Indirect Georeferencing in Terrestrial Laser Scanning: One-Step and Two-Step Approaches

Dung Trung Pham, Long Quoc Nguyen, Tinh Duc Le, and Hai Thanh Tran

Abstract The georeferencing procedure is to transform geospatial data from a local coordinate system to a global coordinate system, notably geodetic coordinate system on a geocentric datum. In this paper, both the one-step and two-step approaches of indirect georeferencing of 3D point cloud from terrestrial laser scanning are investigated. The georeferencing procedure is applied to a real dataset acquired by a Faro Focus^{3M} X130 laser scanner and the control points and targets are measured by total station TS06 plus. Five scenarios are used for the comparison between the one-step and two-step approaches in terms of both accuracies of the 3D model and time consumption. Besides, the influence of the target's configuration on the 3D model is evaluated by changing either the number or the position of the targets. The results suggest that the 3D model's accuracies when using both the one-step and two-step approaches of indirect georeferencing are comparable. Additionally, the target's configuration greatly affects the 3D model with the one-step approach of indirect georeferencing. From the rigorous analyses of the benefit and drawbacks of both approaches evaluated on the real dataset, the paper significantly contributes to the indirect georeferencing procedure when transforming the 3D point cloud acquired from terrestrial laser scanning into the geodetic coordinate system.

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1 Introduction

Terrestrial laser scanner (TLS) is an instrument for fast collection of 3D point cloud (PC) data with high accuracy. The 3D PC of a scan object in many cases is needed to be determined in a reference coordinate system. The procedure to transform a 3D PC into a reference coordinate system (RCS) is known as a georeferencing procedure. Generally, georeferencing can be divided into two basic methods that are direct and indirect georeferencing. Conventionally, the ground RCS can be established by total station or global navigation satellite system (GNSS) before scanning the field work.

The direct georeferencing method is based on additional sensors and equipment to provide the coordinates and orientation at the moment of data acquisition. The additional sensors and equipment normally are low-cost sensors, e.g., an inertial measurement unit (IMU), continuously referencing station, or a telescope for azimuth direction orientation. The direct georeferencing of the TLS has been investigated in many studies [1–5] and can be simply done by using an optical plummet to centering over a control point (CP) and a telescope that is mounted into the TLS to directly determining the orientation [1]. A continuously operating referencing station is also used for the georeferencing procedure in which GNSS receivers are mounted at the center of both the scanner and targets [2]. Furthermore, Schuhmacher and Böhm [3] used a digital compass with low-cost GNSS and tilt sensor for georeferencing. Together with the development of direct georeferencing approaches by using additional sensors, deep analyses about the error sources are investigated by Lichti et al., Reshetyuk, Pandžić et al. [6–8]. Although the direct georeferencing method is available for reducing time of data post-processing in the office, the further equipment leads to an increase in the budget [7]. The difficult and time-consuming calibration procedure in direct georeferencing is the main disadvantage [9]. Moreover, the low accuracy achieved by the direct georeferencing method is also a great consideration when applying this method.

By contrast, the indirect georeferencing method is suitable for obtaining a higher accurate 3D PC data [7]. Several researchers contributed to this method that can be found in [3, 10–14]. The indirect georeferencing method can be classified into two approaches: one-step approach and two-step approach [15]. The two-step approach is based on the registration procedure that PCs from multiple scans are transformed into a common coordinate and then the registered PCs are transformed into the external coordinate system based on ground control points (GCPs). The main advantage of the two-step approach is that it uses a moderate number of CPs. But at least 30% overlap between two adjacent scans is still required that lead to more time for scanning, especially for a large scan object. The one-step approach involves independent georeferencing of individual scans using at least three CPs. No overlap between difference scans is needed for this method that reduces the time for scanning.

However, the georeferencing independently carried out for each scan leads to more extract survey work [7].

Currently, the indirect georeferencing is known as an efficient method in TLS. However, the main problem of this method is inconsistency in the PC accuracy and just few studies have addressed the effect of target's configuration on the accuracy of 3D model. This study addresses two important questions on (1) which approaches in the indirect georeferencing method among the one-step and two-step approaches are better for the accuracy of the 3D model and (2) how the targets' configuration affects the accuracy of the 3D model and what the crucial factors are.

