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Scale Factor Effect in Terrestrial Laser Scanner Datum Transformation

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Abstract. Datum transformation is an inevitable procedure in terrestrial laser scanners (TLSs) pre-processing. By taking into account the uncertainties in multi distances measurement, neglecting the scale factor in registration and georeferencing phases should be reconsidered especially when involved with applications that demand high accuracy data. With the motivation to robustly examine the effect of scale factor in the issue raised, this study has designed experiment which consider the element of multi distances. Two types of TLSs utilised in this study, which are Faro Focus 3D and Leica ScanStation C10 to represent phase and pulse based scanners, respectively. Exploiting robust statistical analysis, all seven (7) parameters were computed from both experiments and scale factors were extracted for the further assessment. Significant analysis was performed by comparing the ideal value of scale factor (i.e. 1.000 or no scale effect) and values obtained from the experiments. The results show that, the null hypotheses for the experiment is accepted with a 95% confidence level. This result also indicates that scale factor can be neglected in datum transformation process for both type of terrestrial laser scanners.

1. Introduction

Investigation of uncertainties in TLSs measurement have been massively studied and most researchers still continue searching any possibilities to simplify and improve current approaches and results [1]-[4]. In contrast, very few research performed were related to uncertainties in TLSs processing. Due to the dependency on the algorithm employed to yield final products, the errors produced in post-processing phase are significantly variant and difficult to standardise the investigation. Differing in implementation, pre-processing use standard algorithm in performing registration and georeferencing. Both procedures employ seven-parameter similarity transformation involving seven parameters, which are three rotations, three translations and one scale factor. However, in TLSs datum transformation procedure, Gordon and Lichti [5] did claim that the scale factor can be neglected because it has shown to be irrelevant in the transformation. Thus, the six parameters that are also known as the rigid-body-transformation parameters (without scale factor) or six degrees of freedom are as follows: i) Translation for the 3 coordinate axes (Δ_x , Δ_y , Δ_z); and ii) Rotation around the 3 coordinate axes (ω , ϕ , κ).

The ability to acquire direct and automated millions of 3D points with considerably rapid and accurate measurement, TLSs have been widely employed in many purposes. Most of the yielded information processed from TLSs data were used for documentation, investigation, preservation and



decision making. Thus, data quality assurance is a mandatory factor. Regarding the scale issue in TLSs pre-processing phase, Rueger [6] did mention that sources of errors that can affect the scale factor are very numerous. Other than instrument causes, there are also external influences that can affect the results of transformation parameters, such as derivation of transformation parameters using poor network can cause a weak solution [7], false determination of target centroid due to the less resolution [8] and algorithm employed for form fitting has wrongly identify the object [9]. Furthermore, dependency of other measurement approaches (e.g. tacheometry and global navigation satellite system) in establishing control points for georeferencing procedure also need to be taken into account. Orienting measurement from various sensors (which utilise different mechanism in range acquisition) into one global coordinate system will definitely cause errors in scale factor. Those arguments have indicated that neglecting scale factor especially in applications that demand high accuracy data is questionable. Further investigation is necessary to robustly prove that contribution of scale factor in TLSs pre-processing phase is insignificant. For such purpose, this study focused on quantitative investigation of scale factor for phase-based (i.e. Faro Focus 3D) and time of flight (i.e. Leica ScanStation C10) scanners. To ensure the evaluation was robustly performed, experiment was performed using multi distances configuration. Statistical analysis was employed to mathematically verify the results obtained from the experiments.

2. Terrestrial laser scanner pre-processing

To ensure TLSs data are significant for further processing, all data need to be oriented from several local coordinates system into one global coordinate system. For mapping and database purpose, registered data are required to be georeferenced or transformed into ground or national coordinate system. Due to the similarity of algorithm employed to derive transformation parameters for both pre-processing procedures [2], thus, discussion on the mathematics were combined using registration example.

Assuming that only two scan stations involves in the registration procedure, coordinates of two scan systems are as following: i) Reference station (X_i, Y_i, Z_i); and ii) Subsidiary station (x_i, y_i, z_i). All seven parameters were computed using resection method, hence, minimum three well-distributed non-collinear common targets need to be measured from both scanner positions (e.g. reference and subsidiary stations). Based on the seven-parameter similarity transformation, relation of the reference target scanned from the subsidiary scanner station can be derived using the equations as follows [10]:

$$X_i = T + S.R.x_i \quad (1)$$

where:

- X_i = Coordinates of the i^{th} target in the reference (or global) scanner coordinate system (X_i, Y_i and Z_i).
- S = Scale factor.
- R = Components of rotation matrix between the two coordinate systems (ω, ϕ, κ).
- x_i = Coordinates of the i^{th} target in the subsidiary coordinate system (x_i, y_i and z_i).
- T = Translations of the subsidiary scanner station in the global coordinate system.

However, as stated by Gordon and Lichti [5], the scale factor can be neglected in TLSs datum transformation, thus, only six (6) parameters were used to relate between two coordinate systems. Thus, the relation between the two coordinate system using seven (6) parameters are as follows:

$$X_i = T + R.x_i \quad (2)$$

In order to investigate the significance of scale factor in TLSs datum transformation for registration and georeference procedures, this study has employed equation 1.

3. Experiments

To ensure the robustness of TLSs measurement with respect to multi ranges observation, this study has established indoor calibration site at Faculty of Built Environment and Surveying, Universiti Teknologi

Malaysia, Malaysia. Six (6) points were marked as visualised in figure 1 with interval 10m, range from wall where targets distribute (right side of figure 3) into last point is 60m. For registration purpose, four (4) plane and two (2) sphere targets were utilised. Both phase-based (i.e. Faro Focus 3D) and pulse-based scanners were positioned in every mark to scan all six (6) targets.

