# Analysis of The Accuracy of Terrestrial Laser Scanning Measurements

**Reha Metin ALKAN and Gokcen KARSIDAG, Turkey**

**Key words:** Terrestrial Laser Scanners (TLS), Point clouds, Analysis of TLS Accuracy.

## SUMMARY

Laser scanning technology is one of the latest techniques that has improved three-dimensional surveying. The major advantage of this surveying technique is that it facilitates complete and detailed 3 dimensional (3D) data acquisition of objects rapidly and at minimum cost for use in many applications. Using the point cloud system Terrestrial Laser Scanners (TLSs) process of 3D point data to produce 3D models. These models make it possible to access much of the necessary geometric and visual data. Thus, the use of TLSs has rapidly increased and TLSs are applied in many areas such as cultural heritage documenting, deformation measurements, planning applications, quality control, prototype production, crime scene analysis and the film making industry.

As with all surveying instruments, errors can occur in the results from TLSs for many reasons such as environmental factors, surface permeability of the surveyed object and the roughness of the surface. In these circumstances, it is vital to identify the accuracy range of all surveying systems including TLS in order to ensure that the survey returns the best quality data. Therefore, in this study, geometric shaped objects were scanned from different distances and different scanning densities. Then using the 3D point data obtained from this scans, drawings of these objects were created. The side lengths of the drawings were compared with base side lengths measured by caliper and the results were analyzed.

# Analysis of The Accuracy of Terrestrial Laser Scanning Measurements

**Gokcen KARSIDAG and Reha Metin ALKAN, Turkey**

## 1. INTRODUCTION

Current technological innovations have had an impact on geodetic surveying methods. Instead of traditional surveying methods; in addition to satellite-based surveying systems providing the user with 3D coordinates, the next-generation surveying tools that are able to undertake more accurate and rapid surveys have begun to be applied more frequently. Laser scanning technology is one of the latest innovations in the area of 3D surveying. This technique, allows the more rapid acquisition of the 3D coordinates of the object thus providing a dramatic reduction in costs and much faster project completion. Furthermore, it is possible to remotely survey very complex, inaccessible and hazardous objects and areas, where the traditional techniques would fail. Also since the data is largely independent of ambient illumination it is even possible to scan at night or in dark conditions.

Today, several 3D coordinates are required to determine the current position of the objects and buildings in many projects. By using 3D point clouds which comprise the processed 3D point data obtained by the laser scanners 3D models can be obtained through which it is possible to access many geometric and visual data.

As computer hardware and software continue to improve, using TLSs has become widespread in many areas such as documenting cultural heritage, deformation measurements, planning applications, quality control, prototype production, crime scene analysis and in the film making industry.

As with all surveying instruments, errors can occur in the results from TLSs this can be for many reasons such as environmental factors, surface permeability of the surveyed object and the roughness of the surface. In these circumstances, it is vital to identify the accuracy range of all surveying systems including TLSs in order to ensure that the survey returns the best quality data. . The accuracy of traditional surveying equipments can be determined using several methods. Similarly, it is also necessary to perform accuracy analysis for TLSs by various control and calibration measurements.

In order to ascertain the accuracy of the TLS to date there has been research by several authors. Some of the earlier accuracy studies are carried out by Lichti et al. (2000), Gordon et al. (2000, 2001), Balzani et al. (2001), Lichti et al. (2002a,b), and Tucker (2002). Johansson (2002) focused on comparative performance of several pulsed laser scanners, is one of the earliest studies in this field. The important researches for the standardized performance evaluation procedures of TLS was carried out at the Mainz University of Applied Sciences, Institute for Spatial Information and Surveying Technology (i3mainz), and they are described in Boehler and Marbs (2005). A number of artifacts were used for the comparative accuracy testing of different scanners (Reshetyuk, 2006; Gumus, 2008). The instrumental errors and accuracy of Mensi GS100/GS200 scanners are investigated in more detail by Kersten et al.

(2004, 2005). The investigation and analysis of the errors occurring in the measurements with pulsed time-of-flight TLSs were carried out by Reshetyuk (2006). Systematic instrumental errors and performance of three pulsed time-of-flight TLSs – Callidus 1.1, Leica HDS 3000 and Leica HDS 2500 – were discussed for developing calibration procedures of these instruments. Gumus (2008) focused on investigation of positioning accuracy of TLSs. 3D models obtained from point clouds data were used for comparing section-lengths.

In this study, the 3D point data of various geometric shaped objects have been obtained using TLS performed over separate distances and at separate scanning intensities. Then using the 3D point data, drawings of the objects have been created. The side lengths obtained from the surveys, were compared with base side lengths obtained by caliper surveys. As the result of these comparisons, accuracy analyses were performed in relation to the scanning distance and intensity.

