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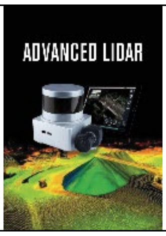

Comprehensive Study on Enhanced Accuracy Analysis of LIDAR Data : The Example of Skopje

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Abstract

By harnessing LIDAR technology, a prominent remote sensing method widely employed today, we explore its efficacy as a rapid and dependable tool for data collection. We focus on generating a numerical terrain model by leveraging the CSF Filter algorithm within the accessible CloudCompare software to filter an urban LIDAR point cloud. This study involves meticulous manual intervention to eliminate noise points, followed by examining the creation of a numerical terrain model by varying cover values (0.1, 0.5, 1, 2, and 5) in the CSF Filter algorithm. Our investigation delves into calculating the volume disparity between a reference model meticulously crafted within a computer environment, integrating manual interventions, and models derived through the CSF Filter algorithm. This approach aims to identify the cover value that best approximates reality in filtering operations. The decryption of volume disparities between the computer-generated reference model and the CSF Filter algorithm sheds light on the most accurate filtering outcome. The results indicates that opting for a cover value of 5 yields the most significant divergence from the reference model, presenting a less accurate model. Conversely, selecting a cover value of 0.5 as input data offers the closest approximation to the truth. However, it remains evident that manual interventions are indispensable for refining filtering operations even in the most precise model derived from these investigations.

1. Introduction

Human beings have been affected by the events and works that have been happening around them from ancient history to the present, they have felt the need to access the information related to these situations, and while reaching this information, they use scientific fields with different disciplines. Remote sensing technologies are coming at the beginning of these areas(Döş & Uysal, 2019).

In the information age we are living in, in addition to accessing information directly, it is aimed to obtain information in a reliable and fast manner at a lower cost (Başambar et al., 2021). Remote sensing technologies Thanks to the sensors located on the ground, air, satellite platforms, the data obtained can be evaluated and information about the objects in the study area and their surroundings can be accessed (Döş & Uysal, 2019).

In recent years, the acceleration in the development of technology has been observed in the field of remote sensing andn every field in general (Yurtsever, 2023). Remote sensing can be defined as a method of collecting data about objects in a general sense without direct contact with objects. Remote sensing can be used in many areas to study the earth and ground resources (Başambar et al., 2021).

Although an important tool that improves the quality of life of human beings has emerged, developments in remote sensing promise to bring more benefits to human life for future generations (Sevinç Tigin, 2023). Unmanned aerial vehicles can also be controlled from the ground, as well as automatic flight planning, and the lack of any pilotage makes them attractive, they usually work

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with cameras installed on them and are used in many different areas of mapping (Akgül et al., 2016; Makineci, 2016).

The need for 3D dense point clouds is increasing more and more today and is being produced with technological developments (Çakmak et al., 2022). Remote sensing technologies present an important option to quickly meet geographical data requirements and the need for a 3D dense point cloud, which has been increasing, especially in recent years. Remote sensing data with low resolution in the initial stages, satellite and sensor technology, as well as advances in software and computer fields thanks to developing technology, and optical solutions, especially since the beginning of the 2000s, much higher resolution data can be obtained, and these data with much higher ground representation become an important component of professional and academic studies (Uça Avcı et al., 2015).

Remote sensing techniques have found diverse applications beyond traditional map creation, encompassing the development of 3D city and building models, land use analysis, and monitoring 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).

The measurements carried out with the use of LIDAR technology enable the collection of raw data on non-man-made objects and man-made objects, that is, all the properties found on the earth's surface (Kostrikov, 2019).

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).

3D DTM is a very important resource for determining the details of the earth's surface and preparing projects. The outstanding feature of LIDAR technology as the biggest advantage is revealed when compared with traditional methods of creating numerical models of the earth's surface. These advantages in question are the values of labor, time and accuracy (Karasaka & Keleş, 2020).

LIDAR technology, which allows data to be obtained by transmitting laser signals in the form of short electromagnetic waves, is an active remote sensing system similar to RADAR technology, which provides data with micro waves (Çelik et al., 2014). LIDAR technologies have been accepted and applied frequently in areas such as remote sensing, geography, geology and transportation due to the high accuracy data obtained compared to radar technology. LIDAR is an accepted technology for use in topographic mapping. It is superior to radar technologies in terms of sensitivity and usage areas (Lu et al., 2011). It enables 3D data to be obtained by sending signals to the ground surface thousands of times. Being faster than aerial photogrammetry, it is a system that tends to obtain data with equal accuracy with classical spatial measurements (Çelik et al., 2014).