The paper is organized as follows: The first section gives a brief overview of georeferencing method in TLS. The second section presents a mathematical principle of indirect georeferencing for both the one-step and two-step approaches. The experiment is introduced in the third section. The fourth section is on the analysis and discussion of experimental results. Some conclusions and future works can be found in the last section.

2 Indirect Georeferencing

Georeferencing is a transformation of PCs from the scanner coordinate system to the external coordinate system (normally a national or local coordinate system) based on known points. To transform between two 3D coordinate systems, seven parameters need to be determined. If two PCs are obtained by the same scanner, the scale transformation parameter equals one. Therefore, in TLS two scanner coordinate systems can be transformed by six parameters. As a result, in indirect georeferencing, six transformation parameters, including three angles (φ, ω, κ) and three coordinates (X, Y, Z), need to be determined. To obtain six parameters, at least six coordinates in both systems (i.e., the scanner and external coordinate systems in Fig. 1) or three points must be known. These points are normally GCPs of which the coordinates are determined by a total station or a GNSS receiver. It is noted that these GCPs should be well distributed vertically and horizontally (not on the same line or plane) [3].

Indirect georeferencing can be realized by two basic ways that are one-step and two-step approaches. The one-step approach means transforming the scan data directly from the scanner coordinate system to the external coordinate system of geodetic network. In contrast, in the two-step approach, the coordinates of points are transformed through two independent steps. The following section will discuss these two approaches in detail.

2.1 Two-Step Approach

The two-step approach (Fig. 2) is performed in the following sequence. In the 1st step, the PCs obtained from multiple scanners are registered in a common (or global)

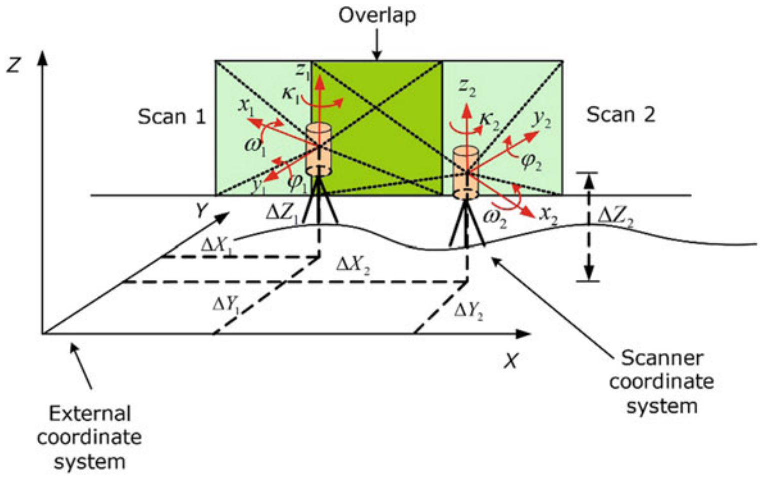

Fig. 1 Relationship between the scanner and external coordinate systems [7] shown by six transformation parameters

coordinate system. In this registration procedure, several methods such as target-based, natural point features, surface matching, and common geometrical objects can be applied separately or based on their combination. In the 2nd step, the PCs in the common coordinate system are georeferenced in a geodetic control network. At least three CPs must be used in this case.

The mathematical model of the two-step approach can be described as follows: In the first step, the coordinates of the PC in the scanner $\mathbf{X}_i$ are transformed into the common coordinate system $\mathbf{X}_g$ by:

$$\boldsymbol{X}_g = \Delta \boldsymbol{X}_{ig} + \boldsymbol{R}_{ig} \boldsymbol{X}_i \tag{1}$$

where $\boldsymbol{R}_{ig}$ and $\Delta\boldsymbol{X}_{ig}$ are the rotation matrix and the translation vector from the scanner to the common system, respectively. In the second step, the coordinates of the PC from the common system are transformed into the geodetic control network as:

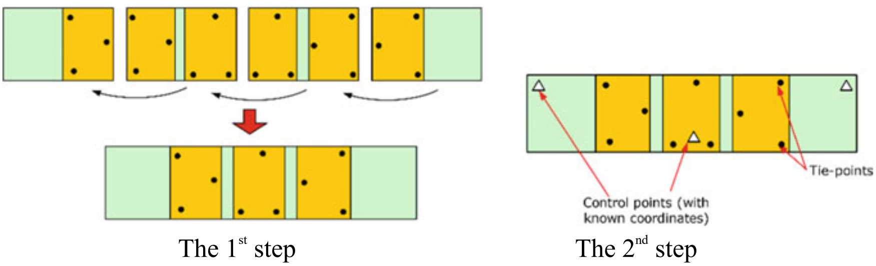

Fig. 2 Two-step approach of indirect georeferencing [7]

$$\boldsymbol{X_e} = \Delta\boldsymbol{X_{ge}} + \boldsymbol{R_{ge}}\boldsymbol{X_g} \tag{2}$$

where $\boldsymbol{R}_{ge}$ and $\Delta\boldsymbol{X}_{ge}$ are the rotation matrix and the translation vector from the common system to the geodetic system, respectively.

