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The Accuracy Assessment of Terrestrial and Mobile Lidar Systems for 3D Modelling

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ABSTRACT

The use of high-precision and sufficiently collected point clouds for 3D data modeling is very important for geomatics and other branches of engineering (such as mechanical and construction), and architectural applications. For this reason, various filtering and interpolation methods are improved for 3D modeling. However, if the point cloud is collected inaccurate or missing, the 3D data modeling is always an issue. Therefore, before the 3D modeling process, the point positioning accuracy and resolution of the point cloud should be investigated. The accuracy assessment can be performed by comparing data obtained from a measurement system that is considered to be more accurate. These analyses are used the accuracy assessment of the maps produced by different Lidar (Light Detection and Ranging) point clouds. In this study, the accuracy of the point clouds obtained using Terrestrial Lidar Systems (TLS) and Mobile Lidar Systems (MLS) was determined by using the Euclidean distances between the surface points measured by total station. The results showed that the accuracy of the TLS system was better than the MLS system. In addition, while TLS should be preferred in studies requiring high accuracy such as 3D cultural heritage documentation, MLS should be preferred in applications such as various topographic maps and 3D city models.

1. INTRODUCTION

Studying with highly accurate and enough point cloud data in 3D modeling is very important. If the point clouds' accuracy and resolution are sufficient for the desired purposes, the steps of the point clouds' registration or modeling can be realized. However, if the accuracy and the resolution of the existing point cloud are not sufficient, it must be georeferenced with a more accurate point cloud.

LIDAR (Light Detection and Ranging) is a measurement technique that allows the collection of large amounts of 3D data in a short time, from airborne or terrestrial. LIDAR creates a point cloud with density values in the local coordinate system and also RGB values of the point cloud are usually provided by internal or external digital cameras of the system (Kuçak, Kiliç, & Kisa, 2016; Kuçak, Özdemir, & Erol, 2017)

Mobile LIDAR systems (MLS) is a widely used method to get rapid and detailed point cloud acquisition in various applications such as cultural heritage, GIS (Geography Information System), geodetic applications, and spatial decision support systems (Rusu, Marton, Blodow, Dolha, & Beetz, 2008) or 3D city modeling (Chen, Weng, Hay, & He, 2018) and also rail and road deformation analysis systems (Wang et al., 2019).

Mobile LIDAR systems consist of laser scanners, cameras, as well as IMU (Inertial Measurement Unit) and GNSS (Global Navigation Satellite System) systems. All of these systems work together to generate the point cloud in a three-dimensional (3D) coordinate system (Kuçak, Özdemir & Erol, 2017). The LIDAR systems having multiple laser scanners may suffer from noise and other error sources such as inertial drift, rigid platform calibration, GNSS errors, etc. The measurements with multiple scanners in Mobile Mapping Systems (MMS) require calibration in order to overcome the disadvantages by high noise rates and errors as well as the overlapping problem in strips. After the calibration steps, CCD Cameras and Laser scanners can become ready to use. However, the calibration may not be sufficient to eliminate all errors and provides inappropriate point clouds for 3D modeling. In such situations, the adjustment (coarse and fine registration) of the multiple scans to minimize the discrepancies in LIDAR point clouds are necessary (Rieger, Studnicka, Pfennigbauer, & Zach, 2010). In well GNSS measurement conditions, the accuracy of the MLS trajectory could be

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realized in cm-level. On the contrary, in difficult conditions, the error increases to decimeters-level (Haala, Peter, Kremer, & Hunter, 2008a). In such situations, the accuracy of the point cloud can be increased with georeferencing or registration during the post-processing stage.

In this study, the accuracy of the point clouds, which were obtained by using the TLS and MLS systems were investigated. However, since the error sources mentioned above are common problems in mobile LIDAR systems, the accuracy comparison of the LIDAR systems carried out relatively using the distance differences of some points taken from each point cloud data to eliminate the error sources in the comparison. In this study, ITU (Istanbul Technical University) Yılmaz Akdoruk Student Dormitory was selected as a test area. The dormitory is located in Ayazaga Campus of ITU in Turkey (Figure 1).