When LIDAR systems are examined, the advantages of the system can be shown as low cost, as well as the fact that the point density allows obtaining high and highly accurate reference numerical altitude data, less land studies compared to classical ground measurements and numerical aerial photogrammetry (Çelik et al., 2014; Ekercin & Üstün, 2004).

When the spectral characteristics of the lasers in LIDAR systems are examined, they are located in very wide spectra such as 50-30000 nm from visible and near infrared. The lasers involved in LIDAR systems are limited to the near infrared spectral region. The reason for this is to enable data to be obtained day and night, in the shade or among clouds (Çelik et al., 2014; Wehr & Lohr, 1999).

When we look at the areas of use of LIDAR technology, there are two different types of LIDAR: Terrestrial LIDAR and Air LIDAR. Land registry and cadastral services, architectural works such as monuments and buildings, such as roads and bridges, such as the use of terrestrial LIDAR technology for the preparation of 3D documents of engineering structures such as Air LIDAR technology are used in areas where it is difficult to perform measurement operations such as forest areas, power transmission lines, city address information systems when the areas of use of Air LIDAR technology are examined (Çelik et al., 2014).

Terrestrial Laser Scanning (TLS): TLS technology is used for various purposes in the studies conducted for cultural heritage and archaeological sites due to the creation of high-precision 3D models of cultural heritage objects, the high level of detail related to the object, high-resolution matching, the study of their changes and the possibilities of presentation (Çömert et al., 2012; Fabris et al., 2009).

Aerial Laser Scanning (ALS): Laser measurement systems consist of sender, receiver, control unit and scanner mirror, and the LIDAR sensor of the laser scanning unit located on the aircraft moving along the flight lane sends the laser beam together with the scanner mirror, measures the scanning angle of the laser beam and records the inclination angle of the entire beam along with the scanning angle and IMU values. Along with this, the time elapsed between the Deceleration and rotation of the laser beam is recorded. The final component of the laser measurement systems, IMU, is the equivalent of the "roll, pitch and heading" values of the X, Y and Z coordinates and indicates the angular deviations in the coordinate plane (Civelekoğlu, 2015; Soycan et al., 2011a).

When we look at the scanning patterns of air LIDAR technologies, it is seen that they are different from each other. The aircraft performs flights in a way that creates overlapping areas and in strips. For this reason, it is necessary to determine the flight line before the flight takes place in order to perform the correct field evaluation of the data sets (Civelekoğlu, 2015).

The formats of the point cloud data obtained using air LIDAR technology may vary, as well as the format often obtained ".las" is an extension structure. When looking at the formats used in the map of this format, point cloud data can also be obtained in the formats of American standard code for informatinon (ASCII), ".xyz text", fast binary, scan binary and grass sites, and data processing studies can be performed (Civelekoğlu, 2015; Habib & Rens, 2017).

Point clouds, which are obtained using ALS technology, allow us to obtain more information about the terrain than many other data acquisition sources. LIDAR point clouds, which have recently been created as a result of obtaining data by airborne (airplane, helicopter) laser scanning, are the main data source to produce high-resolution DEM or DTM (Podobnikar & Vrečko, 2012).

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.

When the studies conducted in the literature are examined, they are generally obtained using measurements made with GNSS receivers as reference data or aerial photographs. By investigating the accuracy values of different filtering algorithms, it is ensured that the algorithm that gives the most accurate results in obtaining ground points is chosen. As a common result with the examination of the literature, it is seen that manual interventions should be made even in data sets that have high accuracy.

1.1. Point Cloud Filtering

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

LIDAR technology 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).

1.2. Softwares

1.2.1. CloudCompare

In addition to being software that processes 3D point clouds, such as point clouds obtained using laser scanning devices, it can also process calibrated images and triangular networks. The purpose of its creation is to quickly detect changes in 3D high-density point clouds obtained in industrial facilities or construction sites using laser scanners only, but later, it evolved to become a more advanced and more general 3D data processing software. CloudCompare, an independent open source project, is a free software (URL-1).

