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Automatic Road Extraction from Mobile Laser Scanning Data

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Abstract—**Extraction of road surface and boundary is essential for autonomous vehicle navigation, road monitoring and important scene structures extraction. Mobile laser scanning (MLS) technology as a new information acquiring manner can quickly scan the whole scene and provide density and accurate 3D coordinate data and other information such as trajectory, color and reflectance. In this paper an automatic road extraction method is proposed based on trajectory information from mobile laser scanning data. Through the trajectory, location and approximated direction of local road patch could be determined. Searching algorithm is applied along the approximated road direction and the orthogonal direction. To determine the road boundary a hypothesis testing method based on local altitude variance is used. To filter false boundary points, local altitude mean value is applied. Experiment results demonstrate the reliability of the proposed algorithm for automatic road surface and boundary extraction.**

Keywords-mobile laser scanning (MLS); road extraction; trajectory

I. INTRODUCTION

Road as an important urban structure plays an important role in many applications such as autonomous vehicle navigation, road monitoring and important scene structures extraction (road signs, lamp posts and traffic lights). To extract road structure, many methods using different types of sensors such as cameras, radar and lidar have been studied.

Camera based methods mainly detect lane marks on structured roads [1, 2] and recognize road boundaries in unstructured roads [3-5]. Although these camera based methods have advantages of sensors including high information content, low operating power, low cost and passive noninvasive type, they are less effective under complex illumination, complex shadows and bad weather. Radar can work in a longer detection range and higher reliability in bad weather conditions. Several approaches using radars sensors have been studied [6-9]. However, radars have low angular resolution against relatively high distance resolution. Thus, it is difficult to detect roads and many objects, and measure their accurate positions by radars with low angular resolution. Lidar sensors can give high accuracy and resolution range data. Additionally, their capabilities in adverse weather conditions have also been improved. In the paper [10], methods for detecting road boundaries using lidar sensors have been classified into two categories determined by the scanning pitch of the sensor: forward and downward looking. The measurements of the forward looking sensors are used to build an occupancy grid map, and then, the road boundaries are estimated by using the grid map and road models, including parabolic [11], clothoid [12,13], and circular [14] models. Some studies extract road boundaries by using extracted roadside obstacles instead of the grid map [15]. Reflectivity information is used to recognize lane markings for downward-looking lidar sensors. Different reflectivity between lane marking and road surfaces is considered. However, inconspicuous or missing lane marking cannot be detected [16-18]. For road boundary detection and tracking, extended kalman (EKF) [19] filter, multiple kalman filters [20, 21] and an interacting multiple model probabilistic data association (IMMPDA) [21] filter are used.

Mounting manner lidar system can be divided into three categories: terrestrial/ground based laser scanning system, mobile laser scanning system and airborne laser scanning system. As a new type of lidar system, MLS system has its advantages. First, compared to terrestrial/ground based system, the mobile laser scanning system can quickly scan the whole urban area. Second, compared to airborne system, the mobile laser scanning data is denser. Meanwhile, airborne lidar system can only acquire the height information of the scene, but mobile lidar system can not only get the height information, but also can get the side information. Third, the mobile laser scanning system can also provide users trajectory information. It is very useful for indicating the driving direction and location of the road. Principle of mobile laser scanning is illustrated in Fig. 1.

In this paper, a road extraction method is proposed based on trajectory information from mobile laser scanning system. Trajectory information not only indicates the approximated road direction but also indicates the road location. Through the trajectory, direction and location of local road patch could be determined. And then searching algorithm could be applied along the road direction and the orthogonal direction. To

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determine the road boundary a hypothesis testing method based on local altitude variance is used. To filter false boundary points, local altitude mean value is applied. Compared to other mobile laser scanning based method [21], proposed method does not need any manual interaction and also does not need to indicate the four corners of road plane. Meanwhile proposed method could handle variance of road direction and road width.

