7th Intercontinental Geoinformation Days

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A comprehensive study on enhanced accuracy analysis of LiDAR data

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Keywords
Remote sensing
CSF Filter
DTM
LIDAR
Accuracy Analysis

Abstract

LIDAR technology, a prominent remote sensing technology widely employed today, offers a highly reliable means of swiftly and accurately gathering data. This research project aims to generate a Digital Terrain Model (DTM) from a LIDAR dataset featuring urban attributes. The chosen tool for this endeavor is the CSF Filter algorithm within Cloud Compare, an open-source software, with an emphasis on assessing the model's precision. Within the CSF Filter algorithm, we examined the accuracy of the Surface Approximation Mesh (SAM) when various cover values were employed: 0.1, 0.5, 1, 2, and 5. Our investigation primarily revolved around calculating the volume disparity between a manually created reference model within a computer environment and the models generated through filtering. This analysis allowed us to pinpoint the most suitable parameter value for creating an accurate model. The results indicated that opting for a cover value of 0.5 produced the most accurate model. Notably, when a cover value of 5 was chosen for the input parameter, the largest disparities were observed between the resulting model and the reference model.

1. Introduction

Remote sensing techniques have found diverse applications beyond traditional map creation, encompassing the development of 3D city and building models, land use analysis, and the monitoring of natural disasters. Among these applications, the generation of digital elevation models (DEMs) that capture comprehensive elevation data of the Earth's surface is of particular significance. It's essential to distinguish between DEMs, which encompass 3D information pertaining to both natural and man-made structures on the Earth's surface, and digital terrain models (DTMs), which exclusively represent the natural land surface, excluding man-made structures not integrated into the Earth's surface (Uray, 2022).

LIDAR technology, an active sensor technology, plays a pivotal role in numerous domains. LIDAR, an acronym for "light detection and ranging," employs scattered light to gather a wealth of information (Lu et al., 2011). This technology excels in swiftly and accurately acquiring physical data, facilitating the automatic generation of precise 3D models, whether they pertain to man-made or natural objects, without requiring physical contact (Fidan & Fidan, 2021). LIDAR data is often referred to as a "point cloud," a nomenclature attributed to the irregular nature of scanning data resulting from changes in target characteristics and aircraft movements (Lu et al., 2011).

The primary objective of this study is to conduct an accuracy analysis of volume calculations, focusing on the pivotal parameter that determines the ground class within LIDAR data. The data input into the CSF filter of the LIDAR point cloud is provided by different individuals in the context of popular research. The CSF Filter, which facilitates reporting and storage, enables the measurement of accuracy rates when varying parameter values are applied to LIDAR point cloud data. This investigation aims to identify the parameter that yields the most successful filtering outcomes and explores the applicability of alternative methodologies while scrutinizing the accuracy levels in question.

1.1. Point cloud filtering

In the realm of remote sensing, applications extend beyond mapping, encompassing 3D city models, land use analysis, and disaster monitoring. Digital elevation models (DEMs) capture comprehensive elevation data. Notably, DEMs encompass both natural and man-made

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Cite this study

Sarıtaş, B., & Kaplan, G. (2023). A comprehensive study on enhanced accuracy analysis of LIDAR data. Intercontinental Geoinformation Days (IGD), 7, 213-216, Peshawar, Pakistan

structures, while digital terrain models (DTMs) focus solely on natural land surfaces (Uray, 2022).

LIDAR technology, or "Light Detection and Ranging," is a versatile active sensor technology, enabling swift and precise 3D modeling of both man-made and natural objects without physical contact (Fidan & Fidan, 2021). LIDAR data, often referred to as a "point cloud," reflects the irregularity in scanning data due to varying target characteristics and aircraft movements (Lu et al., 2011).

This study examines the accuracy of LIDAR data filtering using the CSF Filter algorithm, investigating the ground class determination parameter. Different data sources contribute to the LIDAR point cloud within current research, and the CSF Filter aids in measuring accuracy rates with various parameter values. The goal is to identify the most effective parameter for filtering and explore alternative methods while assessing accuracy (Uray, 2022).

2. Method

In the LIDAR point data processing, we start by manually removing noise points using CloudCompare. Then, we experiment with various parameter values in the CSF Filter algorithm to extract soil-class points and create a Digital Terrain Model (DTM). We establish a reference DTM through manual interventions in CloudCompare and Civil 3D for accuracy assessment. To evaluate parameter effectiveness, we calculate the volüme difference between the reference DTM and the filtered DTM data.

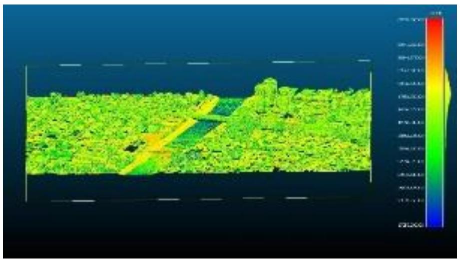


Figure 1. Viewing urban area LIDAR data in CloudCompare software (Sarıtaş and Kaplan, 2023)

2.1. Work area and LIDAR data

The study area is situated in the western part of Skopje, the capital of North Macedonia, encompassing 312 buildings (Figure 1). This region is bisected by the Vardar River, approximately 60 meters wide. On the left side, the area is characterized by a dense grid of low residential buildings with a maximum height of 10 meters, while the right side features taller residential and commercial structures, with a maximum height of 70 meters. The terrain is predominantly flat, with surface elevations ranging from 250 to 327 meters and land elevations between 250 and 325 meters. The study area also includes various trees, bridges, and a 20-meter-wide riverbank (Kaplan et al., 2022).

