A Self-Adaptive Morphological Filter without Consideration of Window Size for Airborne LiDAR Point Clouds

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Abstract. Light detection and ranging (LiDAR) has the capability of rapidly collecting dense and accurate three-dimensional geospatial information, and therefore it is widely applied in various fields of geospatial applications. The morphological filtering approaches can filter non-ground points effectively, which is crucial for many tasks such as land cover classification and digital elevation model generation. A series of different windows are generally in need for removing non-ground objects with different sizes. In order to avoid the limitation of choosing the filtering windows, we adopt the geodesic transformations of mathematical morphology for filtering LiDAR point clouds. This algorithm enhances the robustness and automation without consideration of how to choose different windows. Experimental results demonstrate that this filtering algorithm is capable of effectively preserving terrain details and filtering various non-ground objects.

Keywords. LiDAR; mathematical morphology; point clouds; filtering.

1. Introduction
The dense and accurate three-dimensional spatial data covering large area can be rapidly collected by airborne light detection and ranging (LiDAR). In particular, the LiDAR are able to penetrate tree canopy and have no effects of shadowing and surrounding light conditions. Fewer control points are in need, which make LiDAR work well in forest, marsh or desert [1-3]. Thus, LiDAR has been employed in many fields such as urban planning, natural hazard assessment, topographic mapping, land management, forestry, communications, civil engineering and geology [4-7].

For various geospatial applications and analysis, the first and essential process is generally LiDAR data filtering which is to separate non-ground and ground points [5-16]. A large number of attention and efforts from many researches have been put on the challenging problem of LiDAR data filtering over the past decades. Researchers have developed various significant filtering approaches such as morphological approaches, interpolation-based approaches, triangulated irregular network (TIN) densification approaches, and slope-based approaches [9, 16-21]. The morphological approaches have been proven to be capable of filtering non-ground points effectively, which are easily implemented because of the advantages of simple concepts [8, 22-25]. The structuring element in mathematical morphology, namely the filtering window, plays a crucial role for the success of filtering. On one hand, the filtering windows need to be large enough to filter the objects. On the other hand, the changing features of terrain such as mountain peaks and ridges are more likely to be removed by using the larger filtering windows. The results of filtering are inclined to be influenced by choice of windows [12, 25, 26]. Hence a series of varied window sizes are utilized by most morphological algorithms to filter progressively, and the size of the largest object is needed to be known beforehand for determining the maximum window size. In order to avoid the dependence on different window
sizes, we make use of geodesic transformations of mathematical morphology for filtering LiDAR point clouds. The advantages of this approach is that the choice of different windows and determination of the maximum window size are not necessary because only elementary filtering window is used, which cause this approach has more robustness in practical applications.

The following is organized as follows. Our filtering approach is presented in Section 2, and then Section 3 elaborates on the test experiments. Finally, this research is briefly concluded in Section 4.

2. Methodology

LiDAR points are irregularly distributed, and points contained within a survey strip are usually up to several millions. Therefore, a kind of efficient reorganization is in need to build the topology of irregularly distributed points, which is important for subsequent spatial analysis and calculation. In order to avoid the accuracy loss as well as make use of the simplicity of regular grid, this study employs a simple grid index to restructure point cloud. The average point spacing is generally known and used to construct a regular grid, and the points contained within each grid cell are determined according to its coordinate. In the course of the subsequent processing, the index grid cell is firstly determined by the point coordinates, and then LiDAR points stored in the certain grid cells are picked out to implement operations.

The filtering results are likely to be influenced by low outliers. Due to the laser rangefinder malfunction or multi-reflection of laser pulses in complex environments, point clouds often contain low outliers [9]. The outliers are generally scattered and have relatively far small heights, and thus the outliers are differentiated based on the characteristics.

