

Research on Urban Road Pavement Extraction Method Based on Vehicle Point Cloud Data

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Abstract: In order to extract structured urban road surface efficiently from vehicle point cloud data, this paper proposes a road surface extraction method based on normal vector clustering. First, a cloth simulation based filtering algorithm (CSF) is used to filter the interference of non-ground points; Secondly, the normal vector and curvature of each pavement point are estimated by principal component analysis; Finally, with the similarity of point cloud normal vector as the constraint condition, the road point cloud cluster is segmented. The vehicle-mounted point cloud data in the scene of straight and turning sections are verified, and the completeness and accuracy of road surface extraction are both above 92%. The experimental results show that the extraction results are less affected by the complex environment of urban roads, so the method proposed in this paper has strong applicability.

Keywords: Urban road, Vehicle point cloud, Principal component analysis, Normal vector.

1. Introduction

High precision and high current three-dimensional road information is of great significance for intelligent city construction, traffic management and road maintenance [1]. The vehicle-mounted laser scanning system takes the vehicle as the carrying platform and integrates multiple sensors such as 3D laser scanner, GPS, digital camera, inertial navigation system (IMU), etc., and can obtain the 3D data information and Texture information provides a new way for digital detection of road assets. As an advanced measurement method, the vehicle mounted laser scanning system has the characteristics of fast, real-time, active, and no direct contact. Vehicle mounted laser point cloud system has been widely used in the field of smart city construction.

At present, road surface extraction for vehicle LiDAR point cloud includes three methods: feature image based on point cloud, scanning line based and clustering analysis. The method based on feature image is to convert discrete three-dimensional point cloud into two-dimensional image by projection method, and extract road surface by using mature image processing technology[2-5]. This method has a certain degree of accuracy loss in the process of image generation. The vehicle-mounted LiDAR system uses a linear scanning mode along the vehicle traveling direction. The scanning line is approximately perpendicular to the driving track, which is similar to a cross section of the road. Therefore, many scholars have studied the point cloud feature information in the scanning line[6-9]. This method requires high demand for road conditions, and requires sections with roadblocks or slopes on both sides. The method based on cluster analysis is that the target has similar local features. The point clouds with these features are clustered[10-13] to obtain the road surface, this method is difficult to control the degree of segmentation, and is prone to over segmentation and under segmentation. Based on the distribution characteristics of road surface point cloud normal vectors, this paper proposes a road extraction algorithm based on the similarity of point cloud normal vectors, and tests the effectiveness and accuracy of the algorithm.

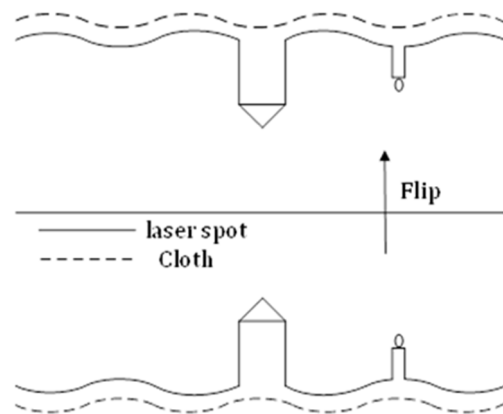


Table 1. Three Scheme comparing

2. Urban Road Extraction Method

2.1. Non-ground points filtering

There are many ground objects in the urban road scene, and the original point cloud contains a large number of trees, street lamps, poles and vehicles on the road. These points that may affect the results of road extraction are called noise points, which interfere with the accuracy of normal vector estimation and the efficiency and accuracy of road extraction. Therefore, it is necessary to filter the original point cloud to remove non-ground points.

In this paper, the cloth simulation-based filtering algorithm (CSF) proposed by Zhang[14] is used to remove non-ground points. This algorithm has the advantages of few parameters and fast speed, and is suitable for vehicle point cloud filtering. The principle is to flip the ground point cloud. Assuming that there is a sufficiently soft cloth above the ground surface, it is evenly covered on the terrain surface under the influence of gravity, and the final shape of the cloth can represent the real ground. Figure 1 is a schematic diagram of the CSF algorithm.