It provides a set of basic tools for manually editing 3D point clouds and triangle meshes. Axis-based projections such as cylinder or cone expansion, registration algorithms such as Iterative closest point (ICF), distance calculation methods such as cloud-cloud or cloud-mesh nearest neighbor distance, statistical calculation methods such as spatial Chi-square test, preliminary propagation-based or It is a software capable of performing segmentation methods such as connected components labeling algorithms and finally geometric feature estimation to obtain information such as density, curvature, smoothness and geological plane orientation (URL-1).

CloudCompare software is very useful because it is designed for change detection and the triangular mesh is a very common way of representing a reference shape. However, it remains a secondary asset, especially since CloudCompare can directly compare two point clouds without creating an intermediate mesh. Looking at the reasons for this, it is usually very difficult to properly create networks in real-life scenes, especially when scanned with a laser scanner, and since the point clouds obtained with ALS or TLS are usually very dense, you have all the information you need (URL-2).

1.2.2. AutoCAD ReCAP

It is used to create 3D models for real-world building and infrastructure projects. It helps designers or engineers to capture high-quality and detailed models of real-world assets. It is used in studies such as understanding and verifying current conditions and built assets to gain insight and make better decisions, providing a point cloud or network to support building information modeling (BIM) processes, and ensuring collaboration between teams in a real-world context, or researching, planning, deconstructing and renovating building and infrastructure projects (URL-3).

1.2.3. AutoCAD Civil 3D

It enables engineers to overcome complex infrastructure challenges in a 3D model-based environment. Accelerating design and documentation increases cooperation and coordination with advanced design automation (URL-4).

Autocad Civil establishes intelligent relationships between 3D objects.Dec. In the event of any change in the design, the processed objects are also updated dynamically. All objects included in the Autocad Civil 3D software are in a connection with each other. In Autocad Civil 3D software, it is possible to perform each of the operations such as design, analysis, reporting and 3D visualization (URL-5).

With Autocad Civil 3D software, DTM can be created using many different data. Data such as terrain models, points, contour lines, AutoCAD objects, slope points or lines, polylines, ASCII point files, DEM files can be created individually or together. The created terrain models have a dynamic structure and are automatically updated if any change in the data makes up the model. A terrain model is created using data from many different sources, and 3D images can be obtained by analyzing the model (URL-6).

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). For accuracy assessment, we establish a reference DTM through manual interventions in CloudCompare and Civil 3D. We calculate the volüme difference between the reference DTM and the filtered DTM data to evaluate parameter effectiveness.

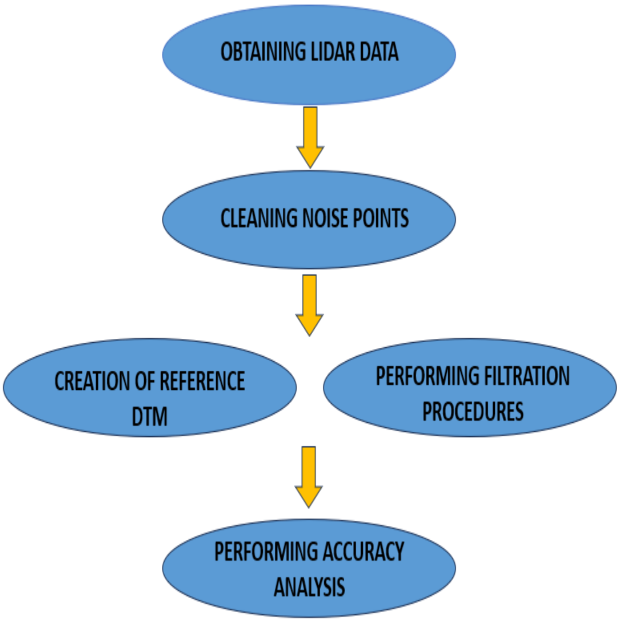


Figure 1. Workflow diagram.

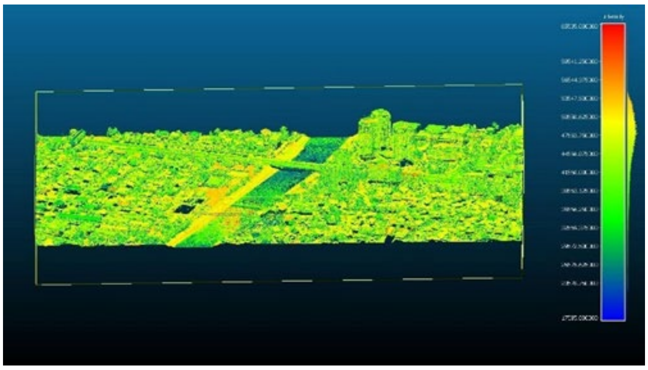


Figure 2. Viewing urban area LIDAR data in CloudCompare software (Sarıtaş and Kaplan, 2023).

