EVALUATION OF ACCURACY OF CONTROL POINTS' POSITION USING A LASER SCANNING SYSTEM LEICA HDS 3000

Martin Štroner, Václav Smítka, Pavel Třasák

Department of Special Geodesy, Faculty of Civil Engineering, Czech Technical University in Prague

1. INTRODUCTION

Control points are inseparable components of the laser scanning measurement process. They are mainly applied to connect point clouds from various standpoints. These points also ensure control in transformations of individual scanning positions and thus significantly affect the accuracy of the whole processing. This article deals with the evaluation of the accuracy of control points' position determination using the Leica HDS 3000 laser scanning system. For this purpose, a special measurement experiment was designed and performed in which a geodetic network consisting of control points of various design and produced by various manufacturers was measured. The measuring experiment checked the "internal accuracy" (by repeated measurements) of the determination of control points' coordinates using the laser scanning method; furthermore, the accuracy of coordinates determined by the laser scanning method was compared with the coordinates measured by the total station. Coordinates determined by means of laser scanning from different standpoints were mutually compared. Last, but not least, the instrument accuracy declared by the manufacturer was monitored and compared with the results of measurements conducted in laboratory conditions. Five types of control points were used for this experiment. Then, the position determination accuracy was evaluated in relation to individual types of control points used.

2. EXPERIMENT DESCRIPTION

A three-dimensional geodetic network with 27 determined points was set up and successively measured at the atrium of the Faculty of Civil Engineering, CTU in Prague on 6. 5. 2010. The measurement by total stations was conducted from five standpoints, 4001 to 4005, and by a laser scanner from standpoints 5001 and 5002.

The measured control points were signalized by five different types of targets. These were six spherical targets manufactured by the Trimble Company, six hemispherical targets by the Leica Company, reflective target plates by Trimble and Leica Companies, again in six pieces each. The last type was a pyramid-shaped target developed at the Laser Scanning Laboratory of the Department of Special Geodesy. This type of target was used in the network three times.

The effort was to use the FCE atrium to the maximum potential to uniformly distribute control points within it. The narrow, oblong-shaped atrium does not allow a fully

uniform configuration of control points and standpoints. A detailed diagram of the positioning of standpoints and control points is presented in Fig. 1.

