Ribbon Road Surface Filtering in Vehicle-Borne Laser Scanning Point Cloud Data

Min Chen¹,a, Rufei Liu¹,²,b* and Shaopeng Ding²,c

¹ Research Institute of Highway Ministry of Transport, Beijing, 100088, China
² College of Geodesy and Geomatics, Shandong University of Science and Technology, Qingdao, Shandong, 266590, China
aemail: 723422052@qq.com, cemail: dingsp18@163.com
b* Corresponding author’s e-mail: liurufei@sdust.edu.cn

Abstract: Terrain data of road is the most commonly used basic data by the traffic department. The high-precision three-dimensional road data can restore the terrain features under the real scene, which has a wider application range. In order to obtain high-precision three-dimensional point cloud road data, taking the vehicle-borne laser scanning data as the research object, a method of ground filtering for ribbon road is proposed. First, the driving trajectory information of the road data collected by the vehicle is read. Then, according to the road characteristics, characteristics of the vehicle driving trajectory is used to control processing direction, and a grid index of the point cloud data is created. Second, feature descriptors based on the spatial distribution characteristics of road point cloud data are established, and rough road point cloud data is obtained. Finally, the profile data of the vehicle-borne laser point cloud in the vertical trajectory driving direction is extracted, and the accurate ribbon road and the micro-terrain data on both sides are obtained by the horizontal constraint line detection algorithm. The experiment and analysis are carried out by using two different ribbon road data. Experimental results show that the method can be applied to different road scenes.

1. Introduction
The three-dimensional road information with high-precision, good reality, and rich details plays an important role in road maintenance, traffic management, and urban planning.[1] Vehicle-borne mobile measurement system adopts a non-contact active measurement method to directly obtain high-precision three-dimensional data, which has the characteristics of fast, real-time, dynamic, active, and high-density.[2] Under the condition of the system without affecting the traffic, the system can quickly access road and road sides of the point cloud data. Through the collected point cloud data, high-precision road terrain can be obtained, and the road digital elevation model can be generated, which can provide basic data for road reconstruction and extension, pavement settlement, and damage analysis. However, how to quickly and accurately extract the micro terrain data of road surface and both sides from the point cloud of different road scene is still difficult to provide the basic data for the traffic department.

The existing vehicle-borne point cloud research mainly focuses on the classification and extraction of independent ground objects[3-6]. The research on point cloud ground filtering algorithm is mainly aimed at extracting all-terrain elements from airborne point cloud data. Due to the differences in scanning distance, target, density, and accuracy of the vehicle-borne mobile measurement system, the method of road surface point cloud data extraction from vehicle-borne point cloud data often needs to
be improved. Lu et al.[7] improved the ground filtering algorithm based on mathematical morphology, optimized the filtering window through the ring structure element, controlled the open operation with the adaptive slope threshold, finally obtained the road surface point cloud. Zeng et al.[8] improved the filtering method based on irregular triangular networks by selecting seed points and adaptive changes of grid size and size, making it suitable for the extraction of vehicle-borne point cloud road. Lu et al.[9] used terrain slope to rotate point cloud data, and then used mathematical morphology algorithm for filtering to solve the problem that mathematical morphology algorithm could not apply to complex terrain. Besides, some scholars also proposed a road filtering algorithm for vehicle-borne laser point cloud data. Fang et al.[10] extracted the road point cloud data by using the difference in time information and scanning Angle of vehicle-borne laser point cloud data; Liu et al.[11] used approximate plane constraints and ordered least-square slope estimation method to extract expressway point cloud data by using a multi-scale filtering window. Yuan et al. [12] first arranged the discrete point clouds into scan lines by using the fuzzy clustering method and extracted approximate horizontal straight lines from each scan line as the road surface point clouds. Yan et al.[13] used normal vector for fuzzy clustering to extract ground point cloud data. Fang et al. [14] proposed an object-oriented vehicle-borne point cloud filtering method, this method takes segmentation surface as the processing unit, but it is difficult to grasp the parameters of segmentation surface. Tian et al.[15] proposed a method of vehicle-borne laser point cloud filtering based on grid stratification, in which only elevation information was used for judgment. The problem of ground information extraction on both sides of the road is not fully considered in the above vehicle-borne point cloud filtering algorithm research. The ground information on both sides of the road is an important data source for road reconstruction, expansion, and traffic planning. Both sides of urban road contain terrain information such as curb and sidewalks, as well as ground objects such as trees and flower beds, the terrain information such as curb and sidewalks, is higher than the road surface; the two sides of the urban expressway mainly include ditches or mountainous terrain with different ground heights. Due to the difference of ground information, curb constraint extraction and other methods cannot be applied to the features on both sides of the road[16]. In this paper, trajectory constraint of vehicle-borne scanning system is adopted to create a grid index that corresponds to the road space distribution, combined with the methods of grid freeway feature recognition and profile curve detection, the freeway and road information on both sides are extracted.