## 2. TERRESTRIAL LASER SCANNING TECHNOLOGY

Terrestrial laser scanning systems have been available for about ten years and in the last five years laser scanning has been seen to be on the way to becoming accepted as a standard method of 3D data acquisition, taking its place beside established methods such as tacheometry, photogrammetry and GPS. In particular, industrial as-built-documentation terrestrial laser scanning systems have played an important role since their first availability as commercial systems. The major advantage of this measuring system is the complete and detailed 3D data acquisition of objects for many different applications. Specifically, the use of terrestrial laser scanning for 3D modeling, deformation measurements, monitoring and analysis has increased over the past years (Kersten et al, 2009). This widespread development has been facilitated by new software and computers with increased CPU power and storage that can process the high intensity 3D point data from the laser (Pinarci, 2007).

### 2.1 Surveying Principles of TLSs

A terrestrial, stationary laser scanner requires distraction mechanisms in two different directions for surveying a certain region of the object of investigation. These two directions can be considered as vertical and horizontal. The modulated light beam travels from the electronic unit (Figure 1, A) and hits the optical element (Figure 1, D), which is rotating at a high velocity. On the surface of this optical unit (which behaves like a mirror) the beam is reflected and exits the laser scanning device at a specific angle $\zeta$ (Figure 1, B). Once the scanner has completed acquiring this $\zeta$-profile, the upper part of the scanner (Figure 1, C) rotates at a very small angle ($\Delta\alpha$) around the vertical axis in order to start capturing the next, adjacent $\zeta$-profile. For each view point, a huge cloud of points are obtained, in which each point is described through the polar coordinates $\alpha$, $\zeta$ and d (measured distance to the spot of the reflected beam on the object) (Vozikis et al, 2004). The device calculates Cartesian coordinates (X, Y, Z) of the point scanned by polar coordinates. The other data that is recorded is the intensity of the reflected laser pulse. (Fangi et al, 2001; Pinarci, 2007).

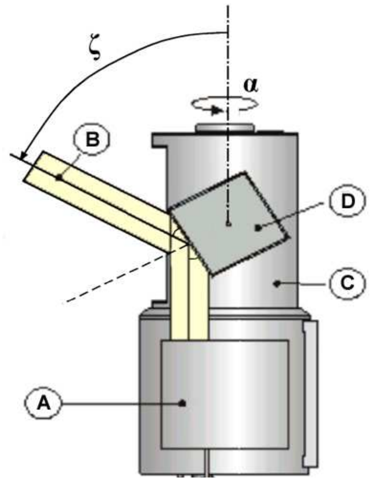


**Figure 1:** Principle of a Laser Scanner (Vozikis et al, 2004).

## 3. NUMERICAL EXAMPLE

In this study, the accuracy analysis was undertaken using terrestrial laser scanning data obtained by surveys performed at separate distances and by separate scanning modes using TLS. For this study, six stainless steel geometric shaped objects were used. Three of the objects; the rectangular prism (30cmx30cmx80cm), cube (40cmx40cmx40cm) and sectional plane (Ø20cmxØ30cmx60cm) were in the original metallic color. The rectangular prism (30cmx40cmx100cm), cylinder (Ø15cmx50cm) and sectional pyramid were painted black (Figure 2). The terrestrial laser scanning surveys are performed in the Hydraulic Laboratory of Istanbul Technical University.

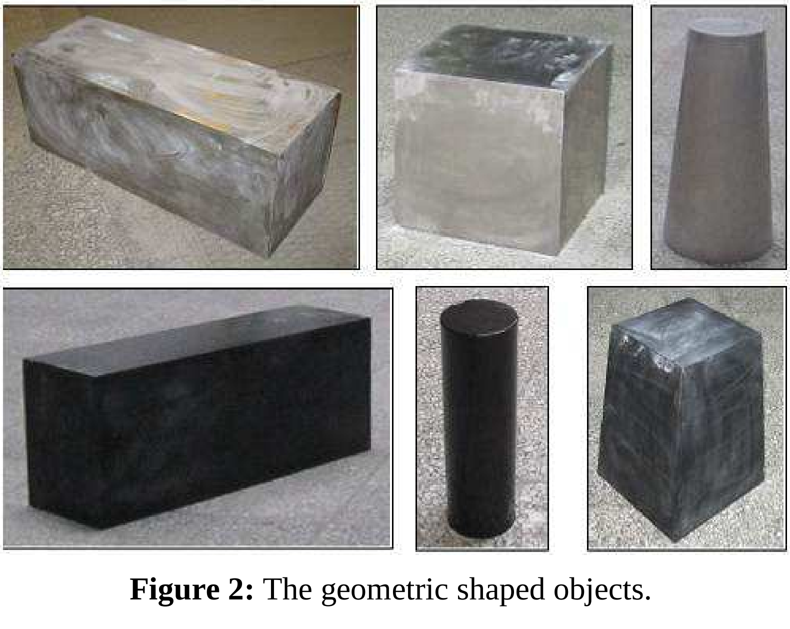


**Figure 2:** The geometric shaped objects.

### 3.1 TLS Surveys

The geometric shaped objects were placed on the ground as shown in Figure 3 and in order to minimize surface brightness powder was spread on the surfaces.

