Verification of Laser Scanning Systems Quality

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SUMMARY

The laser scanning systems are being currently more and more used in a wide spectrum of applications e.g. in documentation of cultural heritage, as-built documentation or for deformation and slide monitoring. Most of those applications require a high quality of the measured data. The measurement and space information processing procedure with a laser scanning system is a black box to a common user so it is necessary to perform the analysis of the data measured in different conditions and to assess their quality on the basis of the analysis. In our experiments we concentrated on observing physical qualities of the laser beam during reflection off the measured object surfaces and assessed accuracy of the measurement on different types of materials under different incidence angles and in different distances. In our next experiment we presumed that distance measurement accuracy determination of the laser scanning systems is easy but angle measurement accuracy determination is much more complicated and in most published cases it is performed indirectly through object modelling from a point cloud. Therefore we concentrated on composition of a new procedure of angle accuracy direct determination from the single points located in a point cloud with using photogrammetric technology, which beside angle accuracy determination enables a more detailed description of laser scanning system internal measurement procedure.

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1. INTRODUCTION

The terrestrial laser scanning systems are a relatively new measurement technology used in geodesy. It serves for contactless collection of space data, modelling and visualization. The measured object is covered with a large amount of detailed points measured in a regular angle distance called point cloud. The individual measurements may contain ten thousands or even millions of detailed points. Two methods are used as a measurement principle for scanning systems, the triangulation method from the known basis, which is used especially for scanning systems of a small extent from tens of centimetres up to several metres, and the space polar method, which is used for scanning systems with a large extent used in the area of classical geodesy, in civil engineering, topographical mapping, etc. In case of the space polar method, the lengths are measured by a pulse or phase distance meter and the angles are determined from reading position of oscillating plane mirrors, prisms or from rotation of the whole head of scanner. This article focused on verifying quality of the measured data by the scanning systems that use the space polar method. The laser scanning system Leica HDS 3000 was used as a representative of the stated scanning systems in the accomplished experiments.
The measurement principle of the Leica HDS 3000 scanning system is the space polar method; the lengths are measured by a pulse laser distance meter with a length of 532 nm. The scanner field of view is 360º in the horizontal direction and 270º the vertical direction. The optimum measurement extent is stated from 1 m to 100 m. The stated measurement accuracy values are 6 mm in the single point position, 4 mm in length measurement accuracy and angle accuracy in both directions is 60 micro-radians. These values are guaranteed by the manufacturer till the distance of 50 m. The scanning speed is up to 1800 points per second. A digital camera is built in the scanner. The Cyclone software is used for operating the scanner and processing the measured data.

To the current user, the terrestrial laser scanning systems are a black box, where the measurement procedure and processing data is covered with a trade secret. The information stated in the technical parameters of the single scanning systems are reliable, but in many cases they are insufficient and their practical verification is complicated. That is why the experiments that we carried out were focused on verifying quality and reliability of the measured data and determination of some scanner parameters. Two accomplished experiments are described in this article. The first experiment dealt with verifying abilities of the scanning system to measure of various material types under various incidence angles in several distances and the second experiment dealt with testing a new method of direct measurement standard deviations of horizontal directions zenith angles of the laser scanners.

2. MEASUREMENT SURFACES OF DIFFERENT MATERIALS IN VARIOUS GEOMETRIC CONDITIONS

Quality of the measured data of the terrestrial laser scanning systems, the principle of which is the space polar method, is influenced by several significant factors. They are measurement accuracy of the scanning system, registration accuracy and transformation of the individual measurements, geometric configuration and physical characteristics of the measured surface and environment.
Accuracy of the laser scanning measurement is influenced by measurement accuracy of the individual components necessary for determination of position of one point, which means by length measurement accuracy of vertical and horizontal direction and further of systematic error of the scanner. Registration and transformation accuracy of the individual measurements is influenced by accuracy of the used identical points or by density and form of point clouds if identical points are not used. The following articles deal with influences of geometric configuration and physical characteristics of the measured surface.

