

THE EVALUATION OF CLOUDCOMPARE SOFTWARE IN THE PROCESS OF TLS POINT CLOUDS REGISTRATION

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Abstract: Terrestrial laser scanner (TLS) is a wide used technique to record objects, especially buildings. Multiple scans are required in order to measure a large object, the process of bringing in coincidence the resulted point clouds being necessary. This is the first and the most important step in the process of the 3D model creation, therefore the registration process should be as accurate as possible. Different methods are mentioned in literature for registration, most of them using common features like points, lines, planes, spheres, automatically or manually measured within the point clouds. In this paper, the tie point-based registration approach for TLS point clouds implemented in “CloudCompare” software was evaluated in terms of accuracy. To obtain the results, two TLS point clouds were used and five point pairs were manually chosen and measured. The estimation of the registration parameters of two point clouds was made by using 3D conformal transformation and the least squares methods.

Keywords: TLS, registration, 3D conformal transformation, CloudCompare

1. Introduction

A terrestrial laser scanner is an active remote sensing system which communicates with an attached computing device (typically a laptop) in order to store millions of points (point cloud) along with their information and also to control the scanning patterns. The operation is almost fully automated and provides a high point density [1]. Each of these points is characterized as position by the X, Y and Z coordinates calculated relatively to the scanner location, by the value of the laser reflectance (I) and its real color, expressed as RGB (Red, Green, Blue) values.

Often, in order to record a complete object, the laser scanner must be moved to different point stations from which additional point clouds are collected. Due to the fact that for each point station an unique and local scanner coordinate system is created, the individual point clouds must be brought into coincidence. This process is called registration and can be done by different methods, the most used being based on tie points.

A tie point within the registration process of TLS point clouds is simply a point that represents the same location in an adjacent TLS point cloud. Usually expressed as a pair, tie points can be used to link point clouds [2].

The two pairs of coordinate values for a tie point will be denoted as X,Y,Z for the reference coordinate system and x,y,z for the arbitrary coordinate system.

2. Material and Method

The main materials for this task are two point clouds acquired with ScanStation 2 terrestrial laser scanner over a dam and five point pairs, manually chosen and measured, representing natural tie points (Fig. 1). The coordinates (Table 1) were measured after the two point clouds were represented in the same coordinate system, namely the one of the left point cloud.

The ScanStation2, produced by Leica Geosystems, is a terrestrial scanner system using laser-pulsed technology for distances measurements with a precision of 6 mm at a distance of 50 m, which has an integrated 5 MP resolution digital camera.

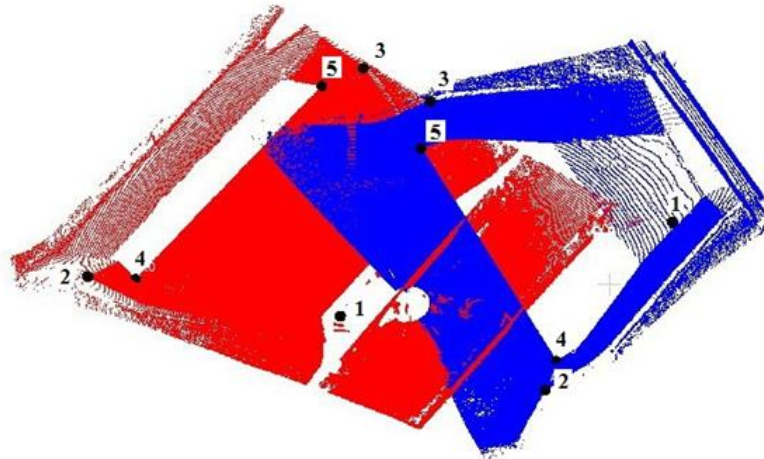


Fig. 1. Graphical representation of TLS point clouds in the left point cloud coordinate system and the five tie points pairs

Table 1. The coordinates of five point pairs in the left point cloud coordinate system

Point no.	X [m]	Y [m]	Z [m]	x [m]	y [m]	z[m]
1	-5.859	2.231	-6.189	22.868	5.665	-2.341
2	-26.652	7.120	-3.285	10.510	-11.627	0.610
3	-5.163	24.609	-4.788	2.501	14.866	-0.951
4	-22.655	7.280	-4.856	11.761	-7.880	-1.004
5	-1.530	24.811	-3.004	3.718	18.389	0.851

One of the most utilized method to register TLS point clouds is 3D conformal transformation, also known as Helmert 3D, defined by seven parameters: 3 translations of the origin of the arbitrary coordinate system (x,y,z) along X, Y and Z axes ($T=[T_x,T_y,T_z]^T$), three rotation angles, ω,φ,k around X,Y and Z axes and one scale factor λ .

