CARTOGRAPHY AND AERIAL PHOTOGRAPHY

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ACCURACY INVESTIGATION OF POINT CLOUDS WITH FARO FOCUS 3D S120 TERRESTRIAL LASER SCANNER

Aim. Terrestrial laser scanning is a powerful method for collecting spatial data. This method of remote sensing allows fast, non-contact and precise measurement of objects. Terrestrial laser scanning systems deliver 3D coordinates and the power of the backscattered laser scan signal of each point which registered it as an intensity value. Intensity values are affected by the characteristic of the measured object and the parameters of the environment. The backscattered electromagnetic signal is influenced in its strength by the reflectivity of the scanned object surface, the incidence angle, the distance between laser scanner and object and the atmospheric respectively system specific setting of the TLS-measurement. Since details about system internal alteration of the signal are often unknown to the user, model driven approaches are impractical. On the other hand, existing data driven calibration procedures require laborious acquisition of separate reference datasets or areas of homogenous reflection characteristics from the field data. Therefore, the impact of qualitative and quantitative characteristics of the scanning object for accuracy investigation of point clouds with the Faro Focus 3D S120 terrestrial laser scanner is the aim of work. **Methods.** According to the tasks, an experiment was performed, which was to investigation the point clouds: density, interval between points, and intensity changes with distance and color of the scanning object. Faro Focus 3D S120 terrestrial laser scanner was used for the research. As a special test target was chosen a polished glass plate with size 30 cm × 30 cm, which was twice covered with an aerosol with white matte paint with a reflectivity of about 80% on one side of the target and black matte paint with a reflectivity of about 20 % on the other side of the target. To perform the experimental work, the test target was mounted on a tripod using a sleeve that attaches to the target. The target was placed on the white side at a distance of 0.6 m from the terrestrial laser scanner and was scanned. Then the target was turned to the black side and the scanning was repeated. The measurements were repeated at distances of 1.5 m, 3 m, 5 m and 10m. Our test data covers 10 terrestrial scans. The intensity values were exported from the point clouds using Faro SCENE software. **Results**. The results of the experimental work were considered for the fragments of point clouds of black and white sides of the test target (the size of the fragment is 15×15 points). The distribution of point clouds in the YX and YZ planes of the upper left and center fragments of the white and black sides of the targets, the intensity of the reflected signal and the standard deviation of the intensity values were analyzed. **Scientific novelty**. The influence of the qualitative and quantitative characteristics of the scanning object on the accuracy of point clouds construction with the Faro Focus 3D S120 laser scanner is presented and analyzed. **Practical significance**. The study will optimize the choice of terrestrial laser scanning settings based on the properties of the object and the scanning distance.

Key words: terrestrial laser scanner, point cloud, reflection, intensity.

Introduction

Terrestrial laser scanning (TLS) is one of the most effective methods of providing high-precision and dense point clouds that can be used to measure Earth's objects, monitor deformations, construct three-dimensional spatial models, and solve other problems in Earth science [Shan, & Toth, 2018].

This method of remote sensing allows fast, non-contact, and precise measurement of objects and allows to immediately receive information about the object as a point cloud, which increases accuracy [Soudarissanane, 2016].

The operating principle of laser scanner, which is to measure not a single point but a point of clouds, significantly complicates the calibration procedure. Scanner models differ in function, so there is still no single approach to laser scanner calibration models and techniques. The most famous are the works of D. D. Lichti, Y. Reshetyuk, and T. Schultz, which summarize these models.

Calibration of scanners is impossible without the use of special high-precision equipment. Since details about system internal alteration of the signal are often unknown to the user, model driven approaches are impractical [Tan, et al., 2018]. On the other hand, existing data driven calibration procedures require laborious acquisition of separate reference datasets or areas of homogenous reflection characteristics from the field data. Let's consider and analyze the sources of terrestrial laser scanning error.

The errors in TLS measurements can be subdivided into the following groups [Staiger, 2005]: instrumental, object-related, environmental and methodological errors. Instrumental errors have both systematic and random influences and depend on the internal construction of the scanner. Since the terrestrial laser scanner consists of two blocks, the errors are respectively divided into the errors of the angular and range blocks.

