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# Comparative Assessment of Terrestrial Laser Scanner Against Traditional Surveying Methods

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*Abstract*— **Terrestrial laser scanner has become a familiar instrument and most used technology for rapidly capturing very accurate and highly detailed 3D point cloud datasets for a variety of applications in Engineering. The advantage of laser scanning is that it can record huge numbers of points in a relatively short period of time. The main idea here is to assess the accuracy of terrestrial laser scanner and compare it relative to the other traditional surveying instruments. This was done throughout four different approaches. First, a grid levelling for a 30,000m$^2$ ground terrain was performed using Total Station (TS), and Terrestrial Laser Scanner (TLS). After which, the RMSE for TLS was computed. Secondly, a control point network consisting of nine points was measured using TS, TLS, and real time kinematic global positioning system (RTK-GPS) and the precision for each instrument was calculated depending on the standard deviation (SD). In addition, the accuracy of TLS and RTK-GPS was calculated depending on the RMSE. Thirdly, the effect of vertical angle on TLS measurements was assessed by measuring fifty-six points fixed on a building façade using different vertical angles. Those points were measured using both TS and TLS, then the absolute height differences between TS and TLS measurements were calculated to figure out the effect of increasing the vertical angle on measurements. Finally, the accuracy of TLS on vertical cut measurements was calculated by surveying a downhill area of 500m$^2$ by both TS and TLS and the RMSE for TLS measurements was calculated. From the research results, it was found that the RMSE for TLS in measuring terrains was about 15cm. In measuring control point networks, TLS was figured out a higher accuracy than RTK-GPS. TLS vertical angle is not preferable to be more than 45 degrees. In vertical cut measurements TLS was figured out a RMSE of 6mm and 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.**

*Index Terms*—**Terrestrial laser scanner, RTK-GPS, Total station, Accuracy.**

## 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. Accuracy of surveying techniques using different instruments such as Level, Real-time Kinematic (RTK) GPS, Total Station (TS) and Terrestrial Laser Scanner (TLS) are dependent on several variables which limit their measurement quality. For example: multipath, the inherent satellite signal accuracy, signal transmission delay, receiver hardware and software limitations, satellite signal obstruction are some of the challenges related to GPS measurement. Also, all other instruments' measurements are subjected to different errors that minimize their accuracies [1]. 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. PREVIOUS STUDIES

According to Ehsani et al. [2], a 50-ha area was surveyed with RTK-GPS, with four established reference points and a base station. RTK GPS method figured out an accuracy of 1cm in horizontal coordinate.

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

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A different research was performed by Pflibsen [4], in which an accuracy and time expenditure comparison of TS versus TLS observing a sand pile was performed. It was concluded from this experiment that 9mm accuracy in horizontal and vertical coordinates could be reached using TLS. Also, the experiment figured out a time saving for the measurements as the time for TLS observations was around 7 minutes.

In another study established by Fregonese et al. [5], TLS was used to assess the accuracy in monitoring deformations of large concrete dams. First a geodetic network was established as a reference by Leica TS. Then, several targets were fixed on the dam, and measured using both TS and TLS. The reference network was established with 2mm horizontal and 3mm vertical coordinate precision. Different targets mounted on the dam were measured precisely with a total station which showed an accuracy of 3mm for the horizontal and 4.5mm for the vertical coordinate, whilst TLS gave accuracy of 4mm for the horizontal and 8mm for the vertical measurement based on (RMSE).

According to Solomon [1], accuracy, precision and time expenditure of three different surveying instruments (TS, RTK-GPS and TLS) were assessed and compared to one another. Comparison was made between TS versus RTK-GPS on the reference network and TS versus TLS on the façade of L building. Based on the gathered observations, the reference network was established using TS with a precision of 1mm standard deviation for both horizontal and vertical coordinates. RTK-GPS method was performed on the same network with precision of 8mm in horizontal and 1.5cm in the vertical coordinates. The accuracy of the RTK-GPS measurements was expressed by RMSE and it was about than 9mm in horizontal and 2.2cm in vertical coordinates. Precision of the TS measurement on the façade of L building has been 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. Standard deviations of 1.6cm and 1.2cm in horizontal and vertical coordinates were reached respectively. The RMSE 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 [6]. 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 [7].

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 (†), and light speed in air (c), then the distance to the target is using the following simple equations [8] :

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

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

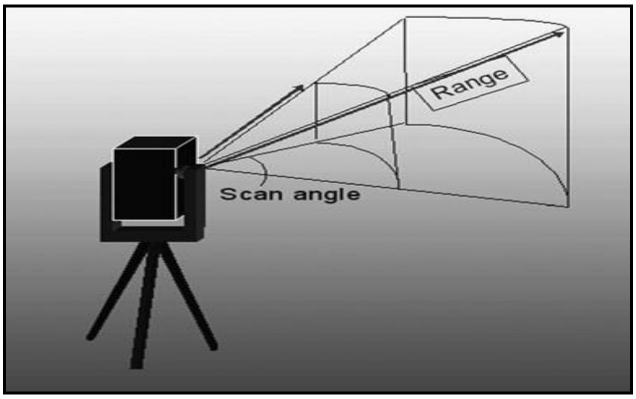


**Figure 1: TLS Idea** [8]

In addition, the TLS measures both the horizontal angle($\alpha$) and vertical angle ($\theta$) 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**) [9]:

