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Published in:
Proceedings. The XXV FIG International Congress 2014

Publication date:
2014

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Jamali, A., Antón Castro, FF., Boguslawski, P., & Gold, C. M. (2014). Trimble LaserAce 1000 Accuracy Evaluation for Indoor Data Acquisition. In *Proceedings. The XXV FIG International Congress 2014* International Federation of Surveyors, FIG.

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Trimble LaserAce 1000 Accuracy Evaluation for Indoor Data Acquisition

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Key words: Indoor surveying, 3D data acquisition, Laser scanning, Accuracy evaluation

SUMMARY

Surveying can be done using several sciences and techniques for outdoor and indoor data acquisition like photogrammetry, land surveying, remote sensing, Global Positioning System (GPS) and laser scanning. Electronic Distance Measurement (EDM) is a reliable and frequently used technique. Laser scanning is costly and time consuming compared to the other mentioned techniques. Currently, GPS is one of the most commonly used techniques to measure coordinates, distances and angles between points in outdoor environments, but it has drawbacks in indoor environments (e.g. signal penetration and multiple paths). Currently, for indoor surveying, EDM and Terrestrial Laser Scanner (TLS) are mostly used. In this paper, several techniques for indoor 3D building data acquisition have been investigated. A rapid technique for indoor building data acquisition, with a special focus put on a rangefinder (a mobile device) is proposed. The accuracy of the rangefinder is evaluated and a simple spatial model from real data reconstructed. This technique is rapid (it requires a shorter time as compared to others), however the results show inconsistencies in horizontal angles for short distances in indoor environments. Results were calibrated by a least square adjustment algorithm. Future research attempts will investigate object reconstruction algorithms to optimize measurements.

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1. INTRODUCTION

Traditional land surveying, photogrammetry, remote sensing, Global Positioning System (GPS) and laser scanning are some of the well-known techniques in the field of surveying engineering which can be used for indoor and outdoor data acquisition. In this paper, we compare three different surveying techniques in the context of indoor mapping: classical land surveying with a total station (Leica 307 TCR), Light Detection and Ranging (LiDAR) surveying with a laser scanner (Leica scanstation C10) and a laser based rangefinder (Trimble LaserAce 1000). Land surveying is “the science of determining the position, in three dimensions, of natural and man-made features on or beneath the surface of the Earth” (Schofield, 2001). In the 1960s, the first Electronic Distance Meters (EDMs) came into existence, but they were too expensive. High demands for EDMs decreased the device price and made it affordable. EDM is one of the most reliable and used techniques in the field of land surveying which can be used for precise distance measurement and determining the coordinates of any point. New EDM equipment is highly accurate and with the current speed of technology development in surveying engineering, more advanced functions of EDM is expected. Remote sensing is defined as information acquisition about an object without physical contact with the object (Elachi and Zyl, 2006). Remote sensing can be passive or active. Passive remote sensing detects natural radiation that is either reflected or emitted. Sun reflection is the most common source for passive remote sensing. Active remote sensing uses sensors, which emit an electromagnetic radiation. DTM and DSM can be captured by using Airborne Laser Scanning (ALS). This technology (ALS/LiDAR) emits or captures signals returned from the surface of the Earth. Inertial Measuring Unit (IMU), GPS and laser scanning systems are the three main parts of an ALS system (Tse et al., 2008). Recently, there has been more interest for 3D building modeling based on LiDAR data, but extracting buildings from huge LiDAR datasets is difficult and time consuming and requires experienced technicians. Indoor positioning has become an important problem in many different applications (Deak et al., 2012). According to Donath and Thurow (2007), considering various fields of applications for building surveying and various demands, geometry representation of a building is the most crucial aspect of a building survey. Laser scanning technology started in the 1990s (Amato et al., 2003) and it can measure a 3D object surface with a high speed pulse. This technology is considered as a tool for remote and rapid data collection and it can be used in many different applications from urban and regional planning to architecture. A scanner can directly measure distance and reflection intensity of 3D object surfaces and automatically store collected data in a spatial database. Recent TLS technology can collect more than 500,000 points in a second with an accuracy of ± 6 mm (Dongzhen et al., 2009). The full scan collects a set of 3D points, which is called a point cloud, or a full

waveform digitizing along each beam. Point clouds are collection of unrelated 3D points defined by their 3D coordinates (X, Y and Z), as well as reflection intensities which can be used in accuracy estimation in a post-processing phase. A point cloud is normally an unordered list but it can be processed and ordered into a 2D array of point coordinates (range image). Nowadays, most of scanners can export collected point clouds in the range image format. An important issue of TLS is that scanners can only acquire points within the direct or reflected line of sight. As a result, in order to acquire full data from a given scene, multiple scans from different viewpoints have to be done, and then they have to be registered accurately in a common coordinate system.

