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Türkiye LİDAR Dergisi

Dergi Hakkında

Türkiye LiDAR Dergisi; LiDAR teklolojisini geliştirme, kullanım ve yer bilimleri ile ilgili çalışmaları yayınlayan ve Uluslararası Dizinler ve Veritabanlarında taranan hakemli bir dergidir. Dergi, LiDAR Sistemleri ve LiDAR Otonom Sistemleri vb. konular ve ayrıca LiDAR'ın tasarım ve uygulamalarına odaklanır.

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- Aşağıdaki konularla doğrudan veya dolaylı faaliyetlerde bulunan bilim adamları, araştırmacılar, mühendisler ve diğer uygulayıcılar arasında bilgi ve deneyim paylaşımını güçlendirecek ve hızlandıracak kolay erişilebilir ve geniş kapsamlı bir tartışma ortamı sağlamak.
- Dünyada ve Türkiye'de teknolojik ve ekonomik kalkınmada rol oynayabilecek mesleki gelişmelerle ilgili sorunların çözümünde büyük önem taşıyan LiDAR teknolojisi ile kurumlar arası işbirliğinin başlatılmasına ve geliştirilmesine katkıda bulunmak.

Türkiye LİDAR Dergisinin kapsamı;

- ✓ Temel LİDAR Uygulamaları,
- ✓ LiDAR Platformları
- ✓ Yersel LiDAR Uygulamaları
- ✓ El Tipi LiDAR Uygulamaları
- ✓ Mobil LiDAR Uygulamaları
- ✓ Giyilebilir LiDAR Uygulamaları
- ✓ Hava LiDAR Uygulamaları
- ✓ İHA LiDAR Uygulamaları
- ✓ LiDAR Otonom Sistemleri
- ✓ LiDAR ile Arttırılmış Gerçeklik ve sanal gerçeklik (VR) uygulamaları,
- ✓ LiDAR verileri ile Coğrafi Bilgi Sistemleri entegrasyonu,
- ✓ LiDAR ile Belgeleme Çalışmaları
- ✓ LiDAR ile Endüstriyel ölçmeler,
- ✓ LiDAR ile Deformasyon ve Heyelan Ölçmeleri,
- ✓ LiDAR ile Madencilik Ölçmeleri,
- ✓ LiDAR ile Şehircilik ve Ulaşım Planları Çalışmaları,
- ✓ LiDAR ile Tarım Uygulamaları,
- ✓ LiDAR ile Hidrografik Uygulamaları,
- ✓ LiDAR ile 3D modelleme
- ✓ LiDAR ile apılan tüm multidisipliner çalışmalar,

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Turkish Journal of LIDAR

TÜBİTAK ULAKBİM

About Journal

The Turkish Journal of LiDAR is a peer-reviewed journal that publishes studies on LiDAR technology development, use, and earth sciences and is scanned in International Indexes and Databases. The journal, LiDAR Systems, and LiDAR Autonom Systems, etc. focuses on the design and applications of LiDAR, including.

Aim & Scope

Turkish Journal of LiDAR,

- To present international developments in the use of terrestrial, wearable, UAV, air, and mobile LiDAR to the information of scientists interested in the fields of Map, Geology, Environment, Mining, Urban Planning, Agriculture, archeology, and architecture.
- To provide an easily accessible and wide-ranging discussion environment that will strengthen and accelerate the sharing of knowledge and experience between scientists, researchers, engineers, and other practitioners who are involved in direct or indirect activities with the following topics.
- To contribute to the initiation and development of inter-institutional cooperation with LiDAR technology, which is of great importance in solving problems related to professional developments that can play a role in technological and economic development in the world and in Turkey.

The scope of Turkish Journal of LiDAR;

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- ✓ LiDAR Platforms
- ✓ Terrestrial LiDAR Applications
- ✓ Hand-Held LiDAR Applications
- ✓ Mobile LiDAR Applications
- ✓ Wearable LiDAR Applications
- ✓ Air LiDAR Applications
- ✓ UAV LiDAR Applications
- ✓ LiDAR Autonomous Systems
- ✓ Augmented Reality and virtual reality (VR) applications with LiDAR,
- ✓ Geographical Information Systems integration with LiDAR data,
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- ✓ Industrial measurements with LiDAR,
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- ✓ Agricultural Applications with LiDAR,
- ✓ Hydrographic Applications with LiDAR,
- ✓ 3D modeling with LiDAR
- ✓ All multidisciplinary studies conducted with LiDAR,

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Documentation of Cultural Heritage with Backpack LiDAR Usage on Photogrammetric Purpose

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Keywords
Backpack Lidar
Cultural Heritage
Documentation
GNSS/IMU Integrated systems
3D Model

ABSTRACT

Architectural documenting is an essential requirement to identify the evidence of historical artefacts, be instrumental in their transmission to future generations, and document the destructions they have suffered. With photogrammetric methods in recent years, a new perspective has been given to survey investigations. The data obtained by 3D modelling can be collected in the digital environment and presented visually. Modelling historical artefacts' external and internal structures together is a task that can be done with many sessions with classical terrestrial laser scanners. Backpack Lidar Systems are a proper newly applied alternative method in large areas of use and historical buildings where many sessions should be held with terrestrial laser scanner systems. These systems quickly acquire coordinate data and omega, kappa and phi angles differences with internal GNSS/IMU components and save time and cost following photogrammetric mentality. In this research, using Backpack Lidar System; The exterior and interior structure of the village mosque, which is an Ottoman artefact built in 1899 at the Dumanoluğu Village in the Şiran District of Gümüşhane City, was modelled in 3D. With its integrated camera, the point data has been coloured and made suitable for architectural survey studies. The village mosque's exterior scan was completed within seven minutes, and the interior scan within five minutes. 2.041.971 points were obtained in the external scanning, and 821.306 points in the internal scanning. Four GCPs were used for the mosque's exterior screening. The point clouds obtained were combined and modelled. Thus, the model is presently digitally documented.

Sırt Lidarının Fotogrametrik Amaçlı Kullanımıyla Kültürel Mirasın Dokümantasyonu

Anahtar Kelimeler
Dokümantasyon
GNSS/IMU
Kültürel Miras
Sırt Lidarı
3B Model

ÖZ

Tarihi eserlerin taşıdığı izleri tespit etmek, gelecek nesillere aktarılmasına vesile olmak, yaşadıkları tahribatları belgelemek için mimari arşivleme çok önemli bir gerekliliktir. Son yıllarda fotogrametrik yöntemlerin gelişimi ile rölöve çalışmalarına yeni bir bakış açısı kazandırılmıştır. 3B modelleme ile elde edilen veri sayısal ortamda saklanabilmekte ve görsel olarak sunulabilmektedir. Tarihi eserlerin dış yapısını ve iç yapısını birlikte modellemek klasik yersel lazer tarayıcılar ile çok sayıda oturumla yapılabilecek bir iştir. Geniş kullanım alanlarında ve yersel lazer tarayıcı sistemleriyle çok sayıda oturum yapılması gereken tarihi yapılarda Sırt Çantası Lidar Sistemleri yeni yeni uygulanan önemli bir alternatif yöntemdir. Bu sistemler koordinat verilerini ve eğiklik, dönüklük, öteleme farklarını dahili GNSS/IMU bileşenleriyle hızlıca elde ederek fotogrametrik anlayışa uygun zamandan ve maliyetten kazanç sağlamaktadırlar. Bu araştırmada, Sırt Çantası Lidar Sistemi kullanılarak; Gümüşhane İli Şiran İlçesi Dumanoluğu Köyü'nde bulunan 1899 yılında yapılan Osmanlı Eseri olan köy camisinin dış ve iç yapısı 3B olarak modellenmiştir. Entegre kamerasıyla nokta verisi renklendirilerek mimari rölöve çalışmalarına uygun hale getirilmiştir. Köy camisinin dış cephe taraması 6 dakika, iç mekân taraması 4 dakika içerisinde tamamlanmıştır. Dış cephe taramasında 2.041.971 nokta, iç mekân taramasında 821.306 nokta elde edilmiştir. Caminin dış cephe taramasında 4 adet YKN kullanılmıştır. Elde edilen nokta bulutları birleştirilmiştir ve modellenmiştir. Sonuç olarak, tarihi cami yapısal olarak sayısal ortamda belgelenmiştir.

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1. INTRODUCTION

Human beings have built important structures for protection, shelter and meeting their basic needs for centuries. These structures have undergone partial or total degeneration due to wars, natural conditions, and people throughout history. Every society has an absolute responsibility to transfer the cultural heritage of humanity to future generations and protect it in the best way. Living in a geography that has hosted the most important civilizations of human histories, such as Anatolian lands, forces a much more important responsibility.

It is a great necessity to use sufficient technological infrastructure and human resources to protect and transfer all cultural artefacts in the borders of our country to future generations. For this purpose, developing and strengthening the use of photogrammetric methods can be seen as a duty. All photogrammetric techniques such as Unmanned Aerial Vehicles (UAV), terrestrial, mobile, and aerial Light Detection and Ranging (lidar) systems, and satellite data can be practised to preserve and document cultural heritage (Kaya et al., 2021; Ulvi et al., 2019; Makineci 2016; Yakar et al., 2014; Yaman & Kurt, 2019; Bakirman et al., 2020; Elfadaly et al., 2020).

All photogrammetric methods have their own advantages and weaknesses according to the area of use and purpose. According to the literature, it is possible to clarify the success of terrestrial laser scanning systems, which have been widely used in recent years in cultural heritage documentation. Studies have shown that Terrestrial Laser Scanning (TLS) systems give better results (Kuçak et al., 2020). However, because of the problems that happen to the loss of time and the increase in the number of sessions (Kör & Cerit, 2020), researchers need new alternatives (Zeybek, 2019). Backpack Lidar systems, carried by human assistance, are also an inherent alternative solution of recent times. Backpack lidars, which generate colored and kinematic spatial data with integrated camera and Global Navigation Satellite Systems (GNSS) systems and, these systems allow working with angular high precision with the Inertial Measurement Unit (IMU) supported operating systems.

In this study, the positional accuracy and final product (3D Model) success of these systems were tested by documenting a mosque's internal and external architectural features using Backpack Lidar quickly. As a result, it has been determined that these systems offer fast results, innovative and promising.

2. MATERIALS and METHOD

2.1. Study Area

The historical village mosque belonging to the Dumanoluğu Village of Gümüşhane Province, Şiran District, located in the east of the Black Sea Region, Turkiye, was chosen as the study area. Although it is not clear who built the mosque, it is on the trade line of caravans on the Silk Road as an Ottoman period structure. Its location and interior-exterior structure are shown in fig 1.

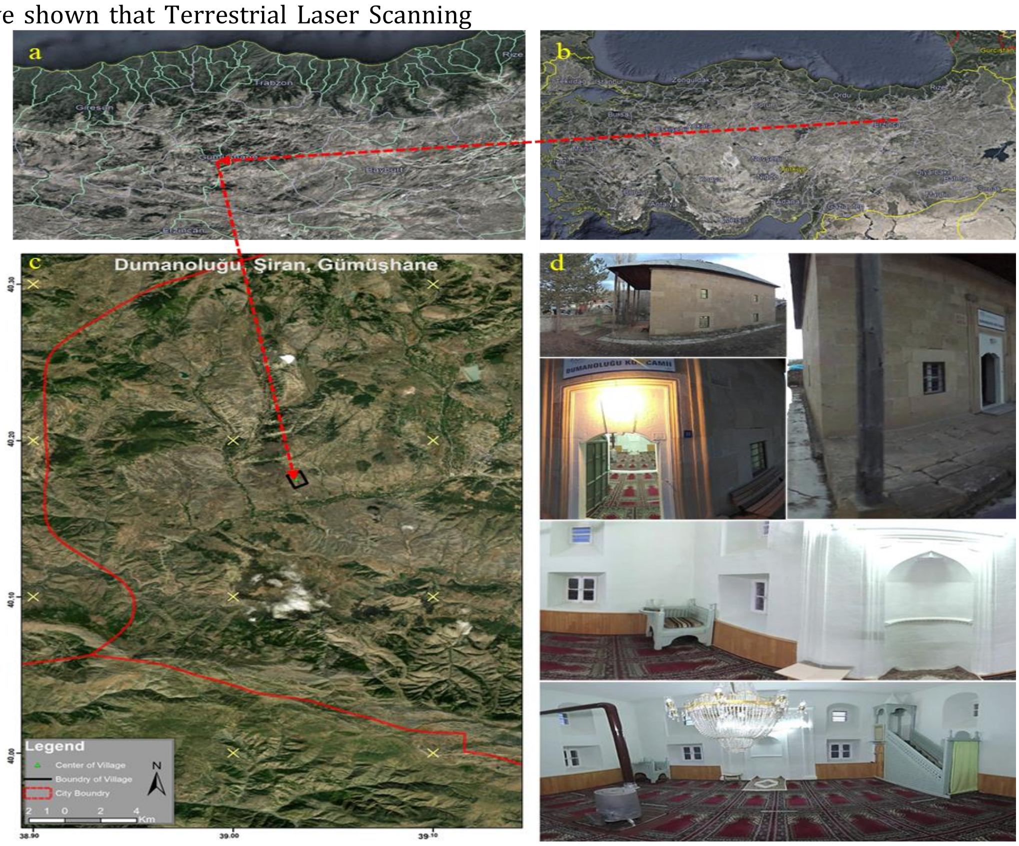

Figure 1. Study area and inside-outside of the mosque (a: Gümüşhane City, b: Position of Gümüşhane City in Black Sea Region, c: Dumanoluğu Village, d: Internal and External Profiles of Mosque)

2.2. Backpack Lidar System

In this study, the Greenvalley Libackpack DGC50 backpack LIDAR system was used. When the backpack LIDAR models are analysed, it is seen that they generally have a single laser sensor and a panoramic camera. Unlike the general, the Libackpack DGC50 model has two laser sensors (one horizontal and one vertical), with a panoramic camera and GNSS/IMU receiver. With the GNSS receiver in the LIDAR system, point data is obtained in coordinates during the sessions held in outdoor dimensions (Fig 2).

The GNSS receiver in the laser scanner works with the PPK method. While providing access to the satellite data required for the PPK, the ground station operating with the static method is used simultaneously. In this way, the horizontal position of the obtained point data can be obtained up to ±7 cm. In addition, the properties of the Lidar used in the study are shown in Table 1 (greenvalleyintl.com 2021).

Table 1. Greenvalley Libackpack DGC50 specs

Specifications	Value
Dimension (mm)	1010 X 344 X 252
Battery	5700 mAh
Weight	10.3 kg
Working hours	~2 h
Laser Sensor	VLP16 × 2
Accuracy	±3 cm
Vertical FOV	-90°~90°
Horizontal FOV	0°~360°
Measuring range	100 m

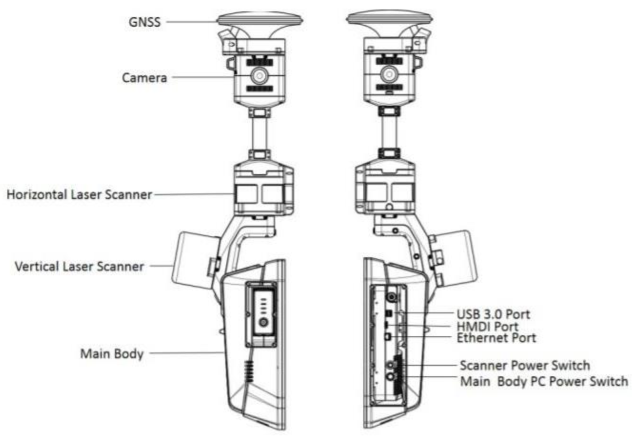

Figure 2. Greenvalley Libackpack DGC50 Profile

2.3. Workflow of Study

The general workflow of the study is divided into fieldwork and office work. There are Ground Control Points (GCPs) used in fieldwork and operations for generating lidar data. Office work includes adjustment of GCPs and analysis of point cloud (fig 3).

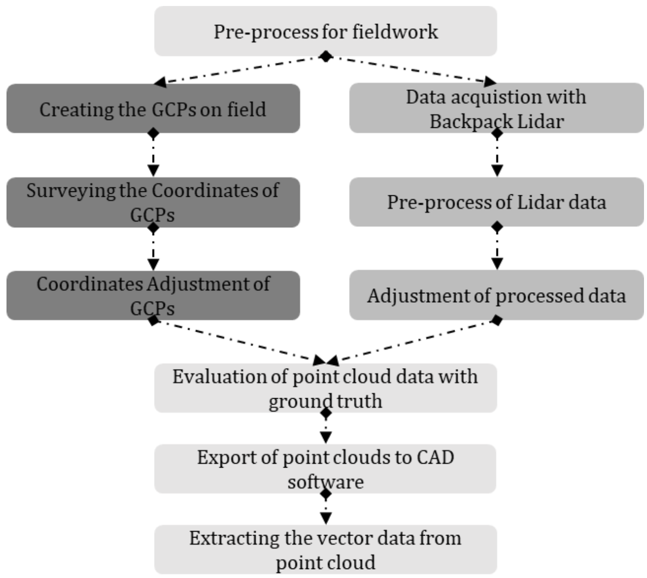

Figure 3. Workflow of fieldwork and office work

2.3.1. Pre-process for fieldwork

Determining the Static GNSS receiver location, which is a part of the Lidar system, is considered the first step of the fieldwork planning studies. It is required to determine the location of the fixed GNSS receiver, taking care that there are no high buildings and trees around it. The distance between the static GNSS receiver and the Mobile GNSS receiver in the lidar system should not exceed 3 km.

