*Optica Applicata, Vol. XLII, No. 4, 2012*
DOI: 10.5277/oa120409

# Accuracy in target center evaluation using Riegl LMS Z390i laser scanner and Riscan Pro software

PAULO C.L. KRELLING[1], HIGINIO GONZÁLEZ-JORGE[2*],
JOAQUÍN MARTÍNEZ-SANCHEZ[2], PEDRO ARIAS[2]

[1]Univesidade Federal do Paraná, Sector de Ciencias da Terra, Departamento de Geociencias, CEP 800000-000 – Curitiba, Paraná, Brazil

[2]Universidade de Vigo, Area de Ingeniería Cartográfica, Geodesia y Fotogrametría, 36310 – Vigo, Spain

[*]Corresponding author: higiniog@uvigo.es

Terrestrial laser scanners are important instruments in architecture, civil engineering, cultural heritage, mining and industry. The accuracy of the system is determined from several parameters of influence (type of laser, quality of encoders, stability of the tripod, measurement range and changes in the environmental conditions). The surveying of large objects requires a number of base stations and a registration process to obtain a point cloud in the same reference system. The registration is typically done using targets fixed on the object surface and the determination of their center is an important source of error. In this work, the accuracy in the evaluation of the center of the targets, using the scanner Riegl LMS Z390i and its software Riscan Pro, is calculated for a set of horizontal and vertical angles. Riscan software automatically detects the center of the targets using intensity based segmentation and the geometrical calculations. Comparing the coordinates obtained from the laser scanner system software and the ground truth, an increasing in the error with the decreasing of the incident angle is observed. A linear fit is used for the study of the trend and there are not important differences between the type of target (circular or square) and the type of angle (horizontal or vertical).

Keywords: laser scanning, accuracy, target model influence.

## 1. Introduction

The laser scanners have been used during the last years for a number of applications in architecture [1], civil engineering [2], cultural heritage [3–5] and environmental studies [6, 7]. These instruments can obtain thousands of points coordinates in a very short time interval. The laser scanners are powerful instruments for inventory and inspection purposes.

Accuracy determination of laser scanners is an important topic of research. LICHTI *et al.* evidence uncorrected systematic errors with the Maptek I-Site laser scanner over and electronic distance measurement (EDM) calibration baseline on the wall of a West Australian rock fill dam [8]. The following years, the same group of researchers developed mathematical models which achieve improvements in the accuracy with the correction of the systematic errors [9–11]. ABMAYR *et al.* performed the calibration of the Z+F Imager 5003 using the error models taken from total stations and proposing a simple method which estimates the trunnion (secondary axis) axis error, collimation axis error and vertical circle index error [12].

Spatial resolution of laser scanners was also investigated to obtain the level of detail that can be resolved from a point cloud [13]. LICHTI *et al.* demonstrate that the sampling interval is not the only indicator of resolution and it must be complemented with the laser beam width. BOEHLER *et al.* developed an experiment to determine the angular accuracy, range noise, resolution and the effects of surface reflectivity [14]. The results showed that the range error increases as the distance between the scanner and the target surface increases. Angular accuracy determination was achieved by comparing the distance between the centers of two spheres using best--fitting techniques for the point cloud and using traditional coordinate measuring techniques.

The performance of a Zoller+Fröhlich Imager 5003 laser scanner has been analyzed by SHULTZ and INGENSAND [15]. They found that the maximum difference between a thousand measurements of single position increases from 5 mm at 5 m range to about 30 mm at 50 m range.

WUTKE [16] used different methods for the evaluation of resolution, precision and accuracy with a laser scanning system, the effects due to different kinds of targets and the dispersion of the point cloud with the distance.

GORDON *et al.* [17] presented the results concerning the accuracy and precision of a Cyrax 2400 3D laser which are about 4–15 mm and 3–5 mm, respectively.

MECHELKE *et al.* [18] compared the accuracy of several terrestrial laser scanning systems: Trimble GX, Mensi Gs 100/200, Leica ScanStaion, Z+F Imager 5006 and Faro LS880HE and the influence of color on range measurement.