2. Ribbon road surface filtering algorithm
The ribbon road filtering algorithm establishes grid according to road features and then extracts road point cloud data accurately through profile straight line detection. Firstly, the point cloud data of the ribbon road is divided into blocks according to the time index, and the grid index is established by collecting the vehicle's trajectory and the spatial distribution characteristics of the ribbon road; then, the point density and grid height difference in the grid are calculated one by one, and the road point cloud feature descriptor is established for initial filtering; finally, the line detection method of the highway section constrained by the transverse direction is used to extract road surface point cloud data. The specific method is shown in figure 1:

Figure 1. Flow chart of banded freeway filtering method.
2.1. Data segmentation and gridding

The ribbon road data with large data volume has the characteristics of long and narrow spatial distribution. In order to facilitate the organization and rapid processing of ribbon road data, the road data is divided into segments based on the scan time recorded in the vehicle-borne scan data. The segmentation time interval is determined by specific data. As shown in Figure 2, the data is segmented at 10s intervals, and render the segmented point cloud data according to time.

![Figure 2. Data segment of ribbon road](image)

(a) Raw point cloud data, (b) Segmented point cloud data.

To obtain the driving trajectory data corresponding to the point cloud data, and then create a grid index with driving trajectory constraints. Vehicle-borne laser scanning data acquires road and roadside data. The vehicle-borne laser scanning system obtains data on the road and both sides of the road, in order to preserve the spatial morphological characteristics of the point cloud data, we establish a grid index that takes into account the spatial distribution characteristics of the ribbon roads, and the grid neighborhood relationship is as consistent as possible with the actual spatial morphology of the ground features. As shown in figure 3(a), the middle dotted line is the vehicle running track line, we compute the angle $\alpha$ between the driving trajectory line and the coordinate Y-axis. As shown in figure 3(b), according to the angle $\alpha$, make the boundary of ribbon road parallel to the Y-axis, and create a grid index that conforms to the road spatial distribution. As shown in figure 3(c), each row of grid data of banded freeway is used as the filtering window, which is arranged perpendicular to the driving direction.

![Figure 3. Ribbon road gridding and filter window extraction](image)

(a) Before the conversion of ribbon road, (b) After the conversion of the ribbon road, (c) Filtering window.

In a single filtering window, spatial distribution of point cloud number has the characteristics of continuity, which is specifically shown as follows: The data near the middle part of the filter window is the road data, and the point cloud data near the two sides is the terrain data on both sides of the road. Therefore, the height difference changes little in the road point cloud data grid with a single filtering window in the middle. In addition to the above characteristics, the road surface is generally flat, and it can be seen from the profile of the filter window that the road surface is a straight line.
2.2. Ribbon road progressive filtering

2.2.1. Feature description and initial filtering

According to the spatial distribution characteristics of the road point cloud data and the grid domain characteristics, we compute the grid network surface point cloud feature descriptor to identify the road point cloud. Two characteristic parameters in the grid are calculated.

The grid height difference $H$ is computed. The maximum value $Z_{\text{max}}$ and minimum value $Z_{\text{min}}$ of the point cloud data elevation in a grid are calculated, and the height difference $H$ of the point cloud in the grid is obtained. According to the characteristics of road point cloud, the height difference of road surface grid is small, and if there are ground objects on both sides of the road, the grid height difference is large. The point cloud density $D$ in the grid is computed. The number of point clouds in the grid is calculated. If the grid index area is the same, the number of point clouds in the grid is the point cloud density per unit area. The density of point cloud in the center of road is small. There are trees and other ground objects on both sides of the road, so the point cloud density is large.

