Mansoura University
Faculty of Engineering
Mansoura Engineering Journal

Assessment of Terrestrial Laser Scanner against Different Surveying Techniques

Ahmed M. Abd-Elmaaboud, *Mohamed E. El-Tokhey*, *Ahmed E. Ragheb* and Yasser M. Mogahed

KEYWORDS:
Terrestrial laser scanner, RTK-GPS, Total station, Accuracy.

***Abstract*— Terrestrial Laser Scanner (TLS) has become a familiar instrument to be used in wide range of engineering application. It can be used for the rapid capture of accurate and highly detailed 3D point cloud datasets. The advantage of laser scanner is that it can record huge number of points in a short period of time. The main idea in this contribution assesses the accuracy of TLS relative to other traditional surveying instruments. This is done throughout four different case studies. In all case studies the 3D coordinates, obtained using total station (TS) are assumed the reference coordinates. First, a control point network, that consists of nine points, is measured using TS, TLS, and real time kinematic global navigation satellite system (RTK-GPS). The precision of each instrument is investigated considering the standard deviation (SD) of measurements. In addition, the accuracy of TLS and RTK-GPS is investigated considering the measurements RMS. Secondly, a grid levelling for a 30,000m^2 ground terrain was performed using TS and TLS. After words, the RMS of TLS measurements is computed and a grid of 5mx5m is generated from both surfaces; formed using TS and TLS measurements. Thirdly, the effect of incidence angle on TLS measurements is assessed by measuring fifty-six points fixed on a building façade using different incident angles. Those points were measured using both TS and TLS, and then the absolute height differences between TS and TLS measurements were calculated to figure out the effect of decreasing the incidence angle on measurements. In the fourth case study, the accuracy of TLS on steep-vertical cut measurements is investigated by surveying a downhill area of 500m^2 by both TS and TLS, the RMS of TLS measurements was calculated. Finally, based on the obtained results, it was found that TLS produces a higher vertical accuracy than RTK-GPS in measuring control point networks. The RMS of TLS measurements was about 5cm. Moreover, TLS incidence angle is not preferable to be less than 45 degrees as the accuracy degrades significantly after this value. In steep-vertical cut measurements, TLS obtained RMS almost of 6mm discrepancies with a lower measurement period. Eventually, despite the fact that TLS is more expensive than traditional surveying techniques, it is more beneficial in terms of time and effort saving. In addition, it can figure out acceptable accuracy ranges with more detailed surveyed data.**

Received: (14 November, 2020) - Revised: (4 January, 2021) - Accepted: (2 February, 2021)

Correspondence Author *Ahmed M. Abd-Elmaaboud, Demonstrator, Public Works Department, Ain Shams University, Faculty of Engineering, Cairo, Egypt. (Email: Engahmed@eng.asu.edu.eg)*

Mohamed E. El-Tokhey, Professor of Surveying and Geodesy, Public Works Department, Ain Shams University, Faculty of Engineering, Cairo, Egypt. (Email: meltoukhy@hotmail.com)

Ahmed E. Ragheb, Associate professor of Surveying and Geodesy, Public Works Department, Ain Shams University, Faculty of Engineering, Cairo, Egypt. (Email: aragheb@eng.asu.edu.eg)

Yasser M. Mogahed, Associate professor of Surveying and Geodesy, Public Works Department, Ain Shams University, Faculty of Engineering, Cairo, Egypt. (Email: yasser_mogahed@eng.asu.edu.eg)

I INTRODUCTION

IN surveying, specifically in engineering projects, more sophisticated instruments are employed such as, total station, laser scanner and GPS, in order to improve the efficiency and accuracy. Specific surveying techniques has been commonly used throughout the history of surveying to collect data from field measurements for various applications with different accuracy capabilities and requirements. During the past year a significant development of surveying techniques has revolutionized the way of performing different surveying tasks, resulted in enabling surveying professionals to reach high accuracy and precision levels [1].

