ADAPTIVE MORPHOLOGICAL FILTERING FOR DEM GENERATION

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ABSTRACT

This paper presents a novel approach to LiDAR filtering of ALS (Airborne Laser Scanning) data. The main effort is devoted to simplify and overcome the shortcomings of the existing morphological filtering algorithms. The proposed approach is based on the morphological erosion operation. The filtering is applied only to the points of discontinuity, which are identified from their residuals. The threshold for identifying the points of discontinuity is adaptively determined during the iteration. Our experiments show the proposed approach produces satisfying results in different terrain conditions with minimal change of parameters.

Index Terms— Morphological filtering, LiDAR, DEM, DSM, filtering.

1. INTRODUCTION

Over the past two decades, LiDAR (**Li**ght **D**etection **A**nd **R**anging) data has become a major data source for measuring topography. Compared with traditional surveying and photogrammetry-based approaches, LiDAR technology can provide high-density and high-accuracy 3D topographic information of the terrain. Measurements from LiDAR system include ground points as well as nonground points (i.e. reflected from nonground objects above the bare earth terrain) such as buildings, trees, cars, bridges, birds and shrubs. Therefore, in nearly all LiDAR applications, ground and nonground points need to be separated first. The separated two groups of points are then used or processed mainly for generating DEM (**D**igital **E**levation **M**odel) and 3D building models, respectively.

DEM, as one of the primary products of LiDAR data, has been used in variety fields of scientific and engineering applications. For example, DEM is one of the important input data sets for simulating flood physics in urban area because it affects flood direction, flow velocity and flood depth [1]. Inaccurate DEM possibly leads to wrong simulation results. For this reason, intensive researches have been conducted and numerous algorithms are proposed. However, due to the variability and complexity of real world, relevant researches are still being studied to improve its performance, accuracy and minimize human interaction.

Most reported filtering algorithms can be grouped based on the similar properties. Sithole and Vosselman [2] categorized existing filtering algorithms into four groups, i.e. slope-based [3, 4], surface-based [5-9], block-minimum and clustering/segmentation methods. Morphological method, within the category of surface-based approach, has been widely used due to its theoretical simplicity and easiness for the implementation. While existing algorithms produce satisfactory results, it is generally required to know a priori knowledge about the study area, such as terrain slope, minimum height of buildings and the size of the largest building. Therefore, it is important to determine appropriate parameters to get the best results for the study area. However, selecting the best parameters is not always straightforward, which may require many trials and updates. It is even difficult when the terrain condition over the study area is not uniform.

In this paper, we propose a novel filtering algorithm to separate ground and nonground LiDAR points. We aim to simplify and overcome the shortcomings of the existing morphological filtering algorithms. Comparing with the existing approaches, the proposed approach is less dependent on parameters such as terrain slope and the size of the largest building, which enables this approach to be applied to different terrain with minimal change of parameters.

The remainder of this paper is organized as follows. Section 2 briefly reviews the existing morphological filtering algorithms in LiDAR filtering. The proposed approach is detailed in section 3, while section 4 discusses how to minimize the initial filtering errors. Section 5 evaluates our approach with two different data sets. Section 6 presents the final conclusion on this approach.

2. MORPHOLOGICAL FILTERING

Mathematical morphology is known as an effective tool for extracting image components useful in representing region shapes, such as boundaries, skeletons, and the convex hull [10]. In the field of image processing, this technique has been employed to remove noise, extract, enlarge or shrink features. Two fundamental operations, i.e. dilation and erosion, are involved, which comprises more complex operations, such as opening, closing, filling, skeletonizing and so on. The opening operation is achieved by applying an erosion of the dataset followed by a dilation, while the closing operation is carried out with the reverse order. In the LiDAR filtering, an erosion operation can remove local peaks smaller than a given window size (Figure 1(a)), while a dilation operation can restore (i.e. preserve) the original shape of objects as shown in Figure 1(b).

One of critical parameters for removing various sizes of nonground objects is the window size of the filter. Kilian et al. [7] used a two-step method to remove nonground points, while Zhang et al. [8] improved the similar algorithm in the point level. They used an increasing window size to remove objects with various sizes.

