LiDAR-Based Cooperative Scan Matching for Relative Pose Estimation of Multiple Vehicles in GNSS-Denied Environments

Ryoga Takahashi\textsuperscript{1}  
Masafumi Hashimoto\textsuperscript{2}  
Kazuhiko Takahashi\textsuperscript{2}

\textsuperscript{1} Graduate School of Doshisha University  
\textsuperscript{2} Faculty of Science and Engineering, Doshisha University

Presenter: Ryoga Takahashi  
Mail: ctwf0141@mail4.doshisha.ac.jp
Resume

Education

Doshisha University, Kyoto, Japan
Apr. 2017 – Mar. 2021
• Major: Science and Engineering
• Dissertation title: “Cooperative Scan Matching using by Ground and Onboard LiDARs”

Graduate school of Doshisha University, Kyoto, Japan
Apr. 2021 – present
• Major: Science and Engineering
Agenda

1. Introduction
2. Experimental System
3. Cooperative Moving Object Tracking
4. Feature Extraction
5. Relative pose estimation
6. Experimental Results
7. Conclusions & Future works
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5. Relative pose estimation
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7. Conclusions & Future works
Introduction

- Tracking (estimation of position, velocity and size) of moving objects, such as cars, bicycles, and pedestrians, is an important issue for the safe navigation and autonomous driving of robots and vehicles.
- Vehicle-mounted LiDAR is used to recognize surrounding environments.

[Marti et al., IEEE ITS Magazine 2019]
Introduction

Individual moving object tracking (IMOT)

- Vehicles cannot track moving objects in blind spots or outside of sensing area of a LiDAR.

Cooperative moving object tracking (CMOT)

- Vehicles can track moving objects in blind spots.
- Improvement in tracking performance

IMOT  ->  CMOT
Introduction

A moving object is recognized as different two objects

Measurements by LiDAR 1
Measurements by LiDAR 2

Cooperative scan matching (CSM)

CSM estimates the relative pose and correct self-poses of the LiDARs

Mapping the LiDAR measurements onto the grid map.

[Ozaki et al., Sensors 2012]
• Cooperative scan matching (CSM) using pole-like objects
  - Pole-like objects, such as utility pole and light pole, are extracted from the LiDAR measurements.
  - Pole-like objects are used as environmental features.

[Kanaki et al., IEEE AIM 2017]

• Many environments do not have such objects.
• Pole-like objects are frequently occluded by surrounding moving objects.

• CSM method can estimate the relative pose using any environment features including pole-like objects.
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Experimental System

**LiDAR 1**

Small car
(Toyota auto body, Coms ZAD-TAK30BS)

**LiDAR 2**

Motorcycle
(Honda Gyro Canopy)
## Experimental System

### LiDAR (Velodyne HDL-32E)

![LiDAR Diagram]

### Specifications (HDL-32E)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement range</td>
<td>70 [m]</td>
</tr>
<tr>
<td>Horizontal viewing angle (Res.)</td>
<td>360(0.16)[deg]</td>
</tr>
<tr>
<td>Horizontal viewing angle (Res.)</td>
<td>41.3(1.33) [deg]</td>
</tr>
<tr>
<td>Scan period</td>
<td>100 [ms]</td>
</tr>
</tbody>
</table>
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4. Feature Extraction
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7. Conclusions & Future works
Overview of cooperative moving object tracking (CMOT)

Central server

Cooperative scan matching (CSM)

Success/failure decision

Cooperative moving object tracking (CMOT)

Results of CMOT

LiDAR 1

Environment sensing
Distortion correction
Self-pose estimation
Detection of static/moving measurements
Point feature extraction

Information for CSM and CMOT
- LiDAR measurements
- Timestamps
- 3D positions of static/moving measurements
- Self poses of a vehicle

LiDAR 2

Environment sensing
Distortion correction
Self-pose estimation
Detection of static/moving measurements
Point feature extraction
Overview of cooperative moving object tracking (CMOT)

Environment sensing using a LiDAR

- LiDARs 1 & 2
- Environment sensing
- Distortion correction
- Self-pose estimation
- Detection of static/moving measurements
- Point feature extraction
Overview of cooperative moving object tracking (CMOT)

- Environment sensing
- Distortion correction
- Self-pose estimation
- Detection of static/moving measurements
- Point feature extraction

LiDARs 1 & 2

LiDAR measurements

Mapping measurements onto the elevation map

Classifying the measurements into two types of measurements

Static measurements

Moving measurements
Overview of cooperative moving object tracking (CMOT)

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Results of CMOT

LiDAR 1

Environment sensing

Distortion correction

Self-pose estimation

Detection of static/moving measurements

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Information for CSM and CMOT

• LiDAR measurements
• Timestamps
• 3D positions of static/moving measurements
• Self poses of a vehicle

LiDAR 2

Environment sensing

Distortion correction

Self-pose estimation

Detection of static/moving measurements

Point feature extraction
Agenda

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7. Conclusions & Future works
Feature extraction

Voxel grid filter

- The measurements obtained by LiDARs are mapped onto a voxel map (grid size of 1 m)
- The centroid of the measurements (feature point) in each voxel is obtained.