In this research, we provide a comparative analysis of the 3D reconstruction and indoor survey of part of a building, done using the Leica scanstation C10 (laser scanner), the Leica 307 TCR (total station) and the Trimble LaserAce 1000 (rangefinder, see Figure 1). The Trimble LaserAce 1000 is a three-dimensional laser rangefinder with point and shoot workflow. This rangefinder includes a pulsed laser distance meter and a compass, which can measure distance, horizontal angle and vertical angle up to 150 meters without a target and up to 600 meters with a reflective foil target. The Trimble LaserAce 1000 has been used for outdoor mapping and measurements, such as forestry measurement and GIS mapping. A rangefinder can be considered as a basic mobile Total Station with limited functionality and low accuracy. In this research, we propose this device for indoor mapping and try to validate this technique in an indoor environment.



Figure 1. Surveying devices: a) Leica scanstation C10 b) Leica 307 TCR c) Trimble LaserAce 1000

In this paper, we conduct a comparative analysis of different surveying devices in the context of indoor surveying. This comparative analysis allows us to validate the use of a rangefinder in an indoor environment. Models reconstructed from a laser scanner point cloud and data collected with Total Station were used as benchmarks for the rangefinder.

2. 3D BUILDING MODELLING AND REPRESENTATION

In a surveying project, data acquisition, processing and modelling will be done separately, which is time consuming and costly. This research is an attempt to integrate these separate procedures of surveying into one step. Acquisition time and accuracy were considered as two

important factors in this paper. The rangefinder was connected to a personal laptop via Bluetooth and data capturing and modelling was done simultaneously. For validating the reconstruction done by the Trimble LaserAce 1000, the Leica 307 TCR and Leica scanstation C10 were used. The number of stations and the time required for data capturing and modelling for each device has been examined (see Table 1). Two rooms and one corridor were measured. The time of measurement and for 3D modelling has been examined, as well as the surveyor's experience. 3D measurement and 3D modelling using the Trimble LaserAce 1000 was done simultaneously. In the case of the other two devices, the collected data was processed and the model was reconstructed in a lab after the field data collection. Table 1 shows the big difference in time for the three investigated devices, due to the separate processing and modelling procedures for the Leica scanstation C10 and Leica 307 TCR, as compared to simultaneous field data acquisition and modelling for the Trimble LaserAce 1000.

Table 1. Time and number of benchmark for surveying.

Surveying Equipment	Time	Number of Benchmarks
Leica scanstation C10	600 (Minutes)	4
Leica 307 TCR	120 (Minutes)	3
Trimble LaserAce 1000	15 (Minutes)	3

Data collection, processing (pre-processing and post-processing), modelling and representation of laser scanner are considered as difficult tasks to handle, which is a drawback and significantly increases the time and cost of mapping. All laser scanning procedures require an expert's knowledge.