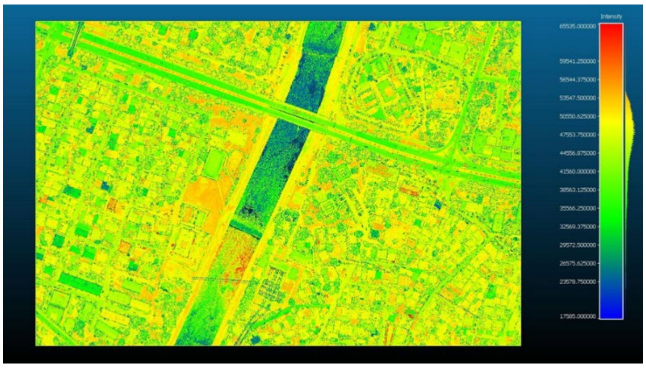


Figure 3. Viewing of Urban Area LIDAR Data from a Top-Down Perspective in CloudCompare Software (Sarıtaş and Kaplan, 2023).

2.1. Work area and LIDAR data

The study area is situated in the western part of Skopje, the capital of North Macedonia, and encompasses 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).

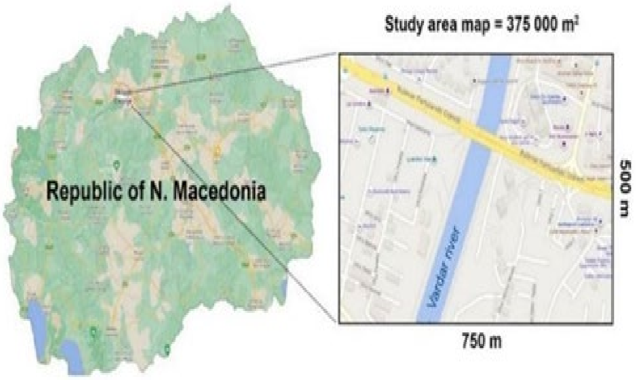


Figure 4. The study area in city of Skopje, used for the analyses (Adjiski et al., 2023).

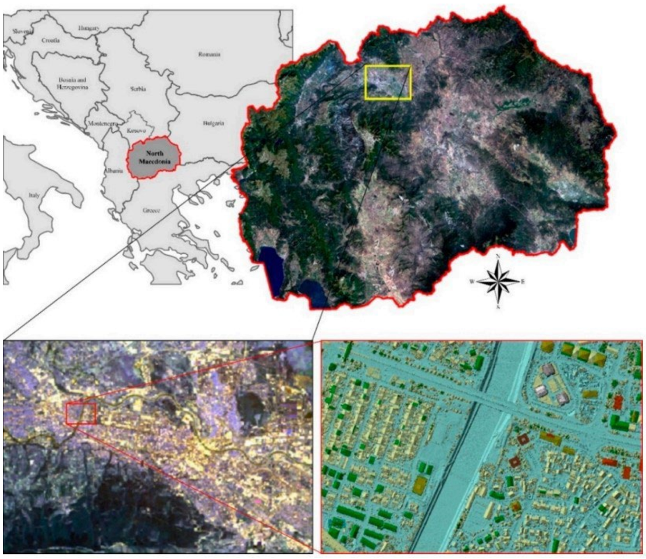


Figure 5. The LIDAR study area (Kaplan et al., 2022).

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/m^2 (Kaplan et al., 2022).

The 3D LIDAR point average 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.