Static measurements  Voxel mapping  Feature point
Feature extraction

Calculating the point feature histograms

- The triple angle features \( (\alpha, \beta, \gamma) \) are defined every feature points.
- The point features \( SPFH(A_j) \) of 3*124-dimensional vector are obtained by calculating the triple features for the 124 feature points \( A_j \) around the point feature \( A_i \).
- The final point feature histograms related to the feature point \( A_i \) is calculated by

\[
FPFH(A_i) = SPFH(A_i) + \frac{1}{124} \sum_{j=1}^{124} \frac{1}{w_j} SPFH(A_j)
\]

[Rusu et al., IEEE ICRA 2009]
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7. Conclusions & Future works
Relative pose estimation using cooperative scan matching (CSM)

**Central server**

- Coarse Registration
  - RANdom SAmple Consensus (RANSAC)-based algorithm
    - A method estimates a coarse relative pose using the result of feature extraction.
  - [Aldoma et al., IEEE RA Magazine 2012]
- Fine Registration
  - Normal Distributions Transform (NDT)-based algorithm
    - A method estimates a fine relative pose using the initial value of the relative pose calculated by the coarse registration.
  - [Biber et al., IEEE/RSJ IROS 2003]
- Success/failure decision
- Cooperative moving-object tracking (CMOT)
Success/failure decision

• The rate of matching measurements of LiDAR 1 with those of LiDAR 2 is defined as the matching rate.
• If matching rate is equal to or greater than 33%, then Cooperative Scan Matching (CSM) is deemed successful.
• Otherwise CSM is deemed failing.
• If CSM is deemed successful...
  (1) Cooperative moving objects tracking (CMOT)
  (2) The result of CSM in current scan is used as an initial value of a fine registration in the next scan.

Reduce the computational cost
Agenda

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Experimental environment

Environment 1
(Urban road)

- Vehicles moving at maximum speed 40 [km/h]
- 20 cars and 5 pedestrians
Experimental results (Mapping results)

Using standard GNSS (Bird’s-eye view)

Using Cooperative Scan Matching (Bird’s-eye view)

Environment 1

Measurements by LiDAR 1  Measurements by LiDAR 2
Experimental environment

Environment 2
(University-campus road)

- Vehicles moving at maximum speed 30 [km/h]
- 3 cars and 10 pedestrians
Experimental results (Mapping results)

Using standard GNSS (Bird’s-eye view)

Using Cooperative Scan Matching (Bird’s-eye view)

Environment 2

Measurements by LiDAR 1  Measurements by LiDAR 2
# Experimental Results

<table>
<thead>
<tr>
<th></th>
<th>Environment 1</th>
<th>Environment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Success rate of Cooperative scan matching [%]</strong></td>
<td>78.9</td>
<td>64.3</td>
</tr>
<tr>
<td><strong>Performance of success/ failure decision</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy [%]</td>
<td>95.5</td>
<td>87.4</td>
</tr>
<tr>
<td>Precision [%]</td>
<td>97.8</td>
<td>86.1</td>
</tr>
<tr>
<td>Recall [%]</td>
<td>96.6</td>
<td>99.0</td>
</tr>
<tr>
<td>F-measure [%]</td>
<td>97.2</td>
<td>92.1</td>
</tr>
</tbody>
</table>

![Environment 1](image1.png)

![Environment 2](image2.png)
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The proposed method of relative pose estimation was performed using FPFH and RANSAC-based coarse registration and NDT-based fine registration.

- The mapping performance of the proposed method is better than that of using regular GNSS.

The performance of proposed method was evaluated by experimental results obtained in two road environments.

- The proposed CSM has better applicability in urban environments with a higher number of streets.
Future works

• Since the spatial resolution of LiDAR is low in the vertical direction, the distance between vehicles where cooperative scan matching (CSM) can be achieved short.
  — Our current research effort aims to improve the CSM algorithm so that the relative pose can be estimated accurately even at long inter-vehicle distances.
• CSM will be implemented to cooperative moving object tracking and cooperative positioning.
Thank you for your attention