DEM GENERATION FROM AIRBORNE LIDAR DATA

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ABSTRACT:

Airborne Lidar (light detection and ranging) sensors provide dense height information of large areas in an efficient manner. But for the production of digital elevation model (DEM) from the point cloud, the filtering of the point cloud should be carried out in order to remove points representing surface of non-ground objects. According to the deficiencies of slope based method, a novel filtering algorithm for Lidar data that combining range information and intensity information is presented in this paper. This method can improve precision and efficiency of filtering, and is very suitable for Lidar data of complex areas. Experiment results show that the proposed method can remove objects in complex areas effectively and rapidly.

1. INTRODUCTION

At present, DEM data becomes one of important geographic data in topographic mapping and thematic mapping, and is used widely in layout and construction of city, design of road and railway, area selection of factory and mining, the navigation, a variety of spatial data application and so on.

DEM is one of important products of digital photogrammetry. But using traditional photogrammetry method, it needs to collect images, make DSM and derive the DEM data finally and the circle of DEM producing is too long. Lidar system, acquiring ground data through airborne laser scanning, is one of new technology appeared in recent years. Airborne Lidar can provide accurate and high sampling 3D geometry data of the earth’s surface. It can provide high density DSM directly. So, extracting DEM data from Lidar data should be an effective approach to acquire DEM fast and with high precision. It is becoming the prime method for large scale acquisition of nation-wide DEM. Several countries are currently using Lidar for creating or updating very detailed regional or nation-wide DEM.

When producing the DEM of complex areas, most current filtering algorithms face the greatest challenges due to the multi-tier buildings, courtyards, plazas, stairways, ramp and discontinuities such as steep slopes and break-lines in the bare earth. Usually, a lot of manual editing is needed to get accurate points on the bare earth. In practice, the time consumed by manual classification (including filtering) and quality control is approximately 60% to 80% of total processing time. Therefore, it is necessary to develop an accurate, efficient, robust and self-adaptive filtering algorithm.

In this paper, a new filter method is presented. The algorithm combines slope based method and region growing. Experiment results show that this approach can improve precision of filtering and reduce computing time.

2. RELATED WORK

For the production of DEM from Lidar data, the many points that are measured on vegetation, buildings and other objects above the ground surface need to be removed from the data set. Many algorithms have been developed for this purpose. These algorithms can be grouped according to different methodologies. Here, the approaches are grouped into morphological filters, densification approaches, surface based filters and segmentation based filters.

The morphological filters take their name from mathematical morphology for grey value images. The grey values refer to the elevation while the structure element describes admissible height difference for a certain horizontal distance. The structure element is placed at each point and off-terrain points can be identified as having larger height differences than admissible. The structure element itself can be obtained from assumptions on terrain or from point clouds with a known classification (training data). Kilian et al. (1996) note that the size of the structure element used for the opening is a critical parameter for which there is no single optimal value. They suggest to use a series of openings with different structure element sizes. For each point, the maximum size at which this point is within some distance of the opened surface is assigned as a weight to this point. Zhang et al. (2003) developed a progressive morphological filter to remove non-ground points by gradually increasing the window size of the filter and using elevation difference thresholds. Vosselman (2000) proposed a slope based filtering algorithm. It is a modification of morphological erosion operator. A point is classified as a ground point if the maximal slope of the vectors connecting the point under test to all its defined neighbors does not exceed the maximal slope with the study area. Sithole (2001) modified the slope based method to use different maximal slope thresholds according to local terrain characteristics. A rough slope map is needed to calculate the local slope threshold.

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The filters of the second group are the progressive filters. Some points are identified as ground points and based on these points, new points will be added to the ground class. In Axelsson (2000), a sparse TIN is derived form neighborhood minima, and then progressively densified to the laser point cloud. In each iteration, a point is added to the TIN, if the point meets certain criteria in relation to the triangle that contains it. The criteria are that the angle a point makes to the triangle must be below a certain threshold and a point must be within a minimum distance of the nearest triangle node. At the end of each iteration, the TIN and the data-derived thresholds are recomputed. The iterative process ends when no more points are below the threshold. Sohn et al. (2002) apply the progressive densification with two different steps. First a "downward step" is taken and points below the current triangulation are added. This is followed by the "upward step", where one or more points above each triangle are added.