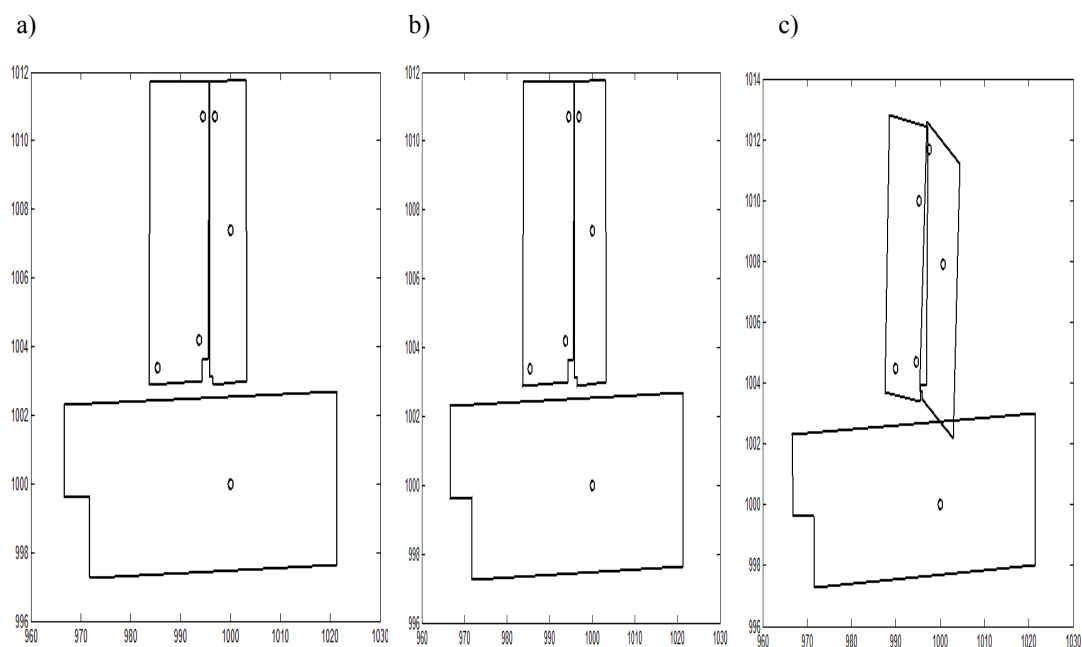


Figure 2. Footprint of a building reconstructed using: a) Leica scanstation C10, b) Leica 307 TCR and c) Trimble LaserAce 1000.

The 3D buildings captured by Leica 307 TCR and Leica scanstation C10 were precise and they showed almost the same results. The Trimble LaserAce 1000 showed inconsistent behaviour over short distances in an indoor environment, with errors in horizontal angles which caused overlapped and rotated models (see Figure 2). Results showed 3D modelling based on the geometry using Trimble LaserAce 1000 is inadequate and topology needs to be considered. Dual Half Edge (DHE) data structure showed compatibility for this research (Jamali et al., 2013). The dual half edge (DHE) data structure is used for 3D spatial modelling. The Dual Half-Edge (DHE) is a new general data structure that can be used to represent the geometry and topology of a 3D digital spatial model with the special application of building interior modelling. Construction operators allows for rapid 3D modelling and model editing.(Boguslawski, 2011; Boguslawski et al., 2011). This rapid indoor data acquisition could possibly be utilized in 3D cadastre, emergency management systems (e.g. evacuation simulation), building information systems and inventory systems. The proposed indoor surveying technique could be beneficial wherever architectural plans are not available or where they are out of date. This research has been done to investigate the reduction of the cost and time of the data acquisition and reconstruction processes.

3. RANGEFINDER CALIBRATION

Coordinates measured by rangefinder are not as precise as laser scanner or total station measurements. According to the device specifications, the accuracies of the Leica scanstation C10, Trimble LaserAce 1000 and Leica 307 TCR are as shown in Table 2.

Table 2. Accuracy of Leica scanstation C10, Leica 307 TCR and Trimble LaserAce 1000 according to the product specifications.

Surveying Equipment	Distance Accuracy	Horizontal Accuracy	Angle	Vertical Accuracy	Angle
Leica scanstation C10	±4 mm	12"		12"	
Leica 307 TCR	±3 mm ± 2ppm	7"		7"	
Trimble LaserAce 1000	±100 mm	7200"		720"	

The 3D building measured by the Trimble LaserAce 1000 can be calibrated and reconstructed from the Leica scanstation C10 or Leica 307 TCR based on the least square adjustment algorithm, in the form of absolute orientation. Least square adjustment is a well-known algorithm in surveying engineering which is used widely by engineers to get the best solution in the sense of the minimization of the sum of the squares of the residuals, which is obtained as in the following normal equations, which express that the derivate of the sum of squares of residuals is zero. Least square adjustment for linear (Equation (1)) system was used to reconstruct 3D objects.

$$X = (A^TWA)^{-1}A^TWL = N^{-1}A^TWL \quad \text{Equation (1)}$$

Where L = observation
W = observation weights
X = unknowns
A = coefficient of unknowns.