The main source of object-related errors is caused by the properties of the scanning object. TLS is a reflectorless surveying technique, subsequently reflectance of the object surface is the first and foremost source of these errors.

Reflectance may be defined as the ratio between reflected and incident laser power [Reshetyuk, 2009]. It is the function of the following factors: material properties of the object (electric permittivity, magnetic permeability and conductivity), the wavelength of the laser, incidence angle of the laser beam, color, roughness, temperature, and moisture of the surface. Obviously, surfaces with high reflectance give more reliable and precise range measurements than those with low reflectance, due to the fact that a larger portion of the laser energy is reflected back to the sensor [Jaafar, et al., 2018].

Environmental impact is related with ambient temperature, pressure, relative humidity, lighting, vibration, etc.

Georeferencing errors are occurr as uncorrected scanning parameters, errors in scanner station and control targets (spheres) coordinate determining, and processing (registration) of scan data.

Though most manufacturers are providing technical information about its laser scanners, it is recommended that experiments be performed to verify the quality of the data [Pesci, et al., 2011]. Let's take a closer look at existing studies of the effects of errors in terrestrial laser scanning.

An analysis of the current state, technical capabilities of terrestrial laser scanning and existing calibration techniques of a terrestrial laser scanner is considered in [Shults, & Sossa, 2015]. The concept of system calibration of terrestrial laser scanners and the basic mathematical model used for calibration are described. An example of solving one of the methodological problems that arise in calibration, namely the determination of the model of the scanner errors was presented. The authors note that the MSE was consistent with the accuracy claimed by the laser scanner manufacturers. However, information about the tested terrestrial laser scanner was not presented.

The results of quantitative analysis of the impact of errors of a terrestrial laser scanner for monitoring purposes are proposed in the publication [Jaafar et al., 2018]. The authors conducted experimental investigations of Leica ScanStation P20 and P40 laser scanners in the laboratory, in order to minimize the effects of atmospheric conditions errors. Accordingly, to reduce the errors associated with the scanning object, it is recommended to select a flat white surface. As the authors note, the average error is better than the accuracy of the point coordinates published by the manufacturer, on the other hand, the maximum error is much larger than expected and reaches 5 cm. It should be noted that the discrepancy between the point clouds is obvious. Also, the presentation of unambiguous conclusions will be complicated by the lack of ability to compare results across distances.

The Zoller + Fröhlich Imager 5003 3D laser scanner was used in [Schulz & Ingensand, 2004; Ingensand, 2006]. Researchers have found that the greatest impact on accuracy is incidence angle and color of surface. In addition, it was found that the noise level is increased in direct proportion to the scanning range. It should be noted that the authors developed a method of noise reduction by processing the data in the original polar coordinate system of the scanner.

The accuracy investigation of TLS systems is proposed in [Mechelke, et al., 2007]. Several terrestrial laser scanners such as the Trimble GX, Mensi GS100 / 200, Leica ScanStation, Z + F IMAGER 5006 and Faro LS880 HE have been compared. The test demonstrated that the point clouds of the impulse scanner had a systematic offset of up to + 6 mm. The accuracy tests of distance measurements in comparison to reference distances showed clearly that the results met the accuracy specification of the manufacturer, although the accuracy is slightly different for each instrument.

The influence of the incidence angle on 3D accuracy can be neglected for time-of-flight scanners, while phase difference scanners show significant deviations, if the incidence angle is less than 45°. The accuracy is also not influenced by the spot size of the laser with respect to the incidence angle. In the investigations into the influence of object color on the quality of laser distance measurements it could be shown that the Faro and Trimble scanners show significant effects of some object colors on the accuracy of the scanning distance. All investigations showed clearly that the used scanners are still influenced by instrumental errors, which might be reduced by instrument calibration.

The studies [Tan, et al., 2015; Sun, et al., 2017; Tan, et al., 2018] present a method for correcting the distance measurement errors caused by target reflections. Eight representative targets with different materials and surface characteristics were scanned by the Faro Focus3D 120. Considering incidence angle, distance and object characteristics individually is infeasible for modeling the distance errors. Therefore, the use of the intensity value is proposed for modeling the distance errors. Priori information about the reflectance of the scanned target, scanning geometry, and instrument mechanism is not required. The authors note that the distance measurement accuracy can be improved after establishing the function between intensity and distance errors. Also, authors consider that distance errors larger than 5 mm are caused by specular reflections.

