Development of a new testfield to model errors in terrestrial laser scanner data

Elnaz Mohammad Zanjanipour[1], Masood Varshosaz[2], Mohammad Saadat Seresht[3]

1.Photogrammetry graduate student, School of Surveying, Khajeh Nasir Toosi University of Technology,Tehran,iran
e.zanjanipour@gmail.com

2.Assistant Professor of Surveying Engineering, School of Surveying, Khajeh Nasir Toosi University of Technology,Tehran,iran

3. Assistant Professor of Surveying Engineering, Technical School Campus Two, Tehran University,Tehran,iran
msaadat@ut.ac.ir

Abstract

Laser scanner technology due to having capabilities in comparison with other surveying methods, is favoured by the users increasingly. However, almost there are different factors that affected the results of this instrument. Thus, the accuracy of the scanner is limited extensively by the systematic instrument errors and thus must be calibrated. In fact calibration is a prerequisite for extracting 3D precise and reliable data from point clouds. Test field has a great role in calibration procedure. so different test fields have been assessed for this purpose so far. In this paper, a new method is presented for constructing a test field in a virtual form. one of the advantages of this method is that through this method the instrument can be calibrated everywhere the project is executed but in the laboratorial conditions.

Key words: Laser scanner, Calibration, Test field.

1.Introduction

Laser scanners as the rather new technologies in the field of topography are developing day by day and determine the point coordinates through measuring the distance and angle such as total stations[2]. As it is obvious, Due to mechanical imperfections, it is impossible to design an instrument exactly to theoretical planning. There are discrepancies between the real instrument and the ideal instrument, and these are called instrumental errors[1].
Calibration is a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument and the corresponding values realized by standards. [1]. Calibration in the laser scanners includes two general sections:

- Separate calibration of each part of system

By this sort of calibration, each part of the system including camera and the laser scanner are analyzed separately and calibrated. This sort of calibration is applied in both radiometric and geometric forms.

- ❖ calibration of whole system

In this section, in addition to the camera calibration, the relationship of its coordinates with laser coordinates is specified.

In this paper, the purpose is to present a new method for calibrating the scanner. Towards, various techniques have been presented so far that are classified briefly as follows:

1-Self calibration

By this method, the modeling coefficients of scanner errors and point coordinates are gained simultaneously [3]. In this mode, usually there is no information about the object that is scanned [3]. The object is scanned from various stations through laser. Whereas the scanner has a lot of similar data between different stations, these data can be used as constraints for modeling the error elements and specifying the external orientation parameters of laser scanner for georeferencing the point coordinates in the different stations. It is notified that considering the structure and function of laser scanner, the coordinates of the points are specified while scanning and their improved coordinates are computable after calibration.

2- Laboratorial calibration:

By this method, the calibration is usually applied in the lab environment with using some specified constraints [5]. In this method, components of distance measurment system and angle measurement system are investigated separately in specific experimental setups. [5]. Different devices such as graduated lines together with special targets which move on these lines with small wagons manually (is called track line) for investigating the accuracy of distance measurement system, an electronic unit for measuring the signal frequency that has been sent by the laser scanner are located in the lab environment for verifying their accuracy [5]. so the calibration of different parts of laser scanner are applied through which. This kind of calibration requires the precise knowledge from scanner's error model and however this knowledge is limited due to different designing characteristics and requires facilities such as base length of calibration that may be not available for the user [5].

Laboratorial calibration in general status, due to requirement of special equipments is often very costly and expensive. Therefore, different test field laboratorial methods have been designed so far in which the targets with different shapes are placed in an enclosed area, through their scanning, control environment is provided for modeling the different scanner errors. Samples of these test fields are seen in figure 1 [6]. As it is specified in these samples, calibration can be applied in point based mode or plane based mode [6]. In first method, targets are designed as circular labels and their centers are used in calibration. While, in second method, laser coordinates that have been returned from the surface of plane-based objects(that are usually wooden or ceramic) are applied [6]. However, these objects have been distributed spatially in the environment around the laser scanner and are measured through it. Point clouds are compared with the data which have higher accuracy with respect to the laser scanner and are deemed as reference amounts for this device (such as measurements of total stations or photogrammetry) and with difference quantities, calibration computations are applied. Forming a calibration test field is not a complex subject generally and thus most of TLS users can calibrate these instruments. In two below images, test fields of point based and plane based targets have been displayed [6].

