The Accuracy Analysis of Leica ScanStation P20 Data by Means of Point Cloud Fitting Algorithm

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Abstract

Terrestrial laser scanning (TLS), although still considered as an exotic method for data acquisition, was successfully introduced in the field of engineering geodesy more than a decade ago. Recent TLS improvements regarding its performance, range and accuracy have opened up new challenges within engineering. TLS is a method of acquiring huge amount of data in a relatively short time period and with acceptable accuracy. Therefore, one can often ask oneself for which engineering tasks this modern method of surveying can successfully take place of classical methods. Aim of this paper was to compare one aspect of quality of the data acquired by a state-of-the-art scanner, Leica ScanStation P20, and by total station (TS). This was achieved by analyzing characteristic planes obtained from acquired data using least squares fitting method. Test field was the building of the Faculty of Civil Engineering in Belgrade. Applied statistical tests showed no significant difference between the plane fitted to the point cloud data acquired by TLS and the one fitted to the data acquired by TS.

Key words: Terrestrial laser scanning, ScanStation P20, Best-fit plane, Accuracy analysis

1 INTRODUCTION

Terrestrial laser scanning (TLS) is a contactless method for acquiring huge amount of data on terrain and various man-made constructions. It has been successfully employed in engineering geodesy for more than a decade now and is constantly developing. Still, just because it is a relatively new surveying method, TLS faces some obstacles regarding its use in engineering. When it comes to doing some "serious" work, most surveyors tend to rely on traditional surveying methods, i.e. employing a total station (TS) for data acquisition. This is mostly due to some unknowns regarding scanner quality performances.

However, these days there have been more and more studies on application of TLS in engineering (Pejić et al., 2013; Kopáčik and Wunderlich, 2004) claiming satisfying quality of data acquired by a scanner. This was to some extent the aim of this paper as well: to compare the accuracy of the results obtained by the terrestrial laser scanner and the total station.

Most frequently used methods of plane fitting are least squares fitting method (Hoppe et al., 1992; Jianfeng and Kazhong, 2013), Principal Component Analysis - PCA (Nurunnabi et al., 2012; Weingarten et al., 2004) and RANdom Sample Consensus - RANSAC (Schnabel et al., 2007; Zhang, 2012).

Hundreds of thousands or even millions of points forming so-called point cloud are not the ultimate goal of terrestrial laser scanning. Point cloud is just a stage in obtaining some final results, whether that would be a model of terrain or construction, characteristic planes or lines, sections or whatever can be used in subsequent analysis. Two construction planes were investigated within this paper, meaning that the comparison between planes obtained from TLS data on one hand and data acquired by a total station on the other hand was performed. Parameters of all of the aforementioned planes, as well as standard deviations of these parameters, were obtained by the least squares method.

2 METHODOLOGY

2.1 CONTROL NETWORK

Test field for the experiment was the building of the Faculty of Civil Engineering in Belgrade. Firstly, the control network was established, consisting of seven reinforced concrete pillars already stabilized in the backyard of the Faculty building (this network has been used as an instrument test field on regular basis). Positions of the control network points (marked as 1 to 7, Fig. 1) in a local coordinate system were determined by employing separate 2D and 1D adjustments in PANDA 4.20 software. Both adjustments were performed by minimizing the trace of variance-covariance matrix. Horizontal directions and distances were measured by using Sokkia SET3130R3 total station, while height differences were obtained by using Sokkia SDL30 digital level combined with fibreglass rods. Declared angular accuracy of the total station is 3", while its accuracy of distance measurement is 2 mm + 2 ppm. The accuracy of digital level is given as standard deviation of 1 mm/km when using fibreglass rods. Prior to fieldwork instruments were tested in laboratory.