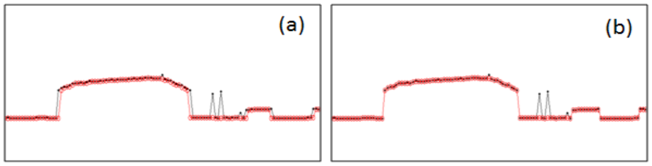

Fig. 1. Morphological opening operation (W=3). (a) and (b) Eroded and dilated surface (red dots).

Another critical parameter in morphological filtering algorithms is the slope of terrain of the study area. Most existing algorithms use a constant slope over the study area. The predefined slope parameter then affects the allowed minimum height difference used for identifying nonground points [8]. However, this simple premise is not always realistic in complex landscape. To overcome this limitation, Chen et al. [9] proposed an adaptive morphological filtering method. The main idea is that nonground objects such as buildings or trees have abrupt height difference along boundaries. In the initial step, potential returns from trees are removed. In the subsequent step, nonground points (mostly on buildings) are removed with the same approach as in [8] by progressively increasing the window size.

3. PROPOSED APPROACH

The proposed algorithm begins with generating a regular grid with a predefined grid size Δg. Elevation of each cell is then assigned with that of LiDAR point falling in the cell. If more than one point falls in the same cell, the lowest elevation is selected. For an empty cell, the elevation of the closest LiDAR point is assigned. As in [8], each cell keeps the index of the original LiDAR points. Therefore, filtering operation applied to the grid directly separates the LiDAR points. In the subsequent step, erosion operation is applied to each LiDAR profile consecutively (i.e. either row-by-row or column-by-column sequence). The window size is fixed such that only three consecutive points are used. Similar to [9], erosion operation is applied only to the points of discontinuity, e.g. boundary between ground and nonground objects. Identifying points of discontinuity can be approached by various discontinuity measures such as slope change or height difference (Figure 2(a)-(b)). In this study, we used the magnitude of vertical distance at the middle point to the line connecting the previous and next points as shown in Figure 2(c). This measure is called ‘residual’ hereafter.

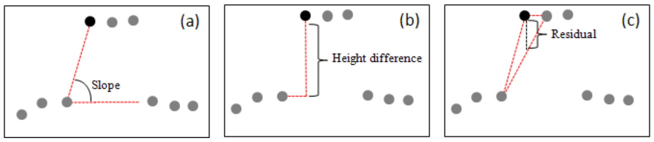

Fig. 2. Discontinuity measures. (a) Slope; (b) height difference; (c) residual.

As shown in Figure 3, LiDAR points lying on discontinuity between terrain and any protruded features have high residuals, while points on smooth terrain (regardless of the slope of terrain) have very small values close to zero. To select points of discontinuity, no fixed threshold is used, whereas a threshold is determined adaptively in each iteration. In this study, points beyond the 50% percentile (of all residuals of the corresponding profile) are considered as points of discontinuity.

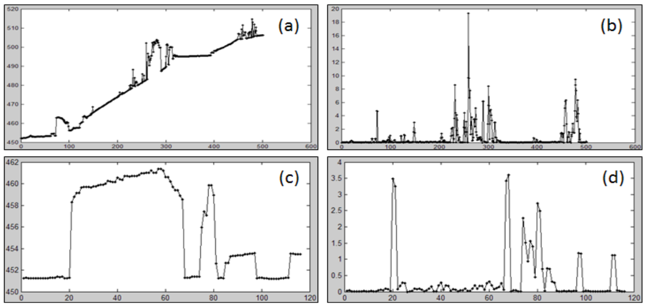

Fig. 3. Residuals. (a) and (c) LiDAR profiles; (b) and (d) corresponding residuals.

If the difference between the original and eroded elevation is larger than a predefined height threshold (d_{min}), the point is marked as a nonground point and the current elevation is replaced with a new eroded elevation. This process is carried out iteratively until no more points are identified as nonground points. The same applies to all rows (or columns) consecutively over the entire grid. Figure 4 describes how this process works. As shown in Figure 4(a)-(d), most sparse nonground points, e.g. mostly on trees, are eliminated during the first few iterations, while points on the building are eliminated progressively from its margin.