Fig1. right:Sample of a test field with point targets.left: Sample of a test field with plane targets[6]

Laboratorial methods require expanded, under control and calibrated laboratorial area, and constituting this area in the executive projects is not possible or is very costly and time-consuming. The purpose of this paper is to present a new method in which through using the minimum test field, laboratorial conditions is arranged. In fact, in the above methods, 3D area was constituted and laser scanner moves in that area. But in this case, only one object is stabilized in a place and 3D area is constituted virtually through laser movements. Utilized object that the targets are placed there on, here is a plate that some point based targets have been set on that. One of the advantages of this method is that the board is portable and provides the conditions for calibrating the device near every place that project is executing but in the laboratorial conditions. Note worthy point in this process is that only the variations of short waves length (high frequency) are identifiable and not variations of long waves length.it Means that in different lengths, the plates are not verifiable in proportion to each other and this method provides inner-plate variations and not the plates in proportion to each other. In this method, against the previous methods in which all the lab area is covered with a lot of point based or plate based targets and it requires spending time and cost, here the desired calibration and test field through a plate and is constituted completely virtual. In continue the constituting procedure of this test field and its assessment process is discussed.

2.Data and material:

Considering the accessibility of laser scanner Rigle LMS Z420i, this type has been chosen for executing the test. This device has a distance measurement system with the range of 800 m without using reflector and it's measuring speed is 12000 point/second [4]. The visibility angle has a rotation of 360˚ on the horizontal plate around the vertical axis and 80˚ on the vertical plate. It has a precision of 10mm that can increase by repeating the measurments up to 5mm, and its vertical and horizontal scanning mechanism is rotational-vibrational and rotational [4]. Riscan pro software that is used in the Rigle system and is applied for reading and processing the coordinate of points, is considered as another saliencies of this system [4]. For fulfilling this project, in addition to the terrestrial laser scanner, the following equipments are used for processing including a MDF wooden plate, size characteristics and other specifications of that will be described, targets, digital camera and software.

Whereas the accuracy of photogrammetry method is higher (hundredth and tenth mm) than laser scanner [5], gained data aiding this method are applied as a precise method in proportion to the resulted data from laser scanner. Figure 2 displays the used laser scanner and digital camera.

Fig2.right:terrestrial laser scanner Riegl LMSz420i.left:digital camera canon powershot pro IS.

Used white MDF wooden plate was chosen in the measure of 60*60cm. for gaining the better accuracy, the board was coated with black label and nine Rigle circular targets with 3cm diagonal were pasted on the board. 2 other targets were placed on the horizontal direction for more precise analyzing the changes. In fig 3 the used board is showed.

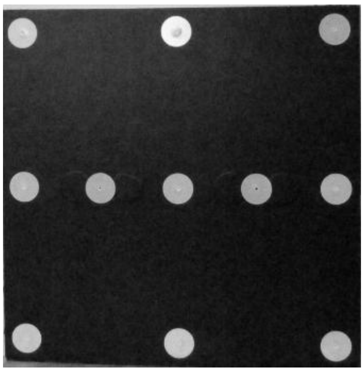
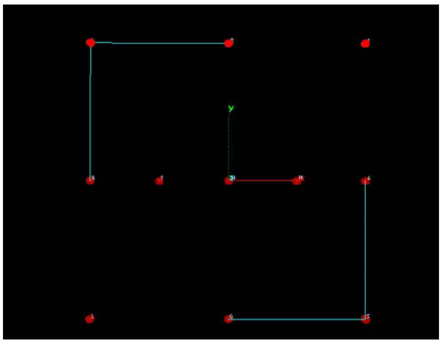


Fig3.used plate board for constitute the test field

3.Research Methodology

3-1- Observations and calibration of board through photogrammetry method aiding australis software

30 photos are taken by digital camera (from 15 stations so that in each location, the camera takes a photo, rotates 90˚ and another photo is taken in order to remove or reduce the dependency of camera parameters.), then the photos are entered into Australis software and process is applied to specify internal calibration parameters of camera through a free adjusment,and moreover 3D coordinates of targets are gained in the board area by considering the central target as the origin of this coordinate system. The coordinates have been obtained with accuracy of 0.52, 0.47 and 0.50 mm respectively in the x, y and z directions and observing the error ovals indicates that the errors exist in all directions monotonously. The designed network via photogrammetry method and the targets errors oval after adjustment in this method, have been showed in fig 4.



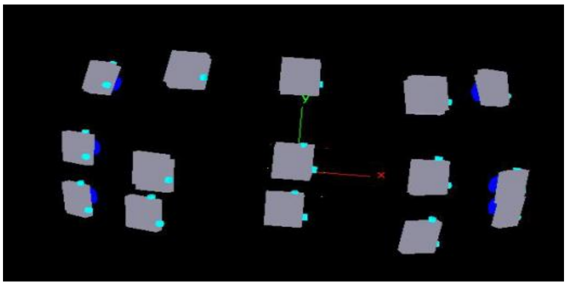


Fig4.right: designed network in photogrammetry method. left: targets errors oval after adjustment in Australis software.