Replacement of Eq. (1) in (2) yields:

$$\boldsymbol{X_e} = \Delta\boldsymbol{X_{ge}} + \boldsymbol{R_{ge}}\left(\Delta\boldsymbol{X_{ig}} + \boldsymbol{R_{ig}}\boldsymbol{X_i}\right) \tag{3}$$

The rotation matrix is the function of the rotation angles ω, ϕ, and κ about the x, y, and z coordinates, respectively. The rotation matrix is calculated by:

$$\boldsymbol{R} = \boldsymbol{R}_3(\boldsymbol{\kappa})\boldsymbol{R}_2(\boldsymbol{\phi})\boldsymbol{R}_1(\boldsymbol{\omega}) \tag{4}$$

where

$$\boldsymbol{R}_1(\omega) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{pmatrix} \tag{5}$$

$$\boldsymbol{R}_2(\phi) = \begin{pmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{pmatrix} \tag{6}$$

and

$$\boldsymbol{R}_3(\kappa) = \begin{pmatrix} \cos\kappa & \sin\kappa & 0 \\ -\sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{7}$$

with $\boldsymbol{R}_1(\omega)$, $\boldsymbol{R}_2(\phi)$, and $\boldsymbol{R}_3(\kappa)$ being the rotation matrices around the x, y, and z coordinates, respectively.

2.2 One-Step Approach

The one-step approach (Fig. 3) is to directly transform the coordinates of the PC of individual scanner into the geodetic coordinate system by using GCPs. Since each PC is registered into the geodetic coordinate system separately, the number of GCPs increases and is inconsistent by control network configurations. The mathematical model of the one-step approach can be described as:

$$\boldsymbol{X_e} = \Delta\boldsymbol{X_{ie}} + \boldsymbol{R_{ie}}\boldsymbol{X_i} \tag{8}$$

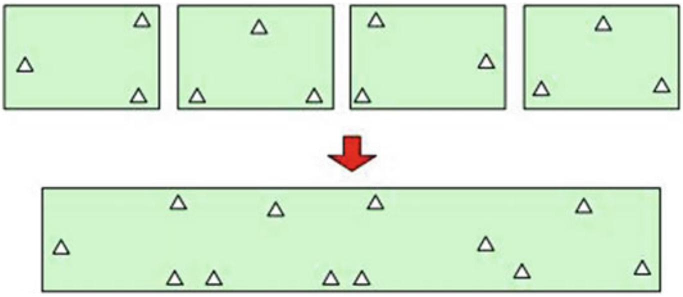

Fig. 3 One-step approach of indirect georeferencing [7]

where $\boldsymbol{R}_{ie}$ and $\Delta\boldsymbol{X}_{ie}$ are the rotation matrix and the translation vector from the scanner to the geodetic systems, respectively.

2.3 Error Model of the Indirect Georeferencing

The main purpose of this paper is to investigate the influence of the indirect georeferencing method on the accuracy of 3D PC. As mentioned above, indirect georeferencing can be dealt with either the one-step approach or two-step approach. According to the one-step approach, the coordinate of PCs is directly transformed into the geodetic coordinate system by Eq. (8). The error in the indirect georeferencing in this case is affected by the scanner random errors and the errors of transformation parameters. The covariance matrix of PC coordinates in geodetic coordinate system can be computed as [8]:

$$\boldsymbol{C}_{X_e} = \boldsymbol{J}_{\text{trans}}\boldsymbol{C}_{\text{trans}}\boldsymbol{J}_{\text{trans}}^{\boldsymbol{T}} + \boldsymbol{R}_{ie}\boldsymbol{J}\boldsymbol{C}_{\text{int}}\boldsymbol{J}^{\boldsymbol{T}}\boldsymbol{R}_{ie}^{\boldsymbol{T}} \tag{9}$$