Considering two points, $P_a = (X_A, Y_A, Z_A)$ from the Leica scanstation C10 or Leica 307 and $P_c = (X_C, Y_C, Z_C)$ from the Trimble LaserAce 1000, the absolute orientation problem can be defined as the transformation between two coordinates systems (Leica scanstation C10 or Leica 307 and Trimble LaserAce 1000). The relationship between two measuring devices, such as a range camera or binocular stereo system can be solved by using absolute orientation. Absolute orientation can be found by a set of conjugate pairs: $\{(P_{c,1}, P_{a,1}), (P_{c,2}, P_{a,2}), \dots, (P_{c,n}, P_{a,n})\}$. For a pair of common points in both (camera coordinates and absolute coordinates) systems; rotation and scale components can be calculated by Equations 2 to 4.

$$X_A = R_{XX} X_C + R_{XY} Y_C + R_{XZ} Z_C + P_X \quad \text{Equation (2)}$$

$$Y_A = R_{YX} X_C + R_{YY} Y_C + R_{YZ} Z_C + P_Y \quad \text{Equation (3)}$$

$$Z_A = R_{ZX} X_C + R_{ZY} Y_C + R_{ZZ} Z_C + P_Z \quad \text{Equation (4)}$$

Twelve unknown parameters, including nine rotations parameters and three scale factors need to be solved. Each conjugate pair yields three equations. The minimum number of required points to solve for the absolute orientation is thus four common points. Practically, to get better results with higher accuracy, a higher number of points need to be used. The coefficients of the unknown matrix A, which is a 4*4 matrix, have been calculated. The coordinates of the points measured by the rangefinder can be adjusted, or their maximum error can be minimized, by adjusting the coefficients of matrix A. One room has been selected by the researcher to calculate its absolute orientation parameters. Table 3 shows the calculated rotation and scale parameters in three axes for the selected room.

Table 3. Coefficient of unknowns including rotation and scale parameters (matrix A).

R	X coefficient	Y coefficient	Z coefficient	Scale coefficient
X	1.33270015372545	-0.10712589017	-0.000399899952	225.02889698743
Y	0.05200432914716	0.956343347497	0.0003783837164	8.3597756922245
Z	-0.0067696326204	0.00591486567	0.9999382391679	0.7221034094691

Absolute orientation can be found by computing the matrix A for any given point. Any points measured by the rangefinder can be transferred or absolutely oriented by using the corresponding matrix A arrays. Results from calibrating the Trimble LaserAce 1000 based on the least square adjustment (Absolute orientation) using the Leica scanstation C10 data were calculated (see Table 4).

Table 4. LaserAce 1000 calibration based on the least square adjustment (Absolute orientation).

Point Number	X _{LaserAce}	Y _{LaserAce}	Z _{LaserAce}	X _{Leica C10}	Y _{Leica C10}	Z _{Leica C10}
1	10.367	3.9172	1.0697	10.424	3.725	1.105
2	2.1958	2.1672	1.1658	2.162	2.249	1.109
3	1.9341	3.2855	1.1022	1.956	3.355	1.109
4	1.4395	3.2418	1.0959	1.396	3.257	1.116
5	-0.01771	10.764	1.0618	0.047	10.605	1.108
6	8.8615	12.081	1.1601	8.803	12.246	1.115
7	10.351	3.8923	-1.6335	10.425	3.725	-1.584
8	2.198	2.1474	-1.5272	2.161	2.25	-1.591
9	1.9392	3.2962	-1.5904	1.957	3.354	-1.582
10	1.4512	3.2245	-1.587	1.395	3.258	-1.575
11	-0.0147	10.784	-1.6109	0.048	10.605	-1.591
12	8.871	12.073	-1.5426	8.802	12.245	-1.575

Results from calibrating the Trimble LaserAce 1000 based on the least square adjustment using Leica 307 TCR data were calculated (see Table 5).

Table 5. LaserAce 1000 calibration based on the least square adjustment (Absolute orientation).

Point Number	X _{LaserAce}	Y _{LaserAce}	Z _{LaserAce}	X _{Leica 307}	Y _{Leica 307}	Z _{Leica 307}
1	995.55	1011.7	101.13	995.73	1011.7	101.07
2	995.86	1003.6	101.3	995.52	1003.6	101.28
3	994.26	1003.5	101.23	994.37	1003.6	101.27
4	994.2	1003	101.23	994.33	1003	101.28
5	983.52	1002.9	101.21	983.6	1002.9	101.15
6	983.98	1011.7	101.23	983.85	1011.7	101.28
7	995.58	1011.7	98.423	995.72	1011.7	98.37
8	995.89	1003.6	98.596	995.53	1003.6	98.59
9	994.25	1003.5	98.534	994.38	1003.6	98.56
10	994.22	1003.1	98.541	994.32	1003	98.58
11	983.49	1002.9	98.528	983.61	1002.9	98.46
12	983.99	1011.7	98.524	983.84	1011.7	98.59