3-2 observations via laser scanner

The board was installed on a heavy tripod (for preventing the probable movements) and was settled in a fixed place. The laser scanner scanned in this height and in the distances of 10-15-20-25-30-40-50-60-70-80 meters from the board. moreover, at distances of 20m and 60m a 45˚ to 45˚ rotation for 360˚ coating (in 8 steps) and also in 4 vertical directions in 20m distance in the angles of 40˚, 20˚, -20˚ and -30˚, and in 60m distance in the angles of 20˚, 30˚, -20˚ and -30˚, (the cause of this non-symmetry was disability of device for reading) and the targets were scanned finely(fine scane). A diagram of scanner settlement place in proportion to the board in 15m distance has been displayed in fig 5.

Fig 5.laser scanner at distance of 15 meter from the plate

After fulfilling these observations, test field was constituted virtually as can be seen in fig 6.

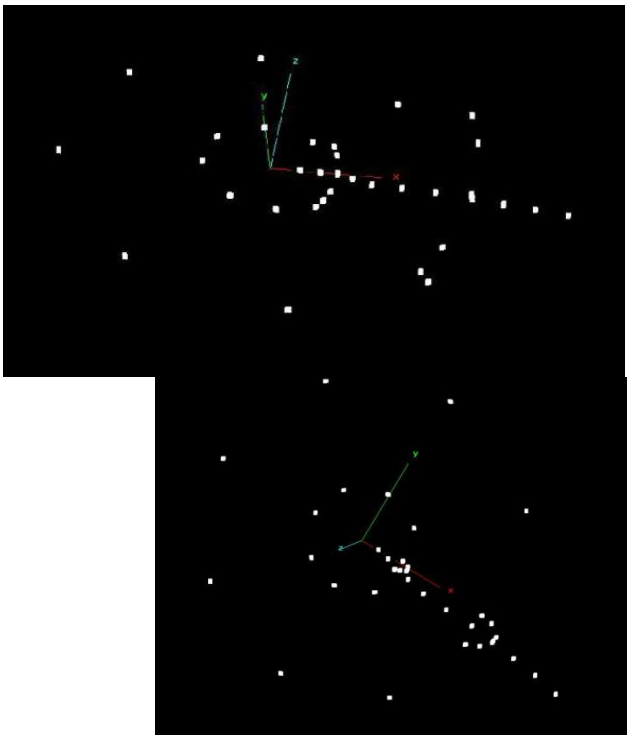


Fig6.:virtual test field that is constituted from the laser scanner movements

4.Results and Analysis

Upon fulfilling the observations, the observation equations are expressed as follows:

$$\rho_{ij} = \sqrt{x^2_{ij} + y_{ij}^2 + z_{ij}^2} + \Delta\rho \qquad (۱)$$

$$\varphi_{ij} = \arctan\left(\frac{y_{ij}}{z_{ij}}\right) + \Delta\varphi \qquad (۲)$$

$$\theta_{ij} = \arctan\left(\frac{z_{ij}}{\sqrt{x_{ij}^2 + y_{ij}^2}}\right) + \Delta\theta \qquad (۳)$$

$i = 1,2,\ldots p \qquad j = 1,2,..m$

where $\Delta\rho$, $\Delta\varphi$ and $\Delta\theta$ are respectively distance, horizontal direction and vertical angle correction, which are added to the observations of distance ρ, horizontal direction φ and vertical angle θ extracted from the laser scanner. p is the number of device stations and m is the number of scanned targets in each station. x, y and z are observed Cartesian coordinates of each target in each station via laser scanner.

The problem of sensor modeling is perhaps the most important part in calibrating the laser scanner [1]. Since one generally has very limited (or, better almost no) knowledge about the inner functioning of modern terrestrial laser scanners due exclusive designing characteristics which the manufacturer doesn't express them, therefore the proper error modeling for TLS is constituted focusing on the hypotheses[4]. Since laser scanners operate similarly to reflectorless total stations, most researchers chose the total station error model as the basis for calibration[4]. According to this model, the developed model for omitting the systematic error of laser scanner is expressed as below:

$$\Delta\rho = A_0 + A_1.\rho + A_2\sin\theta \qquad (۴)$$

$$\Delta\varphi = \frac{B_1}{\cos\theta} + B_2\tan\theta + B_3\varphi + B_4\sin\varphi + B_5\cos\varphi + B_6\sin 2\varphi + B_7\cos 2\varphi + B_9\rho^{-1} \qquad (۵)$$

$$\Delta\theta = C_0 + C_1\theta + C_2\sin\theta + C_3\sin 2\theta + C_4\cos 2\theta + C_5\rho^{-1} + C_6\sin 3\varphi + C_7\cos 3\varphi \quad (۶)$$

Each one of the above parameters, models a part of device systematic errors. These errors are introduced in table 1.