Nowadays, surveying plays a vital role in almost every engineering field in order to ensure an accurate engineering work. Generally, the term accuracy is widely used in different fields to express the quality of observations, measurements or/and calculations. Surveying professionals -as well as those who are involved in technical or scientific fields-differentiate between accuracy and precision. Basically, accuracy can be defined as a measurement of how closely the observations are to a certain (true) value as observations are always subjected to different errors. However, precision concerns about measuring how a group of certain repeated observations are close to one another. Talking about TLS, its accuracy is dependent on the angle of sight and distance from the object to be scanned [1]. As a result, each method has its own merits and demerits in terms of accuracy that could be reached, time consumption, effort, and expenditures. Thus, our aim in this research is to assess the different accuracies that could be reached using different techniques to figure out the optimum approach for performing different surveying tasks.

II LITRATURE REVIEW

In the contribution given in [2], a 50-hectare area was surveyed with RTK-GPS, with four established reference points and a base station. RTK-GPS method gave an accuracy of 1cm in horizontal coordinate, while the less accuracy in vertical direction.

Another experiment to assess the accuracy between RTK-GPS and TS was carried out by Lin [3]. The results showed a horizontal accuracy of 14mm using RTK-GPS, while TS was capable of providing up to 16mm positional accuracy.

According to Solomon [1], accuracy, precision and time consumption of different surveying instruments were assessed and compared to each other, once between TS versus RTK-GPS on the reference network and then TS versus TLS on the façade of an L-shape building. The reference network was established using a TS with a precision of 1mm standard deviation for horizontal and vertical coordinates. RTK-GPS technique was applied to the same network and the obtained coordinates had a precision of 8mm and 1.5cm in the horizontal and vertical directions, respectively. The accuracy of the RTK-GPS measurements was expressed by its RMS reaching 9mm in horizontal and 2.2cm in vertical coordinates. Precision of the TS observations on the façade was determined with a maximum standard deviation of 8mm in horizontal and 4mm in vertical coordinates. In addition, coordinates of the fixed points on the façade were extracted from the TLS measurements, with standard deviations of 1.6cm and 1.2cm in horizontal and vertical coordinates were reached respectively. The RMS for both horizontal and vertical coordinates were 4mm and 7mm respectively.

III TERRESTRIAL LASER SCANNER

Laser scanning is a method where a surface is scanned or sampled using laser technology [4]. It collects data on the object’s shape and its appearance. Data collected can then be used to establish digital 2D drawings or 3D models which can be used widely in various applications. The power of laser scanning techniques is that it can capture a great number of points with high accuracy level in a relatively short time frame [1]. It can be said that laser scanning is like taking a photo with depth information [5].

Typically, laser scanner comprises of a transmitter/receiver of laser beams, a scanning device and a timing device. The scanner sends out laser pulses and receives back the reflected signal (see **Figure 2**). The emitted light is modulated in amplitude and fired onto a surface. The scattered reflection is collected, and a circuit measures the phase difference between the sent and received waveforms. Typical phase-based scanners modulate their signal using sinusoidal modulation, This phase difference can be related to a time delay, The relationship between phase difference ($\Delta\Phi$), modulation frequency ($f_{modulated}$), time delay (t), and light speed in air (c), then the distance to the target is using the following simple equations [6] :

$$\boldsymbol{t} = \frac{\Delta\Phi}{2\pi . fmodulated} \quad (1)$$

$$\boldsymbol{D} = \frac{c}{4\pi} * \frac{\Delta\Phi}{fmodulated} \quad (2)$$

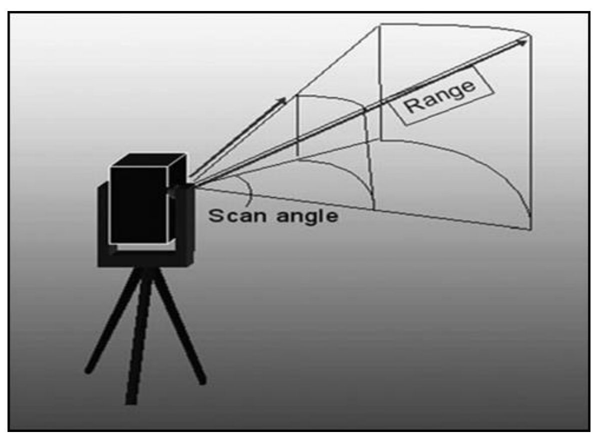

Figure 1: TLS Idea [8]

