Significance of Geometrical Condition in Preserving the Quality of TLS Measurement

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Abstract
To acquire complete three-dimensional (3D) data that cover the whole surface of the scanned object, multiple scan stations are inevitable. Thus, the registration process is compulsory to oriented TLS multi local coordinate into one global coordinate system. Taking into account the fundamental principle of error propagation in network design, an open network solution for TLS measurement is impacted to yield uncertainties. To investigate this issue this study has been carried out to verify the effect of error propagation in the TLS pre-processing procedure. Two types of network configurations have been established: i. Closed; and ii. Open networks. To measure the accuracies of both configurations, 3D traversing has been performed in establishing six (6) reference points. With the aid of the reference points, the results demonstrated that by neglecting the geometrical condition the accuracy of TLS pre-processed data might be reduced up to 33 percent. To preserve the quality of the final real-world representation derived from TLS measurement, it is advisable to take into account this fundamental principal

1. Introduction

With the complex mechanism equipped in terrestrial laser scanner (TLS), this instrument manages to rapidly acquire high precision three-dimensional (3D) data. These advantages have made the TLS become a primary option in obtaining a point cloud of real-world representation. Among the applications, TLSs were utilized in reverse engineering (Helle and Lemu, 2021), digital reconstruction of historical monuments (Gardzińska, 2021), geodesy and surveying, structural deformation monitoring (Medic et al, 2019), forensic crime scene preservation (Galanakis, 2021), and architectural (Salido-Monzú and Wieser, 2019). Often, scanning from a single station cannot afford to provide complete data that cover the whole surface of the scanned object. Thus, multi-station in TLS measurement is unavoidable. As the fundamental measurement principle exploited by TLS that a local coordinate system will be established in every occupied station, hence, orienting multi-local into one global coordinates system is necessary. The procedure that employs a rigid body transformation algorithm is known as registration.

According to Abbas et al., (2014), the registration process can be divided into two main phases, which are coarse and fine registrations. Coarse registration is applied to identify the approximated transformation parameters, while fine registration focuses on minimizing the cost function of corresponding point clouds. Considering the requirement of overlapping point clouds and the propagation of errors suffered from the fine registration approach, most geomatics and engineers have relied on the coarse registration (Lerma Garcia et al, 2008). However, to ensure the quality of the registration solution in deriving the transformation parameters, the targets (i.e., artificial or natural) must be well-distributed in all axes (i.e, X, Y, and Z). As stated in Abbas et al., (2014), the parameters used to orient the TLS multi-local coordinates system are (refer to Figure 1): i. Translation for the 3 coordinate axes (ΔX, ΔY, ΔZ). ii. Rotation around the 3 coordinate axes (ω, φ, κ). Based on figure 1, the determination of 6 transformation parameters from TLS 2 to TLS 1, at least, 6 coordinates, distributed over 3 points not at the same line are required.