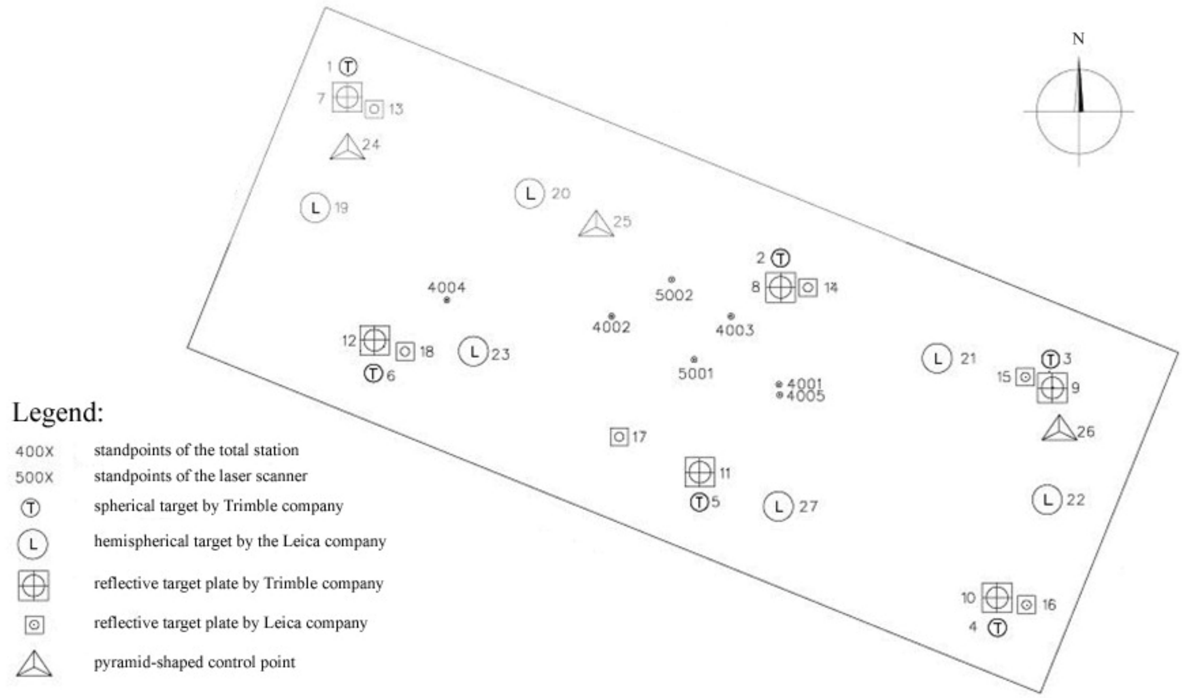

Fig. 1. Diagram of positioning standpoints and control points.

2.1. Methods of control point measurement

Control points were scanned with the Leica HDS3000 terrestrial scanner, and the network was measured using the Trimble S6 – High Precision and Topcon GPT-7501 total stations.

2.1.1. Leica HDS 3000 Laser scanning system

The above-mentioned control points were scanned from two standpoints (5001, 5002) using the Leica HDS3000 scanner. From the first standpoint (5001), each control point was scanned five times. On the second standpoint (5002), each point was only scanned once because of shortage of time.

The HDS 3000 laser scanning system (Fig. 2) is one of the products of the HDS (High Definition Surveying) series of instruments manufactured by the Leica Geosystems Company. It is a scanning system based on the principle of the three-dimensional polar method.

Fig. 2. HDS 3000 Laser scanning system [4].

It has a panoramic field of view with dimensions of 360° in the horizontal and 135° in the vertical plane. The measurement range is 134 m with a reflectivity of 18%. Its spatial position accuracy is 6 mm per 50 m. The pulse laser with which the laser is equipped emits rays at green colour and is classified in the 3R safety class under IEC 60825-1. The laser trace size at a distance of 50 m is smaller than 6 mm. HDS 3000 is mounted on a strengthened surveyor's tripod with a standard Leica tripod stand during measurements. The scanning velocity is up to 4000 points per second. The maximum number of points obtained from one scan is 100 million (20000 x 5000).

2.1.2. Total station

The three-dimensional network was measured using two types of total stations, Trimble S6 – High Precision and Topcon GPT-7501. All points in the network were measured in one group. Spherical targets were aimed at the upper, lower, left and right side of the sphere, always in two positions of the telescope. The resulting horizontal direction was determined as the arithmetic mean of measurements onto the left and right side of the sphere, and the resulting zenith angle was the arithmetic mean from the upper and lower part. The Topcon total station measured the network from standpoints 4001 and 4002, whereas the Trimble total station was used from standpoints 4003, 4004 and 4005.

The servo-motor-driven S6 total station is one of the products of the Trimble Company. Its manufacturer declares its accuracy of measured angles of 0.3 mgon, the accuracy of length measurement in the prism mode of 1 mm + 1 ppm, the range of measured lengths of 5500 m, while its prismless accuracy is over 800 m (on Kodak Grey Card with 90% reflectivity). The prismless accuracy is identical to the accuracy of length measurement with a prism. The velocity of measured lengths in the prism mode is 1.2 s, while in the prismless mode it is 1 − 5 s. The telescope magnification is 30x.

Fig. 3. Trimble S6 total station [5].

The GPT-7501 total station is a product of the Topcon Company. The manufacturer declares the accuracy of measured angles of 0.3 mgon, the accuracy of length measurement in the prism mode of 2 mm + 2 ppm, the range of measured length of 3000 m, and for prismless measurement over 2000 m (under favourable light conditions on Kodak White surface). The accuracy of length measurement in the prismless mode is 5 mm, while in the long prismless mode 10 mm + 10 ppm. The velocity of length measurement with a prism is 1.2 s, while in the prismless mode 1−3 s. The telescope magnification is 30x.

Fig. 4. Topcon GPT-7501Total station [6].

2.2. Used types of control points

In scanning, control points are an ideal accessory for ensuring good accuracy and, at the same time, checking the scan. The accurate determination of the position of control points and their multiple determination from various scanning positions allow reaching the maximum accuracy in the evaluation of the whole project. The accuracy of the position of control points may be verified by classic geodetic methods. The used materials frequently have high reflectivity.