The mathematical relation between the two rectangular tridimensional coordinate systems, the arbitrary coordinate system (xyz) and the reference coordinate system (XYZ), is defined by the well-known equation for Helmert 3D, given in simplified form:

$$X=T+\lambda R x \quad (1)$$

In order to determine the seven parameters, a number of seven equations must be known. These equations can be formed with the help of tridimensional coordinates of at least three points, known in both coordinate systems. If the coordinates of more that three coordinates are known, than the seven parameters are calculated by the least squares method.

3 Results and discussion

3.1 TLS point clouds registration based on point pairs, considering large rotation angles and scale factor

3.1.1 Determination of initial values of the transformation parameters

For this case study, the initial values of the seven parameters corresponding to the 3D conformal transformation, were calculated using the method developed by Dewitt in 1996. This method involves a total of nine steps being extensively tested and found to be successful in all cases [3].

(1) Initial approximation for scale factor

The initial value for the scale factor was calculated using equation (2), based on the distances computed in the reference coordinate system and arbitrary coordinate system respectively, using the coordinates of two selected tie points, for this case study 2 and 5, defining the longest distance.

$$\lambda = \frac{\text{distance } 2-5 \text{ in reference system}}{\text{distance } 2-5 \text{ in arbitrary system}}; \lambda_0 = \frac{\sqrt{(X_5 - X_2)^2 + (Y_5 - Y_2)^2 + (Z_5 - Z_2)^2}}{\sqrt{(x_5 - x_2)^2 + (y_5 - y_2)^2 + (z_5 - z_2)^2}} = 0.99842. \quad (2)$$

(2) Finding three geometrically strongest points

In order to obtain sufficient geometric strength, three points having a widely distributed base must be selected, so, for this case study the points 1, 2 and 3 which form a triangle having the largest altitude were chosen (Table 2).

Table 2. Altitudes calculation of all combinations of three points

Combination of points	Side a	Side b	Side c	Altitude h
1-2-3	27.747	21.557	22.433	17.059
1-2-4	21.557	4.298	17.589	1.491
...
3-4-5	27.514	24.623	4.052	2.682

(3) Compute the normal vectors at a common point in both systems

Table 3 shows a summary of the computation for both normal vectors at tie point 1.

(4) Compute tilt and azimuth for the normal vectors

The values of the tilt and azimuth were calculated with the equations (3) and (4) and the results are presented in Table 3.

$$\text{tilt} = \tan^{-1} \left(\frac{c}{\sqrt{a^2 + b^2}} \right) + 90^\circ; \quad (3)$$

$$\text{azimuth} = \tan^{-1} \left(\frac{a}{b} \right). \quad (4)$$

where a, b and c are the coefficients of \bar{i} , \bar{j} and \bar{k} (the unit vectors of the normal vector), respectively.

Table 3. Summary of normal vectors calculation in both coordinate systems and the tilt and azimuth values

System	Coefficient a	Coefficient b	Coefficient c	Tilt	Azimuth
Arbitrary	-51.1880	-42.9254	-465.8921	8.1600 ⁰	-129.9826 ⁰
Reference	-58.1362	31.1522	-468.7085	8.0101 ⁰	-61.8155 ⁰

(5) Compute initial rotations of tie points 1 and 2 in both coordinate systems

Using the tilt and azimuth values from Table 3 and the swing set equal to 0⁰ the following rotation matrices were calculated:

– arbitrary rotation matrix:

$$\begin{bmatrix} 0.642555139 & -0.766239449 & 0.000000000 \\ 0.758481679 & 0.636049608 & -0.141938152 \\ 0.108758611 & 0.091203089 & 0.989875528 \end{bmatrix}$$

– reference rotation matrix:

$$M_2 = \begin{bmatrix} -0.472312965 & -0.881430918 & 0.000000000 \\ 0.872831333 & -0.467704894 & -0.139347035 \\ 0.122824785 & -0.065815411 & 0.990243608 \end{bmatrix}$$

Then this rotation matrices are applied to two of the three points in each system, resulting in transformed points having equal z coordinates (Table 4).

Table 4. Coordinates of tie points 1 and 2 in both coordinate systems after the rotation is applied

System	x_1'	y_1'	x_2'	y_2'
Arbitrary	10.3532	21.2805	15.6623	0.4897
Reference	0.8008	-5.2949	6.3123	-26.1350

(6) Determine swing by difference in azimuths for the common line

After the azimuth of the line 1-2 is calculated in both coordinate systems, the swing required to align the arbitrary system with the reference system is then computed by Equation (5).

$$\begin{aligned} swing &= azimuth(reference) - azimuth(arbitrary). \\ swing &= -0.4887^0. \end{aligned} \tag{5}$$

(7) Determine the overall rotation matrix

Rotation matrix M_1 is formed using tilt and azimuth of the normal vector in the arbitrary system, in conjunction with the swing value determined with equation (5). Rotation matrix M_2 is the reference matrix calculated in Step 5.