In addition, the TLS measures both the horizontal angle(α) and vertical angle (θ) of the transmitted laser beam through horizontal and vertical circle readings. Then the coordinates of the observed point are computed relative to the occupied point through the following (see **Figure 3**) [7]:

X= D cos θ. cos α (3)
Y= D cos θ. sin α (4)
Z= D sin θ (5)

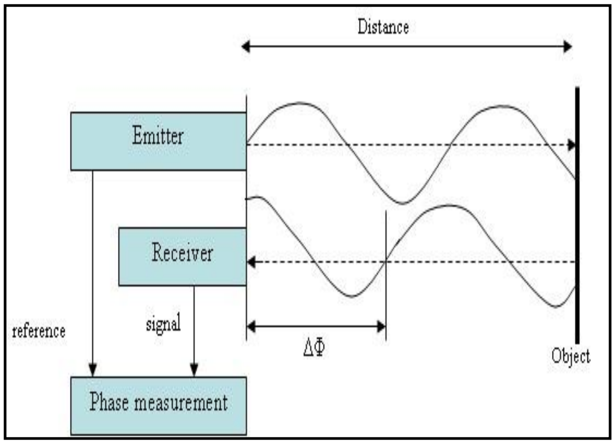

Figure 2: Phase Shift TLS Principle [5]

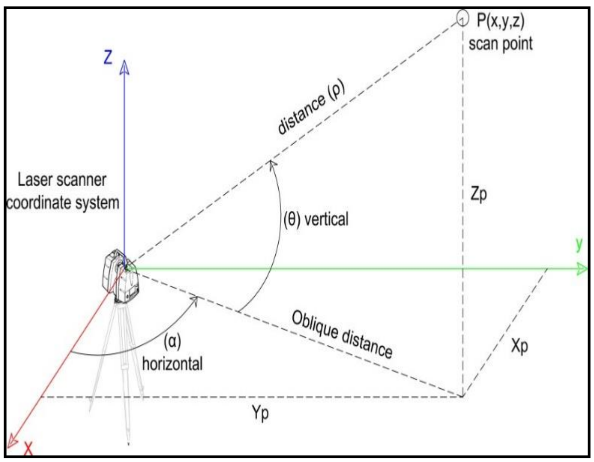

Figure 3: Measurement TLS Principle [7]

Registration is the process of integrating the Scan Worlds into a single coordinate system [1]. Each scan is referenced to a specific local coordinate system. After that, all scans are registered depending on the common targets that are pre-established for this purpose using checker boards and spheres (see **Figure** 4) [5] .

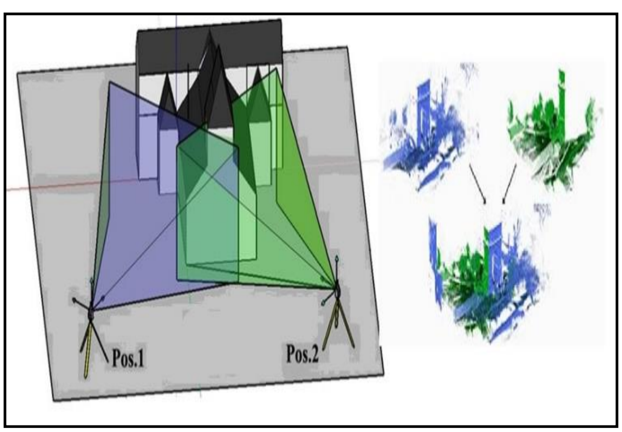

Figure 4: Registration of Two Scan Positions[5]

IV METHODOLOGY AND RESULTS

In order to figure out the accuracy of TLS compared to other traditional surveying instruments; four different approaches were performed in this research. In the following lines each method will be further explained, and the concluded results will be provided.

a. Test Description in Measuring Control Points

In this study, nine different control points were selected, in which they were observed using TS, TLS, and RTK-GPS. Distances between these points were all within 100m and each point could be clearly observed from at least two other occupied points. In order to reach a high precision level, each control point was observed five different times using the three instruments (TS, TLS, and RTK-GPS) (see Figure 5).