4. REFINEMENT

Due to the high variability of landscape characteristics, all filtering algorithms always produce some amount errors.

Two errors are generally reported, i.e. (1) omission (Type I) error and (2) commission (Type II) error. The former is reported when a filtering algorithm removes ground points mistakenly, while the latter is reported when an algorithm classifies nonground points as ground points. It is known that most filtering algorithms have a tendency to minimize 'Type II (commission)' errors, i.e. remove points as much as possible [2]. This is also related to the time efficiency or workload for refining the filtering results. Similarly, the proposed algorithm also leads to these two types of errors. This section discusses how to handle these errors.

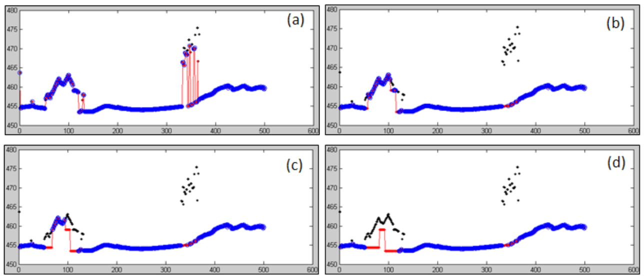

Fig. 4. Intermediate plots of filtering process. (a)-(d) 1,6,15 and 28 iterations). (black dots: original LiDAR points, blue circle: identified nonground points, red line: eroded elevation).

4.1 Type I (Omission) error

A Type I error is commonly found in most filtering algorithms due to various factors such as locally low outliers or improper parameters for the study area. As noted in Section 1, the main difficulty is there is no perfect parameter applied to various terrain conditions. The proposed approach also inherits the same problems, especially in the high relief terrains. Figure 5(a) shows one LiDAR profile (black dots) and determined ground points (red dots with line). Some of ground points (marked as '1' and '2' in Figure 5(a)) are mistakenly removed in the right and left hillside, which is caused by larger height difference at the points of discontinuity than the predefined d_{min} (1 meter in this example) (marked as circle in Figure 5(b)). To resolve this issue, distance from each nonground point to the straight line connecting the two closest ground point (before and after the given point) is analyzed as shown in Figure 5(d). If the distance is less than d_{min}, the point is marked as a ground point. This process is performed iteratively until no more points are found as additional ground points. The final result after this step is shown in Figure 5(c).

4.2 Type II (Commission) error

In most filtering algorithms, this error is mainly caused by a fixed minimum height difference. Therefore, this type of error is commonly occurred when the elevation of nonground objects is lower than a predefined threshold. In contrast, the proposed algorithm often leads to relatively high ground points, which are not removed correctly as shown in Figure 6(a). This is often found in the middle of large buildings, multi-steps buildings or dense vegetation because that the iterative erosion is trapped. However, those points are distinctively higher than their adjacent ground points. To resolve this issue, the height difference and at each ground point is compared with the previous ground point. If the height difference is larger than a predefined threshold (two times d_{min} in this study), the point is identified as a nonground point. This process is continued iteratively until no more points are removed as additional nonground points (Figure 6(b)).

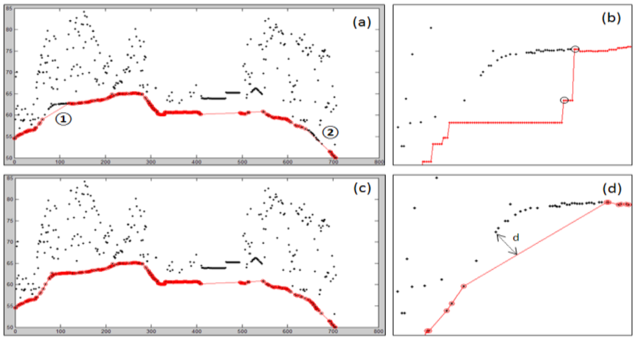

Fig. 5. Resolving Type I error. (a) Initial filtering result; (b) Original surface (black dots) vs. eroded surface (red dotted line) with two points of discontinuity (black circle); (c) Final filtering result; (d) Distance from nonground points to the local surface.

