Ground point filtering method of vehicle-borne laser point cloud in urban street

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Abstract

Through the analysis of the spatial characteristics of vehicle-borne laser point cloud data in urban street, a method to extract ground points accurately from point cloud data is proposed. Firstly, three-dimensional virtual grid is used to organize point cloud. Secondly, the initial low ground point in a grid is extracted by level plane constraint (LPC) method, and then a multi-scale neighbourhood analysis (MSNA) method is taken to optimize the low ground points further. Finally, the ground points from original point cloud data are filtered based on the local slope. The experiment shows that this method can effectively extract the ground points.

Keywords: Vehicle-borne Laser, Urban Street, Ground Point Filtering, MSNA

1 Introduction

With the development of city digitalization and informatization, obtaining the city three-dimensional spatial information by efficient and accurate ways has become a critical issue for the construction of city digitalization and informatization. As an advantaged method of measurement, vehicle-borne laser scanning is fast, non-contact, real-time, dynamic, proactive, high-density and high-precision etc. [1]. A vehicle-borne laser scanning system can collect a large area of high-precision and high-density surface information of objects in urban street, such as buildings, ground and vegetation etc. And high-precision ground elevation data can be extracted from the ground point cloud which provide basis data for further analysis of ground surface subsidence and damage. So that, the fast extraction of the ground point from vehicle-borne laser point cloud data has a vital significance.

In existent researching files, [2] showed that all the data points were projected in the grid, then the grid data were classified by the maximum height of each grid before and after projection, and some characteristic objects such as the ground and buildings were extracted etc. [3] proposed a vehicle-borne laser point cloud filtering method based on scanning line. In this method, the scanning lines were divided into different segments according to the slope difference, and then the different segments were classified by corresponding attribute. [4] put forward a method for point cloud classification based on characteristic of objects. The objects were classified on the basis of geometric features extraction of point cloud data in multiple streets and the summary of characteristic objects knowledge. [5] proposed a filtering algorithm based on change of slope, the key of which was to select the appropriate slope threshold. He thought that slope thresholds should be chosen by prior knowledge of experimental area. The difficulty of the algorithm was increased because of the need for all the ground form samples. [6] introduced a region growing method into airborne point cloud filtering algorithm and obtained ideal classification by some certain conditions. [7] proposed a cluster analysis method based on point cloud spatial feature vector which classified sidewalk, pavement and curbstone by calculating the normal direction and characteristic value.

The current researches on vehicle-borne point cloud data are mostly for independent object extraction. When extracting the ground point, it is judged only on basis of simple elevation threshold without comprehensive consideration of terrain features in urban street. While there are a large amount of researches on the ground point filtering in airborne-borne point cloud data processing, the vehicle-borne point cloud data filtering cannot follow the airborne because of the different scanning range, targets, densities and precision. In this paper, through the study of features of urban street point cloud data, the author design a method for vehicle-borne laser point cloud data processing, which applies the ideas of three-dimensional virtual grid, MSNA and local slope filtering to extract ground points from original point cloud data.

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2 Description of algorithm principle

2.1 THREE-DIMENSIONAL VIRTUAL GRID

The concept of three-dimensional virtual grid is introduced into point cloud data processing, which overcomes the low efficiency and information loss by other data organization operation [8]. Virtual grid diagram is shown in Figure 1, the dot represents the point cloud and rectangle block represents a virtual grid. While establishing a virtual grid, we need to set the appropriate scale of grid depending on the maximum slope and scanning point destiny, rather than according to the airborne scale. There are two ideal conditions:

1) The ground points are approximate horizontal within a single grid;
2) A single grid should have a certain amount of points.

