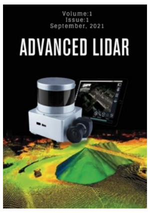

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3D Modeling of Mufti Abdullah Sıddık Mosque using Wearable Mobile LiDAR

Atilla Karabacak *[1], **Murat Yakar** [2]

[1]*Mersin University, Vocational School of Technical Sciences, Mersin, Türkiye*
[2]*Mersin University, Faculty of Engineering, Department of Geomatics Engineering, Mersin, Türkiye*

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Abstract

Mobile LIDAR, which can be attached to any moving vehicle, started to be used after 2000. In recent years, Wearable Mobile LiDAR (WML), which can be carried by wearing it on a person, has started to be used. WML is used for mapping and 3D modeling of interior and narrow places that cannot be reached by any vehicle and only one person can enter. In this study, 3D model and orthophoto of Mufti Abdullah Sıddık Mosque located in Mersin University Çiftlikköy campus were produced. With WML, data were collected in a short time like 13 minutes in the field and the produced orthophoto and 3D models were produced within the error limit. When the system is used fast and based on Ground Control Points (GCP), it gives results within the error limits. This study demonstrates the usability of WML in structure modeling and mapping.

1. Introduction

The world population is constantly increasing. The growing population is generally concentrated in cities. Today, the needs of technologically developing and growing cities are also increasing. For a sustainable development, it is necessary to make earthquake-resistant structures by taking into account the earthquake reality of the buildings and to examine the deformation in the following years. It is thought that it is important in the construction or restoration stages of large buildings or in possible disasters to record cities in 3D. The 3D modeling of the structures made with the WML method also reveals all the details that escape the human eye (Erdoğan et al., 2021;). With the WML method, fast reliable mapping of structures is possible. The number of buildings in our cities is increasing day by day. We think that a 3D model of these structures with their geographical location is necessary in order to be able to recognize, record, respond to their needs, protect people's lives and develop geographic information systems that will help those who govern the city. In this study, the 3D model and orthophoto of Mufti Abdullah Sıddık Mosque located in Mersin University Çiftlikköy Campus were produced using WML.

Point cloud technology is developing day by day (Karataş et al.2022a). Cultural heritage documentation and modelling can be performed with high precision (Karataş et al.2022b). Architectural properties can be defined and determined in a short time (Karataş et al.2022c; Kanun et al., 2021; Kaya et al., 2021; Şenol et al., 2017; Şenol et al., 2020; Ulvi & Yiğit, 2022; Yakar et al., 2009; Yılmaz & Yakar, 2016).

2. Wearable Mobile Lidar (WML)

The method of scanning by a human wearing the Mobile LIDAR platform is called WML. WML is a system in which 3D point cloud data of scenes within a horizontal range of 360o can be viewed and recorded by

* **Corresponding Author**

*(atilakarabacak@mersin.edu.tr) ORCID ID 0000-0002-1096-3949
(myakar@mersin.edu.tr) ORCID ID 0000-0002-2664-6251

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a tablet computer, which is usually loaded by a human being through a backpack.

WML is a compact system that includes a LIDAR sensor, RGB camera and GNSS-IMU, which can work in all light conditions. LiDAR sensors, which can capture full 360° panoramic images, have a range of 100 - 200 m in different brands. A 3D model is created by calculating the distance from the time elapsed until the reflection of the rays hitting the object illuminated by a LIDAR light, and by determining the surfaces over the triangular model consisting of points (NAVVİS, 2021; Lauter, 2020; GEXCEL, 2021; Geoslam 2021).

Since the system is carried on a person's back, it can be easily moved and worked in narrow and complex structures. The system can be easily transported in the trunk of a vehicle. GML is designed to be used in places where people can walk. It is a system designed to be a solution for indoor and outdoor areas, underground mines, tunnels, cultural heritage sites, forests, urban areas, buildings and crime scenes that are difficult to record and complex (NAVVİS, 2021; Lauter, 2020; GEXCEL, 2021; LEICA, 2021). The GEXCEL Heron wearable mobile LIDAR scanner is shown in Figure 1.

Figure 1. GEXCEL Heron GML scanner (GEXCEL, 2021).

Since GNSS does not work in covered areas, other systems are required. Simultaneous localization and mapping "Simultaneous Localization And Mapping" (SLAM) was developed in 2008. The system is mobile, that is, active by movement, while the system is making a map of an unfamiliar environment, it improves the map it produces according to the location it is progressing, and offers an algorithmic approach to solving problems by constantly positioning itself. When mobile robotics travel with SLAM, it positions itself according to the environment by using the distances from LIDAR. It requires LIDAR, GPS, accelerometer, sensors and algorithm data to do this. SLAM technology is a solution against the deterioration of GPS signals in closed areas, forests, inside buildings, tunnels, caves, wells, mines and narrow streets in the city where the sky is not visible at all or completely. SLAM technology has revolutionized mapping in difficult and complex locations. SLAM calculates the instantaneous position of each displacement of the wearable mobile LIDAR by taking the relative and absolute positioning inputs. However, its position calculated in this way cannot be expected to be as precise as a static position (Geoslam, 2021; Thomson, 2020; Thomson, 2021).

2.1. WML Considerations

The points to be considered in the field for the quality of the cartographic data obtained; Filippo, vd., 2018; Stefano, vd., 2021; Chio ve Hou, 2021, Karabacak, 2022; Ulvi et al., 2015; Yakar et al., 2008; Yakar et al., 2010).

- First, a reconnaissance is made in the work area, the walking path is determined, and if there are obstacles on the walking path, they are removed.
- If there is a door that the GML operator will pass through on the walkway, it is made open.
- Take precautions to avoid walking people and moving objects during scanning.
- If you slow your walking pace, you will collect more detailed data.
- Slow down when entering different rooms so that the SLAM algorithm can combine the inside and outside.
- Slow down when transitioning to different light and dark places so that SLAM can combine properly.
- Make the work of the SLAM algorithm easier by placing different objects in uniform spaces. For example, you can place a bicycle or a dustbin in the tunnel.
- Move by drawing an arc on turns.
- If there is another door on the way out than the door you entered, differentiate the scenes by descending from there, or if there is another staircase when going up and down, use it.
- Carry the LIDAR pole upright.
- Finish the route where you started.
- Do not make sudden movements.
- Reduce your walking speed in tasks requiring precision.
- Working by dividing large work areas into small areas will prevent the growth of error amounts.
- Keep the scan time less than 30 minutes.