2.3.2. Data acquistion

Lidar system is started around the historical monument to be scanned outdoors. Since the Greenvalley Libackpack DGC50 consists of a laser scanner + panoramic camera + GNSS components, some issues need to be considered before starting data collection. Check that the camera is ready and make sure that the recording process has begun. It is checked that the GNSS receiver is connected to a sufficient number of satellites and that it is ready. It is necessary to wait at least 3 minutes before starting data collection; It is expected to obtain the satellite data required for an accurate coordinating process of the point cloud. After waiting, data is created to be collected after the "8" mark is made slowly on the ground to perform GNSS calibration.

In indoor scanning, it is checked that the camera is ready and the recording process has begun, and then the scanning is started. Since the Mobile GNSS receiver in the Lidar system will be disconnected from the satellite during indoor data acquisition, the GNSS steps performed in the outdoor scan should not be followed.

After the Lidar system is started, the details of the components mentioned above begin to appear on the control unit screen (tablet etc.). The surfaces that the laser scanner touches instantly appear in the control unit by being coloured in dots according to the height values. Also, the scan number of each frame is displayed on the control unit. Whether the camera is in recording status, recording time; The number of connected satellites, connection status with satellites, distance travelled, walking speed, working time, IMU data are instantly monitored in the control unit.

Data should be collected, taking into account the laser scanner's beam emission of up to 100 meters. Care should be taken to the quality of the satellite connection so that the GNSS receiver is not disconnected from satellites. Point data obtained from indoor scanning performs coordinate transformation in office work.

While the outdoor scan session is ended; the process steps for the lidar system start-up process are performed oppositely; first, the '8' mark is drawn on the floor, then after waiting at least 3 minutes, the session is terminated after it is concluded that there is no problem by checking the details in the control unit. Simultaneously with the Lidar sessions, ground control points are placed on the floor, and the laser scanner scans the GCPs. Then GCPs are surveyed with a different Cors-GNSS receiver.

2.3.3. Evaluation of point cloud data with ground truth

After the fieldwork, camera file, point data file, mobile GNSS data in the lidar system and recording data of the fixed station, an independent part of the system, are obtained. These data are processed in the point data processing software of Lidar company. After uploading the software to convert the data mentioned above into the country coordinate reference system, data parameters are selected. Correction is made to the mobile GNSS data with the data obtained from the fixed station. The process of colouring the point cloud data with the SLAM algorithm with the images obtained in the camera is performed. In this way, the location accuracy of the point cloud data obtained from the laser scanner is ±7 cm. As a result, the accuracy of the coordinated and RGB point cloud obtained is provided with the help of GCPs.

2.3.4. Extracting the vector data from point cloud

Essential details of the historical artefact are drawn in the point cloud, ready for drawing in the CAD environment. These details can be structures such as doors and windows or historical value objects such as a textured object and an icon. CAD software that supports point cloud formats (.las, .laz, .e57 etc.) is preferred for the drawing process.

3. RESULTS AND DISCUSSIONS

In the research, external and internal scanning was carried out to obtain and document the point cloud of the mosque. The external scan of the mosque was completed within 6 minutes (fig 4), and the internal scan within 4 minutes (fig 5). 2.041.971 points were obtained in the external scanning, and 821.306 points were obtained in the internal scanning.

Point data collected with lidar in the study area was transformed into the country coordinate reference system (TUREF / TM39) without any points obtained by terrestrial or photogrammetric methods in the process stage. In the Lidar system, the point cloud data collected by systems without mobile GNSS receivers can be transformed with points obtained by local or photogrammetric methods. The iterative closest point algorithm (ICP), which has been increasingly used in recent years, is preferred for the transformation process. The translation and rotation matrices required for transformation are obtained by using ICP. In order to use the ICP algorithm successfully, at least 3 points are needed (Zeybek, 2019).

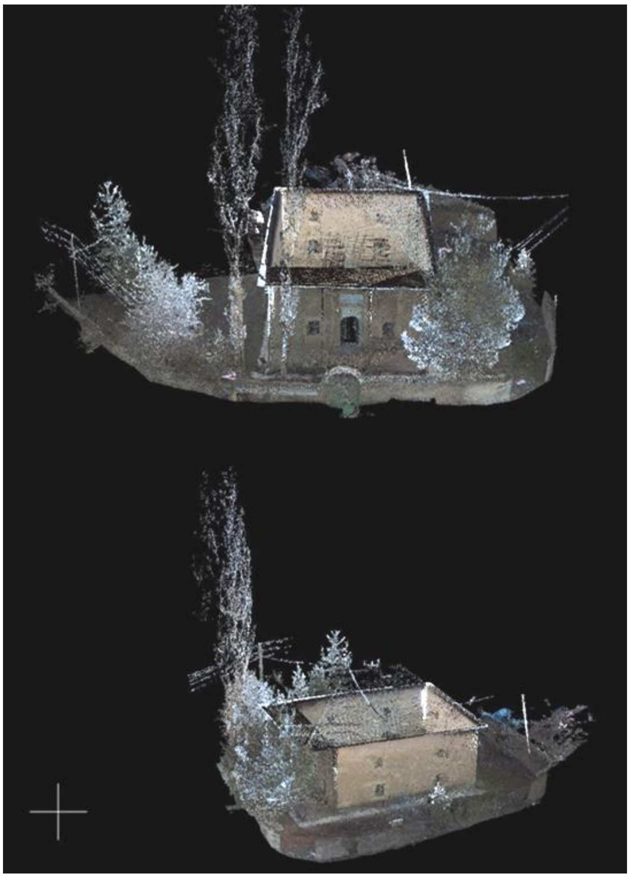

Figure 4. The external scan of the mosque

Today, terrestrial laser scanners are used for historical artefacts, archaeological excavations, etc. It is frequently used in many modelling studies. Terrestrial laser scanners are installed at many points in the area to be scanned, so fieldwork takes a long time. The increase in the number of processes in office work takes a long time due to the efforts to combine the point clouds obtained from different points (Ulvi et al., 2019). When we examine other models of handheld laser scanners, it can be obtained from the laser scanner we use in our work for a long time due to hand-held and single laser scanner fatigue. Less point cloud is obtained from the obtained point cloud (Yaman & Kurt, 2019).

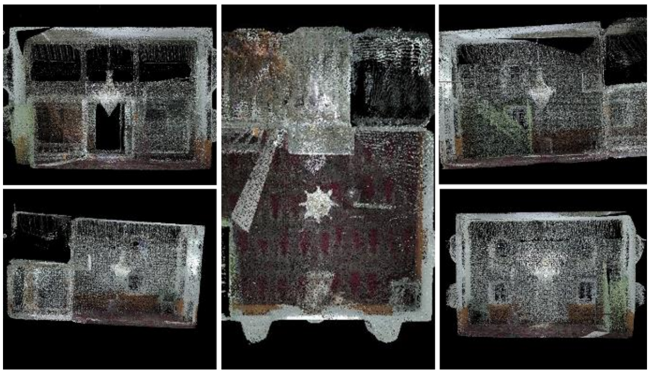

Figure 5. The internal scan of the mosque

Using photogrammetric studies according to the National Large Scale Map Production Regulation (BÖHHBÜY, 2018); It is necessary to use a minimum of 4 checkpoints, up to 30% of the GCP number. Since the point cloud data collected with the GVI Libackpack DGC50 is coordinated, adjustment is not performed in this study. Considering the minimum number of GCPs, 4 GCPs were measured in the exterior scanning of the historic mosque. Error-values of the determined GCPs is given in Table 2.

Table 2. Minimum, Maximum, Mean Errors of GCPs

	Horizontal (X, Y) (m)	***Vertical (Z) (m)***
Min Error	0.020	0.004
Max Error	0.082	0.077
Mean Error	0.047	0.041

As shown in Table 2, successful results have been presented in terms of horizontal and vertical accuracy. The average horizontal error is approximately 5 cm, and the average vertical error is about 4 cm.

The coordinated point cloud is transferred to CAD software. The drawing process (vectorisation of structure) is performed in CAD. In this way, vector data is obtained. The walls of the historical mosque can be obtained in vector form, as in fig 6.

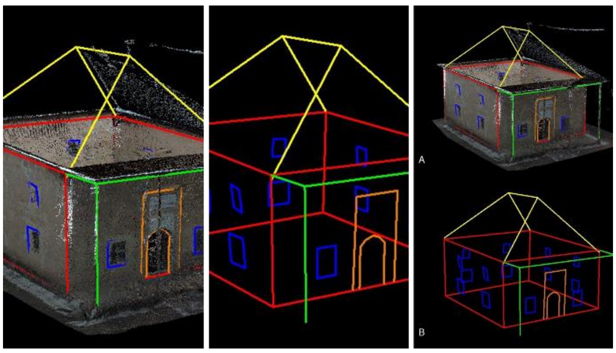

Figure 6. Vectorisation of Structure

4. CONCLUSION

This study aimed to determine that the documentation and modelling of historical buildings can be carried out quickly and effectively with Backpack Lidar. The average horizontal error is about 5 cm, and the vertical 4 cm shows that the study results are adequate. Well-to-do results have been demonstrated with the fieldwork and office work carried out for this purpose.

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Indoor Mapping and Positioning Applications of Hand-Held LiDAR Simultaneous Localization and Mapping (SLAM) Systems

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Keywords
Point cloud
LiDAR
Hand-held laser scanner
Indoor mapping
Building plan extraction
Building Information Modeling (BIM)

ABSTRACT

Indoor mobile laser scanning (MLS) systems, based on the principles of simultaneous localization and mapping (SLAM), have become an approved method in recent years to obtain indoor environment data. 2D and 3D laser scanning systems based on SLAM algorithms have now become portable systems hand-held and on the back. The SLAM approach instantly determines the necessary positioning and mapping parameters by using the sensors' data and thus produces data representing the environment in 2D or 3D with point clouds. 3D and 2D building plans provide reference base maps for indoor location and positioning. These data are also of high importance for architectural surveys and restoration works, and indoor design. However, the SLAM process generating duplicated and noisy point clouds causes challenges in defining the characteristics of linear edges and planes. In this study, preliminary study results of the methodology applied for the semi-automatic drawing of a building plan from a building section obtained from SLAM data are presented. With this proposed method, it is provided to facilitate indoor drawings and extract 2D planar and geometric information from the complexity of 3D point clouds. Since the proposed study is becoming an adaptive methodology, it is a method capable of development, and it is thought that performance criteria can be increased.

El-tipi LiDAR Eş Zamanlı Konumlama ve Haritalama (SLAM) Sistemlerinin İç Mekân Haritalama ve Konumlandırma Amaçlı Uygulamaları

Anahtar Kelimeler
Nokta bulutu
LiDAR
El-tipi lazer tarayıcı
İç mekan haritalama
Bina planı çıkarımı
Bina bilgi modeli

ÖZ

Eşzamanlı konumlandırma ve haritalama (SLAM) prensiplerine dayanan iç mekân mobil lazer tarama (MLS) sistemleri, iç mekan ortam verilerinin elde edilmesinde son yıllarda tercih edilen bir yöntem haline gelmiştir. SLAM algoritmaları temelli 2B ve 3B lazer tarama sistemleri günümüzde artık elde ve sırtta taşınabilir portatif bir sistem halini almıştır. SLAM yaklaşımı, sensörlerden gelen verileri kullanarak gerekli konumlandırma ve haritalama amaçlı parametreleri anlık olarak çözüme ulaştırmaktadır ve bu sayede ortamı 2B veya 3B olarak nokta bulutlarıyla temsil eden verileri üretmektedir. 3B ve 2B bina planları, iç mekân konumlandırma amaçlı referans altlık haritalar sunmaktadır. Üretilen bu veriler aynı zamanda mimari rölöve ve yenileme çalışmaları için ve iç mekan tasarımlarında da büyük bir öneme sahiptir. Ancak SLAM sürecinin tekrarlı ve gürültülü nokta bulutlarını üretmesi doğrusal hatların ve düzlemlerin karakteristiğinin tanımlanmasında zorluklara neden olmaktadır. Bu çalışmada, SLAM verilerinden elde edilmiş bir binanın yarı otomatik olarak bir kesit üzerinden bina planının çıkarımı için uygulanan metodolojinin ön çalışma sonuçları sunulmuştur. Önerilen bu yöntem ile iç mekan çizimlerinin kolaylaştırılması ve 3B nokta bulutlarının karmaşasından 2B düzlemsel ve geometrik bilgilerin çıkarımının kolaylaştırılması sağlanmıştır. Önerilen çalışma adaptif bir metodolojiye açık olduğu için geliştirilmeye açık bir yöntemdir ve performans kriterlerinin artırılabileceği düşünülmektedir.

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1. INTRODUCTION

Drawing out the plans of closed spaces and developing interior space designs are among the main mapping issues from the past to the present (Sirmacek et al., 2016). The existence of maps and plans, especially in the renewal stages of buildings with architectural importance, makes these processes easier to interpret from an architectural point of view. Many studies for geomatics are pioneering these studies today. Building plans and building areas constitute an important subject for many disciplines (Velas et al., 2019).

The development of total station devices with laser signals constitutes an important step in measuring and mapping architectural structures for similar purposes. Advances in technology and physical science enabled the spread of terrestrial laser scanning systems in the early 2000s (Gopi et al., 2018). However, these measurement practices were carried out with multiple sessions and were still insufficient for the surveyors, which led to a new search, and mobile laser scanning systems were developed. These systems have provided solutions to measurement and documentation processes in areas where measurement areas are complex, access is reduced, or the possibility of applying terrestrial laser scanning measurement procedures is limited (Yadav & Singh, 2018).

In the last decade, mobile laser scanning or mobile LiDAR (MLS) systems installed on the vehicle were used for topographic and corridor mapping purposes, but their dimensions did not allow the mapping of indoor spaces (Karasaka, 2012). The development of hand-held or wearable laser scanning systems has led to the elimination of such limitations. In this way, portable systems are important advantages to be adapted with mapping or measurement techniques to provide detailed and geometric information for 2D / 3D data collection, versatile to complex and confined spaces, and reconstruct different environments that respond to common purposes.

Hand-held LiDAR technologies, an innovative approach in modern construction industries, are a system that saves time and money in the mapping manner of the entire field, allows safe observation and investigation, and has the potential to facilitate building information model activities. However, today, the slow evolution of the institutions and organizations dealing with the complex current situation of the buildings and the outdoor layout plans against these developing technologies prevents the widespread use of LiDAR systems. Besides, MLS mapping systems have applications in different fields. These systems make significant contributions to the 3D mapping of large and complex areas with effective and practical, high-performance near/mid/long-range laser devices. However, the expensive and complex technology of MLSs, different equipment, and accessories are also among the factors limiting their use. The complexity of these integrated systems has supported developing technologies that are easier to apply in indoor mapping and portability that better reach the needs.

In recent research, developments in integrated features similar to MLS in measuring applications performed at close range, mainly portable solutions, have been produced. Hand-held or back-mounted devices have thus become available for complex indoor mapping, industrial buildings, forest inventory extraction, tunnel, mine, volume calculations, and the production of 3D spatial models of the cave and its surroundings (Bauwens et al., 2016; James & Quinton, 2014; Sammartano & Spanò, 2018).

As a result, very limited research has highlighted the potential applications of hand-held LiDARs in archeology, architecture, and civil engineering, and management compared to some other fields. It is of great importance to increase awareness of hand-held LiDAR and mobile LiDAR technologies and analyze the benefits they can bring to existing and future building management systems. Therefore, this article aims to investigate the potential applicability of hand-held LiDAR systems to benefit building management, enable indoor mapping, and make an application that can assist various disciplines such as mapping, architecture, construction, and archeology.

In this study, a portable hand-held LiDAR-based scanning system in ZEB-REVO provided by GeoSLAM ™ was analyzed. A deformed building was chosen as the data set. However, the proposed methodology is research that can be adapted to other data sets. In this way, it is possible to extract geometric features of indoor mapping and designs.

2. MATERIAL AND METHOD

In this study, a semi-automatic methodology was developed to produce indoor mapping processing from point clouds obtained with GeoSLAM ZEB-REVO. The process flow applied for this is given in Figure 1. Indoor scanning operations were carried out by starting outside the venue.

In order to evaluate the accuracy potential of the hand-held LiDAR according to manual reference data, the point clouds were first cleaned of the noise parts. False points originating from several surfaces in the ZEB-REVO point cloud should be eliminated by statistical method. The precise extraction of the walls is the main goal. Hence, in the performance evaluation, the error rates of the areas calculated with only the building facade planes were evaluated.