parameter	Modeled error
A0	Rangefindr offset
A1	Scale error
A2	Laser axis vertical offset
B1	Scale error
B2,B3	Horizontal circle eccentricity
B4,B5	Non-orthogonality of encoder and vertical axis
B6,B7	Collimation axis error and Trunnion axis error
B8	Horizontal eccentricity of collimation axis
C0	Vertical circle index error
C1	Scale error
C2	Vertical circle eccentricity
C3,C4	Non-orthoganility of encoder and trunnion axis
C5	Vertical eccentricity of collimaton axis
C6,C7	Vertical axis wobble

Table1.introducing the parameters of expressed model

Error modeling parameters and external oriantation parameters of each station of scanner was computed for transforming its coordinate system to the photogrammetric coordinate system simultaneously in a composited adjustment procedure. Through applying this method on the observations in the constituted virtual test field the precision was improved as seen in table 2. In this table, precision rate before and after applying the parameters and their improvement percent has been showed.

rms	Without AP correction	With AP correction	improvement%
(mm) ρ	2.24$\pm$	2.19$\pm$	%2
(radian) θ	30$\pm$	27$\pm$	%1
(radian) φ	21$\pm$	19$\pm$	%9
x(mm)	2$\pm$	1.5$\pm$	%2.5
y(mm)	1.8$\pm$	1.7$\pm$	%5
z(mm)	2.1$\pm$	1.9$\pm$	%9

Table2. precision rate before and after applying the parameters and their improvement percent

As it is obvious in table 2, after constituting the virtual test field and applying the parameters of presented model, only 2.5%, 5% and 9% improvement in precision has gained in the results and therefore no considerable advancement has been observed.

Considering this subject that in this process only the variation of short waves length (high frequency) are identifiable and not variation of long waves length, can be effective for gaining such results, but in addition, other cases such as very small changes in the board because of its little movement or constituted network structure may be considered. Furthermore, here, only through parametric model regarding internal structure of laser, the errors were modeled and applied parameters were physical and no parameters were applied experimentally.

Considering the mentioned subjects, further researches is recommended regarding designing the suitable place for laser scanner and constituting different networks structures for achieving the best precision and also verifying the methods through which the variations of long waves length may be identifiable and consequently the final precision may be increased.

5.Conclusions

In this paper, the calibration methods in the laser scanner were divided at first in two general self calibration and laboratorial calibration parts, and each one was introduced separately. Whereas laboratorial methods require expanded, under control and calibrated laboratorial area and considering that these areas cannot be constituted in the executive projects and are very costly and time-consuming, a modern method was raised in which utilizing the minimum test field, laboratorial conditions are settled. In fact, through above methods, a 3D area was made and laser scanner moved in that area. But in this mode, only one object stabilizes in a location and 3D area is constituted virtually through laser movements. The object on which the targets are settled is a plate that the point-based targets are installed on it. One of the advantages of this method is that the board is portable and provides conditions for calibrating the device near everywhere the project is executed but in the laboratorial conditions. But considerable point in this process is that only the variations of short waves length (high frequency) are identifiable and not variations of long waves length. It Means in different directions, the plates are not verifiable in proportion to each other and this method provides the inner plate variations and not the plates in proportion to each other. This resulted to inconsiderable advance in adjusment process. Furthermore, other cases such as very small changes in the board because of it's little movement or the structure of constituted network may be considered.

References

1. Lichti, D.D., Licht, M., (2006)," Experiences with terrestrial laser scanner modeling and accuracy assessment", Isprs Volume XXXVI, Part 5, pp. 25-27.

2.Yuriy, Reshetyuk, (2009),"Self-calibration and direct georeferencing in terrestrial laser scanner, InternationalArchives of the Photogrammetry", Remote Sensing and Spatial Information Sciences, vol.XXXVI, part 3/W19, pp. 186-191.

3.Lichti, D.D., (2007),"Error modeling,calibration and analysis of an AM-CW terrestrial laser scanner system", Photogrammetry and remote sensing, No. 61, pp. 307-324.

4. Lichti, D.D.,(2008)," A method to test differences between additional parameter sets with a case study in terrestrial laser scanner self-calibaration stability analysis", Photogrammetry and remote sensing, No.63, pp. 169-180.

5. Damir, Latypov ,(2005)," Effects of laser beam alignment tolerance on lidar accuracy", ISPRS Journal of Photogrammetry and Remote Sensing, Volume 59, Issue 6, Pages 361-368

6. Staiger R (2005)," The Geometrical Quality of Laser Scanner (TLS)". In: Proceedings of FIG Working Week 2005 and GSDI-8, Cairo, Egypt, April 16 – 21. http://www.fig.net/pub/cairo

7. Gordon SJ (2005),"Structural Deformation Measurement Using Terrestrial Laser Scanners". PhD thesis, Curtin University of Technology, Department of Spatial Sciences, Australia.