Only the acquisition configuration and the target surface properties must be considered for the compensation of distance measurement errors because the atmospheric conditions near the surface of the Earth are relatively stable and the instrument mechanism is usually unchanged during one campaign, as shown in [Soudarissanane, et al., 2011]. The effects of incidence angle and distance on distance measurement accuracy have been extensively studied, whereas research about distance measurement errors caused by target properties is relatively rare. The distance errors caused by the properties of rough and dull surfaces usually measure a few millimeters. However, these errors can significantly increase to the centimeter and even decimeter levels for smooth surfaces (water, fresh ice, metal, porcelain, and plastic) because diffuse and specular reflections exist in all-natural surfaces and the type of reflection affects the direction and strength of backscattered light [Voegtle, & Wakaluk, 2009].

There are several suggestions to minimize terrestrial laser scanning errors that can be summarized with the assumption that the instruments are calibrated. Instrumental errors may be reduced by using the instrument with small beam divergence, a small footprint, higher angular precision, an axis compensator, setting up the instrument as near to objects as possible, outliers' removal based on median filter, and by manual editing.

Object-related errors may be minimized by avoiding mirror, high reflective objects and scanning with a high incidence angle, using the instrument with a shorter wavelength, and removing by manual editing.

Environmental errors may be reduced by avoiding to scan hot objects, increasing scanner temperature (from external sources or long working hours), using instruments with optical interference filters, configuration of instrument for correct ambient temperature, atmospheric pressure, and humidity, mounting instrument on a stable platform, preventing any motion obstacles during scanning, and removing by manual editing.

Methodological errors may be minimized by using a sampling interval equal to 86 % of footprint, the target-based registration, direct georeferencing if accurate control points exist, a threshold of a maximum incidence angle of 65°, and set up instrument in suitable location.

Aim

Terrestrial laser scanning systems deliver 3D coordinates and power of the backscattered laser scan signal of each point which registered it as an intensity value. The intensity is usually used as an attribute for realistic visualization of point clouds. However, this value has much greater potential, which is increasingly being used for more complex tasks such as identification and classification of data.

Intensity values are affected by the characteristics of the measured object and the parameters of the environment. The backscattered electromagnetic signal is influenced in his strength by the reflectivity of the scanned object surface, the incidence angle, the distance between laser scanner and object, and the atmospheric respectively system specific setting of the TLS-measurement.

Since details about system internal alteration of the signal are often unknown to the user, model driven approaches are impractical. On the other hand, existing data driven calibration procedures require laborious acquisition of separate reference datasets or areas of homogenous reflection characteristics from the field data. Therefore, it is necessary to investigate the impact properties of the object scanning for accuracy of TLS point clouds.

Method

According to the assigned task an experiment was implemented, which consisted of investigating the point clouds density, interval between points, intensity changes with distance, and the color of the scanning object.

Terrestrial laser scanning was performed in laboratory conditions with stable environmental parameters.

Also, it should be noted that the incidence angle was close to zero, its effect is not investigated in this work.

Faro Focus 3D S120 Terrestrial Laser Scanner (serial number LL S 061 101314) with a wavelength of 905 nm was used for the research, which represents geometric information and the intensity of the returned signal, recorded in 11 bits [0 – 2048] [FARO Laser Scanner Focus 3D Manual, 2013] (Table 1).

Table 1

Faro Focus 3D S120 Technical Specifications

Ranging unit	
Unambiguity interval:	153.49 m
Range:	0.6 m – 120 m indoor or outdoor with low ambient light and normal incidence to a 90 % reflective surface
Measurement speed:	122.000 / 244.000 / 488.000 / 976.000 points/sec
Ranging error:	±2 mm at 10 m and 25 m, each at 90 % and 10 % reflectivity
Ranging noise:	
10 m	– raw data: 0.6 mm – 90 % refl., 1.2 mm – 10 % refl. – noise compressed: 0.3 mm – 90 % refl., 0.6 mm – 10 % refl.
25 m	– raw data: 0.95 mm – 90 % refl., 2.2 mm – 10 % refl. – noise compressed: (0.5 mm = = 90% refl.,1.1mm -10 % refl.
Deflection unit	
Vertical/Horizontal field of view:	300°/360°
Vertical/Horizontal step size:	0.009° (40,960 3D pixels on 360°)
Max. vertical scan speed:	5.820 rpm or 97 Hz
Laser (Optical transmitter)	
Laser power (cwØ):	20 mW (Laser class 3R)
Wavelength:	905 nm
Beam divergence:	Typical 0.19 mrad (0.011°)
Beam diameter at exit:	3.0 mm, circular

A special test target was created to perform the experimental work (Fig. 1).

