IHI Project:

Title

Mathematics for trajectory extrapolation using vehicle and human traffic data toward zero traffic fatalities

Industrial Partner

IHI Corporation (https://www.ihi.co.jp/en/)

IHI Corporation (used to be Ishikawajima-Harima Heavy Industries Corporation) is a comprehensive heavy-industry manufacturer. Our history extends back to the establishment of Ishikawajima Shipyard, Japan's first modern shipbuilding facility, in 1853. The technology that began with shipbuilding has been passed on to social infrastructure and industrial machinery and has expanded its business domain from sea to land and space. We will continue to respond flexibly to social changes and aim for sustainable development.

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Introduction

IHI has developed a unique LiDAR sensor (3D Laser Radar™) to support automation of industrial machinery in harsh environments with poor visibility. LiDAR is an acronym of Light Detection and Ranging. In recent years, LiDAR technology has become widely known as the "eyes" of autonomous vehicles.

LiDAR determines the distance to objects by emitting laser light in multiple directions and measuring the return time. This principle is the same as that of radar (Radio Detecting and Ranging). LiDAR sensors are suitable for detecting smaller objects with higher precision because the laser light has shorter wavelengths.

The 3D Laser Radar™ is equipped with IHI's proprietary algorithm to track objects on the road and accurately measures their size, position, and speed. This product has contributed to improving the safety of traffic systems in many industrial applications such as obstacle detection systems at crossings and driving safety support systems at intersections (see product page[1] for details).

Recently, IHI has been developing an infrastructure-based LiDAR technology for autonomous driving support systems. Through some proofs of concept, we have demonstrated a sensing method that transmits information on oncoming vehicles to autonomous cars from the roadside sensors.

In the future, we aim to develop a "moving city" in virtual space (i.e., digital twin) by combining measurement data with data analysis and simulation technology. If traffic incidents and congestion can be simulated and predicted, they can be prevented in physical space.

Technical Background

Traffic problems such as traffic accidents and congestion are strongly influenced by the number of vehicles and statistical distribution of driver's behaviors (desired velocity, acceleration, deceleration, and other vehicular characteristics). The infrastructure-based LiDAR sensor can be useful to capture these characteristics. However, the more congested and dangerous roads become, the less accurate the measurements will be. This is because the measurement targets overlap with more vehicles and pedestrians on congested multi-lane roadways (Figure 1). To avoid the tracking fragmentation, it is necessary to install a very large number of infrastructure-based sensors to eliminate blind spots.

Incomplete trajectories cause errors in the number of vehicles and distort the distributions of driving behaviors. Therefore, it is important for analysis and simulation to compensate for incomplete trajectories with physically probable values. Mathematical models and statistics are expected to play an important role in this issue.

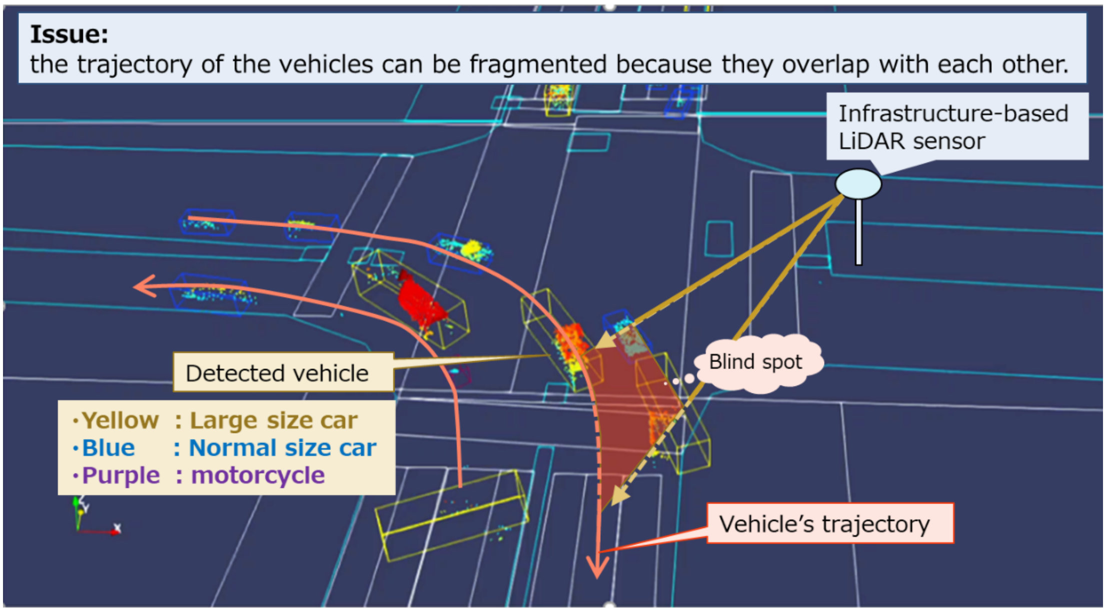

Figure 1. Snapshot of LiDAR measurement at a signalized intersection

Although only one unit is shown in the figure, four infrastructure-based LiDAR systems are actually used to track almost complete trajectories.

