Mediterranean Archaeology and Archaeometry, Vol. 17, No 3, (2017), pp. 53-64

DOI: 10.5281/zenodo.1005466

A STATISTICAL EVALUATION OF REGISTRATION METHODS USED IN TERRESTRIAL LASER SCANNING IN CULTURAL HERITAGE APPLICATIONS

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Received: 03/07/2017
Accepted: 02/09/2017
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ABSTRACT

Terrestrial laser scanning (TLS) systems are used during surveying in cultural heritage applications, supported by recent developments in the electronics and computing. The aim of this article is to present a statistical study of the accuracy of registration methods (target (sphere), specific point and surface-matching) used for merged of the scans captured from different scan stations. A Mensi GS 100 terrestrial laser scanner was used to scan an historical building. The point clouds reflecting the building facade were registered using these registration methods and were transformed into the same geodesic coordinate system. A Leica TPS 1200 Total Station was used to measure the coordinates of specific points on the building facade and compare them with the coordinates of the same points using three different scan-registration methods. The t-student test and Analysis of Variance (ANOVA) were used for point- and method-based comparisons, and it was found that the coordinates did not exhibit any statistically significant variation. Better results were obtained with target-based registration methods compared to other methods, and with surface-matching methods compared to methods using specific points. Although the results of the registration methods used in this study had certain similarities, variation in their accuracy was determined to be statistically significant.

KEYWORDS: Terrestrial Laser Scanning, Statistical analyze, Point Cloud, Registration, Cultural Heritage

1. INTRODUCTION

Developments in electronics and computing have been applied to the Terrestrial Laser Scanning (TLS) technology, enabling fast and efficient surveying of complex geometric data from buildings, machines and other objects. TLS technology has become a viable alternative to other methods of 3-dimensional measuring and modeling.

If the scanned object is complex and large, however, it is not possible to obtain a 3-dimensional point cloud of the entire surface of an object from scan station. Data covering the entire surface of an object can be obtained by performing scans from different scan stations, and the collected data is then analyzed using different methods of registration and georeferencing. The accuracy in reflecting the true surface of an object is dependent upon the registration method used, and affects the accuracy of the final product or visualization. The objective of user-based applications is to obtain an accurate data set quickly and economically. For this purpose, methods offering simplicity in measurement and evaluation are preferred for registration and georeferencing of point clouds. In practice, specific targets (e.g. spheres), specific points on the common object surfaces, common geometric objects (e.g. planes and cylinders) and surface-matching algorithms have been conventionally used in registration methods.

Many recent studies have investigated registration and georeferencing methods. Pesci and Teza (2011) studied the effects on scanning accuracy of artificial targets used in the registration of TLS data. Tests were performed using targets with different reflective surfaces. Lichti and Gordon (2004) analyzed random error budgets encountered during direct registration of point clouds generated by TLS. Gordon and Lichti (2004) addressed error budgets encountered in georeferencing. Scaioni (2005) described a geometrical model involving direct georeferencing. In addition, errors affecting the laser scanner measurements were analyzed. Alba and Scaioni (2007) described the techniques used during registration of TLS data in 3-dimensional (3D) modeling of items of cultural heritage. Miri and Varshosaz (2011) shared results indicating that the angle between the laser beam and target surface, and the distance between the target and scanner, affect the positional accuracy of the targets. In particular, it is very important to register scans captured from different scan stations in order to obtain the optimal point cloud reflecting the exact object surfaces. Therefore, many studies have been conducted to research the effects on the final product of the registration methods used in laser scanning applications. The photogrammetry and dense point cloud methods using images to get 3D measurement data has been applied to historical buildings (Altuntas et al 2017; Salama et al 2017).

The aim of this article is to conduct a statistical study of the effect of the target (sphere) and the specific point- and surface-matching methods used for registration of scans obtained from different scan stations, on the final product. For this purpose, tests were made to determine whether there is a statistical variation between coordinates found using different registration methods for specific points on an historical building facade. The t-student test and Analysis of Variance (ANOVA) were used as point-based and method-based statistical tests in this study. The registration methods applied in this study were analyzed to reveal their effects on the final surface model, their accuracy and any similarities between them.

2. MATERIAL AND METHOD

2.1. Registration Methods

Registration refers to the transformation of the coordinates obtained from multiple scans performed from different perspective points into a common coordinate system. There must be intersecting (overlapping) areas in order to register scans captured from different perspective points. Fig. 1 shows an example of two different scans obtained for the same object from different perspective points (Reshetyuk, 2009). Three translation and three orientation transformation parameters must be determined along the coordinate axes in these coordinate systems in order to transform the coordinate system of scan 2 into the system of scan 1. The used 3D transformation is a Helmert transformation without the scale factor (Reshetyuk, 2009).

