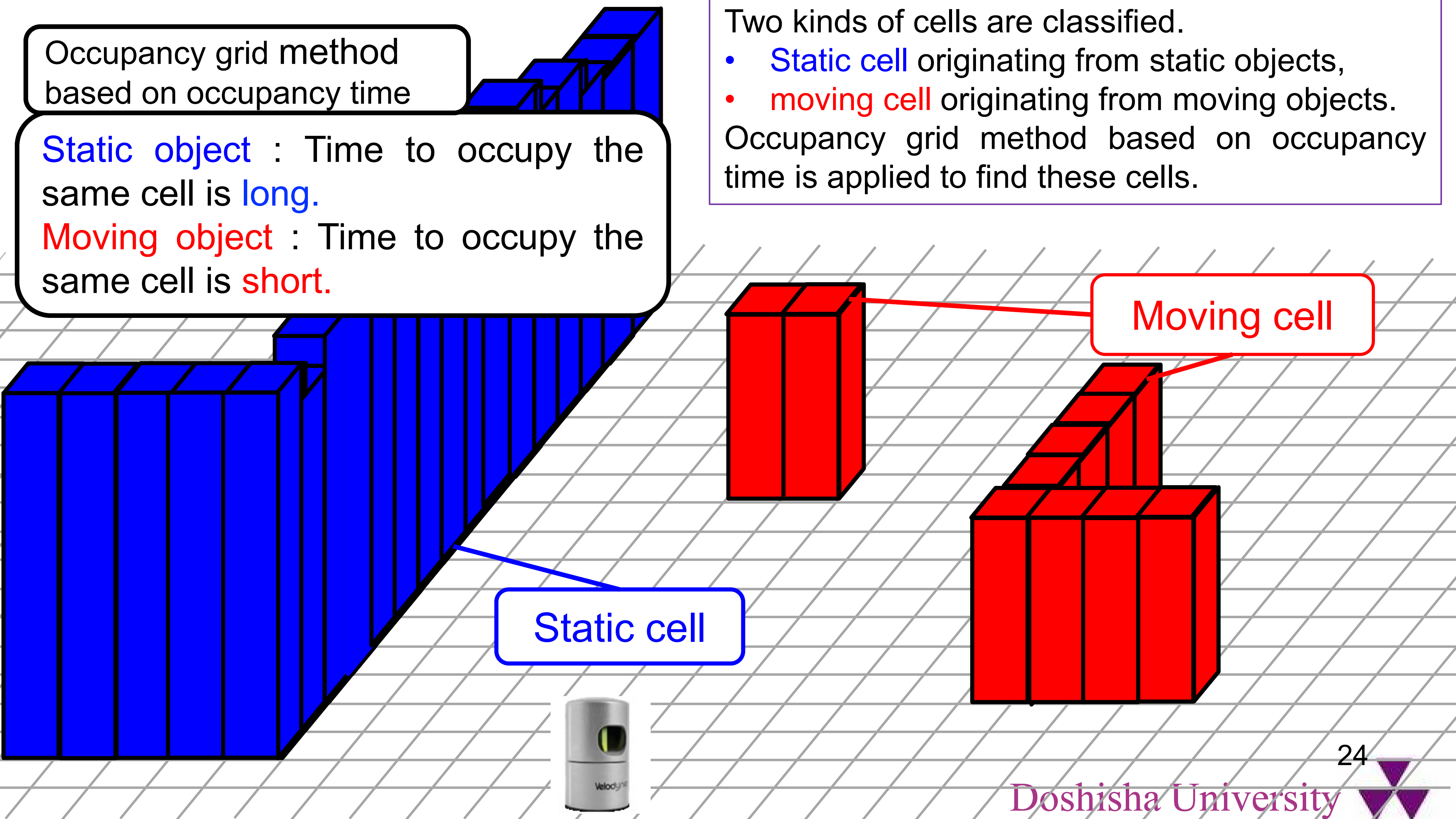
- Static cell originating from static objects,
- moving cell originating from moving objects.

Occupancy grid method based on occupancy time is applied to find these cells.

Occupancy grid method based on occupancy time

Static object : Time to occupy the same cell is long.