The primary dataset of the study is LIDAR remote sensing, acquired from the Cadastral Office of North Macedonia. The data collection was conducted using an aerial platform, Cessna 402B, equipped with the Riegl VQ-780i sensor system. The data acquisition took place on May 3, 2019, under clear skies and at an air temperature of 11 °C. The LIDAR data has a point density of 5 points/m² (Kaplan et al., 2022).

In total, the 3D LIDAR point 214ort 214ort he urban area comprises 4,540,667 data points.

2.2. Obtaining the reference model

In the absence of local measurement capabilities, the reference model is manually generated within a computer environment. Initially, an automatic classification process in CloudCompare identifies ground points, and all other points are subsequently removed. However, a closer examination of the ground point class data reveals the necessity for manual filtering. To enhance the precision of this filtering, Google Earth imagery can be leveraged to ascertain whether the processed points are affiliated with the ground or non-ground areas.

Figure 2. Data Obtained by Leaving the Point Cloud of the Soil Class Alone

The consideration of neighborhood relationships to determine the ground class sometimes results in inaccurate selections, particularly in areas with minimal elevation variations. In these cases, data not associated with the ground may be misclassified as ground points, leading to erroneous classifications. To rectify these inaccuracies, Google Earth images of the region are employed to improve the precision of ground point selection.

Figure 3. Google Earth Image of the Study Area (URL-1)

(a) (b)

Figure 4. (a) Google Earth Image of the Area Closely Examined (URL-1), (b) Classified LIDAR Point Cloud Data of the Closely Examined Area

Due to the challenges of identifying the situation from a top-down perspective, thorough examinations are conducted from a side-view angle. These investigations reveal that the point cluster is situated below the actual road level in the real-world context.

Figure 5. Examining the Image of the Area (URL-1)

A comprehensive examination of the entire point cloud, combined with Google Earth images, unveiled visible issues, which were subsequently resolved through manual point deletion. The subsequent step involves utilizing a triangle model to identify problems that might not be apparent to the naked eye, especially those not pertaining to the ground.

In an effort to enhance the reference model's accuracy, another approach is employed, entailing the creation of a triangular model to detect any abrupt surface irregularities. The data initially in ".las" format, generated by CloudCompare, is transformed into ".rcp" format using ReCAP software. Subsequently, it is imported into Civil 3D, where a triangular model is constructed. During the triangular model operations, adjustments are made to address inaccuracies in areas with sudden deviations. These corrections are pivotal in the process of generating the reference Digital Terrain Model (DTM), which includes contour lines and cross-sections analyzed and refined on the triangular model.

2.3. Performing filtering operations with CSF Filter

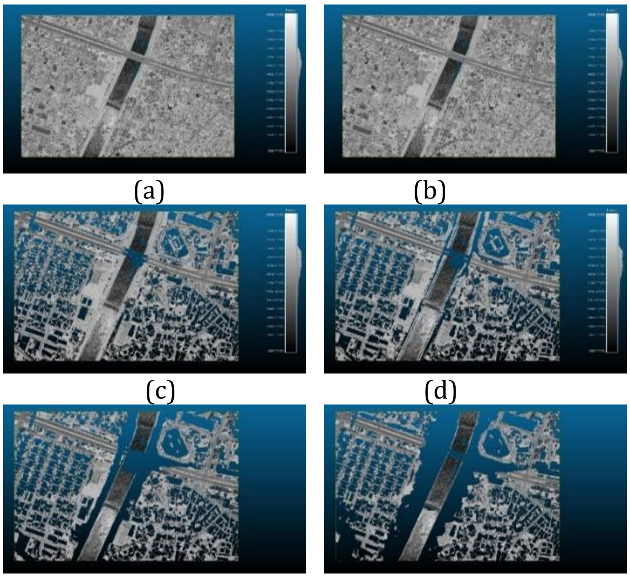
To assess the accuracy of the CSF Filter algorithm, classifications were conducted by varying the cover value at five different levels: 0.1, 0.5, 1, 2, and 5, respectively.

Table 1. Point numbers of LIDAR data created with CSF Filter (Saritas and Kaplan, 2023)

Cover Value	Number of Off-Ground Points	Number of Points on the Ground
0.1	1.661.947	2.878.720
0.5	2.167.155	2.373.512
1	1.748.797	2.791.870
2	2.643.720	1.896.947
5	2.983.257	1.557.410

2.4. Accuracy Analysis

In the volume calculations conducted between the reference DTM and the DTM data resulting from the filtering process, the model with the smallest calculated volume is regarded as the most accurately filtered model. This conclusion is drawn because of the remarkable similarity between the triangular model created using the reference DTM and the triangular model generated from the filtered DTM. In instances where a substantial disparity is observed, it suggests the presence of deviations in the model and a lower level of data accuracy. Figure 7 visually illustrates the potential differences between these two distinct models.