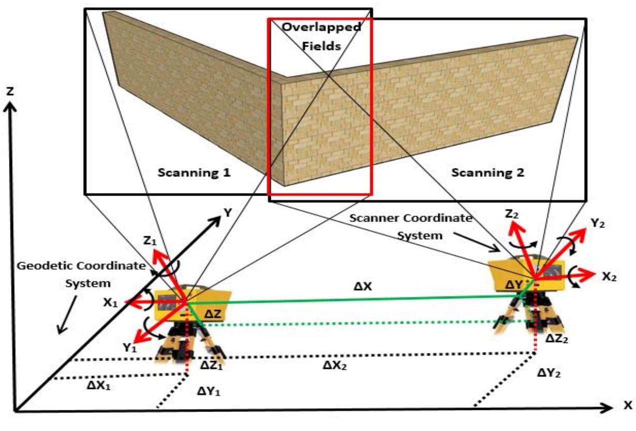

Figure 1. Registration of two scans

There are several registration approaches in TLS applications. These approaches are usually applied based on the user’s preference by selecting any one of the following methods shown in Fig.2 (Reshetyuk, 2009):

• Specific targets (sphere, etc.) placed in overlapping areas
• Specific points present on the common object surface of the scans
• Common prismatic objects (surfaces or cylinders)
• Surface-matching algorithms.

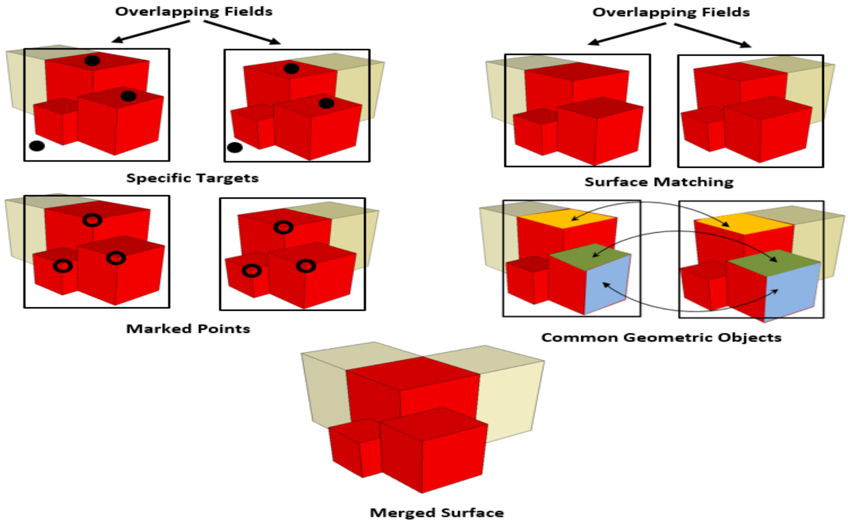

Figure 2. Registration approaches used in TLS applications

In *target-based (sphere) registration*, transformation parameters between scan (1) and scan (2) are determined using at least three special targets, so-called tie points. These points are distributed over the overlapping area in each scan zone and are in different vectors in the two coordinate systems. Sometimes it is not possible to place targets in the overlapping areas, for example, when tall buildings are scanned. In this case, features such as building corners or windows with distinct visible characteristics are selected from the point cloud as tie points for registration of the scans (Jacobs, 2005; Balzani et al., 2001). Common geometrical objects such as cylinders or surfaces visible in both point clouds are used for registration of the scans. These objects can be modeled by adapting to a point cloud such as a surface, wall or floor. Laser scanning software registers the point clouds based on the best resolution of the common geometric objects.

Surface-matching is usually based on the Iterative Closest Point (ICP) Algorithm method (Besl and McKay 1992). In this method, the closest point pairs are found among the points, and operations are continued until alignment (minimal distance) is achieved among these points. Then registration is realized by minimizing the sum of the squared spatial distances between the surface and points of the other point cloud (Pfeifer and Lichti, 2004). In ICP, one set of points is the subset of another. The most important challenge in the ICP algorithm is the requirement to find both surfaces of each point in the overlapping area between the different surfaces. The ICP method has been improved by many authors, such as Masuda and Yokoya (1995), Jokinen and Haggren (1998), Williams et al. (1999), Campbell and Flynn (2001), Okatani and Deguchi (2002). In the aforementioned studies, the ICP method was associated with the least squares parameter estimation procedure. The surface-matching approach is intended to match overlapping areas of point clouds instead of matching common flat targets or natural visible targets. When there is an excess number of points in the overlapping areas, this method obtains better results than the use of distinct tie points (Barber et al., 2001). Surface-matching algorithms are used in laser scanning software packages. In particular, surface-matching methods based on the least square procedure were developed at the Swiss Federal Institute of Technology in Zurich (ETHZ) (Gruen and Akca, 2005). A surface is modeled based on this reference point cloud and then it is registered by minimizing the sum of the squared spatial distances between the surface and points of the other point cloud (Pfeifer and Lichti, 2004).

Registration methods used in practice have certain advantages and disadvantages. For example, natural and artificial targets must be scanned at high resolution independently from the main scan (Jacobs, 2005). In addition, there may be differences in determining the target medians, as the laser beams are coming from different angles and distances. In the surface-matching approach, initial values of transformation parameters must be determined for applying the iterative registration operations. The accuracy of the registration achieved through common geometrical objects is dependent on the overlapping area and overlapping geometry. A good geometry is expected from the overlapping surface areas. The recommended overlapping surface ratio is 30 % of the merged surface areas in which natural or artificial targets are used (Balzani et al., 2001).

