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Reliability of Terrestrial Laser Scanner Measurement in Slope Monitoring

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Abstract.. Dense 3D point clouds provided by terrestrial laser scanner (TLS) has demonstrated significant reliability of TLS in landslide monitoring. However, existence of errors in measurement is inevitable which eventually has decreased the quality of TLS data. To concretely measure the capability of TLS in landslide monitoring, this study has performed two epoch measurements using tacheometry (for benchmarking) and TLS (Topcon GLS-2000) at Kulim Techno City, Kedah, Malaysia. Sixteen (16) artificial targets were well-distributed on the slope to determine the accuracy of the employed TLS. Results obtained revealed that Topcon GLS-2000 provides 0.006m of accuracy. However, the presence of high incidence angles in TLS measurement has limited the capability to identify the significant displacement of the targets.

1. Introduction

Landslide is becoming common issue in worldwide and it can be defined as the deformation of a mass of rock, debris, or earth down a slope. Landslide occurs when the strength of the earth material that composes the slope has less forces than the gravity effect which eventually causes the down-slope movement of soil and rock [1]. Currently, there are two approaches available for land slope monitoring (figure 2), which are using geodetic or geotechnical [2] methods.

Tacheometry and global navigation satellite system (GNSS) methods can be considered as established geodetic approach in deformation measurement and landslide monitoring. Taking into account the accuracy in measurement, reliability of both methods have long been proven [3]-[6]. However, the precision (i.e. point density) provided from tacheometry and GNSS measurement is quite limited. To resolve that limitation, several non-contact measurement techniques were introduced, which are remote sensing [7], photogrammetry [8]-[9] and LiDAR [10]. With the capability to provide dense three-dimensional (3D) data (according to resolution of sensor), these measurement techniques have enabled surface to surface comparison assessment or often known as surface deviation analysis. This kind of analysis can homogenously measure and identify the trend of movement that happened from two differ measurement epochs.

Taking accuracy as first priority among those three approaches that able to provide dense 3D data (i.e. remote sensing, photogrammetry and LiDAR), terrestrial laser scanner (static LiDAR) can be considered as the best. With significantly less errors propagation in measurement and processing procedures, terrestrial laser scanner (TLS) is also not dependent upon the lighting conditions and surface texture as well as able to provide direct, rapid and high-density 3D data compared to other approaches [11]. However, TLS instruments are complex tools with many moving parts whose relative positions can change over time depending on use, handling frequency and care. Furthermore, similar to other optical sensors, observations from TLS is also can be impaired by numerous of errors especially from local environment [11]. Thus, reliability of TLSs in slope monitoring is still remain questionable. For that purpose, this study has robustly examined the accuracy of TLS data in landslide monitoring with the aid of tacheometry measurement.

2. Terrestrial laser scanner measurement

In contrast to traditional 3D data acquisition approaches (i.e. tacheometry and photogrammetry), terrestrial laser scanner is capable to rapidly acquire data without any requirement of direct contact to the object and extensive processing procedure. Similar to reflectorless tacheometry, TLS did measure three main components: i) Range (r); ii) Horizontal direction (ϕ); and iii) Vertical angle (θ). According to Abbas et al. [12], there are three options employed by TLS in order to measure range: i) time-of-flight; ii) phase shift; and iii) triangulation. While the other components were obtained based on the scanner pre-determined axes.