A geometric verification of a terrestrial laser scanner Riegl LMS Z390i was developed by GONZÁLEZ-JORGE *et al.* [19] evolving some metrological procedures. Results obtained are in agreement with the accuracy and precision data given by the manufacturer, 6 mm and 4 mm, respectively.

Previous studies demonstrated the huge importance of the metrological studies of laser scanners. The aim of this work is to evaluate the errors on the center determination of the targets used for a registration process in multistation surveying using the Riegl LMS Z390i scanner and the Riscan Pro software. The center of the targets is automatically determined using an algorithm from the Riscan Pro software and the results are compared versus a ground truth measured by the authors.

# 2. Experiment

## 2.1. Laser scanner and software

A Riegl LMZ Z390i scanner (Fig. 1) has been used for the experiment. It is a rugged and fully portable sensor especially designed for the rapid and accurate acquisition of high-quality three dimensional data and specially indicated for architecture and facade measurement, archaeology and cultural heritage documentation, civil engineering, city modeling and topography. Measurements are performed using the time of flight principle for the range and two encoders for the evaluation of the horizontal and vertical angles [20]. Time of flight scanners use a diode pumped laser and the distance is based on the return flight time of each laser beam. They are specially indicated for large ranges. A rotating mirror with 90° travel is used for vertical measurement and a servo


◀ Fig. 1. Laser Scanner Riegl LMS Z390i.

T a b l e 1. Technical specifications of Riegl LMS Z390i.

| | |
|---|---|
| Measurement range | < 400 m |
| Minimum range | > 1 m |
| Accuracy (50 m) | 6 mm |
| Repeatability (50 m) | 4 mm |
| Measurement rate | 11000 pts/sec |
| Laser wavelength | Near infrared |
| Beam divergence | 0.3 mrad |
| Vertical scanner range | 0° to 80° |
| Vertical angle stepwidth | 0.002° |
| Horizontal scanner range | 0° to 360° |
| Vertical angle stepwidth | 0.002° |

motor that rotates 360° allows the horizontal scanning. The point cloud obtained from the spherical coordinates is then converted to Cartesian coordinates by the software. This laser scanner uses an infrared class 1 laser which is inherently safe without the possibility of eye damage. Table 1 shows the technical specifications of the scanner.

Riscan Pro is the software provided with Riegl terrestrial laser scanners. The Riscan Pro allows the entire data acquisition during a measurement campaign. These data include scans, fine scans, digital images, GPS data, coordinates of control points, and all transformation matrices necessary to transform the data of multiple scans into a common well-defined coordinate system. Control points for registration purposes are automatically obtained from the evaluation of the center of reflective targets situated in the objects. There is no information in the system about the algorithm used in the software for the center target determination and the relationship between the error and incident angles.

## 2.2. Calibration panel

A calibration panel was installed on a vertical plane test area, situated in a laboratory in the School of Mining Engineering at the University of Vigo (Spain). The calibration panel has 39 control points. The scanner was placed leveled and with the 90° horizontal angle approximately orthogonal to the calibration panel (Fig. 2). The distance between

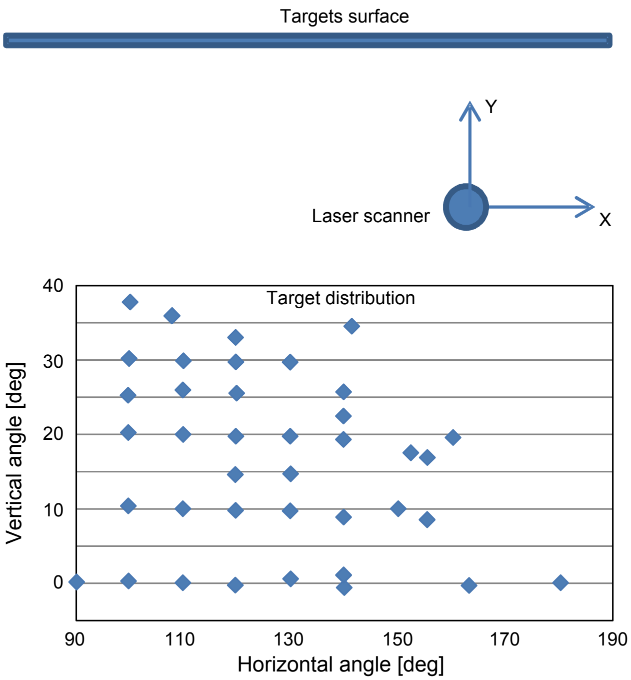


Fig. 2. Scene of the experimental procedure. A graphic of targets distribution is preferred to a photograph, since the contrast between the wall color and the targets is very low for a RGB camera.

the scanner and the calibration panel ranges between 2.1 m to 4.9 m. The angular range is between 90 and 170 degrees for the columns and 0 to 40 degrees for the rows.

