ABSTRACT

Road safety analysis typically relies on the correlation between road surface conditions, lane marking status, or lane width and crash data. Traditionally, this data is surveyed in the field after road construction or car accidents, which is labor-intensive, time-consuming, and hazardous. With the development of mobile mapping systems (MMS) in recent years, the ability to collect lane marking retroreflectivity or lane width information has been greatly improved. By utilizing Light Detection and Ranging (LiDAR) point clouds and RGB images captured by MMS, it is possible to establish lane marking inventory that includes the conditions of pavement markers (such as lane marking retroreflectivity and lane width) for road safety analysis.

This dissertation aims to develop a comprehensive framework to extract lane markings and report their characteristics using MMS datasets for transportation safety. The proposed approaches include geometric/morphological and deep learning-based approaches based on the LiDAR point clouds acquired by MMS. A normalization strategy is developed to ensure consistent intensity values across laser beams/LiDAR units/MMS for the same objects, thereby enhancing the lane marking extraction. In addition, an image-aided LiDAR approach is proposed to improve the extraction process further. Following the extraction, lane marking classification and characterization, including intensity profile generation and lane width estimation, are conducted to establish comprehensive lane marking inventory.

To evaluate the proposed strategies, lane marking extraction with and without intensity normalization is also conducted. The results show that the proposed intensity normalization significantly improves the performance of lane marking extraction, regardless of the approach or data used. The geometric approach using normalized intensity achieves F1-scores higher than 90%, outperforming the learning-based models. Furthermore, the intensity derived from two different MMS is compared for performance evaluation, and the agreement of normalized intensity values is within a range of 3.1 to 3.8 (the used MMS provide intensity as an integer number within 0 to 255). Through the normalization, a positive linear relationship between LiDAR normalized intensity and retroreflectivity is found, with the strongest relationship providing an R^2 of 0.72 and a Pearson's correlation coefficient of 0.85. A compar-

ison of the correlation between original/normalized intensity and retroreflectivity revealed a stronger correlation between original intensity and retroreflectivity. For image-aided LiDAR approach, the image information indeed enhanced the LiDAR-based lane marking extraction approach, as evidenced by the highest F1-score (91.8%) of the image-aided LiDAR approach, outperforming the LiDAR-based (89.5%) and image-based (76.4%) ones. Specifically, the recall increases by 4.0% from 87.6% (LiDAR-based) to 91.6% (image-aided LiDAR) surpasses the slight improvement in the precision of 0.2% from 93.2% (LiDAR-based) to 93.4% (image-aided LiDAR).

Finally, a Potree-based web portal is developed to visualize the results derived through the proposed lane marking extraction/classification/characterization strategies. This portal includes a function that enables the projection between 2D images and 3D point clouds, as well as tools for displaying intensity profiles and lane width estimates. It is is capable of rendering a large dataset of approximately 4.2 billion LiDAR points in around ten seconds and allows for the visualization of intensity profiles and lane width estimates. Users can select points of interest in an intensity profile/lane width plot. This selection will result in the corresponding point being showcased in the LiDAR data on the web portal. Furthermore, the LiDAR point can be projected onto the corresponding image. Based on the above proposed strategies, there is the possibility of regularly updating the lane marking inventory over the lifespan of the markings, which can aid in road safety analysis.