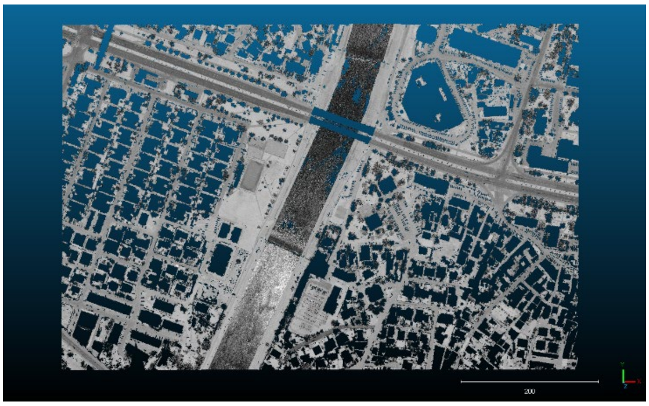
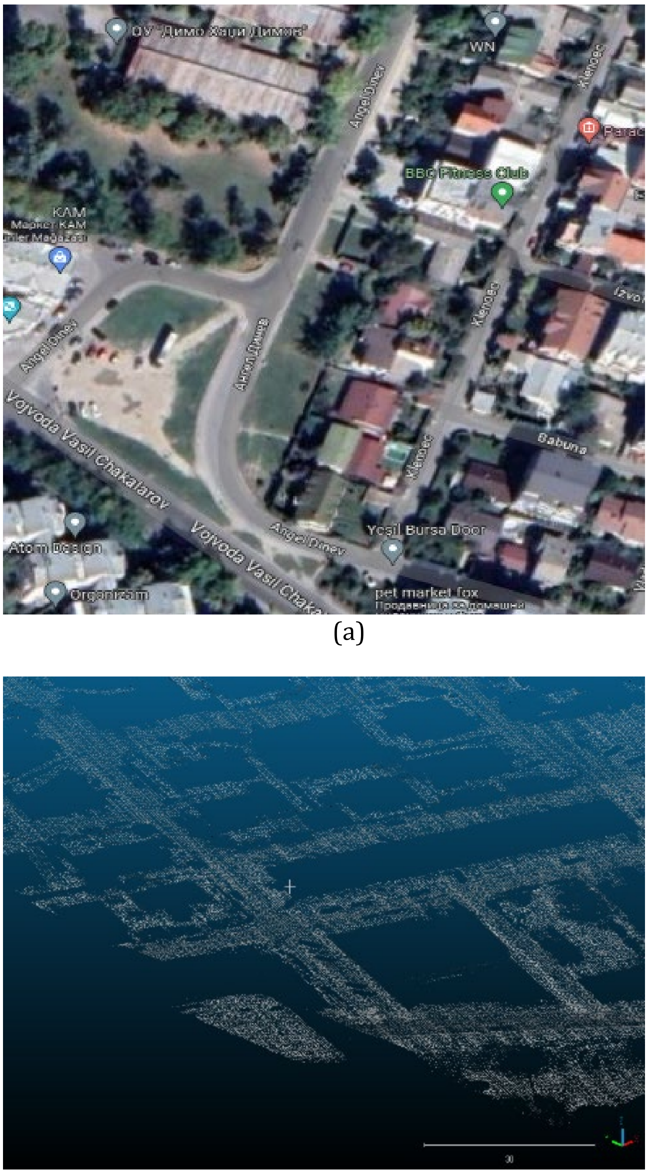


Figure 6. Data Obtained by Leaving the Point Cloud of the Soil Class Alone.

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 7. Google Earth Image of the Study Area (URL-7).



(a)

(b)

Figure 8. (a) Google Earth Image of the Area Closely Examined (URL-7), (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 9. Examining the Image of the Area (URL-7).

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 about the ground.

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.

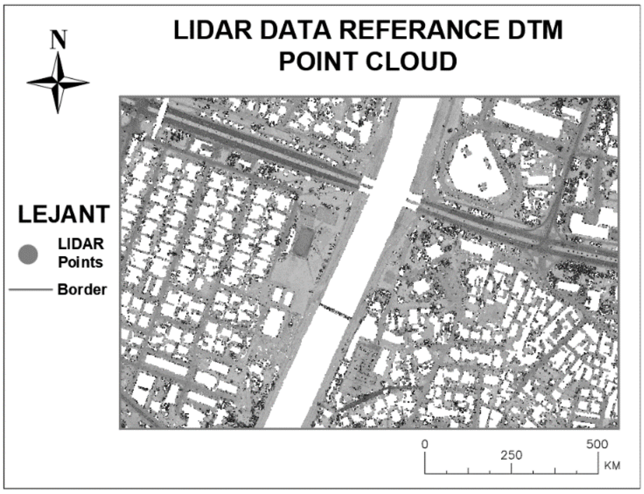


Figure 10. Transferring the Reference Model Created in CloudCompare Software to Autocad Civil 3D Software.

