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Comparison of CSF and SMRF filtering methods for airborne LiDAR point cloud data

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Abstract

Airborne LiDAR System (ALS) technologies are widely used for rapid data collection in a wide range of applications, including cultural heritage, Geography Information Systems (GIS), geodesy applications, 3D city modeling, and deformation analysis systems, and the generation of Digital Terrain Models (DTM). Filtering bare soil from point cloud data is critical for archaeologists, architects, and geomatics professionals employing airborne Light Detection and Ranging (LiDAR). Cloth Simulation Filtering (CSF) and Simple Morphological Filtering (SMRF), both ground filtering techniques, are discussed in this study. Airborne LiDAR point cloud data were split into the ground and non-ground point clouds for evaluation. A thorough evaluation of filtering accuracy necessitates comparing all point cloud data. However, because the data is so huge, this seems implausible. To adequately measure classification success, data manually identified as ground and non-ground was used as a reference. The performance of the CSF and SMRF approaches is enough, but it is impacted by point cloud type, slope, and vegetation type, according to our findings.

1. Introduction

Airborne LiDAR methods are used in geomatics applications for quick data collecting on a broad spectrum of topographic land surveys. In addition, various applications have also employed elevation and geomorphological data from digital elevation models created using these approaches (Erol S. et al.,2020). DTMs, on the other hand, are used to confirm the physical surface and depict the bare soil. As a result, point clouds generated by these measuring methods have become increasingly popular in developing DTMs. To filter DTMs, airborne LiDAR point cloud data are filtered as ground and non-ground point clouds. However, point cloud filtering (removing bare soil from point cloud data) remains a significant problem when creating DTMs.

Over the past two decades, various ground filtering algorithms have been offered in various GIS or Lidar software solutions (e.g., ArcGIS, QGIS, LASTools, PDAL, PCL, and ALDPAT). However, each method of dealing with different terrains has pros and cons, and the benefits of these filtering algorithms vary from landscape to landscape. Therefore, performance evaluation among filtering algorithms is beneficial for selecting appropriate filters, especially for inexperienced users (Chen, C., 2021). Such algorithms are increasingly used to filter point cloud data (Klápště, P., et al. 2021). However, most algorithms are designed for filtering ALS data (Klápště, P., et al. 2021; Meng, X., Currit, N., & Zhao, K., 2010; Susaki, J., 2012; Rashidi, P., & Rastiveis, H., 2017). The ALS records the sequence of multiple laser pulse returns. Therefore, the ground filter algorithm uses these momentum properties to represent the ground.

This study's primary purpose is to evaluate these algorithms' performance on LiDAR point cloud data using the Cloth Simulation Filter (CSF) and Simple Morphological Filter (SMRF) methods. In addition, it is used to analyze the effects of filtering methods applied to various point clouds once the ground surface has been obtained.

2. Method

The case study area is located in the Bergama test site for aerial LiDAR data west of Turkey (Figure 1). The land size is 200 m in length and 100 m in width. After obtaining the point cloud data with Lidar for this study area, the point cloud data were filtered, and the DTMs were gained with CSF and SMRF algorithms. In addition, the performances of the filter algorithms in DTM generation were evaluated and discussed.

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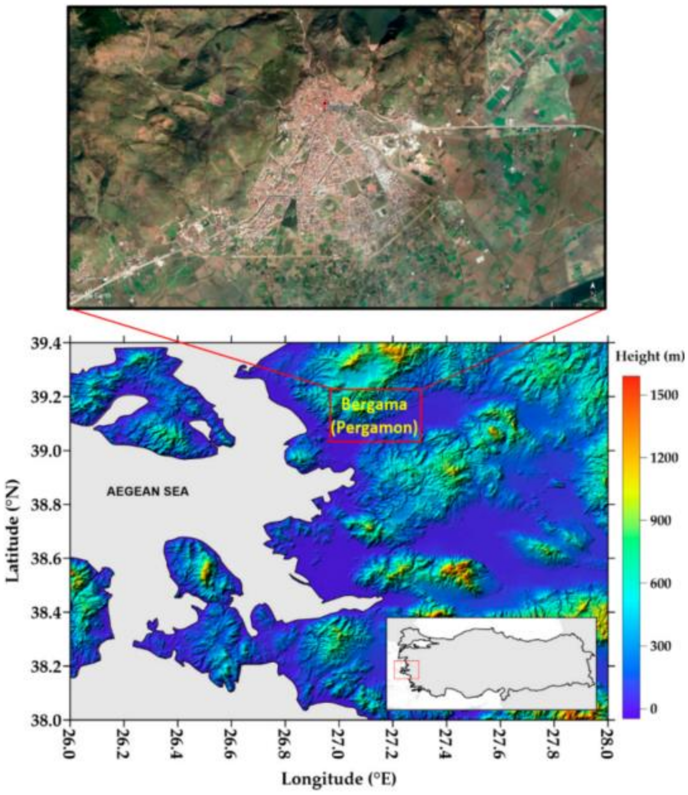