2.2. Data Description

An historical building, part of the palace Yıldız and known as Pigeonry in the Ottoman period, is currently being used by the Technology Development Center Directorate located in the Yıldız Campus of Yıldız Technical University in Turkey. This building has been selected to carry out testing of TLS applications due to its cultural heritage from the Ottoman period and compatibility with the registration methods of building geometry being tested. 3D modelling of this historical building and the point position accuracy of the obtained model have been studied in Gumus (2008) and Gumus (2014). The building's surfaces are symmetrical to each other in both scanning areas, and conform to the field of view used by the laser scanner in terms of building height and the size of the common scanning area. It is rectangular in shape, approximately 15 m x 10 m in horizontal and 10 m in vertical dimensions, and of architectural interest as shown in Figure 3. The scanning was performed so that the average distance between the scanner and the object was 10 m, with a point density of 4 mm. An angular resolution of 0.03 degrees was used to reflect one-to- one the true surface model by considering the size of the building. Measurements performed on this building with TLS and a Total Station theodolite were conducted at the same distance and in the same atmospheric conditions. Where necessary, corrections were made to measurements according to variations in the ambient temperature, pressure, and humidity. In this study, a Trimble Mensi GS 100 Terrestrial Laser Scanner was used to scan an historical building from two different scan stations (Fig. 3).

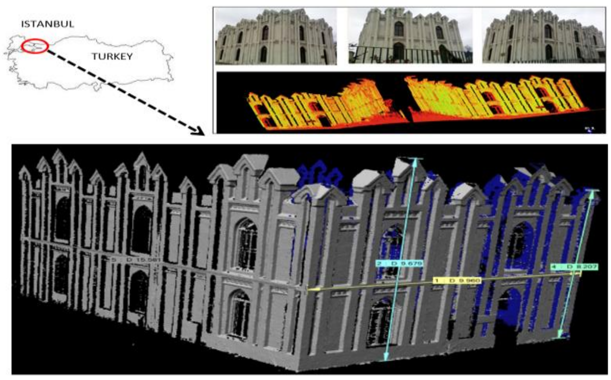

Figure 3. Image of the Historical Building Facade and Point Clouds

PointScape scanning software was used to accomplish this task (Trimble, 2007). Scanning parameters (scanner-object distance, scanning range, angular resolution) were selected to achieve the optimum resolution. The optimum resolution (4 mm) was selected for the distance between the scanner-object and the smallest size of the object detected. Targets (spheres) and specific feature points on the building were scanned at a higher resolution than the ordinary building surface scans.

2.3. Registration Applications

Trimble RealWorks software was used for registration of the points captured from the different perspective points using sphere-shaped targets and easily located specific feature points such as window corners on common (intersecting) surfaces (Trimble, 2014). An attempt was made to determine at least three identical tie or control points on the common scanning area for the purpose of registration and at least three control points for the georeferencing. Fig.4 shows a view of the tie and control points in the point cloud.

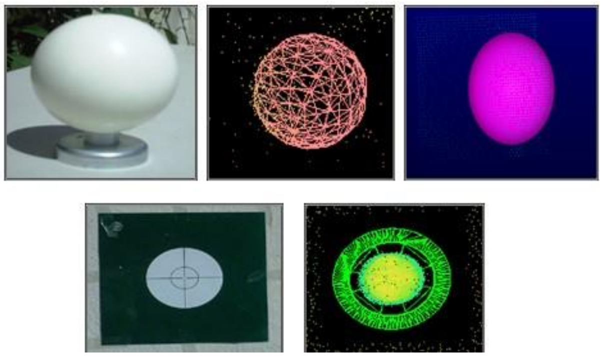

Figure 4. The view of tie and control points in the point clouds

Deviations were identified with millimeter precision when matching the common sphere and natural targets in both scan areas. Scans were registered by considering the deviation values (mm level) obtained from surface-matching (Fig 5).

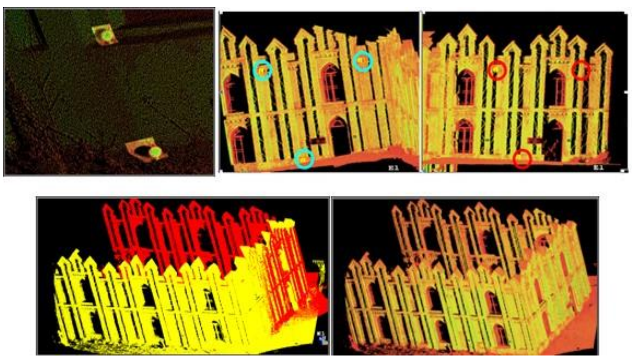

Figure 5. Sphere and natural target-based registration

Polyworks® software was used for surface-matching of the point clouds. Better results are obtained when overlapping areas have thousands of points (InnovMetric Software Inc., 2007). Initial values of the transformation parameters must be determined to initiate the iterative registration operations. For this purpose, at least three points were defined in the overlapping area. An optimum registration can be obtained based on the initial alignment and subsequent iterations. The registration operation was performed by minimizing the sum of the squared distances between the corresponding points of the overlapping areas (Fig. 6).