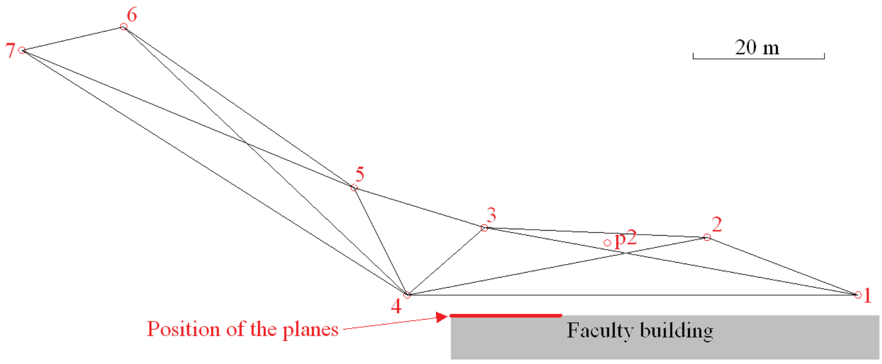

Figure 1 Control network

The standard deviations of the estimated 2D point positions ranged from 0.3 mm (point 3) to 0.4 mm (point 1), while the standard deviations of the estimated point heights were in the range between 0.1 mm (points 3 and 4) and 0.2 mm (point 7). The control network itself is not a prerequisite for scanning, but since it had already been established it was later utilized in scanning and point cloud georeferencing.

2.2 STRUCTURE SCANNING

In the next step, the back part of the building was scanned. The scanning process was carried out by using state-of-the-art terrestrial laser scanner Leica ScanStation P20 (Fig. 2). The Leica's latest pulsed TLS enables ultra-fast acquisition of high quality data with scan rate up to one million points per second and maximum range of 120 m. According to the specifications published by the manufacturer, its horizontal and vertical angular accuracy is

8", while the linearity error is less than or equal to 1 mm (Leica, 2013). This is the first time Leica is using the term "linearity error" instead of "distance accuracy".

Figure 2 Terrestrial laser scanner Leica ScanStation P20

The scanning was performed from two locations: pillar 5 and station p2 (Fig. 1) which required setting up the scanner on a tripod. Pillar 3 was not used as a station because of certain obstacles blocking a view towards the building. For the purpose of georeferencing square black and white (B&W) targets (14 cm x 14 cm) placed on pillars 1, 2, 3 and 4 were used in case of scanning from station 5, and on pillars 1 to 5 in case of scanning from station p2. Fine-resolution scanning was performed on all visible targets, while the building itself was scanned with the resolution of 6.3 mm at 10 m. The average distance between building and stations 5 and p2 was 30 m and 18 m, respectively.

Processing of the data obtained during the scanning procedure was performed in Leica Cyclone 8.0 software. The authors endeavoured to implement the procedure of direct georeferencing in the field but unfortunately the attempt was unsuccessful. Even though the metadata on implemented georeferencing method (station-orientation for 5 and resection for p2) was visible in Cyclone, the software didn't utilize it. None of the scans were actually in the terrain coordinate system, but rather in a coordinate system of the scanner which ultimately required implementing indirect georeferencing.

Indirect georeferencing was done in Cyclone by registering scans from stations 5 and p2 using identical control network points (points 1-4). The mean absolute error of the performed registration was 2.1 mm. The resulting georeferenced point cloud contained a lot of points which represented objects of no interest in this particular case, so "cleaning" of the point cloud was required. Afterwards, this reduced georeferenced point cloud was unified, i.e. the point cloud was resampled with point spacing set to 5 cm. The final point cloud used in the further analysis consisted of a little more than 3 million points.

2.3 PLANE FITTING AND ANALYSIS

Data needed for comparing characteristic construction planes was obtained from the created model, as well as by using the total station. The two chosen construction surfaces cca 6.7 m × 1.3 m in size (Fig. 3, surfaces marked with a red X sign) were discretized with 35 and 30 points respectively, acquired by the laser total station centred over the control network point 5 and oriented towards the control network point 1. The idea was to pick surface points from the model which in a way correspond to the points collected by the total station.