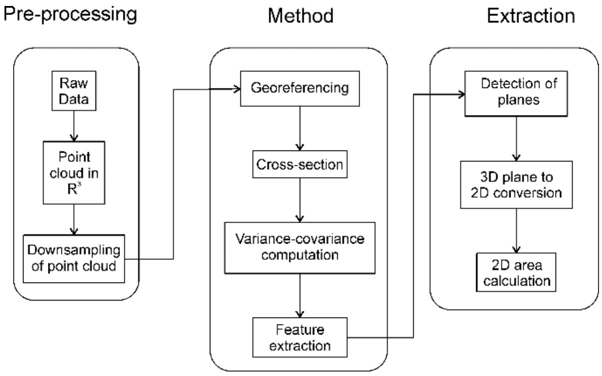

Figure 1. Methodology

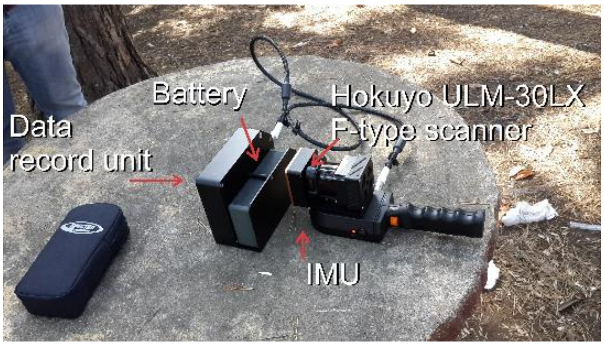

Figure 2. GeoSLAM ZEB-REVO laser scanner system components

2.1 GeoSLAM ZEB-REVO

The hand-held LiDAR scanning system for 3D mapping with the principle of SLAM algorithm is a scanner system widely used among portable scanners. Therefore, the ZEB-REVO scanner produced by GeoSLAM was applied in this study for the 3D mapping solution. The solution to the indoor mapping and positioning problem occurs independently of global positioning satellite systems (GNSS) (Shamseldin et al., 2018). The basis of this is a SLAM-based algorithm that is applied iteratively to detailed geometric properties from distance-based profiles in application areas thanks to the continuously moving scanning sensor (Bauwens et al., 2016; James & Quinton, 2014). The system also includes an inertial measurement unit (IMU) containing triaxial gyroscopes, accelerometers, and triaxial magnetometers (Sammartano & Spanò, 2018).

ZEB-REVO has the Hokuyo ULM-30LX F type scanner (Dewez et al., 2017) and rotates a 360-degree angle perpendicular to the scanner's handle, increasing data collection capacity (Figure 2). It produces 42300 effective signals per second with an angular range of 0.006 rad; that is, it has the capacity to generate 1 point every 6 mm at a distance of 1 m with a single signal transmission on a suitable reflection surface. This system may appear sparse in point density compared to high-resolution terrestrial laser scanner systems, but the coverage and density of the point cloud also increase in terms of mobile data collection indoors.

The maximum distance of the scanner is indicated as 30-m indoors (ZEB-REVO, 2019). For outdoor areas, it can collect data at intervals of 15-20 m. The main reason for this is that the surfaces cannot reflect the signals well outdoors. In addition, the issue of noise, which is common in LiDAR systems, is important in point cloud data. In indoor scans, point clouds are also affected by noise: noisy sections can form small clusters. These small clusters of noise cause errors in the production of the building information model, especially on wall surfaces. Since point clusters away from surfaces are not connected to surfaces, their deletion is solved by different algorithms.

2.2 Point Cloud

Scanning is more straightforward with the hand-held LiDAR system than with typical terrestrial laser scanning systems. The scanning process was carried out by walking freely within the place where mapping of the hand-held device was requested and obtaining 3D spatial information about walls and other objects. There is no need to interrupt the scanning process. Continuous provision of data offers the opportunity to use visions obtained from different perspectives. Alignment is not required after field measurements like in terrestrial laser scanning systems. Particularly after the measurement is finished for the pre-processing of the raw data, the device is a complete point cloud (GeoSLAM Hub Desktop), that is, millions of points in 3D space representing the scanned space (X: 0, Y: 0, Z: 0) is obtained in the cartesian (rectangular) coordinate system. The point cloud obtained with the inspection area is given in Figure 3. Since the point clouds collected in this study do not require a geodetic coordinate system, they are not transformed to a national reference network and studied in a relative coordinate system. However, if spatial data related to the national reference coordinate system are requested, absolute reference coordinates can be brought to geodetic reference coordinates (georeferencing) in a controlled way with a minimum of four points. For this reason, this stage has been included in the workflow.

In order to extract the relevant floor plan from the point clouds, the cross-section is taken by filtering the point clouds between certain heights, and the building plan extraction processes are started. Section location and thickness may vary according to the feature of the point cloud data and the situation of the space. However, it is more appropriate to take sections at certain distances from the sections where the floor and ceiling points are located. If this region is determined correctly, the histogram graph of the height component distributions of the point clouds should be monitored. Since the floor and ceiling points are closer to the scanning device, this causes more intense data to be produced on these surfaces (Figure 3).

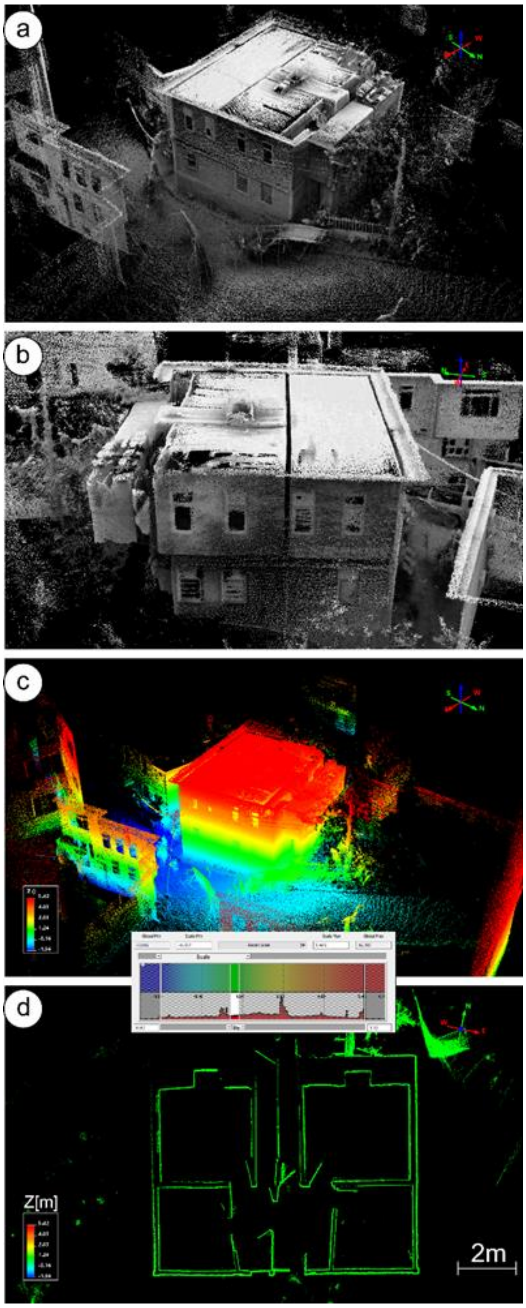

Figure 3. Point clouds obtained with GeoSLAM ZEB-REVO, a) building front perspective view, b) perspective view from the rear (deformed) part of the building, c) point clouds colored with relative height values (-1.56 - 5.42 m), d) sample test section of 30 cm thickness and between 0.82 and 1.12 m.

After the cross-section points are achieved, the surface points should be eliminated from noise and distortion. Thus, statistical noise filtering and moving least-squares surface algorithms were applied (Alexa et al., 2003; Rusu, 2010). The presence of noisy points appears to be a significant problem in processing automated 3D point cloud data (Nurunnabi et al., 2015). The moving least-squares surfaces algorithm is defined as an algorithm for reconstructing the discontinuous and irregular point cloud with continuous functions by calculating the weighted least squares method according to the region around the point for estimating the reconstructed value (Alexa et al., 2003).

2.3 Computation of Locally-Based Eigenvalue Properties

Variance-covariance matrix (C) was calculated according to the local neighborhood value through point clouds. The covariance matrix was calculated with the following formulas to reveal each point's shape (p_i) in the point cloud and its correlation with its neighbors.

$$\bar{p} = \frac{1}{k}\sum_{i=1}^{k} p_i \quad (1)$$

$$C = \frac{1}{k}\sum_{i=1}^{k}(p_i - \bar{p})(p_i - \bar{p})^T \quad (2)$$

where p_i is associated with k adjacent points around it, $\bar{p}$ represents the average value of k adjacent points for each axis. The covariance matrix C is computed to be centered on the p_i point. Eigenvalues $\lambda_1 > \lambda_2 > \lambda_3$ are used as features. However, these properties were used to determine a plane, edge, and corner properties. Thanks to these eigenvalue-based properties, the characteristics of the 3D point clouds could be defined. The formula given below shows the computation of the flatness property with eigenvalues.

$$P_d = \frac{\lambda_2 - \lambda_3}{\lambda_1} \quad (3)$$

With the help of eigenvalues and eigenvectors, different criteria can be obtained to calculate each point's characteristics connected to many neighboring points (Fengguang & Xie, 2017; Weinmann et al., 2013). R programming language codes were used in feature extractions (Team, 2020).

2.4 Region Growing Algorithm

The region-growing algorithm is widely used as an image processing operator (Ketenci, 2011; Sümer & Türker, 2013). Following feature extraction in 3D point clouds data, this study is used to define building walls from each other by surface normals and angular deviations. This algorithm has been applied in order to segment the building walls into sub-groups of large and combined regions according to certain parameters.

In point clouds, surface normals and curvature properties are widely used for grouping (Rabbani et al., 2006). The basic principle of this algorithm ensures that a selected point is assigned to the same group if the criteria for neighboring points are below the threshold values determined by the user. In this study, thanks to this algorithm, the building walls are divided into regions using curvature and surface normals.

In short, the region growing algorithm makes groupings according to the threshold value for determining the similarity properties. The user must give the threshold value, or the process should be started with the pre-group values given as seeds. The threshold value can be determined by examining the deviation value between the property values of the region seed points and their neighboring points. With the deviation value below the threshold value, the region grows, and if the value is greater than the threshold value, a new region definition is realized. The number of regions does not need to be given by the user from the prior.

2.5 Conversion Point Clouds to Raster Data

In this section, 2D information extraction has been performed by transforming 3D data into 2D data. For this purpose, dense point clouds defined in 3D space according to point cloud properties and height value were converted into raster data format with 3 cm resolution. CloudCompare open-source software was used to implement this process (Girardeau-Montaut, 2019). 3D point cloud data provides sufficient information for many goals. However, given the size of the data and tools available to process large volumes of point data, it can be said that working with these data is more difficult, and 2D information extraction is not effective.

Raster or gridded regular data can contain certain properties and values in different bands within a certain cell or pixel ranges on a map (Karakaş & Türker, 2019). The value in each cell represents an area on the true Earth's surface if it has been spatially georeferenced. Raster data consists of a regular grid network of the same size. The closest data type to the raster data format is images. However, raster data are more advantageous because they do have spatial information. The grid intervals in the raster data that is the resolution value determine the fineness of the detail that can be detected on the ground. Knowing the surface density of LiDAR point clouds, sampling intervals, and wall thickness in advance will aid the calculation of the raster resolution parameter that should be determined in this process.

2.6 Extraction of Edges from Raster Data

In this section, edge features in each pixel are calculated on the produced raster data. For this purpose, Orfeo ToolBox open-source software and R programming language were used (Grizonnet et al, 2017; Team, 2020). The input data was selected as raster data. The data in which the properties are calculated is the image obtained from the raster data. An image containing edge elements, edge features are processed by all three methods (slope/gradient, Sobel, and Touzi). The gradient filter calculates the gradient size of the image for each pixel. The Sobel filter uses the Sobel operator to calculate the image gradient and then finds the magnitude of this gradient vector. The Touzi filter is more suitable for radar images. It has a positional parameter to prevent speckle-noise perturbation. The greater the radius applied, the less sensitive the filter to speckle noise. The results obtained on raster images are given in Figure 4.

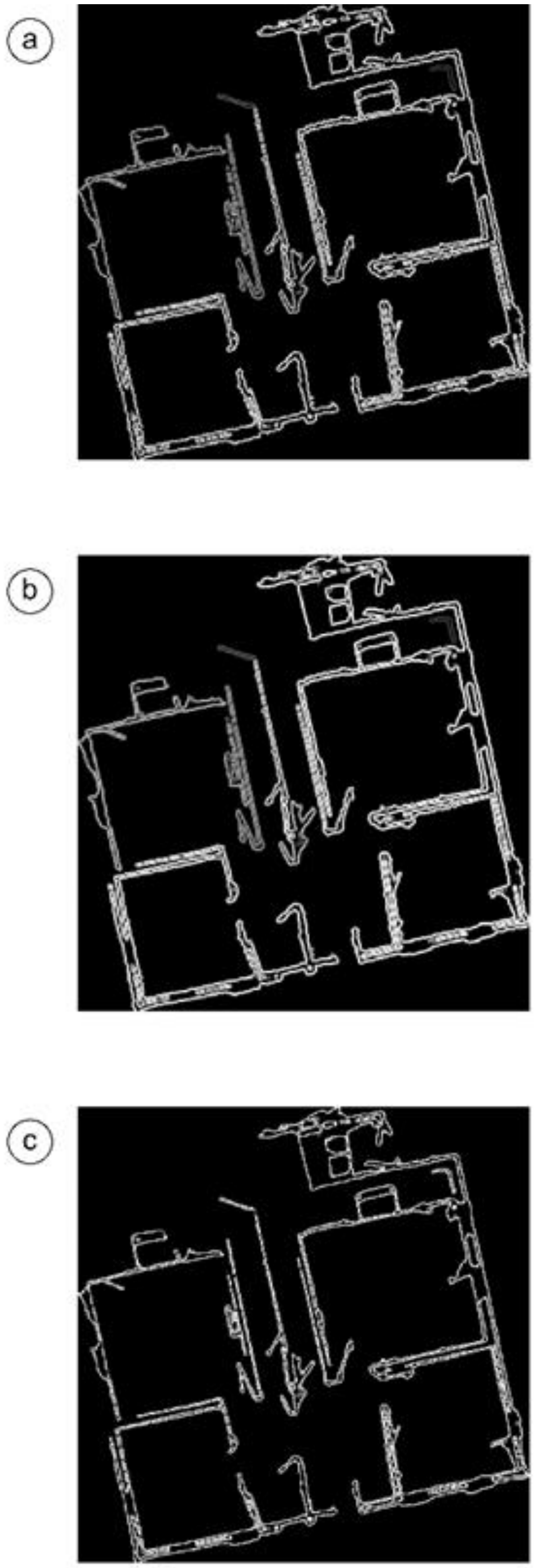

Figure 4. The results of the edge extraction algorithms to derive the layout of the indoor space, a) gradient, b) Sobel, c) Touizi filters.

In order to define the side and interior walls in indoor environments through raster-based data, the boundaries of the relevant objects must be determined. Edge detection or edge extraction algorithms constitute one of the most important research issues by computer vision and image processing societies. Height, flatness, curvature-based values in raster data reveal distinct transitions in raster data, and these changes are revealed by edge detection algorithms of cells representing object objects or wall edges. In the literature, edge detection algorithms are widely used on this subject. Grayscale image processing and analysis and many algorithms in the literature form the basis of these studies (Aybar, 2008).

For raster data, gradients along both the x and y axes are obtained as two components. To be more specific, with mathematical notations, the image density $I(x,y)$ is obtained at the x, y position and with the following estimates:

$$g_x = \frac{\partial}{\partial x} I \quad (4)$$

$$g_y = \frac{\partial}{\partial y} I \quad (5)$$

where it provides information about how fast the gradient values change at each x, y location relative to its surroundings. Inferred edges are predicted due to sudden changes in the images, and their positions are estimated according to the gradient norm. The gradient size is formalized as the following equation,

$$\sqrt{g_x^2 + g_y^2} \quad (6)$$

The image processing stage was applied with the help of R commands and the imager package, and the results are given in Figure 5.

2.7 RANSAC Algorithm Application

In this section, the estimation of plane parameters on points with the high planar feature is performed using the RANSAC algorithm. RANSAC provides an iterative estimation of plane parameters from points according to the minimum number of points and certain threshold values (Güler, 2018; Karslı & Pfeifer, 2012; Sevgen et al., 2018). The determination of the planar feature of the cross-section points before the RANSAC algorithm application increased the process performance and the accuracy of the estimation parameters. The fundamental principle of the RANSAC algorithm randomly selects the point with the minimum requirement for the model to be estimated and calculates the deviation of the other points to this model. According to the threshold values, it is determined which other points will participate in this model or not (Fischler & Bolles, 1981).