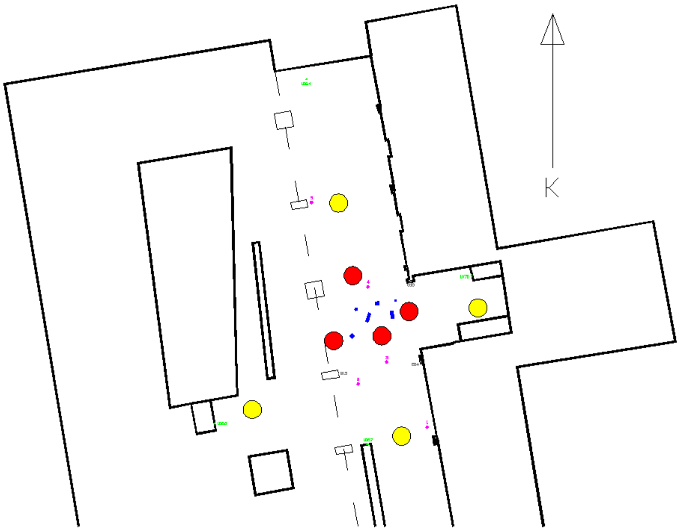
**Figure 3:** Working environment and placement of the geometric objects.

In this study, a Z+F IMAGER 5006i TLS is used which used the phase comparison method. Table 1 presents some technical specifications of the device. The scanner is controlled by Z+F LaserControl software by connecting with laptop, computer, and cellular phone having WLAN. Data from the device to computer or external collector is transferred via Ethernet or a USB connection.

**Table 1:** Some Technical specifications of Z+F IMAGER 5006i TLS (Url-1).

| | **Z+F IMAGER 5006i** | |
|---|---|---|
|  | Measurement Principle | Phase comparison |
| | Measurement Range | 0.4 m - 79 m |
| | Data acquisition rate | ≤508.000 pixel/sec |
| | Field of view vertical<br>Field of view horizontal | 310°<br>360° |
| | Linearity error up to 50 m | ≤1 mm |
| | Laser class | 3R Visible |
| | Data storage | Internal HDD (≥60 GB) |

The TLS surveys were performed by setting the device to eight separate stations from two separate surveying distances (average 3 m and 10 m) (Figure 4).

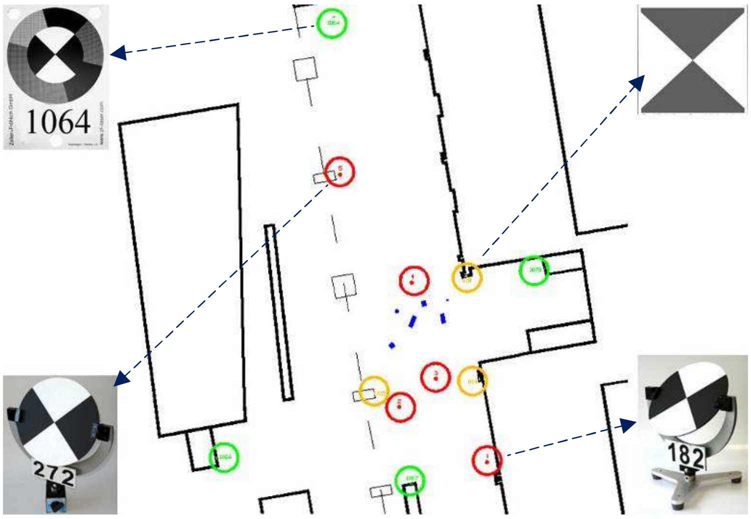


● 1. Group TLS stations (at an approximate distance of 0-3 m).

○ 2. Group TLS stations (at an approximate distance of 10-15 m).

**Figure 4:** TLS stations.

Before the laser scanning process, the reflected targets to be used in the registration of the scans by the TLS from separate stations were placed in appropriate positions at the study area. For this purpose five profile targets (red), three paper targets (yellow) and four automatic targets (red) were used (Figure 5).



O Automatic Targets O Profile Targets O Paper Targets
■ Scanned Objects

**Figure 5:** Distribution of the targets.

In each of the 1st Group laser scanning stations, scanning at “high” and “superhigh” modes (scanning frequency) were performed.

In each of the 2nd Group laser scanning stations, scanning at “high”, “superhigh” and “ultrahigh” modes were performed.