2.1 Physical Characteristics of the Surface

When determining position of a point, the scanning system measures length between the scanner and the point, assigns horizontal and vertical direction to this joint and calculates position of the point. Whether length will be measured and with what quality it will be measured, depends on telemetric signal that will fall on the sensor of the scanner. Quality of the falling telemetric signal is influenced especially by physical characteristics of the surface that do not participate in quality of the measured angles.

Quality of reversed telemetric signal is influenced by incidence angle and physical characteristics of the surface, reflectivity, absorbability and permeability. These characteristics can be identified according to energy conservation law in such a way when total falling radiation intensity E, reflected radiation intensity R, absorbed radiation intensity A and permeabled radiation intensity P, then:

$$E = R + A + P \tag{1}$$

From this relation we will express reflectivity ρ, absorbability α and permeability π:

$$\begin{aligned} \rho &= R / E \\ \alpha &= A / E \\ \pi &= P / E \end{aligned} \tag{2}$$

But variables defined in such a way express total amount of reflected, absorbed and permeabled radiation. Such problems do not appear with absorbed and permeabled radiation, but it is different with reflected radiation because reflectivity ρ states amount of reflected radiation in all directions, whereas only the part of radiation is important for measurement that is reflected back to the scanner and does not fall on receiving sensor of the distance meter. Amount and direction of reflected radiation influences incidence angle ι of telemetric signal and type of surface on which the signal falls.

We distinguish several basic types of surfaces according to form of their reflectivity diagram, which states direction dependence of amount of reflected radiation for the given position of source of falling radiation. Diffusion surface reflects radiation proportionally in all directions. In visible spectre of electromagnetic radiation it is for example plaster, chalk or a non-glazed china. Ideal specular surface reflects falling radiation according to the reflection law. Real specular surfaces as for example polished silver reflect most of radiation according to radiation law and reflect only small part of radiation in other directions. Chequered surfaces reflect radiation most in the direction from which radiation falls on the surface. Example of chequered surface is reflection foil. In figure 1 there are stated illustrations of reflectivity for the above-described surfaces.

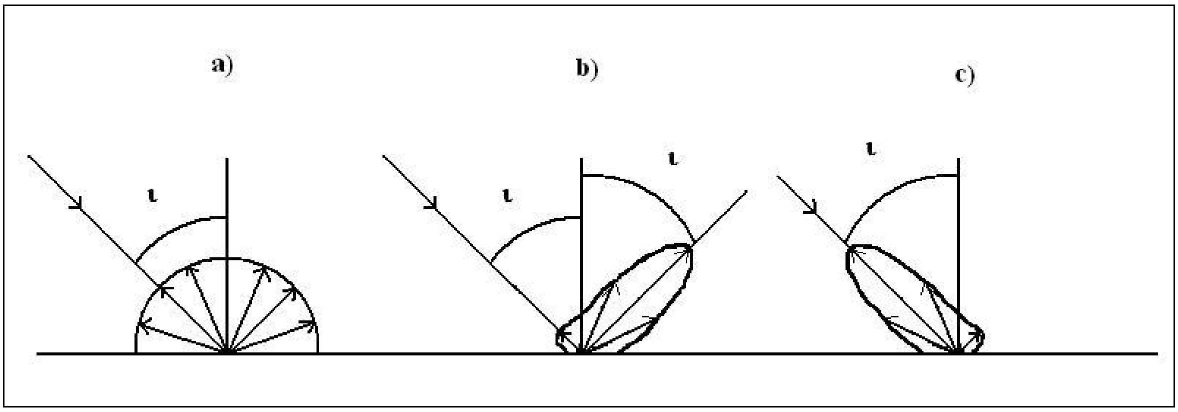

Figure 1. Reflectivity diagrams of main types of surfaces: a) diffusion, b) specular, c) chequered

From what was stated it results that most suitable for measurement with laser scanner is the most suitable diffusion surface with high reflectivity, by which it comes even with big incidence angles so sufficiently big reflection of telemetric signal back to the scanner (Křemen, 2005). They are especially light materials with rough surface (in relation to wavelength of telemetric beam). Problems can appear with surfaces with high absorbability (dark colours), with shining surfaces (specular reflection) and with surfaces with high permeability (glass).