$$X = D \cos\theta . \cos\alpha \quad (3)$$

$$Y = D \cos\theta . \sin\alpha \quad (4)$$

$$Z = D \sin\theta \quad (5)$$

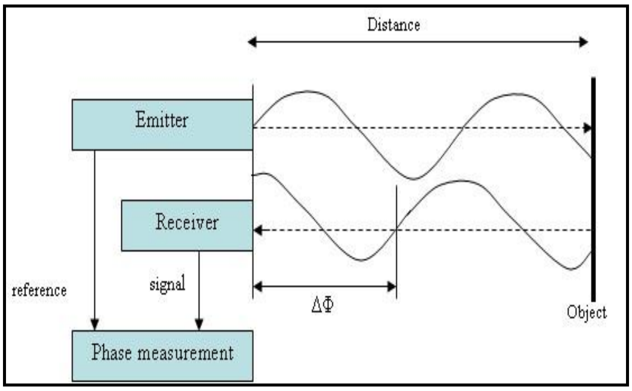


**Figure 2: Phase Shift TLS Principle** [7]

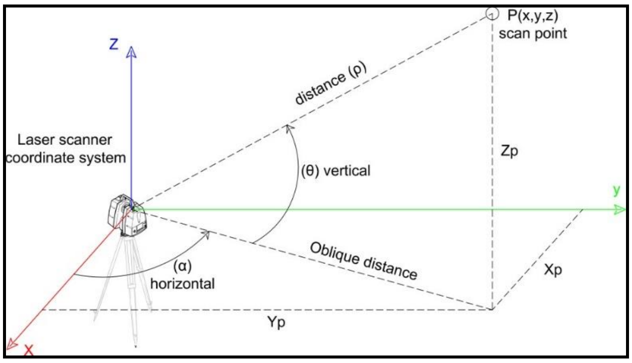


**Figure 3: Measurement TLS Principle** [9]

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**) [7] .

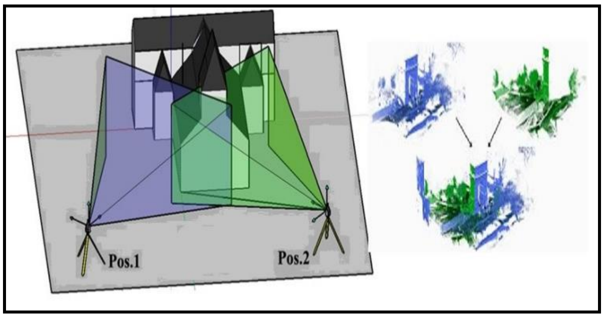


**Figure 4: Registration of Two Scan Positions** [7]

## 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. Accuracy Assessment of TLS in Grid Leveling Terrain Ground*

The data analyzed in this approach was related to an area in El-Mokattam which is located in Cairo, Egypt (see **Figure 5**). 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). Elevations in this site was all between 124m and 180m and the site area was approximately 30,000m$^2$.

**Figure 5: 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 6**), 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 6: 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:

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

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.

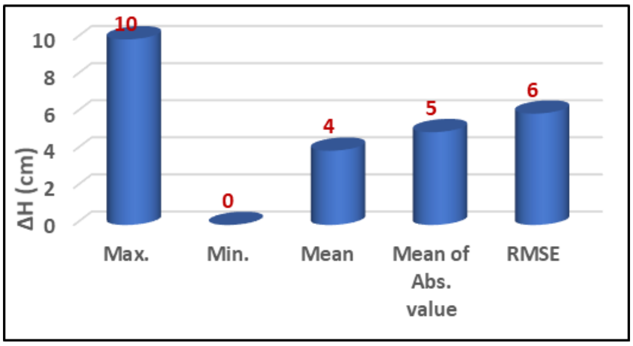


**Figure 7: Statistics of Vertical Component Differences**

As shown in **Figure 7** 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.

### *B. Accuracy and Precision Assessment of Control Points network*

In this approach, 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 8**).

**Figure 8: 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 9**, the standard deviation formula in Eq. (7) has been used.

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

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

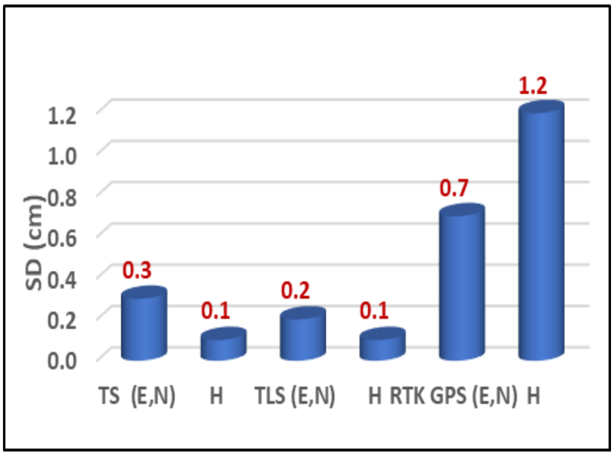


**Figure 9: SD of TS, TLS and RTK-GPS**

As shown in **Figure 9** 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 as the true value see **Table 1** and **Figure 10**, 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 |