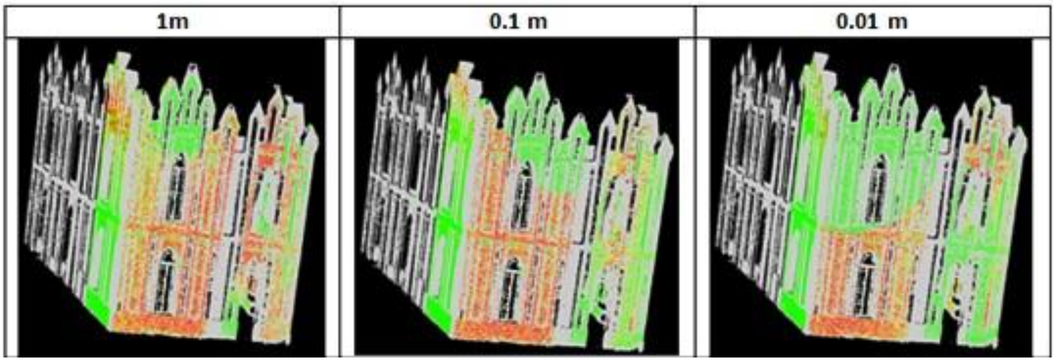

Figure 6. Surface-matching based on the distance between points

Furthermore, point clouds covering the surface facade of the historical building were registered using three different methods: special target-based (sphere) registration, specific feature point registration methods, and surface registration methods based on ICP algorithms. Data from three methods of reflecting the building facade were transformed into the same geodetic coordinate system. For this purpose, a Leica TPS 1201 Total Station, exhibiting better accuracy compared to the initial scanner, was used to obtain the coordinates of at least three targets (or control points) and specific feature points on the building facade in the geodetic system by establishing a geodetic network over the scan area. The coordinates obtained for these specific points measured on the building facade using Leica TPS 1201 were compared with the coordinates of the same points obtained using three different registration methods.

2.4. *Statistical Analysis*

Accuracy criteria were identified for each coordinate component by using the coordinate differences of characteristic points of the building. Weighted and unweighted accuracy criteria were calculated to compare the methods. The weight of each point (Pi) was estimated using the equation $Pi=s_0/s_i$ by selecting the unit length as $s_0 = 10$ m which refers to the average distance between the Total Station and the object points. s_i is the distance between an individual point and scanner. Then 3D positional accuracies (S_{3B}) were calculated with equations (1, 2, 3) below for each method (Mikhail and Ackerman, 1976; Demirel, 2005; Gumus, 2008). Vx, Vy, Vz for each coordinate component (x, y, z) are residual vectors. P is weight matrix, n is number of measurements. Sx_0, Sy_0, Sz_0 are standard deviations for each coordinate component (x, y, z).

$$Sx_0 = \sqrt{\frac{V_x^T V_x}{n-1}} \quad Sy_0 = \sqrt{\frac{V_y^T V_y}{n-1}} \quad Sz_0 = \sqrt{\frac{V_z^T V_z}{n-1}}$$

(Unweighted) (1)

$$Sx_0 = \sqrt{\frac{V_x^T P V_x}{n-1}} \quad Sy_0 = \sqrt{\frac{V_y^T P V_y}{n-1}} \quad Sz_0 = \sqrt{\frac{V_z^T P V_z}{n-1}}$$

(Weighted) (2)

$$S_{3B} = \sqrt{Sx_0^2 + Sy_0^2 + Sz_0^2}$$

(3D Positional Accuracy) (3)

Standard deviation values for unit weighted dimensions and 3D positional accuracies were calculated with equations (4 and 5) below (Mikhail and Ackerman, 1976; Demirel, 2005; Gumus, 2008).

$$Sx_i = \frac{Sx_0}{\sqrt{Pi}}, \quad Sy_i = \frac{Sy_0}{\sqrt{Pi}}, \quad Sz_i = \frac{Sz_0}{\sqrt{Pi}} \quad (4)$$

$$S_{3B_i} = \sqrt{Sx_i^2 + Sy_i^2 + Sz_i^2}$$

The t-student test is generally used to determine the significance of differences between two average values in statistical analyses. Assuming that the coordinate differences and their standard deviations are known, the t-student test was applied to analyze whether there are significant differences between the coordinates obtained from the Total Station and the other methods. Test values were determined using the equations below (6) for the purpose of the t-student test (Mikhail and Ackerman, 1976; Demirel, 2005; Gumus, 2008).

$$t_{xi} = \frac{v_i}{Sx_i} \quad t_{yi} = \frac{v_i}{Sy_i} \quad t_{zi} = \frac{v_i}{Sz_i} \tag{6}$$

Variance analysis is used to determine the presence of differences of more than two average values, using dependent and independent variables. In general, the effect of independent variables on dependent variables is studied. Definition of the type of variance analysis is based on the number of dependent and independent variables. Each of the groups to be tested in ANOVA must have a normal distribution and there must be homogeneous variances between the groups. These assumptions must be tested before conducting a variance analysis. The ANOVA table gives a general idea of whether there is a difference between the averages of groups. Post hoc tests (Tukey or Tamhane's T2) are of great importance to see the source of group difference when a difference is detected between the groups (Tukey, 1949; Sparks, 1963; Kalayci, 2010). Variance analyses and evaluations were performed using Statistical Package for the Social Sciences (SPSS) software (IBM SPSS Statistics). F- value is ratio of residual variances in a model. SPSS software gives a p-value (Sig.) as a table value of F with 95 % significance. If this value is lower than 0.05, then it can be suggested that there is a significant statistical difference between the groups. SPSS software is also used to create subgroups based on dependent variables. These subgroups are used as an indicator to determine whether methods used for identifying the point coordinates are the same, or different (Woodward and Elliott, 2006; Kalayci, 2010). In this study, ANOVA was used in an attempt to determine whether there is a significant difference between the averages of the coordinate groups obtained by using the Total Station and the different registration methods.