Considering the Leica scanstation C10 or Leica 307 data as absolute coordinates, differences between two coordinate systems can be referred as the Trimble LaserAce 1000 accuracy. The accuracy achieved by the least square adjustment was calculated using Equations 5 to 8.

$$\sigma_X = X_{\text{LaserAce}} - X_{\text{Leica C10/leica 307}} \quad \text{Equation (5)}$$

$$\sigma_Y = Y_{\text{LaserAce}} - Y_{\text{Leica C10/leica 307}} \quad \text{Equation (6)}$$

$$\sigma_Z = Z_{\text{LaserAce}} - Z_{\text{Leica C10/leica 307}} \quad \text{Equation (7)}$$

$$\sigma_{XYZ} = (\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2)^{1/2} \quad \text{Equation (8)}$$

Where σ_{XYZ} =accuracy of LaserAce 1000
 σ_X =accuracy of LaserAce 1000 in the X Axis
 σ_Y =accuracy of LaserAce 1000 in the Y Axis
 σ_Z =accuracy of LaserAce 1000 in the Z Axis

Table 6 shows the accuracy of the LaserAce 1000 achieved by calibration using the Leica scanstation C10 for twelve selected points.

Table 6. Accuracy of the LaserAce 1000 achieved by calibration for twelve selected points using the Leica scanstation C10.

Point Number	σ_X	σ_Y	σ_Z	σ_{XYZ}
1	-0.057	0.1922	-0.0353	0.20356
2	0.0338	-0.0818	0.0568	0.10517
3	-0.0219	-0.0695	-0.0068	0.073185
4	0.0435	-0.0152	-0.0201	0.050272
5	-0.0647	0.159	-0.0462	0.17777
6	0.0585	-0.165	0.0451	0.18078
7	-0.074	0.1673	-0.0495	0.18951
8	0.037	-0.1026	0.0638	0.12636
9	-0.0178	-0.0578	-0.0084	0.061059
10	0.0562	-0.0335	-0.012	0.066518
11	-0.0627	0.179	-0.0199	0.1907
12	0.069	-0.172	0.0324	0.18813

Table 7 shows the accuracy of the LaserAce 1000 achieved by calibration using the Leica 307 TCR for twelve selected points.

Table 7. Accuracy of the LaserAce 1000 achieved by calibration for twelve selected points using the Leica 307 TCR.

Point Number	σ_X	σ_Y	σ_Z	σ_{XYZ}
1	-0.18	0	0.06	0.18974
2	0.34	0	0.02	0.34059
3	-0.11	-0.1	-0.04	0.15395
4	-0.13	0	-0.05	0.13928
5	-0.08	0	0.06	0.1
6	0.13	0	-0.05	0.13928
7	-0.14	-0.01	0.053	0.15003
8	0.36	0.01	0.006	0.36019
9	-0.13	-0.11	-0.026	0.17227
10	-0.1	0.09	-0.039	0.14007
11	-0.12	0.01	0.068	0.13829

12	0.15	-0.01	-0.066	0.16418
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Point number eight has a maximum error of ± 36 centimetres and there is minimum error of ± 10 centimetres for point number five (see Table 6). The 3D building calibrated and reconstructed using the Leica scanstation C10 is shown in Figure 3.