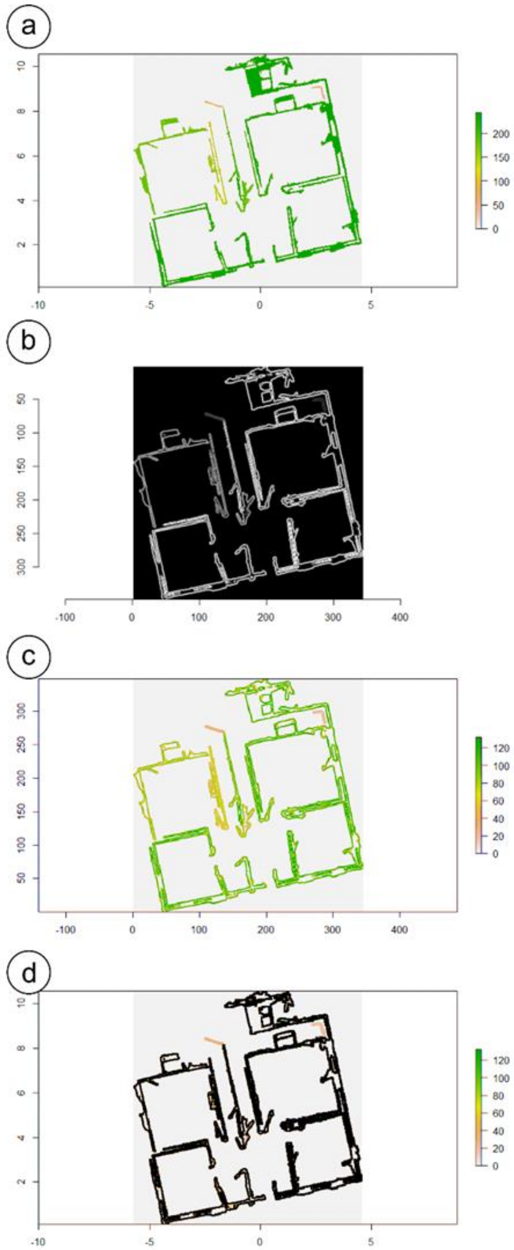

Figure 5. Raster data-based gradient calculations a) height-based raster data, a) image grayscale value, b) conversion raster data to image and calculating gradient c) reconverting the image back to raster data, d) displaying the derived edge lines on raster data.

3. RESULTS AND DISCUSSION

In the study, 7 minutes of LiDAR field measurement was carried out, and a total of 11580016 points were acquired. After manual extraction of the single building feature from the produced points, 9818730 points represented the building. Then, the cross-section was applied, and the number of points was reduced to 85542 points. Local characteristics are computed on these points (Figure 6). Figure 6 shows that effectively eliminated the points that are not connected with the connected components algorithm. However, it is still seen that it is very challenging to filter some object points on the wall surface or close to the side surface.

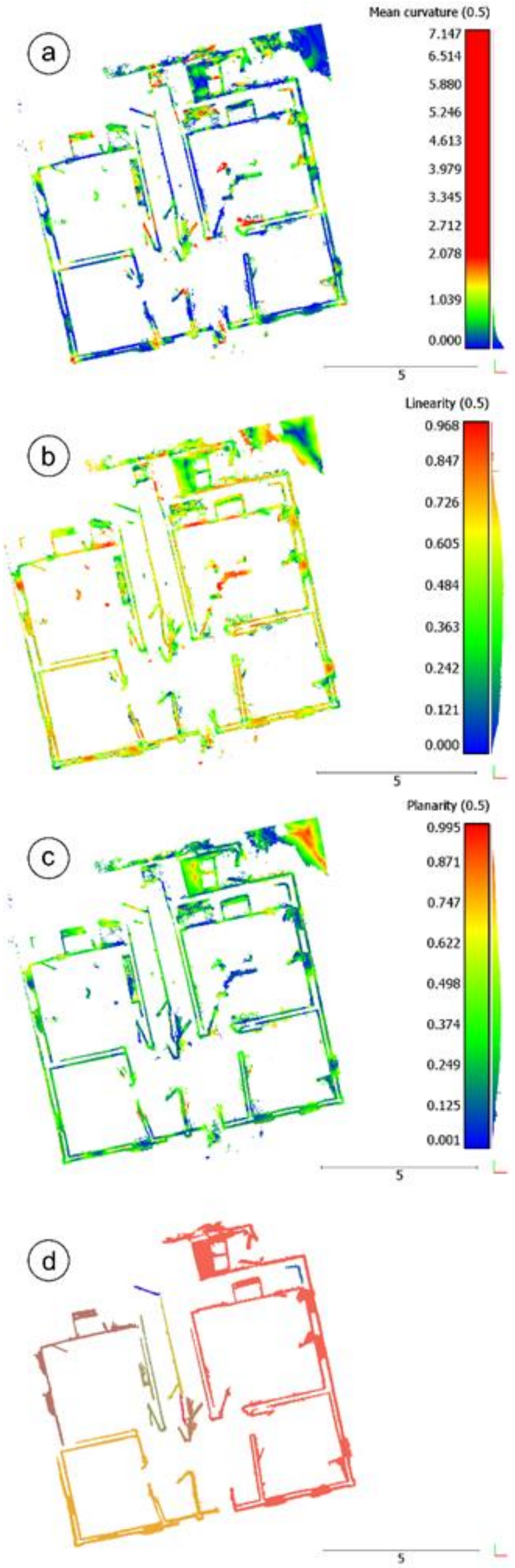

Figure 6. The results of the algorithms applied on the sectioned point clouds, a) mean curvature, b) linearity, c) planarity, d) extraction of walls after analysis of connected point groups.

Figure 7 shows the result of the edges derived after the feature extraction, the application of the connected component algorithm, the manual drawing process by the operator, and the proposed methodology. As it can be understood from here, the produced edges were found effectively, but the objects in the area, especially on the door and wall, could not prevent the methodology's process of finding edges in these areas. In addition, the doors in the area were determined and not drawn by the operator, but the proposed methodology did not separate and eliminate them because of high planarity and adjacent to the wall.

To check the overall metric quality of ZEB-REVO point clouds, their reliability is first performed according to single period/pass measures. The first statistical parameter that comes to mind in evaluating the general reliability is accuracy, and in comparisons made with some surfaces or point clouds derived from more precise measurement systems, it is widely used to examine the deviation of the calculated point clouds with the RMSE value (Zeybek, 2019). However, this study focused on edge extraction integrity and areal accuracies rather than accuracy of measurement data.

Edge extraction with image processing algorithms in raster-based edge extraction provided detailed acquisition of details, but such algorithms were highly affected by the noise of the surfaces and caused the noisy edges extraction. After the application of these algorithms, it has been seen that it is important to integrate further simplifying and orthogonalization algorithms on it.

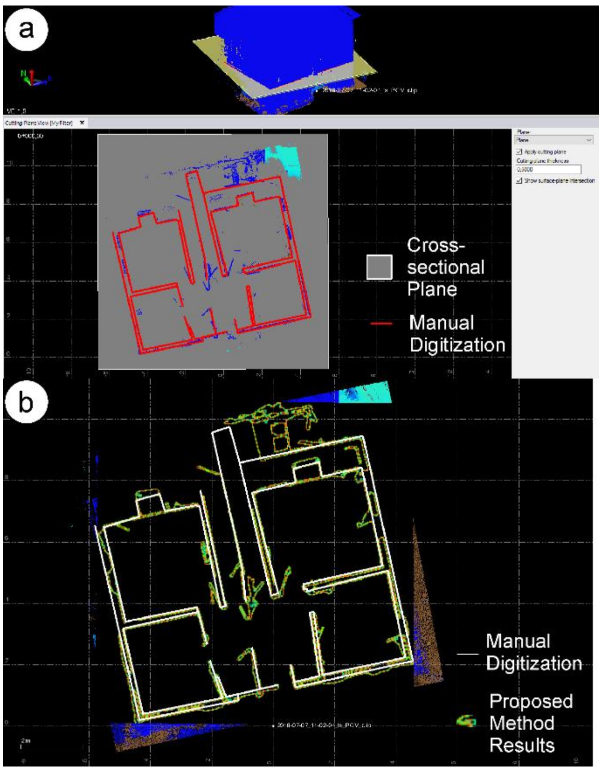

Figure 7. After section and feature extraction, a) manual drawing with CAD program, b) overlay results of manual drawing results with the proposed methodology.

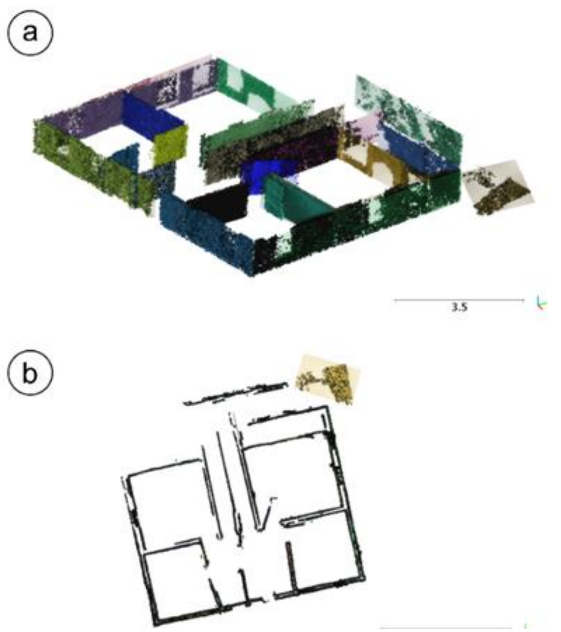

Figure 8. Plane points determined as a result of RANSAC algorithm, a) perspective view, b) top view.

RANSAC application results are shown Figure 8. A minimum of 500 points was chosen to obtain this model. The limit value of the distance to the estimation model is given as 5.5 cm. The point sampling interval is 11 cm. With the predicted plane normal, the maximum angular deviation is 25 degrees.

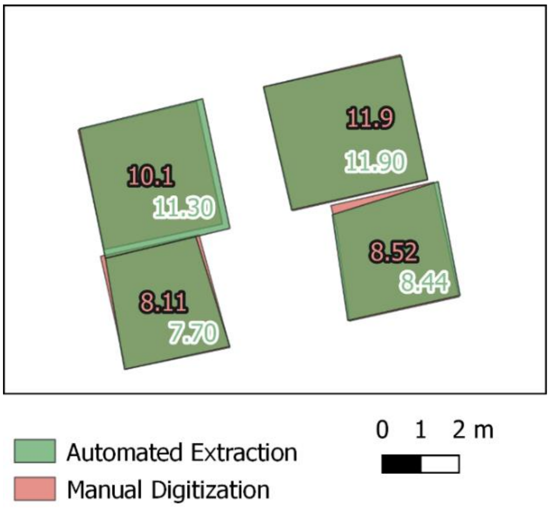

Figure 9. Indoor plans are drawn automatically and with the operator's help (the areas are given in the m^2 unit).

The total area of the four rooms of the building is 38.63 m^2, and this value was obtained from the plans drawn manually with the help of the operator. The areas determined on the plan automatically created from RANSAC planes were determined as 39.34 m^2 (Figure 9). The relative error rate was found to be 1.8%. The main reason for the high error rate is thought to be due to the low planar rates in the interior walls. Besides, some walls were scanned from outside, and some parts were not scanned, which caused a decrease in accuracy in-plane estimation.

In order to improve the results of the study, it has been concluded that future studies should focus on the following issues: improvement of surface normals in the determination of sidewalls, determination of wall intersection directions well and firmly. To improve area drawings, corner points can be determined, and automatic area calculations can be made, and thus, the extraction of fully automatic building plans can be improved. By creating circumstances to obtain only vertical planes, horizontal planes that may occur indoors can be avoided.

4. CONLUSIONS

The purpose of this article is to present a comprehensive approach for indoor mapping and localization of plans, thanks to the 3D spatial essential knowledge of point clouds obtained with a hand-held LiDAR scanning system. The basic structure of the applied methodology is on the geometric extraction of 2D data from the 3D point cloud data and the analysis of the outcomes. Precise mapping of indoor areas is complex and rather difficult under various situations. Thanks to the point clouds obtained with the hand-held LiDAR scanning system, dense spatial information was obtained, and spatial mapping application was shown on a specific test area with the applied sequential algorithms. The results obtained may differ slightly when compared to reference data or when compared to other LiDAR systems. In addition, differences in the distribution, the density of the generated point clouds, laser scanning pattern, size of the area, or any other environmental conditions can affect the results. Also, it has been observed that the inexperience of a surveyor in certain data negatively affects the production of basic structures. For this reason, it has been observed that it is important to make field measurements by experienced, expert and qualified, and competent people. For future studies on this topic, improvements should focus on two main issues. First of all, it is important to develop a standard data collection technique for data acquisition and to be able to view all walls, especially in point clouds. This situation can be reduced by displaying the SLAM technology simultaneously on the screen. However, applying geometric shapes and standards in data collection may still be a solution to this problem. The second issue is that the 2D wall information needs to be further improved with edge extractions, and its robustness should be increased. For this, optimizing the line feature extraction with a segmentation application will provide important convenience. Finally, it is not easy to convert indoor locations, especially complex areas, to 2D data automatically today. The main reasons for this are directly related to the basic improvements stated in the above paragraphs. However, it is also possible to improve the results by developing the methods suggested in this article, and it is inevitable to work on robust and fully automated line extraction in future studies.

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Usability of Terrestrial Laser Technique in Forest Management Planning

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Keywords
Forest management plan
TLS
Point cloud
3D model

ABSTRACT

Studies in forestry in Turkey have great importance between humanity and life. In this direction, many forestry studies are carried out. The purpose of these studies is to protect forest areas and to ensure their continuity. The forestry organization continues to work urgently in line with this purpose. As a result of the researches, it is seen that old methods are lacking in time and cost in the forest management plan and many forestry studies. Nowadays, researches have been made on the use of the old methods, the use of terrestrial laser technology, which is seen as costly but actually offers positive opportunities at a low cost in line with the purpose to be used. In this study, how the methods used in forest management plans can contribute to the forestry sector with terrestrial laser scanning, which is one of today's technologies, and the sensitivity of devices and software that can be used in this direction are scrutinized. The data obtained as a result of the study were compared with the old methods and the usability of the terrestrial laser scanning method was examined.

1. INTRODUCTION

Forestry studies are activities that are carried out in a wide range of long-term and contain difficult conditions (Şafak & Gül, 2012). There is an important need for information in the realization of these activities, which consist of planning, decision-making and management stages (Eker & Özer, 2015; Buğday, 2016; Buğday, 2019).

Turkey has rich forest areas where the various types of wood. the importance given to forest areas in Turkey are progressing in the past with today's sustainable and innovation studies (Polat & Kaya, 2021). As a result of research conducted in the presence of Forests Turkey, prepared a five year Global Forest Resources Assessment (FRA-Global Forest Resources Assessment) in 2020 according to the report; While it rises to 27th place in the world ranking in the forest existence ranking, it is ranked 1st in Europe and 6th in the world among the countries that increase forest existence (URL-2; URL-3). forest assets in Turkey in the past 18 years, 2.1 million hectares have been increased. Turkey's 2023 target is visionary in forested areas are planned to correspond to 30% of my area of the country. The areal value of this ratio corresponds to approximately 23.4 million hectares. (URL1).

Forestry adversely affected to Turkey's contribution to the protection of forest ecosystems is needed in many areas. Forest management; It is a science that investigates how, when and in what criteria forests can be used and how to obtain more efficiency from forests in order to ensure continuity of forests (Kaplan & Şeylan, 2007).

Referring to the historical development of forest management in Turkey when there is no regular continuity until 1857. With the reform edict issued in 1856, many studies were carried out in many areas. When these studies were found, it was desired to benefit from forestry movements to contribute to the conditions. In order to ensure the continuity of developments in the field of forestry, schools for educational purposes were opened and the personnel to work in this field were technically trained. Important steps have been taken in the field of forestry by bringing foreign experts from other countries in order to enact the necessary legislation for the implementation of innovations (Eler, 2008).

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Despite all these steps taken; It is known that there are problems in determining forest boundaries, preserving, managing and transferring current forest assets to future generations, and in preparing forest management plans. In this context, studies to be carried out in forest areas are of utmost importance.Today, in parallel with the advancing technological developments in these studies, different and new methods have been used in addition to the classical methods from the past (Kaya & Polat, 2021). Among these methods are Remote Sensing and Geographic Information Systems (GIS), photogrammetry and LIDAR (Light Detection and Ranging / Laser Imaging Detection and Ranging).

The LIDAR method offers high resolution data regardless of the sparse and dense forest areas. In this context, a local laser scanner using LIDAR technology was used in the study area determined in the study, and the data belonging to the area were obtained precisely and quickly. By processing these data, the usability of the terrestrial laser scanner in forest areas was examined and the results were examined.

1.1. Study Area

As the study area, measurements were carried out in a forested area within the Mersin University Çiftlikköy campus.