Surface based filters start with a surface model approximating all points. This model allows the computation of residuals, i.e. the distances of the points to the surface model itself. The choice of the surface model is the crucial part of these algorithms. Points lying above the surface are unlikely to be ground points and are—depending on the specific filter—down weighted or removed for the next iteration and surface calculation step. Kraus et al. (1998) developed a method known as robust filtering. In that algorithm, the derivation of the terrain as well as the classification of the original points is performed in a hierarchic method. In each hierarchy level, robust interpolation for the classification of the points and the surface derivation is done. A rough approximation of the terrain is first computed using the points of the respective hierarchy level. The vertical distance of the points to this approximate surface is then used in a weight function to assign weights to all points. Points above the surface are given a small weight and those below the surface are given a large weight. The surface is then recomputed using a linear prediction considering the individual weights. The process is iterated until a certain number of iterations have been reached or the computed surface does not change significantly between iterations. Pfeifer et al. (2001) embed this method in a hierarchical setup. This improves performance on large buildings and reduces computation time.

The filters of the fourth group are the segmentation filters. In Nardinocchi et al. (2003), a strategy for the classification of raw Lidar data as terrain, buildings and vegetation is presented. Its main features are a preliminary classification of grid data based on a geometric and topological description and a final filtering of raw data, guided by the previous classification. After raw data have been interpolated to a grid and segmented in connected regions bordered by a step edge, the topology of these regions is built up. Noise, vegetation and data gaps are classified first, mainly based on size and region fragmentation. Then, regions enclosing terrain and building points are labeled analyzing their relationships with adjacent regions. Since regions may enclose more than one instance of different classes, a first check is made on grid data looking for consistency of gradient orientation with class characteristics. Finally, a local analysis is performed on each grid cell to label raw data point, based on the information on the surrounding inferred by the classification. Jacobsen et al. (2003) also use region growing for obtaining the segments. They apply measures like "compactness" and height differences to neighboring segments, in order to classify the segments including a terrain class.

3. THE MECHANICS OF THE FILTER

3.1 The Strategies of algorithm

Slope based filtering algorithm is an algorithm used widely. The basic idea of the algorithm is based on the observation that a large height difference between two nearby points is unlikely to be caused by a steep slope in the terrain. More likely, the higher point is not a ground point. Therefore, it defines the maximum allowed height difference between two points as function $\Delta h_{max}(d)$ of the distance d between these points. When this function is known, the DEM points are defined as a subset of all laser points A by

$$DEM = \{p_i \in A \mid \forall p_j \in A : h_{p_i} - h_{p_j} \leq \Delta h_{max}(d(p_i, p_j))\} \quad (1)$$

However, this algorithm has several deficiencies.

- For points on objects with large and relatively flat areas, e.g. points on large buildings, points in the interior of the roof may be only compared with other points on the roof. In case of flat roofs, these points will not be eliminated.
- How to determine the extent of points used to be compared with. It is well known that Lidar data has a large number of points. Therefore, the efficiency of algorithm must be considered. When using slope based method, if the extent of compared points is too large, it will add lots of calculation unnecessary. And if the extent is too small, some points may not be classified as object points due to the points in the extent including no ground points. It needs to determine the extent self-adaptively, according to the practical situation, to improve efficiency of algorithm.
- Because of the complexity of terrain, using only one slope threshold in the whole dataset is not suitable obviously. The ideal slope should be self-adaptive. That is, different slope threshold should be selected in different areas. But slope of terrain is a function of terrain height, and the destination of filtering is to classify ground points from object points. The exact ground points are unknown, so the accurate slope of terrain can't be determined before filtering.

