Accuracy of 3D Building Models Created Using Terrestrial and Airborne Laser Scanning Data

Andrzej BORKOWSKI, Poland, Grzegorz JOZKOW, USA, Marcin ZIAJA and Kazimierz BECEK Poland

Key words: terrestrial laser scanning, airborne laser scanning, 3D modelling, accuracy

SUMMARY

There is a growing interest in building modelling, especially from laser scanning data; 3D models are used in many professional applications, such as urban planning, spatial analysis, inventories of historical and cultural heritage, promotion of tourist places, and Building Information Modelling (BIM).

This work presents the accuracy assessment of 3D building models created from combined airborne and terrestrial laser scanning data. The investigation was performed on both heritage and residential building models created from LiDAR point clouds acquired using terrestrial Leica ScanStation C10 and airborne Riegl LMS-Q680i scanners. Terrestrial Laser Scanning (TLS) data obtained with average point spacing of about two centimetres was the primary data used in modelling. For the modelling of building elements that were invisible from ground stations, e.g. roofs, Airborne Laser Scanning (ALS) data was used; it was collected with a density of about 12 pts./m2. Stitching of TLS and ALS was simplified by transforming both into the same coordinate system. Finally, textures mapping was applied, whereby textures were created from digital images taken with a camera Canon 40D. Modelling was performed semi-automatically using both the commercial software Leica Cyclone, as well as the author's software.

While the accuracy of models is affected by many factors, such as scanning data accuracy, TLS and ALS data integration errors, model generalization or textures errors, it is challenging to discover the impact of all these parameters separately. In this work the accuracy assessment of 3D models is performed considering the influence of all these factors simultaneously.

The accuracy of models was assessed by comparing the coordinates of characteristic points of the models and the corresponding coordinates of these points measured on the real buildings, obtained by using total station Leica TCR407Power. The field-measured points were treated as error-free reference points.

In order to reduce systematic errors and offset between TLS and ALS point clouds the Iterative Closest Point (ICP) algorithm was applied for better point clouds registration.

As a result of accuracy assessment, it was found that the planimetric offsets for 3D models are below 10 cm, and the vertical offsets are at the zero level. Furthermore, as a result of experiment, it was also found that the geometry of the scanning has negligible impact on final accuracy of the model.

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1. INTRODUCTION

There is a growing interest in 3D building modelling, especially from laser scanning data. The main reason for this phenomenon is the greater availability of laser scanning data and an increase in scan resolution. Highly detailed 3D models are used in many professional applications, such as urban planning, spatial analysis, inventories of historical and cultural heritage, promotion of tourist places, and building information modelling (BIM).

3D building modelling based on laser scanning data is also a current research problem, especially in the development of methods and algorithms that allow for automating the modelling process, which are based primarily on airborne laser scanning data. Such modelling is a complex process in which a number of problems have to be solved, from the identification of the building in the data set to the reconstruction of the vector model. A review and discussion of issues in this research area can be found in the current works (Vosselman and Maas, 2010; Awrangjeb et. al., 2010; Keller and Borkowski, 2011).

A laser scanning product in the form of cloud of points recorded by a terrestrial laser scanner is in itself a good representation of a 3D building model due to its high scanning resolution. However, due to the size of its data sets, such model is not very practical in use. Therefore, there is a need to create geometric 3D models. Automatic modelling in the case of terrestrial scanning data refers to the modelling of building façades (Pu and Vosselman, 2006; Boulaassal et al., 2010).
Information from terrestrial laser scanning data is generally not sufficient for modelling the geometry of building roofs. The needed information may be obtained from the airborne laser scanning data, but it contains fragmentary information about the façades of buildings. Complete data for modelling geometric construction is obtained when datasets of airborne and terrestrial laser scanning are combined. Modelling based on combined datasets does not differ in principle from modelling based on airborne or terrestrial scanning data.