2.2. Positioning Performance with RT-PPP Method

It is a wearable or handheld mobile laser scanner developed in 2015. It uses SLAM Algorithm. It can be used in all kinds of walkable areas. It can capture 3D point clouds and 5K panoramic images to collect both geometry and color information together. The portable Mobile laser scanner tested in this study is the Heron wearable Lidar device manufactured by Gexcel. Emitting infrared laser beams at a wavelength of 903 nm, a 16-channel Velodyne Puck LITE laser scanner achieves 300,000 points per second within a range of 100 m and with a 360° horizontal view and a 30° (-15 +15) vertical field of view. The laser scanner sensor is combined with an XSens MTI, IMU, whose data is used in system trajectory prediction. While working, the LiDAR head is mounted on a telescopic carbon fiber pole, connected to a battery and a control unit.

Parts of the Gexcel Heron wearable 3D mobile mapping system are shown in Figure 2. The scanner head with the laser sensor is screwed onto a pole. The cable connection from the scanner head connects to the battery for power, data exchange and the tablet for the program. The device is controlled and managed with the Heron live program in the tablet. The instantaneous state of the point cloud made on the tablet screen appears and the mobile LIDAR operator stops the work when there is a possible problem on the screen and returns to the beginning if necessary and repeats the work. The pole holding the LIDAR can be used by placing it in a pocket attached to the belt, or it can be used by holding it vertically by hand (Oruç and Baş, 2021; Oruç and Öztürk, 2021; Alptekin & Yakar, 2021; Alptekin et al., 2022).

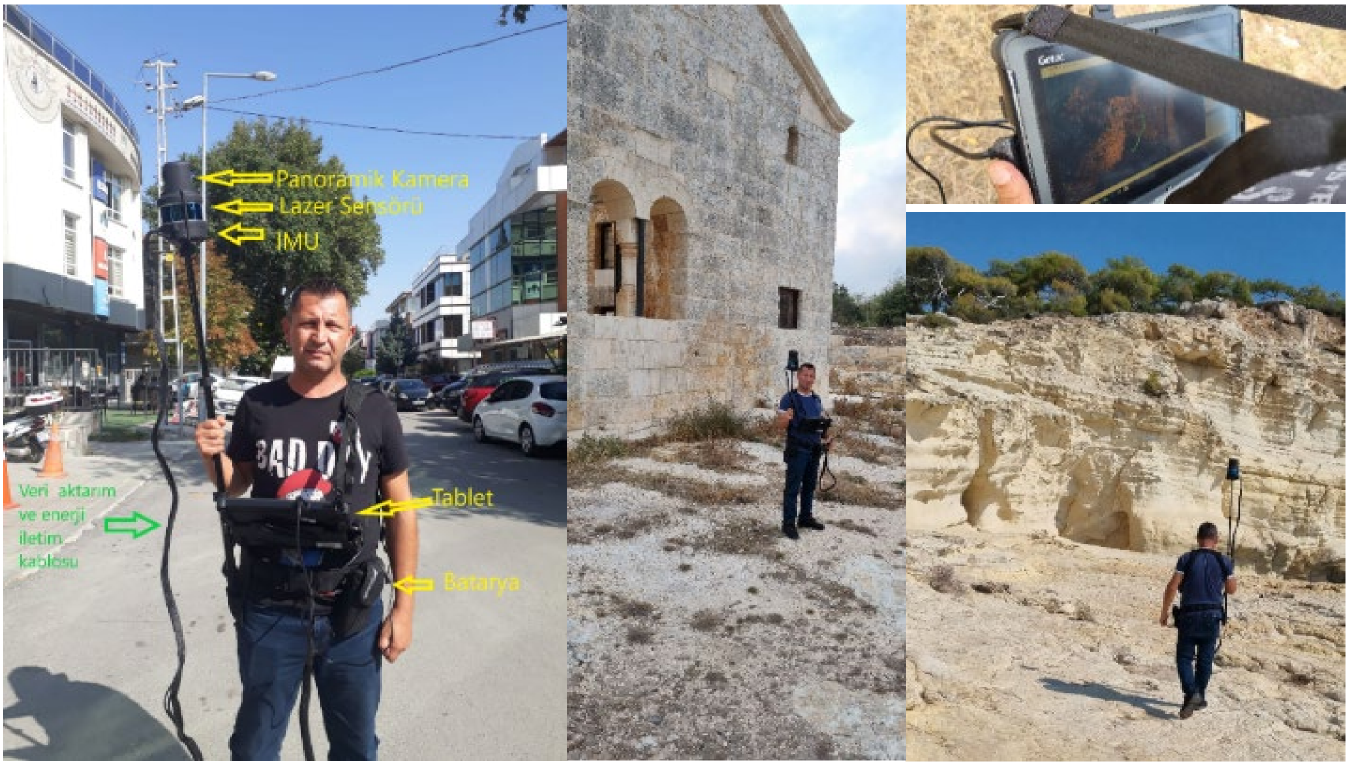


Figure 2. Heron GML

According to the manufacturer's specifications, the system provides a local accuracy of 3 cm and a final global accuracy of 5 cm. The presence of loops and closures, as well as the properties of the scanned environment, may affect the SLAM algorithm and the accuracy may drop to 20-50 cm (Paksoyteknik, 2022, Maset vd., 2021).

Suitable Weather Conditions for Working
• Direct sunlight.
•Wind.
• Dark places
• Operating temperature from -10° C to +45° C.
Unsuitable Weather Conditions for Working
• Rain, snow, heavy rains.
• Very dusty environments.
• Aggressive atmosphere Shaking greater than 500 m/s2, usually lasting 11 ms.
• Strong electromagnetic fields.
• Water coming into the device will destroy the device.

Considerations During Scanning
• Do not shake the sensor.
• Do not splash.
• Avoid sudden movements.
• When scanning and calibrating, make sure that the cables connected to the laser sensor head always face to the right according to your path. The IMU may be affected if the cable direction changes.
• The pole should be kept upright during scanning.