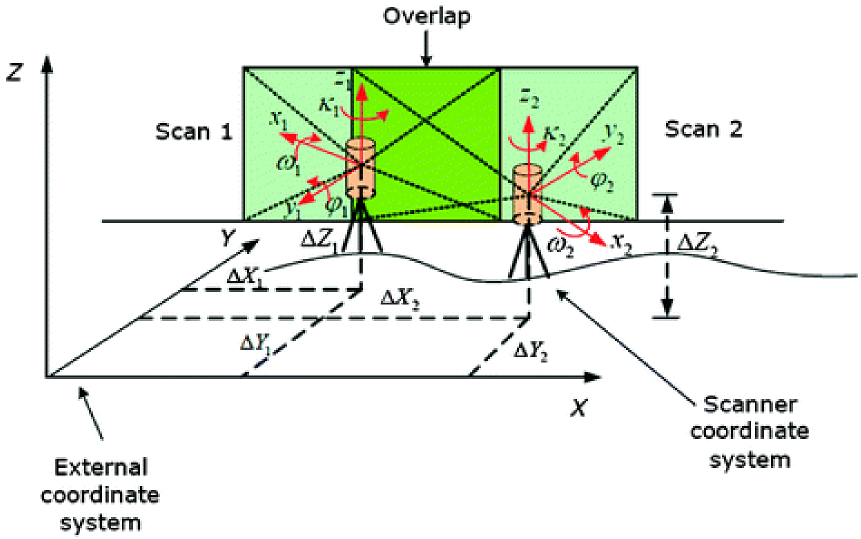

Figure 1: Pairwise registration of two (2) scanners position (Rizka et al., 2013)

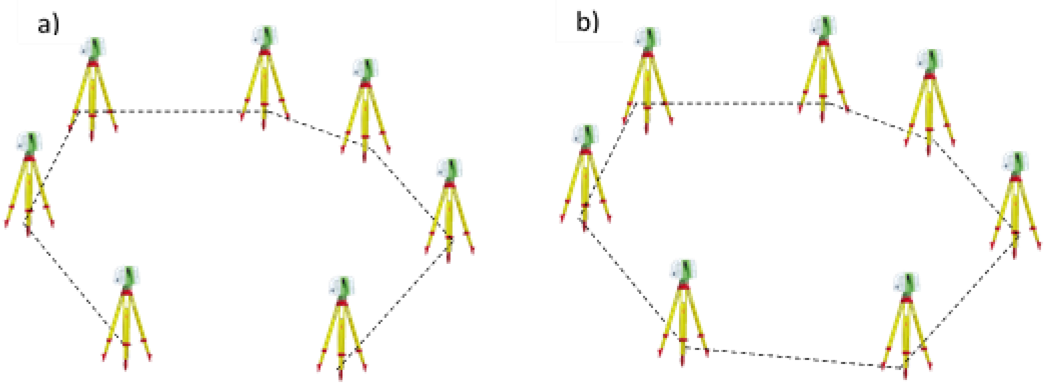

Figure 2: With (a) and without (b) geometrical condition

There are several approaches available to identify those points, and, consequently represented by several different registrations' approaches: i. Point clouds. ii. Artificial targets. iii. Common geometrical objects. iv. Surface matching. v. Information and features from images.

Ghilani (2018) has discussed in detail the issue of errors propagation in geodetic measurement that can significantly affect the quality of spatial data. To examine the existence of errors in the measurement, the geometrical condition is a crucial factor to quantify the value of misclosure in the geodetic network. Neglecting this principle knowledge might expose the augmentation of substantial uncertainties in acquired data. However, advanced technology possessed by TLS with the assistance of the resection approach in TLS pre-processing has caused the assumption that the measurements are exempt from this fundamental requisite. Thus, most of the TLS users are relying on registration errors to evaluate the acceptance of pre-processed data without considering the element of the geometrical condition.

With the misconception on designing TLS network configuration, this study has designed an experiment to measure the accuracy discrepancies between two networks, with and without geometrical conditions (refer to figure 2). Based on other geodetic networks (e.g., traversing and levelling), disregarding the geometrical requirement might jeopardize the quality of the observation, especially when the measurement involves a large area. The propagation of errors might significantly deteriorate the data without proper adjustment procedures. With similar observables to another geodetic measurement (i.e., range, horizontal direction, and vertical angle), the comparable occurrence is expected to happen in TLS network configuration.