Airborne and terrestrial laser scanning datasets must be first properly referenced and aligned. This is because the sensors have varying level of precision, especially in terms of their horizontal accuracy for the points they collect. In this study the connection of point clouds was made using the Iterative Closest Point algorithm (ICP) (Besl and McKay, 1992). Based on the combined point cloud from airborne and terrestrial laser scanning 3D vector models were built and accuracy assessments were made.

The issue of the accuracy assessment of 3D modelling has already been discussed in the literature. Akca et al.'s, (2010) work proposed evaluating of the internal accuracy of the model on the basis of three-dimensional surface matching. Vosselman (2008), in his work, used the roofs of buildings modelled on the basis of the points of two adjacent scan strips to evaluate the horizontal accuracy of airborne laser scanning data. Indirectly, this was also an internal accuracy assessment of modelling the roofs of buildings. Oude Elberink and Vosselman (2011) work presents a comprehensive analysis of errors affecting the accuracy of modelling and the accuracy assessment of modelling various elements of buildings (mainly their roofs). The proposed method of assessing the accuracy is based on point cloud analysis - accuracy parameters resulting from the comparison of the created model and laser scanning data.

This study presents the opposite approach. The assessment of accuracy was based on a comparison of selected elements of the model with the results of measurement of these elements made directly on site. This assessment is based on an analysis of differences between two sets of data and is postulated in the paper (Oude Elberink and Vosselman, 2011). The assumption for this analysis is the availability of accurate reference data. In this study the role of precise reference data fulfil data from the tachymetric measurement of an object.

2. TEST DATA

2.1 TLS Data

Terrestrial laser scanning was performed by a Leica scanner ScanStation C10 with hardware accessories and Leica Cyclone Scan 8.1 software. For the purpose of scanning a few warp points were set up around the objects. These points were measured using the GNSS technique and were supported by ASG-EUPOS ground-based augmentation system. For measurements a Trimble R6 receiver was used. The coordinates of points were determined with better precision than three centimetres. All the coordinates were determined in the coordinate system EPSG:2180 and the Polish system of normal heights.

Warp points were used for georeferencing and connecting single scans. Terrestrial laser scanning was carried out using the resection method with the scanner being orientated to targets that were set up on warp points. The object scanning was made from many positions, with an average resolution of 2 cm on the object (the average distance between points on the object). The combination and transformation of scans were executed with the use of Cyclone Register 8.1 software. The accuracy achieved during registration was better than one centimetre for both horizontal and vertical components.

2.2 ALS Data

Airborne laser scanning was performed with the use of the Lite Mapper system (based on the full waveform scanner Riegl LMS-Q680i). Scanning was performed with a nominal resolution of 6 points per square meter. Because adjacent scans were side lapped up to 50%, the resulting cloud of points for the modelled object had a resolution of 12 points per square meter. The final coordinates of the points were delivered in the same coordinate systems as the coordinates of terrestrial scanning data.

2.3 Data Integration

Due to the differing precision of the TLS and ALS sensors the point clouds, derived from both sensors had a horizontal and height offset. To visualize this fact, a 3D model was created separately from the ALS and TLS data. Vector models of the same building are shown in Figure 1.

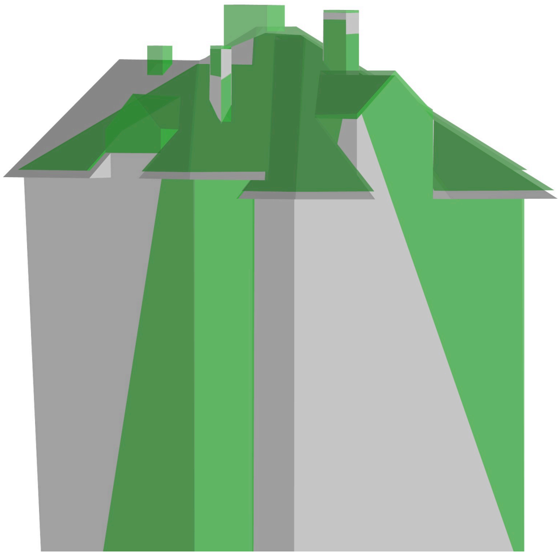

Fig. 1. Vector models of the same building created from airborne (green) and terrestrial (grey) scanning data only

This figure shows that both models intersect. Furthermore, a comparison between the lower edge of the roof shows that the model created from airborne laser scanning data is placed higher than the model created from terrestrial laser scanning data.
Borkowski and Jozkow (2012) found that the mean offset between two models, depending on the buildings, can reach a value up to 0.14 m for horizontal offset and up to 0.17 m for vertical offset, while for RMSE, it can reach up to 0.20 m.

