Turkish Journal of Science & Technology
18(1), 199-206, 2023

Research Paper
https://doi.org/10.55525/tjst.1240901

The Effect of The Number of Reference Points and Distribution on Coordinate Transformation in Underground Mining Measurements

Levent TAŞÇI[1], **Hacı Sait ARSLAN**[2]
[1] Department of Civil Engineering, Faculty of Engineering, Fırat University, Elazığ, Turkey
[2] ETI Chrome Company,, Elazığ, Turkey
[1] ltasci@firat.edu.tr, [2] Haci Sait.ARSLAN@etikrom.com

(Geliş/Received: 24/01/2023; Kabul/Accepted: 25/02/2023)

Abstract: This article focuses on examining the effect of the number and distribution of reference points on coordinate transformations in underground mining measurements using a handheld laser scanner. The points inside the mine were measured as reference using a Total Station. The same point cloud data was subjected to coordinate transformation with different numbers and elevations of reference points. It was observed that the homogeneous distribution of reference points used in the transformation increases precision in the horizontal and vertical directions. Both homogeneous and excessive use of transformation points result in the same good results in the horizontal, but in the vertical, it improves further. Using a large number of transformation points and using them at different elevations results in the same good results in the horizontal, but in the vertical, it increases precision even more. The article concludes that a sufficient number of homogeneously and heterogeneously distributed reference points are necessary for accurate coordinate transformation.

Keywords: Laser Scanner, Point Cloud, 3D Transformation, Geodetic Coordinate,

Yeraltı Madenciliği Ölçümlerinde Referans Noktası Sayısı ve Dağılımının Koordinat Dönüşümüne Etkisi

Özet: Bu makale, el tipi lazer tarayıcı kullanılarak yer altı maden ölçümlerinde referans noktalarının sayısı ile dağılımının koordinat dönüşümlerinin etkisini incelemeye odaklanmıştır. Maden içindeki noktalar, Total Station kullanılarak referans olarak ölçülmüştür. Aynı nokta bulutu verileri farklı sayıda ve yükseklikteki referans noktalarının dağılımı ile koordinat dönüştürme işlemine tabii tutulmuştur. Dönüşümde kullanılan referans noktalarının homojen dağılımının yatay ve dikey yönde hassasiyeti artırdığı gözlemlenmiştir. Hem homojen hem de aşırı sayıda dönüşüm noktasının kullanımı yatayda aynı iyi sonuçları verir, ancak dikeyde daha da geliştirir. Büyük sayıda dönüşüm noktasının ve bunları farklı yüksekliklerde kullanmanın, yatayda aynı iyi sonuçları verdiği, ancak dikeyde hassasiyeti daha da artırdığı gözlemlenmiştir. Makale, doğru koordinat dönüşümü için yeterli sayıda homojen ve heterojen şekilde dağıtılmış referans noktalarının kullanılmasının gerekli olduğu sonucuna varmaktadır.

Anahtar kelimeler: Lazer Tarayıcı, Nokta Bulutu, 3D Dönüşüm, Jeodezik Koordinat

1. Introduction

Underground mining surveying is the process of measuring and mapping the underground mines to determine the location, shape and size of mining operations. This is a critical step in the mining process as it allows mining companies to safely and efficiently extract resources while minimizing the potential for accidents and damage to the environment. The main objective of underground mining surveying is to create a detailed map of the mine, including information on the location of the ore body, the shape and size of the mining area and the location of any underground infrastructure such as ventilation shafts and tunnels. This information is then used to plan and execute mining operations, such as drilling and blasting, as well as to monitor and control the mining process to ensure safety and efficiency. One of the key challenges in underground mining surveying is the need to accurately measure and map the mine in a three-dimensional environment. This requires the use of specialized surveying equipment and techniques, such as laser scanning and underground GNSS, which can accurately measure the position and orientation of underground features. Another challenge in underground mining surveying is the need to transform coordinates between different reference systems. This is necessary because different mining operations may use different coordinate systems and the data collected by surveying equipment may also be in different formats. Coordinate transformation is the process of converting coordinates from one reference system to another and it is critical for ensuring that the data collected by the surveying equipment is accurate and can be used effectively in the mining process. In conclusion, underground mining surveying is a critical step in the mining process that allows mining companies to safely and efficiently extract resources while minimizing the potential for accidents and damage to the environment. The challenges of measuring and mapping in a three-dimensional environment and transforming coordinates between different reference systems require the use of specialized surveying equipment and techniques, as well as careful coordination and data management.