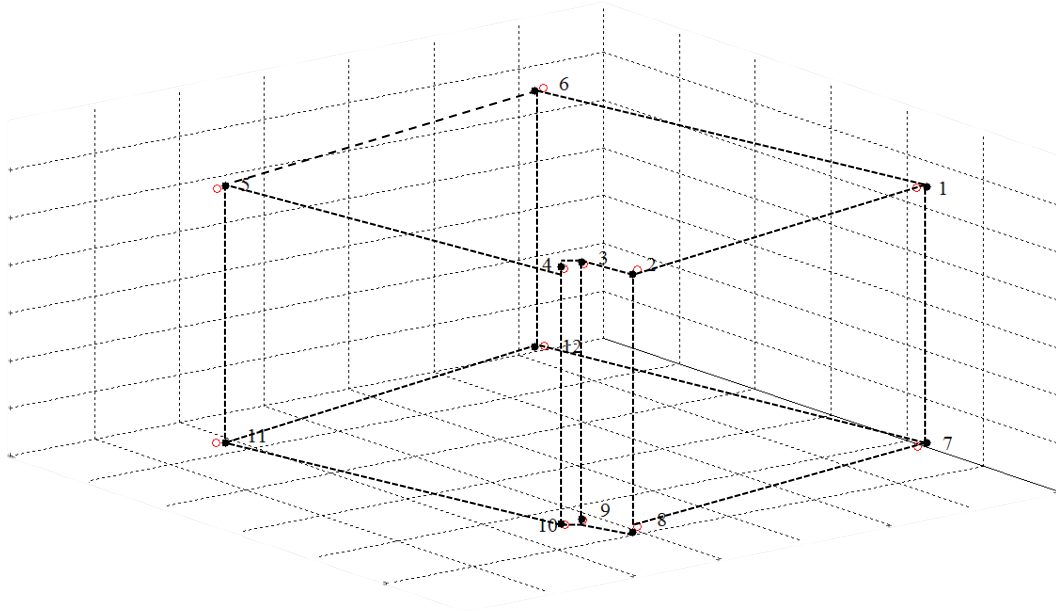


Figure 3. 3D model calibrated and reconstructed based on the least square adjustment; Trimble LaserAce 1000 (White circles) and Leica scanstation C10 (Black dots)

The 3D model calibrated and reconstructed using Leica scanstation C10 is shown in Figure 4.

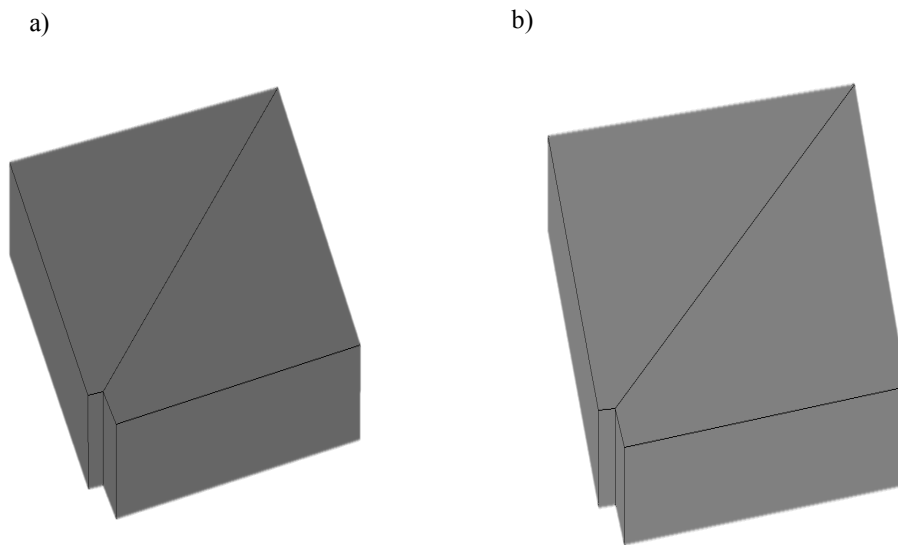


Figure 4. 3D model calibrated and reconstructed based on the least square adjustment: a) Trimble LaserAce 1000 b) Leica scanstation C10

The 3D building calibrated and reconstructed using the Leica 307 TCR is shown in Figure 5.