The following types of control points were used for the experiment: a hemispherical target by the Leica Company, a reflective target plate by Leica, a spherical target by the Trimble Company, a reflective target plate by Trimble and a control point of a pyramid type.

2.2.1. Circular flat target combined with hemisphere by Leica Company

Leica Geosystems HDS flat blue targets allow automatic identification using the Cyclone software. This is thanks to varied differences in reflexivity between the target surface of the centre and the main target surface. The combined type of hemisphere and a reflective target plate is suitable for both sighting and evaluation. The reason is accurate total station's aiming at the central point of the target and also automatic evaluation of the target when the point cloud is projected onto the sphere of the Cyclone programme.

Six-inch circular targets are larger in dimensions and, therefore, more suitable for large-scale scanning or for scanning at larger distances. Flat targets may be fixed on the surface by means of plastic or magnetic holders.

Fig. 5. Circular flat target combined with hemispherical shape by Leica [8].

2.2.2. Reflective target plate by Leica Company

These plates are made of the same material as the Leica 6" flat circular targets above. Square targets have dimensions of 3" x 3". Therefore, they are suitable for use in scanning at shorter distances.

Fig. 6. Reflective target plate by Leica Company [9].

2.2.3. Spherical target by Trimble Company

Spherical targets belong to basic types of control points used in laser scanning. They are white spherical shapes mounted on short brackets; the control point coordinates are the

coordinates of the centre of the sphere. Spherical targets by the Trimble Company are produced of cured plastic and their diameter equals 3“.

Fig. 7. Spherical target by Trimble Company [10].

2.2.4. Reflective target plate by Trimble Company

Reflective target plates by the Trimble Company have a similar structure and appearance as reflective target plates by Leica. It is a white circular central surface with a diameter of 70 mm situated in the middle of a green background square with outside dimensions of 150 mm x 150 mm. They only differ from reflective target plates by Leica by the colour of the reflective foil forming the background and the dimensions of individual parts. The Trimble reflective target plate is fitted with black cross hairs for easier aiming in sighting the target with the total station.

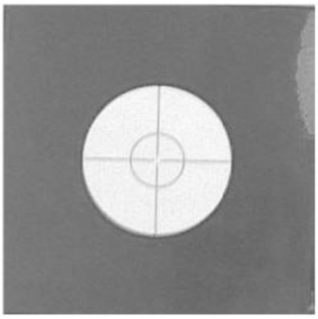

Fig. 8. Reflective target plate by Trimble Company.

2.2.5. Pyramid-shaped control point

The pyramid-shaped control point was developed in the laboratory of the Department of Special geodesy. It has been designed so that the evaluation of coordinates of its apex is performed on the basis of the intersection of three planes. This shape of a control point was selected to simulate any naturally stabilized corner which could be used as a control point in measurement using the laser scanning method.

Fig. 9. Pyramid-shaped control point.

3. MEASUREMENT PROCESSING

3.1. 3D network adjustment

The three-dimensional network with 27 determined points was adjusted by the method of least squares in the GNU Gama programme developed at the Faculty of Civil Engineering, the Department of Mapping and Cartography under the supervision of prof. Aleš Čepek, CSc.

Adjusted coordinates of individual control points were in the geodetic coordinate system, i.e. with the south-west orientation of the axes. The positive -axis is oriented towards the south, and the positive -axis is oriented towards the west. For the transformation into the mathematical system, which will further be used, the values of and axes were swapped and each coordinate was multiplied by −1. The positional deviation of the coordinates determined by adjustment was calculated as the quadratic mean of all positional deviations and it is equal to = 0.6 mm. The mean coordinate deviation = 0.4 mm.

3.2. Processing of data from Laser Scanning

As was described above, the control points were scanned from two standpoints; from the first standpoint each control point was scanned five times, while from the second standpoint only once because of time shortage. The evaluation of individual scans was made in the Cyclone programme. It is a software application by the Leica Company for processing 3D point clouds in surveying, engineering surveying, technological and structural applications.