5. TESTS AND COMPARISONS

The proposed filtering algorithm is applied to two different data sets summarized in Table 1. To identify points of discontinuity, residual value at each point is compared with 50% percentile of all residuals of corresponding profile. One more tunable parameter, d_{min} is set as 1.0 meter for both data sets. The shaded relief maps from the original LiDAR points and filtered ground points are presented in figure 7(b) and (d). It is seen that most tress and buildings shown in Figure 7(a) are removed correctly, while some of nonground points (mostly on vehicles) remain as ground points. Another example shown in Figure 7(c) and (d) also shows promising result. It should be noted that the filtering is applied with the same parameters without any fixed slope or window size. Most of dense vegetation either on hillside or flat terrain is removed correctly while keeping terrain unchanged.

To compare the proposed approach with the existing morphological filtering algorithm, two more results are presented in Figure 8. 2D progressive morphological filtering algorithm by [8] is used, which is implemented in an open source software ALDPAT [11]. Among various parameters, slope parameters are only adjusted as 0.10 and 0.20 respectively. As it can be seen from Figure 8, only filtering result with slope 0.20 shows a correct result comparable to that of the proposed approach.

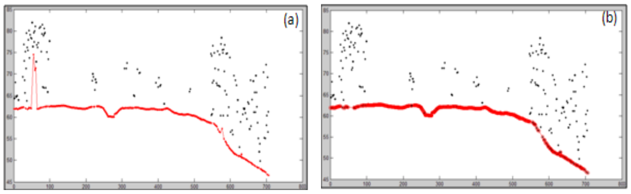

Fig. 6. Resolving Type II error. (a) Initial filtering results; (b) Refined result.

	Locations	Comments
1	Purdue	- Almost flat terrain mixed with buildings and trees (1 pt / m^2).
2	Toronto, Canada	- Flat to high relief terrain (up to 20^o) with dense vegetation (1 pt / m^2).

Table. 1. Summary of the two data sets.

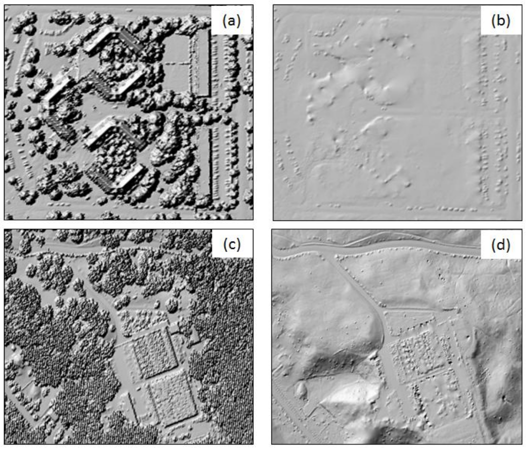

Fig. 7. Filtering results. (a) and (c) Shaded relief maps of #1 and #2, respectively); (b) and (d) Shaded relief maps of filtered ground points.

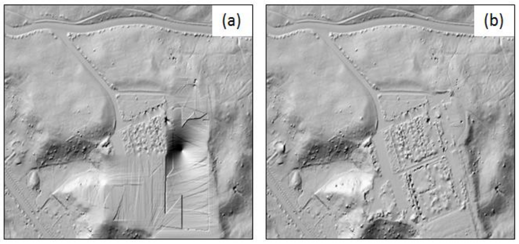

Fig. 8. Filtering results by 2D progressive morphological filtering. (a) Slope = 0.10; (b) Slope = 0.20.

6. CONCLUSION

In this paper, we proposed a variation of the existing morphological filtering algorithms. Comparing with the existing algorithms, our approach minimizes the number of parameters to be considered for different terrain conditions.

Morphological erosion operation is only applied to points of discontinuity and corresponding threshold is adaptively adjusted during iteration process. The main advantage is that the proposed algorithm can be applied to various terrains with different characteristics with the minimal change of parameters.

7. REFERENCES

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