The relationship formula between the step of urban street grid and the slope is as follows:

$$slope = \frac{\Delta h}{\sqrt{(\Delta x)^2 + (\Delta y)^2}}. \quad (1)$$

In the formula, Δh is the ground elevation difference in grid(In the LPC model, the elevation difference between any two points should be less than the threshold value), Δx and Δy are respectively the step length of the direction of x and y. Assume that the maximum terrain slope is 5%, and the maximum elevation difference (Δh) is 0.1m when the grid is appropriate horizontal, then you can calculate the diagonal distance of a single grid is $\sqrt{2}$ m according to the formula, and determine the grid is 1m*1m. Therefore, the usual step length of urban street grid is always 0.5m—2m.

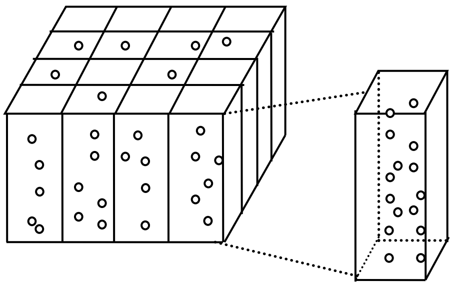


FIGURE 1 Three-dimensional virtual grid

2.2 NOISE POINTS REMOVAL BASED ON GRID STATISTICS

Due to the presence of random errors, in the processing of data acquired, noise points inevitably exist in original point cloud data, which need to be eliminated before filtering processing [9, 10]. The noise points' elevation is far higher or lower than the normal ones in a three-dimensional grid, which makes noise points distribute discretely in space with others, as the red dot shown in Figure 2. Therefore, the number of points with different elevation interval layers in the grid could be analysed statistically, and the point is considered to be noise point when the number of points in the layer is less than a certain threshold value.

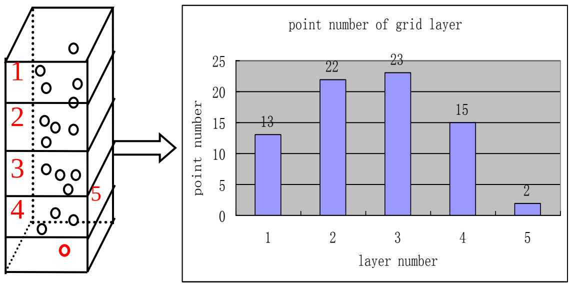


FIGURE 2 Principle diagram of grid statistical denoising

2.3 INITIAL GROUND POINT EXTRACTION OF ONE GRID

In the three-dimensional virtual grid, the lowest point is defined as the initial ground in each grid usually [11-12]. In this paper, the initial ground point is got by the method of LPC method, so as to improve the robustness of the lowest point in the grid. The principle is: The surface of the local area of urban street is usually approximate level. If a single grid contains ground point, there should be an approximate level surface plane, which requires at least three non-collinear points on ground. Three factors, which are point elevation, triangular plane shape and area need to be considered when selecting three points. All the points in the grid should be removed when there does not exist three points that meet the conditions. By this way, the probability of the low point as the ground point in a grid can be raised. As it is shown in Figure 3, the red dot is the lowest point of grid. If it is a ground point, the two blue ground points must exist and they can form an approximate level triangular plane.

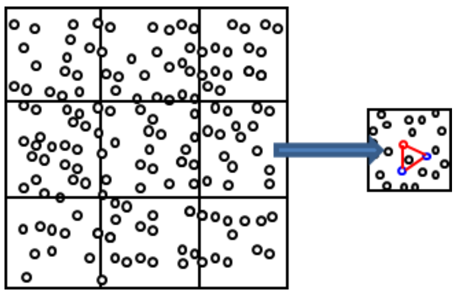


FIGURE 3 Low ground points by LPC model

2.4 MULTI-SCALE NEIGHBORHOOD ANALYSIS

The initial ground point with much more probability can be obtained by LPC. Due to the diversification of urban surface features, grid low point will be misinterpreted as ground point when the approximately parallel surface to the ground plane is scanned, such as the low and neat vegetation surface. To solve this problem, this paper designs MSNA method to do the multiple filtering for target grid, further determining whether the low points within the grid are the ground points.