2.3. WML Usage Areas

It can meet the many mapping and modeling in documentation of cultural heritage, forestry and forest mapping studies, indoor modelling, open mine surveys, determination of deformation in structures caused by seismic events, tunnel, cave modeling, renewal of cadastral maps, measurement of energy transmission lines, infrastructure maps and recording of the crime scene. (Filippo vd. 2018, Masiero vd. 2018, Rodríguez-Martín vd. 2022, Carlos Coba vd. 2018, Xu, vd., 2020, Hyyppä, vd., 2020, Ko, vd., 2021, Zhou, 2019, Geoslam, 2021, Otero, vd., 2020, Maset, vd., 2021, Maset, vd., 2022, Vassena ve Clerici, 2018, Sánchez-Aparicio, vd. 2021, Di Stefano, vd., 2021, Chio ve Hou, 2021, Velas, vd., 2019, Ulvi, vd., 2021; Kabadayı, 2021; Kabadayı & Uysal, 2020).

3. 3D Modeling of a Mosque With WML

The 3D model and orthophoto of Mufti Abdullah Sıddık Mosque, located in Mersin University Çiftlikköy campus, were produced. For mosque measurement, ITRF coordinates were obtained by measuring 6 polygons in the field with GNSS and total station. Pictures from field studies for mosque measurement are shown in Figure 3.

Figure 3. Mufti Abdullah Sıddık Mosque field study

3.1. Scanning Inside and Outside of Mosque with Closed Route Using GCP

The route was planned by visiting the inside and outside of the mosque, using 6 GCPs as the closed route, so that the inside and outside of the mosque would be completed in the same purchase. Closed doors were opened and a plan was made according to the obstacles. The route was planned to be closed, but considering that the retaining wall around the mosque with a ladder would disrupt the dimensions, the route that started over the wall was closed by coming to the bottom of the wall from the garden of the mosque. The route was completed in 13 minutes. When we walk on the rough slope, the route is disrupted (Figure 4).

Figure 4. The sloped land around the mosque.

Trying to solve it at different intervals to fix it. Odometering the route and the problematic place on the route are seen in the odometer stage with a red line (Figure 5).

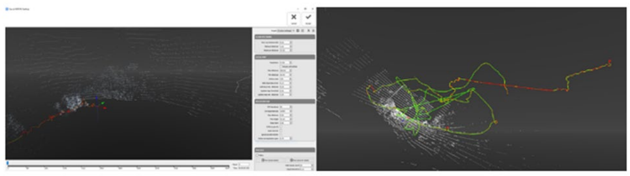


Figure 5. Odometer of the Closed and GCP Route.

The automatically generated ties with the GCP points included are given in Figure 6.

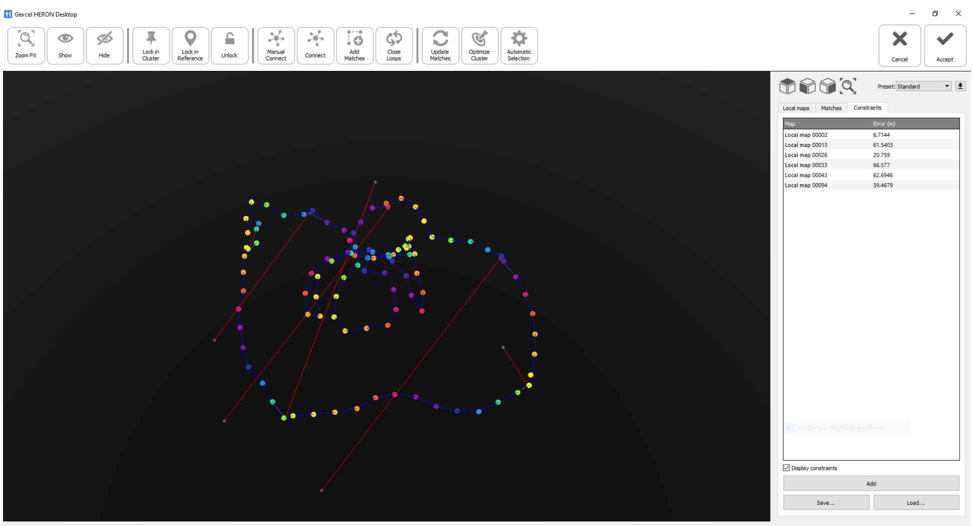


Figure 6. Tie with GCP points included

New ligaments were pulled (Fig. 7).

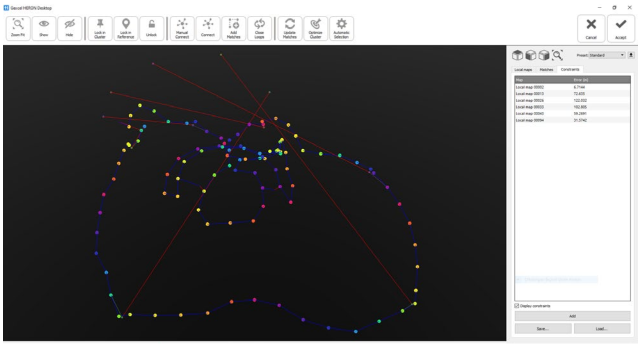


Figure 7. Tie when new links are added

As a result of newly added ligaments and balancing, the error in the RMSD range of 4.1 cm on average 2.5 cm was calculated as 8 cm at most and 3 cm on average (Figure 8).

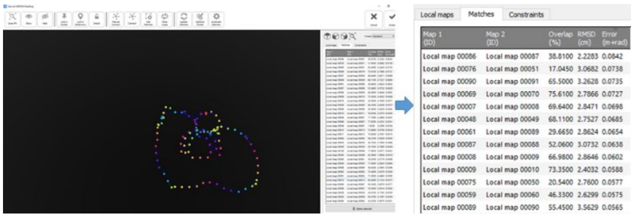


Figure 8. The biggest mistakes in ties as a result of balancing.

As a result of balancing, the error in the control points was 0,1,1,3,4,5 cm. Average output was 2.3 cm (Fig. 9).