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2. Methodology

With the determination to investigate the effect of neglecting geometrical conditions in TLS network configuration, the experiment has been conducted at Dewan Seri Semarak (DSS), Universiti Teknologi MARA Perlis Branch (UiTMPs) located at Arau, Perlis, Malaysia (refer to figure 3). To determine the overall proportions of the building, the survey only covered 1.61 acres. In the beginning, two (2) network configurations were exploited in obtaining the 3D point clouds using a terrestrial laser scanner. The first configuration yields the data without geometrical conditions, while the latter configuration has distributed three (3) artificial targets to close the network. For benchmarking purposes, traversing has been carried out to establish reference points at the test field. To ensure that the propagation of errors can be quantified, several reference points have been established at the site using Topcon ES105 total station (refer to figure 4). With an accuracy of one (1) second and 2mm + 2ppm (part per million) for angular and distance measurement, respectively, the selected total station has demonstrated reliability to establish the reference points. Furthermore, to strengthen the reliability of the reference points, the least-square adjustment method has been utilized to compute the most probable values of the traversing data. As illustrated in figure 5, there are six (6) well-distributed reference points have been positioned around the scanned object (DSS) from nine (9) traverse stations.

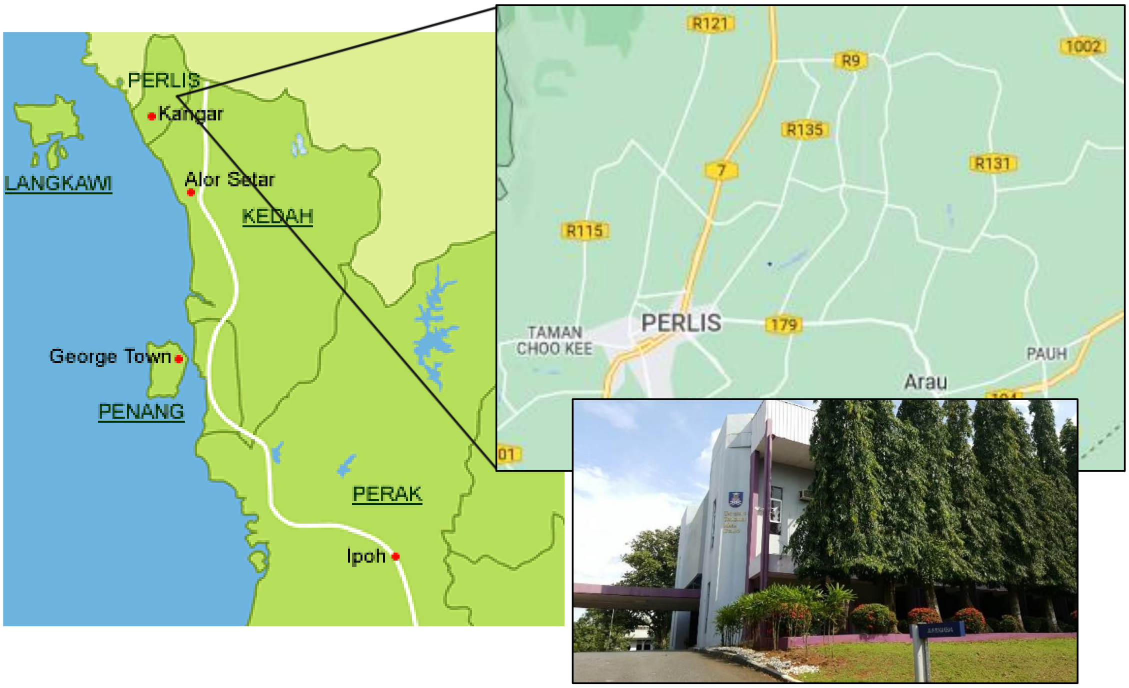

Figure 3: Location of Dewan Seri Semarak

Topcon ES-105 Specifications	
Angle Accuracy	1 second
Maximum Measurement	4000m (with prism)
Distance Accuracy	2mm + 2ppm
Advance feature	Reflectorless/ No Prism