(a) (b) (c) (d) (e) (f)

Figure 6. For an urban LIDAR point cloud; (a) The Original Point Cloud, (b) Data Obtained As a Result of Entering the CSF Filter Algorithm Cover Value as 0.1, (c) Data Obtained as a Result of Entering the CSF Filter Algorithm Cover Value as 0.5, (d) Data Obtained As a Result of Entering the CSF Filter Algorithm Cover Value as 1, (e) Data Obtained as a Result of Entering the CSF Filter Algorithm Cover Value as 2, (f) Data Obtained as a Result of Entering the CSF Filter Algorithm Cover Value as 5 (Saritas and Kaplan, 2023)

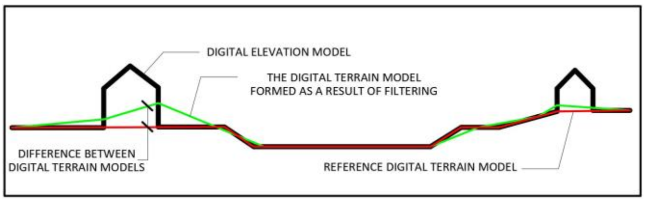


Figure 7. Difference Between Reference DTM and Filtering DTM

In AutoCAD Civil 3D software, a separate triangular model is established for each DTM dataset. This analysis method facilitates volume calculations between the triangular models derived from the DTM data obtained through filtering, individually compared to the triangular model accepted as the reference DTM. These results serve as an indicator of data accuracy. When interpreting the result data, both low and high areas are jointly assessed in relation to the reference model, as illustrated in Figure 8, and the overall discrepancy is taken into account.

This analysis method incorporates volume calculations and also generates a difference surface, highlighting variations between two distinct triangular models. This approach provides a comprehensive evaluation of data accuracy and aids in the identification of optimal parameters.

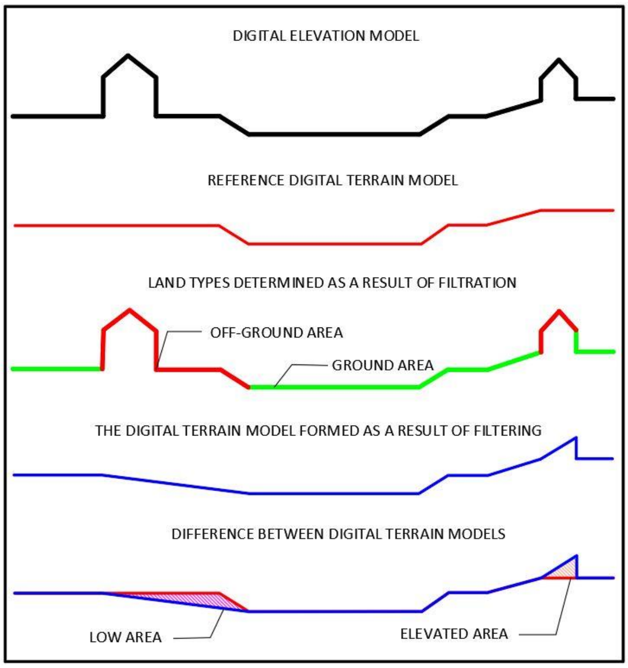


Figure 8. Comparison of DTM

Table 2. Accuracy analysis results of models obtained using the CSF Filter algorithm

CSF Filter Parameter Value	Low Area (m³)	Elevated Area (m³)	Total Difference (m³)
0.1	6563.38	376124.16	382687.54
0.5	24232.04	23732.29	47964.33
1	85385.72	13880.86	99266.58
2	187682.76	9098.31	196781.07
5	493952.45	4434.26	498386.71

3. Results

Upon evaluating the obtained results, it becomes evident that selecting a parameter value of 0.5 for the filtering process yields a Digital Terrain Model (DTM) that closely aligns with reality. Conversely, among the parameter values considered, it is apparent that a value of 5 creates a model that deviates furthest from reality. Even when assessing the models that provide the closest outcomes, it is worth noting that manual interventions can further enhance the accuracy of the results.

4. Discussion

Employing terrestrial measurement methods for crafting the reference model has the potential to significantly enhance its accuracy. In contrast, generating the reference model manually in this particular study may introduce variables that could impact the precision of the subsequent accuracy analysis. The inclusion of terrestrial measurements, characterized by their physical, ground-based nature, can reduce the potential for errors and enhance the overall reliability of the reference model. This approach aligns more closely with the actual topography of the study area, contributing to the accuracy of subsequent comparisons and assessments.

5. Conclusion

By increasing the accuracy of the reference model used in the study by using terrestrial measurement methods, the usability of the cubage calculation, which is the accuracy analysis method investigated in the study, can be determined more accurately.

Acknowledgement

This study was adapted from Berkan Sarıtaş's master's thesis.

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