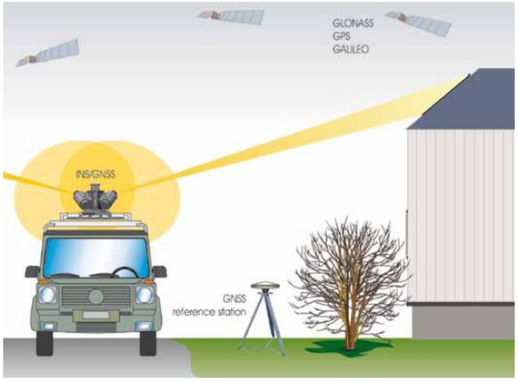

Figure 1. Principle of mobile laser scanning

The rest of the paper is organized as follows. In section II, mobile laser scanning system used in the experiments is described. In section III, the road surface and boundary extraction method is presented. In section IV, experiments results are presented and discussed. Conclusions and future works are given in section V.

II. Mobile Laser Scanning System

The Mobile Laser Scanning System used in the experiments is RIEGL VMX-450 system. This system offers extremely high measurement rates providing dense, accurate, and feature-rich data even at high driving speeds. The measurement rate of the system up to 1.1 million meas./sec, and the scanning rate up to 400 lines/sec. Meanwhile the system has a high penetration of the obstructions (e.g. fences, vegetation) by means of echo digitization and online waveform processing.

The carrier integrates two RIEGL VQ-450 laser scanners as well as inertial measurement and GNSS equipment, housed under an aerodynamically-shaped protective cover. A well-designed camera platform ensures user-friendly mounting and setup of up to six digital cameras (Fig. 2).

Fast 3D data collection, featuring high accuracy and high resolution, provides a basis for a variety of applications including mapping of transportation infrastructure, city modeling, fast mapping of construction sites, surveying of mining/bulk materials, network planning.

III. Road Extraction

The road extraction algorithm proposed here is based on these two observations: first, trajectory indicates location and direction of local road plane; second, altitude of the point at the boundary of the road varies heavily. Trajectory is composed of INS/GNSS data, which the coordinate system is conform to the point cloud coordinate system. Original trajectory is recorded at a very high time frequency. Through selecting some trajectory points at constant time step, a trajectory point set with approximated constant distance each other is generated. Although in many situations, the road is not a perfect flat surface, but in a local road plane patch it is can be roughly approximated as a 3D best fit plane. In the algorithm we only consider a local patch, not a whole scene and assume that every local road patch between two adjacent trajectory points is plane.

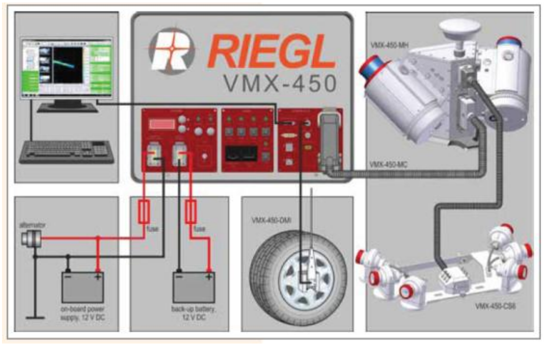

Figure 2. RIEGL VMX-450 system

A. *Trajectory*

Airborne and Mobile Laser Scanning Systems provide data acquired by the laser scanner(s) and data from an INS/GNSS system. The laser scanner data is frequently referred to as scan data, whereas the INS/GNSS data or position and orientation data is called in short trajectory data after post processing. There are two trajectories exhibited in the Fig. 3.

Nowadays many laser scanning systems provide the trajectory information in addition to point cloud. By including the trajectory information someone could then be able to review the original work, do accuracy assessment and perhaps improve the quality of the results by substituting better control points or perhaps even a smarter post processing solution.

In this paper the trajectory information is used to indicate the road location and direction since the scan data are transformed into the coordinate system of trajectory, and usually is WGS84 (world geodetic system). Concretely, every point in the trajectory can be served to indicate the location of the road, and the direction of the line segment between two adjacent trajectory points can be used to approximate the local road section direction. Based on this direction the method could handle the variance of the road direction.