Figure 6 shows an example of the 3D point clouds obtained from the 1$^{st}$ groups of scanning stations at a distance of 3m.

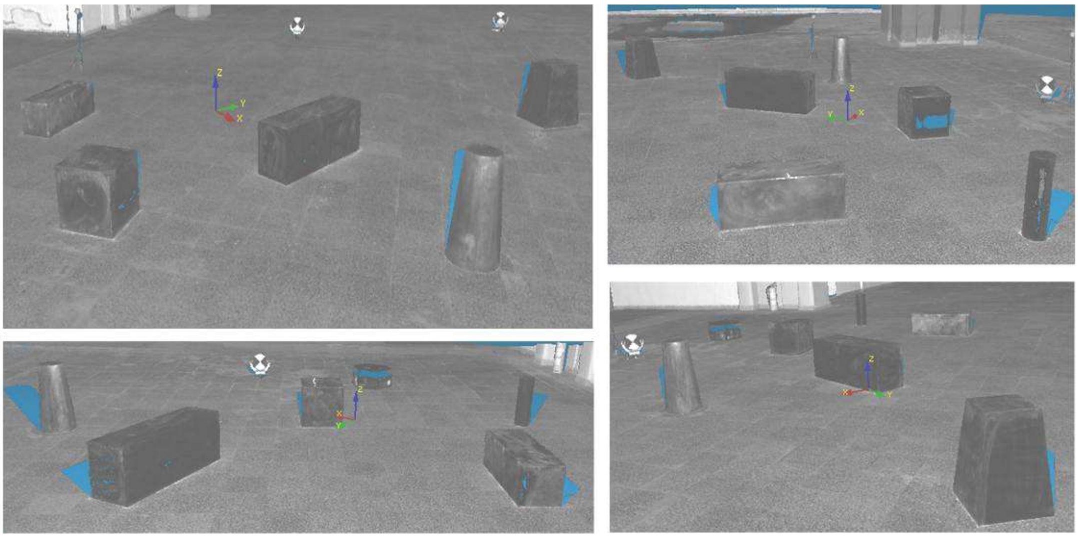


**Figure 6:** 3D point clouds (3m-high scanning) obtained from separate stations.

## 3.2 Evaluation of TLS Surveys

The data obtained as the result of TLS surveys were evaluated with the Z+F LaserControl software and the following five separate project files were created in Z+F LaserControl program.

- Performed from 3m is in “high” mode,
- Performed from 3m is in “superhigh” mode,
- Performed from 10m is in “high” mode,
- Performed from 10m is in “superhigh” mode,
- Performed from 10m is in “ultrahigh” mode.

The various stages of the processing are shown in Figure 7.

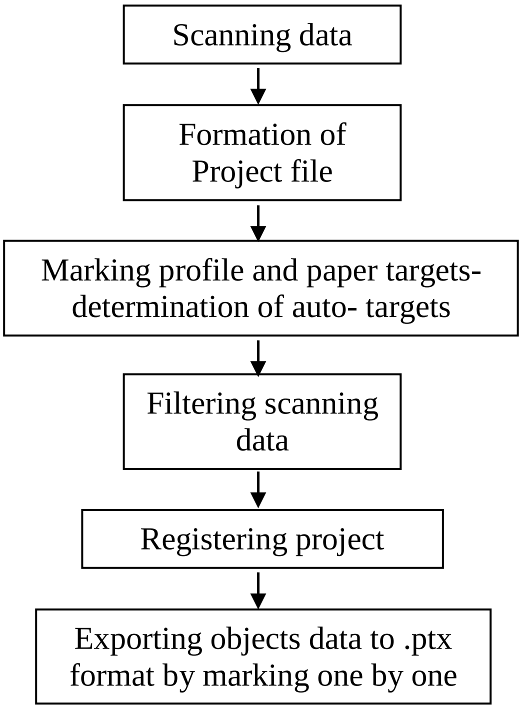


**Figure 7:** Processes performed by Z+F LaserControl software.

The profile and paper targets within scanning data in the projects were marked and defined. Then point clouds data within the five project files was registered. The six objects data; was selected separately from point clouds data obtained from separate positions within registered five project files; was exported in .ptx format. Following this step, the Cyclone software was applied.

Noises were cleared from the integrated point cloud data. In Figure 8, the cleared form of the point clouds obtained in “high” scanning mode of the objects from 3 m of distance can be seen.