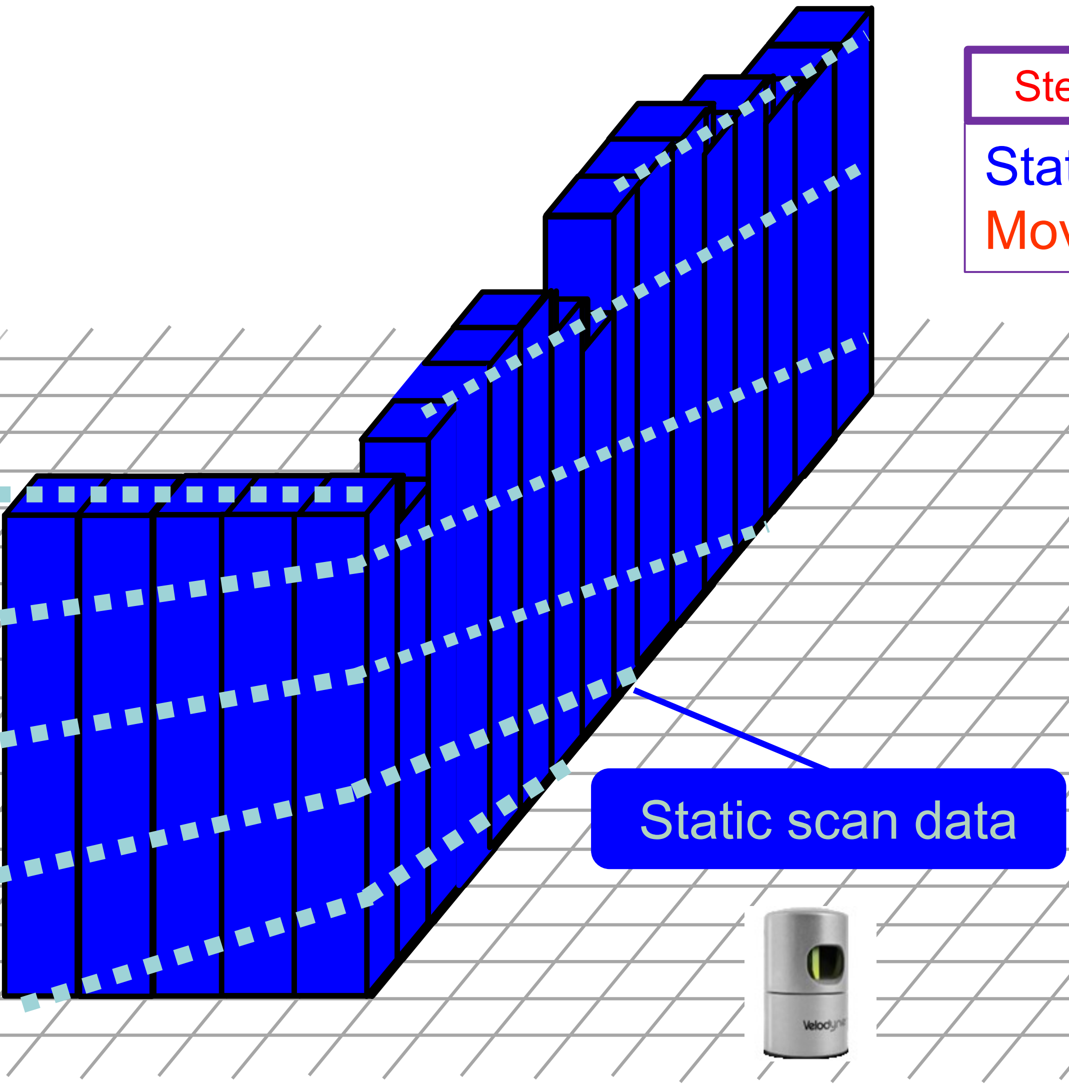
Moving object : Time to occupy the same cell is short.