It is necessary to create a triangular model of the point cloud. By selecting the point cloud, the "Create TIN Surface from Point Cloud" window opens and selects the name and style of the triangular model to be created and whether any filtering methods will be applied. In our study, no filtering studies are being performed at this stage. Since it is desired to create an accurate model with manual interventions, this model should not be created with the algorithm that the software has. By selecting the unfiltered option, a triangular model was created.

The accuracy of the model is investigated by creating profiles and sections belonging to the created triangular model. The sections created are passed with an decoupling distance of 50 meters, allowing for clearer information about the terrain. One profile and eleven sections are being created. After it is decided that the model created after the cross-sections are examined can be used as reference data, the filtering operations of LIDAR data are started.

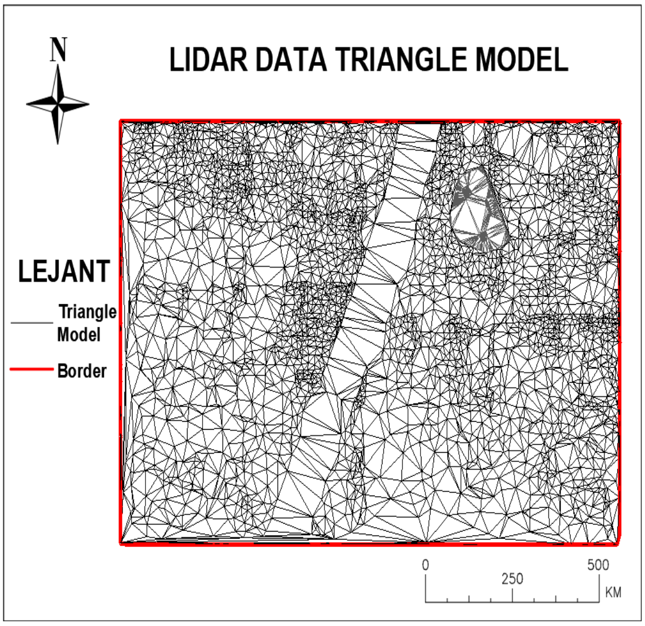


Figure 11. Triangle Model Created in Autocad Civil 3D Software.

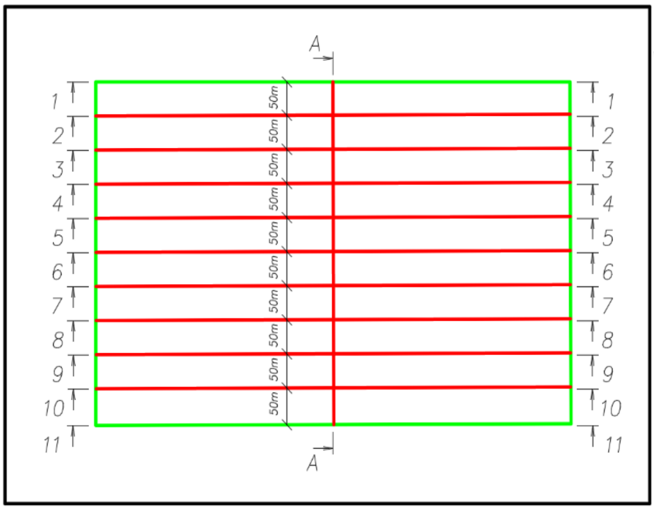


Figure 12. Sectional layout.