Project and Expectations

In this project, we will study mathematical methods to generate continuous driving behaviors by extrapolating physically probable values from incomplete traffic flow data. IHI will provide vehicle and human traffic datasets that were obtained by measurements of infrastructure LiDAR systems. These measurements were taken in real traffic situations (and not on specific test courses), such as multilane traffic intersections with traffic lights in downtown Tokyo, as shown in Fig. 1. These datasets include almost complete trajectories by measuring from multiple LiDAR sensors. We plan to use these datasets to validate the method by masking some of the data to create incomplete trajectories.

The mathematical method is expected to estimate not only the trajectory of the vehicle's coordinates, but also the profiles of velocity and acceleration as if they were physically probable. We should use mathematical models such as equations of rectilinear and circular motion, and car-following models based on traffic flow theory (e.g., [2]-[4]).

In addition, the framework of state estimation (Kalman and Bayesian filters [5]) and multiple object tracking will be helpful to combine the measurement data with the physical models. Many useful tutorials on these topics have been published on websites of MathWorks (e.g., [6][7]).

As an advanced "stretch goal", we also expect to analyze the distribution of driver's behaviors and to study matching methods for integrating fragmented trajectories by using the generated trajectories.

Requirements

- Required and recommended knowledge (some references will be provided later for recommended items)
  - Mathematics
    - Required: mathematical statistics, basic regression analysis, probability theory
    - Recommended: Kalman and Bayesian filters
  - Mathematical modeling for dynamics
    - Required: equations of motion
    - Recommended: car-following model (traffic flow theory)
  - Programming language
    - Required: Python
    - Recommended: MATLAB

  We will provide sample Python code with the dataset. This is because the Python library and its original textbook[5] are helpful for state estimation. However, you may as well use MATLAB if you have experience using it.

- Prerequisites

  We recommend that students read the following references before starting this project.

  - Research activities of IHI [8][9]
  - References for the items recommended above
    - Car-following model [2]-[4]
    - State estimation and multiple object tracking [5]-[7]

References

[1] IHI website, “3D Laser Radar”, https://www.ihi.co.jp/3DLaserRadar/en/

[2] G. Liu, “W99 Car Following Model - How It Works”, http://w99demo.com/

[3] H.U. Ahmed, Y. Huang, P. Lu, “A Review of Car-Following Models and Modeling Tools for Human and Autonomous-Ready Driving Behaviors in Micro-Simulation”, Smart Cities, Vol. 4, No. 1, pp. 314–335 (2021). https://www.mdpi.com/2624-6511/4/1/19#

[4] J.J. Olstam, A. Tapani, “A. Comparison of Car-Following Models”, Swedish National Road and Transport Research Institute: Linköping, Sweden, Vol. 960 (2004). https://scholar.google.com/scholar_lookup?title=Comparison+of+Car-Following+Models&author=Olstam,+J.J.&author=Tapani,+A.&publication_year=2004

[5] R. R. Labbe Jr , “Kalman and Bayesian Filters in Python”, https://github.com/rlabbe/Kalman-and-Bayesian-Filters-in-Python (GitHub)

[6] The MathWorks, Inc. website, “State Estimation Using Time-Varying Kalman Filter”, https://jp.mathworks.com/help/ident/ug/estimating-states-of-time-varying-systems-using-kalman-filters.html?lang=en

[7] The MathWorks, Inc. website, “Track Vehicles Using Lidar: From Point Cloud to Track List”, https://jp.mathworks.com/help/lidar/ug/track-vehicles-using-lidar-from-pointcloud-to-track-list.html

[8] ASEAN DXPF Corporate Innovation Program, “IHI Challenge: Smart Cloud Data Platform for IHI Future Smart City” (2020), https://www.jetro.go.jp/singapore/DX/DXPF2/IHIchallenge.html

[9] IHI website, “Monitoring Intersections to Alert Drivers Practical application of 3D laser radar is close at hand in playing a central role in the Intelligent Transport Systems”, IHI ENGINEERING REVIEW, Vol. 49, No.2 (2016). https://www.ihi.co.jp/ihi/technology/review_library/review_en/2016/_cms_conf01/__icsFiles/afieldfile/2020/04/10/ee0cb8e72599b2292c46f3dc5c74b524.pdf