Figure 5: Control Point Fixation

On the reference network, all control points were surveyed five times by TS, RTK-GPS and TLS so as to evaluate the precision of the measurements. To compute the precision of each method for the repeated measurement of the reference network, see **Figure 5**, the standard deviation formula in Eq. (7) has been used.

$$\boldsymbol{SD} = \sqrt{\sum_{i=1}^{n} \frac{(\bar{X}-X_i)^2}{n-1}}, \bar{X} = \frac{\sum X_i}{n} \quad (7)$$

Where: -
Xi: the individual measurements,
$\bar{X}$: the mean value of the measurements,
n: the number of measurements.

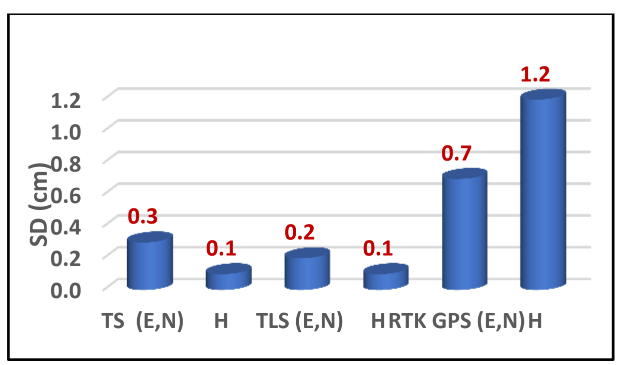

Figure 6: SD of TS, TLS and RTK-GPS

As shown in Figure 6 standard deviations of TS for the horizontal and vertical coordinates were 3mm and 1mm respectively. Standard deviations of RTK-GPS were 7mm for horizontal coordinates and 1.2cm for vertical coordinates. Standard deviations of TLS for the horizontal and vertical coordinates were 2mm and 1mm respectively.

Same as in the previous approach, the accuracy of the observations was evaluated using RMSE where evaluating how much the measurements were close to the established value, considering the TS measurements the true value see Table 1 and Figure 7, the RMSE was calculated using Eq. (6).

Table 1
RMSE of TLS and RTK-GPS

Point	TLS (cm)			RTK-GPS (cm)		
	ΔHZ	ΔVL	ΔP	ΔHZ	ΔVL	ΔP
A1	1.3	0.1	1.3	0.9	2.8	3.0
A2	1.2	-1.2	1.7	1.0	-0.3	1.0
A3	1.7	-1.3	2.1	1.5	0.2	1.6
A4	1.4	-1.1	1.8	1.4	-0.5	1.5
A5	0.5	0.6	0.8	0.5	-1.1	1.2
A6	1.7	0.5	1.8	0.8	-0.1	0.9
A7	2.0	1.2	2.3	1.1	0.0	1.1
A8	1.6	-0.9	1.8	0.7	-4.4	4.5
A9	1.4	0.3	1.5	1.4	-3.4	3.7
RMSE	1.5	0.9	1.7	1.1	2.1	2.4

Where: -
ΔHZ: is the discrepancies in horizontal coordinates,
ΔVL: is the discrepancies in vertical coordinates,
ΔP: is the discrepancies in 3D coordinates.

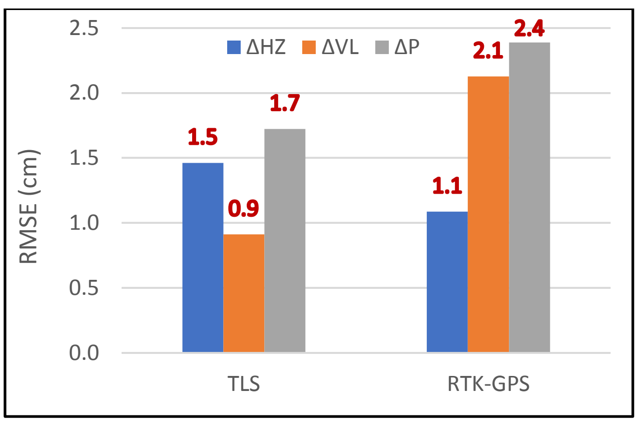

Figure 7: Average RMSE of TLS and RTK-GPS for all Nine Points

Table 1 and Figure 7 indicate the RMSE of RTK-GPS for the horizontal and vertical coordinates to be within 1cm and 2cm respectively. RMSE of TLS was within 1.5cm for horizontal coordinates and 1cm for vertical coordinates.