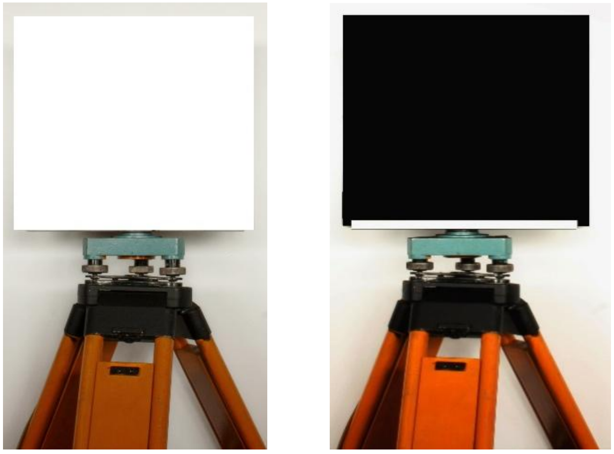


Fig. 1. Test target

To create the test target, a polished glass plate with size 30×30 cm, which was twice covered with an aerosol with white matte paint with a reflectivity of about 80 % on one side of the target and black matte paint with a reflectivity of about 20 % reflectivity on the other side of the target. In this case, the coating thickness does not exceed 2–3 microns and will not affect the accuracy of the measurements.

To perform the experimental work, the test target was mounted on a tripod using a sleeve that attaches to the target. The target was placed on the white side at a distance of 0.6 m from the terrestrial laser scanner and scanned. Then the target was turned to the black side and the scanning was repeated. The measurements were repeated at distances of 1.5 m, 3 m, 5 m, 10 m (Table 2).

Table 2

Measurement setup

Distance, m	Interval, °	Interval, mm
0.6		0.1
1.5		0.3
3	0.009	0.6
5		0.8
10		1.5

The test data covers 10 terrestrial scans captured with a FARO Focus 3D S120 scanner. The intensity values were exported from the point clouds using Faro SCENE software.

Results

The distribution of point clouds of the upper left and center fragments (15×15 points) for each scan were analyzed to evaluate the study results.

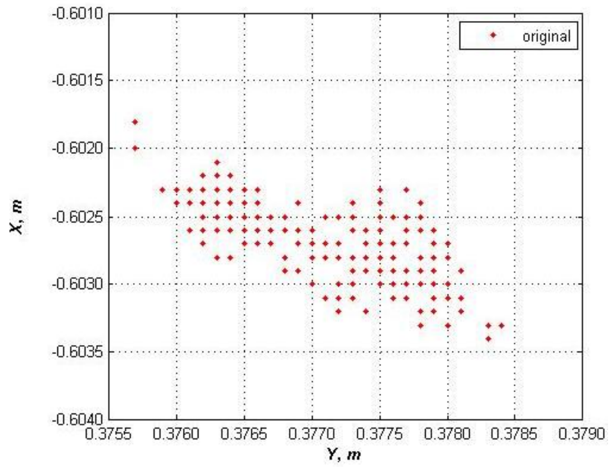
The mean squared errors (MSE) of the Y and Z coordinates are presented in Table 3.

Table 3

The MSE of Y and Z coordinates

Distance	0.6, m		1.5, m		3, m	
Target color	m_Y, mm	m_Z, mm	m_Y, mm	m_Z, mm	m_Y, mm	m_Z, mm
White	0.4	0.1	0.5	0.2	1.0	0.1
Black	0.7	0.1	0.7	0.2	1.7	0.1
Distance	5, m		10, m			
Target color	m_Y, mm	m_Z, mm	m_Y, mm	m_Z, mm		
White	1.9	0.1	4.1	0.2		
Black	2.1	0.2	4.9	0.6		

The graphs of the distribution of the central fragments of point clouds in the YX and YZ planes for the white and black sides of the target are presented in Fig. 2–7.