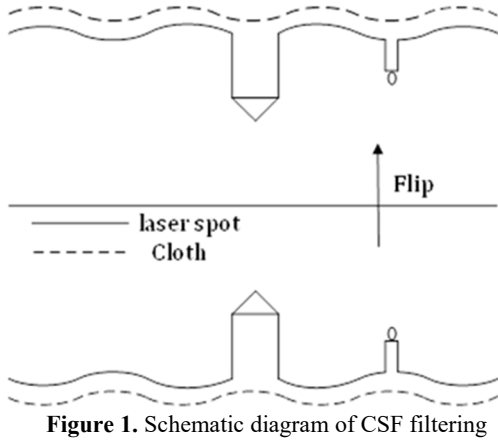


Figure 1. Schematic diagram of CSF filtering

2.2. Point cloud normal vector and curvature estimation

Scholars at home and abroad have proposed many methods for normal vector estimation[15,16]. Among them, for vehicle point cloud data, the process of modeling based on Delaunay/Voronoi method and robust statistics method is very complex, which requires a lot of time to calculate. This paper adopts a method based on local surface fitting, as shown in Figure 2, which is to directly obtain geometric features on the point cloud model. This method assumes that the point cloud sampling plane is smooth, and the local neighborhood of the sampling point can be fitted with a plane. Therefore, the geometric features of the sampling point can be estimated with the parameters of the plane.

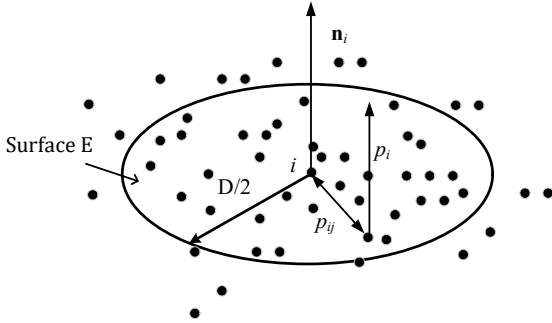


Figure 2. Schematic diagram of normal vector estimation principle

3D point cloud $p = \{p_1, p_2, \dots, p_n\}$, any point p_i in $p_i \in R^3$, use KD-tree algorithm[17] to find k adjacent points $M(p_i) = \{p_{ij} | 1 \leq j \leq k\}$ of a point. Finally, use the least square plane to fit a local plane E to minimize the following equation:

$$error = \sum_{j=1}^k ((p_{ij} - p_i) \cdot \mathbf{n}_i)^2 \quad (1)$$

Where \mathbf{n}_i is the normal vector of plane E .

Perform principal component analysis (Principal Component Analysis, PCA) on the covariance matrix of vertices. The covariance matrix of the p_i neighborhood can be written as:

$$C = \begin{bmatrix} p_{i1} - \bar{p}_i & \dots & p_{i1} - \bar{p}_i \\ p_{i2} - \bar{p}_i & \dots & p_{i2} - \bar{p}_i \\ \dots & \dots & \dots \\ p_{ik} - \bar{p}_i & \dots & p_{ik} - \bar{p}_i \end{bmatrix} \begin{bmatrix} p_{i1} - \bar{p}_i \\ p_{i2} - \bar{p}_i \\ \dots \\ p_{ik} - \bar{p}_i \end{bmatrix} \quad (2)$$

where p_i is the center of gravity of the neighborhood point set $M(p_i)$, considering the following characteristic problems:

$$C \cdot e_m = \lambda_m \cdot e_m, m \in \{1, 2, 3\} \quad (3)$$

Let $\lambda_1 \leq \lambda_2 \leq \lambda_3$, the characteristic direction e_1 corresponding to the minimum eigenvalue λ_1 of matrix C can be used as an effective estimate of the normal vector \mathbf{n}_i . The corresponding curvature formula can be estimated by the following formula:

$$H_i = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \lambda_3} \quad (4)$$

2.3. Normal vector clustering algorithm

The normal vector distribution of the vehicle point cloud on the road surface is relatively concentrated, and the direction of the road surface normal vector does not change much, but there is a significant difference between the normal vector normal phase at the edge of the road and the curbstone and other objects. Therefore, the normal vector similarity is used as the constraint, and the normal vector clustering algorithm is used to segment the road surface point cloud.