Figure 4: Total station ES105 (Topcon) with technical specifications

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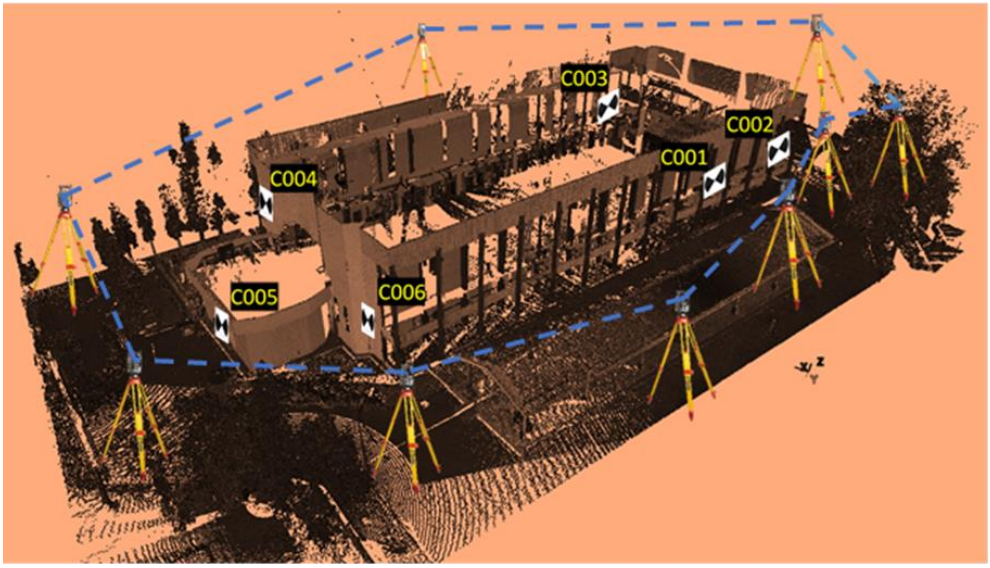

Figure 5: Traverse network & distribution of references points

Leica ScanStation C10 Specifications	
Architecture	Hybrid
Field of view	360°/270° (horizontal/vertical)
Range measurement	Pulse-based
Maximum range	300.00m
Range accuracy	4mm

Figure 6: Leica ScanStation C10 with technical specifications

To avoid the effect of uncertainties dissemination in coordinates transformation, rather than transforming all reference positions to the TLS coordinates system, those points will be projected into five (5) independent vectors.

Depicted in figure 7, eight (8) scan stations were employed to acquire the complete 3D surface of the Dewan Seri Semarak façade. There are thirteen (13) artificial targets distributed at the field site, which consist of six (6) plane targets and seven (7) sphere targets. In this study, a hybrid scanner (i.e., Leica Scan Station C10 as depicted in figure 6) with an accuracy of 4mm and 6mm for distance and positioning, respectively has been utilized. With a medium resolution setting, complete 3D point clouds that cover the whole surface have been acquired using two configurations. As shown in figure 7, the first configuration has a strong registration connection without geometrical conditions. The setup did not close the network by breaking the configuration at the first and last stations. Considering the fundamental principal as stated by Ghilani (2008) the second configuration has employed three (3) well-distributed targets to ensure the close connection of all scan stations.

To perform the registration procedure, Leica Cyclone software has been used. Registration report provided by the software will demonstrate the quality of the registration solution by presenting the common target displacement from adjacent scanner position. Since the pairwise solution was adapted in rigid body transformation, it is expected that results from both configurations are almost identical. To mathematically evaluate the significance of geometrical condition in TLS network configuration, as mentioned earlier, five (5) reference vectors (derived from reference points) were exerted. Two sets of vectors were extracted from both TLS configurations and the discrepancies obtained concerning reference vectors have been computed. Root mean square of error (RMSE) has been obtained to represent the accuracies of both configurations which eventually indicates the effect of disregarding the fundamental geodetic principle in TLS measurement.

