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Laser data based automatic recognition and maintenance of road markings from MLS system

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ABSTRACT

Mobile LiDAR Systems (MLSs) have recently been recognized as an effective way to extract road markings. Although existing studies have achieved good accuracy (about 90%) in road marking extraction, the majority of them are based on image processing methods; only a few researchers directly use laser points, especially for the recognition and assessment of road markings. This study introduces a three-step automated method for the extraction, recognition, and maintenance of road markings based on the intensity information from the MLS data: (1) an automated mechanism to filter the ground surface in laser data, (2) an adaptive block and multi-threshold method to detect road markings, (3) an automated method to achieve the classification, recognition, and assessment of road markings. Qualitative and quantitative analyses based on experimental datasets with eight types of road markings were used to evaluate the feasibility and robustness of the proposed method. Experimental results show that the average values of completeness (CPT), correctness (CRT), and F-measure of the road marking detection results are 94.35%, 98.35%, and 95.7% and the average values of CPT, CRT, and quality (QUA) of recognition results are 99.0%, 93.2%, and 92.3%, respectively, indicating that the proposed method is feasible and effective. The detection and recognition results were used to reconstruct, improve, and update the road features database; provide guidelines for road applications and maximum assistance for road maintenance; and deliver a valuable solution for maintenance and management of constructed facilities.
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1. Introduction

Rapidly increasing population and urbanization in large cities have directed the attention of researchers to the importance of traffic services including timely road maintenance [1], updated road information [2,3], road safety, and comprehensive management. These services highlight the need for a variety of specialized software for road design, expansion, and asset inventory to achieve accurate, comprehensive, and systematic road management and improve road safety [4,5]. The timely extraction of road features information, such as road markings [6], has become increasingly important. As a primary road feature in traffic systems, road markings provide guidance to drivers and pedestrians and play a major role in traffic safety [5,7–9]. Measuring, detecting, classifying, and recording road markings are essential for road management, expansion of safety conditions, and providing high-precision information to road users [5,10].

Although some researchers have successfully extracted road markings from images [11–19] or videos [13,20,21], the extraction results are influenced by weather conditions, shadows of cars or trees, surface material, and the type of road marking, thereby decreasing the geometric accuracy [13,21–27]. At present, Mobile LiDAR Systems (MLSs) [4,5,28–35] are already being applied to the road infrastructure and surrounding road corridors to extract timely road information [4,36]. MLS is a multi-sensor system that integrates laser scanners, a navigation system, and cameras. MLS can accurately, continuously, and reliably acquire three-dimensional (3D) geometrical and texture data [33–36]. The efficient, reliable, high-density, high-accuracy, and low-cost acquisition of road and surrounding road corridor data proves that the MLS technology is suitable for extracting road markings [1–4,34,35].

The majority of researchers have focused on extraction of road markings; only a few have studied their recognition. To eliminate the influence of road corridor objects with highly reflective surfaces and the overload of the central processing unit (CPU) of computers, road surface extraction from laser scanning data is the first

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step. Road markings are then extracted from the extracted road surface data. For road surface extraction, Yang et al. [35] segmented the road surface based on the parameters of height jump, density, slope, or intensity. Yan et al. [38] extracted the road surface using the moving least squares line fitting that relies on the seed road points, acquired by the height difference between the road surface and trajectory data. Kumar et al. [5,10,34] used the combination of two modified active contour models to extract road points based on the parameters of slope, reflectance, and pulse width. Guan et al. [3,4] used curbstone information located on both sides of the road to extract road points by detecting the small height jumps. Riveiro et al. [37] segmented the road points by the principal component analysis based on the elevation and deflection angle of each point. Wang et al. [29] segmented the road surface by constructing a saliency map based on 3D unorganized MLS data supported by trajectory data. Despite successfully extracting the road points, most of these methods are based on the parameters of elevation, slope, density, intensity or road width, which are easily affected by road conditions.