b. Test Description in Grid Leveling of Terrain Ground

The data analyzed in this approach was related to an area in El-Mokattam which is located in Cairo, Egypt (see Figure 8). The reason behind choosing this site is that it contains variable slope gradient and a limited presence of non-terrain features. In addition, the site includes all three different types of terrain (flat, rolling, and mountainous). Ellipsoidal heights in this site were all between 124m and 180m and the site area was approximately 30,000m^2.

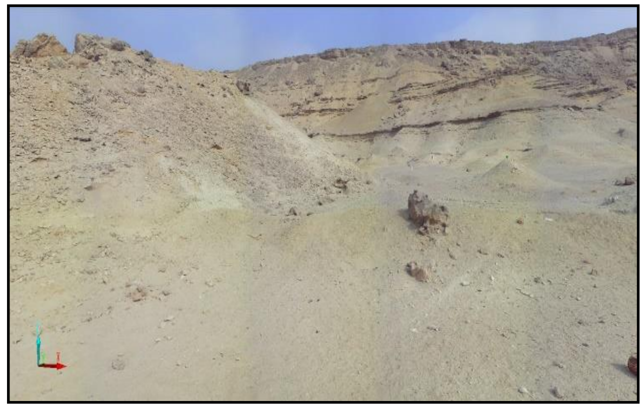
Figure 8: Elmokattam Site

Data was acquired using two different instruments. First, grid points were observed using a traditional Topcon TS. 1000 points spaced 5mx5m were observed within four hours and they were referenced to a local coordinate system. Then, the same area was scanned using (Trimble TX5) TLS. The spacing between scanned points was about 2cm and the range of the scanner was in the range of 75m. It is also interesting to note that the measurements' density depends on the range of the scanner as measurements' density decreases with increasing the scanning range.

Using TLS, two scans were performed within 30 minutes (15 min. each), then those scans were registered together depending on their common artificial targets (see Figure 9), keeping in mind that targets locations were carefully selected so as to be easily observed in both scans. It is also important to note that common targets used in those scans were three checker boards and two spheres, which were observed using TS and then referenced to the same local coordinate system of TS observations.


Figure 9: Used Checkerboard and Sphere

Data from TLS were processed using the respective software of the instrument (Scene). As mentioned before, the two scans captured were registered together, then they were referenced to the same TS coordinate system depending on the coordinates of the checker boards. The 3D point cloud created from Scene was used within AutoCAD Civil3D application to build a 3D surface using the traditional triangulated irregular network (TIN). After which, points observed by TS were imported into Civil3D and their observed levels were compared to the TLS surface levels at the same location.

In order to assess the accuracy of the TLS measurements, RMSE method was used, considering the TS observations as the true value, the RMSE was calculated using the following equation:

$$\boldsymbol{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(X-X_i)^2}{n}} \qquad (6)$$

Where:
X: is the true value.
X_i: the individual measurements.
n: the number of observations.

Figure 7 shows the vertical accuracy of TLS, considering the TS observations as the true value.

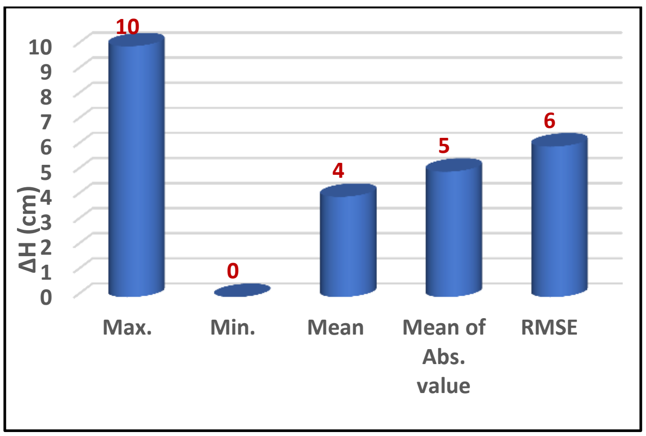

Figure 10: Statistics of Vertical Component Differences

As shown in Figure 10 the height differences were computed with maximum error of 10cm, minimum error zero, mean error 4cm and mean of absolute errors 5cm, in addition with RMSE 6cm.