2.2 Experimental Measurement

Ability of the HDS 3000 laser scanning system to measure surfaces of different types of materials under different incidence angles in two distances was tested in this experiment. Influence on quality and accuracy of measured points were observed.
Shining colours, dead colours, emery papers, metals, stones and bricks were tested. The single types of surfaces with parameters 200 mm x 200 mm were placed into plane on several desks made of chipboard and covered with white lamina. Colours were laid on the desks, metal sheets and emery papers were stuck to the desks and for stone tiles

and bricks they were let into holes that were cut into the desks. Surfaces were measured under the following incidence angles: 0; 30; 50; 55; 75; 90 gon in distances 15 m a 25 m from the scanner. Three point clouds with density 5 mm x 5 mm were procured for each incidence angle and distance. In figure 2 there is an illustration of one desk with stones and bricks (upstairs from left side lime stone, gabbro, sand stone, downstairs from the left side lime-cement, chamotte and classical burnt stone).

Figure 2. Desk with different materials

Number of points that fell on the measured surface and theoretical number of points that should be measured on the surface were determined during the evaluation. Then a plane was fitted by the Cyclone program through each measured surfaced and error standard deviation s_N, absolute error mean M.A.D. and maximum absolute error E_{max} were determined:

$$s_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \underline{x})^2}$$
$$M.A.D. = \frac{1}{N}\sum_{i=1}^{N} f_i \left|x_i - \underline{x}\right| \qquad (3)$$
$$E_{\max} = \max_i \left|x_i\right|$$

where $\underline{x}$ is average of errors, N is total number of points, x_i is the error of the i^{th} point, i is point count 1 through N and f_i is absolute frequency.

2.3 Illustration of Results from Experimental Measurements

Considering that 46 surfaces were tested, a series of black materials as illustration of the obtained results was chosen. It was black shining BALAKRYL Uni Lesk 1999 colour, black dead BALAKRYL Uni Mat 0199 colour, polished gabbro Impala and four emery papers with granulity 80, 100, 180 a 400. Results of these 6 surfaces measured in distance 25 m are stated in table 1.

Surface	Angle of Incidence [gon]	Number of Points	%	s_N [m]	M.A.D. [m]	E_{MAX} [m]	Note
Glossy Black Colour	0	4658	100	0.0019	0.0015	0.0069	
	30	2726	68	0.0032	0.0025	0.0214	
	50	238	8	0.0025	0.0020	0.0116	
	55	84	3	0.0031	0.0021	0.0104	
	75	1	0				37
	90	24	3	0.0007	0.0006	0.0020	648
Mat Black Colour	0	4692	100	0.0016	0.0013	0.0054	
	30	4090	100	0.0026	0.002	0.0099	
	50	2159	70	0.0027	0.0021	0.0174	
	55	1360	50	0.0029	0.0023	0.0161	
	75	8	0				
	90	0	0				6
Gabbro Impala	0	4903	100	0.0021	0.0017	0.0069	
	30	4299	100	0.0020	0.0016	0.0090	
	50	3364	100	0.0017	0.0013	0.0065	
	55	3231	100	0.0016	0.0013	0.0073	
	75	1774	100	0.0011	0.0008	0.0043	
	90	158	22	0.0012	0.0008	0.0077	467
Emery 80	0	4231	100	0.0019	0.0015	0.0082	
	30	3884	100	0.0022	0.0017	0.0088	
	50	3025	100	0.0018	0.0014	0.0069	
	55	2725	100	0.0017	0.0013	0.0066	
	75	1620	100	0.0012	0.0009	0.0038	
	90	765	100	0.0007	0.0006	0.0023	
Emery 100	0	4193	100	0.0019	0.0015	0.0066	
	30	3778	100	0.0023	0.0019	0.0092	
	50	2946	100	0.0020	0.0016	0.0075	
	55	2704	100	0.0018	0.0015	0.0069	
	75	1620	100	0.0013	0.0010	0.0042	
	90	713	100	0.0009	0.0007	0.0025	
Emery 180	0	4153	100	0.0019	0.0015	0.0073	
	30	3672	100	0.0022	0.0017	0.0083	
	50	2902	100	0.0019	0.0015	0.0070	
	55	2607	100	0.0018	0.0014	0.0066	
	75	1575	100	0.0012	0.0010	0.0040	
	90	702	100	0.0008	0.0007	0.0027	
Emery 400	0	4211	100	0.0019	0.0015	0.0068	
	30	3774	100	0.0017	0.0014	0.0066	
	50	2935	100	0.0014	0.0012	0.0053	
	55	2638	100	0.0014	0.0012	0.0048	
	75	1569	100	0.0010	0.0008	0.0040	
	90	700	100	0.0006	0.0005	0.0020	