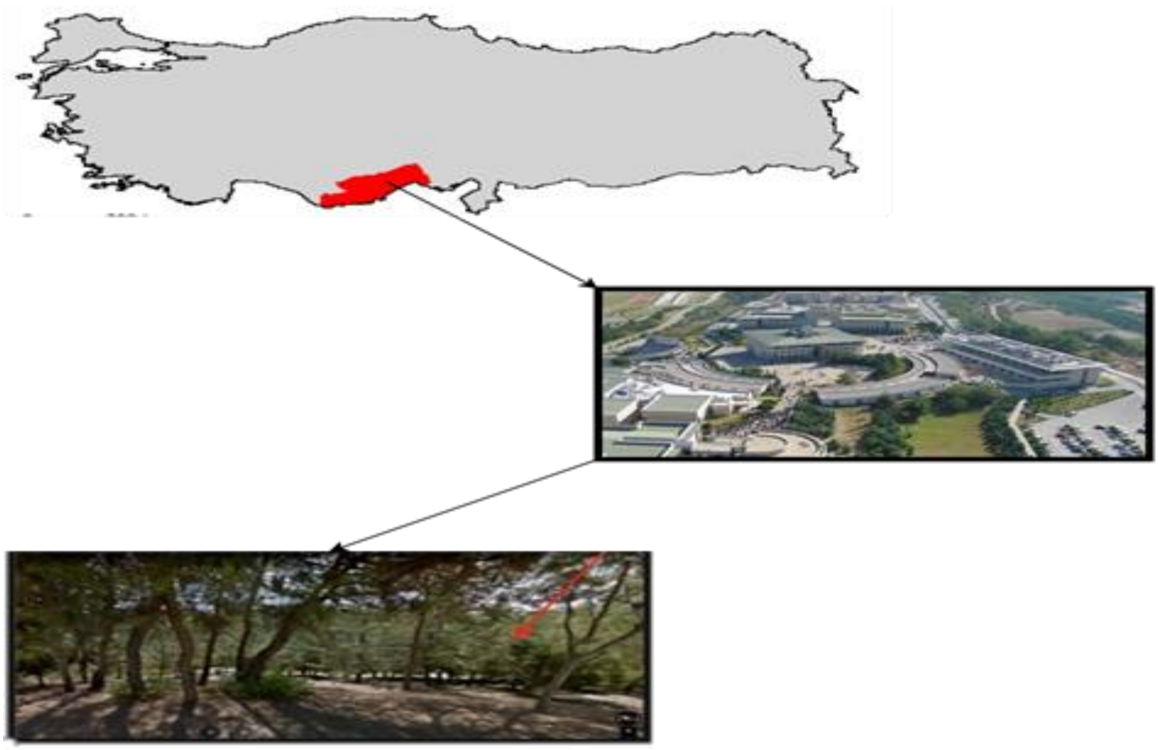

Figure 1. Study area

2. MATERIAL and METHOD

The terrestrial laser scanning (TLS) method was used in the study (Figure 2). With the laser beam emitted from the laser scanner device, the distance between the object and the device is measured. Thus, the point cloud of the scanning area can be obtained and three (3D) models of the desired object can be produced (Çelik et al., 2020; Ulvi et al., 2019). The distance between the laser scanning device and the object can be determined by means of the optical source, which is called the laser beam (Yakar et al., 2015). It has properties (monochromaticity, compatibility, divergence, reflection, density) that distinguish the laser beam from normal light. Thanks to these features, data about the shape and size of real objects can be easily collected and analyzed (Yakar et al., 2014; Ulvi et al., 2014). By means of mirrors, also known as laser optical scanning mechanism, the scanning of the object or the surface is performed by directing the laser beam in horizontal and vertical directions. The capacity of a laser scanner to deflect the laser beam in horizontal and vertical directions is given as the viewing angle in the technical information. In order to create a 3D model of an object, it may be necessary to use more than one scanning station with different viewing angles (Yakar et al., 2016).

The result obtained as a result of scanning is a point cloud consisting of millions of points that vary in proportion to the product measuring distance. Point cloud data; It contains information such as location information, density information, RGB value, scanning angle, number of reflections, and length of reflection. One of the most important advantages of laser scanning is that it can record dense point location information with high accuracy in a short time. Data collected by laser scanning technology can be used to create digital 2D drawings or 3D models that are useful for various applications.

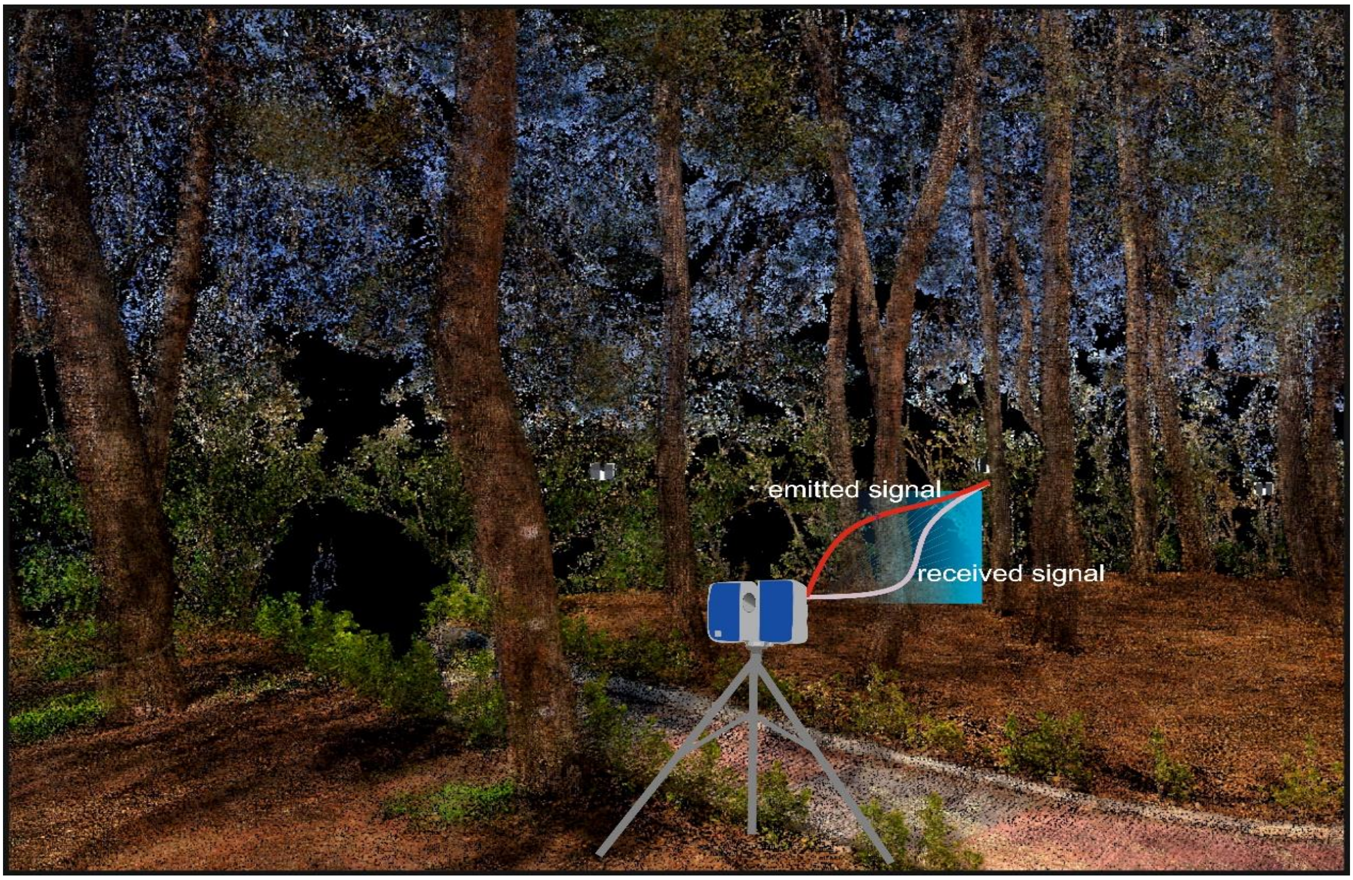

Figure 2. TLS method

In the TLS method, measurement can be performed from one point or several points with the terrestrial laser scanner. Although the measurements made from a single point are very practical, they are not preferred much in practice. Since scanning is performed from only one direction, it is highly possible that complete and healthy data regarding the scanned object cannot be obtained. Therefore, this application is not used except in compulsory cases. Instead, scanning is performed from more than one point (Senol et al., 2017; Senol et al., 2020). In this study, scanning was not carried out from a single point, the scans were carried out at more than one station point. Scan data has been processed in point cloud and a variety of commercial and open source software that enables 3D modeling.

2.1. Data Collecting

The determined working area was scanned with the local laser scanner Faro FocusS 350 model.

A forest area has been chosen as the study area. Testing the applicability of the ylt method played an important role in selecting such a field. As a result of the literature research, it has been determined that the predominant presence of pine trees in the forests in the Mediterranean region, the length of the trunk of these trees and therefore the tree branches will not prevent screening. Therefore, the application was carried out in the pine area located in the Mersin University Çiftlikköy campus. The laser scanner was positioned to take the trunk parts of the trees from every angle with frequent sessions and the measurement process was completed in 11 sessions in total (Figure 3).

Table 1. Faro FocusS 350 specifications (Çelik et al., 2020)

Scan Distance	0.6 m - 350 m
Resolution	1/1, 1/2, 1/4, 1/5, 1/8, 1/10, 1/16, 1/20, 1/32
Quality	2x, 3x, 4x, 6x
Measuring Speed	976.000 dot/second
Internal straightness	±1mm
Weight	4,2 kg
Size	230x183x103mm

The perimeter of the tree trunk was measured from the reference points determined with the help of a rope by marking the reference points at 50, 100, 150 cm height of the tree trunks and the values were measured with the help of a steel tape measure (Figure 3, 4).

Figure 3. Fieldwork

Figure 4. Scan samples performed in the study

2.2. Data Processing

The necessary data for processing the data were obtained by field measurements. FARO SCENE software, which is a commercial software, and various programs were used in the process of data processing. The scans made by processing the data in the software were combined. The point cloud of the study area was obtained as a result of the merging (Figure 5). A solid model was created through the obtained point cloud. Body circumferences and diameter values of the tree were measured on the 3D model. If desired, precise data can be obtained by coordinating the points with the TLS method and producing 3D models (Kaya et al., 2021; Yiğit & Ulvi 2020).

Faro Scene software used for data processing has been developed to process scans obtained from all laser scanning devices. The software offers technical features such as automatic object recognition of objects found in scans, creating records in scans, and positioning.

After the scanning, the data were transferred to the software. First, the process process was applied. At this stage, the process of merging data with cloud to cloud point merging method has been completed. Considering the combined data, a simpler data was obtained by deleting the noise pollution data found in scans other than what was desired. This process is a noise removal process, and as a result of the process, it offers the user the opportunity to obtain a simpler and more usable data. After this step, the solid model (mesh) was created from the generated point cloud (Figure 6). In the product that emerged in the point cloud and solid model, the leaf parts of the trees combined with the sky, creating a confusion as green and blue color. However, this situation did not prevent our purpose. Because the volume calculation was made on the tree trunk parts.

Figure 5. Point cloud view

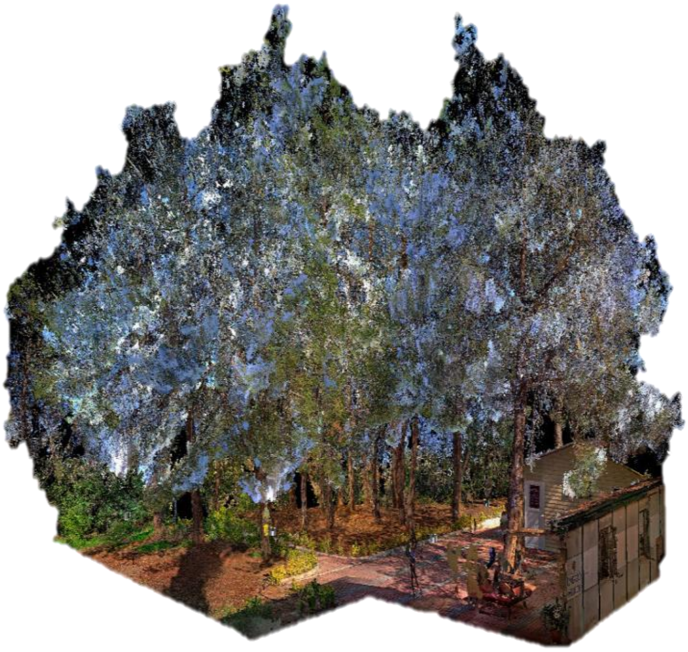

Figure 6. Solid model view

The data processed in Faro Scene software was exported in (.las) format and cut at the reference trunk heights of the determined trees and transferred to another software, Cloud Compare. This software allows many operations to be performed on point cloud data.

Figure 7. Point cloud data transferred to Cloud Compare software

In this software, the process of passing the tree trunks into the trees as a solid object through the software was applied (Figure 7, 8, 9). The volume calculations of the tree trunks were made by obtaining the cylinder radius and height information passed to the trunk parts. Then, the average diameter value was found according to the locally measured environmental measurements from the reference heights of the trees determined, and the volume calculation was made according to the huber measurement scale from the log volume calculation engine (Table 3).

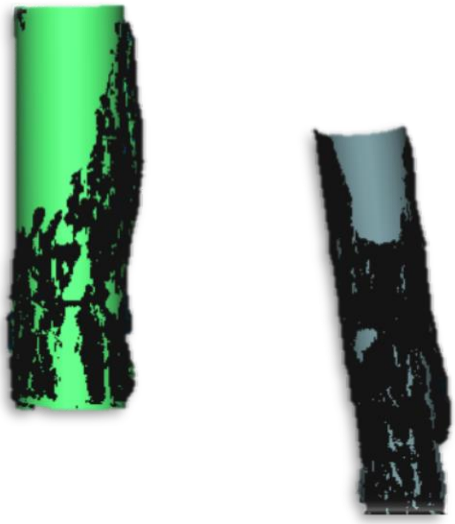

Figure 8. Cylinder views attached to tree trunks in cloud compare software

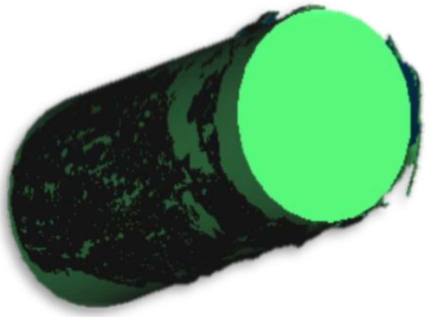

Figure 9. Cylinder views attached to tree trunks

In addition to the study, a volume calculation was made based on the locally obtained measurement values according to the volume calculation formula used in forestry. The sensitivity of the TLS method was examined by comparing the values found in this volume calculation with the volume calculations obtained by the TLS method. Volume calculation formula used in the study;

$$V = \frac{\pi}{4} x\, r^2 x\, L \quad (1)$$

Here;
r: middle diameter value (m),
L: length (m)

As a result of this formula, it is calculated gradually, together with the middle diameter value taken from the measured trees and certain height values(Table 4). In this study, volume calculations were made from the middle diameter values in accordance with the formula. The point cloud data obtained was exported and transferred to another software, Reconstructor software. The volume of the trunk of a tree for control purposes has been calculated.

3. RESULTS

In order to calculate the volume of the point cloud data obtained by the TLS method in the study, a cylinder was inserted into the trees in the Cloud Compare software according to the middle diameter value of the specified points. The volume calculations of these cylinders of known dimensions are made and the volume calculations of the values obtained by the spatial method are compared (Table 6). As a result of finding similar values in the volume calculations, it was seen that the TLS method can be used in similar studies like this.

As another method, another comparison factor was created by making the volume calculations obtained from the volume calculation formula, which is generally used in forestry studies (1). It has been observed that this formula is used locally in field measurements.

Table 2. Calculations obtained by spatial measurements

Tree number	circumference (cm)	diameter (cm)	radius (cm)	height (m)
1	124.5	39.65	19.82	1.50
2	73.2	23,31	11.65	1.50
3	99,1	31,56	15.78	1.50
4	104.6	33.31	16.66	1.50

Table 3. Volume calculation of spatial measurements with Huber method

Medium Diameter	Length	Volume
39.65 cm	1.5 m	0.19 m^3
23.31 cm	1.5 m	0.06 m^3
31.56 cm	1.5 m	0.12 m^3
33.31 cm	1.5 m	0.13 m^3

Table 4. Results obtained from the formula used to calculate the volumes of trees

Tree number	Medium Diameter	Length	Volume
1	39.65 cm	1.5 m	0.1852 m^3
2	23.31 cm	1.5 m	0.06 m^3
3	31.56 cm	1.5 m	0.12 m^3
4	33.31 cm	1.5 m	0.1307 m^3

Table 5. Volume calculations obtained by cylinder passing method in Cloud Compare software

Medium Diameter	Length	Volume
39.0646 cm	1.5 m	0.18 m^3
21.96 cm	1.5 m	0.06 m^3
30.42 cm	1.5 m	0.11 m^3
34.43 cm	1.5 m	0.14 m^3

Figure 10. Volume value obtained in Reconstructor software (tree number: 1)

As a result of the volume calculation in the reconstructor software, an approximate result has been found for the volume values obtained from other spatial methods and software. This has been an indicator that reliable results can be obtained at the point of volume calculation made in the study. Likewise, the volume value of the tree numbered 1 was found to be 0.18 m^3 in cloud compare software. In the Reconstructor software, it was found to be 0.1740 m^3 (Figure 10). The volume calculation obtained in both software was found with a difference of 0.006 m^3. Comparison was made for all methods used and volume calculations obtained, and other methods were examined according to the referenced method. The volume value for the tree numbered 1 was used as the comparison data.