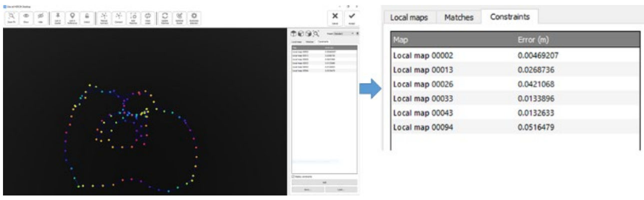


Figure 9. Errors hitting YKN as a result of balancing.

The error rate is higher in the vineyards at the stair exits to the upper floor of the mosque. Therefore, it was tried to reduce the error in the route by creating links between the route on the first floor of the mosque and the ground floor (Figure 10).

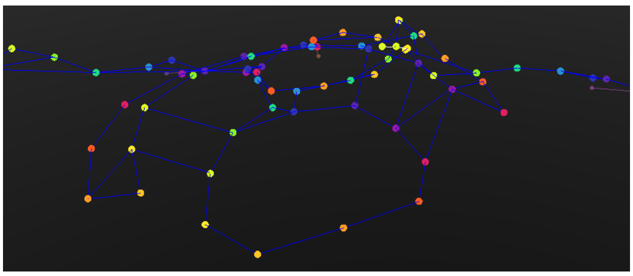


Figure 10. The ties added between the first floor and the ground floor in the mosque.

The representation of the ties together in the 3D model is given in Figure 11.

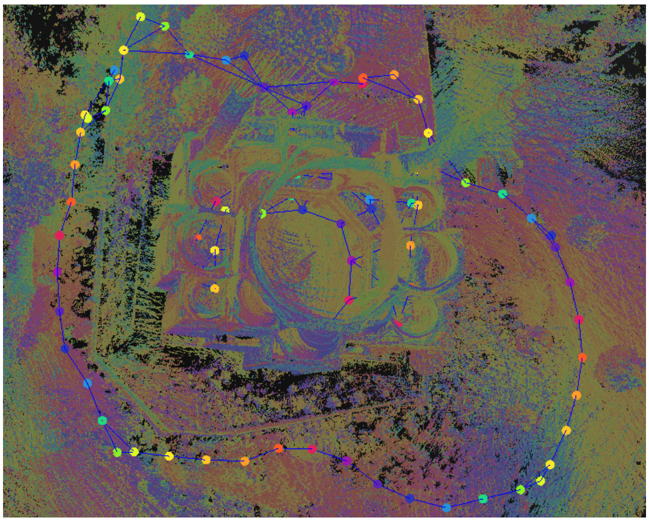


Figure 11. View of the 3D model together with ties.

The work is transferred to the Reconstructor program (Figure 12).

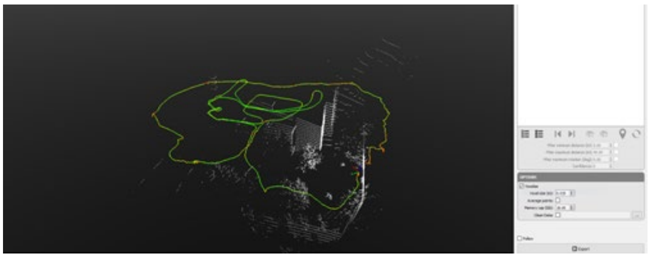


Figure 12. Exported to Go to Reconstruct.

In Reconstructor, the 3D model of the Mosque can be examined from different angles and measured (Figure 13).

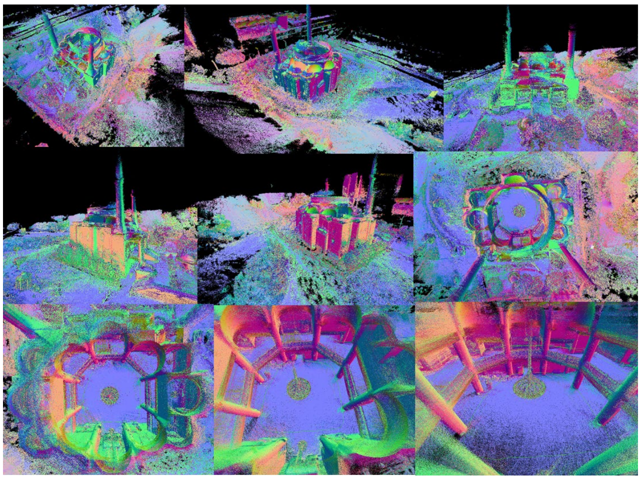


Figure 13. Mosque 3D model from different angles in Reconstructor.

An orthophoto of the structure was produced in Reconstructor (Figure 14). The edges measured on the orthophoto were measured with a steel tape measure as 5.56, 3.33, 5.66, 6.70, 3.77, 5.47, 7.40 m clockwise starting from the northwest in the field. The differences between the measurements were calculated as 4.1, 1.3, 1.2 and 1 cm, respectively, and the average of the differences was 1.9 cm (Table 1), (Figure 15).