Table 1. The results measurements of six black surfaces in distance 25 m

Table 1 shows number of points measured on surface and from this resulting percentage stating number of really measured points in relation to theoretic number, error standard deviation s_N, absolute error mean M.A.D. and maximum absolute error E_{max} for single surfaces and incidence angles. Then a number of points is stated in the note for which it came to multiple reflections during measurement length.
It is interesting that for all emery papers it came to decrease in amount of determined errors with growing incidence angle, which confirms conclusions of the following experiment that for a small field of view there appears length measurement error in point cloud whereas angle measurement error is slight.

2.4 Summary

The results of the accomplished experiments confirmed that the most suitable surfaces for scanning are light surfaces with diffusion reflection of falling radiation. For surfaces with specular reflection of falling radiation it came to multiple reflection of telemetric signal for steeper incidence angles. Longer distance between the point and the scanner than in reality was measured and thus it came to incorrect determination of point position. Significant difficulties can appear in practice in connection with this phenomenon for example during scanning food industry technology made of highly shining metals (diaries, breweries). For surfaces with specular reflection and high absorbability of the falling signal, the amount of signal reflected back into scanner sensor was so small that the length was not measured in many cases. Especially for black shining colour, the phenomenon gained so significant influence that from incidence angle 50 gon and more almost no detailed points were measured.

3. THE ORIGINAL METHOD OF DIRECT MEASUREMENT STANDARD DEVIATIONS OF HORIZONTAL DIRECTIONS AND ZENITH ANGLES FOR LASER SCANNERS AND ITS USE FOR TESTING THE HDS 3000 SCANNER

With entry of laser scanner technology there appeared a need to compare the scanners and to verify the characteristics stated by the manufacturers. In case of this technology that is quite new, the testing methods are not acknowledged unequivocally and belong mainly in the research area.

There has been published a large amount of articles dealing with determination of standard deviations of measured lengths under various conditions, for example (Boehler, 2003) and (Kersten, 2005). These tests are not very complicated, because a standard deviation of length can be assessed for example from a "noise" of data during scanning a perpendicular plane. Another method is assessment of distances between objects radially situated to measurement (for example balls). Nevertheless, this method does not determine standard deviations of lengths but a length error between two objects that are somehow modeled from a large number of points. The result is also influenced by not very clear effects on the edges of the measured object. This method can be used for a relative comparison of different scanning systems.

Several articles deal with total calibrations of the laser scanning systems on the basis of measuring on a large amount of superfluous variables, for example (Lichti, 2005) and (Rietdorf, 2004). These methods enable to reveal systematic errors of laser scanning systems as for example collimation error, index error etc.