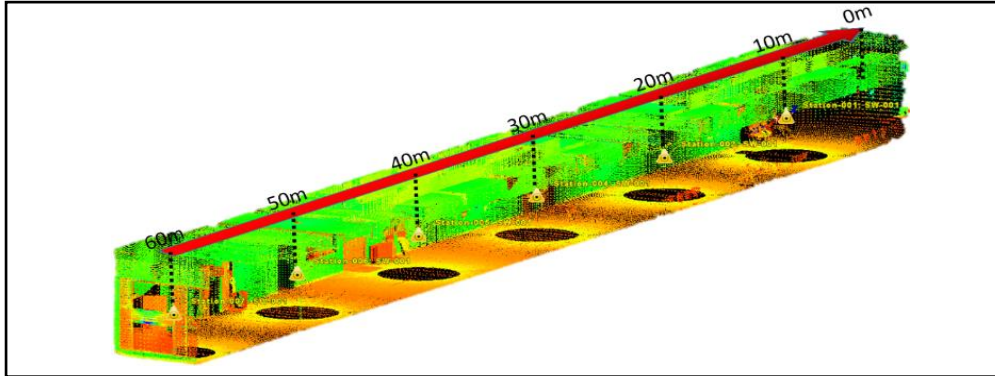


Figure 1. Calibration site for multi-distances experiment.

Taking into consideration that the closest scan station (with range 10m from targets) will contribute less errors in determining target centroids, pairwise registration for other stations was performed by exploiting this closest station as reference. This has result five (5) registration pairs yielded for multi-distances investigation. To concretely support the results obtained, this study has consumed statistical analysis to verify the significant of scale factor in TLSs registration processing.

4. Results and Analyses

The experiment was conducted by exploiting the multi ranges of scan stations from distributed targets. Both scanners were move gradually every 10m until 60m. Considering 10m position able to well-determine the targets centroid among others, thus, this occupied station was selected as reference for datum transformation computation. The scale errors obtained for 20m until 60m ranges were illustrated in figure 2. The largest scale error (i.e. 0.001) was contributed 40m range by pulse based, while the largest for phase based scanner is 0.0004. The largest uncertainty occurred in pulse based scanner may be due to the 40m position has high exposure of light compare to others [12]. This argument is supported by similar trend demonstrated by phase based scanner. Nevertheless, the conducted statistical test to determine whether the calculated scale factors are similar to the ideal value (i.e. one) at a 0.005 level of significance has yielded fascinating results. As presented in table 1 and table 2, in all conditions computed values of t are smaller than the tabulated or critical t , thus, the null hypothesis can be accepted at 95% level of confidence. In other words, multi distances experiment has mathematically proved that scale factor is insignificant in TLSs datum transformation.

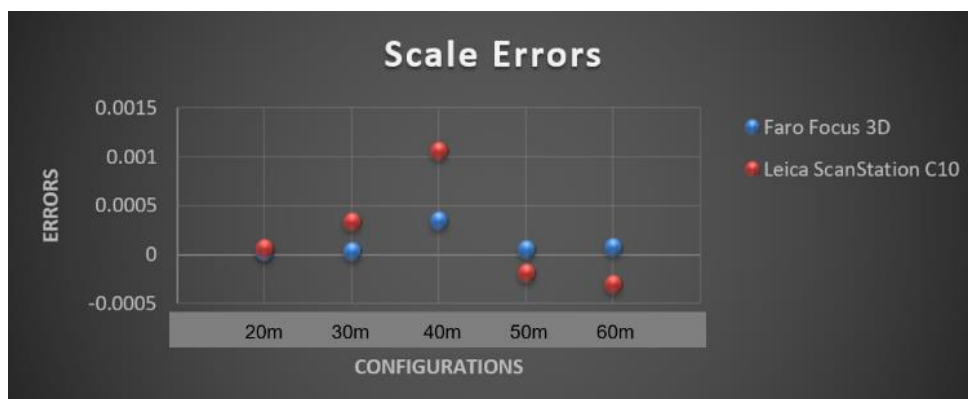


Figure 2. Multi sensors experiment using phase based (a) and pulse based (b) scanners.

Table 1. Multi distances statistical test for Leica ScanStation C10 (pulse based scanner).

Configuration	Scale	DoF	Calculated T	</ >	Critical T
20m	1.000065	11	0.228666	<	2.201
30m	1.000338	11	0.513983	<	2.201
40m	1.001061	11	0.385331	<	2.201
50m	0.999815	11	0.181687	<	2.201
60m	0.999697	11	0.272587	<	2.201

Table 2. Multi distances statistical test for Faro Focus 3D (phase based scanner).

Name	RSO Geocentric			Orthometric Height	
	North (m)	Easting (m)	Horizontal RMS (m)	Height (m)	Vertical RMS (m)
GNSS01	172129.333	628106.384	0.002	17.645	0.004
GNSS02	172148.751	628444.568	0.001	24.488	0.002

5. Conclusions

With the aim to quantitatively examine the significant of scale factor in TLSs (i.e. phase and pulse based scanners) datum transformation, this study has performed robust experiment. The experiment which employed multi distances configuration has shown the effect of light in TLS measurement that can affect the quality of data. However, statistical analyses have indicated that null hypotheses of the experiment showed that the scale factor yielded from both scanners can be neglected. In other words, the scale factor is not significant in TLSs datum transformation. This conclusion is applicable for the phase and pulse based scanners with medium range measurement. Further significant study on scale factor is necessary when measurement involved with long range measurement.

Acknowledgements

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