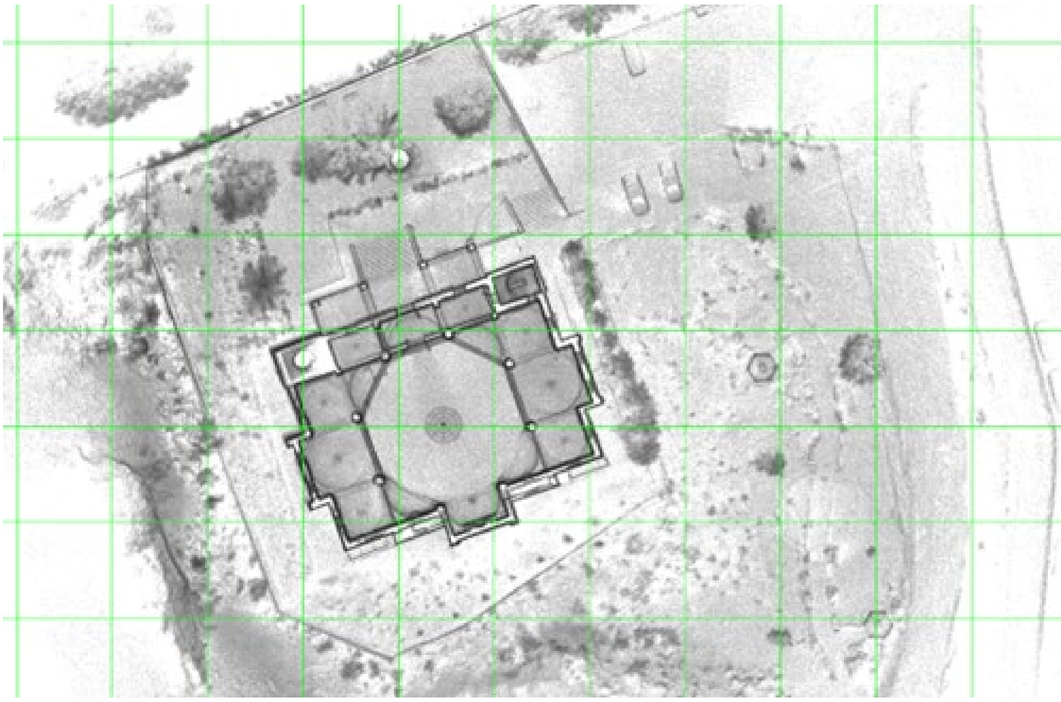


Figure 14. Mosque orthophoto.

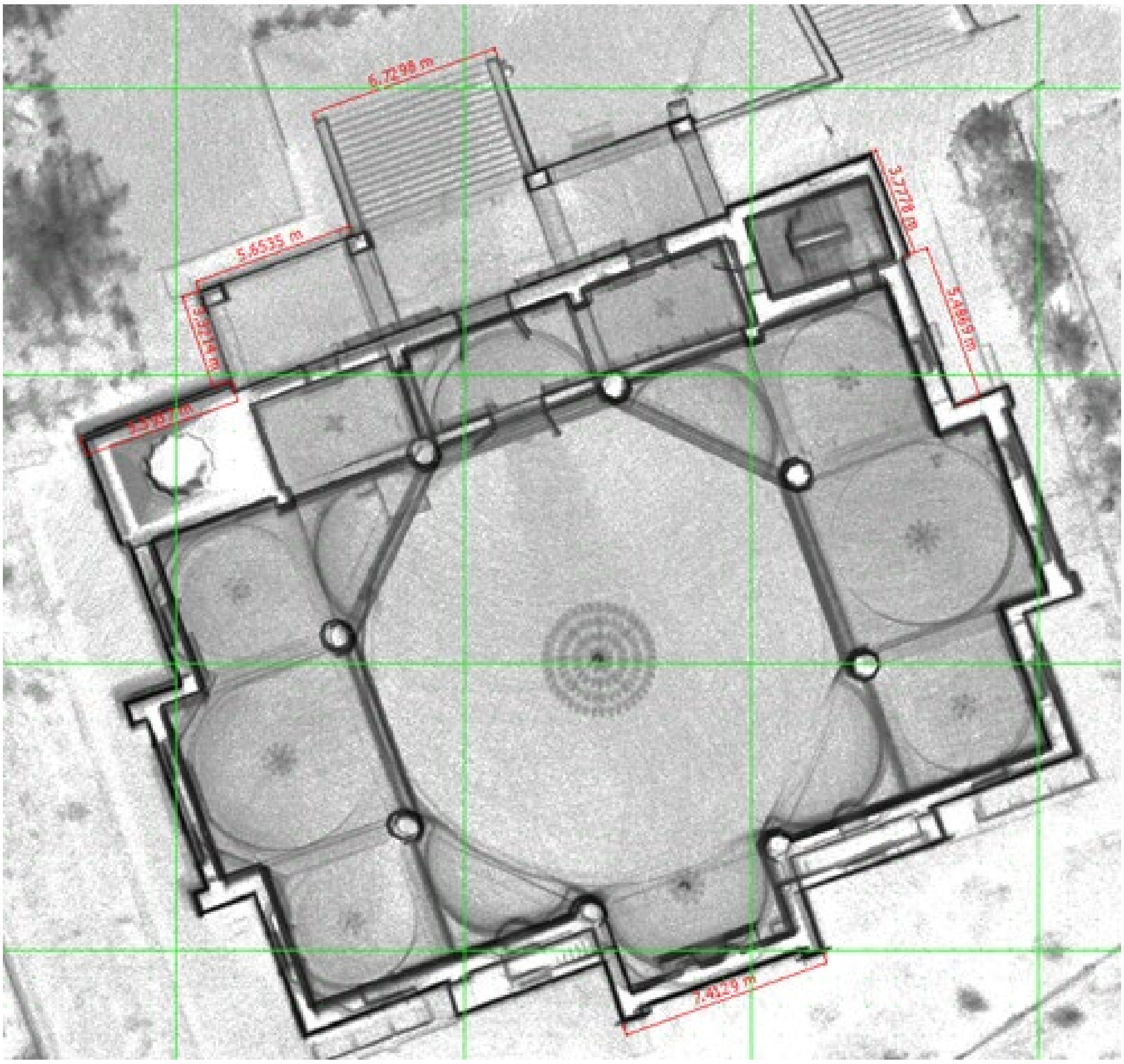


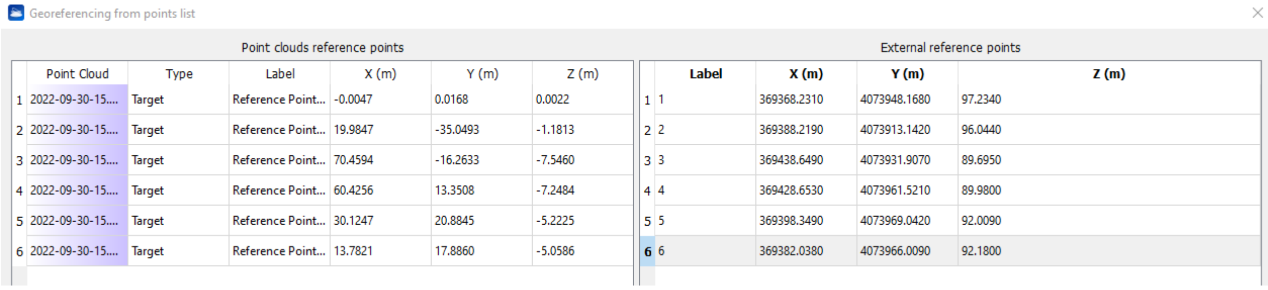
Figure 15. Lengths measured on the mosque orthophoto.