The laser scanning method was first introduced in Poland in 2003 and has since been extensively researched by cartographers and other experts. Prior to this, the only way to measure inaccessible places was through photogrammetric methods. However, advancements in technology have made it possible for the concept of point clouds to be used in geodesy and underground mining measurements [1-2]. The laser scanning technique involves -measuring the time it takes for a laser beam emitted from a scanning device to strike an object surface, reflect and return, which is then converted into a distance measurement and compared to photos taken. This measurement method has reduced the need for GNSS, Total Station and other geodetic measurement devices, as it requires less personnel, can be completed faster and can produce millions of point clouds representing a structure. Laser scanning technologies are also used in situations where traditional measurement methods are unable to generate enough points [3]. In his 2011 study, Dumalski [2] highlighted the potential applications of laser scanning and conducted practical tests on the use of laser scanners in vertical displacement analysis. In 2010, Yue and colleagues [4] used the laser scanner measurement method to measure slope deformations and found that the slope displacement trend was stable and the degree of landslide risk was low. In 2013, El-Tokhey and colleagues [5] conducted an experimental study to compare the results of measuring 9 points on a slope using both the total station technique and laser scanning and to evaluate the accuracy of the laser scanning data. They found that polynomial transformation was the best approach for converting from laser data to total station data and that it improved the accuracy of the results. In 2012, Gonzalez and colleagues [6] presented a new technique for determining the real accuracy that can be obtained using surface fitting techniques and found that the RIEGL laser scanner system could detect small deformations and could be used for monitoring deformations of engineering structures. In their 2009 study, Yıldız and Altuntaş [3] found that the number and distribution of reference points used for converting point clouds obtained by terrestrial laser scanning into the Geodetic Coordinate System have an impact on the accuracy of the conversion. They observed that as the number of Ground Control Points increases, errors in monitoring points decrease.

2. The aim of this study

This study aimed to use a hand-held laser scanner (Zebrevo by GeoSLAM) to measure and analyze an underground chrome mine in Elazığ, Turkey. The coordinates were transformed using total station measurements taken at various points within the mine gallery, which were distributed in different ways (heterogeneously and homogeneously) and at different heights. The goal of the study was to understand the impact of the distribution, number and height of the reference points on the transformation process within the mine gallery.

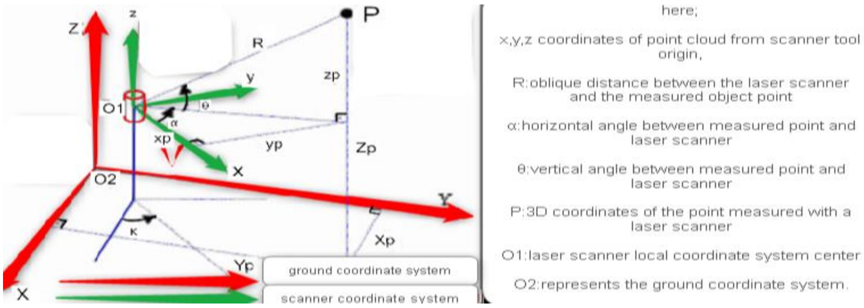
3. Laser scanner coordinate system

Geodetic coordinate measurement of an object is done in 3 different ways, depending on the size, location and characteristics of the scanner. These are: direct geodetic coordinate measurement, indirect geodetic coordinate measurement and data-based geodetic coordinate measurement [7].