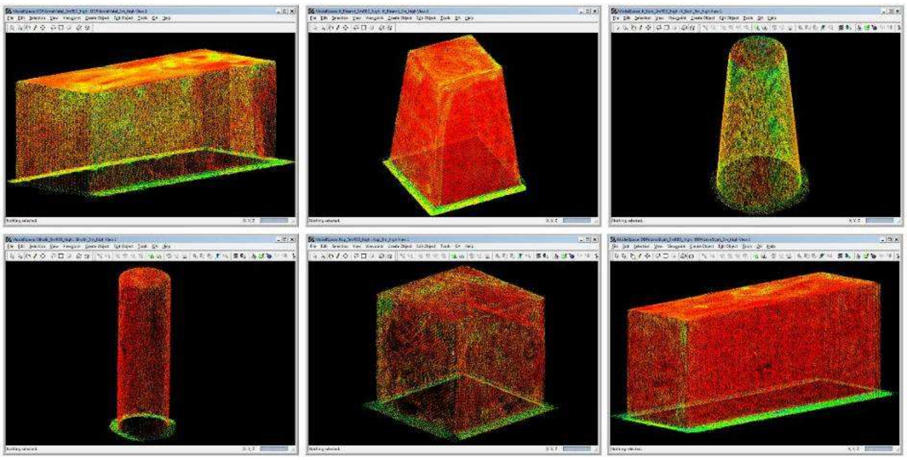


**Figure 8:** The cleared 3D point clouds of the objects (3m-high).

In Figure 9 the cleared form of the point clouds obtained in “superhigh” scanning intensity from 3 m of distance is shown.

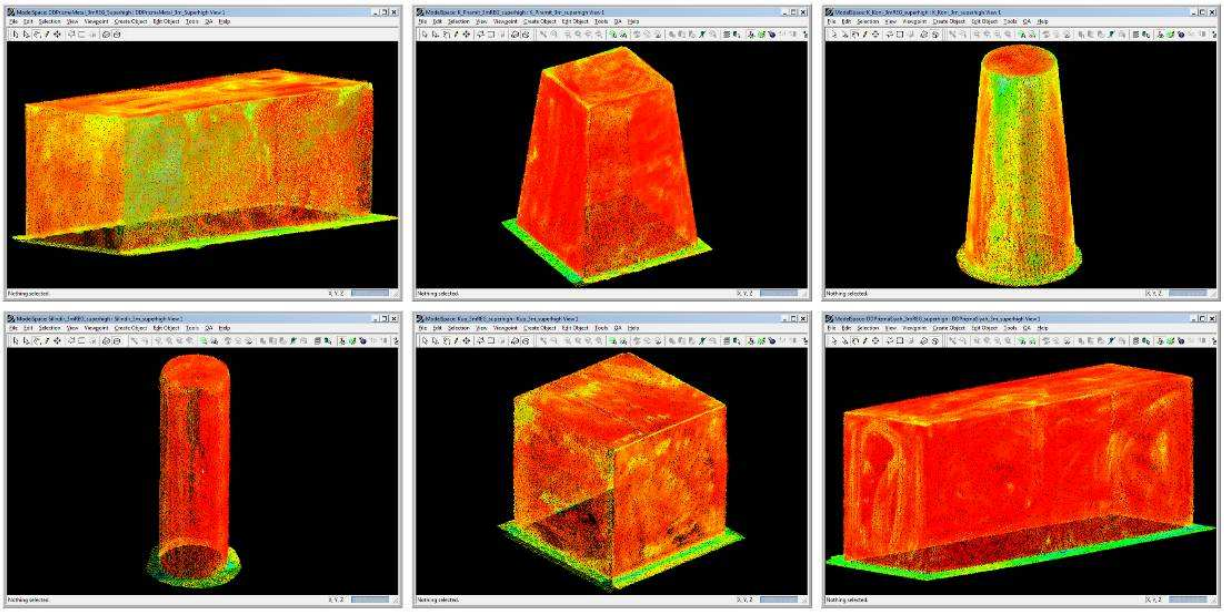
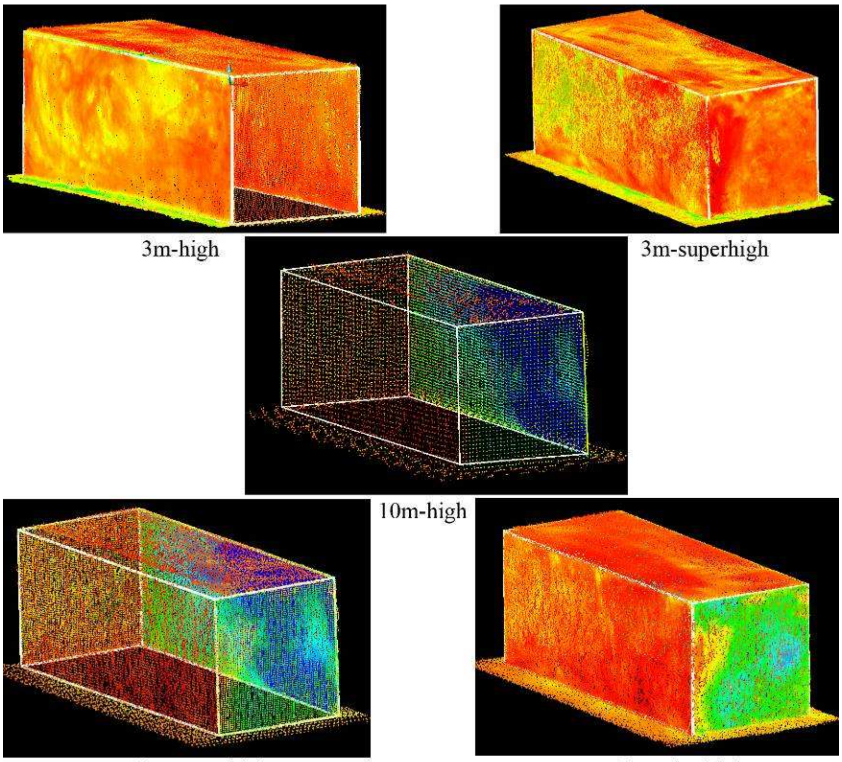