3. RESULTS AND DISCUSSION

Twenty-two points, consisting of visible corner points such as windows and doors, were selected on the building facade for determining the relative accuracy of three different registration methods. The coordinates of these points were determined using the Leica TPS 1201 Reflectorless Total Station. In addition, coordinates of twenty-two points positioned in point cloud sets were obtained by three different registration methods. These coordinates were then compared with the coordinates determined by the Total Station (Fig. 7).

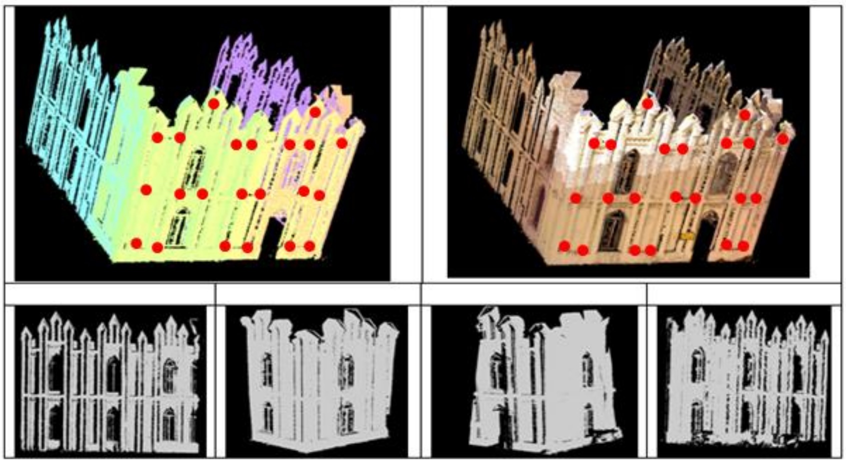

Figure 7. Coordinate points identified for the purpose of comparison

The length-measuring accuracy of the Leica TPS 1201 is 1 + 1.5 ppm, and the measuring accuracy of the scanner is 6 mm for lengths up to 100 m. In this case, as the measuring accuracy of the Leica TPS 1201 is better than the measuring accuracy of the first scanner, the differences were calculated between the point coordinates found using the registration methods and the Total Station coordinates. The main statistical parameters of the calculated differences are given in Table 1.

Table 1. Statistical values of coordinate differences (m)

	Target (Sphere)			Surface Matching			Specific Point		
Statistical Values	ΔX	ΔY	ΔZ	ΔZ	ΔY	ΔZ	ΔX	ΔY	ΔZ
Minimum	- 0.006	-0.010	-0.008	-0.009	-0.011	-0.011	-0.017	-0.017	-0.019
Maximum	0.009	0.005	0.009	0.011	0.008	0.011	0.015	0.011	0.013

Average	0.001	0.001	0.003	0.002	0.002	0.004	0.001	0.004	0.005
Median	0.000	0.002	0.004	0.002	0.005	0.007	0.004	0.009	0.011
1st Quarter	0.003	0.004	0.006	0.005	0.006	0.009	0.008	0.010	0.012
3rd Quarter	0.007	0.002	0.002	0.009	0.005	0.004	0.011	0.007	0.008
Standard Error	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.002	0.002
95% Conf. Int.	0.002	0.002	0.002	0.003	0.003	0.003	0.005	0.004	0.005
99% Conf. Int.	0.003	0.002	0.003	0.004	0.004	0.004	0.006	0.006	0.006

It was found that the registration method using sphere targets exhibited lower deviations than the other methods (Table 1). Better results were obtained with the target-based (sphere) registration method compared to the other methods and with the surface-matching method compared to the method using specific points. Standard deviations for each coordinate component (Sx_0, Sy_0, Sz_0) were calculated as weighted and unweighted values by the least squares procedure using the coordinate differences of characteristic points of the building (Table 2).

Table 2. Unweighted (equal weight) and weighted (different precision) values (mm)

Unweighted									
	Target (Sphere)			Surface Matching			Specific Point		
	Sx_0	Sy_0	Sz_0	Sx_0	Sy_0	Sz_0	Sx_0	Sy_0	Sz_0
Std. Dev.	5.398	4.053	5.381	7.502	6.576	8.074	10.726	9.99	11.796
3D Std. Dev.	8.633			12.834			18.815		
Weighted									
	Target (Sphere)			Surface Matching			Specific Point		
	Sx_0	Sy_0	Sz_0	Sx_0	Sy_0	Sz_0	Sx_0	Sy_0	Sz_0
Std. Dev.	4.762	3.688	4.717	6.747	5.916	7.108	9.651	9.109	10.477

Point positioning accuracy calculated by the unweighted estimation must be the same at all points. The comparison made between the weighted and unweighted results showed that weighted values reflect the positioning precision better than the unweighted values. Therefore, an analysis was performed based on the weighted estimations. Standard deviation values of each weighted measurement and 3D positional accuracy of each point were calculated for each method (Table 3).