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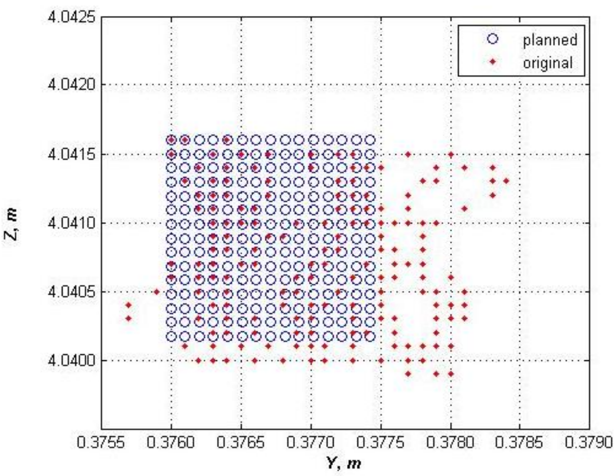

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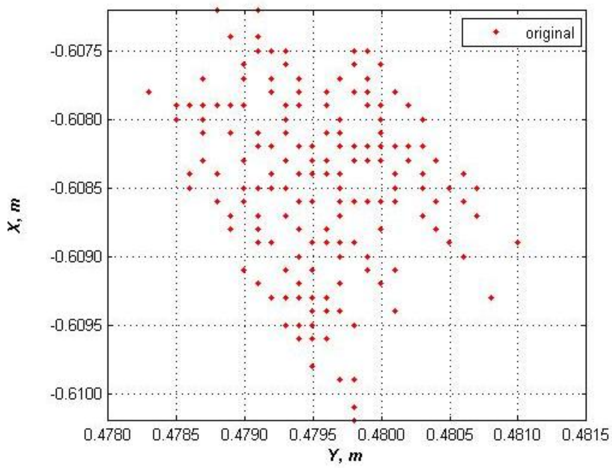
Fig. 2. Distribution of the central fragment of the point cloud of the white side of the target in the planes YX (a) and YZ (b) with a scan distance of 0.6 m

Analyzing the results of the experimental work (Fig. 2–7), can conclude that heterogeneity of point cloud density is the most obvious at a distance between the scanning object and the scanner at 0.6 m. The situation is improving with the increase of distance, however, the scanning step does not meet the planning for fragments of point cloud of the black side of the test target at a distance of 10 m.

As for the intensity values, the greatest power of the returned signal is observed for scanning distance of 0.6 m and 5 m (Fig. 8).

Fig. 9 shows the distribution of the standard deviation of the intensity with change in distance.



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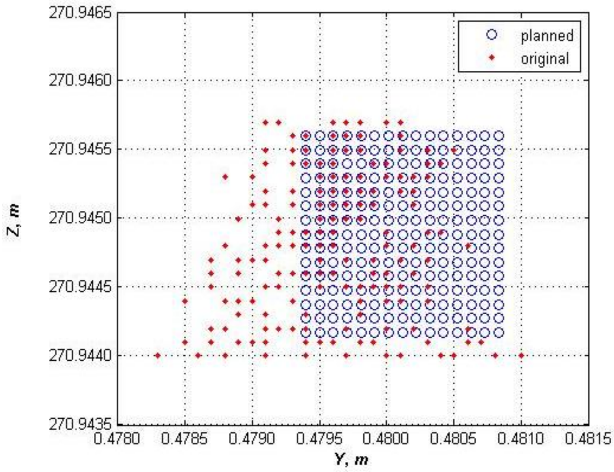