Tablo 1. The lengths of the mosque walls over the land and its orthophoto

	1	2	3	4	5	6	7
Length on land (m)	5.56	3.33	5.66	6.70	3.77	5.47	7.40
Length in orthophoto (m)	5.60	3.32	5.65	6.73	3.78	5.49	7.41
Difference (cm)	4	1	1	3	1	2	1

In the Reconstructor, the location of the GCP points given by GML and the ITRF coordinates given by GNSS and totalstation can be viewed (Figure 16). In the Reconstructor, the errors hitting the YKN and their deviations relative to the coordinate axes can be displayed (Figure 17).

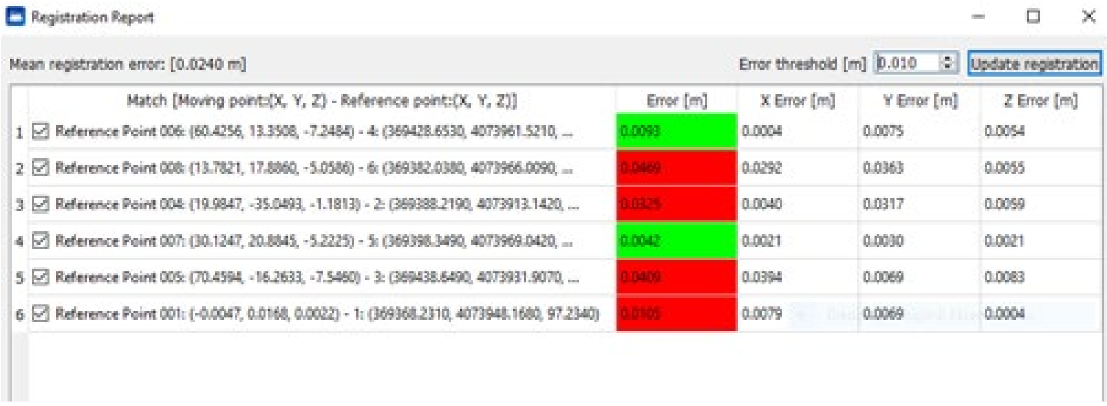
A coordinate transformed 3D point cloud can be displayed in Reconstructor (Figure 18).



	Point Cloud	Type	Label	X (m)	Y (m)	Z (m)
1	2022-09-30-15....	Target	Reference Point...	-0.0047	0.0168	0.0022
2	2022-09-30-15....	Target	Reference Point...	19.9847	-35.0493	-1.1813
3	2022-09-30-15....	Target	Reference Point...	70.4594	-16.2633	-7.5460
4	2022-09-30-15....	Target	Reference Point...	60.4256	13.3508	-7.2484
5	2022-09-30-15....	Target	Reference Point...	30.1247	20.8845	-5.2225
6	2022-09-30-15....	Target	Reference Point...	13.7821	17.8860	-5.0586

	Label	X (m)	Y (m)	Z (m)
1	1	369368.2310	4073948.1680	97.2340
2	2	369388.2190	4073913.1420	96.0440
3	3	369438.6490	4073931.9070	89.6950
4	4	369428.6530	4073961.5210	89.9800
5	5	369398.3490	4073969.0420	92.0090
6	6	369382.0380	4073966.0090	92.1800

Figure 16. GCP position and ITRF coordinates.



	Match [Moving point:(X, Y, Z) - Reference point:(X, Y, Z)]	Error [m]	X Error [m]	Y Error [m]	Z Error [m]
1	Reference Point 006: (60.4256, 13.3508, -7.2484) - 4: (369428.6530, 4073961.5210, ...	0.0093	0.0004	0.0075	0.0054
2	Reference Point 008: (13.7821, 17.8860, -5.0586) - 6: (369382.0380, 4073966.0090, ...	0.0469	0.0292	0.0363	0.0055
3	Reference Point 004: (19.9847, -35.0493, -1.1813) - 2: (369388.2190, 4073913.1420, ...	0.0325	0.0040	0.0317	0.0059
4	Reference Point 007: (30.1247, 20.8845, -5.2225) - 5: (369398.3490, 4073969.0420, ...	0.0042	0.0021	0.0030	0.0021
5	Reference Point 005: (70.4594, -16.2633, -7.5460) - 3: (369438.6490, 4073931.9070, ...	0.0409	0.0394	0.0069	0.0083
6	Reference Point 001: (-0.0047, 0.0168, 0.0022) - 1: (369368.2310, 4073948.1680, 97.2340)	0.0105	0.0079	0.0069	0.0004

Figure 17. GCP hitting errors and their deviations relative to the coordinate axes.

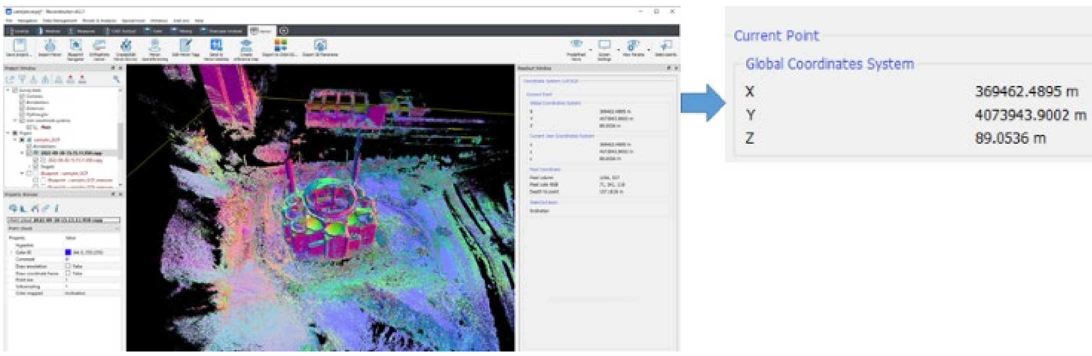


Figure 18. 3D mosque model in ITRF coordinate system

4. Conclusion

With the GML, the exterior and interior of the mosque were completed on the same route in a short time like 13 minutes. Since the walking path in the western direction of the mosque is sloped and stony, mistakes grow in the vineyards where it is difficult to walk. When going up the stairs in the mosque, the error is big in the vineyards on the stairs. In this case, errors were reduced by pulling ties from the first floor of the mosque to the entrance floor of the mosque. Since there is no GNSS support in the GML used in the study, the growth of errors was prevented with YKN and the mosque map and 3D model could be produced in the ITRF coordinate system within the error limits. The weak point of the system is that GCP should be used to give reliable results and this increases the working time in the field. In this study, it is suggested to use GML to produce maps and 3D models of structures.