To ensure TLS data are significant for further processing, most of the TLSs on-board software have automatically convert raw TLSs data (i.e. spherical coordinate system) into Cartesian coordinate system. However, raw data in spherical coordinate system is essential for this study to conduct least square adjustment for TLS data. Conversion from Cartesian (X_A, Y_A and Z_A) and spherical (range, horizontal direction and vertical angle) coordinates system can be expressed as follows [12]:

$$\begin{aligned} &\text{Range, } r = \sqrt{x_A^2 + y_A^2 + z_A^2} \\ &\text{Horizontal direction, } \varphi = tan^{-1}\left(\frac{x_A}{y_A}\right) \\ &\text{Vertical angle, } \theta = tan^{-1}\left(\frac{z_A}{\sqrt{x_A^2 + y_A^2}}\right) \end{aligned} \tag{1}$$

3. Experiments

Due to the active slope movement that occurred as reported by Kedah state authorities, this study was conducted at Kulim Techno City, Kedah, Malaysia. For benchmarking reason, as illustrated in figure 1, sixteen (16) artificial targets were well-distributed over the land slope area. Other than TLS measurement, this study also exploited conventional approach (i.e. reflectorless tacheometry) to establish 3D known coordinates for each target. Based on the reference coordinates obtained from tacheometry measurement, accuracy of TLS data can be mathematically determined.

For the tacheometry measurement, Topcon ES-105 with accuracy of 0.0014° and 2mm for angular and range measurement, respectively was utilised to measure all the artificial targets. To secure the accuracy yielded, triangulation observation technique was employed and least squares adjustment has been entrusted to compute the most probable values of all targets along with their quality (i.e. precision).

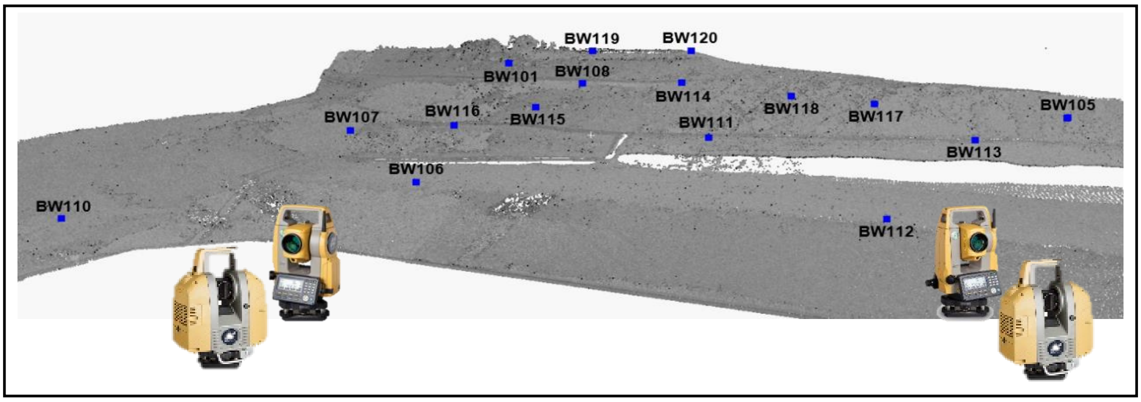

Figure 1. Research site located at Kulim Techno City, Kedah, Malaysia.

As depicted in figure 1, Topcon GLS-2000 scanner was used to scan all targets with the surface of the land slope. According to the instrument specification sheet, this time-of-flight scanner able to provide accuracies of 3.5mm and 0.0017° for range and angular measurements, respectively. It should be noted that the accuracies mentioned above are based on single point measurement, if involves with determination of target centroid procedure, the accuracy is theoretically decrease due to the error propagation with other uncertainties during measurement phase.

4. Results and analyses

Assigned 0.0014° as precision for tacheometry angular measurement, least squares adjustment manage to converge at third iteration. Reference standard deviation obtained from tacheometry observation is 0.0027°, which is equal to 2mm data quality for 50m range measurement. To evaluate the accuracy of Topcon GLS-2000 scanner data acquisition, fifteen independent vectors were established from sixteen (16) targets. Employing target BW111 as reference point, fifteen (15) vectors were obtained from both tacheometry and scanner data as shown in table 1.