Figure 1. Google Earth image (top) and SRTM DTM (bottom) of Bergama test area (Erol, S. et al., 2021)

In this study, LiDAR point cloud data were obtained by making test flights from 1200 m heights with the Riegl LMS-Q1560 LiDAR system provided by the general directorate of mapping of Turkey. For the performance of filtering, a manual accuracy assessment approach was preferred. The primary purpose of this study is to evaluate the performance of CSF and SMRF methods in different point clouds in the same area.

2.1. Filtering

Filtering is the process of determining whether data belongs to the ground or non-ground surface in digital terrain model development. There are several filtering algorithms, which may be classified into five types. [Štular, B., & Lozić, E., 2020; Pfeifer, N. and G. Mandlburger, 2018; Süleymanoğlu, B. and Soycan, M., 2019):

- morphological filtering (PMF, SBF, SMRF),
- progressive densification (PTIN),
- surface-based filtering (WLS, CSF),
- segmentation-based filtering (SegBF),
- other (MCC), and hybrid (BMHF).

The point cloud data were filtered in this case study using the CSF and SMRF algorithms, and DTMs were produced. The foundation of SMRF is mathematical morphology. By figuring out the height of nearby locations, morphological filtering algorithms maintain the characteristics of the landscape [Pfeifer, N. and G. Mandlburger, 2018; Buján, S., Cordero, M. and Miranda, D., 2020). A morphological abrasion with the core function and a test for the difference between a point's original height and the eroded height are the two fundamental phases in the filtering process (Figure 3). Surface-based filtering techniques are the foundation of CSF. They initially acknowledge that all points are ground points and gradually eliminate all non-ground points. Using basic kriging, the surface is typically defined utilizing all of the points in the first stage. Then, an average surface is created between the ground and non-ground locations. The distance from the mean surface determines the residual value (Pingel, T. J., 2013; Süleymanoğlu, B. and Soycan, M., 2019).

In this study, ground and non-ground data were utilized to examine the effectiveness of filtering techniques using a manually edited methodology (Visual inspection). When ground truth data are unavailable, visual inspection is a manual accuracy evaluation method that is frequently utilized. In addition, three indices based on a confusion matrix were used: error type I, II, and accuracy (Table 1). Equations (1), (2), and (3) demonstrate these equations (Susaki, J., 2012).

$$\text{error type I} = b/(a+b), \tag{1}$$
$$\text{error type II} = c/(c+d), \tag{2}$$
$$\text{accuracy} = (a+d)/(a+b+c+d), \tag{3}$$

Table 1. Structure of Confusion Matrix

		Ground Points	Non-Ground Points
Reference Points	Ground Points	a	b
	Non-Ground Points	c	d

3. Results

DTM filtering (CSF and SMRF) was implemented to LiDAR data (the experimental field) using Cloud Compare and Matlab software. The accuracy of filtering algorithms was checked manually using reference data.

3.1. SMRF Algorithm

The SMRF algorithm was applied to Lidar point clouds and filtered ground and non-ground points in this case study. For the study area, approximately 215.000 points were filtered as ground points. Also, approximately 45.900 points were filtered as non-ground points (Figure 2).

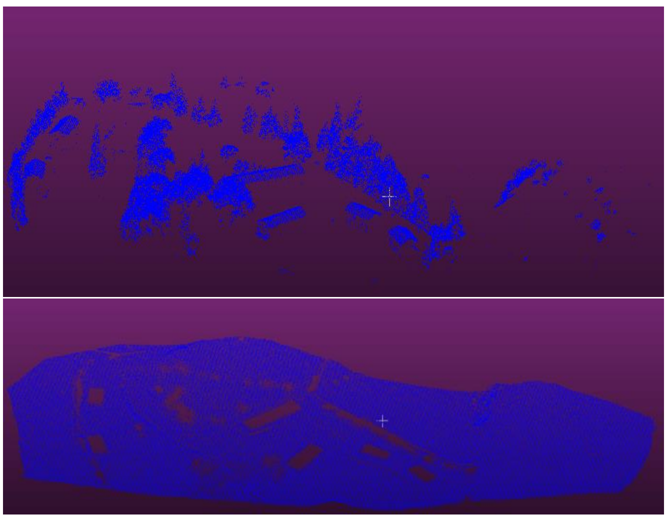

Figure 2. The ground (bottom) and the non-ground (top) points of Bergama test area with SMRF

3.2. CSF Algorithm

In this case study, the CSF algorithm was applied to Lidar point clouds and filtered ground and non-ground points. For the study area, approximately 206.000 points were filtered as ground points. Also, approximately 55.000 points were filtered as non-ground points (Figure 3).