**Figure 9:** The cleared 3D point clouds of the objects  (3m-superhigh).

The details of rectangular prisms, sectional prism, and cube were drawn using 3D Point clouds. In cases when there were no appropriate and adequate points available at the edges of the objects, the edges were formed by intersecting the lines drawn by the points in-between. At the same time, by separating point cloud by horizontal and vertical sections, controls were performed.

For the cylinder, using horizontal sections of the point cloud, bottom, medium and top circles were drawn and the height of the cylinder was obtained from the vertical position of the point cloud. The same process was carried out for the sectional cone.

The drawings of the metal rectangular prism in five diverse modes together with 3D point cloud are shown in Figure 10.



3m-high

3m-superhigh

10m-high

10m-superhigh

10m-ultrahigh

**Figure 10:** Drawings of metal rectengular prism by 3D point cloud.

From the drawings of the objects, side lengths were determined. The difference between these side lengths and the base side lengths obtained by caliper surveys are calculated.

### 3.3 Survey of Base Side Lengths of the Objects By Caliper

In order to determine base length values to be used in the comparison, the sides of each of the objects were measured by a mechanic caliper (Figure 11). In the surveys, 1.000 mm calipers with a reading fineness of 0.02 mm and 500 mm calipers with a reading fineness of 0.1 mm were used.

**Figure 11:** Survey by caliper.

The side lengths of the rectangular prisms, cubes and sectional pyramids were obtained by taking the average of multi-surveys. The bottom and top diameters and inclined length of the sectional cone were obtained as the average of the multi-surveys and the average height was calculated. The diameter and height of the cylinder were obtained as the average of the multi-surveys (Figure 12).

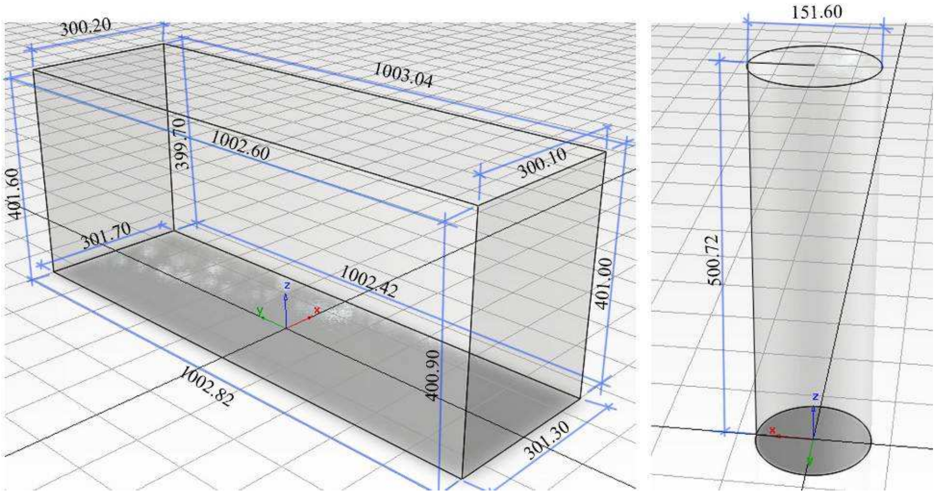


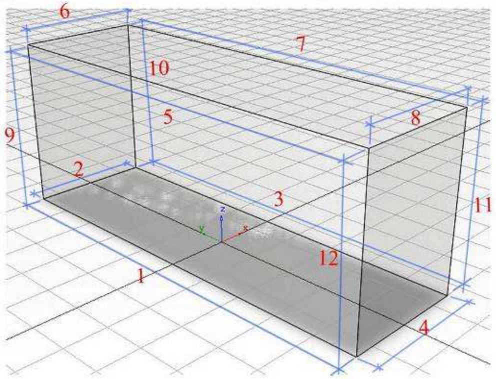
**Figure 12:** The sizes (mm) of the black rectangular prisms and cylinder obtained by caliper surveys**.**