c. Test Description of TLS Incidence Angle

A building facade was selected and eight groups each of seven points, were fixed on constant heights of the facade using paper prisms. Eight incident angles were used (90°, 80°, 70°, 60°, 50°, 40°, 30°, 20°). The 56 points were fixed on the different incident angels using TS. A point was selected to be occupied by the TS and then by TLS, and all the 56 points were observed using both instruments. The instrument height, occupation point, and incident angle for each point group were all fixed. The absolute differences between TS heights and TLS heights were then plotted versus the measured incident angle, see Figure 11.

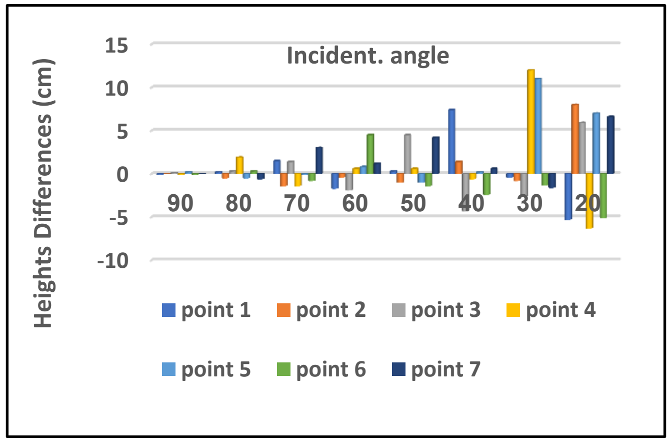

Figure 11: The effect of the incident angle on the resulted height difference

In addition, the incidence angle has a significant effect on the accuracy of TLS measurements, see Figure 12.

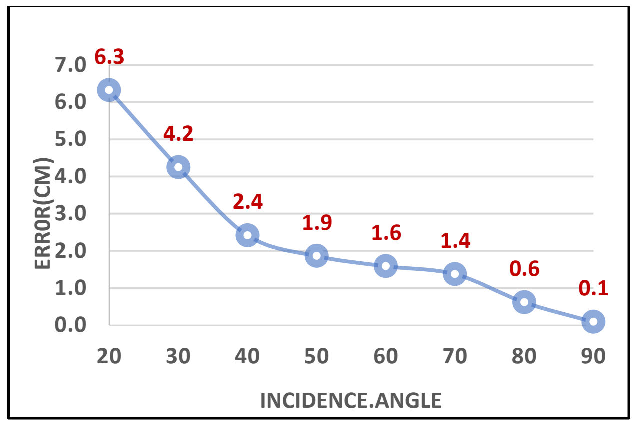

Figure 12: Average Absolute Difference Versus the Incidence Angle

As shown in Figure 12, the incidence angle is inversely proportional to the error resulting from observations.

d. Test Description of Steep-Vertical Cut Leveling

Here in, a steep downhill slope in El Mokattam site, Cairo, Egypt (see Figure 13) was selected to be observed by TS and TLS and the results were then compared to each other and the RMSE of TLS was calculated as previously done. The observed area was around 450m^2 and all observed points were inaccessible. Using TS, five hundred points spaced 1mx1m were observed within approximately two hours and they were referenced to a local coordinate system. Then, the same area was scanned by TLS within only one scan lasting for 15 minutes, while points were spaced approximately 2cm and the distance between the instrument and the Steep- vertical cut was in the range of 25m. Three checker boards were used to reference the scan of the TLS to the same coordinate system as TS.