From the viewpoint of determination of angle errors of scanning systems, the number of publications is significantly smaller, for example (Boehler, 2003). These publications do not deal with determination of standard deviations of horizontal directions and zenith angles, but only with assessment of a transverse error between the measured and modelled objects. The method has again its hazards mentioned above and it can be used only for relative accuracy assessment of different laser scanning systems.

That is why the new method of direct determination of standard deviations of horizontal directions and zenith angles of laser scanners was proposed. Because of using a digital camera, the method can be used only for scanning systems with a distance meter with a wave length of a visible area of electromagnetic radiation. The method assesses only interior accuracy of the scanning system within a small field of view (1x1 gon) and therefore the results are not influenced by systematic errors of the device as a collimation error, index error and other errors. On the other hand, the method shows real measurement accuracy for modelling of smaller objects.

The method is based on a modified photogrammetric method of directive linear transformation (DLT) in 2D. A calibration field is created, which is placed across to the measurement direction. The field is photogrammetrically measured. After switching the lightning off, the plane with a calibration field is measured with a laser scanning system, during which it is photogrammetrically measured. On the basis of the photogrammetric method, it is possible to determine a plane position with a scanner of the measured points with accuracy approximately 0.1 mm to each coordinate. The measurement is transformed from the scanner into the plane system of the calibration field (x axis vertical, y axis horizontal and z axis is perpendicular to the field plane). Real errors of the scanner are assessed, as differences of the coordinate differences of photogrammetric method and scanning method.

3.1 The Calibration Field

The calibration field was created by sticking suitable targets in a regular raster 50x50 mm onto a fixed plane white pad and by its exact measuring (see figure 3).

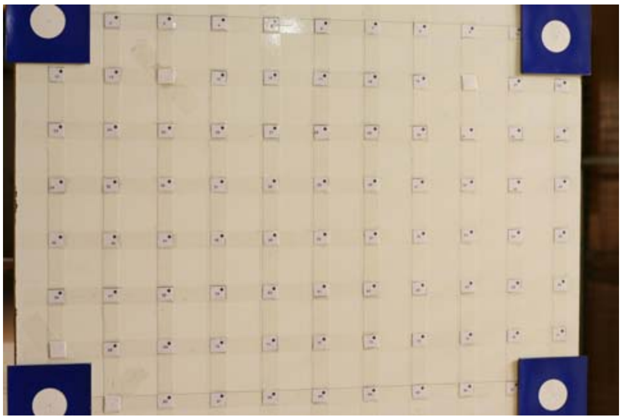

Figure 3. A calibration field

The field was twice independently measured by a planimeter of the Altec Corporation Company. Measurement accuracy of the calibration field was assessed by a coincidence transformation. The unit standard deviation (4) of this transformation is 0.12 mm:

$$\sigma_0 = \sqrt{\frac{\sum_1^{r1}\left(v_x^2 + v_y^2\right)}{r1 + \frac{q-p}{2}}}, \qquad (4)$$

where v_x and v_y are corrections, $r1$ is number of points, q is number of subsidiary conditions (for this transformation 5) and p is number of unknowns (for this transformation 8). For transformation of this and other below stated transformations, the public library "alltran" was used (more information see (Koska, 2006)), which was built in the gMatVec library (more information see (Čepek, 2005)). The coordination system of the calibration field was consequently transformed into the system defined by the two upper Leica targets.

3.2 The Photogrammetric Measurement the Calibration Field

The calibration field was placed in the distance of 50 (or. 32) metres from the scanner upright to the measurement direction. The digital camera was placed in front of the field so that it did not cover the scanner's field of view and so that the calibration field covered at the same time the camera's field of view as much as possible (see figure 3). A Canon EOS D350 camera (8M pixel) and a Canon EF 50 objective (f/1.8) were used for the measurement.

For reading the photo coordinates, a software "odecitacv2" of Ing. M. Štroner, Ph.D was used. This software enables a sub pixel selection of points by a method of RGB filter setting. After clicking into a single point fulfilling the set filter, all neighbouring pixels fulfilling the RGB filter are automatically selected and their average is calculated.

