10th IMEKO TC14 Symposium on
Laser Metrology for Precision Measurement and Inspection in Industry
Braunschweig, GERMANY, 2011, September 12-14

A Procedure for accuracy Investigation of Terrestrial Laser Scanners

Sinisa Delcev, **Marko Pejic**, **Jelena Gucevic**, **Vukan Ogizovic**,
Serbia, Faculty of Civil Engineering University of Belgrade, Belgrade

Keywords: terrestrial laser scanner, testing, accuracy

ABSTRACT

Surveying instruments have to meet certain specifications in order to provide the necessary accuracy standards for a certain application. The main purpose of testing a used terrestrial laser scanner (TLS) is does an instrument still meets factory accuracy standards or not. This paper outlines the procedures for the investigation of the TLS accuracy in laboratory conditions without high expensive equipment e.g. a calibration track line and a laser interferometer. The test field contains control targets and observation pillars. 3D position of the pillars and the targets are derived from an adjustment of highly precise measurements and they are considered as a true standard compared with the scanned data. A proper statistical model of the data analysis is proposed. In addition to the theoretic model, a particular sample of the highly precise TLS measurements is analyzed.

INTRODUCTION

The terrestrial laser scanners give 3D interpretations of different surfaces, depending on what they record. The formed surfaces are based on a large number of gathered coordinate differences of densely recorded points in the relation to the centre of the scanner. Basically, the scanner measures the angles (vertical and horizontal) and the lengths to the points. Further it calculates the coordinate differences. This means that the accuracy of the formed surfaces directly depends on the accuracy of the measured angles and the lengths. The procedures and the standards for the calibration of these measuring instruments are not yet applied. This paper shows one of the possibilities for the calibration of the lengths and the positions using the terrestrial laser scanner.

In accordance with the metrological regulations, it is necessary to confirm, or disprove, the declared measurement uncertainty, using independent measurements. The first step towards a simple test was made in 2000 [**11**], and further published research are based on more or less time-consuming field or laboratory tests. Also, there are some suggestions for standardized procedures [**9**], [**12**].

Almost all suggested procedures are based on the indirect measurement of unknown lengths. The difference between the suggested procedures is in the number and arrangement of the measured lengths, as well as in the number of measurements of those lengths. This paper shows the method for calibrating laser scanners using the measurements of known, accurate lengths and positions.

The factory accuracy specification of the scanner is given as the 3D positional error of the scanned data, the accuracy of the angles, distances, and the model of the scanned object in specific environmental conditions. Here we tested the pulsed Leica HDS3000 and Leica Scan Station 2 TLS. The samples of the data on different setups are analyzed to reach the actual error on the given control points.

TARGET RECOGNITION TESTING

In order to investigate the accuracy of the scanner without the influence of outer sources of errors such is the setup error, the influence of not levelled point cloud, the error of the measured heights of the instrument and the target, we established in the laboratory the field of typical black/white scanner targets (Figure 1) as the control points and the observation pillars (Figure 2).

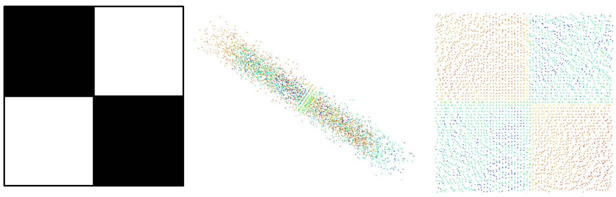

Fig. 1: Black/white Leica target and its point cloud model

Fig. 2: Testing - metrological laboratory

Previously, the measurements were carried out by a high precision total station. After the performed adjustment, we achieved a sub-millimetre order 3D positional accuracy of the control points and the pillars (Table 1). On the other side, the factory specification of the standard deviation of a 3D position of recognized black/white target of the typical pulsed scanner is about 2 mm, when the distance is shorter than 50 m. If we apply the principle of negligence (α=0.05), these positions of the control points should be considered as a true value, with aim of the testing positional accuracy of a pulsed terrestrial scanner.