The clustering segmentation method based on the similarity of normal vectors used in this paper is a segmentation method derived from the region growing algorithm[18]. The basic idea of the algorithm is: Select a seed point from the point cloud, use the seed point as the starting point, set a threshold value, and judge whether the points within a certain range around it can meet the normal vector difference with the seed point within the threshold value range. If it meets the requirements, add it to the point cloud cluster, and it can be used as the seed point that continues to grow until there is no similar feature point in the seed point area. The key of this algorithm lies in the selection of seed points. Considering the characteristics of urban roads as shown in Figure 3, the road surface is relatively flat, and the elevation of road points is generally slightly lower than other features such as the channels on both sides of the road. Therefore, first arrange the original point cloud in ascending order of elevation, and select the point with the lowest elevation as the seed point. The algorithm process is as follows:

(1) Arrange the original point cloud data in ascending order of elevation difference, calculate the curvature H_i and normal vector \mathbf{n}_i of all points, and the seed point is the point with the smallest curvature.

(2) Search the neighborhood of the current seed point, calculate the normal vectors and curvature values of all points in the neighborhood, and the included angle S_i with the seed point normal vector.

(3) Set the smoothing threshold S_α and the curvature threshold H_β , examine the angle between the current point and the normal vector of the points in the neighborhood, if $S_i < S_\alpha$, add the current point to the seed point area; examine the curvature value H_i of the current point, If $H_i < H_\beta$ can be satisfied at the same time, the current point is added to the seed point queue.

After the normal vector clustering is completed, some plane point groups may be clustered outside the road surface range. Considering that the difference between these plane point groups and the road point cloud cluster is that the

average elevation of the road point cloud cluster is low and it is the largest connected area. Therefore, the road point cloud and the non-road point cloud can be separated by the method of elevation filtering by setting the elevation threshold.

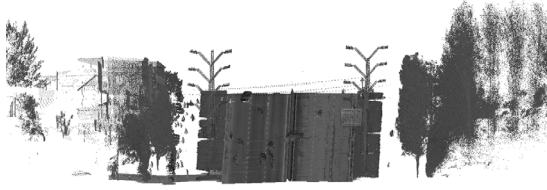
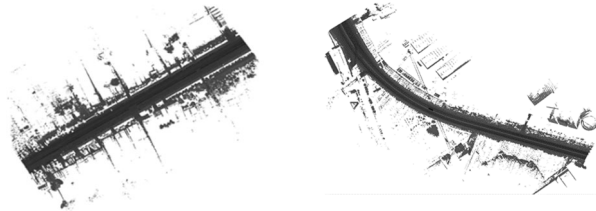


Figure 3. Point cloud of urban road scene

3. Experiment and Analysis

3.1. Experimental data

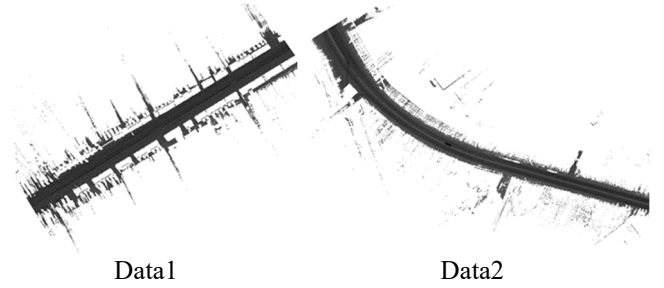
The experimental data uses the SSW mobile measurement system developed by Beijing GEO-VISION Technology Company Limited as the data acquisition platform to collect data on the urban roads of Xinzheng City, Henan Province, and verify the urban road extraction method proposed in this paper. Aiming at the complex conditions of urban pavement scenes, two typical point cloud data were selected for the experiment. Data 1 is an urban straight road with a length of about 300 meters and a total of 1,893,456 points. The road width is uniform and the slope is large. Data 2 is a curved road in the urban area, which contains 2,504,565 points in total, with a length of about 350 meters. There are local inconsistencies in the width of the road surface, and the road surface slope is not large.