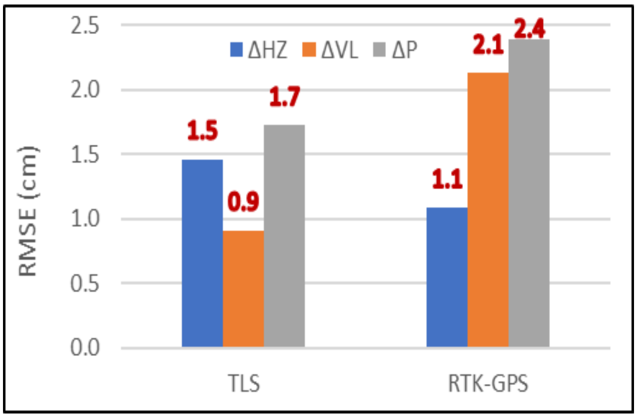


**Figure 10: Average RMSE of TLS and RTK-GPS for all Nine Points**

**Table 1** and **Figure 10** 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.

### *C. Accuracy Assessment of TLS Vertical Angle*

A building façade was selected and eight groups of seven points were fixed on constant heights of the façade using paper prisms. This resulted in eight different vertical angles (0˚,10˚,20˚,30˚,40˚,50˚,60˚,70˚). A point was selected to be occupied by TS and then by TLS and all the 56 points were observed by both instruments. The instrument height, occupation point, and vertical angle for each point group were all fixed. Then, the heights of all points were observed by both instruments. The absolute differences between TS heights and TLS heights were then plotted versus the measured vertical angle, see **Figure 11**.

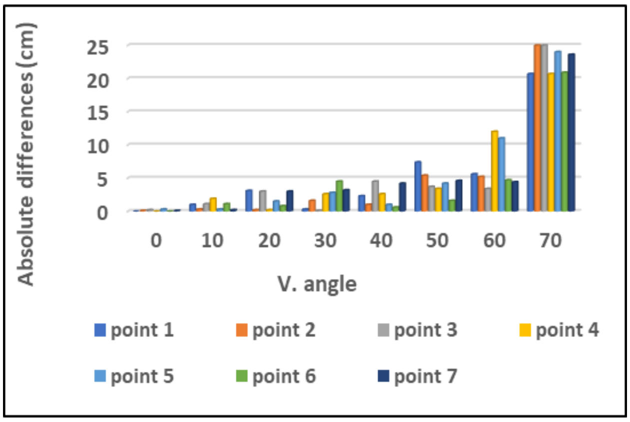


**Figure 11: Absolute Differences between TS heights and TLS heights**

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

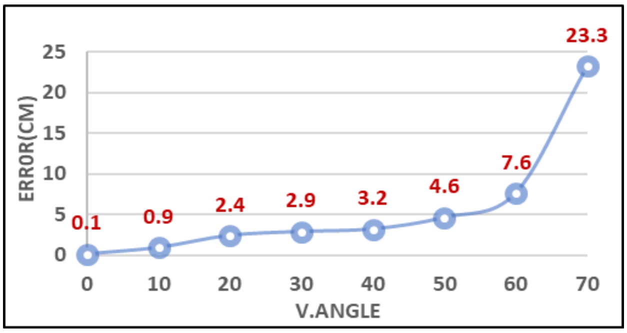


**Figure 12: Average Absolute Difference Versus the Vertical Angle**

As shown in **Figure 12**, the vertical angle is directly proportional to the error resulting from observations.

*D. Accuracy Assessment of 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 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: 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 approach, 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: RMSE of TLS for 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 |
| RMSE (mm) | | | 6.27 |

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

## V. Conclusion

Here in, the obtained accuracy of using TLS was compared to traditional techniques using total station or RTK GPS through four different approaches. Accordingly, these approaches performed along with their results can be summarized as follows:

- In natural ground grid levelling, TLS has surveyed an area of 30,000m$^2$ within only thirty minutes with an accuracy of 6cm, while TS has consumed around four hours to survey the same area.

- In assessing the precision and accuracy of measuring a control points network:
  - TS has a SD of 3mm horizontally and 1mm vertically, While RTK-GPS has a SD of 7mm horizontally and 1.2cm vertically, and TLS has a SD of 2mm horizontally and 1mm vertically.
  - Considering the RMSE for the RTK-GPS and TLS, RTK-GPS has a RMSE of 1cm horizontally and 2cm vertically, and TLS has a RMSE of 1.5cm horizontally a 0.9cm vertically.
- In assessing the effect of the vertical angle on the accuracy of measurements for TLS, it was found that increasing the vertical angle is inversely proportionate to the accuracy and hence, it is not recommended to increase the vertical angle of measurement to more than 45 degrees.
- In vertical cut grid levelling, TLS has surveyed an area of $500m^2$ within only fifteen minutes with an accuracy of 7mm, corresponding surveying the same area with the TS for 2 hours.

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

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