Table 1: Adjustment results in millimetres

Adjustment results									
T	S_Y	S_X	S_H	S_{3D}	T	S_Y	S_X	S_H	S_{3D}
Observation pillars					Scanner targets				
1	0.08	0.16	0.07	0.19					
2	0.14	0.08	0.10	0.19	**84**	0.18	0.17	0.23	0.34
3	0.10	0.15	0.20	0.26	**85**	0.15	0.21	0.23	0.34
4	0.06	0.07	0.07	0.11	**86**	0.11	0.44	0.23	0.51
5	0.13	0.09	0.08	0.18	**87**	0.19	0.40	0.23	0.50
Scanner targets					**88**	0.30	0.35	0.23	0.51
72	0.23	0.10	0.23	0.34	**89**	0.38	0.26	0.20	0.50
73	0.23	0.09	0.23	0.33	**90**	0.26	0.12	0.23	0.36
74	0.21	0.15	0.23	0.34	**91**	0.22	0.09	0.23	0.33
75	0.16	0.19	0.23	0.34	**92**	0.23	0.11	0.23	0.34
76	0.16	0.23	0.23	0.36	**93**	0.18	0.17	0.23	0.34
77	0.15	0.45	0.23	0.53	**94**	0.15	0.21	0.23	0.34
78	0.25	0.38	0.23	0.51	**95**	0.11	0.44	0.23	0.51
81	0.26	0.12	0.23	0.36	**96**	0.19	0.40	0.23	0.50
82	0.22	0.09	0.23	0.33	**97**	0.30	0.35	0.23	0.51
83	0.23	0.11	0.23	0.34	**98**	0.38	0.27	0.23	0.52

The statistical interpretation of the results has to consider a sample of the tested scanner data and the confidence interval. If the standard deviation of the acquired targets is given as *σ*, the confidence interval of the sample of the errors is:

$$\left(A-\sigma \cdot z_{\alpha/2}, A+\sigma \cdot z_{\alpha/2}\right) \ . \qquad (1)$$

In the case where the true value of the coordinate differences (*A*) is 0, and if the actual errors are analyzed, $z_{\alpha/2}$ is the quantile of the normal Gaussian distribution, and if $z_{\alpha/2}=1$, then 68.3% of errors need to be in the defined 1*σ* interval of the confidence.

The same statistical analysis need to be performed at E95 or/and E99 level of confidence.

If the level of confidence is α=0.05, then $z_{0.025}=1.96$ and the confidence interval is:

$$\left(0-\sigma \cdot 1.96, 0+\sigma \cdot 1.96\right) \ . \qquad (2)$$

The sample of the measurements needs to be in this interval in 95% of cases.

If this is true, the instrument satisfies the factory standards of the three-dimensional error of the recognized targets.

The testing in the laboratory was performed with the terrestrial pulsed laser scanner Leica HDS3000. The factory declared 3D accuracy of the recognized targets is 2 mm. The same targets were scanned from tree pillars 4, 1 and 5. Independent 3D distances from the scanned targets are calculated and compared with adjusted ones. The differences were considered as the true error in 3D distances.

Then, the positional errors were calculated and presented in Table 2. These errors are considered as a statistical sample of the measurements.

Due to the short distances, it is clear that all results belong to the desired confidence interval. Further, it is clear that there is a trend of a multiplication of errors when the distance is longer. There is a suspicion that the scanner has an error in scale. To investigate the size of this error, the testing field need to have the longer distances between the targets. This is a task of a future work.