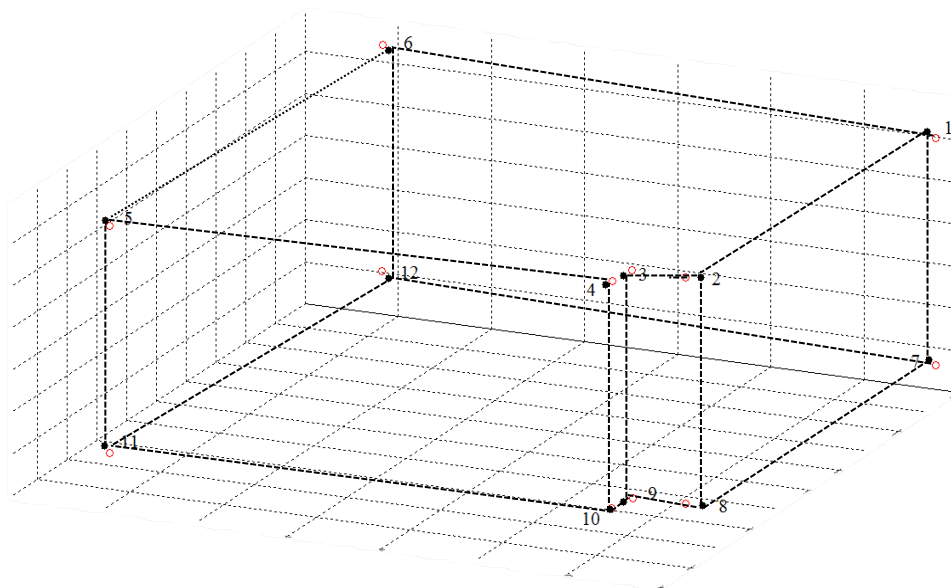


Figure 5. 3D model calibrated and reconstructed based on the least square adjustment; Trimble LaserAce 1000 (White circles) and Leica 307 TCR (Black dots)

The 3D model calibrated and reconstructed using the Leica 307 TCR is shown in Figure 6.

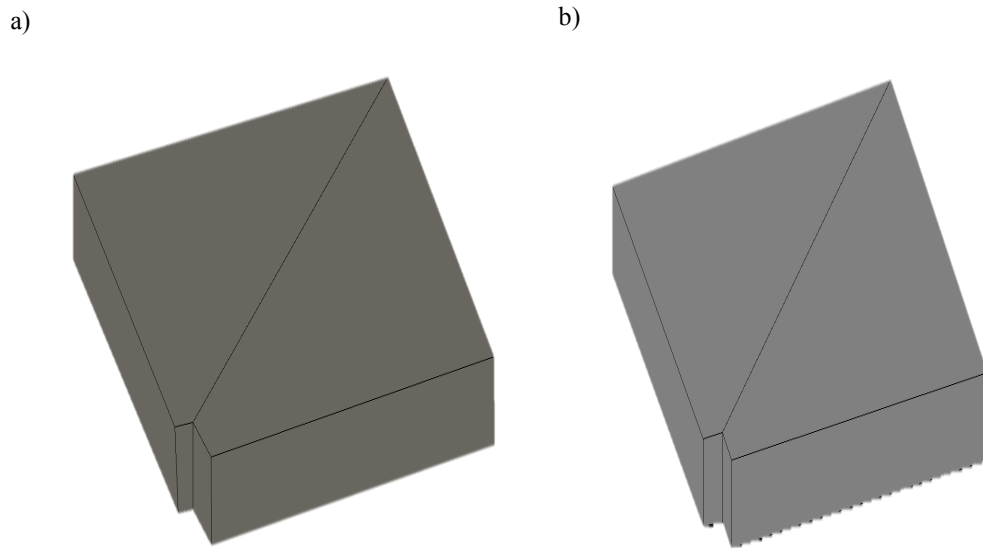


Figure 6. 3D model calibrated and reconstructed based on the least square adjustment:
 a) Trimble LaserAce 1000 b) Leica 307 TCR

Figure 7 shows the comparison between the Leica scanstation C10 and the Leica 307 TCR for the Trimble LaserAce 1000 calibration for twelve selected points.