Compared with the continuous and smooth ground surface, the non-ground objects often cause the drastic elevation changes. Morphological gradients are employed for the irregularly distributed points because of the merit of easily calculation. Morphological gradients can be further divided into two categories, namely internal gradient and external gradient [27]. Different transition points of height changes can be indicated by the two morphological gradients. Points a, c of figure 1, namely the lower jump points generally have larger external gradient compared with neighbors, while points b, d of figure 1, namely the higher jump points generally have larger internal gradient.

![](image.png)

**Figure 1.** Different transition points of height changes.

Some ground points of drastic changes, e.g. point e in figure 1 also have relatively large gradients. In order to distinguish the steep slope points and the low transition points, the gradient of external gradients can be expressed as the following formula:

$$\triangle (\rho^*_B) = \rho^*_B - \min\{\rho^*_B (x+i, y+j) | i,j \in D_B ; (x+i), (y+j) \in D_f\}$$

Since the ground elevation changes are gradually, the slope points have smaller $\triangle (\rho^*_B)$ than the low transition points.

In order to avoid the dependence on the choice of window sizes, we take with geodesic transformations for LiDAR data filtering in this study, which only utilize an elementary 3x3 window for operating elementary erosions and dilations. The morphological reconstruction operations can be categorized to reconstruction by dilation and reconstruction by erosion. A new morphological primitive used for this filtering approach can be constructed by combining the reconstruction
operations as figure 2. Only the top slope $\theta$ and the height $h$ need to be predefined without consideration of the width of primitives. As shown by the objects a, c of figure 2, various objects can be fit naturally and closely by the primitive which sequentially carrying out the morphological reconstruction operations.

The two sides of non-ground objects generally both have abrupt gradient changes. Therefore, the portions a, c in point clouds are classified as objects since they are higher than the whole primitive. Ground surface usually have no drastic gradient changes, so the portion b is classified as ground. Specially, one side of ground surface may be steep (e.g. cliffs), so the portion d is judged as ground because of only some part beneath the primitive.

![Figure 2](image-url)  
*Figure 2.* LiDAR data filtering by using the morphological primitive: (a) The cross section profile of point cloud $f$; (b) different portions are fit by the morphological primitive.

3. Experimental Results

The practical point clouds collected by the Actueel Hoogtebestand Nederland (AHN) (http://www.ahn.nl) are utilized to evaluate the filtering results of this proposed approach. An industrial procedure has been carried out to classify the point clouds. The used dataset is located at the Meerssen City as shown in figure 3. The reason of choosing the area is that it covers complicated landscapes such as buildings, steep slopes, and dense vegetation. The data contains 333,729 points. The average point density is 1.4 points/m$^2$. Thus, the grid cell for reorganizing point cloud is $0.5m \times 0.5m$. The two parameters, i.e. height $h$ and slope $\theta$ for morphological primitive are set to $0.1 \times \text{pointSpacing}$ and $\arctan(0.3)$, respectively.

Figure 3 shows the DEMs created from true ground points and the filtering results of the proposed approach. The results indicate that the significant features of ground can be retained effectively, and various objects can be successfully removed. Reasonable results can be expected to be produced by this filtering approach within complicated area.
Figure 3. Filtering performance using this approach: (a) DSM created by AHN data; (b) DEM created by true ground points; (c) DEM created by this filtering approach.

4. Conclusions
The dense and accurate three-dimensional spatial data covering large area can be rapidly collected by LiDAR. Thus, LiDAR obtain widely attentions and applications within various fields. For various geospatial applications and analysis, the first and essential process is generally LiDAR data filtering. The morphological approaches have been proven to be capable of filtering non-ground points effectively, which are easily implemented because of the advantages of simple concepts. Aimed at solve the problem of choosing windows, we make use of geodesic transformations of mathematical morphology for filtering LiDAR point clouds. The geodesic transformation converges through a finite number of iterations until stability making the choice of window size unnecessary. The advantages of this approach is that the choice of different windows and determination of the maximum window size are not necessary because only elementary filtering window is used, which cause this approach has more robustness in practical applications. The experimental results demonstrate that the significant features of ground can be retained effectively, and various objects can be successfully removed.
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