The main idea of the algorithm is: As it is shown in Figure 4a, firstly, comparing the lowest point of the unknown grid A with the lowest points in the 8-neighborhood grids as shown in Figure 5, calculating the slope by formula (1) in which Δh is elevation difference between two points, and Δx and Δy are the difference of x and y; and then comparing the slope with the initial threshold. If the slope value between grid A and other grids are all less than the initial threshold value, the lowest point in grid A is considered to be a ground point, Otherwise, all points within grid A are non-ground points which should be removed, and that grid will not be calculated in the next step filtering. However, the grid A is difficult to be removed by the above method if the low points in A and other 8-neighborhood grids are all non-ground points and with similar elevation. So the important precondition of the 8-neighborhood analysis method is that at least one grid should contain ground points. From above analysis, we propose MSNA method. Firstly, using the same neighbourhood window to iterate the last results, and then expanding the neighbourhood analysis window size and repeating iterative processing until the window area is greater than the area of the largest non-ground approximate level plane. The algorithm is iterative processing until the difference between the numbers of reserved grid is zero. As it is shown in Figure 4b, the neighbourhood window is expanded from blue line to red line.

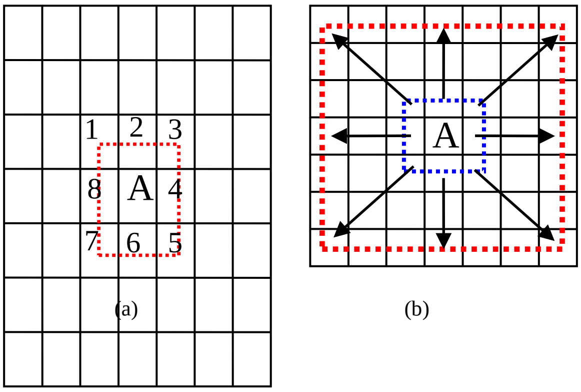


FIGURE 4 Principle of MSNA

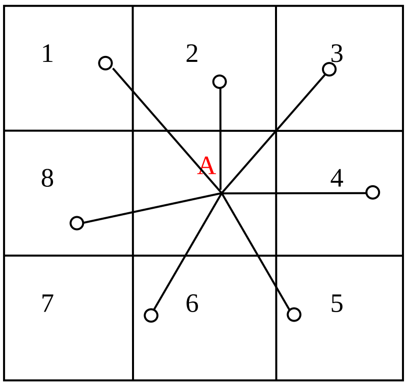


FIGURE 5 Principle of neighbourhood slope calculation

2.4 EXTRACTING GROUND POINTS BASED ON LOCAL SLOPE FILTERING

In order to improve the filtering accuracy of ground points cloud, range is limited within 8 neighbourhood window so that we can set lesser threshold during slope filtering. The method is described as follows. Firstly, the slope between unknown-point in grid A with low points in eight neighbourhoods is calculated. Due to the spatial relationship, the neighbourhood grid number of continuous topography cannot be less than two. If the grid number is less than two, the window size should be increased until it is less than 10m. If the number is also less two, the grid A should be judged as an isolated grid, which should be removed. Then taking the maximum slope value to compare with the slope threshold, those within the threshold value range are the surface points.

3 Experiment and analysis

In this paper, the above algorithm was implemented by using C++ programming language. In order to test the validity of the algorithm proposed in this paper, some typical area was selected for filtering experiment. The feature types include roads, building elevation, vegetation, cars and an uncompleted building frame in the test area. The parameters of original data are shown in Table 1.

Figure 6 shows a comparison before and after noise removal, in the red circle the noise points were successfully removed. Figure 7 shows the situation of inquiring the low point before and after MSNA, As can be seen from the figure that a large number of non-ground points are successfully removed after MSNA. Figure 8 shows the results of the ground point filtering; we can see that the point such as vegetation, traffic facilities and so on, are filtered exactly.