Indirect geodetic coordinate measurement is done by converting the point cloud produced by the laser scanner into geodetic coordinates using known control points. At least three control points are used to calculate the transformation parameters between coordinate systems [8-9]. The control points can be marked in the measurement area with special markers (such as paper targets or sphere and cylinder targets) before the laser scanning process, or any detail point that can be selected on the model can also be used as a control point. In this method, the geodetic coordinates of the control points must be measured by terrestrial methods. The geodetic coordinates of the points used in the transformation can be measured with a total station or GNSS receivers. Direct geodetic coordinate measurement is applied in different ways depending on the characteristics of the laser scanner. It can be done by setting a theodolite on the scanner and setting the scanner on a known coordinate point, by mounting a GNSS receiver and compass on the scanner, or by mounting 2 GNSS receivers on the scanner. Data-based coordinate measurement is applied by combining laser scanning measurements with previously converted laser scanning measurements or other data in a geodetic coordinate system. This combination can be done using any point cloud merging method or image processing techniques [7].

4. Coordinate transformation

In laser scanners with GNSS, the resulting point cloud is obtained in the desired coordinate system. In systems without GNSS, point clouds are obtained locally and, if desired, are transformed into the desired geodetic coordinate system using a transformation method based on known coordinates. Coordinate transformation is a common practice in geodesy. Coordinate transformation is done to fully establish the relationship between point coordinates produced in different coordinate systems and to ensure datum unity. If it is desired to create local coordinate information obtained from laser scanner measurements in the country's coordinate system, it is necessary to connect the scanner coordinate system to a geodetic network with at least 3 control points. As a result of this connection, a three-dimensional coordinate transformation is carried out and the transformation is made to the desired coordinate system. The size measured by terrestrial laser scanners and the scanner coordinate system is shown in Figure 1.



here;

x,y,z coordinates of point cloud from scanner tool origin,

R:oblique distance between the laser scanner and the measured object point

α:horizontal angle between measured point and laser scanner

θ:vertical angle between measured point and laser scanner

P:3D coordinates of the point measured with a laser scanner

O1:laser scanner local coordinate system center

O2:represents the ground coordinate system.

Figure 1. Terrestrial laser scanner measurements, scanner coordinate system and earth coordinate system

In this study, coordinate transformations were performed using the "3D Surface Matching Method with Least Squares" found in the Leica Cyclone 3DR software. This method is the process of matching inclined surfaces with the least squares method. The 7 transformation parameters between surfaces are calculated with a 3D similarity transformation. If the surface elements of a single object are selected as the reference window, f(x,y,z) and the research window, g(x,y,z) in two different point clouds, the problem that arises is to find the best match between the reference window elements and the research window elements in terms of position, orientation and shape similarity. A random error value, e(x,y,z) is added to this and the following connection is obtained [10].

$$f(x,y,z) + e(x,y,z) = g(x,y,z) \qquad (1)$$

To express the relationship between conjugate surfaces, the 7-parameter 3D similarity transformation given in equation 2 is used. (Yıldz ve et al., 2008)

$$[X\ Y\ Z]^T = mR_{\omega\varphi\kappa}[x\ y\ z]^T + [t_x\ t_y\ t_z]^T \qquad (2)$$

$[X\ Y\ Z]^T$: 2. system coordinates
$R_{(\omega,\varphi,\kappa)}$: orthogonal transformation matrix elements
$[t_x\ t_y\ t_z]^T$: translation vector
$[x\ y\ z]^T$: 1. system coordinates
m: is the scale coefficient

The study was carried out in the underground chrome mine of Eti Chrome Company located within the boundaries of Incebayır village, Alacakaya district in Elazığ province. The underground chrome mine located within the boundaries of Incebayır village is 80 km away from the city center of Elazığ province and 15.4 km away from the Alacakaya district of Elazığ province. The satellite image of the location of the underground chrome mine within the boundaries of Elazığ is shown in Figure 2.