Data1 Data2
Figure 4. Raw vehicle points cloud data

3.2. Experimental results

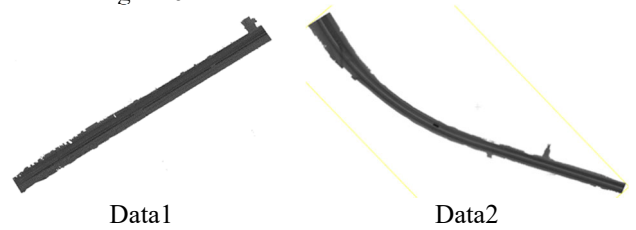
First, the non-ground points are removed by the filtering algorithm, and the filtering operation is performed by the cloth simulation filtering algorithm in the point cloud processing software Cloud Compare. The grid resolution is set to 1.2m, and the extracted terrain roughness can meet the requirements. The number of iterations is set to 500, and the distance threshold is set to 0.5m. Considering that road segment 1 has a relatively large slope, while road segment 2 is relatively flat, the hardness of road segment 1 is set to 2, the hardness of road segment 2 is set to 1, and the remaining parameters are kept the same. The filtered results of the two sections are shown in Figure 5. This process removes the street lights, poles, sidewalk trees and other features above the ground, and mainly retains the road and the sidewalk areas on both sides. Due to the occlusion of the vehicle in the process of collecting data, there are holes on the road surface after filtering.



Data1 Data2
Figure 5. CSF filtering results

ed outside the road surface range. Considering that the difference between

The method proposed in this paper is implemented using C++ programming in the VS2019 environment, and the filtered point cloud is processed to extract road point cloud clusters. Among them, when the normal vector is clustered, the point cloud neighborhood search method is KNN, the number of search points is set to 30, the curvature threshold of the two sets of data is set to 0.05, the normal vector angle threshold of data 1 is set to 8°, and data 2 is set to 5°. Finally, the road surface extraction results of the two sets of data are shown in Figure 6.



Data1 Data2
Figure 6. Road surface extraction results

3.3. Experimental data

Accuracy p , completeness r , and detection quality q are widely used quantitative metrics for evaluating road extraction accuracy.[16] In order to quantitatively evaluate the accuracy of the method proposed in this paper, the artificially extracted road pavement points are used as reference data, and the above three evaluation indicators are calculated in combination with the non-road points extracted from the test. The evaluation formulas of the three indicators are as follows:

$$p = TP / (TP + FP) \quad (5)$$

$$r = TP / (TP + FN) \quad (6)$$

$$q = TP / (TP + FP + FN) \quad (7)$$

In the above formula, TP is the number of road points correctly extracted in the test; FP is the number of non-pavement points extracted; FN is the number of road points not extracted.

The statistical analysis results of the pavement points extracted from the experiment are shown in Table 1. The accuracy p , completeness r and detection quality q of the two groups of data are all above 92%. A small amount of missing at the edge of the road is caused by the occlusion of road vehicles, ground objects, etc. The experimental results show that the method proposed in this paper can effectively extract the urban road pavement, and the factors such as road shape

and width have little influence on the extraction results.

Table 1. Precision statistics of extraction results

Data Source	q/%	r/%	p/%
Data1	96.15	93.76	96.49
Data2	93.89	95.27	97.34

4. Conclusion

Aiming at the normal vector distribution characteristics of urban road pavement point cloud, this paper proposes a clustering method based on point cloud normal vector characteristics to extract road pavement. In order to test the reliability of the method proposed in this paper, two representative urban road sections are used for experimental verification, and finally the extraction results are quantitatively analyzed. The experimental results show that the method proposed in this paper has good applicability for urban road point cloud extraction. However, there are still a few missing point clouds at the edge of the road. Further road reconstruction and road edge line detection are the main work in the next step for the extraction results.

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