where $\mathbf{J}_{\text{trans}}$ is the Jacobian matrix of point coordinates in the geodetic coordinate system with respect to the transformation parameters and $\boldsymbol{J}$ is the Jacobian matrix of point coordinates in the scanner coordinate system with respect to the scan measurements (horizontal and vertical angles and distance) and is computed as [10]:

$$\boldsymbol{J} = \begin{bmatrix} \frac{\partial x_j}{\partial r_j} & \frac{\partial x_j}{\partial \varphi_j} & \frac{\partial x_j}{\partial \theta_j} \\ \frac{\partial y_j}{\partial r_j} & \frac{\partial y_j}{\partial \varphi_j} & \frac{\partial y_j}{\partial \theta_j} \\ \frac{\partial z_j}{\partial r_j} & \frac{\partial z_j}{\partial \varphi_j} & \frac{\partial z_j}{\partial \theta_j} \end{bmatrix} \tag{10}$$

$\boldsymbol{C}_{\text{trans}}$ is the covariance matrices of the transformation parameters between the scanner and geodetic coordinate systems. $\boldsymbol{C}_{\text{int}}$ is the covariance matrix that is a combination of noise measurement and laser beam width as [10]:

$$C_{\mathrm{int}} = \mathbf{diag}\left(\sigma_r^2 \ \sigma_\varphi^2 + \sigma_{\mathrm{beam}}^2 \ \sigma_\theta^2 + \sigma_{\mathrm{beam}}^2 \right) \tag{11}$$

with σ_r^2, σ_φ^2, σ_θ^2, and σ_{beam}^2 are the standard deviations of the distance and horizontal and vertical angles, and the beam width, respectively.

3 Experiments

The experiment in this study is carried out by a real dataset collected by a TLS. The following subsection will present in detail the experiment.

Scan object. The scan object is a façade of five-story and two-story buildings located on the main campus of Hanoi University of Mining and Geology (HUMG) on 10th November 2021.

Instruments. The data are collected with a Faro Focus^{3M} X130 scanner in two different scan stations for the whole study area in 40 min. The resolution and quality parameter settings for scanner are 6 mm point spacing at a 10 m distance (or 28,000 points per one square meter), which corresponds to a 4X level of resolution of this scanner. A total station Leica TS06 plus is used to establish a control network and measured the coordinates of the targets.

Geodetic control network. To carry out indirect georeferencing of the PC, a geodetic control network is established by a traverse network including six GCPs (see Fig. 4) in the VN-2000 coordinate system.

Targets. The targets are both checkerboard and clearly natural objects, which are measured by a Leica total station TS06 plus. In these experiments, 11 checkerboards

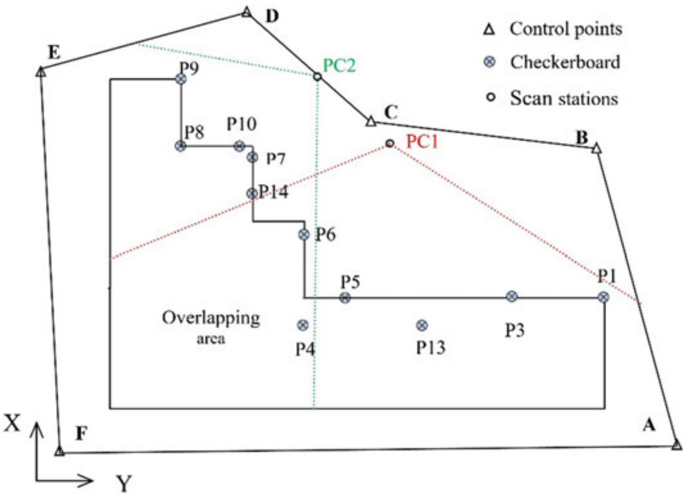

Fig. 4 Geodetic control network and checkerboard

(see Fig. 4) and 10 natural objects (see Table 2) are used. The coordinates of these points are determined in the geodetic coordinate system based on the control network shown in Fig. 4.

Scenarios. In this experiment, five scenarios are carried out for both the one-step and two-step approaches of the indirect georeferencing method. The following subsections will describe these scenarios in detail.