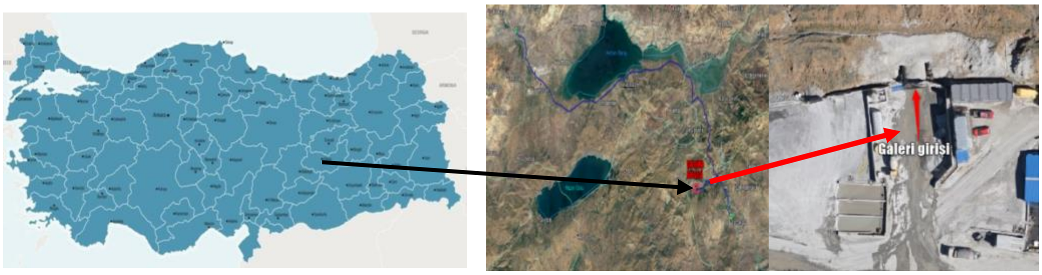
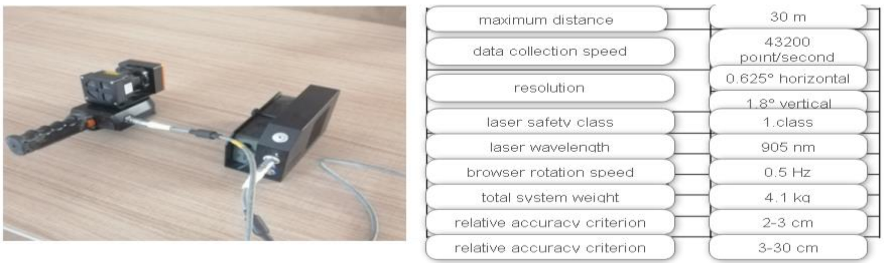


Figure 2. Satellite image of the study area within the borders of İncebayır Village, Alacakaya district of Elazig Province

5. Application

The study was carried out in an underground chrome mine, using a Zeb-Revo handheld laser scanner in an area with a 250 m inclined distance and a 20 m elevation difference. The device weighs 665 g and is easy to carry, making the measurement process easier. According to the manufacturer, it works with a closing technique and the accuracy of the measurement points is evaluated as 5 mm + 1 mm / m. The image and technical features of the device are shown in Figure 3.



maximum distance	30 m
data collection speed	43200 point/second
resolution	0.625° horizontal 1.8° vertical
laser safety class	1.class
laser wavelength	905 nm
browser rotation speed	0.5 Hz
total system weight	4.1 kg
relative accuracy criterion	2-3 cm
relative accuracy criterion	3-30 cm

Figure 3. Geo Slam Zebrevo laser scanner image and technical features

The laser scanner measurement was transformed into the geodetic network in four different ways. The accuracy of the transformations was studied based on total station measurement. Conical objects with distinguishable geometry and identifiable iron bars on the gallery ceiling were used for coordinate system transformation in the laser scanner measurement. The image of the conical objects used for the transformation in the gallery is shown in Figure 4.

Figure 4. Conical object used in the transformation of the point cloud obtained from laser scanning.

The gallery side walls were measured using the classical measurement device, the total station, using the backsight method. The total station measurement was accepted as the reference for the comparison of the transformations. The ED-50 coordinate system values were given to the endpoints of the conical objects and the identifiable iron points on the ceiling using the Leica brand total station. For the coordinate transformation, three points were placed close to the starting point of the measurement (approximately 5m.), one point approximately in the middle of the measurement area, 1 point at the end of the measurement area and two iron rods with identifiable geometry on the ceiling. In addition, 1 control cone was placed to compare the transformation results that will not be used in the coordinate transformation. As a result of the values given in the ED-50 coordinate system, the point cloud obtained from the measurement was connected to the geodetic network from the scanner's coordinate system by making four different transformations. The measurement geometry is shown in Figure 5.