Figure 1. Yılmaz Akdoruk Student Dormitory

2. DATA and METHOD

The study area scanned with Leica C10 TLS, which can get 50,000 points per second with 6 mm accuracy until 50 m and uses impulse method for distance measurement. 3D point cloud of the building processed with Cyclone Software by Leica Geosystems (Figure 2).

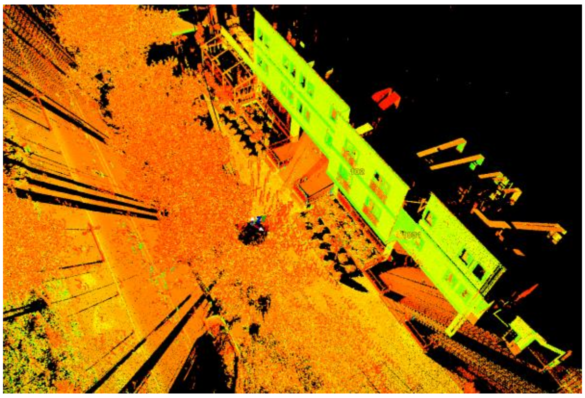

Figure 2. Point Cloud with Leica C10 Scanning

Mobile Mapping data was obtained by using the Riegl VMX 450 LIDAR System, which can get 1,000,000 points per second with 8 mm accuracy and use impulse method for distance measurement (Figure 3).

Figure 3. ITU Ayazaga Campus Scanning by Riegl VMX 450 MLS

2.1. Error Propagation

The error propagation was applied for some test points from the surface to determine the point positioning accuracy of instruments. The test points of the surface also positioned with the "Pentax W1503" total station for the accuracy assessment of the TLS and MLS point clouds. The reflectorless distance measurement accuracy of the total station is "3 mm + 2 ppm" and the angle measurement accuracy is 3″. The Leica C10 TLS distance measurement accuracy is 4 mm, angle measurement accuracy is 12″ and the positional accuracy is 6 mm. The Riegl VMX 450 MMS system (Figure 4) includes VQ-450 laser sensors (2-laser scanners) and the laser sensors' positional accuracy is 8 mm. Table 1 also gives the technical specifications of the sensor' in VMX 450 (Toschi et al., 2015).

Figure 4. Riegl VMX-450 MMS System

Table 1. Technical characteristics of the RIEGL VMX-450 MMS (Toschi et al., 2015).

Sensor	VQ-450
Measuring principle	Time of Flight
Laser wavelength	Near infrared
Laser measurement rate	300 – 1100 kHz
Maximum range	140 – 800 m
Minimum range	1.5 m
Accuracy	8 mm, 1σ
Precision	5 mm, 1σ
Sensor	**IMU/GNSS**
Absolute position	0.020 – 0.050 m
Roll and pitch	0.005 °
True heading	0.015 °
Sensor	**VMX-450-CS6**
Resolution	5 Mpx
Sensor size	2452 x 2056 px
Pixel size	3.45 µm
Nominal focal length	5 mm

According to given measurement accuracies, the error propagation was applied to the following equations.

$$X_B = X_A + (S_{Slope} * CosZ_a * Cost_a) \quad (1)$$

$$Y_B = Y_A + (S_{Slope} * CosZ_a * Sint_a) \quad (2)$$

$$Z_B = Z_A + (S_{Slope} * SinZ_a) + i_a \quad (3)$$

In Equations 1-3, X_A is the x coordinate component of the local coordinate system at the standing point, X_B is the x coordinate component of the measured point, "t_a" is the horizontal angle, "Z_a" is the vertical angle (slope angle) "i_a" is instrument height, "S" is distance. The accuracy $(m_{X_B}, m_{Y_B}, m_{Z_B})$ of the measured point coordinate components (x, y, z) could be calculated as;

$$m_{X_B}^2 = m_{X_A}^2 + (Cost_a^2 . CosZ_a^2) m_s^2 + (S^2 . CosZ_a^2 . Sint_a^2 *) \frac{m_t^2}{\rho^2} + (S^2 . Cost_a^2 . SinZ_a^2 *) \frac{m_Z^2}{\rho^2} \quad (4)$$

$$m_{Y_B}^2 = m_{Y_A}^2 + (CosZ_a^2 . Sint_a^2) m_s^2 + (S^2 . Cost_a^2 . CosZ_a^2) \frac{m_t^2}{\rho^2} + (S^2 . Sint_a^2 . SinZ_a^2) \frac{m_Z^2}{\rho^2} \quad (5)$$

$$m_{Z_B}^2 = m_{Z_A}^2 + (SinZ_a^2) m_s^2 + (S^2 . CosZ_a^2) \frac{m_Z^2}{\rho^2} \quad (6)$$

In Equations 4-6, m_t is the angle measurement accuracy and m_s is the distance measurement accuracy of the instrument ($\rho = 200/\pi$).