Parameters of the DLT 2D method (more information see (DLT Method, 2006)) were calculated from the identical points for transformation from the calibration field into the photo. Then it came to calculation of parameters of the modified DLT 2D method introducing terms correcting the radial object distortion, which are currently used for the general DLT method (e.g. see (DLT Method, 2006) and (Hanzl, 1986)). Photo coordinates of the beginning of the radial distortion x_0 and y_0 multinomial were newly added to the unknown variables. The form of new equation is:

$$
\begin{aligned}
x &= \frac{X \cdot L_1 + Y \cdot L_2 + L_3}{X \cdot L_7 + Y \cdot L_8 + 1} + \left(x - x_0\right) \cdot \left(k_1 \cdot r^2 + k_2 \cdot r^4 + k_3 \cdot r^6\right) \\
y &= \frac{X \cdot L_4 + Y \cdot L_5 + L_6}{X \cdot L_7 + Y \cdot L_8 + 1} + \left(y - y_0\right) \cdot \left(k_1 \cdot r^2 + k_2 \cdot r^4 + k_3 \cdot r^6\right) \\
r^2 &= \left(x - x_0\right)^2 + \left(y - y_0\right)^2
\end{aligned}
\tag{5}
$$

In the stated equations, $L_1 - L_8$ are parameters of DLT, *x, y* are photo coordinates to the identical points, *X, Y* are coordinates in the system of calibration field of identical points, x_0, y_0 are photo coordinates of the beginning of the radial distortion polynomial and k_1, k_2 and k_3 are coefficients of radial distortion polynomial. Unit standard deviation of this transformation is according to the formula (4) ($q = 0$, $p = 13$) 0.42 pixel (80 identical points) for the first position and 0.45 pixel (proportion of pixel is c. 0.15 mm) for the second position.
This method was verified in the first position as well. Only half of the points, which is 40, were used for the calculation of the key. The other half of the points were transformed into the photo coordinates on the basis of this key. The calculated and measured photo coordinates were compared and a standard deviation was calculated, which came out in accordance with the previous results 0.49 pixel. During inverse transformation of the read photo coordinates into the field of calibration system, standard deviation 0.1 mm was calculated in position of the point and approximately 0.07 mm in x and y coordinates. These results confirmed suitability of the used method.

The library "alltran" (dlt_2d, dlt_2d_rd2, inv_dlt_2d_rd2) was used for all the stated transformations.

During photographing the calibration field and the scanned points, the camera was placed on the tripod and operated from the notebook by the Canon EOS Capture software. The camera setting was: manual sharpening (switched on the objective), manual operating made, screen number F 5.6, exposition 1 – 15 seconds.

3.3 Photogrammetric Measurement of the Scanned Points

The measurement was carried out with lightning switched off in a cellar room. The exposition time 15 seconds slightly exceeded time of the scanner measurement. Example of the measured photo is stated below.