The evaluation procedure differed for different types of control points. The evaluation of the centres of original targets by Leica, both hemispherical targets and reflective target plates was performed automatically. The same applied to reflective target plates by Trimble. The evaluation of the centres of spherical targets by Trimble and the apices of pyramids was performed manually.

3.2.1. Automatic determination of control points' centre

In scanning the scanner either automatically recognizes a control point (e.g. thanks to materials with high reflectivity) or we manually select a control point in the Cyclone

programme. Identified (or selected) control points are scanned with a very high density and their centres are subsequently automatically evaluated in the Cyclone programme.

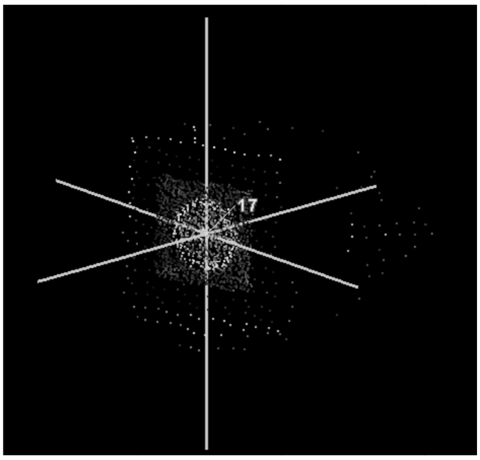

Fig. 10. Automatic searching of reflective target plate by Leica Company.

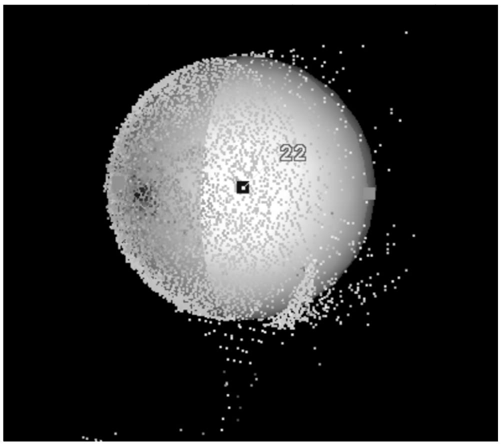

Fig. 11. Automatic searching of hemispherical target by Leica Company.

3.2.2. Manual determination of control points' centre

In order to project the scanned spherical surface onto the sphere we must first remove the area corresponding to the control point from the total scan and clean it of points which do not lie on the respective area. The cleaned point cloud is subsequently projected onto the corresponding geometric shape (sphere, plane depending on the type of control point) by means of an algorithm in the Cyclone software.

This procedure was applied for spherical control targets by the Trimble Company where a spherical area was projected on the cleaned point cloud and also on pyramid-shaped control points where the sought point was obtained as the intersection of three planes onto which the cleaned point clouds had previously been projected.

4. EVALUATION OF ACCURACY OF POSITION DETERMINATION

As was already mentioned, the coordinates of the first scan were determined five times, while the coordinates of the second scan only once. The evaluation of the accuracy of both scans is performed in a common coordinate system in relation to the coordinates determined by adjustment using the method of least squares in the GNU Gama programme [7]. First of all, however, we must evaluate the internal accuracy of

coordinates obtainrd from repetitive measurements on the first standpoint (5001). Then, it will be clear which types of control point targeting are suitable for the Leica HDS3000 scanner and which are not.

4.1. Internal accuracy of coordinate determination

The coordinates determined five times on the standpoint 5001 served for the calculation of their average values (φ_X, φ_y, φ_Z) and for subsequent corrections (v_X, , v_Z) for each coordinate. Furthermore, standard coordinate deviations (σ_X, σ_y, σ_Z) were calculated from these corrections using the formula [BÖHM et al. 1990]:

$$\sigma_x = \sqrt{\frac{\sum v_x v_x}{n-1}} \quad (1)$$

where the variable x represents X, Y, Z coordinates. The resulting error of the position of a respective control point was calculated from the formula [BÖHM et al. 1990]:

$$\sigma_p = \sqrt{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2} \quad (2)$$

For each type of used control point, the standard positional deviation was calculated as the quadratic mean using the formula [BÖHM et al. 1990]:

$$\sigma_p^{\emptyset} = \sqrt{\frac{\sum_{k=1}^{n} \sigma_p^2}{n}} \quad (3)$$

where n is the number of control points.