Figure 13: Steep-Vertical Cut

Data from TLS were processed by the same software, and then imported into Civil3D, and a 3D TIN surface was created using this point cloud. Data from TS was also imported into Civil3D and another 3D TIN surface was created. Grid of 5mx5m was extracted from both surfaces, and the levels of both grids were compared to calculate the RMSE.

In this study, TS observations were considered as the true value to assess the accuracy of the TLS measurements, where difference between TS heights and TLS heights were computed, see Table 2.

Table 2
RMS of TLS for Steep-Vertical Cut

P	H(TS) m	H (TLS) m	(H_{TS}-H_{TLS}) m
1	130.347	130.41	-0.063
2	128.672	128.73	-0.058
3	128.203	128.26	-0.057
4	130.874	130.93	-0.056
5	128.392	128.44	-0.048
6	150.783	150.82	-0.037
7	128.405	128.44	-0.035
8	130.927	130.96	-0.033
9	132.121	132.15	-0.029
10	134.942	134.97	-0.028
11	129.594	129.62	-0.026
12	134.346	134.36	-0.014
13	128.836	128.85	-0.014
14	127.697	127.71	-0.013
15	128.748	128.76	-0.012
16	148.209	148.22	-0.011
17	133.14	133.15	-0.01
18	134.431	134.44	-0.009
19	134.044	134.05	-0.006
20	128.347	128.35	-0.003
21	129.947	129.95	-0.003
22	131.422	131.42	0.002
23	134.248	134.24	0.008
24	129.538	129.53	0.008
25	128.271	128.26	0.011
26	138.082	138.07	0.012
27	130.705	130.67	0.035
28	134.134	134.07	0.064
29	139.835	139.77	0.065
RMS (mm)			**6.27**

As shown in Table 2, the RMS for the TLS measurements in this study was around 6 mm**.**

V CONCLUSIONS

Herein, the obtained accuracy of using TLS was compared to traditional techniques (i.e., TS, RTK-GPS and level) through five different case studies. Accordingly, the results of these studies can be summarized as follows:

- In assessing the precision and accuracy of measuring control points,
  - TS coordinates have a SD of 3mm horizontally and 1mm vertically, while RTK-GPS coordinates have a SD of 7mm horizontally and 1.2cm vertically. TLS coordinates have a SD of 2mm horizontally and 1mm vertically.
  - Considering the RMS of discrepancies for the RTK-GPS and TLS with respect to the TS, RTK-GPS gave a RMS of 1cm horizontally and 2cm vertically, while TLS gave a RMS of 1.5cm horizontally and 0.9cm vertically.
  - The accuracy of using TLS is better than RTK-GPS in observing control points. However, the RTK-GPS technique has the advantage regarding the needed field time.
- In natural ground grid levelling, TLS surveyed an area of 30,000m^2 in thirty minutes only with an accuracy of 5cm, while TS consumed around four hours to survey the same area. This indicated the acceptable accuracy of using TLS in topographic surveying works. However, the large amount of data acquired from the scans may be an obstacle while processing the data, even if the needed field time is less.
- In assessing the effect of the incident angle on the accuracy of TLS measurements, it was found that the value of the incidence angle is directly proportional to the accuracy and hence, it is not recommended to decrease the incident angle of measurements to less than 45 degrees.
- In steep-vertical cut grid levelling, TLS scanned an area of 500m^2 in fifteen minutes only with an accuracy of 7mm, while the same area was surveyed using TS in 2 hours. This indicates that TLS can be used efficiently in this application considering both accuracy and time factors.

Hence, for practical use, TLS can be used in natural ground grid levelling with an approximate accuracy up to 6 cm. In addition, it is not recommended to increase the TLS vertical angle to more than 45° in order to keep the accuracy of measuring within acceptable ranges. It is also preferable to use TLS in vertical cut measurements as it exhibits a higher accuracy level and a lower measuring time than TS.

REFERENCES

[1] Solomon D. C. (2014). Surveying with GPS, total station and terrestrial laser scanner: a comparative study, Master thesis in Geodesy, KTH, Stockholm, Sweden.

[2] Ehsani, M. R., Upadhyaya, S. K. and Mattson, M. L. (2004). Seed Location Mapping Using RTK GPS; Trans. ASAE. Vol. 47(3): 909-914.