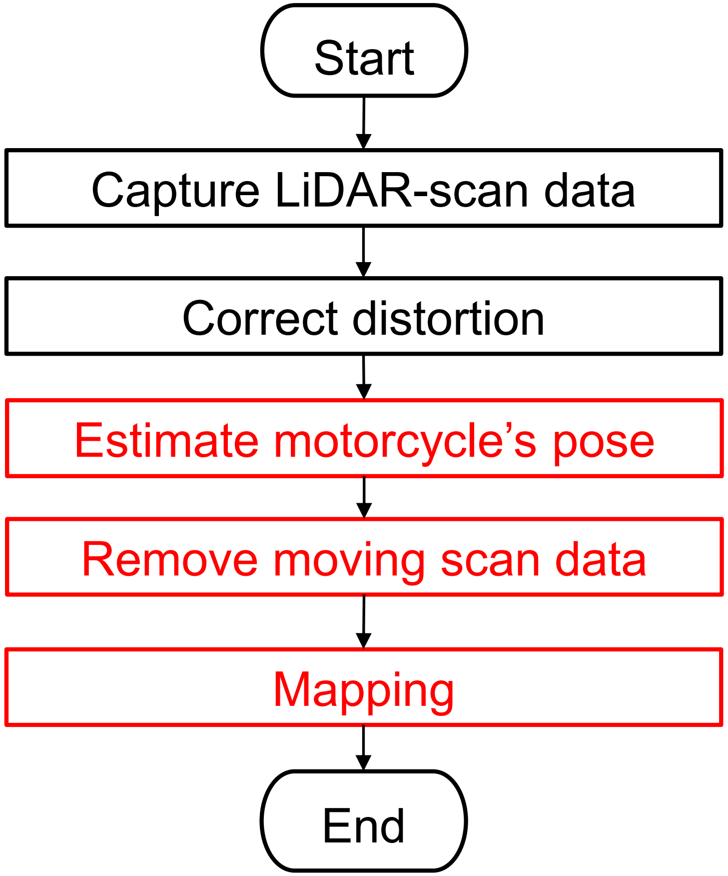
Removal of Moving Scan Data

Step 4

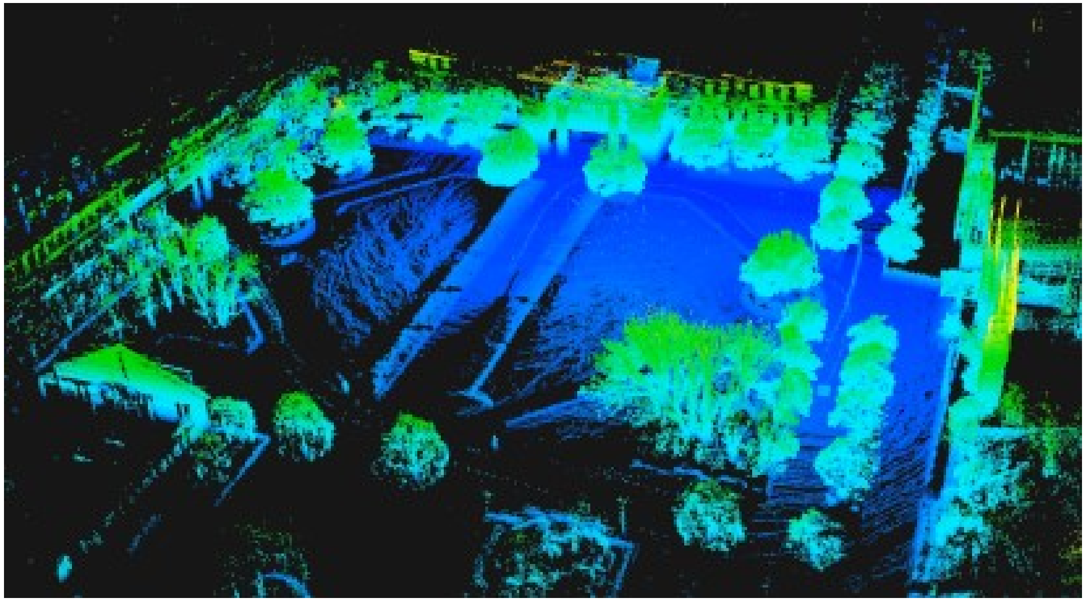
Static scan data are extracted.
Moving scan data are removed.



Point Cloud Mapping



- Point cloud mapping by repeating the process every LiDAR-scan period.