Table 6. Comparison of number 1 tree volume among the methods used.

Method used	Calculated volume	Reference
Formula calculation	0.1852 m^3	-
Huber method	0.19 m^3	0.0048 m^3
Cloud Compare	0.18 m^3	0.0052 m^3
Reconstructor	0.1740 m^3	0.0112 m^3

As a result of the comparison, the margin of error is very low. That is, the usability of the methods is stipulated. But when looking at the errors, the method with the lowest error was the Huber method calculated by the local method, and the volume value calculated with the cloud compare software from the data obtained by the TLS method.

4. CONCLUSION

In this study, since a forested area was preferred, the point cloud obtained was combined with high resolution and low error to obtain a point cloud and a solid model. However, it has been determined that a single software is not sufficient for software. On the other hand, since the surface shapes in the study area have various geometric shapes and the leaf regions in the upper parts of the tree are scattered and thin coniferous, a healthy data was not obtained in the point cloud. The sensitivity of the laser scanner used in this study was examined by comparing the measurements of the reference points marked on the body parts of the tree with a steel tape measure and the measurements made from the 3D solid model produced from the scans.

With the results obtained, error values were calculated and values very close to the results obtained by local methods were obtained. Since more area can be scanned in a short time in the TLS method and the volume calculations of trees will be calculated more easily with the software used, the usability of the ylt method is envisaged. With the TLS method, it provides a great advantage both in time and in the workforce of the measurements to be made in the field. However, today, the use of such methods due to different perceptions has not gained much place. Because this technique, which is considered to be too costly, can be more advantageous than local measurements in terms of cost. In terms of both precision and time saving, it was aimed to determine the forest existence and to show its usability sensitively in the studies to be done in this area. Since there is not a single tree in the field of forestry and forest management planning, it is predicted that such methods can be used technologically in many aspects.

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CAD-Based Modeling Using Three Dimensional Point Cloud Data

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Keywords
LiDAR
Terrestrial Laser Scanning
Point Cloud
Documentation
3D CAD Modeling

ABSTRACT

Preserving historical and cultural artifacts through generations is essential for maintaining the roots and ensuring the development of any civilization. Conservation and restoration works are crucial in order to save numerous historical and cultural heritages in our country and the world and also pass on them from generation to generation. Nowadays, the increasing development in measurement technologies and the integration of photogrammetry into architectural applications have provided different perspective in architectural documentation applications. In this context, Terrestrial laser scanning method is a current method used in documentation studies today. The most important advantages of terrestrial laser scanning in this study are as follows: -the point cloud data obtained by terrestrial laser scanners provides the opportunity to reach the correct data at the desired frequency in a short time, -obtaining appropriate and practical results for the targeted study,- the possibility of using scanners in different working areas. In this context, laser scanners have become one of the popular methods in which effective and successful results are obtained in architectural documentation projects such as survey, restitution and restoration. Within the scope of this study, ''Ali Efendi Muallimhanesi'', which is one of the historical and cultural heritage of Konya province, was scanned with a terrestrial laser scanner and 3D drawing and modeling was carried out with the help of the cad-based modeling tools only using 3D point cloud data.

1. INTRODUCTION

Our country has an extremely rich and important cultural potential that contains numerous historical and cultural artifacts (Ministry of Culture and Tourism, 2021). Although today's modern buildings are designed to withstand various events, historical structures have suffered many natural or human-induced damages until today. Architectural documentation studies for the transfer of these precious historical artifacts from the past to the present have proven to be an effective and useful method for the reconstruction and preservation of the building (Kushwaha et al., 2020). Nowadays, different perspectives have been obtained in architectural documentation applications thanks to the increasing developments in measurement technologies and the integration of photogrammetry into architectural applications. Terrestrial laser scanning method has become a more effective and current method compared to traditional measurement methods for architectural documentation studies. Terrestrial laser scanning technique is basically evaluated within the LIDAR (Light Detection and Ranging) system (Yakar et al., 2020). LIDAR technology is the name given to a remote sensing technology, commonly known as laser scanning technology, referred to as beam capture and distance determination (Sevgen, 2018). TLS is a non-destructive technique, and in recent years, has experienced great advances, which has resulted in important development in the field of graphic and metric documentation of objects in which no direct contact is involved. The advantage of using remote sensing technique is that it doesn't need any physical contact with the surface. Remotely accessed data are very important in case of cultural heritage site (Kushwaha et al., 2020; González et al. 2010). TLS is a method based on obtaining the XYZ coordinates of many points as a result of sending laser pulses to the target object and measuring the distance between the device and the target. A point cloud is represented as a function of the intensity of the reflected laser beam (Gumilar et al., 2020; Uzun & Spor, 2019).

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Using 3D point cloud data obtained by laser scanning method, the following studies can be performed through CAD applications: basic measurement data, orthophoto image extraction, 2D or 3D drawings, solid surface models, 3D animations, texture covered 3D model extraction. It is seen that high resolution 3D point cloud data is used in architectural survey studies, in the production of orthophoto to ready for CAD drawing (Hassan & Fritsch, 2019; Lin et al., 2019; Bonfanti et al., 2013). In this study, 3D CAD drawings of Ali Efendi Muallimhane, one of the historical and cultural works of Konya province, were created from high resolution 3D point cloud data and their orthophotos.

2. METHOD

2.1. Terrestrial Laser Scanner Method

Terrestrial laser scanning technology is a method that samples or scans objects directly, precisely and automatically obtaining 3D coordinates (x, y, z) with the help of LiDAR technology (Beg, 2018; Bonfanti et al., 2013). It is based on a system that scans the target object in series of points within limited angles in horizontal and vertical directions and enables it to be displayed as point clouds (Lichti & Gordon, 2004). The location of a point is determined by the time it takes for the LiDAR signal to hit the target and the beam reflected from the target back to the scanner (Equation1). Scanner centered polar coordinates are obtained as a result of these operations. These polar coordinates are converted into cartesian coordinates (Figure1).

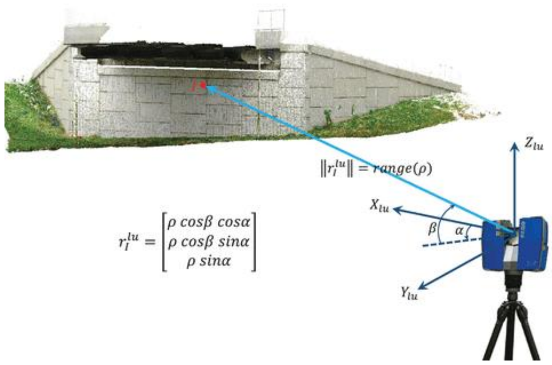

Figure 1. A typical pulsed laser telemeter, the operating principle (Lin et al. 2019).

$$\Delta R = c\frac{\Delta t}{2} \quad (1)$$

R: the distance between point A and point B
c: the velocity of electromagnetic radiation
r: measured time interval

As a result, the point cloud formed by millions of points is obtained. A point cloud is the sum of XYZ coordinates that enable understanding of the spatial distribution of an object or a region within a general reference system. These point clouds contain different resolutions, sampling densities and attributes as well as different scenes and objects (Kushwaha et al., 2020; Beg 2018; Altuntaş & Yıldız, 2008).

In this study, data acquisition was carried out with the help of Terrestrial Laser Scanner (TLS) FaroFocus 3DX 330. This laser scanner is suitable for 3D documentation and land surveys. It can produce detailed 3D images of complex structures in a few minutes. Focus 3D, based on phase shift measurement method. This type of scanner uses a continuous wave laser as the carrier for a modulated signal (Figure 2). The phases of the emitted and received signals are compared. Scanners of this type have a lower range, higher measurement speeds and better precision than scanners based on the principle of time of flight. Since this method has a comprehensive signaling structure, it offers more accurate and precise results compared to laser scanners working with other methods (Karasaka & Beg, 2021: González et al., 2010). The relation between phase difference and range is (Equation2):

$$D = \frac{c.\theta}{4\pi f} \quad (2)$$

D: Distance between laser scanner and object
c: Speed of light
Θ: Phase difference
f: Frequency

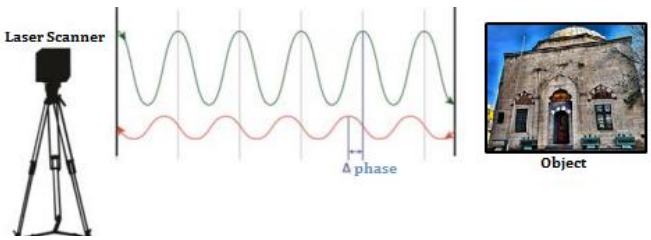

Figure 2. The working principle of Phase shift measurement

2.2. Usability of Terrestrial Laser Scanners in Architectural Documentation Studies

High resolution 3D point cloud data is frequently used in documentation studies of historical and cultural heritage such as survey, restitution and restoration (Wojtkowska et al., 2021). In the documentation process of a building, terrestrial laser scanners are frequently preferred in architectural facade scans because they provide an accuracy of mm level. Thanks to this point cloud data representing the structure, 3D coordinate data of objects or structures that are difficult to survey can be obtained (Okuyucu & Çoban, 2019; Kersten et al., 2009; Hassan & Fritsch, 2019). Architectural documentation studies are carried out within certain standards. The survey work to be carried out with 3D point cloud data of any object or area to be recorded shows the feature of base data for restitution and restoration works to be carried out in the future. Using this data, the 3D model of the object or structure to be scanned can be recorded and stored. When compared with traditional measurement methods, it is seen that models created with point cloud data make accurate measurements at a rate of 99.9%. Thanks to this method, in which the most complex geometries of the structures are revealed exactly, the process-result relationship in architectural documentation processes works extremely quickly (Uzun & Spor, 2019).

With the transfer of the obtained point cloud data of the object or structures to the CAD program, the preparation of floor plans and section drawings and technical drawing operations can be performed. Thanks to the high quality orthophotos obtained from the point cloud data, 2D technical drawings can be made in architectural survey studies. In this way, the details of the object or the building can be shown on the 3D point cloud data and the current state of the building can be completed in the form of architectural survey work. Restitution studies can be prepared for problematic sections by integrating with previously obtained photographs and data obtained during the survey on the works that have been destroyed or structurally damaged (Uzun & Spor, 2019).

Today, there are many software (AutoCAD, Sketchup, etc.) that offer the opportunity to work on point cloud. For example, AutoCAD software provides certain improvements and enhancements when working over the point cloud. With the point cloud plugin, using clipping tools, an existing area on the cloud can be focused and drawings can be made on the cropped area with the help of points. The cropped area includes any objects left within this area, along with the crop border. In addition, since these clipped areas now show a cross-section feature, they allow object creation with using point clouds depending on the density of the cloud. Another drawing method is to correctly identify the dynamic user-defined coordinate system on the target surface to be drawn (Prota Altar, 2020).

2.3. Study Area

The determined working site called "Ali Efendi Muallimhanesi" is located opposite to the northern entrance of Şerafettin Mosque in Karatay District of Konya Province. The 'Muallimhane', which was built by Hacı Ali in the early 15th century, was initially named 'Daru'l Kurra', and depending on the need, the school and 'Daru'l Huffaz'sections were opened and turned into an educational institution that includes levels that complement each other. It was closed at the end of the 19th century and was opened as Ali Efendi Madrasa instead. Before the Republic period it was used as a health museum and then as a mufti office. After 1968, it was transformed into a Children's Library under the Ministry of Culture, and after 1993 it was used as Ali Efendi Public Library. The library was evacuated in 2000 for repairs, and when the repairs were completed, it was allocated to the Konya Provincial Directorate in 2001. It was allocated to Konya Provincial Mufti in February 2015 by Konya Governorship for use in Quran and Islamic Related Services (Konya Metropolitan Municipality, 2021).

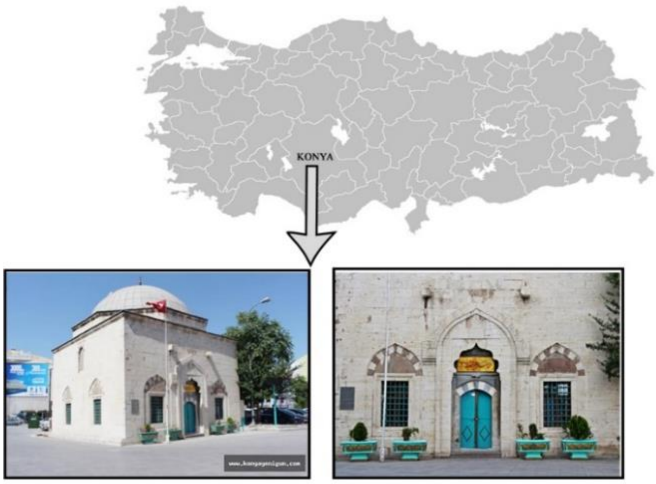

Figure 3. Study area**, "**Ali Efendi Muallimhanesi'', Konya

3. APPLICATION

Point cloud preprocedure consists of scan registration, alignment, noise cancellation, scaling and segmentation. These steps can be performed in TLS native software. Architectural survey with terrestrial laser scanning method workflow in general is definition as below (Moyano et al., 2021):

i. Planning survey
ii. Detecting the angle and location of the scanner
iii. Scanning and acquiring point cloud data
iv. Processing of data in computer software
v. Transferring data to CAD environment
vi. Drawing plans, sections and views of the building in CAD environment

In this study, Faro Laser Scanner X-330 Hdr was used. It is capable of scanning objects up to 330 meters away in direct sunlight with 0.2 mm accuracy, and objects up to 330 meters away with deviations between 3 and 5 cm. It enables us to obtain colored point cloud data by integrating the photos taken at 360 degrees into the point cloud on the scanned data with 170 megapixel camera resolution. The scanner can produce point cloud data by generating 976,000 points per second (Table1). In this study, Scene Faro was used for the acquisition and processing of data. With Scene software, users can create stunning 3D visualizations of real world objects and environments and export that data in various formats (Faro, 2020).

Table 1. Features device of FaroFocus 3D X 330 (Faro 2020)

Scan Distance	0.6 - 330m
Size	240 x 200 x 100mm
Weight	5,2kg
Measuring Speed	976,000 points / second
Accuracy	±2mm
Camera	70 megapixels
Resolution	1/1, 1/2, 1/4, 1/5, 1/8, 1/10, 1/16, 1/20, 1/32

Scanning operations of the target object were carried out from the station points determined in such a way that one or more facade of the target can be seen and from the appropriate distance. The process of combining the scan data and creating the point cloud cluster for the target object has been completed in the faro scene software (Figure 4). From this stage on, the survey drawings of the façades of the building were made by taking 2D orthophotos obtained from the point cloud data (Figure 8). In addition, a drawing has been made illustrating the details of the building that has been made through points with the help of point cloud (Figure 6; Figure 7). There are a lot of plug-in for CAD softwares to processing and drawing of point clouds.

Figure 4: Point cloud data of Ali Efendi Muallimhanesi

Mesh model is generated in SCENE software via point cloud data (Figure 5).

Figure 5: Mesh Model data of Ali Efendi Muallimhanesi

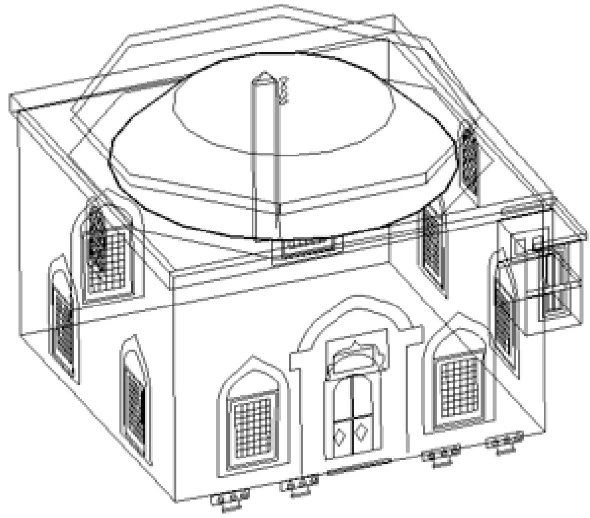

Figure 6. Drawing made by using Point Cloud

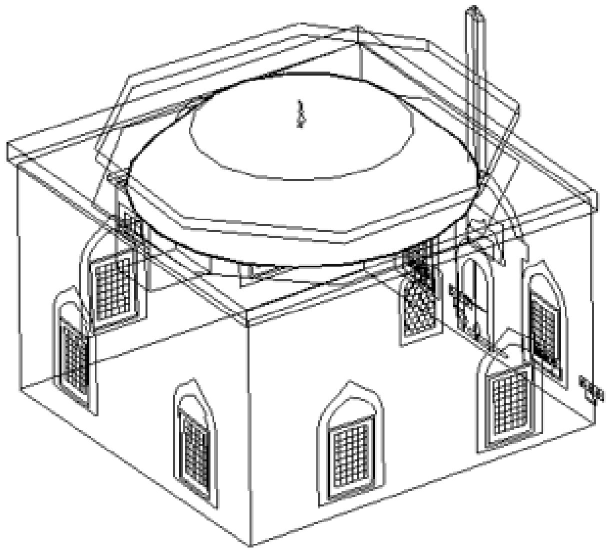

Figure 7. Drawing made by using Point Cloud

However, in accordance with the standards accepted in the survey studies, it is not possible to show the details of the building exactly in the drawings to be obtained by this method. This is due to the fact that points in a frequent and complex arrangement do not allow the drawing of the details of the building. In order to make 2D drawings for use in survey studies, orthophotos are produced over the desired sections from the point cloud data. In this way, 3D data is reduced to 2D data in the most accurate way. By means of orthophotos obtained, 2D or 3D technical drawings, 3D models in the form of solid surfaces and animations can be obtained.