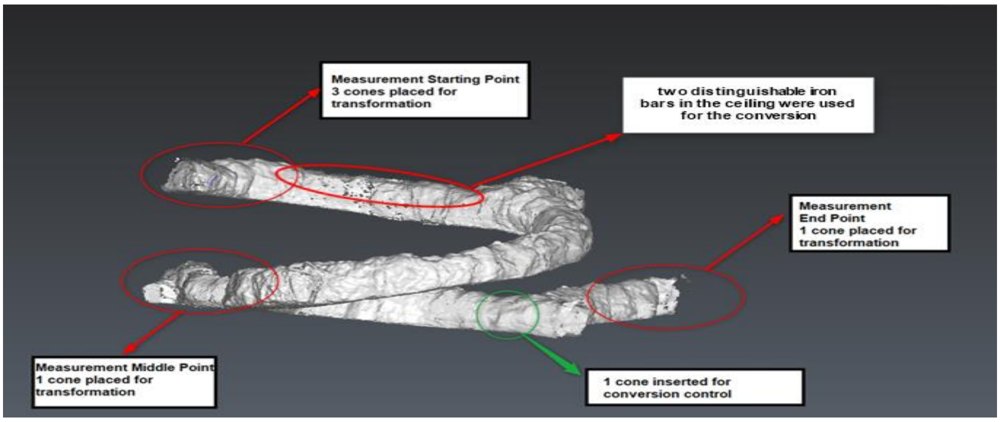


Figure 5. The underground mine measurement and measurement geometry were conducted using the laser scanner.

To connect the point cloud data in the scanner coordinate system obtained from measurement to the geodetic network, four different transformations were used. In the first transformation, three closely located cones were used at the starting point. In the second transformation, three cones, one at the starting point, one at the middle of the measurement and one at the end of the measurement, were used. In the third transformation, five cones left in the measurement area for reference were used. In the fourth transformation, two distinguishable iron objects on the ceiling were added to the three cones in the second transformation and a total of five reference points were used, the same as in the fourth transformation. The transformation points in the first transformation were evaluated as heterogeneous and in the second transformation, as homogeneously distributed. In the third transformation, the number of transformation points was increased differently from the first and second transformations and in the fourth transformation, the reference point number was the same as in the third transformation (five transformation points) but evaluated differently by using distinguishable iron on the ceiling instead of 2 cone objects on the ground.

A laser scanner called Zebrevo was used to produce two compressed files with the extensions bag and params. The data was processed using the GeoSlam Hub program, resulting in a point cloud file with the extension LAS. The point cloud processing program Leica Cyclone was then used to convert this file. In Leica Cyclone, the three-dimensional point cloud file was opened and noisy points around the cones and iron rods were removed. The cones and iron rods' coordinates in the Ed-50 coordinate system were added to the program as an a. txt file and 3-dimensional transformations were performed using 3 coordinates from 3 cones in the first and second transformations, 5 coordinates from 5 cones in the third transformation and 3 coordinates from 3 cones in the fourth transformation, as well as the coordinates of 2 iron rods from the ceiling.