In Scenario 1, the two-step approach is used in which the first step is a registration procedure and the second step is a georeferencing procedure. Figure 5 shows two PCs before processing by both registration and georeferencing procedures. The align function in the Cloud Compare (CC) software is applied for both registration and georeferencing procedures. In Fig. 6 (left), the registration is carried out based on five tie points, which are distributed over the overlapping area between PC1 and PC2. These tie points are normally chosen at clear natural objects like the corners and windows. The georeferencing procedure is to transform the registered PC into the geodetic coordinate system based on five GCPs (see Fig. 6, right). Five GCPs are used since these points are well distributed around the PC and adequate for evaluating the accuracy of georeferencing procedure. The accuracy of this procedure is estimated by root mean square (RMS) by the iterative closest point (ICP) algorithm [5] in the CC software. The RMSs of the five points in the registration and georeferencing procedures are 2.5 and 1.5 cm, respectively.

In Scenario 2 to Scenario 5, the one-step approach is used that allows us to transform directly the PC into the geodetic system based on CPs. It is noted that no

Fig. 5 Unregistered PCs (PC 1-lelf and PC2-right) and compared area (Scenario 1)

Fig. 6 Registered PC based on five tie points (left) and georeferenced PC based on five CPs (right) (Scenario 1)

registration procedure is needed in these scenarios. These scenarios are to evaluate the effect of target's configuration on the 3D model, so the number and position of the targets (or CPs) are varied as follows. In Scenario 2, four CPs are distributed at the bottom of PC1 and PC2 (see Fig. 7). Scenario 3 uses five and four CPs, which are located in one side of PC1 and PC2 as illustrated in Fig. 8. In Scenario 4, four CPs spread throughout PC1 and PC2 (see Fig. 9). Finally, Scenario 5 is extended from Scenario 4 by adding two more CPs for each PC, in which six CPs and seven CPs are also spread throughout PC1 and PC2, respectively, as shown in Fig. 10.

Table 1 summarizes the number of CPs and the error of alignment of these above scenarios in which the error of alignment is computed by the RMS between targets in these scenarios and the RMSs are from 1.5 to 2.2 cm.

Fig. 7 Scenario 2—CPs are distributed at the bottom PC1 (left) and PC2 (right)

Fig. 8 Scenario 3—CPs are distributed on one side of PC1 (left) and PC2 (right)

Fig. 9 Scenario 4—CPs are evenly distributed on both PC1 (left) and PC2 (right)

Fig. 10 Scenario 5—CPs are evenly distributed on both PC1 (left) and PC2 (right)

Table 1 Number of targets and error of alignment (RMS) in the one-step approach

Scenarios	Numbers of targets		Errors of alignment (RMS)	
	CP1	CP2	CP1 (cm)	CP2 (cm)
Scenario 2	4	4	1.8	2.2
Scenario 3	4	5	2.2	2.2
Scenario 4	4	4	1.8	1.5
Scenario 5	6	7	1.9	1.9

Table 2 Difference in 3D coordinates of natural points using the one-step approach

No.	Name	Δ_x	Δ_y	Δ_z	No.	Name	Δ_x	Δ_y	Δ_z
1	T51	– 4.0	– 1.5	2.7	11	LCR1	1.2	1.0	0.3
2	T52	– 4.6	0.5	5.4	12	LCR2	0.3	0.5	– 0.1
3	T53	– 0.3	2.9	0.8	13	PTN	– 2.0	– 0.6	– 1.2
4	T54	– 0.5	2.9	3.9	14	XD	0.5	– 1.5	– 0.1
5	T24	– 2.2	2.2	– 3.4	15	T41	– 1.1	1.5	– 5.7
6	QLDA	– 3.1	0.3	– 1.7	16	T42	0.2	4.3	– 5.7
7	A108	– 3.0	– 0.9	1.3	17	T31	– 1.2	– 0.1	2.4
8	VPD	1.3	0.9	– 0.6	18	T32	– 1.4	0.5	1.0
9	QHCC1	0.5	0.0	– 0.8	19	A105	– 2.9	0.8	– 0.2
10	QHCC2	0.3	– 1.4	0.9	20	A106	– 3.0	– 0.3	– 0.2

Evaluation of the 3D model. Both the one-step and two-step approaches are used to transform the 3D model generated from PCs into the geodetic coordinate system. To evaluate the georeferenced 3D model using the two above approaches, two investigations are carried out in the case study. First, the accuracy between the one-step and two-step approaches is compared using 20 natural points in the 3D model (see Fig. 11). The two-step and one-step approaches are described in Scenario 1 and Scenario 2, respectively. In these scenarios, each of the four CPs (checkerboard) measured by the Leica total station TS 06 plus is used for georeferencing. These above natural points are also measured by this total station in the geodetic coordinate system