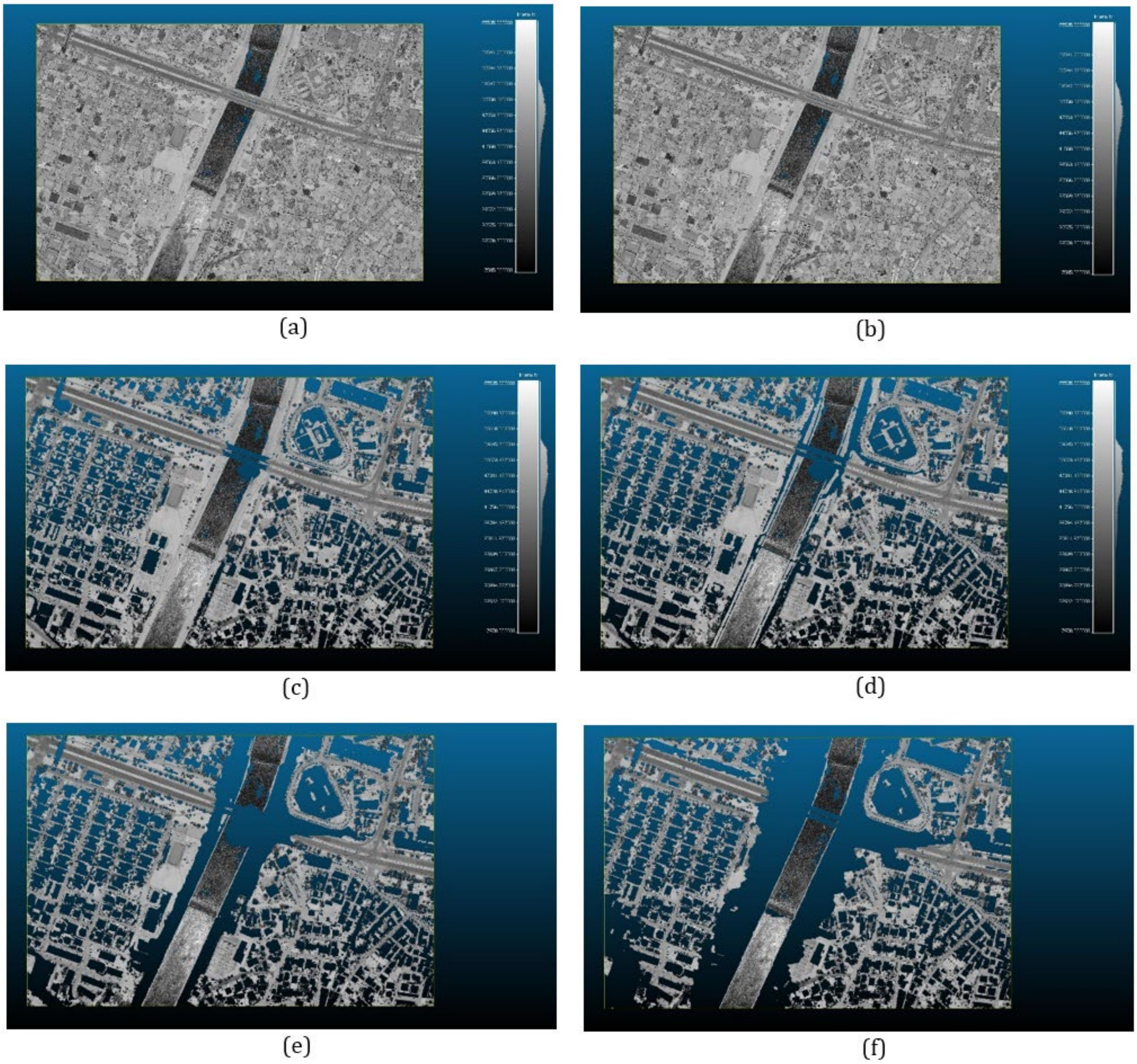


Figure 13. For an urban LIDAR point cloud; (a) The Original Point Cloud, (b) Data Obtained As a Result of Entering the CSF Filter Algorithm Cover Value as 0.1, (c) Data Obtained as a Result of Entering the CSF Filter Algorithm Cover Value as 0.5, (d) Data Obtained As a Result of Entering the CSF Filter 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 (Sarıtaş and Kaplan, 2023).

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. Number of LIDAR point cloud points in the urban area (Sarıtaş and Kaplan, 2023)

Clouth Resolution	Number of LIDAR Points
Original Data	4.537.424
0.1	2.878.720
0.5	2.373.512
1	2.174.743
2	1.896.947
5	1.557.410

Table 2. Point numbers of LIDAR data created with CSF Filter (Sarıtaş 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

The volume calculation method is accepted as an alternative proposal to the classical accuracy analysis methods in the study. Since it is not possible to control the ground points with a proven DTM and geodetic measurements, the result data is obtained by calculating the volume between the manually prepared reference DTM and the DTM obtained through filtering studies.

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 14 visually illustrates the potential differences between these two distinct models.