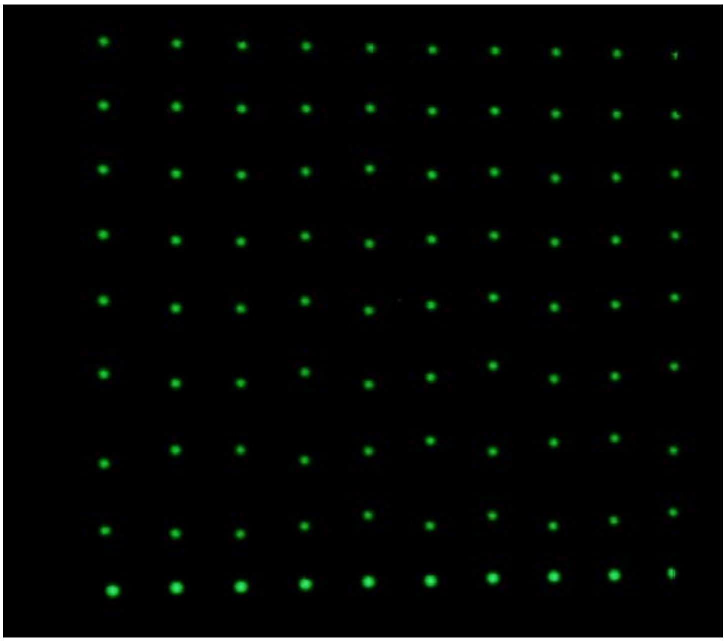

Figure 4. Photography of scanner measurement

The photo coordinates of the laser trail were scanned by the "odecitacv2" software again. During examining settings of different RGB filter values (so that the number of the chosen pixels was one hundred and more) it came to changes in the read photo coordinates at most by 0.5 pixel (0.15 mm). Standard deviation of the laser trail reading can be estimated approximately 0.1 mm in the position and thus 0.07 mm in x and y coordinates. The read photo coordinates were transformed into the coordinated system of the calibration field by the modified inverse 2D DLT (inv_dlt_2d_rd2) transformation.

3.4 Calculation of Standard Deviation of Horizontal Directions and Zenith Angles

Measurements of the HDS 3000 scanner were also transformed into the system of the calibration field defined by the Leica targets. It means that in one system there were at disposal plane coordinates determined by the photogrammetric method and by the laser scanning method.
Coordinate differences between the points for both methods were calculated. Pairs of the neighbouring points were always considered in both directions, so each point will appear only once in the calculation. The points the photogrammetric reading of which was difficult were excluded from the calculations (for example when the laser trail was situated on a black identical point).

The measurement was carried out from 3 positions (50 metres, 50 metres and 32 meters after new turning of the scanner). The measurement was repeated five times with the same setting from each position. The measured matrix contained 10x8 points. Numbers of pairs for calculation of lengths was 38, 37 and 39 for the individual positions after excluding the unsuitable points. The calculated results are summarized in the following tables:

Horizontal direction				
Position/ Distance	Measur. scan/photo	σ Δ(Δx -ΔX) [m]	σΨ [gon]	Number of comb.
1/50	1	0.00018	0.00016	38
	2	0.00023	0.00020	38
	3	0.00014	0.00012	38
	4	0.00019	0.00017	38
	5	0.00017	0.00015	38
			0.00016	
1/50	1	0.00037	0.00033	37
	2	0.00036	0.00032	37
	3	0.00037	0.00033	37
	4	0.00032	0.00029	37
	5	0.00039	0.00035	37
			0.00033	
1/32	1	0.00025	0.00036	39
	2	0.00024	0.00033	39
	3	0.00028	0.00040	39
	4	0.00025	0.00036	39
	5	0.00027	0.00038	39
			0.00037	

Table 2. Standard deviations in the horizontal direction

Vertical direction				
Position/ Distance	Measur. scan/photo	σ Δ(Δy -ΔY) [m]	σΨ [gon]	Number of comb.
1/50	1	0.00030	0.00027	38
	2	0.00025	0.00023	38
	3	0.00028	0.00025	38
	4	0.00028	0.00025	38
	5	0.00027	0.00024	38
			0.00025	
1/50	1	0.00019	0.00017	37
	2	0.00026	0.00024	37
	3	0.00025	0.00022	37
	4	0.00026	0.00023	37
	5	0.00024	0.00021	37
			0.00022	
1/32	1	0.00036	0.00051	39
	2	0.00019	0.00027	39
	3	0.00022	0.00031	39
	4	0.00026	0.00036	39
	5	0.00021	0.00030	39
			0.00035	

Table 3. Standard deviations in the zenith angle

3.5 Evaluation of Results

Accuracy of the photogrammetric method in the determined coordinate of the point is according to the above stated data contemplated as 0.1 mm (0.07 mm standard deviation in the coordinate of the modified inversion 2D DLT transformation method on the basis of test and 0.07 mm standard deviation in coordinate in reading the laser trail). This represents the standard deviation for distance 50 metres in direction 0.13 mgon.