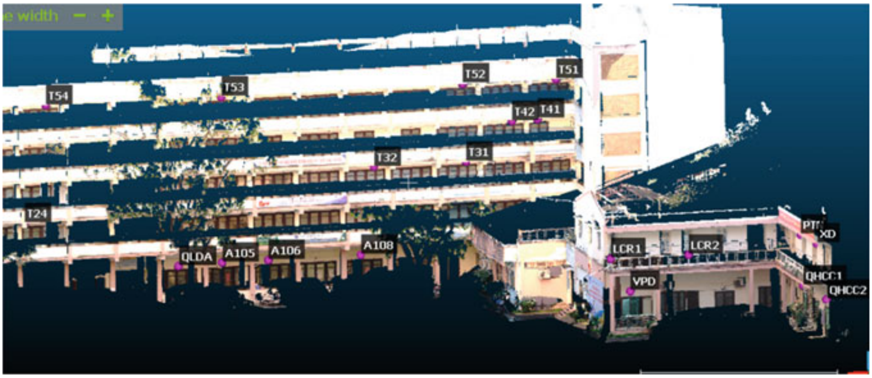

Fig. 11 Twenty natural points used for comparison between the one-step and two-step approaches

and then are compared to their coordinates in the 3D model. The difference in 3D coordinate can be computed as:

$$\begin{aligned} \Delta_x &= x_{TS} - x_{\text{Model}} \\ \Delta_y &= y_{TS} - y_{\text{Model}} \\ \Delta_z &= z_{TS} - z_{\text{Model}} \end{aligned} \tag{12}$$

where x_{TS}, y_{TS}, and z_{TS} are the coordinates measured by the total station; x_{Model}, y_{Model}, and z_{Model} are the coordinates measured in the 3D model. The accuracy of the 3D model is assessed by RMSs as:

$$\begin{aligned} RMS_x &= \pm\sqrt{\Delta_x \Delta_x / n} \\ RMS_y &= \pm\sqrt{\Delta_y \Delta_y / n} \\ RMS_z &= \pm\sqrt{\Delta_z \Delta_z / n} \end{aligned} \tag{13}$$

where Δ_x, Δ_y, and Δ_z are the differences in the x, y, and z coordinates in Eq. (12), and n is the number of compared points.

Second, the influence of target's configuration on the 3D model's accuracy is investigated from Scenario 2 to Scenario 5. In these scenarios, the target's configuration is changed by either the number of targets or the location of targets. The compared area in the overlapping area between PC1 and PC2 is shown in Fig. 5. Theoretically, no overlapping PC is needed for georeferencing when using the one-step approach. However, to evaluate the influence of target's configuration on the georeferencing error, an overlapping area between PC1 and PC2 is used. Two PCs (PC1 and PC2) are not perfectly coincided in the overlapping area because of errors in scan observations, registration and georeferencing procedures, and the control network, etc. The distance between the two point clouds is used as a parameter for

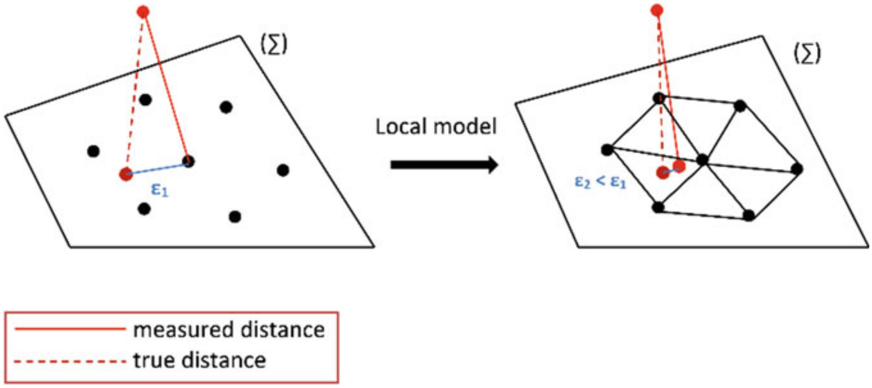

Fig. 12 Concept of local surface model of the C2C method. The local surface allows us to better approximate measured distance ($\varepsilon_2 < \varepsilon_1$) [16]

this evaluation. The distance is computed by the Cloud-to-Cloud (C2C) method in the CC software, as shown in Fig. 12.