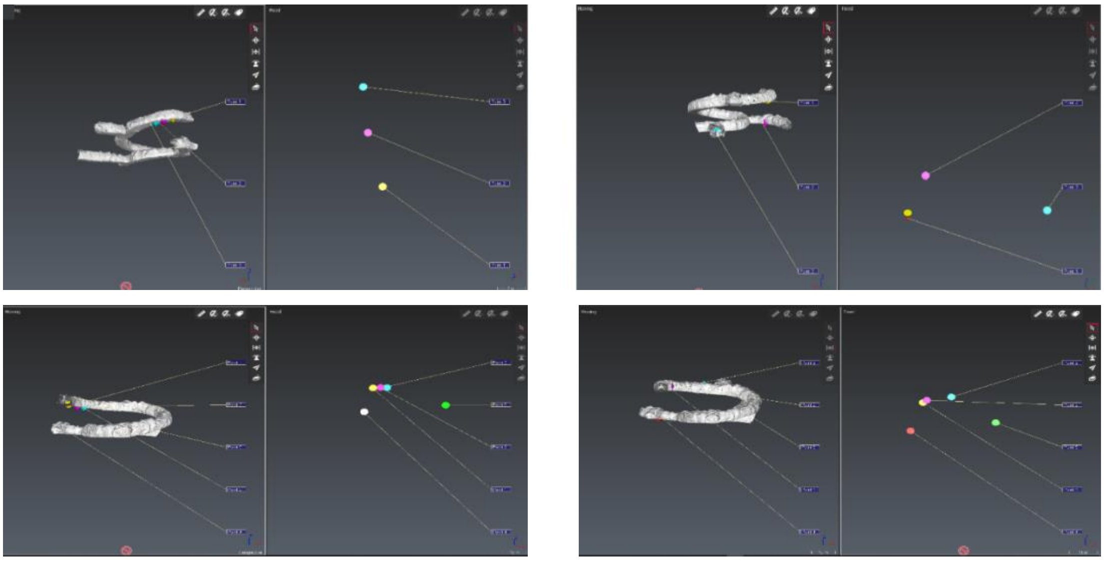


Figure 6. The first, second, third and fourth transformation processes in the Leica Cyclone program.

6. Results

In the first and second transformations, only the starting point's transformation cone was used in common, so it was observed that the measurement data at the starting point of the two transformations were consistent with each other. However, it was observed that there were significant differences in the horizontal and vertical directions between the point clouds obtained from the two transformations throughout the entire measurement area, excluding the starting point. When the total station gallery measurement, which is considered as a reference, is taken into account, it was determined that the second transformation (transformation in which the transformation cones are distributed homogeneously) is precise and the first transformation (transformation in which the transformation cones are distributed heterogeneously) is inaccurate in the horizontal and vertical directions. The situation in which the first transformation point cloud, the second transformation point cloud and the total station measurement are compared horizontally and vertically is shown in Figure 7.

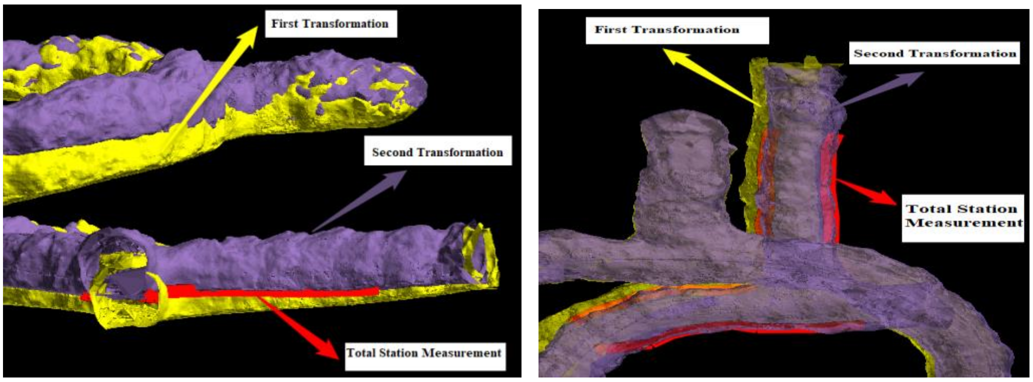


Figure 7. Horizontal, vertical comparison of first transformation and second transformation point cloud and total station measurement

In the third transformation, a total of five cones were used for the transformation using two other cones at the starting point in addition to the second transformation. It was observed that the precision did not change much on the horizontal, but increased significantly on the vertical. In the fourth transformation, the number of transformation points is the same as in the third transformation, but two iron rods located on the gallery ceiling were used instead of two cones on the ground. It was observed that the precision of the four different transformation is not much different from that of the third transformation, but the vertical precision increased slightly. To compare the transformation results with numerical values, a control cone was placed at the end of the measurement area. When the coordinate value of the control cone was read from the point cloud generated by the four transformations and compared with the coordinate value taken by the total station, the deviations in the Y and X directions are given in Table 1.

