UTC Project Information	
Project Title	Efficient Extraction and Evaluation of Complex Pavement Markings from Mobile Laser Scan Data
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Funding Source(s) and Amounts Provided (by each agency or organization)	University of Washington PacTrans $30,000 Oregon State University $30,000
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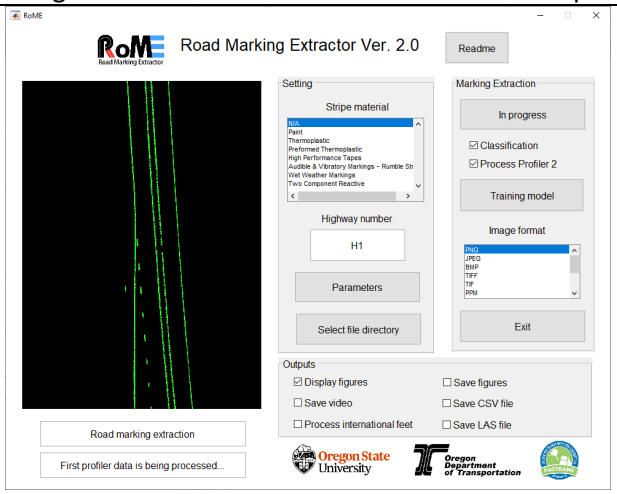
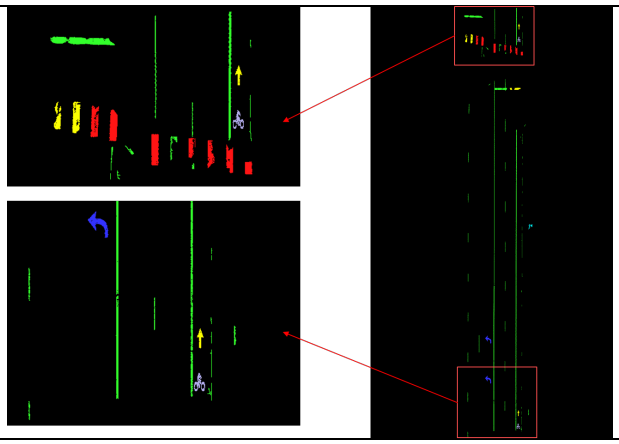
Brief Description of Research Project	This research project aimed at developing a systematic methodology for automated extraction and classification of complex road markings (e.g., pedestrian crosswalk, bike, lane, and left, straight, right arrow markings). The proposed approach can be divided into three principal steps: road surface extraction, road marking extraction, and road marking classification. For road surface extraction, based on the rich geometric information of a point cloud, ground filtering is applied to extract the road surface, which is likely to include road markings. Next, using the radiometric information available (i.e., point cloud intensity), the extracted road surface point cloud data are rasterized into 2D intensity image to segment high-intensity pixels, likely representing road markings. Finally, in road marking classification, common linear lane markings with lengths greater than a predefined threshold are first segmented, and the remaining markings are then classified using a template matching model. To generate training data for the matching process, the research team has collected a set of templates from MLS data and also created additional synthetically-modified data using a data augmentation approach to account for a variety of marking conditions, such as different orientation, skewness, and scale. This tool will be implemented in software developed by the research team for Oregon DOT, which currently only extracts linear pavement markings. By leveraging existing MLS data being collected by state DOTs, this framework provides significant cost savings given that it is relatively inexpensive to implement and minimizes redundancy in data collection efforts since the MLS data can be used for many other applications.

Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	The developed tool is designed for maintenance personnel, engineers, and other authorities in transportation departments who need this information to help make appropriate decisions for the evaluation of road markings. The tool contains a simple interface that does not require the user to have extensive knowledge of the program or point cloud data in order to run it successfully. The inputs to the program are the point cloud(s) in ASPRS LAS v1.2 format, which is the current version provided by Oregon DOT, and trajectory (asciitrj) data obtained by a mobile lidar unit. The outputs include a road marking point cloud that can be utilized in many decision-making processes and applications, such as retroreflectivity evaluations. At this time, road marking extraction has been tested and evaluated with ODOT's current mobile lidar system (Leica Pegasus:Two) and may not produce correct results for other systems. The classification is currently only capable of classifying pedestrian crosswalk, bike, lane, and left, straight, and right arrow markings. The user needs to retrain the template-matching model to classify other types of road markings. In addition, the tool is designed to support both a single and dual profiler configuration. The dual profiler increases the point density and provides data from a greater variety of acquisition geometries. In this project, it was found that the dual profiler is particularly advantageous in capturing road markings distant from the lane from which MLS system operates. The developed program has a great potential for supporting evaluation of road markings for many transportation agencies worldwide. Presentations have been given at the 2019 Pactrans Annual Meeting and the 2020 Northwest Transportation Conference. The developed program is now receiving significant attention from Oregon DOT for integration into their workflow to evaluate complex road markings.
	

	
Impacts/Benefits of Implementation (actual, or anticipated)	Pavement markings are an important traffic control device, enhancing both the safety and efficiency of various modes of transportation by aiding vehicles, bicyclists, and pedestrians in effectively navigating transportation networks. Pavement markings degrade due to vehicles passing over them and weathering. Therefore, transportation agencies must periodically assess the condition of these markings to ensure they meet specifications. These evaluations are typically performed using a handheld or mobile retroreflectometer, or through visual, qualitative assessment. Each of these existing methods has associated limitations, related to various factors such as safety, cost, time, and repeatability. A potential alternative is the use of mobile laser scanning (MLS) data. Surveys of roadways with MLS are currently being conducted on a regular basis by many transportation agencies, and the lidar intensity (return signal strength) data can be used to estimate retroreflectivity of pavement markings in support of condition evaluation. In a recent project with the Oregon Department of Transportation (ODOT), the research team developed an automated method to extract linear lane markings from MLS data and to evaluate the retroreflectivity of those markings. In this PacTrans project, they built upon that effort to develop advanced techniques to handle more complex markings (e.g., pedestrian crosswalk markings, bicycle markings, and arrows) that were not considered in the prior ODOT project but nevertheless are still important to support mobility for multi-modal transportation. The extracted road markings will enable performance-based procedures for transportation agencies to evaluate pavement marking quality by providing detailed information, including spatial coordinates and types of markings. This, in turn, supports informed decision making by DOT management for effective resource allocation. Improved maintenance of pavement markings will also lead to improved mobility with technologies such as autonomous vehicles.
Web Links • Reports • Project Website	Report: https://depts.washington.edu/pactrans/research/projects/efficient-extraction-and-evaluation-of-complex-pavement-markings-from-mobile-laser-scan-data/