The final rotation matrix $M_{k\varphi\omega}$ is calculated as $M = M_1^T \cdot M_2$ resulting:

$$M_{k\varphi\omega} = \begin{bmatrix} 0.379724537 & -0.925098765 & 0.001245422 \\ 0.925095139 & 0.379726542 & 0.002595660 \\ -0.002874162 & 0.000166498 & 0.999995856 \end{bmatrix}$$

(8) Compute initial rotation angles (ω_0, φ_0, k_0):

The initial rotation angles that relate the arbitrary to the reference system, are calculated using the equations (6), (7) and (8), using the elements of the rotation matrix:

$$\omega_0 = \tan^{-1}(-r_{32} / r_{33}); \quad (6)$$

$$\varphi_0 = \sin^{-1}(r_{31}); \quad (7)$$

$$k_0 = \tan^{-1}(-r_{21} / r_{11}). \quad (8)$$

resulting:

$$\omega_0 = -0.0095^\circ,$$

$$\varphi_0 = -0.1647^\circ,$$

$$k_0 = -67.6833.$$

(9) Compute initial translations (T_{X0}, T_{Y0}, T_{Z0}):

Translations can be calculated with the help of equation (1) by passing this terms in the left side of the equation, as:

$$T = X - \lambda R_{k,\varphi,\omega}^T X, \quad (9)$$

or:

$$\begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} - \lambda \begin{bmatrix} r_{11} & r_{21} & r_{31} \\ r_{12} & r_{22} & r_{32} \\ r_{13} & r_{23} & r_{33} \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}. \quad (10)$$

As translations can be calculated using any tie point, three values were obtained for each of the three points, the final values being obtained as average (Table 5).

Table 5 Translations between arbitrary and reference coordinate system

Point	T_{X0} [m]	T_{Y0} [m]	T_{Z0} [m]
1	-19.768	21.205	-3.895
2	-19.896	21.235	-3.877
3	-19.845	21.283	-3.880
Average	-19.836	21.241	-3.884

3.1.2 *Determination of final values of the transformation parameters by least squares method*

The final values of the seven parameters corresponding to the 3D conformal transformation, were calculated using the least squares method. All the necessary steps were described in detail by Brazeal in 2013, so for more informations see [2].

After performing three iterations, the compensated values of the 3D conformal transformation parameters were obtained (Table 6). The standard deviation (μ) obtained after the third iteration was 4.4 cm and the corrections of the X, Y and Z coordinates corresponding to the five tie points range between -6.8 cm and 5.7 cm.

3.1.3 Transformation precision evaluation

Based on the standard deviation and the variation terms of the transformation unknown parameters, the mean square errors of the transformation (residuals) (Table 6) were calculated using the following equation:

$$s_j = \pm \sqrt{C_{ij}}, j = \overline{1,7}, \quad (11)$$

where:

C_{ij} – is the element situated on the principal diagonal of the variance-covariance matrix of the transformation parameters ($C_{\mathbf{x},\mathbf{x}} = \mu^2 \cdot (A^T A)^{-1}$).

Table 6. 3D conformal transformation parameters and residuals

Parameter	Value	Residuals
λ	1.000675	± 0.00141
ω	-0.05128 ⁰	$\pm 0.00251^0$
ϕ	-0.12945 ⁰	$\pm 0.00235^0$
k	-67.50008 ⁰	$\pm 0.00141^0$
T_X	-19.896 m	± 0.02509 m
T_Y	21.220 m	± 0.02512 m
T_Z	-3.881 m	± 0.03895 m

3.2 TLS point clouds registration in „CloudCompare” software based on point pairs

There are four different methods implemented in „CloudCompare” software [4], [5] in order to bring in coincidence two TLS point clouds. For this case study we have chosen the „Align (point pairs picking)” method, from *Tools-Registration* menu. This tool lets the user align two TLS point clouds by picking at least three equivalent point pairs in both clouds. So, in order to be able to use this function, the two TLS point clouds must be selected, then we have to chose the role for each point cloud, *Reference*, respectively *Aligned*. The software offers the possibility to pick points directly on the clouds (3D view) or to manually input points, by X, Y and Z coordinates, using the option “Add Aligned Point”. In this step, the last option was chosen, because there is no garanty that the user will klik exactly in the same place as when the data was collected for the calculation step.

The “CloudCompare” software will have calculated and displayed the resulting *RMS-Root Mean Square*, for this case study 5.6 cm and the error contribution for each pair, so the user can remove and pick again the worst pairs or can add new points to both sets. By pressing the “align” button the result of the registration process was preview (Fig. 2).