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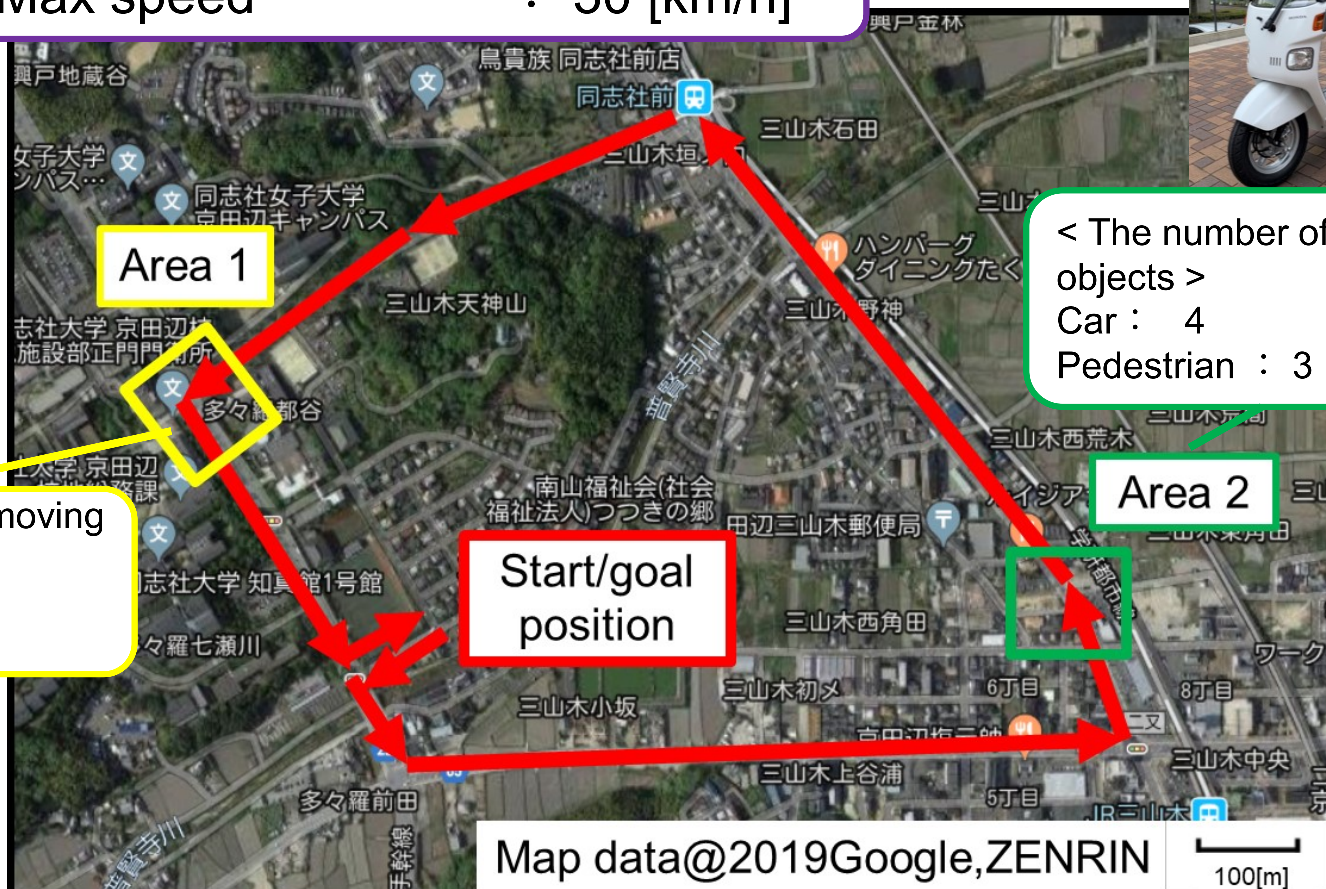
Experimental Environment