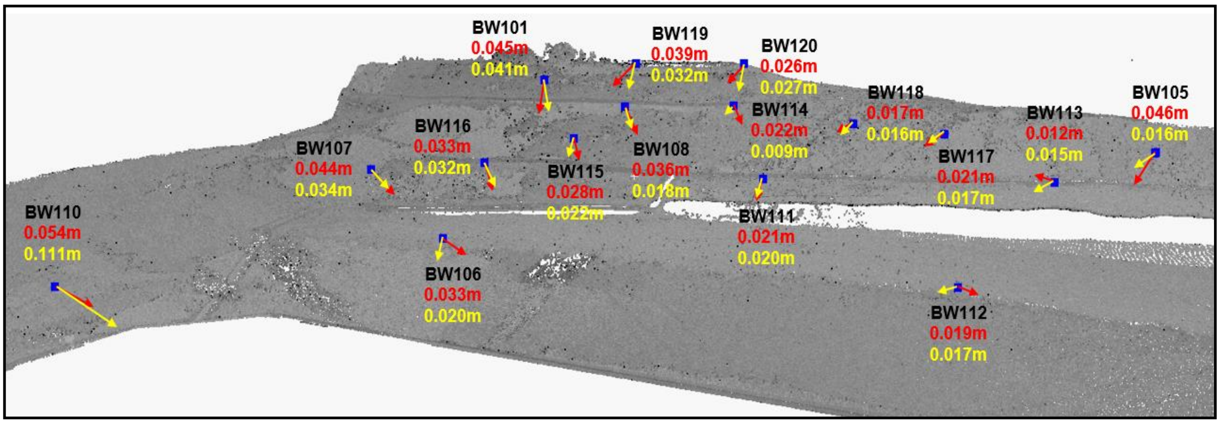

Figure 2. Magnitude and direction of computed displacement vectors for both tacheometry and TLS data.

Based on the computed vectors and with the aid of law of propagation of variance algorithm, it was found that the accuracy of Topcon GLS-2000 scanner is 6mm. As expected, under 95% confidence interval (two sigma), accuracy of the scanner as stated by manufacturer is 7mm. Depicted in figure 2 is magnitudes and directions for all displacement vectors obtained from tacheometry and TLS measurements. Through graphic evaluation, all displacement vectors have shown similar trend for both measurement approaches except for target BW112. The uncertainty that occurred may be due to the position of target which is quite close to the sensors location (refer figure 1). Thus, high incidence angle was expected to reduce the quality of measurement for targets that are near to the occupied sensors (e.g. BW112, BW106 and BW110).

Table 1. Independent vectors for TLS accuracy assessment.

Vector	Tacheometry (m)	TLS (m)	Discrepancies (m)
BW111 - BW101	23.427	23.424	0.003
BW111 - BW105	24.727	24.729	0.001
BW111 - BW106	21.174	21.177	0.003
BW111 - BW107	27.793	27.792	0.001
BW111 - BW108	14.607	14.610	0.003
BW111 - BW110	41.379	41.359	0.020
BW111 - BW101	20.624	20.622	0.002
BW111 - BW105	17.927	17.927	0.000
BW111 - BW112	9.783	9.786	0.003
BW111 - BW113	15.371	15.371	0.000
BW111 - BW114	20.113	20.110	0.003
BW111 - BW115	13.186	13.194	0.009
BW111 - BW116	9.013	9.012	0.002
BW111 - BW117	19.920	19.917	0.003
BW111 - BW118	16.417	16.415	0.002

5. Conclusions

The aim of this study is to examine the reliability of TLS measurement in slope monitoring. Robust experiments were performed through vector deviation analysis to eventually conclude the capability of TLS measurement. Sixteen (16) artificial targets were well-distributed on the land slope and measured using tacheometry (for benchmarking) and TLS approaches. As claimed by manufacturer, with 95% confidence interval, the experiment demonstrates that accuracy of Topcon GLS-2000 scanner is 0.006m. However, the accuracy has been constrained by incidence angle when later experiment (deformation analysis) has indicated that only 50% of the findings are similar to tacheometry output. It is essential to reduce the existence of high incidence angle by properly selecting the position of the scanner.

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