Two types of reflective targets are prepared according to the recommendations for the material from Riegl. One set of targets is made of circular shape (5 cm of diameter) and the other one is made of rectangular shape (5 cm of edge). The center of the circles and the center of the squares (diagonals crossing) is marked in all the targets with a small hole. The purpose of this marking process is to make the center of the target easily identified in the process of accuracy evaluation. In addition, this procedure was adopted to secure that, when replacing the targets, they remain exactly in the same place which the other occupied during the observations.

## 3. Results and discussion

Two series of observations were performed from the calibration panel to evaluate the metrological behavior of the Riscan Pro software. First series is indicated for measuring the circular targets and the second one for measuring the square targets. This study allows to obtain the accuracy of the Riscan Pro software in the evaluation of the targets centers and also to compare the different behavior between the circular and square targets. Fine scan mode is used to evaluate all the targets to improve the point density and accuracy. Since this study is mainly focused on the performance of the algorithms implemented in the Riscan Pro software, it is not necessary to use external reference measuring systems. Thus, the source of the data is the laser scanning coordinates in all cases.

The accuracy of a measurement system is the degree of closeness of measurements of a quantity to the true value. In this experiment, the accuracy value comes from the difference between the values of the center of the targets, automatically obtained with the software, and the coordinates digitized from the orthophotographs generated (ground truth). Each target data was represented as a surface in the Surfer software. Horizontal angles, vertical angles and intensity were considered as the coordinates of the graph. As the targets have well visually identifiable center, it could be digitalized from the orthographic image of the surface and taken as the ground truth, using the Surfer software. The same procedure was applied for the circular and square targets.

Figure 3 shows some examples of circular and square targets plotted using the Surfer program. In ideal conditions, a circle (orthogonal case) changes to an ellipse when the incident angle diminishes and a square (orthogonal case) changes to a rhombus. However, horizontal angles about 30–40° produce geometric shapes different from the previous predicted, which makes difficult any evaluation of the geometric center by the algorithm implemented in the Riscan Pro. This behavior can only be observed in the horizontal angle. For the vertical angle, the limits of the calibration panel (60°) do not allow to produce such higher angles.

Figure 4 shows the accuracy results for the circular and square targets and their dependence on the horizontal and vertical angles. In all cases, the error in the deter-