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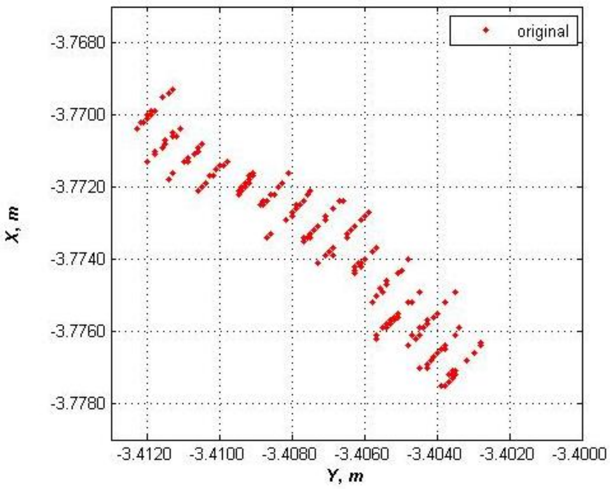
Fig. 3. Distribution of the central fragment of the point cloud of the black side of the target in the planes YX (a) and YZ (b) with a scan distance of 0.6 m



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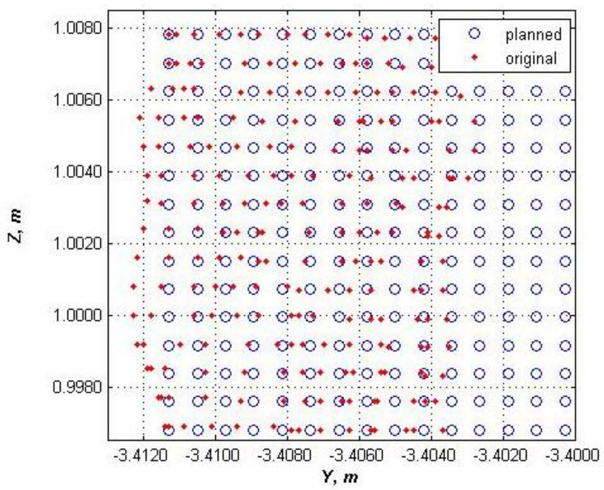

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Fig. 4. Distribution of the central fragment of the point cloud of the white side of the target in the planes YX (a) and YZ (b) with a scan distance of 5 m

As can be seen from the Fig. 9, the standard deviation values are greatest for a distance of 3 m. It is also obvious that the values for the white surface of the target are much smaller. This indicates the homogeneity of the intensity of the returned signal for the white surface of the target.

Scientific novelty and practical significance

The influence of the qualitative and quantitative characteristics of the scanning object on the accuracy of point clouds construction with the Faro Focus 3D S120 terrestrial laser scanner is presented and analyzed. The results of research will optimize the choice of terrestrial laser scanning settings based on the properties of the object and the scanning distance.

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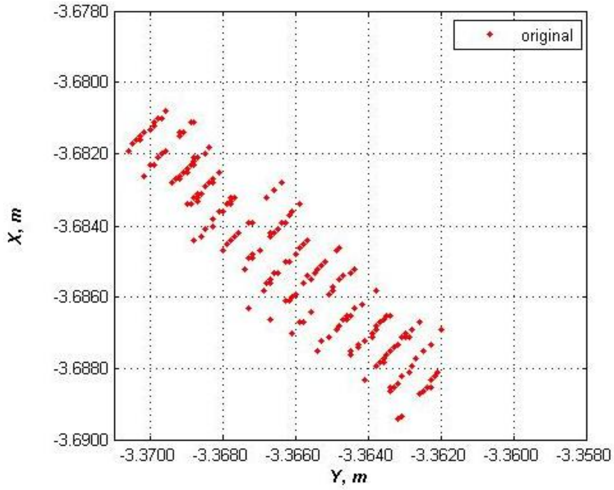

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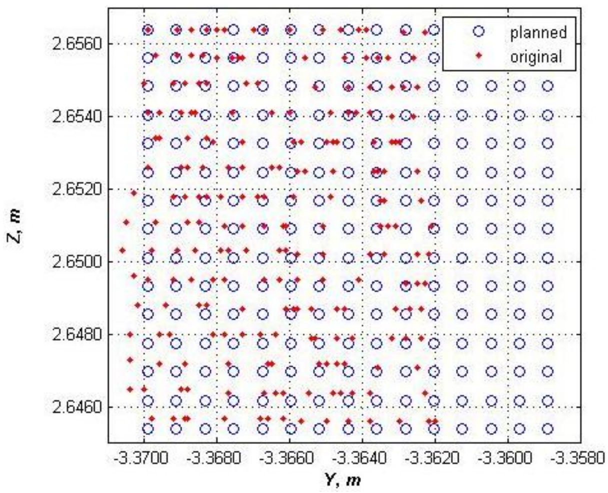