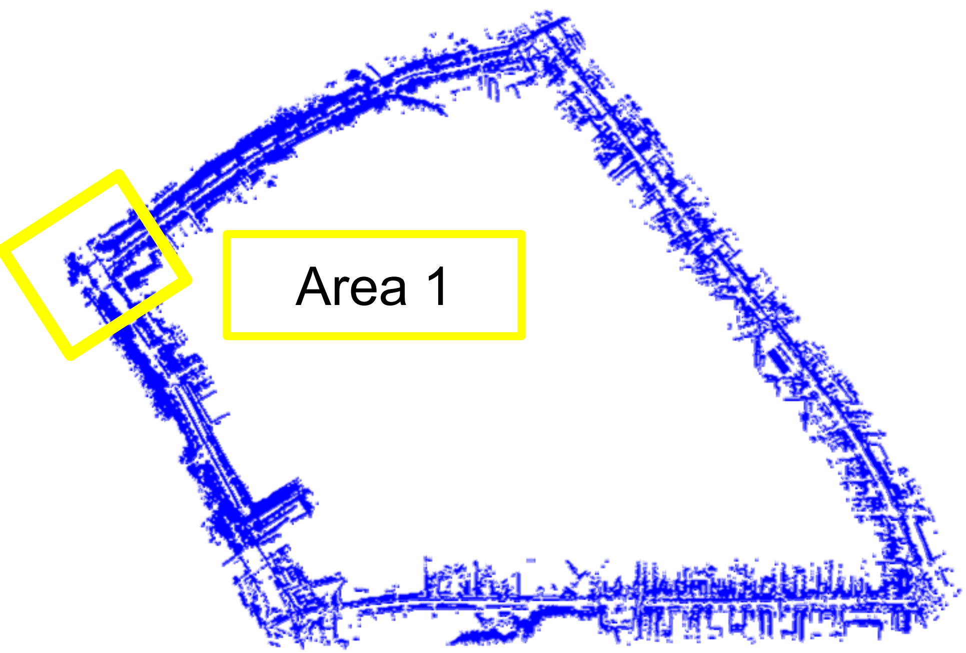
Distance traveled ： 2886 [m]
Max speed ： 30 [km/h]



< The number of moving objects >
Car ： 4
Pedestrian ： 3

< The number of moving objects >
Car ： 4
Pedestrian ： 4

Experimental Environment (Area 1)



Mapping result (top view).

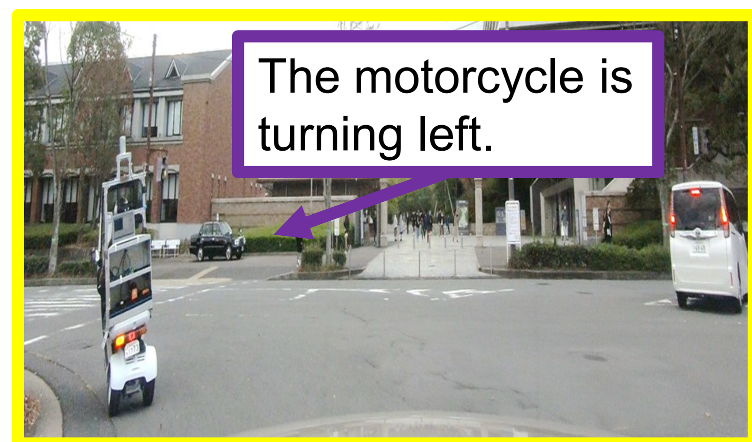
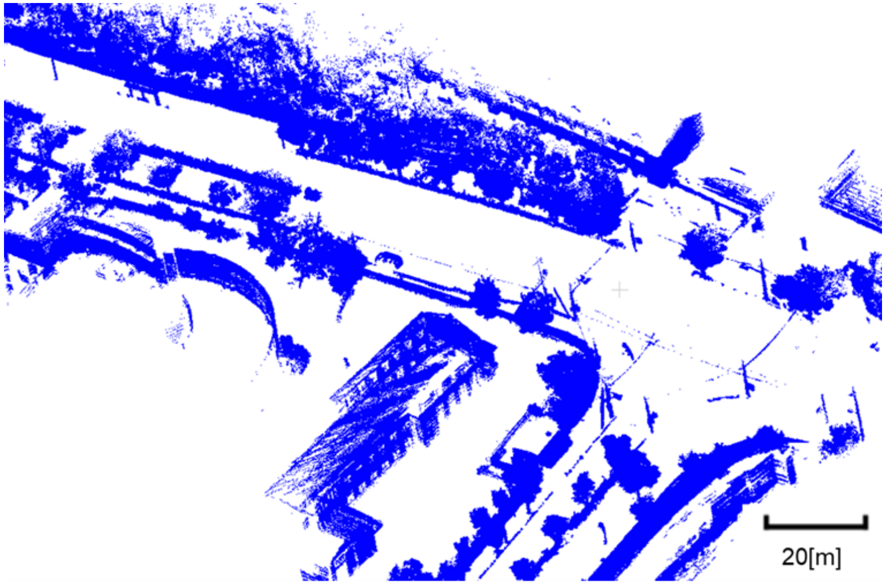