TABLE 1 Experimental data parameters

Experimental Region	Point number	Area (m*m)	Average point distance(m)		Surface slope (%)
			Travel direction	Scanner direction	
Region 1	**2892491**	**184*120**	**>0.11**	**>0.027**	<4
Region 2	5017200	224*150	>0.06	>0.033	<5

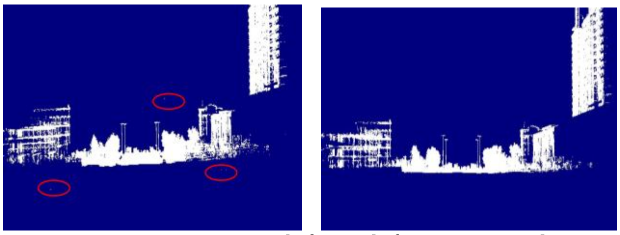


FIGURE 6 Comparison before and after noise removal

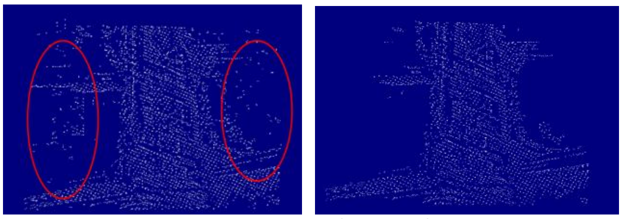
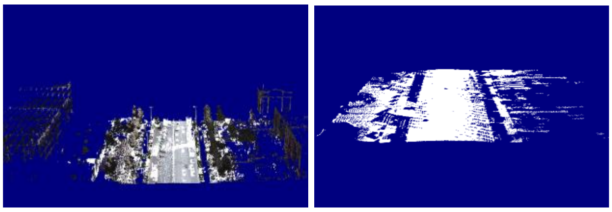
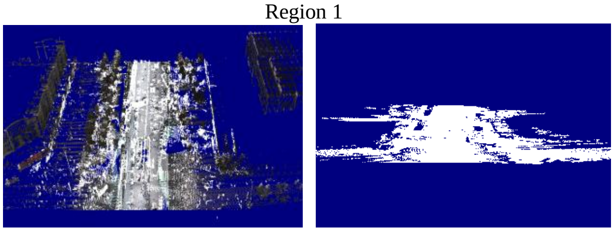


FIGURE 7 Comparison before and after MSNA



Region 1



Region 2

FIGURE 8 Ground filtering results of different region

The statistical results of algorithm processing are in Table 2. Grid horizontal step length and vertical direction are respectively 1m*1m*2m when removing noise points. According to the scanning point density and feature of space rod-shaped object, it is determined to be noise grid when the point's number in grid is less than 10 points, which need to be removed. In the experiment, 39582 noise points are removed in region 1 and 8685 noise points are removed in region 2. It can be known that the LPC and MSNA can effectively increase the probability of the initial low ground points and at the same time it can greatly reduce the grid number required for processing. 5690 non-ground grids of region 1 are removed by two step operation and 5882 non-ground grids of region 2 are removed.

4 Conclusions

A vehicle-borne laser scanning system can quickly acquire urban street ground point data with high accuracy. By analysing urban street spatial features of point cloud data, the filtering algorithm is proposed in several aspects, which include establishing three-dimensional virtual grid, removing point outliers and determining initial ground low points. Experimental results show that the filtering method of urban street ground points proposed by this paper is strong adaptability and high stability. In addition, the threshold parameter of algorithm requires some human experience and the adaptive threshold needs to be further researched.

TABLE 2 Statistics of data processing results

Experimental region	Noise removal (point number)		LPC (grid number)		MSNA (grid number)		Ground Point (point number)	Time (s)
	Before process	After process	Before process	After process	Iterative number	After process		
Region 1	**2892491**	**2852909**	**7138**	**1620**	**3**	**1448**	**987174**	45
Region 2	5017200	5015489	8090	2499	4	2208	1520717	82

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