According to error–propagation, the calculated position accuracy was between 4.02 – 4.21 mm for the total-station, and was between 5.56-5.67 mm for the TLS in the test points.

3. RESULTS

In the building facade, the most prominent and corner points were selected as test points. The coordinates of the test points obtained from the Total station measurements are accepted as reference coordinates and the Euclidean distance between the surface test points was calculated. Then, the distances between the test points derived from TLS and MLS point clouds compared with the reference distance calculated from the total-station. The position of the selected test points is given in Figure 5.

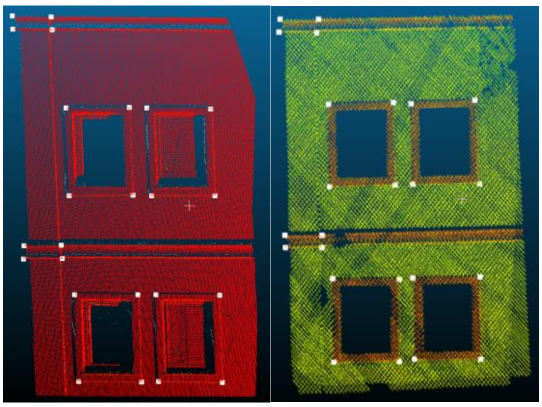

Figure 5. Key points TLS (Left), MLS (Right)

The distance differences and its statistics between the TLS and MLS key points distances with total station distances are given in Table 2 and in Figures 6a and 6b.

According to the results, the standard deviation of the TLS was obtained 1.5 cm. On the other hand, the standard deviation of the MLS was 2.8 cm. (Haala et al., 2008a) mentioned that with the obtained cm-level positional accuracy, MMS could be used for some applications include mapping purposes.

Table 2. The distance differences between TLS, MLS key points' distances and Total Station corner' distances

TLS_Total	0	1	2	3	7	8	10	11	16	18
0	-									
1	-0.021	-								
2	-0.009	0.011	-							
3	-0.020	0.000	-0.016	-						
7	-0.023	-0.004	0.020	-0.010	-					
8	-0.042	-0.020	0.039	0.017	-0.003	-				
10	-0.027	-0.005	0.041	0.010	-0.020	0.013	-			
11	-0.023	-0.001	0.040	0.006	-0.011	0.018	-0.003	-		
16	-0.019	0.002	0.023	0.011	-0.015	0.020	0.007	-0.002	-	
18	-0.018	0.004	0.030	0.005	-0.003	0.024	0.006	0.007	-0.010	-
MLS_Total	0	1	2	3	7	8	10	11	16	18
0	-									
1	0.008	-								
2	0.086	0.080	-							
3	0.049	0.042	-0.042	-						
7	0.038	0.064	0.064	0.002	-					
8	0.010	0.021	0.069	0.019	0.032	-				
10	0.048	0.051	0.040	-0.020	0.025	0.033	-			
11	0.027	0.044	0.078	0.020	-0.028	0.025	0.037	-		
16	0.083	0.083	0.029	0.019	0.035	0.062	0.030	0.057	-	
18	0.088	0.097	0.044	0.008	0.047	0.077	0.046	0.075	-0.002	-

In Figures 6a and 6b, the distributions of 45 Euclidean distances differences were shown for MLS and TLS after removing the blunders from the data groups. While MLS-Total differences show the normal distribution, TLS-Total differences show a close curve to the normal distribution. According to the differences between Total-station and TLS, the mean value was -1 mm, and the maximum difference was 3 cm. On the other hand; MLS had a 3.3 cm mean, and the maximum difference was 8.6 cm. (Haala, Peter, Kremer, & Hunter, 2008b) investigated the quality of building facades of an existing 3D city model of the city of Stuttgart. They proved that an accuracy better than 3 cm (standard deviation of the differences between measured and reference data) can be achieved by the system in robust GNSS conditions. Similar results are seen in the literature. A similar result was also obtained in this study.