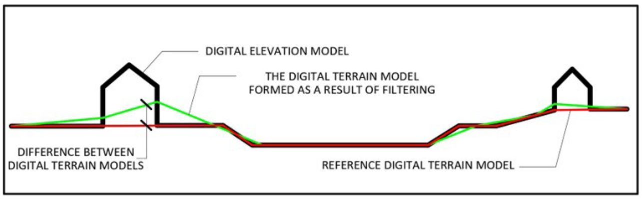


Figure 14. Difference Between Reference DTM and Filtering DTM

AutoCAD Civil 3D software establishes a separate triangular model 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 15, 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.

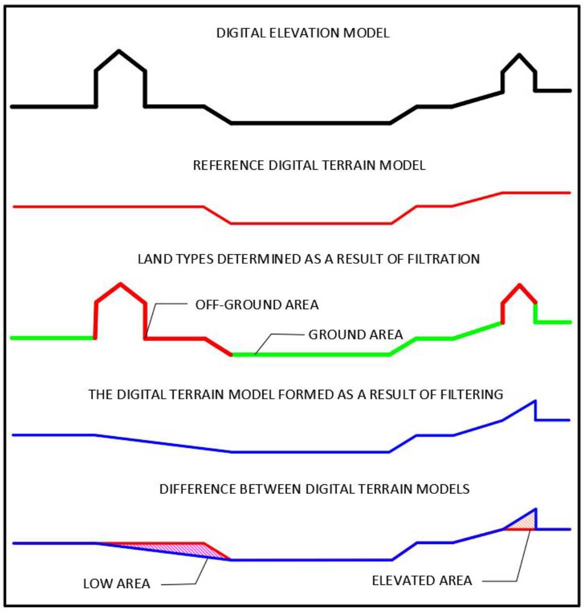


Figure 15. Comparison of DTM

Table 3. Accuracy analysis results of models obtained using the CSF Filter algorithm

CSF Filter Parameter Value	Low Area (m^3)	Elevated Area (m^3)	Total Difference (m^3)
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.

The evaluation of positional accuracy also becomes possible with the volume calculation. In addition to the volume values obtained by the analysis method, it also enables the creation of the difference surface between the two triangular models used in volume calculation. In this way, it plays an important role in obtaining positional accuracy with the height information obtained from any part of the difference surface obtained in this way.

Differences can be detected positionally by using the Spot Elevations command on the difference surface obtained by volume calculation. The average heights of the difference surface are determined by randomly marking the point.

4. Discussion

When the literature is examined, reference models have been created in previous studies both with GNSS receivers and with the help of aerial photographs, and the accuracy value of the filtering algorithm to be tested is calculated, but in the study we are doing, the reference model is prepared by making manual interventions to the data to be filtered by not using any different measurement methods. The reference model is created by examining from the very beginning to the last stage, fully complying with the belief that manual intervention should be performed even in the most accurate reference models that are determined during literature reviews. The part of this situation that is seen as a disadvantage is that it is not evaluated with a different evaluation method and can be taken into account that it is not compared with a model that cannot be obtained due to a different measurement method.

Cross sections and triangular models created during the studies carried out in Civil 3D software are used in large-scale projects (road, tunnel, dam, etc.) the substrate provides the advantage of being used as data. These data provide the creation of a data that can be used at all stages from project costs to project completion.

Deciphering the positional differences between the difference surface obtained during the creation of the volume account and the DTM data obtained as a result of reference and filtering based on location is seen as a different advantage of the method being used.

When all the DTM data obtained as a result of filtering were examined, it was revealed that each of them should be manually intervened. It is concluded that supporting the model accepted as a reference with ground measurements or aerial photographs can increase the reliability of the study.

Employing terrestrial measurement methods for crafting the reference model has the potential to significantly enhance its accuracy. In contrast, manually generating the reference model in this 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. Conclusıon

In the studies to be conducted for the purpose of classifying and then evaluating LIDAR point cloud data, volume calculation can be performed and accuracy analysis can be performed, if desired, the data to be used as a reference should first be obtained by ground measurements or aerial photographs, and then manually correcting the parts that need correction in the resulting model can increase the confidence value of the reference data.

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Author Contributions

Conceptualization and design: Berkan Sarıtaş, Gordana Kaplan
Data collection: Gordana Kaplan
Analysis of data and interpretation of results: Berkan Sarıtaş
Writing the first draft of the manuscript: Berkan Sarıtaş
Review and editing: Gordana Kaplan

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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