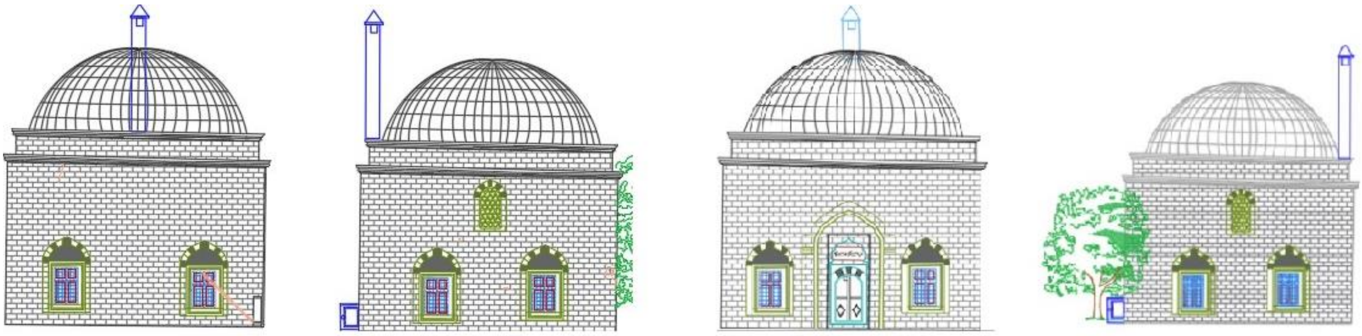

Figure 8. Architectural drawings of building facades made by using orthophoto

In addition, floor plans and section drawings of the whole building can be obtained easily (Figure 10). Precise thickness of the wall and all the dimensions can be obtained with the help of point cloud through laser scanner (Kushwaha et al., 2020). In this sudy, All the drawings that were extracted were of mm accuracy. In this study, meaningful drawings have been created in which the details of the object can be reflected more easily as a result of the drawing made using orthophotos.

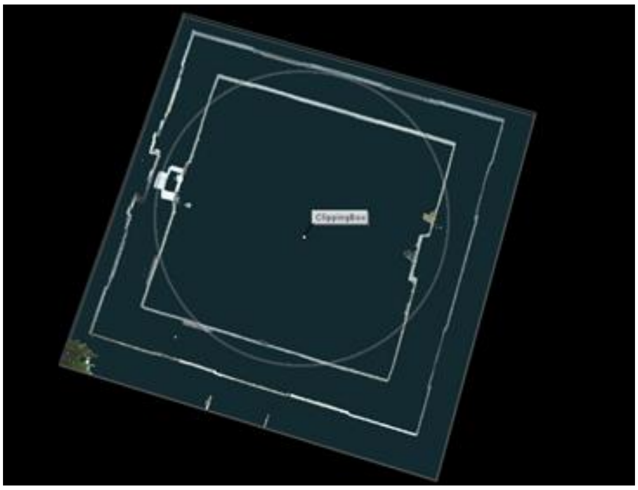

Figure 9. Ground floor plan section extraction

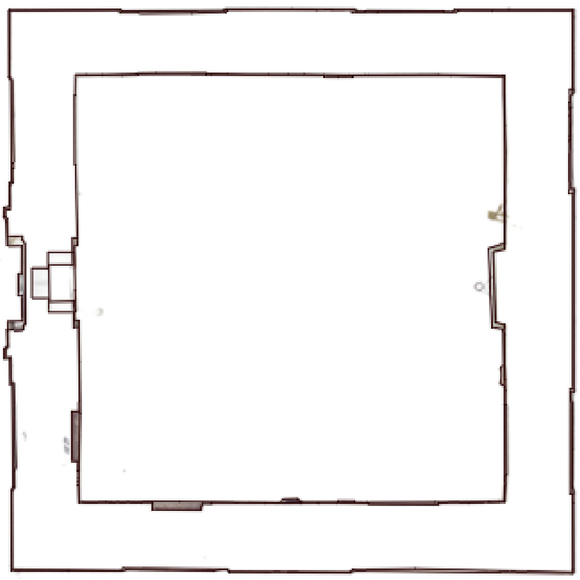

Figure 10. Manual drawing of the ground floor plan with CAD envoirement

4. RESULTS

Preserving cultural heritage is a requisite duty for all civilizations around the World. In order to keep the traces of civilizations alive, it is extremely necessary to pass on historical and cultural artifacts from generation to generation. The terrestrial laser scanning method has become the reason of preference for many disciplines with its potential to obtain cost effective, high-accuracy data in a short time (Okuyucu & Çoban, 2019). Laser scanners, which ensure that the architectural documentation studies are carried out in a healthy way and in the specified standards, have become preferred by users in our country and in the world.

In this study, we present a new method for approach which reconstructs building façade models using terrestrial laser scanning data. In addition, the usability of Faro Focus 3D laser scanner and Scene software in architectural documentation studies was investigated. It was concluded that terrestrial laser scanning is a suitable method for the documentation of the heritage structure.

In the last few years, 2D representation of historical and cultural heritage and 3D modeling studies have accelerated the design processes thanks to the developing CAD software. Technical drawings, analyzes and simulations can be obtained with CAD software, which includes many modules that allow 2D and 3D work. Thanks to the point cloud function that comes with the AutoCAD software used within the scope of the study, points in the point cloud can be captured and 3D visualization can be done. It is extremely important that the software enables 3D drawing through the point cloud.

In our country, 3D modeling studies are preferred in documenting our historical and cultural heritage values. With the constantly developing CAD software facilities, the opportunity to work on 3D point cloud data will become easier and the details of complex objects will be drawn more easily. In this way, studies conducted over point clouds can provide different dimensions and new gains to heritage documentation studies. Today, this method has experienced a popular transformation, thanks to the architects who adopt the TLS technique.

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Applications of Terrestrial Laser Scanning (TLS) in Mining: A Review

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LIDAR
Mining
3D
Measurement

ABSTRACT

This study investigates in depth Terrestrial Laser Scanning technology (TLS), its working and measurement principle, 3D Terrestrial Laser Scanning softwares and the advantages of this scanning method. This paper also stresses the advantages of adopting this technology in quarries and mines and provides examples of researches that have demonstrated the superiority of TLS systems over the traditional scanning methods in terms of practicability, reliability and accuracy in numerous mining engineering applications such as deformation measurements, rock fall and landslide control, volume calculations and detection of discontinuities.

1. INTRODUCTION

Airborne Laser Scanning (ALS) and Terrestrial Laser Scanning (TLS) technologies were developed in the 1970s. The core of these technologies is based on the LIDAR (LIGHT Detection and Ranging) technique which enables emitting laser pulses to the studied surface or object and measuring the time required by the reflected waves to reach back the laser sensors allowing to measure the distance between the TLS device and the object/surface. This technology was adopted as a reflectorless distance measurement method in geodetic instruments in the 1990s after the development of the first total station (TS) without a reflector at Ruhr University in Germany in 1994 (Reshetyuk, 2006; Scherer, 2004). The end of the 1990s marked the commercial launch of Terrestrial Laser Scanners (TLS) as their performance, functionality and efficiency substantially improved.

TLS technology enables acquiring 3-dimensional (3D) point information much faster than traditional measurement techniques. The obtained set of data points are defined as "point clouds". Combining, saving and deleting unnecessary point clouds allows creating 3D models of different objects (Karasaka & Beg, 2021). Geodesic and photogrammetry methods are less effective than the TLS method in terms of accuracy, speed and efficiency in conducting the necessary calculations during the measurement process (Engin & Maerz, 2016).

Today, on account of its reliability, accuracy and efficiency, TLS technology has become an efficient tool in numerous applications. The usage areas of this technique keep expanding as it has been proven to be a more advantageous than the traditional methods in terms of operability, reliability and time and cost efficiency. Numerous softwares can be utilized for the interpretation of TLS data for the purpose of conducting measurement calculations and modeling objects of different sizes and geometries. Terrestrial laser scanners are commonly used in numerous engineering applications such as cross sectional area and volume calculations, monitoring and measurement of deformations, historical artifacts documentation studies and creating 3D city models (Karasaka & Beg, 2021).

2. METHOD

Measurement Principle of Terrestrial Laser Scanners

Terrestrial laser scanners allow determining with high accuracy the time elapsed between sending a laser beam to the surface/object to be studied and the return of the transmitted laser beam (Figure 1). Equation (1) enables calculating the distance between the measured surface and the TLS device (Özdoğan et al., 2018; Engin & Maerz., 2016).

$$D = c \times t/2 \qquad (1)$$

D = Distance between the TLS device and the measured surface (m)

c = Speed of light (299 792 458 m/s)

t = Time taken by the emitted light beam to reach the studied surface, reflect back from it and return to the laser sensor placed on the device (s).

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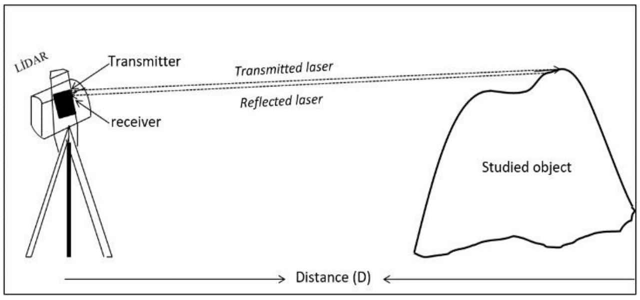


Figure 1. The measurement principle of LIDAR technology

The measurement principle of electronic tachometers and terrestrial laser scanners show strong similarities (Boehler & Marbs, 2002). These devices allow acquiring accurate and precise measurements for long distances (Fröhlich & Mettenleiter, 2004; Karşıdağ, 2011). Figure 2 highlights the equipment used with TLS systems.

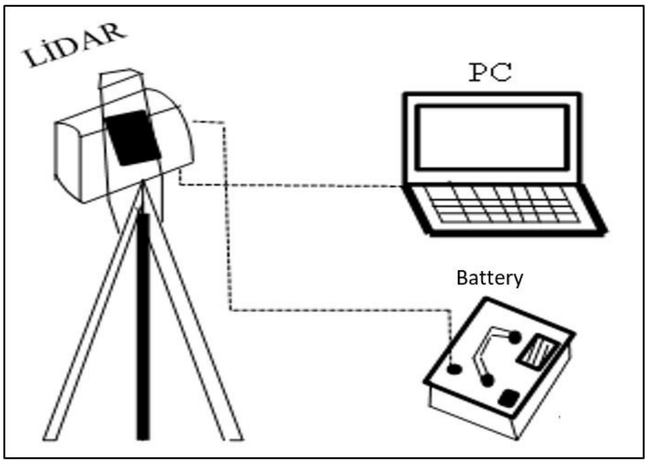


Figure 2. The equipment used with TLS systems

Working Principle of Terrestrial Laser Scanners

The terrestrial laser scanner has both a horizontal and a vertical axis laser beam emission mechanism. The laser beam emitted from the electronic unit of the terrestrial laser scanner hits the optical unit located on the body of the TLS device and reflects from the optical unit at a certain angle with the horizontal to beam toward the studied surface. As the terrestrial laser scanner emits laser beam and receives data, it rotates at a very small angle around its vertical axis along the line to be scanned. This process continues until the screening process is complete (Kraus, 2004; Özdoğan, 2015).

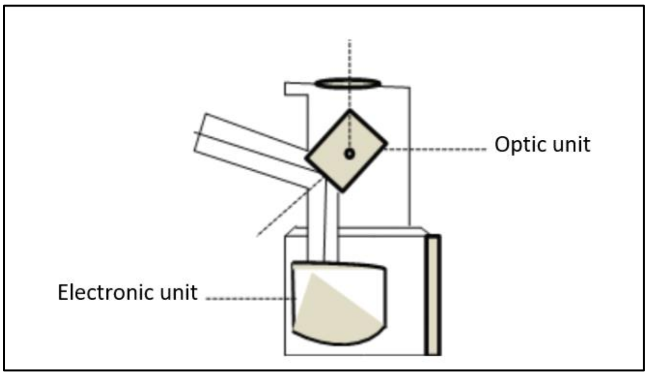


Figure 3. The working principle of the TLS device

A point cloud data is obtained at the end of each scanning process. Each laser point in this point cloud is recorded by the terrestrial laser scanner using its polar coordinates (r, φ, θ). The Cartesian coordinates (x, y, z) of these points expressed in polar coordinates are determined using the software of the scanner. Besides the polar coordinates of each laser point, the scanner also records the density of the energy that hits the object and reflects back from it (Slob et al., 2004; Özdoğan & Deliormanlı, 2018). Figure 4 demonstrates the working principle of the TLS device.

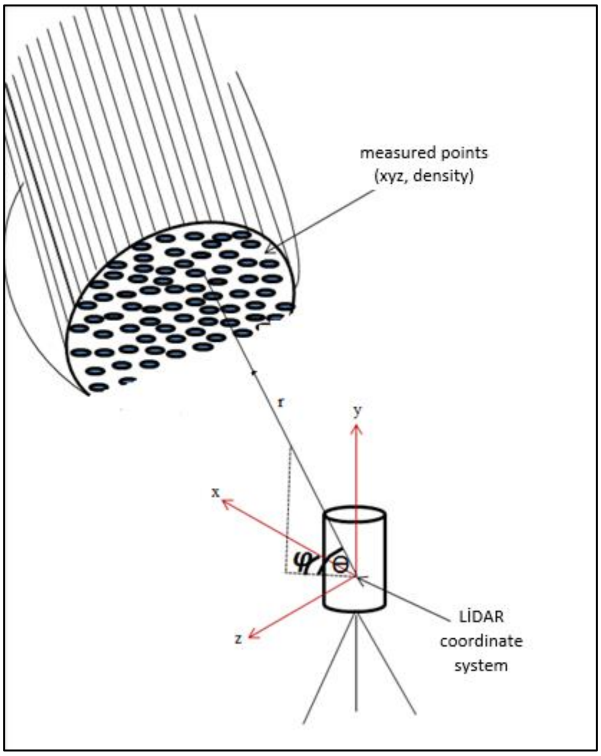


Figure 4. The working principle of the Terrestrial Laser Scanning device

The matrix equation used to convert the polar coordinates obtained from the laser scanner to Cartesian coordinates is given below.

$$X=\begin{bmatrix} xj \\ yj \\ zj \end{bmatrix}=\begin{bmatrix} rjsinjcos\Theta j \\ rjsin\Theta j \\ rjcos\varphi jcos\Theta j \end{bmatrix}$$

rj = The measured distance of a point j
φj = The horizontal direction of a point j
θj = The vertical angle of a point j

The object to be studied is scanned in both the horizontal and vertical directions using optical-mechanical scanners. The point clusters consisting of millions of data points acquired from the scanned object using intense laser signals are called "point clouds". These point clouds enable creating a 3D model of the investigated object. Since the surface of the studied object can have a very complex shape, the scanning process is conducted from different locations and the obtained data is combined and converted to the geodetic coordinate system (Ingensand, 2006; Gümüş, 2008).

The most important advantage of terrestrial laser scanners is that they allow creating practical and

accurate 3D models in a fast and precise manner. Objects of different sizes and mixed geometries can be scanned using this technology (Kushwaha et al.2020; Perc, M. and Topolšek, D .; 2020; Wieczorek, T. et al.2018).
The 3D spatial data generated for laser scanning is useful to support a diverse range of mining activities, such as:

- Exploration and resource evaluation
- Design and construction of mine plant and infrastructure
- Determination of ore body, pit and void volumes for mine planning
- Periodic determination of pit, bench, pre-strip and spoil surface volumes for auditing payments to earthworks contractors
- Periodic determination of stockpile volumes for inventory and accounting purposes Environmental planning, monitoring and reporting for the mining operation and the neighboring region.

Terrestrial Laser Scanners Softwares

Scene: Scene is the most frequently used software for terrestrial laser scanners. This software, which efficiently processes and manages the scanned data, has numerous advantageous features. These features cover recording the scanned data, positioning and automatic object recognition. Scene was especially designed for the FARO Focus3D and Freestyle3D modeling scanners.

3DReshaper: 3DReshaper is a versatile software used in 3D modeling and processing point clouds. Because of its practical use in volume calculation, mesh creation and CAD applications, this software is frequently adopted in 3D modeling applications (URL8).

JRC 3D Reconstructor: Together with the versatility and high resolution of JRC 3D Reconstructor, this software is capable of processing point clouds and images obtained from various sources. Using its LineUp feature, JRC 3D Reconstructor can conduct unoriented scanning and geolocation processes (URL5).