For the extraction of road markings, previous methods have depended on georeferenced image processing, generated from the MLS data. Wang et al. [29] presented a methodology for road marking detection and classification from extracted road surface data. Road markings were extracted using an adaptive binary thresholding method from binary raster images, which were generated from the filter laser points based on their reflective properties. The classification of road markings is achieved using neural network models. However, the methodology of Wang et al. [29] is only used to extract pedestrian crossings and arrows. Chen et al. [39] used retro-reflective features to achieve automatic road marking extraction. Yang et al. [35] proposed an automated approach for extracting road markings using interpolation to generate intensity images from road surfaces and segments based on their size, shape, and pattern. Guo et al. [1] proposed an automated method for reconstructing road surface features using intensity images, generated from extracted road points; road markings were extracted by an image processing method (e.g., morphological operations), which is influenced by the threshold of elevation and uses a fixed road width. Kumar et al. [5] proposed a range-dependent threshold function that extracts road markings and acquires the shape of road markings using the method of morphological operation. This method extracts road markings using blocks with different thresholds. Guan et al. [3] proposed a scheme that uses an extended inverse distance weighting method to generate intensity images, a multi-threshold method to filter road marking areas, and a morphological method to extract road markings. Although different types of road markings are extracted, these methods rely on the trajectory data and the accuracy of the extraction results based on image processing is reduced during the conversion of 2D image and 3D laser points.

Yu et al. [40] extracted seven types of road markings directly from the MLS data using the multi-segment and multi-threshold methods. Large-sized road markings were classified based on the curb-lines and trajectory data and small-sized markings were classified based on deep learning methods and principal component analysis. Yan et al. [38] extracted road marking points using the Edge Detection and Edge Constraint (EDEC) method and eliminated the fake road marking points by segmenting and dimensionality-based refinement. Note that these methods use trajectory data. Ma et al. [6] presented a method to automatically extract road markings directly from the MLS data based on the intensity jumps, region growing, and template matching, but only five types were successfully extracted. These methods used traditional parameters (height jump, slope, density, and road width) and involved only the extraction and classification, not the road maintenance.

This study proposes an automated method for the recognition of road markings based on the MLS data without using any trajectory data. Only the elevation parameter was used to extract road points; eight different types of road markings were extracted using the laser data with the multi-threshold method and the method of template matching with the normalized cross-correlation (NCC) value. The detection and recognition results provide useful information to the road surface database for road maintenance and safety. The remainder of this paper is organized as follows. The key road feature recognition method used for road markings is presented in Section 2. Experiments and analyses conducted are discussed in Section 3. Concluding remarks are presented in Section 4.

2. Proposed method

Our proposed method extracts and recognizes road markings from MLS laser points. The procedure includes three steps. (1) Extraction of the road surface with a smaller number of parameters by a moving window. (2) Detection of road markings by the adaptive block and the multi-threshold methods. (3) Recognition of road markings by template matching method with NCC function. The framework of recognition is shown in Fig. 1.

2.1. Road surface filtering

The MLS acquires a large amount of road corridor laser points that need to be segmented to reduce the data size, avoid the overload of computer hardware, and accelerate the computing speed. Ibrahim and Lichti [41] used the K-D tree structure to organize laser points, which is time-consuming. To effectively organize laser points, we directly used the moving window along the scan line to perform the calculation. Since the elevation values of adjacent points have similar characteristics, we used the moving window filtering process based on the adjacent scan lines to extract ground

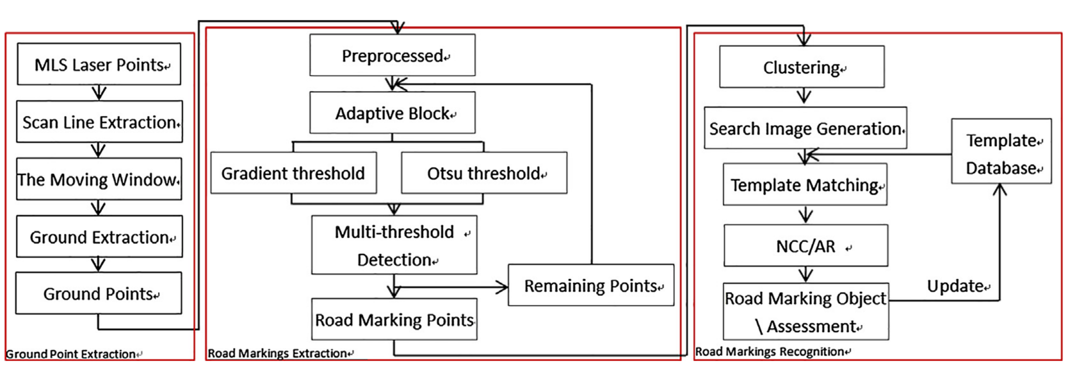

Fig. 1. Framework for recognition of road markings from the MLS point cloud.

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