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Author contributions

Atila Karabacak: Data curation, Writing-Original Draft Preparation, Validation, Data curation, Writing, Visualization, Control and Validation
Murat Yakar: Conceptualization, Methodology, Software, Investigation, Software

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

References

Alptekin, A. & Yakar, M. (2021). Lazer Tarayıcının Jeolojik Olayların Modellenmesinde Kullanımı. *Türkiye Lidar Dergisi,* 3(2), 71-75. DOI: 10.51946/melid.1018197

Alptekin, A., Çelik, M. Ö., Doğan, Y. & Yakar, M. (2022, February). Illustrating of a landslide site with photogrammetric and LIDAR methods. In Research Developments in Geotechnics, Geo-Informatics and Remote Sensing: Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019 (pp. 303-305). Cham: *Springer International Publishing.*

Cabo, C., Del Pozo, S., Rodríguez-Gonzálvez, P., Ordóñez, C. & Gonzalez-Aguilera, D. (2018). Comparing terrestrial laser scanning (TLS) and wearable laser scanning (WLS) for individual tree modeling at plot level. *Remote Sensing*, 10(4), 540.

Carla LAUTER'in 13 Mayıs 2020 tarihli yazısı (Yeni giyilebilir VLX tarayıcıları ile NavVis, mobil haritalamayı ana akım haline getirmeyi hedefliyor) www-geoweeknews-com. (son erişim 01.10.2021)

Chio, S. H. & Hou, K. W. (2021). Application of a Hand-Held LiDAR Scanner for the Urban Cadastral Detail Survey in Digitized Cadastral Area of Taiwan Urban City. *Remote Sensing*, 13(24), 4981.

Di Filippo, A., Sánchez-Aparicio, L. J., Barba, S., Martín-Jiménez, J. A., Mora, R. & González Aguilera, D. (2018). Use of a wearable mobile laser system in seamless indoor 3D mapping of a complex historical site. *Remote Sensing,* 10(12), 1897.

Di Filippo, A., Sánchez-Aparicio, L. J., Barba, S., Martín-Jiménez, J. A., Mora, R. & González Aguilera, D. (2018). Use of a wearable mobile laser system in seamless indoor 3D mapping of a complex historical site. *Remote Sensing*, 10(12), 1897.

Di Stefano, F., Chiappini, S., Gorreja, A., Balestra, M. & Pierdicca, R. (2021). Mobil 3D tarama LiDAR: bir literatür taraması. *Geomatik, Doğal Tehlikeler ve Risk, 12*(1), 2387-2429.

Di Stefano, F., Torresani, A., Farella, E. M., Pierdicca, R., Menna, F. & Remondino, F. (2021). 3D surveying of underground built heritage: Opportunities and challenges of mobile technologies. *Sustainability*, 13(23), 13289.

Erdoğan, A., Kabadayi, A. & Akin, E. S. (2021). Kültürel mirasın fotogrametrik yöntemle 3B modellenmesi: Karabıyık Köprüsü Örneği. *Türkiye İnsansız Hava Araçları Dergisi*, 3(1), 23-27.

Geoslam (2021). https://geoslam.com/

GEXCEL (2021). https://gexcel.it/en/solutions/heron-portable-3d-mapping-system

Hyyppä, E., Kukko, A., Kaijaluoto, R., White, J. C., Wulder, M. A., Pyörälä, J. & Hyyppä, J. (2020). Accurate derivation of stem curve and volume using backpack mobile laser scanning. *ISPRS Journal of Photogrammetry and Remote Sensing*, 161, 246-262.

Kabadayı, A. & Uysal, M. (2020). Çok yüksek çözünürlüklü İHA verilerinden bina tespiti. Türkiye İnsansız Hava Araçları Dergisi, *2*(2), 43-48.

Kabadayı, A. (2021). Unmanned aerial vehicle usage in rough areas and photogrammetric data generation. *Advanced UAV*, 1(1), 8-14.

Kanun, E., Metin, A. & Yakar, M. (2021). Yersel Lazer Tarama Tekniği Kullanarak Ağzıkara Han'ın 3 Boyutlu Nokta Bulutunun Elde Edilmesi. *Türkiye Lidar Dergisi*, 3(2), 58-64. DOI: 10.51946/melid.1025856

Karabacak A. (Kasım 2022) Mobil Haritalama Yöntemlerinin Farkli Yerlerde Uygulamalari ve Karşilaşilan Sorunlar, Mersin Üniversitesi Fen Bilimleri Enstitüsü, Uzaktan Algilama ve Coğrafi Bilgi Sistemleri Anabilim Dalı, Yüksek Lisans Tezi,

Karabacak, A. & Yakar, M. (2022). Giyilebilir Mobil LİDAR Kullanım Alanları ve Cambazlı Kilisesinin 3B Modellemesi. *Türkiye Lidar Dergisi, 4*(2), 37-52. DOI: 10.51946/melid.1146383

Karataş, L., Alptekin, A. & Yakar, M. (2022a). Determination of Stone Material Deteriorations on the Facades with the Combination of Terrestrial Laser Scanning and Photogrammetric Methods: Case Study of Historical Burdur Station Premises. *Advanced Geomatics*, 2(2), 65-72.

Karataş, L., Alptekin, A. & Yakar, M. (2022b). Creating Architectural Surveys of Traditional Buildings with the Help of Terrestrial Laser Scanning Method (TLS) and Orthophotos: Historical Diyarbakır Sur Mansion. *Advanced LiDAR*, 2(2), 54-63.

Karataş, L., Alptekin, A. & Yakar, M. (2022c). Analytical Documentation of Stone Material Deteriorations on Facades with Terrestrial Laser Scanning and Photogrammetric Methods: Case Study of Şanlıurfa Kışla Mosque. *Advanced LiDAR*, 2(2), 36-47.