Applications of Terrestrial Laser Scanning in the mining field

It is generally accepted that the identification and characterisation of discontinuities in discontinuous rock masses is one of the most important aspects in rock mass modelling.
Prevention of negative effects of phenomena occurring in the rock mass is based on detailed recognition of the geological structure (discontinuity, crack, etc.) and mechanical properties of rocks and soils, as well as continuous monitoring of the processes in due course (Bazarnik,2018). In rock mass characterization, examining the properties of the discontinuities is a crucial step toward predicting the mechanical behavior of the rock mass (Bieniawski et al., 1989). In fact, the accurate analysis of these discontinuities (joint bedding planes, fractures, cracks, etc.) is a substantial task in most civil and mining engineering studies. Therefore, it is essential to define the characteristics of each discontinuity set i.e. its orientation, roughness and spacing parameters.
The properties of the discontinuities of a rock mass can be measured using standard methods such as cell mapping or screening line studies (Priest and Hudson, 1981; Priest, 1993). Each of these methods has its own advantages and disadvantages. However, all of these manual field study methods share some common disadvantages (Kemeny and Post, 2003). These drawbacks consist of:

- The emergence of false and inaccurate data because of sampling difficulties (e.g. sampling method selection, human bias, device error, etc.)
- High safety risks. Usually field measurements are carried out at the foot of the existing slopes in quarries, mines and tunnels or along busy highways and railways.
- Direct access to rock surfaces is often difficult or impossible.

Also, traditional manual field survey methods for gathering discontinuity properties are biased, hazardous, difficult , expensive and time-consuming (Slob, 2004).
Thus, adopting TLS technology in combination with an automatic discontinuity analysis has several advantages over the above-mentioned traditional methods:

- TLS technology is less expensive than the traditional methods and provides unbiased, more precise and accurate data on discontinuity orientations.
- Terrestrial Laser scanning can be completed within minutes. This technology minimizes accident risks by providing a controlled safety perimeter of 4 to 800 m from the study field.
- Laser scanning techniques allow a detailed exploration of rock surfaces. Furthermore, the properties of the discontinuities located in inaccessible areas can be easily obtained.

Investigating the properties of the discontinuities of a rock mass using remote sensing is not a new technique. Analog stereo photogrammetric techniques allowed measuring the orientation of individual discontinuities since the 1960s (Rengers, 1967). Digital images and data processing are also commonly used to determine the properties of discontinuities. Basic photogrammetric techniques combined with pattern recognition allow acquiring 3D models of almost any object (Pollefeys et al., 2000). Applications in the field of rock mechanics have been developed using this technique (Engineering Geology, 2001; Roberts, 2000). When the photogrammetric technique is used, it is still necessary to conduct field measurements at a few control points in the rock mass. In addition, the obtained 3D model requires manual summarization of the discontinuity surfaces to calculate the orientations and reach a suitable 3D model (Feng et al., 2001). In fact, despite the good results offered by this technique, the amount of data points obtained using the photogrammetric method is limited.

In addition, the manual operation of the total station requires a large amount of time and effort.

An important advantage of 3D laser scanning is its ability to combine rock surface data remotely. Depending on the scanner type, rock surfaces can be reliably and safely scanned from large distances up to even 250 meters. In 3D laser scanning, each scanned point is represented by its coordinate in the 3D space (X, Y, and Z relative to the scanner's position) and based on the intensity of the reflected laser beam, a digital dataset illustrated by a dense "point cloud" is obtained. With the use of at least 4 reflectors in the scanned scene, the absolute positions of the scanned points can be obtained and the entire point cloud can be projected onto a local (north-facing) grid in real time.

Today, terrestrial laser scanning technology is widely used in numerous mining engineering applications due to its outstanding advantages. These applications cover the following subjects:

- Determination of discontinuities in open pit and underground mines (Slob et al.2004; Slob et al., 2005; Kemeny et al., 2006; Decker, 2008; Sturzenegger and Stead, 2009; Maerz et al., 2012; Lato et al., 2013; Feke¬ te and Diederichs, 2013, Deliormanlı et al., 2014),
- Calculating shotcrete thickness in tunnels, determining possible deformation measurements in tunnels, automating lighting fixtures in tunnels (Chun-Lei et al., 2019; Puente et al., 2014; Delaloye and Diederichs, 2011; Fekete et al., 2009),
- Conducting deformation measurements to control rock falls and landslides (Bauer et al., 2005; Aksoy & Ercanoglu, 2006; Özdoğan et al., 2018; Teza et al., 2008; Abellán et al., 2008; Salvini et al., 2013),
- Designing 3D slope and bench geometry (Feng & Röshoff, 2004; Yanalak, 2005; Oparin et al., 2007),
- Conducting different volume calculations (Yanalak and Baykal, 2003; Yakar et al., 2008),
- Analyzing blasting results (Engin and Maerz., 2016).

Sturzenegger & Stead (2009) used a laser scanner to conduct a 3D modeling analysis of an open pit and characterize the identified discontinuity sets (Figure 5). Examples of models obtained using the TLS technology for different mining engineering applications are presented below.

Maerz et al. (2012) conducted a LiDAR scan to create a point cloud of a Missouri ignimbrite rock cut rock and painted each point by its corresponding optical color (Figure 6).

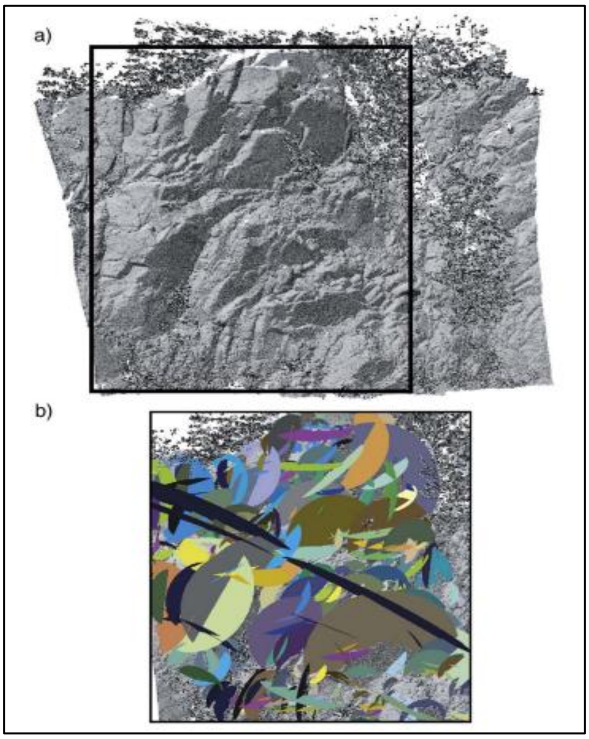


Figure 5. Discontinuity characterization in 3D models. (a) Laser scanner point cloud with a selected sampling window, (b) circles and traces placed on recognizable discontinuity surfaces (Sturzenegger & Stead, 2009).

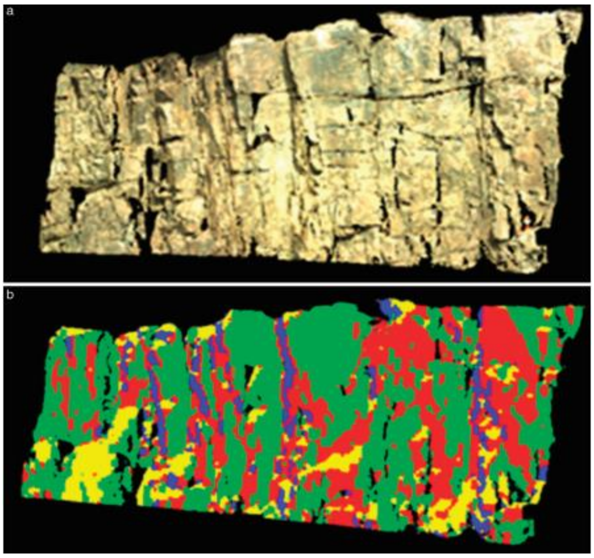


Figure 6. (A) LiDAR scan of a Missouri ignimbrite rock cut. This point cloud was generated with a Leica ScanStation II, which incorporates optical imaging and allows each point in the point cloud to be painted by its corresponding optical color. (B) Automatic identification of discontinuity orientations; the different colors are assigned to discontinuities of similar orientations based on cluster analysis. Green color represents mean orientation of 88/186, blue represents mean orientation of 89/277, yellow represents mean orientation of 37/338, and red represents mean orientation of 82/203. (Maerz et al., 2012).

Fekete et al. (2009) used laser scanners to create a 3D model the opening of the Sandvika tunnel near Oslo, Norway. The results of the conducted TLS measurement campaign enabled specifying the necessary thickness of the shotcrete, defining the properties of the support quality control and predicting the leakage behind the lining. In addition, valuable information on the orientation, spacing and roughness of the joint sets, structurally controlled overbreak geometry and identification of discontinuities visible as lineations in successive rounds were obtained using this technology.

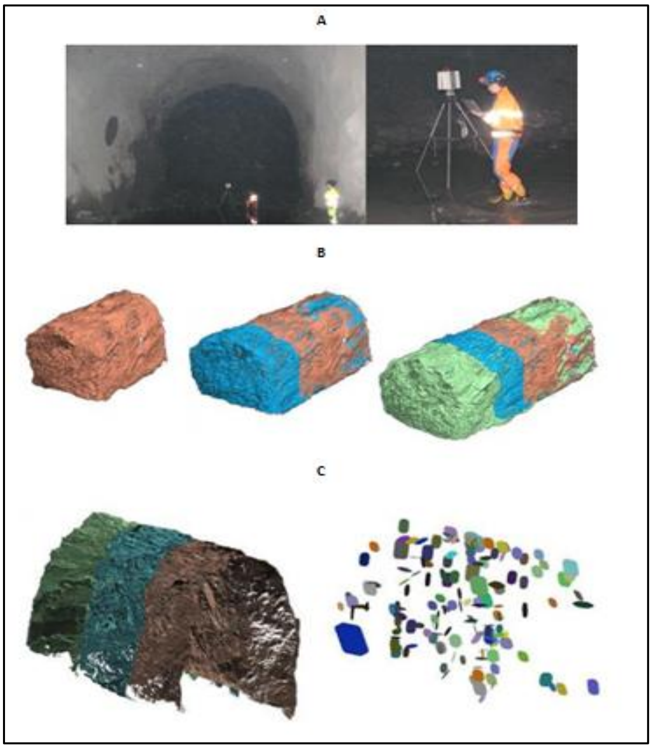


Figure 7. (A) Lidar tripod set up at 10 m diameter Sandvika tunnel near Oslo, Norway. (B) Alignment of three 5 m rounds of an advancing drill and blast tunnel, meshed model, Sandvika. (C) Bare rock polygonal model (left) and 158 identified joint surfaces (right) from three 5 m rounds, Sandvika site (Fekete et al., 2009).

Abellán et al. (2008) conducted a study on the rockfall at Vall de Núria located in the Eastern Pyrenees using a long-range terrestrial laser scanner. The authors performed 8 scans at 3 different stations to obtain the coordinated of approximately 4 million points. The acquired data allowed creating a highly accurate Digital Elevation Model (DEM) and reconstructing the joint geometry in the studied area. The paper also attempted to model the geometry and volume of the source area in recent rockfalls.

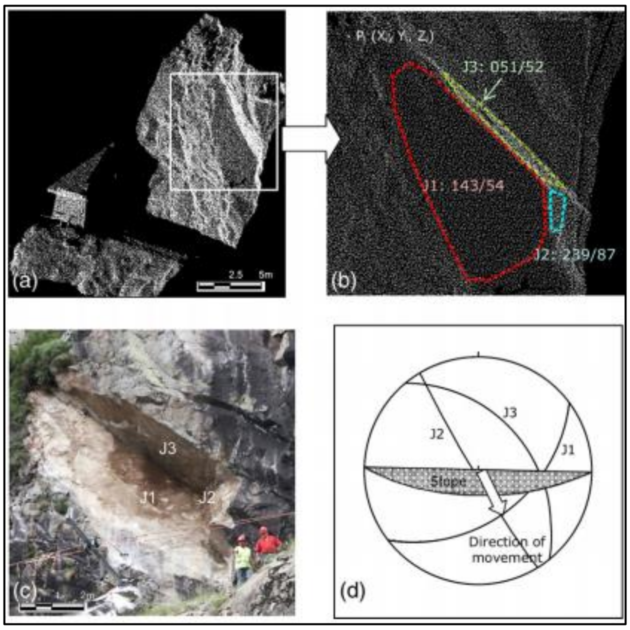


Figure 8. (a) 3-dimensional point cloud of the detachment area in c. The selected area is magnified in b. (b) Geometry model of the 3D point cloud of the joints: J1, J2, and J3. (c) Photograph of the same area. (d) Stereographic projection of the joints: J1, J2, J3 and the wedge between the direction of movement J1 and J2 (Abellán et al., 2008).

Oparin et al., (2007) developed a 3D digital model to describe the hierarchical structure of geoblocks at a limestone deposit. The ready-made 3D digital model of the open-pit side surface developed based on the surface laser scanning allowed linear measurements of the rock mass geoblocks with no in-situ linear and angular measurements. The obtained digital model was also used to determine the properties of objects for lay-outs, cross-sections and profiles and to evaluate metric (linear and angular) areas and volumes.

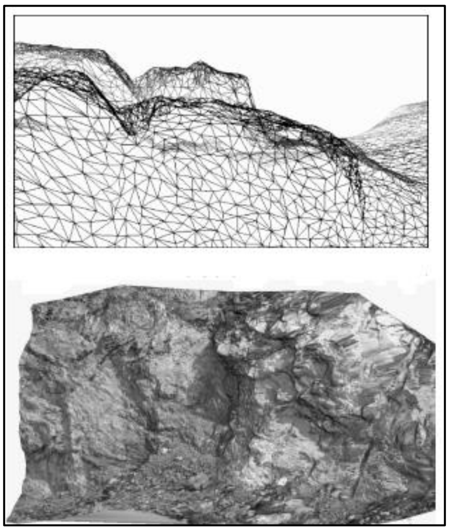
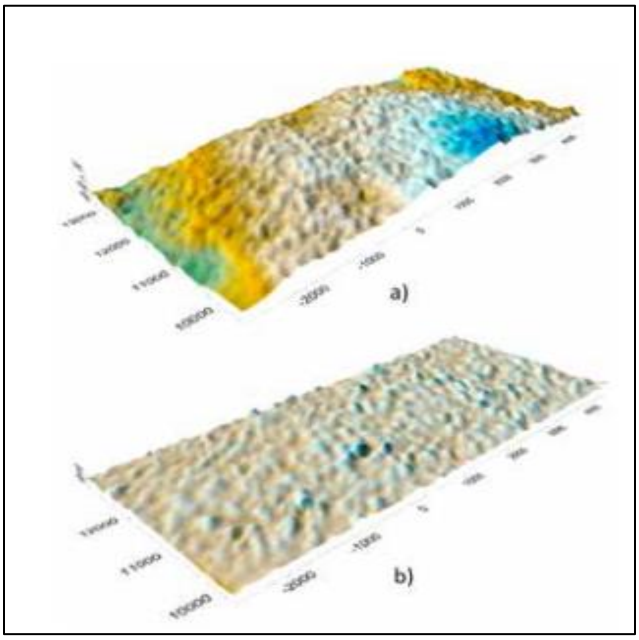


Figure 9. Fragment of the 3D digital model of the vertical pit side surface, developed by the surface laser scanner with a precision of 15 mm (Oparin et al., 2007)

Engin & Maerz (2016) developed a method that enables determining the particle size distribution resulting from blasting operations by evaluating the point cloud data obtained from terrestrial laser scanners. The particle size distribution of a laboratory-scale aggregate mixture and a pile obtained from a stone quarry with an already known size distribution were firstly determined using TLS technology. When the obtained point clouds were compared to the results of the sieve analysis conducted on these two samples, it was found that TLS technology provides highly accurate results. This paper demonstrated the efficiency of this Terrestrial Laser Scanning in analyzing the particle size distribution of the blasted materials.



Şekil 10. (a) Original 3D model of the crushed aggregate pile in the studied quarry (b) A view of the same model after correction (Engin & Maerz, 2016).

3. CONCLUSION

This study reviews Terrestrial Laser Scanning technology (TLS), its measurement and working principle, its advantages and the main softwares that can be used to model the results obtained from this technology. Numerous studies highlighted that geodesic and photogrammetry methods are less effective than the TLS method in terms of accuracy, speed and efficiency in conducting the necessary calculations during the measurement process which explains the increasingly higher popularity of this technology.

Numerous softwares can be used to interpret Terrestrial laser scanning data for the objective of modeling objects of different sizes and geometries, conducting numerous calculations and for reconstructing purposes.

Today, Terrestrial Laser Scanning technology is widely used in numerous mining engineering applications due to its outstanding advantages. These applications cover the determination of discontinuities in quarries and mines, deformation measurements, evaluating and monitoring blasting results, investigating rock falls and landslides and 3D design of slope and bench geometry.

Nowadays, terrestrial laser scanning technology became an efficient tool to most engineering applications. On account of its reliability, accuracy and efficiency, Terrestrial Laser Scanning technology has become an efficient tool in numerous applications. The usage areas of this technique keep expanding as it has been proven to be a more advantageous than the traditional methods in terms of operability, reliability and time and cost efficiency.

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