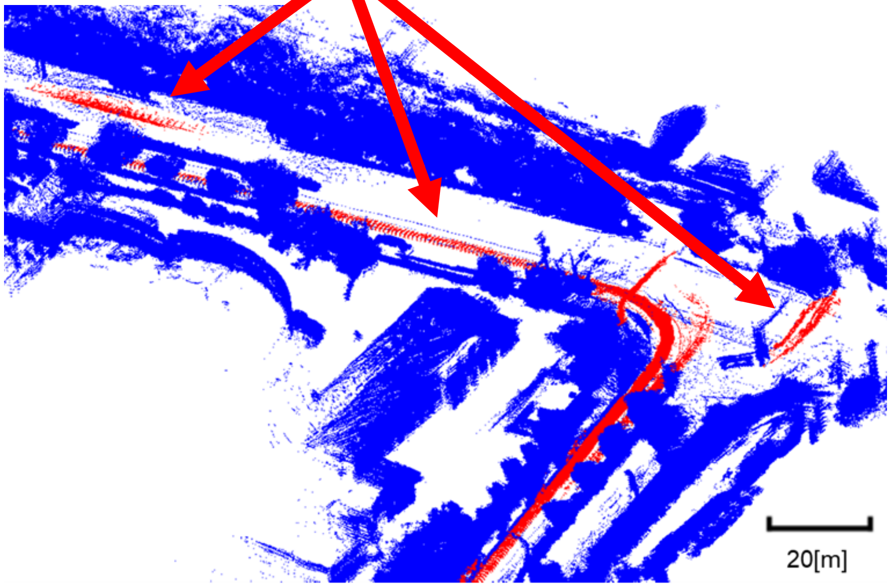
Photo of environment.

Mapping Result (Area 1)

Moving scan data from cars and pedestrians remain

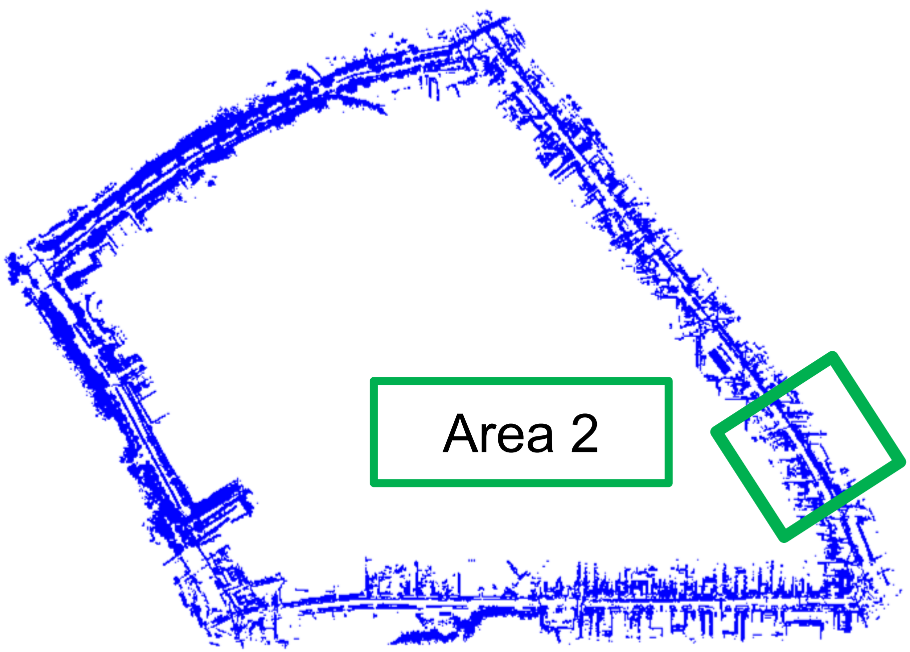


Case 1 (Proposed method)
Mapping with distortion correction and removal of moving scan data



Case 2
Mapping without either method

Experimental Environment (Area 2)



Mapping result (top view).