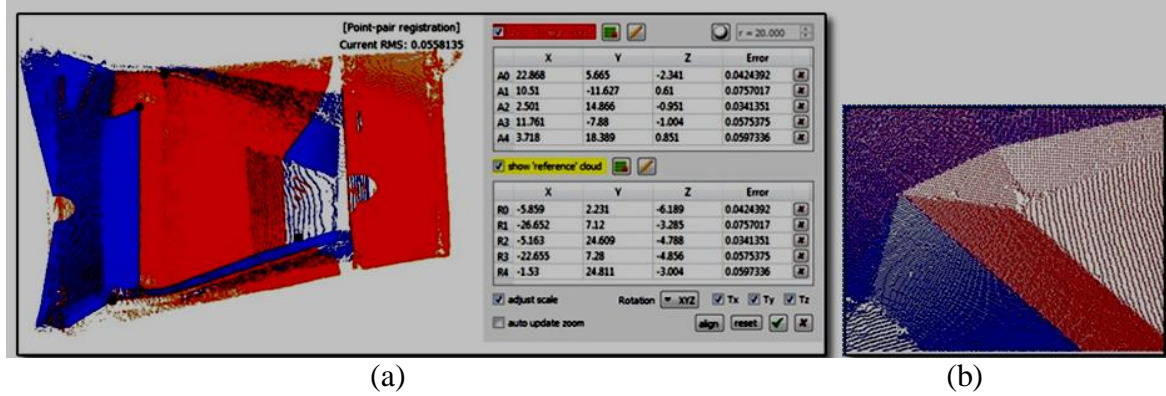


Fig. 2. (a) TLS point clouds brought in coincidence after the registration process based on tie points pairs, (b) detail

By using this registration method, we can also determine the most probable value of the scale between the two point sets, using the option “*adjust scale factor*”. If the registration process is validated, “*CloudCompare*” will display a report, the same information being displayed in “*Console*”, but with increased digit accuracy.

3.2. Comparative study between the TLS point clouds registration process made by calculation and the one automated made in „*CloudCompare*” software.

As mentioned before, the transformation matrix contains the scale factor. So, in order to obtain the transformation matrix without the scale factor, we have to divide each matrix element with his value.

The transformation matrix is a composition of the rotation matrix (3×3) and the translations vector (a 3D vector). It can be written as a 4×4 matrix, (the rotation matrix corresponds to the upper part of the 3 first columns, the translation vector corresponds to the upper part of the 4th column and the bottom line is always filled with 3 'zeros' and a 'one') [4].

The general form of the transformation matrix is given as:

$$M_{transformation} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & T_x \\ r_{21} & r_{22} & r_{23} & T_y \\ r_{31} & r_{32} & r_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (12)$$

The transformation matrix that doesn't contain the scale factor is:

$$M_{transformation} = \begin{bmatrix} 0.3826829 & 0.9238821 & -0.0022594 & -19.8959503 \\ -0.9238833 & 0.3826856 & 0.0008950 & 21.2200146 \\ 0.0016915 & 0.0017449 & 1.0000017 & -3.8811846 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

In order to extract the angular parameters of the 3D conformal transformation, the following relations were used:

$$\omega = \tan^{-1}(-r_{23} / r_{33}); \varphi = \sin^{-1}(r_{13}); k = \tan^{-1}(-r_{12} / r_{11}). \quad (13)$$

The values of the transformation parameters as well as the differences between the values obtained by calculation and those obtained based on the transformation matrix resulted in „CloudCompare” software, are listed in Table 7.

Table 7. Parameters of 3D conformal transformation, obtained by calculation, respectively based on the transformation matrix resulted in “CloudCompare” software and the differences between their values

Parameter	Value obtained by calculation	Value obtained in “CloudCompare”	Diferences
λ	1.000675	1.000670	0.000005
ω	-0.051281 ⁰	-0.051281 ⁰	0.000000 ⁰
φ	-0.129454 ⁰	-0.129455 ⁰	0.000001 ⁰
k	-67.500083 ⁰	-67.500081 ⁰	-0.000002 ⁰
T _X	-19.896 m	-19.896 m	0.000 m
T _Y	21.220 m	21.220 m	0.000 m
T _Z	-3.881 m	-3.881 m	0.000 m

4 Conclusions

This paper presents a performance analysis on the registration algorithm based on tie points pairs implemented in the „CloudCompare” open source software. In order to prove its potential, the registration parameters were calculated using five point pairs by 3D conformal transformation and least squares methods. The coordinates of the five point pairs were manually chosen and measured in the „CloudCompare” software after the two TLS point clouds were represented in the same coordinate system. The same coordinates were then used to register the point clouds into the „CloudCompare” software.

As we concluded that the transformation parameters are almost identical, when looking from an economic point of view, using the „CloudCompare” open source software is the better option, the solution being cheap and fast.

5. References

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