The X coordinates of the points-to-be were obtained from the model derived from the TLS data at the same Y and Z positions as the ones of the points surveyed by the total station. Thereby it was possible to have two point datasets (TS and TLS) differing only in X coordinates. The aforementioned X coordinates of the chosen points were obtained from the model created in the AutoCAD Civil 3D 2012 software package (the model was based on the previously resampled point cloud). Prior to obtaining the point coordinates from the model, all data was transformed. A simple rotation of the coordinate system about the Z-axis was performed by defining the Y-axis via two horizontally most distant points from the TS dataset. The intention was to bring the observed façade planes to be parallel to the YZ plane of the coordinate system. This should not be taken too formally since the mentioned parallelism cannot strictly be achieved in practice. For the purpose of facilitating further analysis the planes were assumed to be vertical.

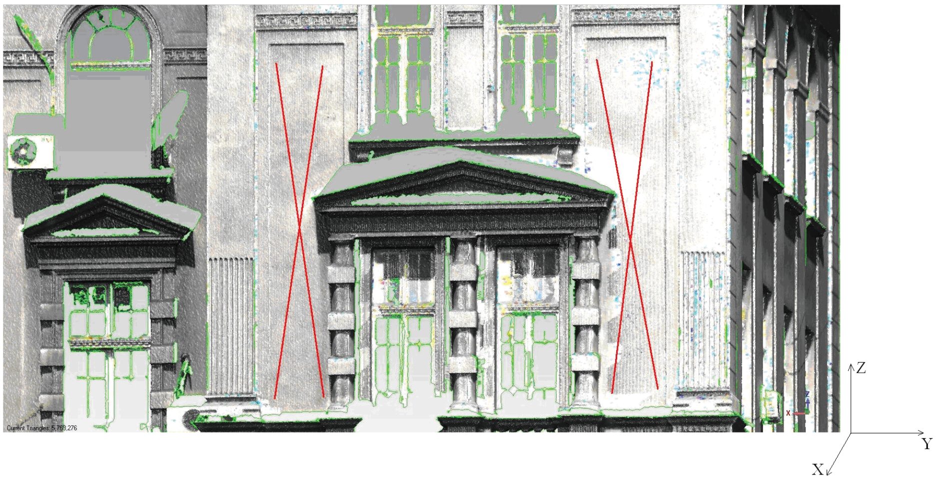

Figure 3 Characteristic construction planes

Planes were fitted to the point data by the means of ordinary least squares method. The whole estimation procedure was conducted in the MATLAB software package. In accuracy analysis it had been presumed that Y and Z coordinates were error-free (only X coordinates were treated as measurements), thus giving the general plane equation in the form:

$$X = A \cdot Y + B \cdot Z + C\,. \tag{1}$$

Estimation of the plane parameters was obtained by minimizing the sum of squares of point-to-plane residuals by the X-axis. In addition to estimating plane parameters, their standard deviations were assessed as well. These parameters and standard deviations were further used in statistical testing.

The first thing that was put on a test was the significance of the estimated plane parameters, i.e. the equality of these parameters and their corresponding assumed values. Both of the observed construction planes are assumed to be parallel to the YZ plane of the coordinate system, leaving the normal vector to the plane to be (1,0,0). This led to defining the null and the alternative hypothesis of the statistical test:

$$\begin{aligned} H_0 &: \quad \hat{A} = 0 \ \ (\text{and } \hat{B} = 0) \\ H_a &: \quad \hat{A} \neq 0 \ \ (\text{and } \hat{B} \neq 0) \end{aligned}, \tag{2}$$

with $\hat{A}$ and $\hat{B}$ being the estimated plane parameters.

The value of the test statistic in this case was obtained through:

$$T = \frac{|\hat{A} - 0|}{\hat{\sigma}_A} \left(\text{and } T = \frac{|\hat{B} - 0|}{\hat{\sigma}_B} \right) \tag{3}$$

and it was compared to the corresponding critical value, i.e. the corresponding quantile of Student's t-distribution. The value of 0.05 was adopted for the significance level of all the tests conducted within the experiment.