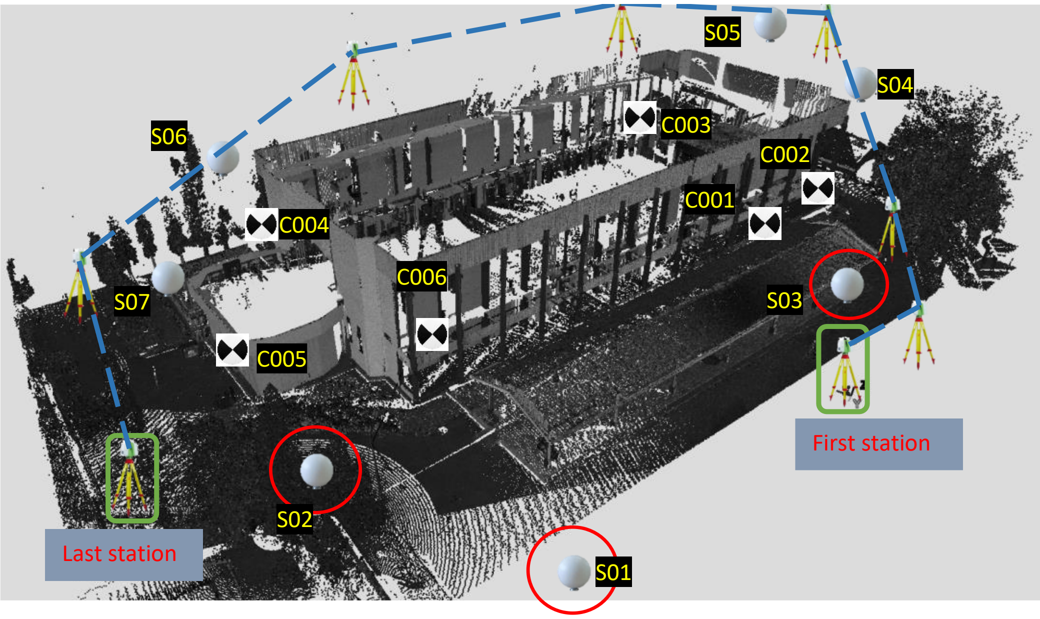

Figure 7: Distribution of Laser Scanner Station and Target Points

Table 1: Adjusted coordinates and standard deviations of reference points

Reference Points	Northing (m)	Easting (m)	Elevation (m)	$\sigma_{Northing}$ (m)	$\sigma_{Easting}$ (m)	$\sigma_{Elevation}$ (m)
C001	-39720.621	53626.938	35.551	0.002	0.003	0.004
C002	-39718.351	53615.750	36.415	0.002	0.002	0.004
C003	-39739.554	53628.848	33.851	0.003	0.004	0.004
C004	-39740.590	53580.848	34.737	0.004	0.003	0.006
C005	-39728.652	53568.090	34.019	0.003	0.004	0.006
C006	-39718.631	53576.628	36.123	0.002	0.003	0.004

3. Results

To measure the reliability of geometrical conditions in preserving the quality of TLS data, six (6) reference points have been established at the test field using the 3D traversing method. With the aid of a comprehensive adjustment procedure (i.e., least-square adjustment), the most probable coordinates were computed with a preset standard deviation of six (6) second, 0.005m, and 0.0057m for angular, distance, and elevation, respectively. The adjustment manages to converge after the second iteration and passed the chi-square test at a 95 percent confidence level. table 1 exhibit the 3D adjusted parameters with standard deviations obtained from the LSA computation. The results demonstrated that the maximum precisions for Northing and Easting elements are 4mm, while Elevation is 6mm. Taking into account the effect of environmental factors during the measurement, the positioning accuracy of Leica Scan Station C10 should consider the probability of random errors. If 95 percent of the TLS data were expected to be augmented with errors, thus, the position accuracy might reduce up to 12mm. With this consideration, the yielded coordinates of reference points can be exploited as a benchmark for this study.

To avoid the dissemination of errors from employing the coordinates transformation procedure, this study has derived five (5) independent vectors from six (6) reference points. Similar vectors are also extracted from both TLS configurations (i.e., open and closed networks). table 2 depicts the values of the vectors obtained from reference points, TLS open network (without geometrical condition), and TLS closed network (with the geometrical condition). Illustrated in figure 8, the plotted accuracies have demonstrated the significance of geometrical conditions in preserving the quality of TLS measurement. This conclusion has been strengthened by the computed RMSE that exemplifies the ability of the closed network to increase the accuracy of TLS measurement from 0.009m (open network) to 0.006m (closed network).