Table 2: Results of the accuracy investigation of Leica HDS3000 scanner in the laboratory

From	To	3D distance	Setup 4		Setup 1		Setup 5	
			3D distance error	3D position error	3D distance error	3D position error	3D distance error	3D position error
90	89	11.351 m	-2.17 mm	-1.25 mm	-1.75 mm	-1.01 mm	-0.63 mm	-0.36 mm
81	98	11.350 m	-2.16 mm	-1.25 mm	-1.31 mm	-0.76 mm	-1.67 mm	-0.96 mm
72	78	8.928 m	-2.33 mm	-1.34 mm	-0.82 mm	-0.48 mm		
91	88	8.589 m	-2.14 mm	-1.23 mm	-0.43 mm	-0.25 mm	1.01 mm	0.58 mm
82	97	8.557 m	-1.59 mm	-0.92 mm	-0.82 mm	-0.47 mm		
92	87	6.179 m	-1.83 mm	-1.06 mm	-0.17 mm	-0.10 mm		
83	96	6.108 m	-1.02 mm	-0.59 mm	0.25 mm	0.15 mm		
73	76	5.612 m	-0.66 mm	-0.38 mm	0.03 mm	0.02 mm	0.66 mm	0.38 mm
93	86	3.585 m	-0.63 mm	-0.36 mm	0.45 mm	0.26 mm		
84	95	3.511 m	-0.05 mm	-0.03 mm	0.22 mm	0.13 mm		
74	94	3.036 m	-0.73 mm	-0.42 mm	0.24 mm	0.14 mm	-0.08 mm	-0.05 mm
75	85	1.145 m	0.28 mm	0.16 mm	0.44 mm	0.26 mm	-0.005 mm	0.00 mm
Horizontal setup error			3.42 mm		1.79 mm		0.13 mm	

In addition, the horizontal setup error of the scanner is determined by the 3D transformation of the projection centre of the scanner to the observation pillars coordinate system. The error ranges from 0.13 mm to 3.42 mm. This error is the consequence of a significant horizontal pitch of the scanner which also affects the point cloud to be not levelled. It is very important to realize that this error source only affects the direct measurements from the known position to the target. Newer scanners, for example Leica Scan Station series, have a dual axis compensator which compensates this pitch, traditionally built in the high precision total stations and levels.

DIRECTLY MEASURED LENGTH ACCURANCY TESTING

The directly measured distances have to be statistically considered as a single sample of the measurements. There we can consider hypothesis testing about the mean *A* of a single, normal population where the variance of the population σ^2 is known. We will assume that a random sample $X_1, X_2, \ldots, X_n$ has been taken from the population during scanning one small area. The sample mean is an unbiased point estimator of *A* with variance σ^2/n. In the case where true value of a measured distance *A* is known, we specify the zero and alternative hypotheses as:

$$H_0 : A = E(\overline{X}) \qquad H_a : A \neq E(\overline{X}), \qquad (3)$$

where $E(\bar{X})$ is the mathematical expectation of a measured distance.

Since $\bar{X}$ has a normal distribution, the test procedure for H_0 uses the test statistic:

$$Z_0 = \frac{|\bar{X} - A|}{\sigma / \sqrt{n}} \qquad (4)$$

Consequently, if $H_0 : A = E(\bar{X})$ is not rejected, the probability is 1-*α* that the test statistic Z_0 falls between $-z_{\alpha/2}$ and $z_{\alpha/2}$. Finally, it means that the sample belongs to the same population as true value *A* and it can be state that measured distance is equal with true one for adopted level of confidence.

In the case of scanning, there is a very high redundancy of the measurements. This affects the standard deviation of the arithmetic mean ($\sigma / \sqrt{n}$) to be a very small number, and the hypothesis H_a in most cases is accepted. This means also that in $\bar{X} - A$ difference remains only the systematic errors sources, dominantly setup error and the scale in the distance (multiplication constant).

To calibrate the terrestrial laser scanners, the pillars with the forced mounting of the Metrological laboratory of the Faculty of Civil Engineering have been also used. Total of 10 pillars, 5 within the laboratory and 5 in the yard of the Faculty (the lengths between the pillars are 4.5 m - 74 m) have been used. The lengths between the pillars are known with the accuracy of 0.2 mm.