The height difference $H$ and point cloud density $D$ in a filter window is computed. To count the filter window in order from left to right, and the statistical results are shown in figure 4 and figure 5. We can see from the figure 4 that a row of data has the characteristic of continuity. The first five grids are on the left side of road, the grid height difference increases from small to large. The point density of No.1 and No.2 grids is also lower than the average value, which indicates that there are less ground features and flat data in this area. The grid height difference $H$ and point cloud density $D$ of No.6 and No.7 grid are small, it indicates that is a flat road surface. The height difference and point density of grid No.8 increase, which indicates that the grid is located at the road boundary and contains a large number of feature points. The last three grids are located on the right side of the road, the point density decreases and the grid height difference becomes larger, it indicating that there are high sparse surface points.

![Figure 4. Height difference distribution of filter window grid.](image1)

![Figure 5. Point cloud density of filtering window grid.](image2)
The feature descriptor is used for initial filtering. First, grid height difference $H_i$, point cloud density $D_i$, and the average values of two description parameters $H_{jmean}$ and $D_{jmeasn}$ in the filtering window are calculated. When the grid description parameters meet equation (1), as shown in figure 6 (a), it is considered that there are tall objects data in the grid. The maximum of the minimum elevation value in the three adjacent grids is selected as the threshold value.

$$H_i > H_{jmean} \& D_i > D_{jmeasn}$$  \hspace{1cm} (1)

If the grid description parameters meet equation (2), as shown in figure 6 (b), it is considered that there are discrete high feature points on the ground in the grid, and the grid is stratified by elevation. If the number of point clouds in the bottom grid is greater than 90%, the bottom layer will be retained Grid data. Otherwise, the number of point clouds is obtained upward from the bottom grid. If the point cloud number of grid layer is zero, the point cloud data is kept below the grid layer.

$$H_i > H_{jmean} \& D_i < D_{jmeasn}$$  \hspace{1cm} (2)

If the grid description parameters meet equation (3), as shown in figure 6 (c), the point cloud data in the grid is clustered. Then, the nearest grid that does not meet equation (3) is found, and if the height difference between the lowest points of the two grids is less than 0.5m, the point cloud data in the grid is regarded as the surface points.

$$H_i < H_{jmean} \& D_i > D_{jmeasn}$$  \hspace{1cm} (3)

If the grid description parameters meet equation (4), it is considered that the point cloud data in the grid is ground point cloud data or ground point data with a small amount of near-surface features, as shown in figure 6 (d). The mean grid height difference $H_{jmean}$ of all point cloud data satisfying equation(4) in the filtering window is calculated, and the point cloud data less than $H_{jmean}$ in each grid is retained.

$$H_i < H_{jmean} \& D_i < D_{jmeasn}$$  \hspace{1cm} (4)

Perform the above initial filtering process on all filtering windows to obtain initial road surface point cloud data. The initial filtering method set a dynamic threshold by different road features, instead of setting a fixed threshold to filter all data[17].

2.2.2. Straight line extraction of section road
The road point cloud data is transformed into a profile[18], and a road profile feature image is generated. The road surface is detected by the line detection algorithm with lateral constraint[19-20], and the point cloud of the ribbon road surface is extracted accurately.

First, a two-dimensional grid of the profile image is established in the XOZ plane of the filtering window. The grid edge length $PG$ is the point cloud thickness, which can be set as 0.05m according to experience. The road profile feature image is generated by marking the data with point cloud. The road at the bottom of the feature image of road profile is a horizontal straight line, and the remaining features such as tree trunks and street lamp poles are all vertical straight lines. Therefore, the horizontal long straight line at the bottom of the data in the image is extracted to obtain road data.
Based on the continuity of the point cloud road surface data, we perform horizontal straight line detection by computing the horizontal line direction. If the grid has a longer continuity in a certain direction, we consider it a straight line. Take the grid with point cloud data in the first column on the left as a straight grid, and detect the presence of point cloud data in the upper, middle, and lower three grids in the second column to the right. If there is point cloud data, record the continuous grid direction, and mark the grid with point cloud data as a straight grid; based on the straight grid in the following column of grids, continue straight line detection until there is no suitable grid.

The grid with the same continuous direction is extracted. The point cloud data in the grid is used to fit the line, and the length of the line segment is calculated. The line with the lowest elevation and the longest length is retained as the road line. The distance $D_i$ between the point cloud data and the line is calculated, and the road point cloud data is obtained by setting the distance threshold $D$.