B. *Searching Strategies*

In searching algorithm there are two things we must consider. The first is where we can start the searching method. The second is the direction which we can continue the searching method. In the proposed algorithm, every trajectory point is served as the seed of the searching algorithm. The line segment connected two adjacent trajectory points indicates the direction of the local road patch between these two points. Direction and orthogonal direction of the line segment indicate the searching direction. Because the distance between two adjacent trajectory points may be bigger than the searching diameter, the algorithm must search along the line segment direction and the opposite direction to cover the whole scene. This strategy will reduce the computing time.

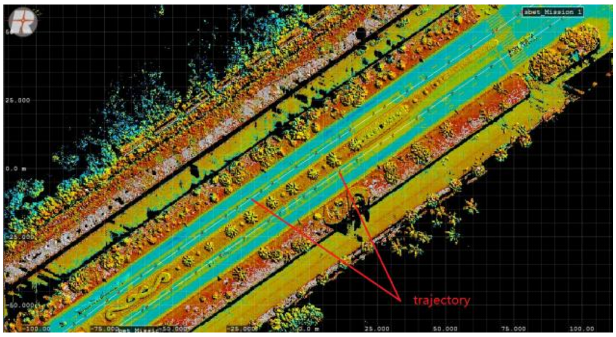

Figure 3. Trajectory in the project

C. Boundary Detection

To detect boundary of the road, a statistical hypothesis testing method based on the altitude of point set is used. At the beginning an initialized local road plane patch P_0 is assumed which could be acquired easily from the neighborhood of the seed points, and it will be updated upon all points have been classified as road surface.

Given a point set P representing which to decide whether it belongs to road surface or road boundary. The altitude distribution function of point set is assumed Gaussian function, labeled as $N(\mu,\sigma)$, and μ is unknown. Number of points in this point set is N. Considering following hypothesis testing problem,

$$H_0:\ \sigma^2 \geq \sigma_0^{\ 2} \quad \mathrm{H}_1:\sigma^2 < \sigma_0^{\ 2} \tag{1}$$

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{2}$$

$$\sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2 \tag{3}$$

where $\bar{x}$ is the mean value and σ^2 is the variance, σ_0^2 is the height variance of the P_0.

Through the hypothesis testing theory, the statistic variable used is,

$$\chi^2 = \frac{1}{\sigma_0^2}\sum_{i=1}^{N}(x_i - \bar{x})^2 \ \sim \chi^2(N-1) \tag{4}$$

Region of rejection is,

$$\chi^2 \leq \chi^2_{1-\partial}(N-1) \tag{5}$$

where ∂ is significance level or confidence, usually $\partial = 0.05$. If statistic variable locates inside of the region of rejection, hypothesis H_0 is denied, H_1 is accepted, and no road boundary is found, that is to say this point set is part of road surface. Otherwise, hypothesis H_1 is denied and H_0 is accepted, and this point set is selected as candidate for road boundary.

However, in many situations there are many objects on the road such as cars and pedestrians. Hypothesis testing method for altitude variance can detect all altitude abnormal points compared to road surface. Cars and pedestrians may also be though as the boundary. So altitude mean value $\bar{x}$ must be applied to filter all false boundaries. If the mean value is lower than the given threshold, it is considered as part of road boundary, otherwise it is part of objects on the road.

D. Summary

The proposed algorithm can be summarized as follows:

1) Fisrt of all, according to the height threshold filters all points above it. All remaining points are be considered as the candidate of road surface and boundary.

2) According to the selected trajectory point set, every point in it is served as the seed point and every direction and orthogonal direction of the line segment between two adjacent trajectory points are served as the searching direction.

3) For every searching range, all points in it are used to compute the altitude variance and altitude mean value described above. Through statistical hypothesis testing method the candidate road surface and boundary are delected, and all other objects on the road can be filtered by the mean vlaue.

4) The above process iterates for all trajectory points and then the road surface and boundary will be extracted.