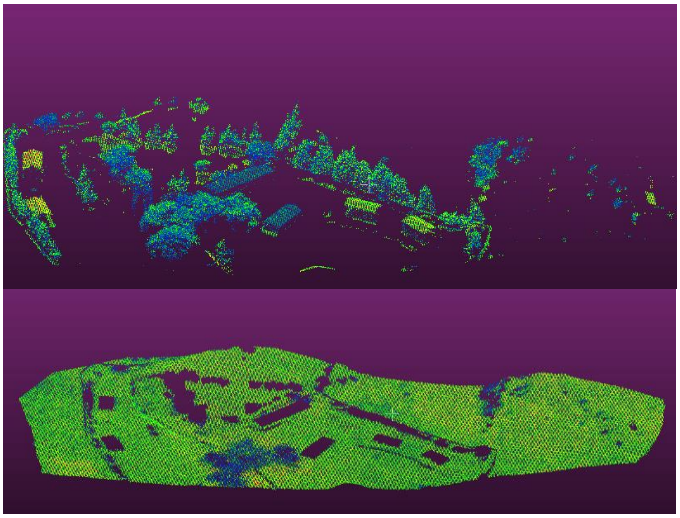

Figure 3. The ground (**bottom**) and the non-ground (**top**) points of Bergama test area with CSF

3.3. Evaluation of Filtering Data

During DTM filtering, Matlab and Cloud Compare software was used. Ground data and non-ground data were utilized as references for the filtering procedures, which were performed using manually edited reference data (Table 1). For the SMRF filtering approach, the filtered point cloud's accuracy achieved 94% accurate segmentation. The accuracy for LiDAR data was 94% when measured using the CSF algorithm (Table 2). In conclusion, both algorithms' accuracy is the same, proving that the approach used to filter the LiDAR data is adequate. Table 2 displays the outcomes of the filtering strategies.

Table 2. The Confusion Matrix of the filtering methods

Sample Dataset	Type Error I (%)	Type Error II (%)	Accuracy
Lidar CSF	5	11	94
Lidar SMRF	1	25	94

Confusion Matrix has performed a visual evaluation. The SMRF algorithm has produced the most trustworthy findings compared to the CSF approach. The computed type I, type II, and accuracy for the test samples are shown in Table 2. Lidar SMRF, in contrast, has the most significant type II error (%25). The LiDAR point cloud filtering techniques, however, produced identical findings.

4. Discussion

The reference data chosen with the manually edited methodology was utilized for the performance of filtering methods, including both ground and non-ground data. For the SMRF filtering approach, the accuracy of the filtered point cloud achieved 94% correct segmentation. Likewise, the accuracy of LiDAR data was 94% when examined using the CSF algorithm. Finally, the accuracy of both methods is the same, indicating that the implemented method has a favorable effect on filtering LiDAR data.

The SMRF set of rules was designed to be aggressive with different ground filtering algorithms for LiDAR data, particularly in city environments on enormously varied topography. The SMRF algorithm is successful when optimized and even when using a single set of parameters, suggesting that novice users can achieve good results. Also, SMRF establishes a baseline performance for a progressive morphological filter implemented in its simplest form. The essence of the SMRF algorithm requires the input of a minimum surface and two parameters – a maximum window radius that corresponds to the most significant feature to be removed and a single slope parameter that governs the cell-based ground / non-ground flagging at each iteration. To categorize the original LiDAR points as bare earth (BE) or object, the SMRF creates a provisional ground surface (DTM) using these two characteristics and a provided minimum surface (OBJ). The primary benefit of SRMF is that it offers a straightforward conceptual and computational foundation for achieving effective outcomes. (Pingel, T. J., 2013)

5. Conclusion

This paper presents an experimental investigation of existing methods for ground filtering on point clouds. Two ground filtering approaches were compared for the same point cloud data, and the trials revealed several of the methods' properties. Bergama was chosen as the case study location for airborne LiDAR data. The accuracy values for both datasets and methods are sufficient for ground filtering, indicating that the provided approach effectively filters LiDAR data. Additionally, topographic features such as houses and trees are filtered when the ground point cloud is created. As a result, these items are the result of filtering failures. As a result, existing algorithms must be improved.

In future Lidar filtering applications, new filtering algorithms will be tested for large fields, and the influence of UAV point cloud quality on filtering outcomes will be examined.

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