4.1.1. Internal accuracy of spherical targets by Trimble Company

The maximum standard positional deviation of this type of control point takes the value of 0.9 mm. The quadratic mean of standard positional deviations for this type of control point takes the value of 0.6 mm. In terms of the resulting positional accuracy of these targeted points, these targets are suitable for measurements using this type of scanner. If, however, the demands for measurement are considered (left, right, upper, lower – all this in both positions of the telescope) and the demands for manual evaluation of the centre of the spherical area in the Cyclone programme as was described above, this type of target is unsuitable for projecting the scanned spherical area as it is very time consuming.

4.1.2. Internal accuracy of reflective target plates by Trimble Company

The maximum standard positional deviation of this type of control point takes the value of 21.1 mm. The quadratic mean of standard positional deviations for this type of control point takes the value of 11. 8 mm. Reflective target plates by the Trimble Company have a much larger surface area of a highly reflective centre than original targets by the Leica Company. The HDS 3000 scanner is fitted with implicit setting of the reflective target area size, therefore, while scanning Trimble reflective targets the reflective area is incompletely scanned and, successively, the centre of this target is erroneously evaluated in the automatic processing in the Cyclone programme. Trimble

reflective targets are manufactured for a different type of scanner and have proved unsuitable for the Leica HDS3000 scanner.

4.1.3. Internal accuracy of reflective target plates by Leica Company

The maximum standard positional deviation of this type of control point takes the value of 0.4 mm. The quadratic mean of standard positional deviations for this type of control point takes the value of 0.3 mm. The presumption that original targets should be the most suitable was confirmed. They are suitable not only in terms of accuracy of position determination using the Leica HDS3000 scanning system, but also in terms of evaluation and sighting by the total station. The centre signalized by a small black circle was aimed, and the scans were automatically evaluated in the Cyclone programme. The time savings in aiming a large number of control points will be significant observing the maximum demands for accuracy.

4.1.4. Internal accuracy of hemispherical targets by Leica Company

The maximum standard positional deviation of this type of control point takes the value of 0.7 mm. The quadratic mean of standard positional deviations for this type of control point takes the value of 0.4 mm. In repetitive measurements, the flat part of the respective hemispherical target was used. The used material is identical to the Leica reflective target plate differing only by dimensions (reflective target plate 3” x 3”, hemispherical target 6”). Therefore, it corresponds by its accuracy to the preceding type of target. At the same time, the other positive qualities also apply to it. The internal accuracy of the determination of the hemispheres’ coordinates cannot be evaluated, as they were measured from the second standpoint (5002) and only once. The evaluation of the centres of these hemispherical targets was automatic, unlike the spherical targets by the Trimble Company.

4.1.5. Internal accuracy of pyramid-shaped control points

The maximum standard positional deviation of this type of control point takes the value of 1.1 mm. The quadratic mean of standard positional deviations for this type of control point takes the value of 0.8 mm. This type of control point is definitely not superior to original targets supplied by the manufacturer, nevertheless, it was manifested that this type of targeting is applicable. Evaluation in the Cyclone programme is relatively demanding and lengthy, but the resulting standard positional deviation for this type of control point is below 1 mm. In places where a reflective plate cannot be fixed, a naturally targeted intersection of three planes may be used under the condition that all sides have been scanned with roughly the same density.

4.1.6. Overview of internal accuracy of control points

Provided the Trimble reflective target plate, which was found unsuitable for this type of scanner, is removed from the evaluation, all the other positional deviations have complied with the expected internal accuracy up to 1 mm. It was confirmed that the most suitable solution are original targets, but the accuracy of the other two target types is not dramatically worse and in case of need they are usable. Numerical values are presented in the table below.