With the development of technology, now, many airborne Lidar systems can acquire more than 10 points per square meter. In urban areas, the ground region is usually continuous without abrupt changes in topography. Given Lidar data with a certain resolution and accuracy, such a smooth ground can be observed locally as a planar surface. That means a group of neighboring ground Lidar points, for example points within one 3 by 3 window, can form a local planar surface. Such a planar surface can be derived using a regression method, such as the least square method, with a fitting accuracy no worse than the accuracy of the original data points. Moreover, most building roofs are composed of several planar surfaces. So points on roofs of these buildings are on planar surfaces.

According to the deficiencies of slope based method, some modifications are done to the slope based method in this paper. The strategies of proposed algorithm are:

- For one ground point, its neighboring points are used to calculate a regression planar surface; and how well the point under test matches the regression planar surface tells if it is on a planar surface. The neighbor can be defined as a 3 by 3 square window. Points with a small height difference are classified as points on ground. For one object point, the rule of region growing is to use its intensity information, because in local areas, points of one object usually have almost the same intensity. Through this method, do region growing from seed points and most points on smooth ground and building roofs will be determined.

- For other uncertain points, most of them are edge points of objects and other points with low height. Through comparing height of these points with points within some extent, the type of these points can be determined. Here, when selecting extent, just need to contain ground points that have been determined. This makes the selection of extent of compare points self-adaptive, and can improve precision of filtering and reduce processing time. Here, we use the information of ground points to estimate the local slope threshold. It can avoid using only one threshold to the whole area.
- The selection of ground seed points. For ground seed points, we can select them automatically or manually. When selecting ground seed points automatically, we can select the lowest points of some extent. For example, selecting the lowest points per 200 m by 200 m as ground seed points. Selecting ground seed points manually, can avoid the influence of some abruption terrain.

3.2 The implementation of algorithm

To obtain DEM, the proposed algorithm is performed based on the first return echoes, which can reduce low outliers. In addition, for easier processing, the Lidar point data are converted into a regular grid data format using a Delaunay triangulated network process with a grid size corresponding to the spatial of Lidar data. The work flow of the algorithm is explained in the following five steps.

Removing outliers

In Lidar data, there are some outliers, including outliers above the ground surface and that below the ground surface. They are points that normally do not belong to the landscape. Outliers above the ground surfaces will be eliminated by the filtering, while outliers below the ground surface need to be removed first. Here Median filter is used to remove these outliers.

Labeling ground points

For a point, using its neighboring points to calculate a regression planar surface by the least squares. If the distance between this point and its fitting plane is smaller than a threshold, the point can be thought in the same plane with its neighboring points. Selecting some bare ground points as seed points in raster point clouds. Then, according to the rule above, these known bare ground points can be treated as seed points to do region growing to recognize other bare ground points. Points in these regions are labeled as bare ground points. This process can reduce processing time used to test lots of ground points using slope-based method greatly. The selection of ground seed points can be manual or automatic. For selecting ground seed points automatically, it is assumed that the lowest point of within a certain extent is a ground point. For selecting ground seed points manually, you can select some key ground points to improve the precision of filtering, for example, select ground points on both sides of a discontinuity as ground seed points.

Labeling object points

The main purpose of this process is to recognize most points on building roofs. Here, building roofs in urban areas are thought to be composed of several planar surfaces. So these planar surfaces can also be recognized through region growing. For points on building roofs, their height is much larger than their neighboring bare ground points. Therefore, searching in the points which are not labeled as bare ground points, if one of the height difference between a point and its neighboring points is larger than a given threshold(e.g., 1 m), it is labeled as an object point. Then, this known object point can be treated as a seed point to recognize other object points on a same planar surface. During the process of region growing, it can't enter into points which have been labeled as bare ground points, or cancel this region and don't label it. Through this process, most points on building roofs are recognized and it can remove building with large roofs, which is a problem in slope based method.