For this reason, the ALS point cloud was aligned to the TLS point cloud, using the ICP algorithm (Besl and McKay, 1992). The data was transformed using CloudCompare V2. For each test object, TLS and ALS data were available. Both datasets have georeferences in the EPSG:2180 coordinate system. The connection and transformation of the data was performed separately for each building. Terrestrial laser scanning data were treated as a reference cloud (which does not move). For both test objects, the scale factor was fixed (equal to 1). The resulting transformation matrix was similar in each case. In the result a uniform point cloud for each building was made.

3. 3D MODELLING

The 3D modelling of buildings was performed through a project commissioned by the regional authorities in south-west Poland. The aim of the project was to develop 3D models of historic buildings in several cities in south-west Poland. 3D models have been created for regional promotion on the Internet and for internal local authorities for the protection of historic buildings. The 3D model developed for the historic centre of Opole is shown in Figure 2.

Fig. 2. A 3D model of the city of Opole

Modelling was performed using the Cyclone Model 7.1 software. The process of reconstruction a 3D vector model of building can be divided into the following stages (Borkowski and Jozkow, 2012):

- Use planes to approximate scanning data: To make subsequent texturing easer, the buildings' elements and architectural details were approximated by planes. The algorithm of growing regions was used to identify various planes in the data set.
- Model the edges of the building: The edges of the building were modelled as a result of the intersection between neighbouring planes.
- Check and correct the topology: This problem occurs most often in modelling the complex roofs of buildings. Three roof planes define only two edges. The next roof plane defines two edges additional, which often do not intersect with the previous ones at one point.
- Extend building walls: Each wall that has a connection to the ground has to be extended to DTM. In this work DTM was created as a mesh from ground points of airborne laser scanning data set. Walls were extended to their intersections with DTM mesh.
- Create a final 3D vector model: After geometric reconstruction, each building model was exported to DXF format.
- Texturing.

4. ACCURACY ASSESMENT

An accuracy assessment of the developed model was made by comparing the model with the measurement results made directly on site. The measurement was performed using a Leica TCR407 Power reflectorless total station from the warp points, where coordinates were determined with the use of the GNSS technique supported by the ASG-EUPOS system. Based on tachymetric measurements the coordinates of 115 reference points there were determined:

70 points for vector elements (corners of vector model) and 45 points for texture elements (corners not present in vector model but on textures). An example of reference points location for one building is shown in Figure 3.

Fig. 3. An example of the location of control points: vector (red) and texture (green) components of the model

For the corresponding control points, differences between heights and distances, (both horizontal and spatial) were calculated. This allowed for the vertical, horizontal and three-dimensional absolute accuracy of the model to be determined. The tachymetric measured points are highly accurate and can be treated as error-free. The results of the accuracy assessment are shown in Table 1.

	Building 1	Building 2
Horizontal		
min. residue	0.012m	0.013m
max. residue	0.203m	0.205m
mean residue	0.067m	0.092m
RMSE	0.078m	0.104m
Vertical		
min. residue	-0.166m	-0.135m
max. residue	0.138m	0.128m
mean residue	-0.011m	0.001m
RMSE	0.067m	0.075m
Three-dimensional		
min. residue	0.023m	0.048m
max. residue	0.208m	0.230m
mean residue	0.094m	0.118m
RMSE	0.103m	0.128m

Table 1. The results of the accuracy assessment.

Table 1 shows planimetric error for both buildings below 10 cm. In terms of height, it also shows that systematic error was almost completely eliminated and that the vertical offset was equal to zero. All errors were at the level of 10 cm or below.