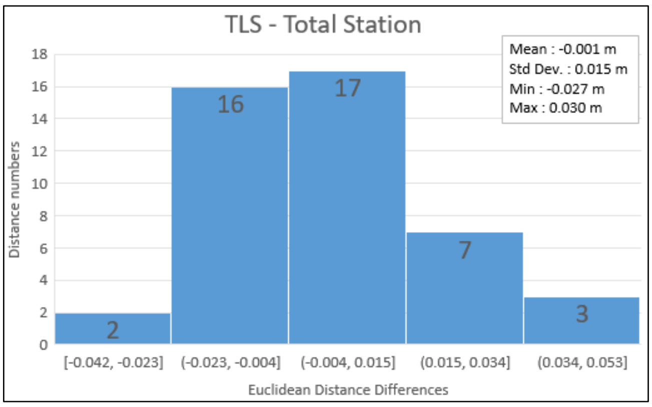

Figure 6a. The distribution of distance differences between TLS and Total station.

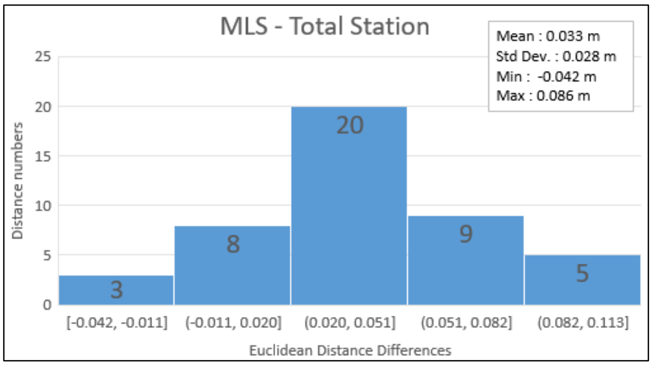

Figure 6b. The distribution of distance differences between MLS and Total station.

In this study, Total station data is accepted as the most accurate measurement system and the Euclidean distances between the surface points were calculated. The accuracy ($m_{X_B}, m_{Y_B}, m_{Z_B}$) of the measured points was calculated to determine the point position accuracy with free from point cloud resolution errors. The primary reason for using the Euclidean distance between surface points is to compare the accuracy of the two systems, neglecting GNSS and calibration errors. The results show that the accuracy of the TLS system is much better than the MLS system as expected.

4. DISCUSSION

The distance differences of surface points between reference distances calculated by Total Station and the distances calculated from the TLS and MLS point clouds were obtained and the blunders were removed from both data groups, and then the statistics calculated. According to the calculated standard deviations of the distance differences, the accuracy of the point clouds was obtained as 1.5 cm for TLS and 2.8 cm for MLS. These histograms show that the accuracy of TLS and Total station are close to each other. However, the accuracy of MLS is low due to un-eliminated errors in the system.

This study shows that each of these systems has both advantages and disadvantages. MLS (Mobile LiDAR System) is a product of the latest technology towards the fast acquisition of 3D spatial data. However, the lack of calibration in these systems leads to undesirable results. These misalignments frequently appear in MLS (Rieger, Studnicka, Pfennigbauer, & Zach, 2010). The errors mentioned above text are common problems in Mobile LIDAR Systems. Because of that, the point cloud coordinates are not compared directly in this study.

The results show that TLS can be preferred for studies that require high accuracy such as cultural heritage, Building Information Management (BIM). However, MLS should be preferred in applications such as various topographic maps and 3D city models rather than 3D cultural heritage documentation.

5. CONCLUSION

TLS and MLS Technology is a rapidly developing technology today. The experiments performed in this study show that each of these methods has both advantages and disadvantages. The ease of use in the field and the ability to measure millions of points in a very short time provide great convenience to the user. The advantages of the LIDAR systems are seen when compared with other 3D documentation methods in terms of time. Under proper GNSS conditions and with good calibration values, 3D models and topographic maps can be produced by MLS in a very short time and with the desired accuracy. The results obtained in this study show that LIDAR systems comply with the regulation (Regulation on Production of Large Scale Maps and Map Information, 2018) for 3D topographic map production.

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