Table 3. Standard deviation values of points in 3D model and axis directions x, y, z (mm)

Weighted (the values in mm units)												
Point	Target (Sphere)				Surface Matching				Specific Point			
No	Sx (i)	Sy (i)	Sz (i)	3D-S(i)	Sx (i)	Sy (i)	Sz (i)	3D-S(i)	Sx (i)	Sy (i)	Sz (i)	3D-S(i)
1	6.082	4.711	6.025	9.771	8.618	7.557	9.078	14.621	12.327	11.635	13.382	21.596
2	5.866	4.543	5.811	9.424	8.311	7.288	8.756	14.102	11.889	11.221	12.906	20.829
3	5.539	4.290	5.487	8.899	7.849	6.882	8.268	13.316	11.227	10.597	12.188	19.669
4	5.405	4.187	5.355	8.684	7.659	6.716	8.069	12.995	10.956	10.341	11.894	19.194
5	4.665	3.613	4.621	7.494	6.610	5.796	6.963	11.214	9.455	8.924	10.264	16.564
6	4.548	3.523	4.506	7.308	6.445	5.651	6.789	10.935	9.219	8.701	10.008	16.151
7	4.922	3.812	4.876	7.907	6.974	6.115	7.347	11.832	9.976	9.416	10.830	17.477
8	4.820	3.733	4.775	7.744	6.829	5.989	7.194	11.587	9.769	9.221	10.605	17.115
9	6.112	4.734	6.054	9.819	8.660	7.594	9.123	14.693	12.388	11.692	13.448	21.703
10	5.994	4.643	5.938	9.631	8.494	7.448	8.948	14.411	12.150	11.468	13.190	21.286
11	4.970	3.849	4.923	7.985	7.042	6.175	7.418	11.948	10.073	9.508	10.935	17.648

12	4.724	3.659	4.680	7.590	6.694	5.870	7.051	11.357	9.575	9.037	10.394	16.775
13	5.132	3.975	5.084	8.245	7.271	6.376	7.660	12.337	10.401	9.817	11.291	18.222
14	5.320	4.121	5.271	8.548	7.539	6.611	7.942	12.791	10.784	10.178	11.707	18.892
15	5.202	4.029	5.153	8.357	7.370	6.463	7.764	12.505	10.543	9.951	11.445	18.471
16	5.314	4.116	5.264	8.537	7.529	6.602	7.932	12.775	10.770	10.166	11.692	18.869
17	4.766	3.692	4.722	7.658	6.754	5.922	7.115	11.459	9.661	9.118	10.488	16.925
18	5.005	3.877	4.958	8.042	7.092	6.219	7.471	12.033	10.145	9.576	11.013	17.774
19	6.178	4.785	6.120	9.926	8.754	7.677	9.222	14.853	12.522	11.819	13.594	21.939
20	6.279	4.864	6.221	10.089	8.898	7.802	9.373	15.096	12.728	12.013	13.817	22.298
21	6.018	4.662	5.962	9.669	8.528	7.478	8.983	14.468	12.198	11.513	13.242	21.371
22	6.122	4.742	6.064	9.836	8.674	7.606	9.138	14.717	12.408	11.711	13.470	21.738

It was observed that, in TLS applications, point positional accuracies vary based on the registration method used (Table 3). For target-based (sphere) registration methods, the mean standard deviation values for axis directions x, y and z were within the range of 4.189 mm to 5.408 mm, and 3D positional accuracy was 8.689 mm. For the surface-matching registration method, the mean standard deviation values for axis directions x, y and z were within the range 6.720 mm to 8.3073 mm, and 3D positional accuracy was 13.002 mm. For the feature point registration method, the mean standard deviation values for axis directions x, y and z were within the range 10.172 mm to 11.900 mm, and 3D positional accuracy was 19.205 mm. Standard deviation values showed that target-based registration methods are the most accurate. Results obtained from the surface-matching method are better compared to the feature point registration method. Figure 8 shows weighted 3D positional accuracies for each point found with the three registration methods

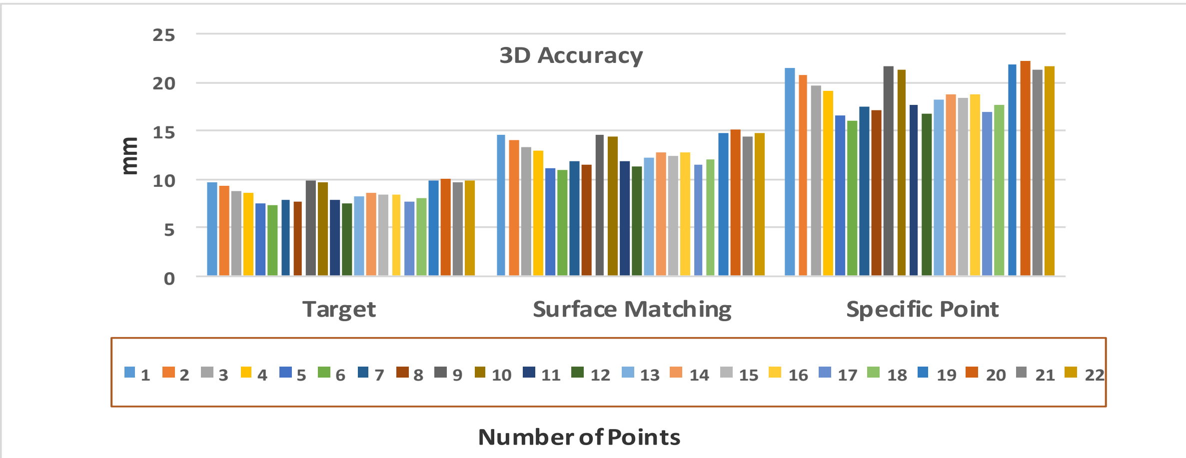

Figure 8. Weighted 3D positional accuracies (mm)