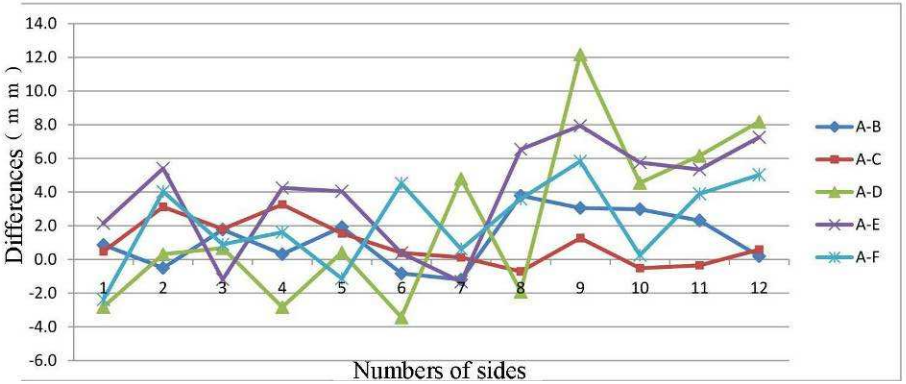
## 4. RESULTS

In this study, geometric shaped objects were measured by TLS and drawings created from the 3D point clouds. It was detected that the point data at the edges of the rectangular prism, sectional pyramid, and cube was less compared that obtained from the surfaces of the objects. In cases where there were no appropriate points available at the edges, then by drawing lines the edge points were obtained at the intersection of two of the lines. The lengths obtained from the drawings were compared to the base lengths obtained by the caliper surveys. It was observed that the differences of the lengths were between -4.5 mm and 8.2 mm in the 3 m high mode scanning, between -2.8 mm and 9.2 mm in the 3 m superhigh mode scanning, between -7.3 mm and 17 mm in the 10 m high mode scanning, between -1.8 mm and 11.6 mm in the 10 m superhigh mode scanning, and between -2.4 mm and 5.8 mm in the 10 m ultrahigh mode scanning for geometric shaped objects results. Thus, the differences are inversely proportional to the scanning intensity and directly proportional to the scanning distance. The comparisons of the lengths of the black rectangular prism in five diverse modes are shown in Table 2 as an example.

**Table 2:** Comparisons of the lengths of Black Rectangular Prism

| Rectangular Prism Black | Base Side Lengths (mm) (A) | SIDE LENGTHS (mm) | | | | | DIFFERENCES (mm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | High Model (3m) (B) | Superhigh Model (3m) (C) | High Model (10m) (D) | Superhigh Model (10m) (E) | Ultrahigh Model (10m) (F) | A-B | A-C | A-D | A-E | A-F |
| 1 | 1,002.82 | 1,001.95 | 1,002.35 | 1,005.64 | 1,000.67 | 1,005.20 | 0.9 | 0.5 | -2.8 | 2.2 | -2.4 |
| 2 | 301.70 | 302.21 | 298.58 | 301.39 | 296.30 | 297.67 | -0.5 | 3.1 | 0.3 | 5.4 | 4.0 |
| 3 | 1,002.42 | 1,000.64 | 1,000.62 | 1,001.74 | 1,003.60 | 1,001.52 | 1.8 | 1.8 | 0.7 | -1.2 | 0.9 |
| 4 | 301.30 | 300.99 | 298.04 | 304.12 | 297.05 | 299.69 | 0.3 | 3.3 | -2.8 | 4.3 | 1.6 |
| 5 | 1,002.60 | 1,000.68 | 1,001.05 | 1,002.17 | 998.55 | 1,003.73 | 1.9 | 1.5 | 0.4 | 4.0 | -1.1 |
| 6 | 300.20 | 301.03 | 299.81 | 303.64 | 299.81 | 295.68 | -0.8 | 0.4 | -3.4 | 0.4 | 4.5 |
| 7 | 1,003.04 | 1,004.23 | 1,002.91 | 998.24 | 1,004.36 | 1,002.42 | -1.2 | 0.1 | 4.8 | -1.3 | 0.6 |
| 8 | 300.10 | 296.32 | 300.81 | 302.01 | 293.57 | 296.51 | 3.8 | -0.7 | -1.9 | 6.5 | 3.6 |
| 9 | 401.60 | 398.55 | 400.33 | 389.42 | 393.67 | 395.77 | 3.1 | 1.3 | 12.2 | 7.9 | 5.8 |
| 10 | 399.70 | 396.72 | 400.21 | 395.15 | 393.95 | 399.45 | 3.0 | -0.5 | 4.5 | 5.7 | 0.3 |
| 11 | 401.00 | 398.69 | 401.35 | 394.84 | 395.66 | 397.10 | 2.3 | -0.3 | 6.2 | 5.3 | 3.9 |
| 12 | 400.90 | 400.71 | 400.31 | 392.72 | 393.64 | 395.87 | 0.2 | 0.6 | 8.2 | 7.3 | 5.0 |