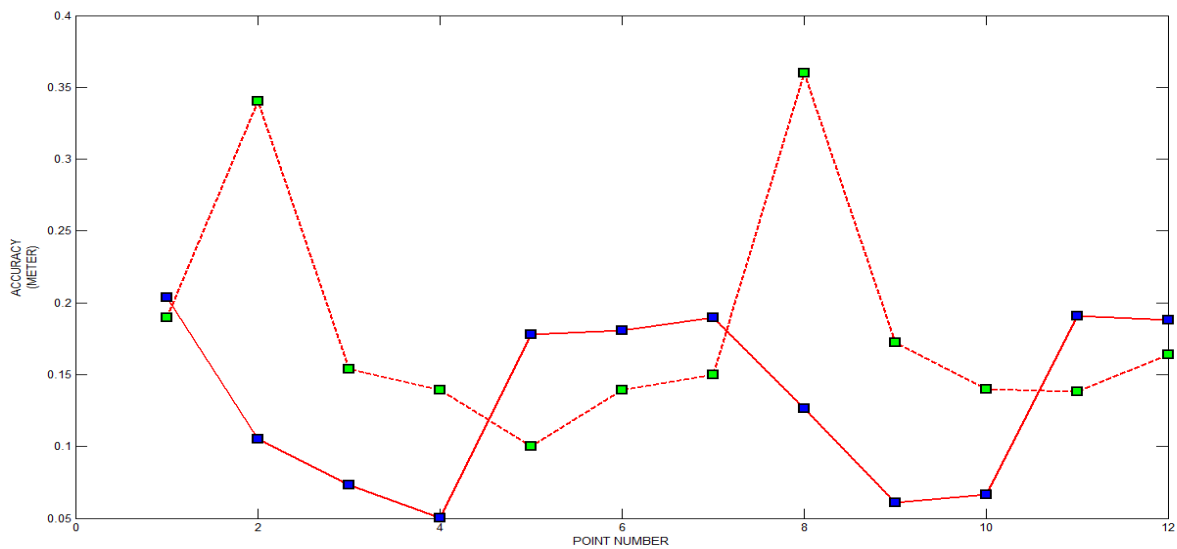


Figure 7. Result of Trimble LaserAce 1000 calibration using Leica scanstation C10 (continuous solid line) and Leica 307 TCR (dash line) for twelve selected points.

CONCLUSION REMARKS

This research has been done to investigate a technique of rapid indoor surveying and its accuracy in an indoor environment. The main objective of this research was to propose a methodology for data capturing and 3D modelling simultaneously. A rangefinder was compared to two high accurate surveying devices (Leica 307 TCR and Leica scanstation C10). In an indoor environment, the Trimble LaserAce 1000 showed inconsistency for short distances in the horizontal angle (see Figure 2). Rangefinder data was calibrated by least square adjustment (absolute orientation) which shows a maximum error of ± 20 centimetres and a minimum error of ± 5 centimetres using the Leica scanstation C10 as a benchmark and maximum error of ± 36 centimetres and minimum error of ± 10 centimetre using the Leica 307 TCR as a benchmark (see Figures 3 and 5). The Leica 307 TCR and Leica scanstation C10 have results with consistent 3D models (see Figure 2). This research showed that reconstruction of 3D Buildings based on the geometry using Trimble LaserAce 1000 is inadequate and topology needs to be considered. The authors of this paper intend to investigate model reconstruction algorithms in the near future based on the geometry and topology modelling.

ACKNOWLEDGEMENT

This research is supported by the Ministry of Higher Education in Malaysia (ERGS grant, vote no. 4L047, Universiti Teknologi Malaysia). We also would like to thank Prof. Alias Abdul Rahman for his contribution in this research at Universiti Teknologi Malaysia.

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BIOGRAPHICAL NOTES

Ali Jamali holds an MSc degree in Geoinformatics from Universiti Teknologi Malaysia in Malaysia and a BSc degree in Civil engineering (Surveying engineering) from IAU in Iran. He is currently a PhD researcher with the 3D GIS group of the faculty of Geoinformation and Real Estate at the Universiti Teknologi Malaysia. His current research interest includes indoor surveying and 3D building modeling.

François Anton is an Associate Professor at the Danish National Space Institute, Technical University of Denmark in Denmark. . He completed his Ph. D. in Computer Science (at the interface of Scientific Computation, Computational Algebraic Geometry and Computational Geometry), at the University of British Columbia, Vancouver, British Columbia, Canada, with courses in Algebraic Geometry and Algebraic Topology from the Department of Mathematics at U.B.C..

Pawel Boguslawski is a Senior Lecturer at the Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia. He completed the PhD research at the GIS Department, University of Glamorgan, United Kingdom. He was graduated MSc degree in Computer Science from Bialystok Technical University, Poland. His main research area is 3D modelling, in particular building interior modelling.

Christopher Gold completed his PhD in Geology & Computer Science (at the University of Alberta, Canada). In 1990 he was appointed the Senior Researcher of an Industrial Research Chair funded by the Quebec Forest Industry and the Canadian National Science and Engineering Research Council (NSERC). From 2000-2004 he was Professor and Research Director, Land Surveying Dept., Hong Kong Polytechnic University. From 2004-2007 Prof. Gold held the post of "EU Marie Curie Chair" with the GIS Research Group at the University of Glamorgan. Currently he is a Visiting Professor at several universities in China and Malaysia. He is Associate Editor (GIS) of the journal 'Geo-spatial Information Sciences'. Professor Gold has been active for over 30 years in the development of spatial data structures, spatial models of perception and adjacency, Geo-informatics applications, and algorithms. He has approximately 200 publications and presentations in many fields – GIS (Geographic Information Science), Computer Science, Geology, Forestry and others. He is known in the Geo-informatics community for his work on spatial data structures, Voronoi diagrams, dynamic mapping and 3D modelling.

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