Table 1. Internal accuracy of control points

Control point type	$\sigma_p\ [mm]$
Trimble spherical target	0.6
Trimble reflective target plate	11.8
Trimble reflective target plate	0.3
Leica hemispherical target	0.4
Pyramid	0.8

4.2. Measurement accuracy from first standpoint in relation to adjusted coordinates

Having determined internal accuracy from the five times repeated first scan, the accuracy of the determination of control points' coordinates in relation to adjusted coordinates may be evaluated in the GNU Gama programme. First of all, however, the coordinates of control points obtained by means of the laser scanning methods had to be transformed [PAVELKA et al., 2001] into a coordinate system in which adjusted coordinates had been determined using the GNU Gama software. The positional accuracy of the control points' coordinates thus determined was 0.6 mm. If the effect of the accuracy of adjusted coordinates was to be eliminated, it would be necessary to quadratically subtract the positional deviations of control points' adjusted coordinates from positional deviations of the coordinates determined by scanning (and transformation). The introduction of this correction produced a correction of positional deviations in the order of tenths of a millimetre, therefore, this correction was not used. The evaluation was performed by comparing transformed coordinates (X_T, Y_T, Z_T) from individual repeated measurements from the first standpoint with the control points' coordinates determined by adjustment in the GNU Gama programme. Corrections (v_X^G, v_Y^G, v_Z^G) were calculated from adjusted coordinates and from them standard coordinate deviations (σ_X^G, σ_Y^G, σ_Z^G) for each control point were calculated using formula (1). The positional deviation of a respective control point σ_p^G was calculated from formula (2). The positional deviation $\sigma_{\emptyset p}^G$ of a specific type of control point was determined as the quadratic mean using formula (3).

4.2.1. Overview of control point accuracy in relation to adjusted coordinates

As compared to the evaluation of internal accuracy of repeated scanning, positional deviations in relation to adjusted coordinates are by one order less accurate. It is not possible to evaluate the effect of transformation into a common coordinate system on the accuracy of coordinates determined by scanning. Provided the Trimble reflective target plate, which was found unsuitable for this type of scanner, is removed from the evaluation, the accuracy rate of all the other types of control points is comparable. It was confirmed that the most suitable are original targets, but the accuracy of the other two types of target is not dramatically worse. It is possible that a control point located too close to the scanner is determined with lower accuracy than more distant points. The resulting standard positional deviations are presented in the table below.

Table 2. Overview of control points' accuracy in relation to adjusted coordinates

Control point type	$\sigma^G_{\emptyset p}[mm]$
Trimble spherical target	1.7
Trimble reflective target plate	11.8
Trimble reflective target plate	1.2
Leica hemispherical target	1.4
Pyramid	1.5

4.3. Accuracy of measurement from both standpoints in relation to coordinates determined by adjustment

After the unification of the coordinate systems of both completed scan positions was performed, the accuracy of the determination of control points' coordinates in relation to adjusted coordinates may be evaluated in the GNU Gama programme. The effect of these coordinates' determination is not considered as it is of minimum value. The evaluation was performed by comparing the mean coordinates of five repeated measurements in the first scan and the once measured coordinates in the second scan with adjusted coordinates. These coordinates were used for calculating corrections (v^G_X, v^G_Y, v^G_Z) and from them the positional deviation of a respective control point σ^G_p was calculated using formula (2). The positional deviation $\sigma^G_{\emptyset p}$ of a specific type of control point was determined as the quadratic mean using formula (3). The same procedure was used for the calculation of standard coordinate deviations ($\sigma^G_{\emptyset X}$, $\sigma^G_{\emptyset Y}$, $\sigma^G_{\emptyset Z}$).

4.3.1. Overview of accuracy of control points from standpoints 5001, 5002 in relation to adjusted coordinates

The values of standard deviations of points determined from the second standpoint are in all cases greater than the values of standard deviations of points from the first standpoint. These differences, however, are practically negligible for some types of control points (Leica and pyramid targets) with respect to the statistical error in determining standard deviations. A slightly lower accuracy in the determination of control points on the second standpoint is attributed to numerous random errors which were eliminated by repeated measurement on the standpoint 5001. For both types of targets manufactured by the Leica Company, the difference between the five times and once measured control points is the least. The Cyclone software is, therefore, able to evaluate control points to maximally eliminate the random error component so that only the systematic error mainly remains.