In the evaluation of the 3D point data, it was observed that 3D point cloud data obtained from regular and smooth object surfaces are irregular and corrupted. Figure 13 shows the corruption in the point cloud data of the cube among the 3d point data obtained by scanning in a 3 m superhigh mode.

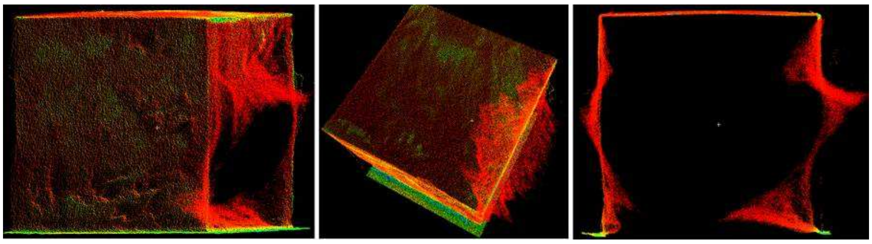


**Figure 13:** 3D point cloud data of the cube (3m superhigh).

Additionally, it was seen in the evaluations that black objects reflected laser beam less, and even no point data could be obtained in some of the zones of the objects' surfaces. This can be seen in Figure 14 which shows the 3D point cloud data of the cylinder obtained by scanning in a 3 m superhigh mode.

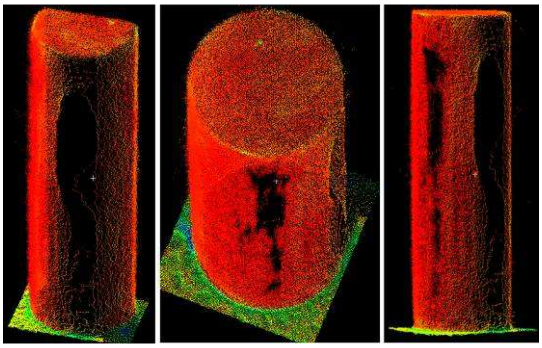


**Figure 14:** 3D point cloud data of the cylinder (3m superhigh).

## 5. CONCLUSION

The use of TLSs is rapidly increasing and TLSs are applied in many areas, furthermore, it is possible to collect the 3D data of the object rapidly and in detail by TLSs. However, the essential step to decide the type of scanner to be applied. If the TLS device uses the operating phase difference method, these scanners produce the best results when at close distances to the objects and the high scanning densities. As seen in this study, the measurement differences between two methods are inversely proportional to the scanning intensity and directly proportional to the scanning distance to objects.

Additionally, it is concluded that features such as reflectivity, color, and brightness of the object surfaces have impact on the quality of the data, therefore, although 3D point cloud data is very useful it should be considered that the data can be sometimes irregular and corrupted and thus not exactly reflecting the features of the scanned object.

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## BIOGRAPHICAL NOTES

**Gokcen KARSIDAG** was graduated in 1998 as Geodesy and Photogrammetry Engineer from Selcuk University. Obtained MSc degree in 2011 from Istanbul Technical University. She has worked in private sector at several projects as a survey engineer since 1998. She is currently working for Istanbul Metropolitan Municipality Bimtas Corporation at Department of Laser Scanning since 2006.

**Reha Metin ALKAN** is currently working at Istanbul Technical University, Istanbul, Turkey as an Associate Professor. He holds MSc and PhD degrees in Geodesy and Photogrammetry Engineering Department from the same university. His research area mainly covers GPS and its applications, Hydrographic Surveying, Deformation Measurements and Analysis, Operational Research.

## CONTACTS

**Gokcen KARSIDAG**
Istanbul Metropolitan Municipality Bimtas Corporation.
Evliya Celebi mah. Mesrutiyet cad. No:50
34430 Tepebasi - Beyoglu
Istanbul
TURKEY
Tel. +90 532 7483113
Email: gokcenka@gmail.com

**Prof. Dr. Reha Metin ALKAN**

Hitit University, Corum, Turkey

Istanbul Technical University (ITU)
Faculty of Civil Engineering
Geomatics Engineering Department
Maslak, TR-34469,
Istanbul, TURKIYE

Telephone : +90 212 285 6564
Fax : +90 212 285 6587
E-mail : alkanr@itu.edu.tr