The calibration on all the pillars was carried out in two steps – first the lengths have been measured to the corresponding labels, and then to the flat surface. The measurements were made using one pillar in the laboratory and one in the yard. This procedure was implemented in order to minimize the duration of the measurements. According to the existing standards, the duration of the measurements should not be longer than 90 minutes.


a.


b.

Fig. 3: Targets used in testing

In the first step, the typical scanner targets that come with the scanner were used (Figure 3a), and for the second, one Zeiss target that acts like a small plane surface (Figure 3b). First, target recognition is performed to check the calibration of the instruments and to determine the uncertainty of measurement of the angles and lengths. After that, the same procedure was repeated for the Zeiss targets, in order to calculate the uncertainty of length measurements.

In comparison with the true values of horizontal and vertical angles between the pillars, the differences for ScanStation 2 range between -7.8" and +8.2", which meets the declared uncertainty (12"). For HDS 3000 the angle differences are between -21.6" and +15.6", and they are not in the range of the declared uncertainty.

The differences of mean values of measured lengths and the true lengths for ScanStation 2 (for all lengths - in the laboratory and in the yard of the Faculty, and both targets) range between -3.3 mm and +2.56 mm, and they also meet the declared uncertainty (4 mm). The differences obey the normal Gaussian distribution of errors (Figure 4).

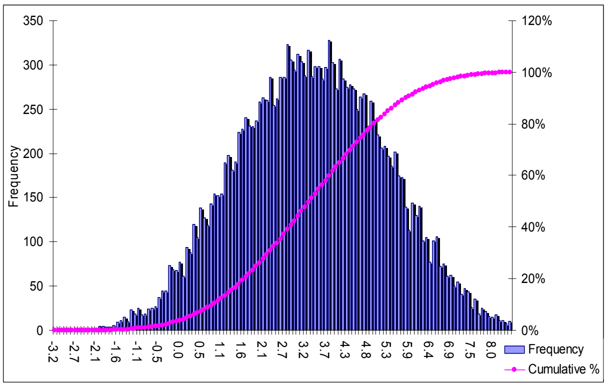

Fig. 4: Differences between true and measured distances (ScanStation 2, d=74.3 m)

The differences of mean values of measured lengths and the true lengths for HDS 3000 in the laboratory for Leica recognized target ranges between -1.94 mm and -5.25 mm, and they meet the declared uncertainty. The differences of the mean values of the measured lengths and the true lengths for the plane target (Zeiss) are between -14.12 mm and +6.37 mm. The differences given with HDS 3000 also obey the normal Gaussian distribution of errors (Figure 5).

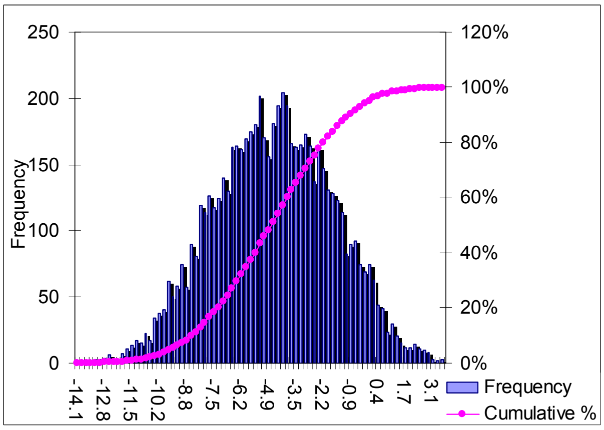

Fig. 5: Differences between exact and measured distances (HDS 3000 d=5.3 m)

Analyzing these differences, one can concluded that the HDS 3000 has a large length differences that does not meet the declared uncertainty. Range of lengths on one Zaiss targets is in the range of 15.2 to 18.8 mm.

The length measurements in the yard of the Faculty showed significant differences between the measured and the true values. These differences, measured to the Leica recognized targets, are in the range from -9.17 mm to +15.70 mm, and are not within the declared accuracy due to setup error and scale influence.

