Joint Transportation Research Program

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SPR-4126 2018

LiDAR-Based Mobile Mapping System for Lane Width Estimation in Work Zones

Introduction

Road digital maps that include road characteristics (e.g., lane marking, lane width, slope, curvature, clothoid, shoulder width, and shoulder barriers) are useful for driver assistance systems, road safety inspection, traffic accident reduction, and infrastructure monitoring. FHWA reported that there were an estimated 96,626 accidents in work zones during 2015, out of which 642 accidents involved at least one fatality.* Lane width evaluation is one of the crucial aspects of road safety inspection, especially in work zones where a narrow lane width can result in a reduced roadway capacity and also increase the probability of severe accidents. In the past, collecting geospatial data for building road digital maps was an expensive, time-consuming, and labor-intensive task. Moreover, manual on-site data collection can expose field crew to dangerous road traffic. Using mobile mapping systems (MMS) equipped with LiDAR units and cameras, geo-referenced point clouds, and images can be collected rapidly in work zone areas to derive road characteristics without affecting traffic.

This report presents an approach to derive lane width estimates using point clouds acquired from a calibrated mobile mapping system. To derive point clouds with high positional accuracy, estimating the mounting parameters relating the different laser scanners to the onboard GNSS/INS unit is the first and most necessary step. This report proposes a multi-unit LiDAR system calibration procedure where the mounting parameters can be estimated through minimizing the normal distance between conjugate planar/linear features in overlapping point clouds derived from different drive-runs. After generating the LiDAR point cloud using the estimated mounting parameters, the road surface can be extracted with the assistance of navigation data, which in turn is used to identify lane markings. Lane markings have a high retro-reflective property that will be exhibited as high intensity points when scanned by a laser scanner. This property can be used to distinguish lane markings from the extracted road surface in the LiDAR point cloud. Then, non-lane marking points among the extracted high intensity points are identified and removed. Next, the lane marking centerline is derived for lane width estimation.

Various experimental setups are used in order to evaluate the performance of the proposed calibration strategy as well as the lane width estimation approach. First, the performance of the proposed calibration strategy is evaluated through the quality of fit of the adjusted point cloud to planar surfaces and linear features before and after the calibration process. Then, to demonstrate the feasibility and performance of the proposed lane width estimate approach, a comprehensive testing is conducted with six datasets collected in different seasons and using different sensors. The first experiment shows the importance of accurate estimates of mounting parameters for identification of lane markings and lane width estimation. The second demonstrates the compatibility of estimated lane width from two different types of spinning multi-beam laser scanners. The third indicates the accuracy of calibration results and the precision of lane width estimates by comparing the results obtained from five datasets for two road segments scanned by different sensors in different seasons. The last experiment demonstrates the accuracy of lane width estimates by comparing the results obtained for a test dataset collected for a road segment with those derived from manually digitized lane markers and on-site manual measurements. These experimental results indicate that the proposed strategy can provide lane width estimates that are precise to around 2 cm and have an accuracy of about 3 cm.

Findings

- When the mounting parameters are inaccurate, the derived point cloud would be distorted. In this case, precise lane width estimates cannot be derived.
- The lane widths derived from HDL32E and VLP16 laser scanners are found to be compatible. However, VLP16 generates sparse points than HDL32E, which would cause incomplete centerline extraction resulting in inaccurate lane width estimation for curved road segments. Therefore, to avoid the discrepancies caused due to the sparse nature of point cloud acquired from VLP16, it is recommended to have a slower driving speed during (e.g., 25 miles/hour) data collection.
- The lane width estimates for two road segments from five different datasets are derived, and the results demonstrate that the precision of the proposed lane width estimation strategy can range from 1 cm to 3 cm.

*https://ops.fhwa.dot.gov/wz/resources/facts_stats/safety.htm

- The accuracy of lane width estimates is evaluated by comparing the results obtained for a test dataset collected for a road segment with those derived from manually digitized lane markers and on-site manual measurements (ground truth). The difference between the derived lane width estimates using the proposed strategy and ground truth is 3.04 cm, which validates the accuracy of the lane width estimates from the proposed strategy and also indicates the accuracy of mounting parameter estimates from the system calibration. Also, the difference between the lane width obtained from the manually digitized centerline and ground truth is around 1.31 cm, which again illustrates the accuracy of mounting parameter estimates.

Implementation

Data Collection

The first step in the process of data collection is to mount the mapping system onto a mobile platform (here, a car) and test the operation of the different equipment in order to avoid any technical glitches during the course of data collection. The setup of MMS takes about 30 minutes. As discussed before, each data collection is preceded by a calibration dataset collection for which the calibration targets are set up in an outdoor environment, which is accomplished in another 30 minutes. It is followed by 5 minutes of dynamic alignment of the GNSS/INS unit, and then a total of approximately 10 minutes of drive-runs at an average speed of 4 miles per hour around the calibration test field. After that, work zone data is ready to be collected and needs to be monitored. The driving speed is around 40 miles per hour for work zone data collection. Finally, the data collection is ended with another dynamic alignment of the system for 5 minutes.

Data Processing

3D Point Cloud Reconstruction

The first step for 3D point cloud reconstruction is the processing of GNSS/INS data to generate the navigation dataset using the post-processing software provided by NovAtel or Applanix, which takes about 30 minutes. The Velodyne laser units store the captured data in PCAP format that needs to be decoded to extract useful information about the scanned points; it is used along with the navigation data and initial estimates of mounting parameters to reconstruct an initial 3D point cloud (in *.las format). The time taken to reconstruct the PCAP files depends on the amount of data collected and the number of threads used during reconstruction. For instance, a mission of 2.5 hours will result in a total of about 82 PCAP files, which would take a total of approximately 1.5 hours for reconstruction with five threads.

System Calibration

After reconstruction, the mounting parameters of MMS are calibrated in order to be able to obtain a point cloud with higher positional accuracy. First, the navigation data is used to extract the beginning and ending times for each of the parallel drive-runs around the calibration targets. Next, the point cloud captured in each drive-run is stored as a separate *.las file. These files are used to carry out a semi-automatic conjugate feature extraction process for calibration by determining seed points for highly reflective sign boards and checkerboards, diagonally opposite corners of ground/wall patches, and end points of linear features. The track separation and feature extraction can be achieved in a total of about 1 hour. Next, the extracted conjugate features are used as input for calibration (which takes about 10 minutes), thus resulting in accurate estimates of mounting parameters.

Lane Width Estimation

Having accomplished a successful calibration, all the PCAP files (raw laser scanning measurement) are again reconstructed using the new accurate estimates of mounting parameters to generate revised *.las files (point clouds) that can be used for lane width estimation. In order to estimate lane width, first the road surface is extracted, which takes from 30 minutes to 1 hour. Next, the high intensity points representing the lane markings are extracted from the road surface in 5 minutes. Then, the navigation data is used along with the high-intensity points to derive the lane marking centerline, which requires 10 minutes. Finally, the derived centerlines from opposite sides of the road are separated out and used to derive the lane width estimates, which takes about 10 minutes. Based on these time estimates for each step, the total data processing time for any collected dataset can be estimated.

Recommended Citation for Report

Habib, A., Lin, Y.-J., Ravi, R., Shamseldin, T., & Elbahnasawy, M. (2018). *LiDAR-based mobile mapping system for lane width estimation in work zones* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2018/10). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284316730

View the full text of this technical report here: https://doi.org/10.5703/1288284316730

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