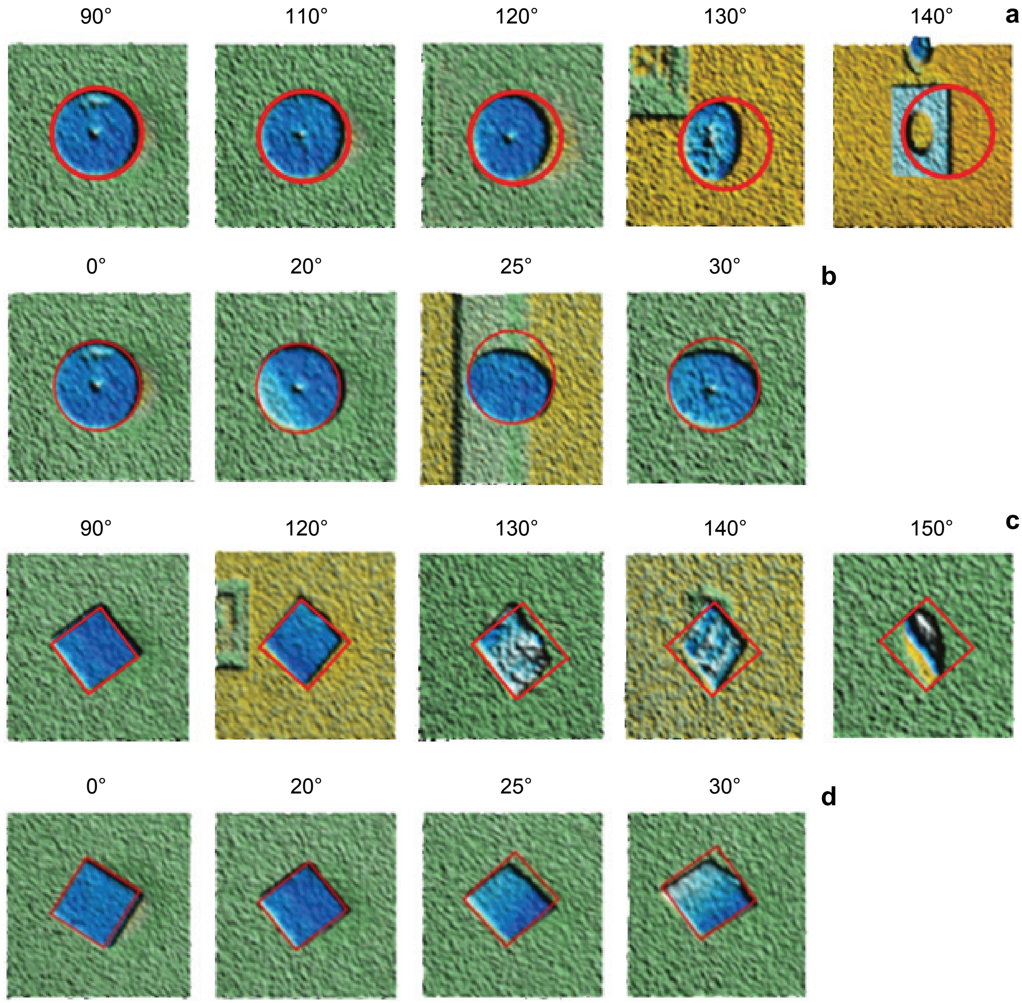


Fig. 3. Relationship between the shape of the target automatically detected by the Riscan Pro software and the incident angle. Horizontal angle, circular shape (**a**), vertical angle, circular shape (**b**), horizontal angle, square shape (**c**), vertical angle, square shape (**d**).

mination of the target center increases with the decreasing of the incident angle. These results are in agreement with the decreasing of one of the semiaxes of the ellipse and the rhombus, which makes difficult an exact measurement of the center of the geometric figure, and in addition, with the collapse of the figure for the extreme angles.

A linear fit is performed for all the data series. The slope of the fitting is an indicative parameter of the accuracy dependence on the incident angle. The results show similar values for the slope in all cases ranging between 0.1565 and 0.1891. The dependence between the accuracy trend and the type of measured angle (horizontal or vertical) is not observed. In addition, there is no significant difference between the type of target used (circular or square). Although the trend of the graphs is clear