Table 3. Overview of accuracy of control points from standpoints 5001 and 5002 in relation to adjusted coordinates

Control point type	$\sigma^G_{\emptyset p5001}[mm]$	$\sigma^G_{\emptyset p5002}[mm]$
Trimble spherical target	1.7	2.6
Trimble reflective target plate	11.8	12.4
Trimble reflective target plate	1.2	1.0
Leica hemispherical target	1.4	1.2
Pyramid	1.5	1.4

5. CONCLUSION

The objective of this article was to evaluate the accuracy of positional determination of control points using the Leica HDS3000 terrestrial laser scanner. Five types of control point targets were used for this experiment: reflective targeting plates and hemispherical targets produced by the Leica Company, reflective target plates and spherical targets by the Trimble Company and pyramid-shaped control points manufactured exclusively for this experiment at the laboratory of the Department of Special Geodesy. First of all, internal accuracy of the determination of control points' position was monitored with the Leica HDS3000 scanner, using five times repeated measurements from one standpoint. The hypothesis that original targets are the most suitable option for this type of scanner was confirmed; their accuracy of position determination is 0.4 mm. Reflective Trimble target plates, on the contrary, proved unsuitable for this type of scanner as their dimensions are incompatible. Trimble spherical targets and pyramid-shaped control points are usable for this type of scanner, but the evaluation of point clouds poses much greater demands on time than the evaluation of original targets. Here, the accuracy of 0.6 mm may be obtained for Trimble spherical targets and 0.8 mm for pyramids.

Furthermore, the accuracy of their position determination was compared in relation to coordinates measured by total stations, which were adjusted in the GNU Gama programme. The standard positional deviation of adjusted coordinates is 0.6 mm. It was performed in a common coordinate system (control points determined by scanning were transformed), and thus the evaluation is not completely independent. The results, however, confirm previous measurements. And, like in the evaluation of internal accuracy, Leica control points again appear the most suitable option (the standard deviation of position determination using Leica targets was only 1.0 mm), but the other types of targets, except for Trimble reflective target plates, are also applicable (the standard deviation of position determination of Trimble spherical targets being 1.4 mm, and of the pyramid 1.2 mm).

To conclude, the coordinates of control points measured from the second standpoint were compared in relation to adjusted and also averaged coordinates from five times repeated measurements. It was confirmed that by repetitive measurements random errors are eliminated and what remains is mostly only the systematic error component.

The manufacturer declares the accuracy of the determination of coordinates for a target of 2 mm; this value was reached during five times repeated measurements for each type of control point, except for the Trimble reflective target plate (11.8 mm). In the measurement performed once, the value declared by the manufacturer was exceeded in the evaluation of Trimble reflective target plates and spherical targets (12.4 mm or 2.6 mm respectively), while for pyramids (1.1 mm) and original control points the accuracy was observed (1.0 mm or 1.4 mm respectively).

It should be emphasized that if we use original targets the accuracy of the determination of control points' position is practically doubled against the value declared by the manufacturer (the standard deviation being half its value). The experiment was performed in laboratory conditions; the distance from the scanner to control points was in the interval of 5 m to 25 m.

This project was supported from the CTU Student Grant Competition grant No. SGS10/152/OHK1/2T/11.

REFERENCES

Böhm, J. - Radouch, V. - Hampacher, M.: *Teorie chyb a vyrovnávací počet (Theory of Errors and Adjustment Calculus)*. Geodetický a kartografický podnik Praha, 2nd edition, Praha, 1990. ISBN 80-7011-056-2.

Pavelka, K. - Štroner, M.: *Lineární prostorová transformace (Linear 3D Transformation).* In: Geodetický a kartografický obzor. 2001, Vol. 47, No. 3, pp. 233-235. ISSN 0016-7096.

Štroner, M. - Pospíšil, J.: *Terestrické skenovací systémy (Terrestrial Scanning Systems)*. 1st edition. Praha: Česká technika – CTU publishing house, 2008. 187 pp. ISBN 978-80-01-04141-3.

http://hds.leica-geosystems.com/en/5574.htm

http://www.geotronics.cz

http://obchod.geodis.cz/geo/gpt-7500

http://www.gnu.org/software/gama

http://www.leica-geosystems.com/en/Target-Mounts_19144.htm

http://hds.leica-geosystems.com/en/Targets_19143.htm

http://www.surveying.com/products/details.asp?prodID=6700-02