The C2C approach applies the Hausdorff distance, which is defined by a max–min distance. The Hausdorff distance between any two finite point sets $A = \{a_1 \ldots a_p\}$ and $B = \{b_1 \ldots b_p\}$ is defined as [17]:

$H(A, B) = \max(h(A, B), h(B, A))$, (14).

where

$$h(A, B) = \max_{a \in A} \min_{b \in B} a - b, \tag{15}$$

and $\|\cdot\|$ is a norm on the points of A and B (e.g., the Euclidean norm).

Function $h(A, B)$ is called the directed Hausdorff distance from A to B. This approach is also used in cloud matching techniques such as ICP [18].

4 Results and Discussion

In this section, the results of the two abovementioned evaluations are shown. First, the one-step and two-step approaches are compared based on the accuracy of the 3D model. The accuracy of the 3D model is evaluated through 20 natural points that are measured in both the georeferenced 3D model and using the total station. The difference in coordinates of these points is summarized in Tables 2 and 3. In the one-step approach, RMSs with respect to the x, y, and z coordinates computed by Eq. (13) are 2.1, 1.6, and 2.7 cm, respectively. Similarly, RMSs are 1.8, 2.2, and 3.2 cm by using the two-step approach.

The results suggest that the accuracy of the 3D model is not significantly different when using two different approaches of the indirect georeferencing procedure. The

Table 3 Difference in 3D coordinates of natural points using the two-step approach

No.	Name	Δ_x	Δ_y	Δ_z	No.	Name	Δ_x	Δ_y	Δ_z
1	T51	1.7	1.3	− 2.0	11	LCR1	0.4	− 1.1	2.5
2	T52	2.0	4.7	− 2.7	12	LCR2	0.0	− 1.8	3.4
3	T53	0.6	0.3	− 5.1	13	PTN	− 1.3	− 2.3	− 4.2
4	T54	− 1.0	1.8	− 2.5	14	XD	0.2	− 2.2	− 2.7
5	T24	− 3.0	3.3	− 2.8	15	T41	2.5	1.1	− 3.2
6	QLDA	− 2.9	2.8	− 4.0	16	T42	2.2	3.4	− 3.4
7	A108	− 2.5	− 0.9	− 4.1	17	T31	− 0.4	0.2	− 0.2
8	VPD	− 1.5	− 0.8	− 3.7	18	T32	− 0.3	− 0.7	− 3.6
9	QHCC1	− 0.2	− 3.1	− 2.8	19	A105	− 2.7	0.8	− 2.4
10	QHCC2	− 1.1	− 3.5	− 3.8	20	A106	− 2.6	− 0.9	− 2.6

RMS values are approximately 2 cm with respect to the x and y coordinates, while these values are about 3 cm with respect to z coordinate. As a previous mention, the important advantage of the two-step approach is that the number of CPs used for georeferencing can be considerably reduced. For georeferencing two PCs, the two-step approach only uses five CPs compared to eight in the one-step approach. It is referred that when using the two-step approach in the case of many PCs, the number of CPs will be significantly reduced. However, the potential drawback of the two-step approach is that it needs more time for the registration procedure. By contrast, the one-step approach is able to directly georeferenced PC without the registration procedure. It allows reducing the time for registration processing. But more CPs need for georeferencing that is the main disadvantage of the one-step approach. Because each PC needs at least three CPs (normally four CPs in practice), the extra survey should be done by a total station or GNSS.

Second, this section also presents the effect of the target's configuration on the 3D model in the case of using the one-step approach for georeferencing procedure. Figure 13 shows that the target's configuration greatly influences the 3D model. When the CPs are in one side of the PC (scenarios 2 and 3), distances between two PCs as previously mentioned in Fig. 12 with respect to the x, y, and z coordinates are approximately from 1.5 to 2 times larger than that in the case that CPs spread around the PC (Scenario 4 and Scenario 5). The maximum values of the mean distance in the x and y coordinates are approximately 8 and 4 cm, respectively, while this value in the z coordinate is about 15 cm, which are two and three folds larger than those values in x and y coordinates.