Comparisons of weighted 3D positional accuracies found with the three methods showed that results obtained from target-based (sphere) registration methods reflect relatively realistic positional accuracies compared to other methods (Figure 8). Assuming that coordinate differences and their standard deviations are known, the t-student test was used to analyze the significance of the differences between the coordinates obtained with the Total Station and the other three methods. These values were compared with the limit value in the t table using the degree of freedom ($f = n-1$) and error probability $\alpha = 0.05$ (Table 4). The t-student test limit value is 2.080 ($f = 22-1 = 21$ degree or freedom and $\alpha = 0.05$ error probability). Values below this value are considered statistically consistent and values above this value are considered statistically inconsistent.

Table 4. T-student test values calculated from coordinate differences and standard deviations

Point	Target (Sphere)			Specific Point			Surface Matching		
No	Tx	Ty	Tz	Tx	Ty	Tz	Tx	Ty	Tz
1	0.987	1.061	0.83	0.928	0.926	0.771	0.892	0.688	0.822
2	0.341	1.101	0.516	0.602	0.823	0.571	0.589	0.802	0.542
3	1.444	1.165	1.093	1.147	1.017	1.209	0.713	0.755	0.903
4	0.555	0.478	1.307	0.653	0.596	1.115	0.73	0.87	1.093
5	0.214	0.554	0.649	0.303	1.208	1.005	0.846	0.896	0.779
6	1.319	0.568	1.554	1.552	0.885	1.178	1.302	1.149	1.199
7	0.406	1.049	0.41	0.574	1.308	0.544	0.601	1.168	0.831
8	0.415	1.679	0.419	0.732	1.336	1.112	1.74	1.301	1.414
9	1.309	0.634	1.156	1.039	1.053	1.096	0.888	0.941	0.892
10	0.667	0.431	1.179	0.235	1.208	1.229	0.329	0.959	1.061
11	1.006	1.039	0.812	0.852	0.972	0.674	0.397	1.052	0.549
12	0.635	0.547	1.709	0.896	0.852	1.276	0.731	1.107	1.154
13	1.364	0.342	0.393	1.238	0.784	0.522	1.154	0.815	0.709
14	1.316	0.243	0.569	1.326	0.605	1.133	1.298	0.982	1.623
15	0.961	0.248	1.164	1.221	0.774	1.03	1.138	1.005	0.874
16	0.941	1.458	1.14	1.063	0.757	1.009	1.207	0.885	0.855
17	1.678	1.354	0.635	1.629	1.757	0.984	1.346	1.864	1.049
18	0.599	0.516	0.605	0.846	0.643	0.937	0.789	0.731	0.908
19	0.486	0.836	0.98	0.457	0.782	1.084	0.639	0.931	0.956
20	0.319	0.617	1.447	0.45	0.769	1.174	0.943	0.749	0.941
21	1.495	0.858	0.671	1.29	0.669	0.557	1.23	0.608	0.906
22	0.817	0.211	0.495	0.807	0.657	0.547	0.645	0.085	0.742

Values of 90%, 95%, and 99% are the most commonly used confidence intervals in statistical applications. In this study, a 95% confidence interval was used to determine whether significant differences in the comparison to provide the same standards both t-student test and ANOVA test performed using the SPSS software. For example, if confidence interval is taken as 90% in this study, then some of the obtained results may be statistically significant.

Table 4 shows that all test values are below the limit value according to the confidence interval (95 %). It was found that coordinate differences determined as a result of the various registration methods used in this study are within the limits of measurement accuracy, and the t-student test revealed that the differences are consistent. In other words, there are no inconsistencies between the coordinates obtained by applying the three methods. The results obtained by each of these methods can be used for the purpose of TLS studies. It was observed that target coordinates of the identical points obtained using target-based (sphere) registration methods are closer to the Total Station coordinates considered as precise values in comparison to other methods.

In addition, the table below shows the results of the ANOVA test performed to determine whether there is a significant difference between the group mean values of the coordinates obtained with different registration methods compared to the Total Station. Each of the groups to be tested must have a normal distribution and have a homogeneous variance between the groups. Table 5Table 5 shows the homogeneity test results of the variances.

Table 5. Homogeneity test of variances

Test of Homogeneity of Variances				
Axis Direction	Levene Statistic	df1	df2	Sig.
x	0.000	3	84	1.000
y	0.000	3	84	1.000
z	0.000	3	84	1.000

It can be suggested that the variances are homogeneous as the p-value (Sig.) in Table 5 is greater than 0.05. As the main assumption of the variance analysis has been met, the results obtained from ANOVA have higher accuracy. Table 6 tests whether there is a significant difference between group mean values of the coordinates obtained from the Total Station and the different registration methods shown in the ANOVA table.

