Distance-Limited Filter for Extracting Ground Points

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Abstract  The extraction of points on the bare earth from point clouds acquired by airborne laser scanning is one of the most important steps for the generation of digital terrain models (DTM). This process is called “filtering”. However, most of the current filters erode the bare earth in steep sloped landscapes and at discontinuities, and they retain low vegetation. Therefore, a new filtering method for extracting ground points based on a distance limit is proposed in this paper. The angle criterion is used to assure the robustness of the algorithm. The experimental results show that the proposed filtering method can effectively derive the ground points from point clouds in complex urban areas.

Keywords  distance-limited; point cloud; filtering; LIDAR

Introduction

Airborne laser scanning, or LIDAR, has become a widely used technique in the fields of topographic mapping, urban modeling, corridor mapping, engineering works, coastal engineering and military operation[1]. However, the original data acquired by LIDAR not only consists of points located on bare earth, but also contains object points on houses, trees, or other objects. For DTM generation, it is necessary to remove these object points. This process is called “filtering”[2], which has been a very important issue in LIDAR research[3].

Most filters work by searching for the lowest points in a neighborhood as bare earth, by robustly fitting surfaces and searching for points closest to the fitted surfaces as bare earth, or by clustering points and treating small clusters as objects. Some major problems identified in the former two methods are [4] as follows.

- Eroding of the bare earth in steep sloped landscapes and at discontinuities of the bare earth surface
- The low vegetation is retained.

The third method is able to better separate points on a (ground) surface from other points and yields better results[5].

In this paper, a new distance-limited filter is presented to cluster ground points into one group. The experimental results show that this method can effectively remove object points (low vegetation, etc.) and retain ground points even in steep landscapes and at discontinuities.
1 Distance-limited filter

1.1 Characteristics of landscapes

According to the characteristics of landscapes, the whole earth can be divided into two categories. The bare earth, which is a continuous and smooth surface, is composed of the topsoil or thin pavements, while the aboveground features include vegetation, artificial objects, etc. The two height differences cause discontinuities.

Assuming that the spacing between LIDAR points is \( r \), in evenly distributed case, the distance between one point with its 4-neighbor points is \( r \) on flat ground surface or the top of buildings; while the distance between any two points located on ground surface and buildings separately is larger than \( r \). In other words, distance can be used to separate objects from bare earth.

1.2 Processing of filtering method

As is known, the distance \( D(S_1, S_2) \) between two neighboring points \((S_1(x_1, y_1, z_1) \text{ and } S_2(x_2, y_2, z_2))\) in 3D can be simply expressed as:

\[
D(S_1, S_2) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}
\]  

(1)

If \( S_1 \) and \( S_2 \) are both located on bare earth or objects, the distance \( D(S_1, S_2) \) should be relatively small, so bare earth points are clustered into one whole single group, while objects into several different small groups. Here, we can extract ground points as Eq.2:

\[
\text{Count}(P) = \begin{cases} 
\text{the biggest, bare earth} & \text{if } P \\
\text{else, objects} & \text{if } P
\end{cases}
\]  

(2)

1.3 Workflow

Distance-limited filtering method applies the following steps:

1. Pre-processing is executed and profile points are eliminated as it may induce confusion and instability if not wiped off;
2. Based on the distance-limited filter, a point cloud is clustered into bare earth and objects;
3. Count the number of points of each group;
4. The group with the biggest number is bare earth and extracted;
5. Post-processing and application.

2 Experiments and results

2.1 Study area

In order to test the filtering algorithm, a data set covering Gamla Stan was used. Gamla Stan is one of the oldest islands in Stockholm, the capital of Sweden. The main features in the area include steep slopes, large buildings, low vegetation, narrow roads between tall buildings, and discontinuities of the bare earth surface. The data contains 809 343 laser points with a point space of about 0.5 m.

2.2 LIDAR data pre-processing

Profile data exists for the influence of visual angle, topographic undulations, flight attitude, etc. Taking angle as a criterion, profile points can be removed. Fig.1 represents the angle \( \theta \) of any two points in the neighborhood within the horizontal distance of \( d \). By Eq.(3), angle \( \theta \) of line \( S_1(x_1, y_1, z_1) \to S_2(x_2, y_2, z_2) \) with horizontal plane is obtained.

\[
\theta = \arctan \frac{|z_2 - z_1|}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}
\]  

(3)

If \( \theta \) is larger than a predefined threshold, then points with higher \( z \)-values are eliminated. Ground points escape from the risk of being removed in such a strategy, because lower points are most likely located on bare earth. In this paper, \( d = 0.8, \delta = 45^\circ \).

2.3 Filtering and extraction of ground points

After the processing in section 2.2, the data can be considered as lacking of profile information. For the distance-limited filter we choose a distance threshold of 1.3 m. The results are illustrated in Fig.2.
Compared with the original point cloud in Fig. 2(a), objects such as buildings, trees, etc. are removed after filtering (Fig. 2(b)). It is shown that narrow roads are retained very well. While low vegetation (rectangular zone in Fig. 2(c) and Fig. 2(d)) and cars (elliptical zone in Fig. 2(c) and Fig. 2(d)) are perfectly eliminated, points at steep sloped landscapes (elliptical zone in Fig. 2(c) and Fig. 2(d)) and at discontinuities (in Fig. 2(e) and Fig. 2(f)) are reserved.

![Fig. 2 Filtering results](image)

### 3 Results analysis

#### 3.1 Qualitative analysis

Fig. 3 depicts the test scene before and after filtering. The DTM generated by filtered ground data is smooth in visual aspect. No unexpected objects are left. Some main roads are represented clearly (denoted with black arrow). Obviously, the distance-limited filtering method performs well. Although objects are removed effectively, ground details are retained. The result fulfills the anticipated purpose.

![Fig. 3 Comparing filtering results using DSM and DTM](image)

#### 3.2 Quantitative analysis

In order to get more insights into the filtering results, statistical analysis of elevation and slope are used (shown in Table 1). Compared with original data, mean and median values of elevation/slope are much smaller after filtering. It demonstrates that the filtered data congregate to low elevation and smooth slope. Standard deviation, which is a measure of how a distribution is spread out, is also smaller. Changes in elevation and slope decrease evidently.

The distribution of elevation or slope before and after filtering is given in Fig. 4. The Y-axis represents

| Class                  | Point number | Elevation/M |         | Slope(°)         |         |
|------------------------|--------------|-------------|---------|------------------|---------|
|                        |              | Mean        | Median  | Standard deviation | Mean   | Median  | Standard deviation |
| Original data          | 809 343      | 13.68       | 10.81   | 10.74            | 52.548  | 8      | 58.348  | 6          | 31.501  | 4 |
| Ground data after filtering | 329 480    | 6.02        | 4.42    | 4.16             | 17.721  | 4      | 16.140  | 4          | 12.485  | 7 |

![Table 1 Elevation and slope comparison before and after filtering](image)
the normalized point number, which is calculated by dividing the point number of a certain elevation/slope with total point number. The X-axis shows the elevation in meter or the slope in degree. In low elevation and smooth slope, statistical lines keep the same shape, while nearly no data in high elevation and steep slope is left after filtering. It can be concluded that ground points are almost retained and objects are eliminated effectively and robustly.

4 Conclusion

The distance-limited filtering method proposed in this paper is essentially a kind of clustering method. From the experiment and analysis, it is demonstrated that the result is better and more reliable after filtering. However, bridges are classified as ground or object according to different situations, which is beyond the scope of this paper. Courtyards surrounded by a block of buildings are not retained in all places. Therefore, further work needs to be done in order to improve this method.

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