The differences of mean values of measured lengths and the true lengths of the plane Zeiss target are in the range from -14.68 mm to +25.76 mm. As with the measurement in the laboratory, there is a great dispersion of the measuring results in this case, too. The differences of the measured length to one pillar (intraday) are in the range from 14.6 mm to 21.2 mm. These differences also obey the normal Gaussian distribution of errors (Figure 6).

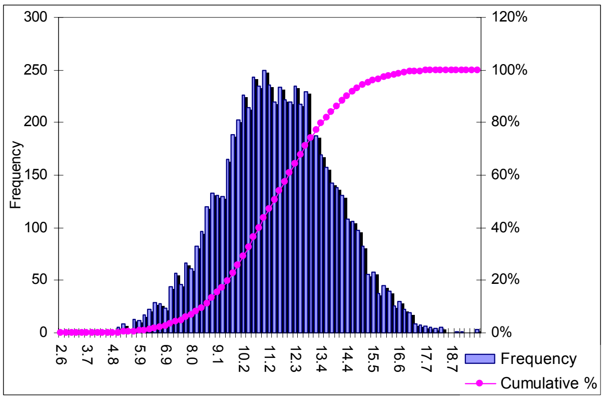

Fig. 6: Differences between exact and measured distances (HDS 3000 d=33.4 m)

CONCLUSION

The scale in the distance and the horizontal pitch of the scanner mostly affect the accuracy of the acquired targets in the case where the dual axis compensator is not installed. Random errors, in the case of the special scanner targets recognition, are negligible due to the big redundancy in the target determination.

The tests have shown that the particular Leica HDS 3000 to measure the length to any surface has the significant length errors, outside the declared accuracy due to influence of the setup error and the lack of dual axis compensator. In this case it is recommended that only indirect lengths between two targets have to be analyzed.

Leica ScanStation 2 proved to be the stable scanner, free of the significant lengths errors.

The applied procedure for the calibration of the terrestrial laser scanners satisfies the requirements of standards that the measurements do not last longer than 90 minutes in the laboratory conditions. Using this procedure, we can get the reliable scanner calibration data (possibly the distance meter constants) which can be used in the further interpretation of the scanning results.

ACKNOWLEDGMENT

This work is part of the technological development project No TR36009: *The Application of GNSS and LIDAR Technology for Infrastructure Facilities and Terrain Stability Monitoring*, which is funded by the Ministry of Science and Technological Development of Republic of Serbia.

REFERENCES

1. C. Ghilani, P. Wolf, editors, *Adjustment computations, spatial data analysis*, John Wiley & Sons, 2006.
2. D. C. Montgomery and George C. Runger, *Applied Statistics and Probability for Engineers*, John Wiley & Sons, 2003.
3. D. Lichti; *ISPRS Journal of Photogrammetry & Remote Sensing,* 61 (2007), pp 307–324.
4. G. Vosselman, H. Maas, editors, *Airborne and Terrestrial Laser Scanning*, 2010.
5. M. Pejic; *Tehnika,* 64/1 (2010), pp 13-18.
6. T. Schulz; *Technical University of Berlin*, PhD dissertation, (2007).
7. Y. Reshetyuk; *Royal Institute of Technology (KTH),* PhD dissertation, (2006).
8. X. J. Cheng and W. Jin; Journal of Physics: Conference, Series 48, 2006, pp. 843–849.
9. R. Gottwald; FIG Working Week 2008, Stockholm, Sweden, June 14-19, 2008.
10. H. Ingensand; 3rd IAG/12th FIG Symposium, Baden, May 22-24, 2006.
11. D. D. Lichti, et.al.; Int. Arch. of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B5, 2000, pp. 485 - 492
12. D.D. Lichti; Invited paper: Boletim de Ciências Geodésicas, 16 (1), 2010, pp. 3-19.
13. Y. Reshetyuk; Survey Review, Vol. 38, Nr. 302, October 2006, pp. 703-713(11).