IV. EXPERIMENTAL RESULTS

The algorithm proposed is tested on different urban scenes collected in Xiamen, China using RIEGL VMX-450 system. The data used in the experiments are collected along Island Ring Road. Programming was done in C++ on a Window 7 64 bit platform. The hardware system is an off-the-shelf computer with 4GB of RAM and a dual-core 3.3 GHz processer.

The experiments results are exhibited in Fig. 4, Fig. 5 and Fig. 6. Fig. 4 shows a local road patch with no objects on it, and our algorithm can extract all points of road including road surface and road boundaries. Fig. 5 shows a local road patch with a car on it. Proposed algorithm can decide whether the searching method reaches the boundaries rightly. Fig. 6 is another viewpoint to show the results. Through the experiments the algorithm is proved reliability.

V. CONCLUSION

This paper presents a road extraction method based on trajectory information from mobile laser scanning data. Compared to other road extraction methods, proposed method is fully automatic and does not need any manual interaction. Instead of manually selecting seed points and searching for all directions, the method selects seed points and constrains the searching direction through trajectory information. And this procedure reduces the searching range and time. Meanwhile proposed method could handle variance of road direction and road width. The proposed algorithm is demonstrated useful through experiments. Future improvements will consider optimizing the algorithm to reduce computing time.

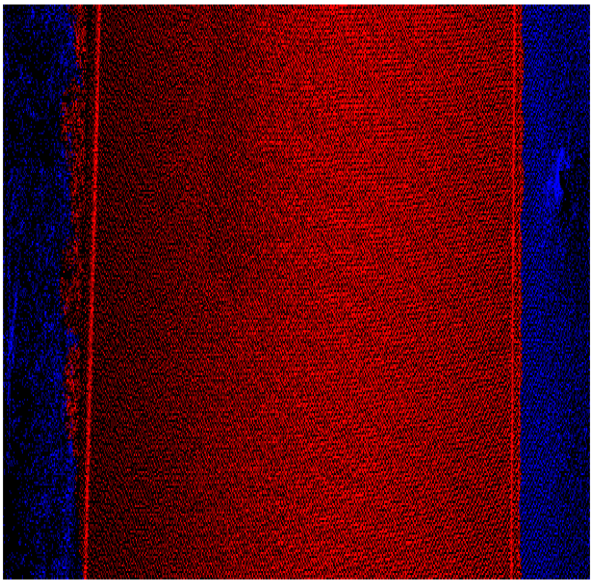

Figure 4. Local road patch with no objects on it

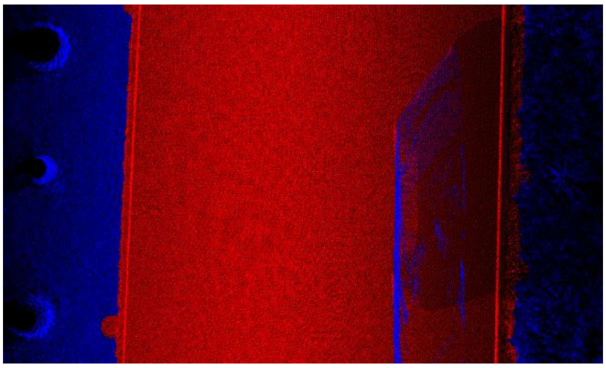

Figure 5. Viewpoint1:a local road patch with a car on it

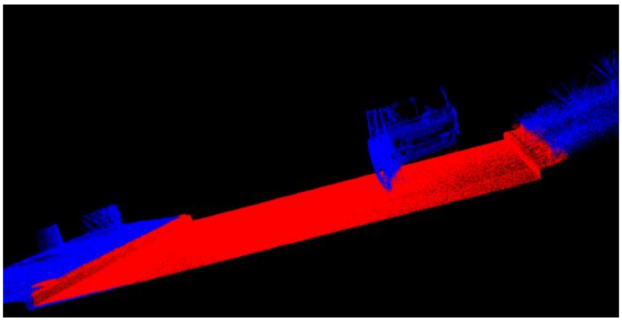

Figure 6. Viewpoint2: a local road patch with a car on it

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