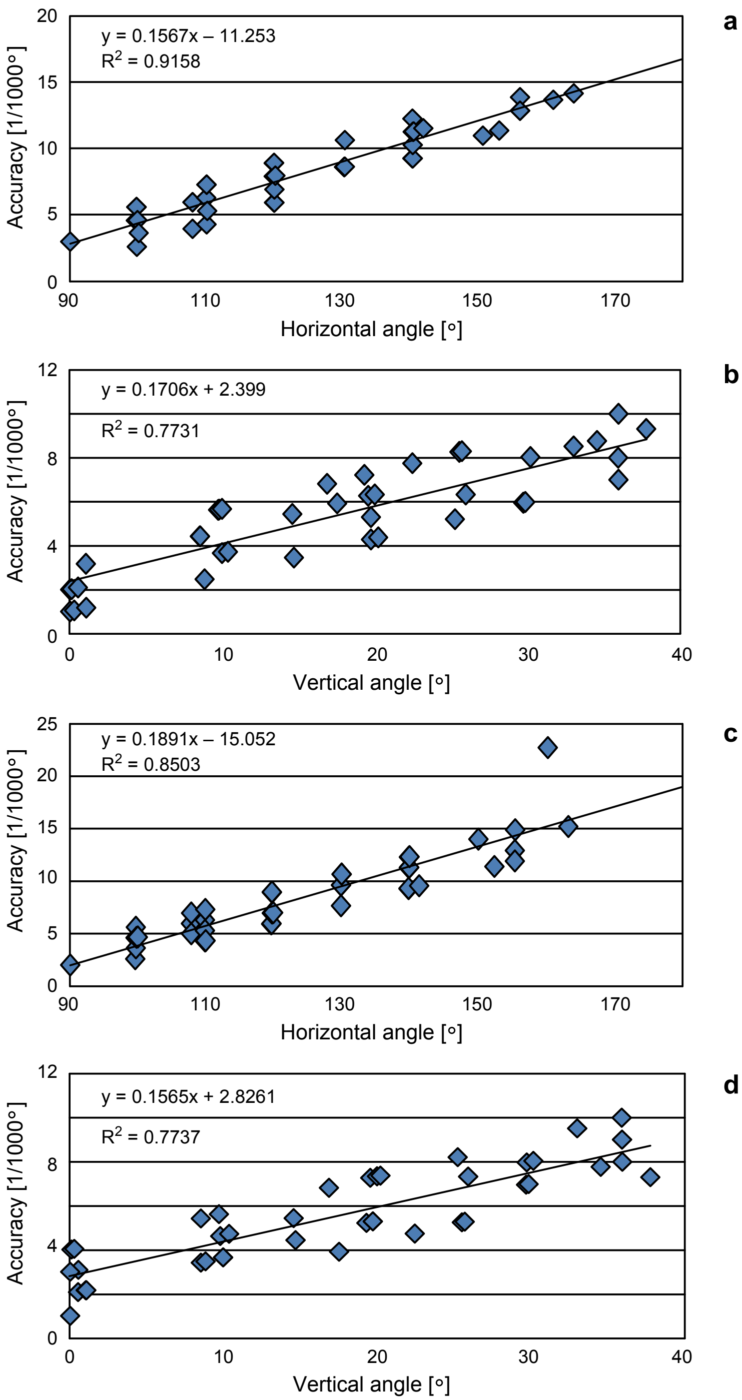


Fig. 4. Accuracy versus scanner angle. Horizontal angle, circular shape (**a**); vertical angle, circular shape (**b**); horizontal angle, square shape (**c**); vertical angle, square shape (**d**).

in all cases, the correlation coefficient shows the high dispersion of the data and depicts values between 0.7737 and 0.9158. There is no relationship observed between the correlation coefficient and the type of target or angle under study.

## 4. Conclusions

An experiment for the evaluation of the accuracy in the determination of the target centers and its influence on the incident angle (horizontal or vertical) and the shape of the target is developed under laboratory conditions.

All the cases under study exhibit an increasing of the error with the decreasing of the incident horizontal and vertical angles. These results are in agreement with the decreasing of one of the semiaxes of the geometrical figures and the collapse of the figures for low angles. An approximate trend can be established using a linear fitting. The slope obtained is similar in all cases and the correlation coefficient shows a high dispersion in all cases.

Accuracy in the determination of the geometrical center of the targets is a key aspect in the registration processes done in multistation surveying. This study can help to predict the limits in the minimum incident angles to do high accurate data acquisition.

*Acknowledgements* – Authors would like to give thanks to CNPQ – Conselho Nacional de Pesquisa e Desenvolvimento (Brazil) and to Consellería de Economía e Industria (Xunta de Galicia) and Ministerio de Ciencia e Innovación (Gobierno de España) for the financial support given, human resources programs (IPP055 - EXP44) and projects (INCITE09 304 262 PR and BIA2009-08012).

### References

[1] BARRILE V., MEDURI G., BILOTTA G., *Laser scanning surveying techniques aiming to the study and the spreading of recent architectural structures*, [In] *Proceedings of the 2nd WSEAS International Conference on Engineering Mechanics, Structures and Engineering Geology, (EMESEG '09)*, WSEAS Press, 2009, pp. 25–28.

[2] BERENYA A., LOVAS T., BARSI A., DUNAI L., *Potential of terrestrial laser scanning in load test measurements of bridges*, Civil Engineering **53**, 2009, pp. 25–33.

[3] ARMESTO J., ROCA-PARDIÑAS J., LORENZO H., ARIAS P., *Modelling masonry arches shape using terrestrial laser scanning data and non-parametric methods*, Engineering Structures **32**(2), 2010, pp. 607–615.