The table value (Sig.) of F with a 95 % significance was used to determine whether there is a statistical difference between group mean values of the coordinates obtained with the Total Station and the different registration methods. Although no significant difference was found between the group mean values, post hoc tests (Tukey Honestly Significant Difference (HSD)) were used to make comparisons in pairs. Table 7 shows the comparisons between group mean values.

Table 6. ANOVA values determined based on different variables

Coordinate Axes Directions	Source	Method				
		S.S	df	M.S	F	Sig.
x	Between Groups	0.000	3	0.000	0.00	1.000
	Within Groups	958.367	84	11.409		
	Total	958.368	87			
y	Between Groups	0.000	3	0.000	0.00	1.000
	Within Groups	1059.963	84	12.619		
	Total	1059.963	87			
z	Between Groups	0.000	3	0.000	0.00	1.000
	Within Groups	645.102	84	7.680		
	Total	645.103	87			

S.S: Sum of Squares, df: degrees of freedom, M.S.: Mean Square, Sig.: p- value

Table 7. Comparisons of mean values obtained from different methods in pairs

Tukey HSD

Independent Variable		x		y		z	
Method (I)	Method (J)	Mean Diff. (I-J)	Sig.	Mean Diff. (I-J)	Sig.	Mean Diff. (I-J)	Sig.
Total Station	Target	0.001	1.000	-0.001	1.000	-0.003	1.000
	Surface Matching	0.002	1.000	-0.002	1.000	-0.004	1.000
	Specific Point	0.001	1.000	-0.004	1.000	-0.005	1.000
Target	Total Station	-0.001	1.000	0.001	1.000	0.003	1.000
	Surface Matching	0.000	1.000	-0.001	1.000	-0.002	1.000
	Specific Point	-0.001	1.000	-0.003	1.000	-0.003	1.000
Surface Matching	Total Station	-0.002	1.000	0.002	1.000	0.004	1.000
	Target	0.000	1.000	0.001	1.000	0.002	1.000
	Specific Point	-0.001	1.000	-0.002	1.000	-0.001	1.000
Specific Point	Total Station	-0.001	1.000	0.004	1.000	0.005	1.000
	Target	0.001	1.000	0.003	1.000	0.003	1.000
	Surface Matching	0.001	1.000	0.002	1.000	0.001	1.000

Sig.: P value, Dependent Variable: Coordinate Axis Direction (x, y, z)

Subsets were created to determine the effectiveness of methods considered as independent variables on the mean point coordinates considered as dependent variables, and whether they exhibit the same or different properties (Table 8).

Analysis of the subsets created, based on the coordinate axis directions (x, y, and z), showed that they exhibit similar statistical properties to the results obtained from the methods used in the registration of the scans captured from different perspective points.

Table 8. Subsets of coordinates for each registration method

	Tukey HSD		
	x	y	z
Method	Subset		
	1	1	1
Surface Matching	991.679550	1008.47000	104.06518
Target	991.679730	1008.47114	104.06791
Market Point	991.680550	1008.47182	104.06959
Total Station	991.681180	1008.47373	104.07064
Sig.	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
Subset for alpha = 0.05, Sig. = the P-value.

The results presented were obtained to compare the accuracy of different registration techniques on the same test object in the same atmospheric and environmental conditions. The results may vary with different material properties, electrical conductivity, magnetic validity and conductivity, surface color, surface roughness, surface temperature and humidity and other features on objects and in different environmental conditions (temperature, pressure, and humidity). Therefore, a further study is planned to investigate the accuracy of different registration techniques on different objects and in different environments.

4. CONCLUSIONS

In this study, a statistical analysis was performed on the final product accuracy of target-based (sphere) specific points and surface-matching methods used for the registration of scans made on an historical building from different perspective points. The statistical t-student test and Analysis of Variance (ANOVA) were used to determine whether there is a statistical difference between coordinates found by registration of the specific points on an historical building facade. Registration methods were analyzed to reveal their effects on the final surface model, their accuracy, and their similarities

The result of the comparisons made on weighted 3D positional accuracies found in the three methods, based on the least squares procedure, shows that target-based (sphere) registration methods reflect the positional accuracy more realistic than the other methods. The surface-matching method revealed better results compared to the method using specific points.

The t-student test revealed no significant statistical differences in the comparison of point-based coordinate registration methods. It was found that coordinate differences are within the limits of measurement accuracy and the t-student test revealed that the differences are consistent. The statistical ANOVA confirmed that there are no differences between the mean values of coordinate groups obtained with the registration methods and the Total Station. Subgroups were created to determine the effectiveness of methods on mean point coordinates and whether they exhibit the same or different properties. Methods used for determining the characteristic point coordinates in the building scanned for the purpose of this study, showed similar properties.

The results obtained suggest that target selection in laser scanning applications is particularly important for determining the target centers in the point cloud. The surface-matching method can lead to erroneous registrations on non-flat surfaces with limited details. In particular, the accuracy in marking the specific points in a point cloud can vary based on the person performing the marking. It is likely for the user to select an incorrect point on the front- or back-plane. Statistical data obtained with the software following the registration must be checked. The accuracy of tools and methods such as GPS or the Total Station, used for georeferencing, may affect the accuracy of the final surface model.

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