To check the influence of the scanning angle on the error of the final model, an analysis of deviations on the same wall fragments was performed. A comparison of the wall fragments that were scanned from two scanner positions, (located in different geometrical configurations in relation to the scanned object) was made. In the first case, the angle of incidence of the laser beam to the scanned surface was close to a right angle. In the second case, the wall was scanned at an angle of about 40^o. The analysed wall was approximated as one plane on the basis of all scanning points that were referenced to this wall. For selected points within the test fields their distances from the approximated plane of the wall were calculated. Histograms of deviations and basic precision parameters for both scanning variants are shown in Figure 4. From this figure it can be seen that the histogram of the deviations better corresponds to the normal distribution when scanning is perpendicular and, when the normal distribution of skew scanning deviations is more degenerate. Overall, on the basis of the average deviations and RMSE errors, it can be concluded that the errors arising from the scanning geometry have no significant impact on the accuracy of the model. This result confirms previous research of this problem. In Soudarissanane et al.'s (2011) work laboratory tests showed, that the scan angle of this order (approximately 40^o) had no significant impact on the scanning error. There was also a huge decrease in the number of points in the case of skew scanning.

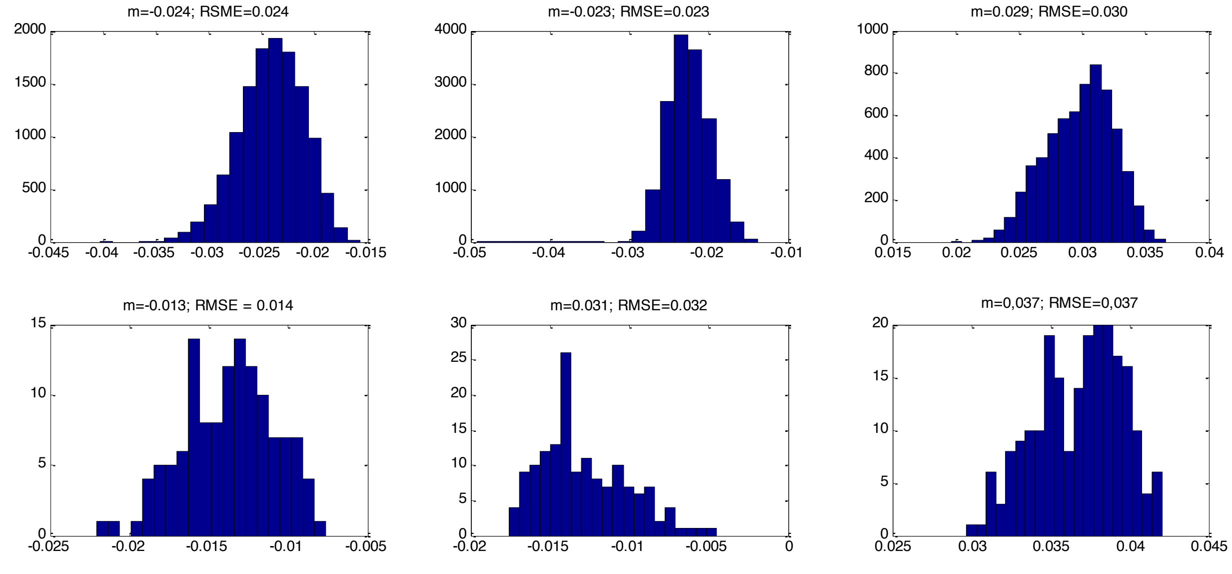

Fig 4. Distribution of residuals between modelled and scanned wall surface. For the top line, scanning was done perpendicular to the wall. For the bottom line skew scanning was done to the wall ("m" is the mean value of the residuals)