[4] MANCERA-TABOADA J., RODRÍGUEZ-GONZÁLEZ P., GONZÁLEZ-AGUILERA D., *Turning point clouds into 3d models: The aqueduct of Segovia*, Lecture Notes in Computer Science **5592**, 2009, pp. 520–532.

[5] BORNAZ L., LINGUA A., RINAUDO F., *Terrestrial laser scanning: Increasing automation for engineering and heritage applications*, GIM International **17**(3), 2003, pp. 12–15.

[6] POULTON C.V.L., LEE J.R., HOBBS P.R.N., JONES L., HALL M., *Preliminary investigation into monitoring coastal erosion using terrestrial laser scanning: Case of study at Happisburgh, Norfolk*, Bulletin of the Geological Society of Norfolk, No. 56, 2006, pp. 45–64.

[7] PENA GONZÁLEZ E., SÁNCHEZ-TEMBLEQUE DÍAZ-PACHE F., PENA MOSQUERA L., PUERTAS AGUDO J., *Bidimensional measurement of an underwater sediment surface using a 3D-scanner*, Optics and Laser Technology **39**(3), 2007, pp. 481–489.

[8] LICHTI D.D., STEWART M.P., TSAKIRI M., SNOW A.J., *Benchmark tests on a three-dimensional laser scanning system*, Geomatics Research Australasia, No. 72, 2000, pp. 1–23.
[9] LICHTI D.D., FRANKE J., *Self calibration of the iQsun 880 laser scanner*, [In] *Optical 3D Measurement Techniques VII*, Vol. I, Vienna, Austria, 2005, pp. 112–121.
[10] LICHTI D.D., LICHT M.G., *Experiences with terrestrial laser scanner modeling and accuracy assessment*, IAPRS Dresden **36**(5), 2006, pp. 155–160.
[11] LICHTI D.D., *Terrestrial laser scanner self-calibration: Correlation sources and their mitigation*, ISPRS Journal of Photogrammetry and Remote Sensing **65**(1), 2010, pp. 93–102.
[12] ABMAYR T., DALTON G., HÄTRL F., HINES D., LIU R., HIRZINGER G., FRÖLICH C., *Standarization and visualization of 2.5D scanning data and color information by inverse mapping*, [In] *Optical 3D Measurement Techniques VII*, Vol. I, Vienna, Austria, 2005, pp. 164–173.
[13] LICHTI D.D., JAMTSHO S., *Angular resolution of terrestrial laser scanners*, The Photogrammetric Record **21**(114), 2006, pp. 141–160.
[14] BOEHLER W., BORDAS VICENT M., MARBS A., *Investigating laser scanner accuraccy*, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences **34**(5), 2003, pp. 696–701.
[15] SCHULTZ T., INGENSAND H., *Influencing variables, precision and accuracy of terrestrial laser scanners*, FIG Regional Central and Eastern European Conference on Engineering Surveying, Bratislava, Slovakia, 2004.
[16] WUTKE J.D., *Metodos para avaliação de um sistema laser scanner terrestre*, Universidade Federal do Paraná, Departamento de Geomática, Curitiba, Brasil, 2006, p. 99.
[17] GORDON S., LICHTI D., STEWART M., TSAKIRI M., *Metric performance of a high-resolution laser scanner*, Proceedings of SPIE **4309**, 2001, pp. 174–184.
[18] MECHELKE K., KERSTEN T.P., LINDSTAEDT M., *Comparative investigations into the accuracy behavior of the new generation of terrestrial laser scanning systems*, [In] *Optical 3D Measurement Techniques VIII*, Zurich, 2007, pp. 319–327.
[19] GONZÁLEZ-JORGE H., RIVEIRO B., ARMESTO J., ARIAS P., *Standard artifact for the geometric verification of terrestrial laser scanning systems*, Optics and Lasers Tecnology **43**(7), 2011, pp. 1249–1256.
[20] GOLNABI H., *Design and operation of a laser scanning system*, Optics and Laser Technology **32**(4), 2000, pp. 267–272.

*Received December 29, 2011*
*in revised form February 25, 2012*