Kaya, Y., Yiğit, A. Y., Ulvi, A. & Yakar, M. (2021). Arkeolojik alanların dokümantasyonununda fotogrametrik tekniklerinin doğruluklarının karşılaştırmalı analizi: Konya Yunuslar Örneği. *Harita Dergisi*, 165, 57-72.

Ko, C., Lee, S., Yim, J., Kim, D. & Kang, J. (2021). Comparison of Forest Inventory Methods at Plot-Level between a Backpack Personal Laser Scanning (BPLS) and Conventional Equipment in Jeju Island, South Korea. *Forests*, 12(3), 308.

LEICA (2021). https://leica-geosystems.com/products/mobile-sensor-platforms/capture-platforms/leica-pegasus-backpack

Maset, E., Cucchiaro, S., Cazorzi, F., Crosilla, F., Fusiello, A. & Beinat, A. (2021). Investigating the Performance of a Handheld Mobile Mapping System in Different

Outdoor Scenarios. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 43, B1-2021.

Maset, E., Scalera, L., Beinat, A., Visintini, D. & Gasparetto, A. (2022). Performance Investigation and Repeatability Assessment of a Mobile Robotic System for 3D Mapping. *Robotics*, 11(3), 54.

Masiero, A., Fissore, F., Guarnieri, A., Pirotti, F., Visintini, D. & Vettore, A. (2018). Performance evaluation of two indoor mapping systems: Low-cost UWB-aided photogrammetry and backpack laser scanning. *Applied Sciences*, 8(3), 416.

Oruç, M. E. & Baş, G. (2021). Kompleks Yapı ve Alanlarda Yersel Lazer Tarama Teknolojisinin Kullanımı. *Türkiye Lidar Dergisi*, 3(2), 39-47.

Oruç, M. E. & Öztürk, İ. L. (2021). Usability of Terrestrial Laser Technique in Forest Management Planning. *Türkiye Lidar Dergisi*, 3(1), 17-24.

Otero, R., Lagüela, S., Garrido, I. & Arias, P. (2020). Mobile indoor mapping technologies: A review. *Automation in Construction*, 120, 103399.

Paksoyteknik (2022). https://paksoyteknik.com.tr/index.php/paksoy-topcon/lazer-tarama/gexcel-heron

Rodríguez-Martín, M., Sánchez-Aparicio, L. J., Maté-González, M. Á., Muñoz-Nieto, Á. L. & Gonzalez-Aguilera, D. (2022). Comprehensive Generation of Historical Construction CAD Models from Data Provided by a Wearable Mobile Mapping System: A Case Study of the Church of Adanero (Ávila, Spain). *Sensors,* 22(8), 2922.

Sánchez-Aparicio, L. J., Mora, R., Conde, B., Maté-González, M. Á., Sánchez-Aparicio, M. & González-Aguilera, D. (2021). Integration of a wearable mobile mapping solution and advance numerical simulations for the structural analysis of historical constructions: A case of study in San Pedro Church (Palencia, Spain). *Remote Sensing*, 13(7), 1252.

Şenol, H. I., Erdogan, S., Onal, M., Ulukavak, M., Memduhoglu, A., Mutlu, S. & Yilmaz, M. (2017). 3D Modeling of A Bazaar in Ancient Harran City Using Laser Scanning Technique. International Archives of *The Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42.

Şenol, H. İ., Memduhoglu, A. & Ulukavak, M. (2020). Multi instrumental documentation and 3D modelling of an archaeological site: a case study in Kizilkoyun Necropolis Area. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 11(3), 1241-1250.

Thomson C., (2020), (What is SLAM?) https://info.vercator.com/blog/what-is-slam

Thomson C., (2021), 3 types of terrestrial laser scanners https://info.vercator.com/blog/3-types-of-terrestrial-laser-scanners.

Ulvi A., Yiğit, A. Y., Çelik, M. Ö. & Alptekin, A. (2021). Detection of existing infrastructure lines with wearable laser scanners and making infrastructure map: a case of Mersin University. *Mersin Photogrammetry Journal*, *3*(2), 61-68.

Ulvi, A. & Yiğit, A. Y. (2022). Comparison of the Wearable Mobile Laser Scanner (WMLS) with Other Point Cloud Data Collection Methods in Cultural Heritage: A Case Study of Diokaisareia. *ACM Journal on Computing and Cultural Heritage*, 15(4), 1-19.

Ulvi, A., Yakar, M., Toprak, A. S. & Mutluoglu, O. (2015). Laser Scanning and Photogrammetric Evaluation of Uzuncaburç Monumental Entrance. *International Journal of Applied Mathematics Electronics And Computers, 3*(1), 32-36. DOI: 10.18100/İjamec.41690

Vassena, G. & Clerici, A. (2018). Open pit mine 3D mapping by tls and digital photogrammetry: 3D model update thanks to a slam based approach. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42(2), 1145-1148.

Velas, M., Spanel, M., Sleziak, T., Habrovec, J. & Herout, A. (2019). Indoor and outdoor backpack mapping with calibrated pair of velodyne LiDARs. *Sensors*, 19(18), 3944.

Xu, S., Sun, X., Yun, J. & Wang, H. (2020). A new clustering-based framework to the stem estimation and growth fitting of street trees from mobile laser scanning data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 13, 3240-3250.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2008). Lazer Tarama Teknolojisi ve Fotogrametrik Yöntem ile Hacim Hesabı. *TÜBİTAK*, Proje No: 105M179, 90s.

Yakar, M., Yilmaz, H. M. & Mutluoglu, O. (2009). Comparative Evaluation of Excavation Volume by Terrestrial Laser Scanner and Total Topographic Station Based Methods. *Lasers in Engineering*, 19(5), 331.

Yakar, M., Yılmaz, H. M. & Mutluoğlu, Ö. (2010). Comparative evaluation of excavation volume by TLS and total topographic station based methods. *Lasers in Engineering*,19, 331–345

Yılmaz, H. & Yakar, M. (2016). LiDAR (Light Detection and Ranging) Tarama Sistemi. *Yapı Teknolojileri Elektronik Dergisi*, 2 (2), 23-33.

Zhou, S., Kang, F., Li, W., Kan, J., Zheng, Y. & He, G. (2019). Extracting diameter at breast height with a handheld mobile LiDAR system in an outdoor environment. *Sensors*, 19(14), 3212.