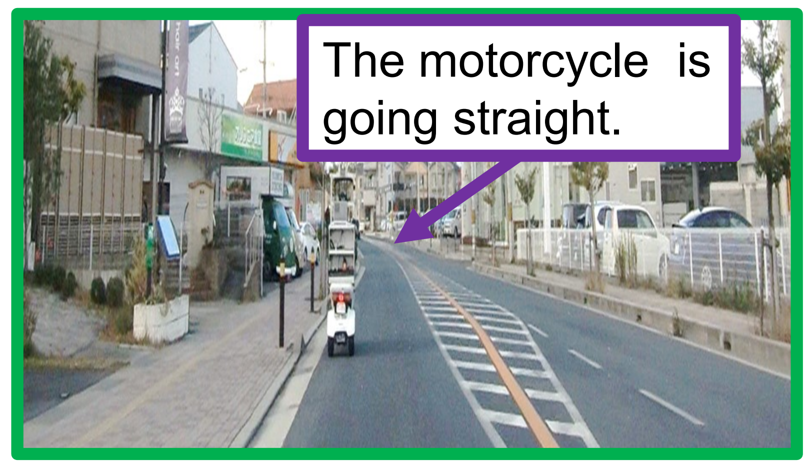
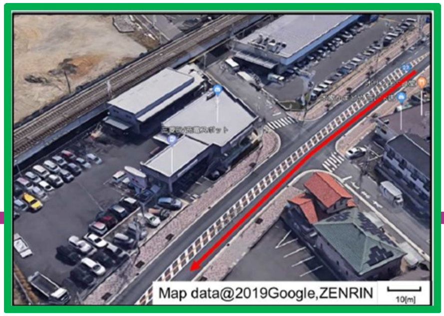
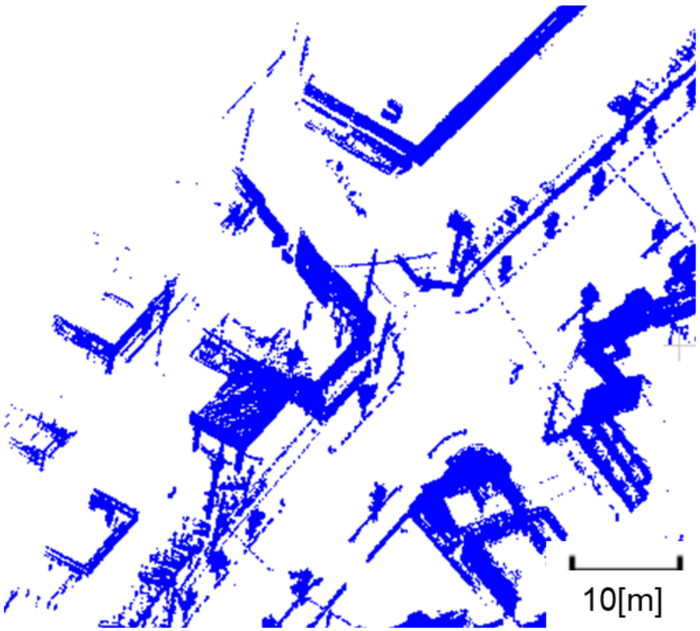