Equality of the estimated plane parameters and their assumed values was not the only thing that was tested. The second test checked whether the corresponding parameters of the plane obtained from TLS data and the one obtained from the data acquired by the total station could be considered equal. The null and the alternative hypothesis of the corresponding plane parameter testing were:

$$\begin{aligned} H_0 &: \quad i_{TS} = i_{TLS} \\ H_a &: \quad i_{TS} \neq i_{TLS} \end{aligned}, \tag{4}$$

where *i* stands for estimated A, B or C plane parameter. The value of the test statistic was obtained through:

$$T = \frac{|i_{TS} - i_{TLS}|}{\sqrt{\hat{\sigma}^2_{i_{TS}} + \hat{\sigma}^2_{i_{TLS}}}} \tag{5}$$

with $\hat{\sigma}^2_{i_{TS}}$ and $\hat{\sigma}^2_{i_{TLS}}$ being the corresponding variances of an observed plane parameter. This test statistic was compared to the corresponding critical value, i.e. the corresponding quantile of Student's t-distribution.

3 RESULTS AND DISCUSSION

As already mentioned, plane parameters and their standard deviations were estimated by using the ordinary least squares method. Total of four planes were fitted to the point data: left and right plane (Fig. 3) for both the TLS data and the data acquired by the total station. The plane parameters along with their standard deviations used in statistical testing are given in Table 1.

Table 1 Plane parameters and their standard deviations

Plane	Data source	$\hat{A}$	$\hat{B}$	$\hat{C}$	$\hat{\sigma}_A$	$\hat{\sigma}_B$	$\hat{\sigma}_C$
left	TS	0.0008	0.0021	3092.888	0.0015	0.0003	7.429
	TLS	0.0003	0.0015	3095.623	0.0011	0.0002	5.540
right	TS	-0.0042	-0.0003	3119.097	0.0025	0.0006	12.709
	TLS	-0.0040	-0.0012	3117.799	0.0023	0.0005	11.710

In case of the left plane, statistical testing of the equality of the estimated plane parameters and their corresponding assumed values showed that, for the adopted significance level of 0.05, it cannot be claimed that the estimated plane is parallel to the YZ plane of the coordinate system. As opposed to the parameter B, parameter A was found not to be significant, thus implying that the plane is rotated only about the Y-axis, i.e. that it is not vertical. This conclusion is valid for both planes, TLS and TS. Statistical testing of the equality of the corresponding plane parameters was also done. Plane fitted to the TLS data proved to be statistically equal to the plane fitted to the TS data for the chosen significance level of 0.05.

Similarly, the right TLS plane proved to be slightly inclined, i.e. rotated only about the Y-axis of the coordinate system and consequently nonvertical. On the other hand, in case of the right TS plane, both parameters, A and B, proved not to be significant for the adopted significance level of 0.05, thus implying that the plane is vertical, as well as parallel to the YZ plane of the coordinate system. As in case of the left plane(s), statistical testing did not show significant difference between the plane fitted to the TLS data and the plane fitted to the TS data.

4 CONCLUSION

Rapid development of terrestrial laser scanning urged the question whether this surveying technique is convenient for using in particular engineering tasks. Although majority of surveyors still tend to rely on traditional methods such as surveying by using a total station, TLS slowly establishes itself as an equally suitable surveying method, if not better in some cases. This paper was an attempt to shed light on the issue of accuracy of the data acquired by the terrestrial laser scanner Leica ScanStation P20, by comparing this data to that acquired by the laser total station.

The idea was to assess to which extent quality of data acquired by using two different techniques could be considered comparable. Two construction planes of the building of the Faculty of Civil Engineering in Belgrade were chosen as basis for the analysis. The planes were fitted to the data by the means of the ordinary least squares method. Further statistical testing involving the estimated plane parameters and their standard deviations showed no significant difference between planes fitted to the TLS data and those fitted to the TS data for the adopted significance level of 0.05. Yet, all construction planes except for the right TS plane proved to be slightly inclined (not ideally vertical) for the same significance level.

Still, methodology applied within this paper has some drawbacks reflecting primarily in impossibility of claiming certain accuracy of TLS. All one could claim is to which extent the results of scanning agree with those of surveying using total station. Furthermore, restrictions in the form of instrument errors, structure being scanned itself (material of which it was built, its roughness), number of points used for plane fitting, as well as dependence of the X coordinate on the Y and Z coordinates should be considered.

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