Table 1. Horizontal and vertical numerical comparison of measurements and conversions using a control cone

	Y (m)	**X(m)**	**Z (m)**	**ΔY (cm)**	**ΔY (cm)**	**ΔY (cm)**
Total Station	**566077.477**	**4262431.940**	**1086.150**	**---**	**---**	**----**
1. Transformation (3 Cone objets Heteregene)	**566077.087**	**4262431.990**	**1083.970**	**139.0**	**-105.0**	**-218.0**
2. Transformation (3 Cone objets Homegene)	**566077.511**	**4262431.928**	**1086.084**	**-3.4**	**1.2**	**-6.6**
3. Transformation (5 Cone objets Homegene)	**566077.508**	**4262431.923**	**1086.102**	**-3.1**	**1.7**	**-4.8**
4. Transformation (3 Cone objets+ 2 Iron Rod on the Celling Homegene)	**566077.504**	**4262431.921**	**1086.123**	**-2.7**	**1.9**	**-2.7**

7. Conclusion

In this study, four different transformations were compared. In the first and second transformations, the transformation cones were placed in the measurement area homogeneously and heterogeneously. It was found that the transformation was precise when the cones were placed homogeneously and not precise when the cones were placed heterogeneously. In the third transformation, the number of points used in the transformation was increased compared to the second transformation and it was observed that the precision did not change much in the horizontal but increased significantly in the vertical. In the fourth transformation, the number of points used in the transformation is the same as in the third transformation, but the iron rods located on the gallery ceiling were used instead of the two cones on the ground. It was also observed that the precision of the fourth transformation is not much different from that of the third transformation, but the vertical precision increased slightly. In conclusion, it was observed that the homogeneous distribution of reference points used in the transformation increases precision in the horizontal and vertical directions, both homogeneous and excessive use of transformation points result in the same good results in the horizontal, but in the vertical, it improves further, using a large number of transformation points and using them at different elevations results in the same good results in the horizontal, but in the vertical, it increases precision even more.

References

[1] Schmitz B, Holst C, Medic T, Lichti DD, Kuhlmann H. How to Efficiently Determine the Range Precision of 3D Terrestrial Laser Scanners. Sensors 2019; *19*, 1466.

[2] Dumalski A. Evaluation of the possible application of terrestrial laser scanner-scanstation in vertical displacement measurements. Technical Sciences/University of Warmia and Mazury in Olsztyn, 2011; 33-43.

[3] Yıldız F, Altuntaş C. Yersel Lazer Tarayıcı Nokta Bulutlarının Jeodezik Koordinat Sistemine Dönüştürülmesi, Harita Dergisi 2009; Sayı:142.

[4] Yue D, Wang J, Zhou J, Chen X, Ren H. Monitoring slope deformation using a 3-D laser image scanning system: a case study. Min Sci Technol (China) 2010; *20*(6), 898-903.

[5] El-Tokhey M, Abdel-Gawad AK, M Yasser, El-Maghraby AM. Accuracy assessment of laser scanner in measuring and monitoring deformations of structures 2012; 26. 144-151.

[6] Gonzalez H, Solla M, Armesto J, Arias P, Range, Close & Sensing, Remote & Group, Photogrammetry. Novel method to determine laser scanner accuracy for applications in civil engineering. Optica Applicata 2012; 42.

[7] Altuntaş C. Yersel Lazer Tarayıcı Nokta Bulutlarının Birleştirilmesi ve Jeodezik Koordinat Sistemine Dönüştürülmesi: Literatür Araştırması, Selçuk-Teknik Dergisi 2017; Cilt:16, Sayı:1-2017, Konya.

[8] Scaioni M, Forlani G. Independent model triangulations of terrestrial laser scanner data, In proc. of Vision Techniques for Digital Architectural and Archaeological Archives, Portonovo - Ancona , Italy, ISPRS Archives 2003; Vol.XXXIV-5/W12, 308-313.
[9] Elkharachy I, Neimeier W. Optimization and strength aspects for georeferencing data with terrestrial laser scanner systems, 3D IAG712th FIG symposium, Baden, Austria,2006; p.10 pages, May 22-24.
[10] Zeybek M. El-tipi LiDAR ölçme sistemleri ve 3B veri işleme. Türkiye Lidar Dergisi 2019; 1(1), 10-15.