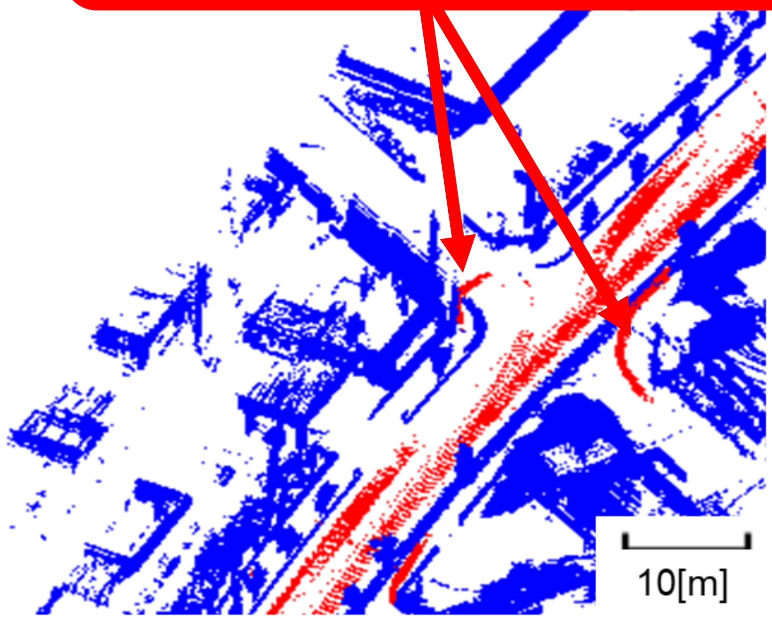
Photo of environment.

Mapping Result (Area 2)



Moving scan data from cars and pedestrians remain





Case 1 (Proposed method)

Mapping with distortion correction and removal of moving scan data

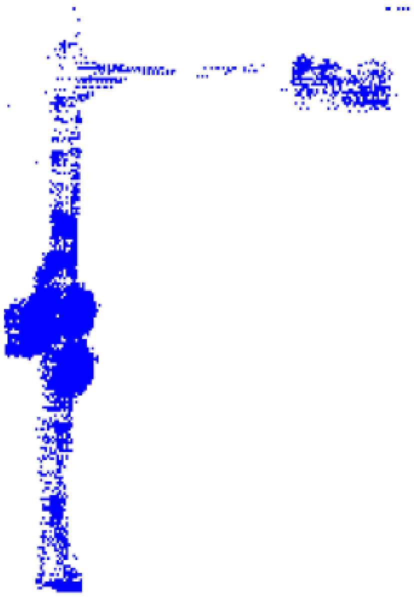
Case 2

Mapping without either method

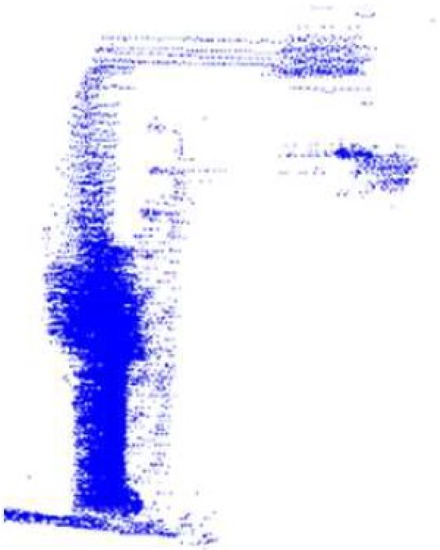
Mapping Result of Traffic Sign

The mapping result obtained in case 1 is more crisp than that obtained in case 2.

Traffic sign in area 1



Case 1
(Proposed method)



Case 2

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Conclusions

NDT-based mapping using a scanning LiDAR mounted on a motorcycle in GNSS-denied and dynamic environments.

- The distortion in the LiDAR-scan data was corrected based on the information from the NDT scan matching and the IMU via EKF.
- The moving scan data were removed from the entire LiDAR-scan data using the occupancy grid-based method.
- The static scan data were applied to 3D point cloud maps using the NDT scan matching.
- Validation of the proposed method through experiments in public road environment

Future Works

- The distortion correction of the LiDAR-scan data requires a great deal of computational time, graphical processing unit (GPU) must be utilized in real-time operations.

- NDT SLAM degrades the mapping accuracy over time due to the accumulation error and must be integrated with Graph SLAM to reduce the drift.

- NDT SLAM with moving-object detection should be extended to SLAM with detection and tracking of moving objects (DATMO) for advanced rider assist systems.

Thank you for your attention