### 3. Experimental results and analysis

In order to test the effect of the algorithm, two pieces of data of typical urban roads and freeways with undulating slope characteristics are selected for experiments. Figure 9 shows urban road data, which mainly contains data such as vegetation, cars, guardrails, and street lights. The slope of the road is 4%. The point number of point clouds is 12688777, and the average distance between the points is 0.05m. Figure 10 shows freeway data which mainly contains data such as vegetation, and cars. The slope of the road is 2%. The terrain on both sides of the road has slight undulating slopes, and the slope is about 40%. The point number of point clouds is 837703, and the average distance between the points is 0.08m.

The appropriate parameters are set according to different experimental data. The specific filtering parameters are shown in table 1.
Table 1. Filter parameter.

| Parameter | Mean          | Threshold setting |
|-----------|---------------|-------------------|
| t         | Split time    | Urban road data   |
|           |               | Freeway data      |
| W_{size}  | Point cloud grid side length | 1m | 2m |
| PG        | Image grid side length | 0.05m | 0.1m |
| D         | distance threshold | 0.2m | 0.2m |

Figure 11 shows the filtering results of urban road point cloud, and the flat road in the figure remains intact without data missing. In order to take into account the micro terrain characteristics of the road, the distance parameter $D$ is set to be larger than the point cloud thickness in the process of linear fitting filtering. In area 1, the noise of about 3cm in the tire part of the vehicle is not completely filtered out, and the curb and above parts of the roadside in area 2 are kept intact.

![Figure 11. Filtering result of urban road point cloud data.](image)

Figure 12 shows the filtering results of the freeway point cloud. The center of the freeway is the isolation zone, which has been basically removed by the initial filtering. The road is flat as a whole, and the feature points can be completely removed by horizontal straight line fitting. Area 1 is the joint of road and small slope, the flat part is kept relatively intact, and a small part of shelter plate in sloped area is not filtered out. Area 2 is the protruding part of the slope, because only the straight line fitting is carried out, the part with more protuberances can not be retained completely, resulting in a small range of cavities.

![Figure 12. Filtering result of freeway point cloud data.](image)

The point cloud data is evaluated quantitatively and compared with the improved morphological algorithm. According to the evaluation standard of filtering point cloud data proposed by International Society of Photogrammetry and Remote Sensing, the error of point cloud is divided into three categories: one is the error of classifying ground points into surface feature points, the second is the error of classifying ground feature points into ground points, and the third is the total error. The first type error and the second type error are used to verify the effectiveness of the algorithm, and the total error is used to verify the applicability of the algorithm. The calculation results are shown in table 2. Through the
comparison of table data, it is found that the two algorithms can achieve high accuracy error results, and the total error is low. In order to ensure the effect of micro terrain extraction, the improved morphological method sets a larger threshold parameter, which results in the larger error of the second type. In the highway data, the method extracts more complete terrain data, but there is over filtering in the slope on both sides of the terrain, and the overall error is less than 10%, which indicates that the algorithm has certain applicability to the data; however, the improved morphological algorithm cannot retain the slope feature data, resulting in a large type of errors and overall errors.

| Table 2. Error comparison of filtering results. |
|-----------------------------------------------|
| Urban road (%) | Freeway road (%) |
|----------------|------------------|
|                | method in this paper | improved morphology method | method in this paper | improved morphology method |
| first type error | 8.4 | 6.7 | 9.3 | 13.6 |
| second type error | 0.8 | 5.1 | 9.4 | 0.2 |
| overall error | 3.4 | 2.7 | 9.3 | 12.3 |

4. Conclusion
In this paper, grid index that conforms to the characteristics of the ribbon road is established by using trajectory data. Then, feature descriptors are established by using grid parameters and initial filter point cloud data is obtained according to different characteristics. Instead of just setting a fixed threshold parameter for simple elevation filtering, this method takes into account the point cloud data of microtopography on both sides of a flat road, increasing the applicability to terrain. Then, through the straight line detection algorithm and the direction constraint in the detection process, the road point cloud data is accurately extracted, and a higher precision ground filtering result is obtained. In the next step, the algorithm still needs to further optimize the feature descriptor and threshold settings to improve the filtering accuracy of the algorithm.

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