5. CONCLUSION

In recent years, the process of modelling buildings in 3D from laser scanning data has become more popular. 3D models are usually based on point cloud data from terrestrial or airborne laser scanning. In this paper an accuracy assessment of the 3D models of buildings was made based on the assessment of airborne and terrestrial laser scanning data. Both point clouds were registered by transforming the ALS point cloud into the TLS point cloud using the ICP algorithm. This operation eliminated the ALS systematic error which was equal to about 17 cm in the vertical direction. An assessment of accuracy was performed for two historic buildings with complex architecture. An absolute accuracy assessment was made by comparing the coordinates from homologous points (which were characteristic of the model) with the points that were measured directly on site. A direct measurement on site was performed with high accuracy using geodesic techniques. As a result of this comparison, it was found that the planimetric offset for both buildings was below 10 cm, and that the vertical offset was at the 0 level. 3D displacement of the model in relation to the measurements was at a level of about 10 cm. In addition, RMSE errors were also at the level of about 10 cm.

An experimental result also found that the geometry of the scan had negligible impact on the model's final accuracy. In conclusion, we can say that the 3D model created on the basis of the combined point cloud from ALS and TLS complies with the precision requirements of a wide range of customers, including those who require geodetic mapping.

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BIOGRAPHICAL NOTES

Andrzej Borkowski obtained his PhD in Geodesy from Dresden University of Technology, Germany. He has worked on different aspects of geo-data modelling, especially on modelling of geoinformation from airborne and terrestrial laser scanning point clouds. Andrzej has worked also on application of ALS and TLS data for landslides monitoring and for DTM generation and has published almost 200 journal and conference papers. He is a Fellow of International Association of Geodesy (IAG). Currently he is the Head of the Institute of Geodesy and Geoinformatics at the Wroclaw University of Environmental and Live Sciences in Poland.

Grzegorz Jozkow is currently working at The Ohio State University as a post-doctoral researcher. He obtained his M. Sc. degree in Geodesy and Cartography from the Agricultural University of Wroclaw (Poland) in 2003. From 2006 he studied at the Wroclaw University of Environmental and Life Sciences and defended his PhD in Geodetic Science in 2010. His research focuses on photogrammetry and remote sensing, in particular on methods for LiDAR data filtering and other processing. He is an author and co-author of more than 20 scientific publications, including proceedings and peer reviewed papers.

Marcin Ziaja graduated from Wroclaw University of Environmental and Life Sciences in 2013 with a Master Degree in Geodesy and Cartography. Currently he is a Research Assistant and a PhD student at the Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences, Poland. His main field of research is LiDAR data processing with a focus in data filtering.

Kazimierz Becek obtained his PhD and DSc (‘Habilitation’) from the Dresden University of Technology, Germany, in 1987 and 2010, respectively. He worked at the School of Surveying, UNSW, Sydney, Australia, from 1989 to 1994 before joining a publishing house on the Gold Coast, Australia in 1995 as head of the Cartography and Data Acquisition Department. He also worked for the Queensland state government and the Gold Coast City local government (both in Australia) from 1998. In 2003 he began working at the Geography Department, University of Brunei Darussalam, teaching Cartography, GIS, Photogrammetry, Remote Sensing and Surveying. His research interests include mathematical modelling of environmental systems, including landslide monitoring, natural hazard mapping, and applications of remote sensing methods for environmental studies. He is a former Vice-President of the Brunei Institution of Geomatics. He is currently holding the position of Senior Consultant at Soartech Systems, Brunei Darussalam, and Visiting Professor at the Wroclaw University of Environmental and Life Sciences, Poland.

CONTACTS

Prof. dr. habil. Andrzej Borkowski
MSc. Marcin Ziaja
Dr. habil. Kazimierz Becek
Institute of Geodesy and Geoinformatics,
Wroclaw University of Environmental and Life Sciences
ul. Grunwaldzka 53
50-357 Wroclaw
POLAND
Tel./Fax. +48 3205617
andrzej.borkowski@up.wroc.pl
marcin.ziaja@up.wroc.pl
kazimierz.becek@up.wroc.pl
www.igig.up.wroc.pl

dr Grzegorz Jozkow
Department of Civil, Environmental and Geodetic Engineering, The Ohio State University
211 Bolz Hall
470 Hitchcock Hall
2070 Neil Avenue, Columbus, OH 43210-1275
USA
Fax: 614-292-3780
jozkow.1@osu.edu