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Table 2: Five (5) vectors extracted from reference points and TLS data

Vectors	References (m)	TLS Open Network (m)	TLS Closed Network (m)
C02-C01	11.448	11.453	11.453
C02-C03	25.053	25.059	25.059
C02-C04	41.419	41.413	41.418
C02-C05	48.820	48.806	48.811
C02-C06	39.125	39.115	39.119

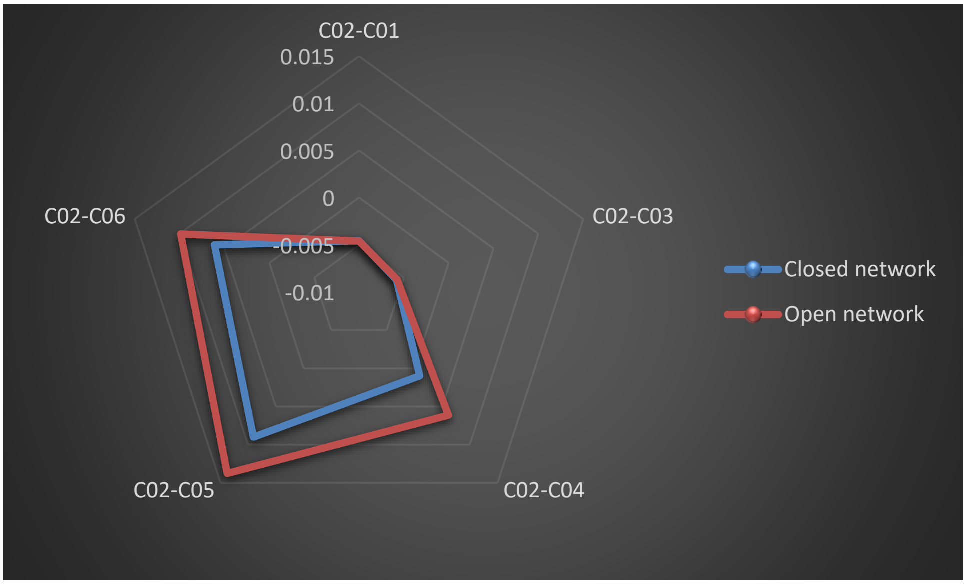

Figure 8: Accuracies plot of TLS network configuration with (closed network) and without (open network) geometrical condition

With a 50 percent accuracy decrement, disregarding the fundamental requirement in designing a geodetic network has been mathematically verified to jeopardize the quality of TLS data. Even though the RMSE discrepancy is only 0.003m but considering the object's dimension of 51.0m (length) x 23.5m (width), this accuracy decrement might be significantly bigger when the scanning involves the larger area

4. Conclusion

The advantages demonstrated by TLS measurement has caused this sensor widely employed in acquiring precise 3D point clouds that depict the real-world representation. However, most of the TLS users are relying on registration errors to evaluate the acceptance of pre-processed data without considering the element of the geometrical condition. Similar as observables obtained from another geodetic measurement (i.e., range, horizontal direction, and vertical angle), the comparable occurrence of uncertainties are expected to happen in TLS network configuration. So, the goal of this research is to examine the impact of error propagation on TLS pre-processing, closed and open networks were both used in this investigation. With the aid of 3D traversing in establishing reference points in the test field, the evaluation has verified the crucial geometrical conditions in TLS network design. Disregard this essential condition, especially when the data acquisition involved with the large area is expected to significantly deplete the quality of spatial data. Therefore, the conclusion can be made that geometrical conditions for terrestrial laser scanners are unavoidable, for ensuring the quality of the final product.

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