Angle standard deviation of the HDS 3000 scanner stated by the manufacturer (and also of the HDS 2500 scanner) is 60 micro-radians, which means 3.8 mgon. Standard deviation in direction should therefore be 2.7 mgon.
Photogrammetric method is considered accurate because it is more than ten times more accurate than the expected accuracy of the HDS 3000 scanner.

The achieved results can be considered very surprising. If we consider the first and the second position (50 metres) and average the result values, we will obtain standard deviation 0.25 mgon for horizontal direction and standard deviation of zenith angle 0.24 mgon. These are values that approach accuracy of the reference photogrammetric method. That is why they cannot be directly considered characteristics of the HDS 3000 scanner. These characteristics can be additionally calculated with an easy contemplation on the basis of knowledge of the result standard deviation and standard deviation in direction in the following way:

$$\begin{aligned} \sigma^2_{\varphi,\,final} &= \sigma^2_{\varphi,HDS3000} + \sigma^2_{\varphi,\,photogrammetry} \\ \sigma_{\varphi,HDS3000} &= \sqrt{\sigma^2_{\varphi,\,final} - \sigma^2_{\varphi,\,photogrammetry}} \,. \end{aligned} \qquad (6)$$

It results from the stated information that for the HDS 3000 scanner standard deviation in horizontal direction 0.21 mgon is valid and for zenith angle it is 0.2 mgon.
For position on 32 metres, the expected standard deviation in direction from the photogrammetric point is 0.2 mgon. Final deviations in horizontal directions are 0.37 mgon and in zenith angle 0.35 mgon. For the HDS 3000 scanner, standard deviation in horizontal direction 0.31 mgon is valid and for zenith angle it is 0.29 mgon.

Differences in standard deviations from different positions are surprising and they can be influenced by their dependence on measurement time and scanner turning position. But more significant is influence of no perpendicular turning of the calibration desk on scanning direction. This influence was not considered in first accuracy analyses by reason of expected standard deviations of the scanner (it can cause an influence of standard deviation in coordinates in dimension of tenths of millimetres).

3.6 Summary

The original method for direct measurement of standard deviations for horizontal directions and zenith angles of laser scanners was introduced and verified. The method can be used for all laser scanners the distance meters of which use electromagnetic radiation with wave length in visible spectre. The method judges only internal accuracy of the scanning system within small field of view (1x1 gon). In our concrete realization, the method is suitable for scanners with standard deviation in direction 1.3 mgon and higher because it is ten times lower accuracy than the accuracy of the photogrammetric method. The angle standard deviation stated by the manufacturer for the Leica HDS 3000 scanner (exactly as for the HDS 2500 model) is 60 micro-radians, which represents standard deviation in direction 2.7 mgon. That is why the result of experiments can be considered very surprising, where standard deviation in horizontal direction and also zenith angle comes from approximately between 0.2 to 0.3 mgon, which is roughly ten times more accurate.

4. CONCLUSION

The article describes more complex view of the issue of testing parameters of laser scanning systems using space polar method. Light surfaces with diffusion reflection of falling radiation were stated as the most suitable surfaces for scanning during testing of many various types of materials under various geometric conditions. Emery papers showed very good characteristics. The surface with high absorbability and specular reflection of falling signal (glossy black colour) was stated as the least suitable surface. On the surface with specular reflection it comes to the multiple reflection of telemetric signal with steeper incidence angles. In this case it comes to incorrect determination of point position. The original method for direct determination of standard deviations of vertical directions and zenith angles of laser scanners with distance meters working in visible part of spectre was used for assessment of internal accuracy of the scanning system. The method is based on modified photogrammetric DLT method in 2D, during which a laser trail falling on the plane is read by the digital camera. Deviations of coordinate differences of the scanning method from the photogrammetric method are judged. Standard deviation in horizontal direction and zenith angle until 0.3 mgon comes out for the tested HDS 3000 scanning system.

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