Determining uncertain points

There are some points neither belong to ground points nor object points. In these points, some are facets of objects, some are low objects and some are bare ground points. Calculate the slope between these points and their neighboring points in a small area including points labeled as bare ground points and compare the difference between them. If one of the slopes calculated is larger than a given threshold, it will be labeled as object points. Otherwise, it will be labeled as ground points. The low objects and facets of objects can be removed especially, because most of them are edge points of objects and has a large slope. For the slope threshold, we use the points labeled as ground points to calculate the slope of every small area (e.g. 200㎜×200m). The maximum slope of each area is considered as the slope of this area. And then use these slopes to interpolate the slope threshold of each area. In this process, it can select extent of points used to be compared with automatically and use local slope thresholds instead of only one slope threshold. Therefore, it can improve precision and efficiency of filtering.

Producing DEM

In order to generate DEM from the known bare ground points, it needs to fill the holes caused by the removal of non-terrain objects. Because there are still some low object points left in the data, an interpolation method which can discover errors is needed. Here, we adopt linear prediction method to interpolate height of these points according to known bare ground points.

4. EXPERIMENTS

We have implemented our proposed algorithm in C++. Lidar point clouds of complex cityscapes are used to test the algorithm. The test data is acquired by ALS50-II made by Leica corporation. The test area is about 1 km×0.85 km in China. The spatial resolution of data is about 0.8 m. The test data sets contain some typical features such as multi-tier and irregular shape buildings, courtyards, trees, and steep slopes. Figure 1 is the image of test area.

First a triangulated network is constructed for the point cloud, based on a Delaunay triangulation of its elevation data. Then a rectangular grid of pixels is extracted from each TIN using linear interpolation with a constant sampling interval of 1 m. Finally, the raster DEM with 1 m spatial resolution is generated.

Figure 2 is the shaded relief image of the result after interpolating.

Figure 1. Image of test area

Figure 2. Shaded relief image before filtering

Figure 3. Shaded relief image after filtering

Then, select ground seed points. Here, the ground seed points are selected automatically. We assume no objects are larger than 100m by 100m. That is to say, the lowest point of an extent of 100m by 100m must be a ground point. Therefore, the test area is divided to regions with areas of 100m by 100m, and the lowest point of every small region is regarded as a ground seed point.

Figure 3 is the shaded relief image after filtering according to the algorithm of this paper. In order to compare conveniently, the two shaded relief images use the same colors, that is to say the same height has the same color.

Experiment results show that the algorithm presented in this paper has a good performance which can filter objects effectively and rapidly. It is capable of recognizing complex non-terrain objects accurately, and at the same time preserving discontinuous features on the bare earth to some extent. This method uses a plane fitting method which uses more context to improve filtering precision and can select points with which used to compare and slope thresholds automatically to improve precision of filtering and reduce computing time. It is suitable for extracting DEM from Lidar data.

5. CONCLUSIONS

In this paper, a novel filtering algorithm that combining slope based method and region growing is presented. By using a large context through a local estimate of a planar surface, the algorithm improves the precision and reliability of result. In addition, searching out most ground points and object points firstly can avoid using slope based method to judge them. Also, the selection of extent points in which to compare with and the selection of slope thresholds are both self-adaptive. Both of them can reduce processing time and improve efficiency of filtering. The algorithm can preserve discontinuous features in the bare earth and has no impact from the size and shape of buildings. It is fit for processing Lidar data from complex cityscapes due to its high automation and efficiency.

In the algorithm, though interpolating Lidar raw data to a grid can make operation to data relatively simple and improve the calculation speed, it can also cause interpolation error. By modifying data structure and the algorithm, the idea of this paper can also be used to process Lidar raw data.

Because of the complexity of terrain and characteristics of Lidar data, using DSM data from Lidar only to acquire DEM accurately is difficult to be realized. Especially, the low objects are very difficult to be recognized. One way to improve the precision of filtering is to combine Lidar data with additional information, e.g. multi-spectral aerial images and maps. If such additional information is incorporated in filter strategies, it could provide a much better understanding of a scene and thereby improve filter performances.

In the next work, we will investigate methods combining Lidar point clouds and multi-spectral aerial images to obtain more accurate DEM.

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