By contrast, when the CPs are evenly distributed around the PC, the distance between two PCs becomes smaller (Scenario 4 and Scenario 5). The maximum values of the mean distance between two PCs with respect to the x and y coordinates are 3 and 1.5 cm, respectively, while the value in the z coordinate is approximately 10 cm. In these scenarios, the distance between two PCs in the z coordinate is still 3 time larger than those values in the x and y coordinates.

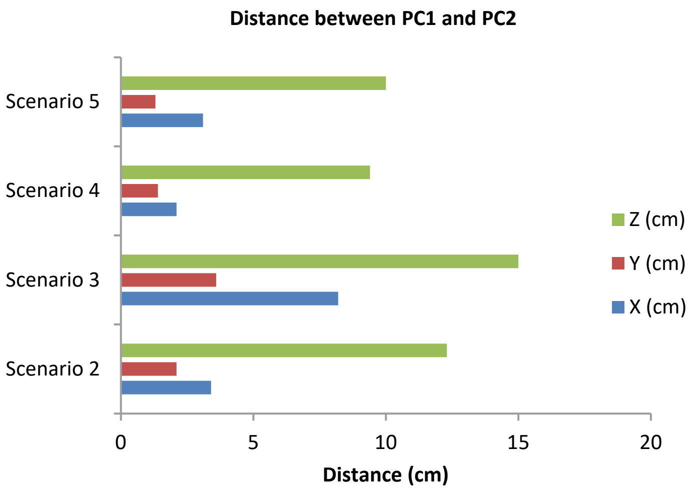

Fig. 13 Influence of target's configuration on the accuracy of the 3D model evaluated by the distance between two PCs in four different scenarios

These results can be explained by the quality of the target's configuration. In Scenario 2 and Scenario 3, when the CPs are in one side of PCs, the distance between PCs is large because of the bad target's configuration. Inversely, when the CPs are distributed throughout the PC, the distance between PCs is small because of a good target's configuration.

In Scenario 3, the distance between two PCs is largest when the CPs are selected in unfavorable positions and far from the compared area (see Fig. 5). A possible reason for the results of this scenario is the significant distortion in the georeferenced model due to unsuitable placement of CPs. These results are in agreement with the theory about the relationship between accuracy and configuration and that is consistent with the results in [19]. In addition, the distance between two PCs in the z coordinate is about from two-fold to three-fold compared to that in x and y coordinates. These results are also consistent with the result in Tables 2 and 3.

Another important result is that the accuracy of the 3D model is insignificantly influenced by adding more numbers of CPs. In Scenario 5 (see Fig. 10), some more CPs are added from Scenario 4 (Fig. 9). Although the number of CPs increases, the distance between two PCs in the compared area remains unchanged. This result can account for the unchanged quality of target's configuration and is in agreement with the result in [19]. In that study, the amount of ground control point considerably changes but RMS is very little different.

Our results show that surveyors need to consider not only the position of targets used for the indirect georeferencing by the one-step approach, but also a moderate amount of targets used to avoid the extra survey for control points. Besides, some limitation of the experiment should be presented here. First, the CPs in PC1 are distributed over the scan object, but the depth of them is quite small at 1.5 m compared to about 50 m of its length. Second, some control point targets are located far from the scanner so that the divergence of laser beam width increases. They are the main reasons why the accuracy of 3D model is centimeter level with respect to the x, y, and z coordinates in Tables 2 and 3.

5 Conclusions

The georeferencing procedure is one of the important steps to transform 3D PC acquired from TLS into the geodetic coordinate system. This paper has given a comparison between the one-step and two-step approaches of indirect georeferencing procedure. The main results of this paper can be summarized as follows.

The accuracies of 3D model when using the one-step and two-step approaches were equivalent. The benefit of the one-step approach was that it can reduce time for data post-processing in the office and the overlap between multiple scans is not need. But this approach needs more control points for georeferencing that needs extra survey of control points since each PC used at least three control points. Inversely, in the two-step approach, a certain overlap PC (30%) was necessary for registration procedure. However, the amount of control points used for georeferencing could considerably reduce especially for complex objects.

The target's configuration greatly influenced the accuracy of the 3D model. The control points should be spread over the scan object. It was recommended that the control points should not be distributed over one part of scan object. The georeferencing procedure could distort the 3D model due to poor configuration.

The combination between the one-step and two-step approaches should be considered to enhance the benefits and diminish the drawback of these approaches when applying for the complex construction like tunnels, bridges, and complex buildings in the subsequent works.

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