[3] Lin, L.S. (2004). Application of GPS RTK and total station systems on dynamic monitoring land use. Proceedings of the ISPRS Congress Istanbul, Turkey.

[4] Mogahed Y. M. and Selim M. (2016). Ability of Terrestrial Laser Scanner Trimble TX5 in Cracks Monitoring at Different Ambient Conditions, World Applied Sciences Journal, Vol. 34 (12): 1748-1753.

[5] Quintero, M.S., Alonzo A. and Scot R. (2008). Theory and Practice on Terrestrial Laser Scanning Training material based on practical applications [Book], version 4.

[6] Lemmens M. Geotechnologies, Applications and the Environment [Book], 2011. Springer, - Vol 5.

[7] Abdullah T. (2014), Accuracy Assessment of Terrestrial Laser Scanning and Digital Close-Range Photogrammetry for 3D Cultural Heritage, Master thesis, Ryerson University, Canada.

Title Arabic:

تقييم الماسح الضوئي بالليزر في المساحة الطبوغرافية

Arabic Abstract:

أصبح ماسح الليزر الأرضي جهاز مألوف وأكثر التقنيات استخدامًا لالتقاط البيانات ثلاثية الأبعاد بدقة عالية ومفصلة للغاية لمجموعة متنوعة من التطبيقات في الهندسة. تتمثل ميزة المسح الضوئي بالليزر في أنه يمكنه تسجيل أعداد هائلة من النقاط في فترة زمنية قصيرة نسبيًا. الفكرة الرئيسية هنا هي تقييم دقة الماسح الضوئي الأرضي ومقارنته بأجهزة المسح التقليدية الأخرى. وقد تم ذلك من خلال أربع تجارب مختلفة.

أولا تم عمل شبكة تحكم تتكون من 9 نقاط وتم رفعهم مساحيا بثلاث طرق مختلفة (خمس مرات). تم استخدام جهاز محطة الرصد المتكاملة و RTK-GPS وماسح الليزر الأرضي وتم تعيين دقة كل طريقة على حدي عن طريق الانحراف المعياري ((SDوتم حساب دقة كلا من RTK-GPS و ماسح الليزر الأرضي باعتبار ان قيم محطة الرصد المتكاملة قيم صحيحة عن طريق RMS.

ثانيا تم إجراء عمل شبكية لمنطقة في المقطم التي تبلغ مساحتها 30000 متر مربع باستخدام جهاز محطة الرصد المتكاملة وتم ايضا عمل مسح لنفس المنطقة باستخدام ماسح الليزر الأرضي ثم عمل مقارنة بين الجهازين وحساب دقة الماسح الارضي عن طريق RMS.

ثالثا تم دراسة تأثير زاوية السقوط على دقة ماسح الليزر الأرضي فتم تثبيت 56 نقطة على واجهة رأسية وتم رفعهم باستخدام محطة الرصد المتكاملة وتم رفعهم ايضا باستخدام ماسح الليزر الأرضي وتم عمل مقارنة بين النتائج عن طريق حساب فروق الارتفاعات بين القياسات.

اخيرا تم دراسة دقة ماسح الليزر الأرضي في رفع المناطق شديدة الانحدار أو القطاعات الرأسية فتم دراسة منطقة تبلغ مساحتها 500 متر مربع وتم رفعها باستخدام محطة الرصد المتكاملة و ماسح الليزر الارضي وتم حساب RMS.

من نتائج البحث ، وجد أن RMS لماسح الليزر الارضي في قياس التضاريس كان حوالي 6 سم. لا يُفضل أن تكون زاوية السقوط لماسح الليزر الارضي أقل من 45 درجة. عند قياس القطع الرأسية وجد أن RMS لماسح الليزر الارضي 6 مم وله فترة قياس أقل.

في النهاية على الرغم من أن ماسح الليزر الأرضي أغلى من تقنيات المسح التقليدية ، إلا أنها أكثر فائدة من حيث توفير الوقت والجهد بالإضافة إلى ذلك يعطي دقة مقبولة نسبيا مع توضيح تفاصيل كثيرة.