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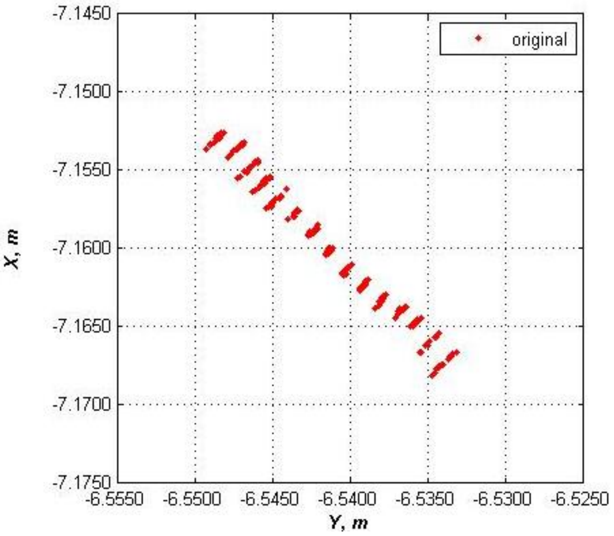
Fig. 5. Distribution of the central fragment of the point cloud of the black side of the target in the planes YX (a) and YZ (b) with a scan distance of 5 m



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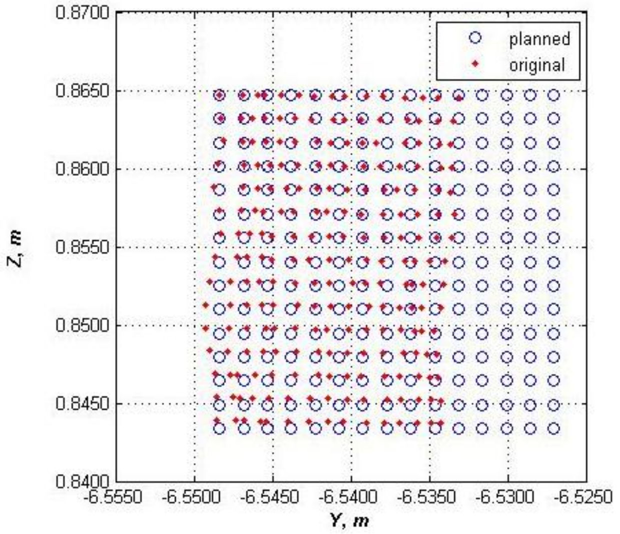

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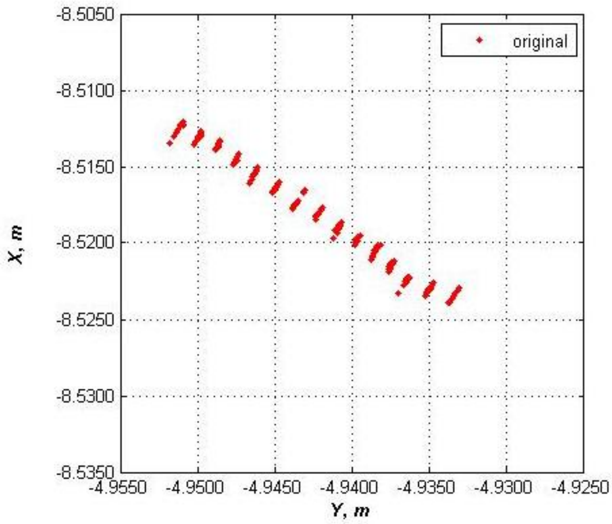
Fig. 6. Distribution of the central fragment of the point cloud of the white side of the target in the planes YX (a) and YZ (b) with a scan distance of 10 m

Conclusions

1. According to the results of the experimental work, the heterogeneity of the point cloud density for a scan distance of 0.6 m is obvious.
2. The highest values of intensity are recorded for scanning distances of 0.6 m and 5 m.
3. The average value of the standard deviation of intensity for the white surface of the target is 4.9 and for the black – 9.8. This indicates that the homogeneity of laser intensity values is higher for the white surface of the target.
4. In the investigated range, maximum accuracy can be obtained for a scan distance of 5 m.
5. In future, it is planned to carry out similar field studies and increase the scanning range.



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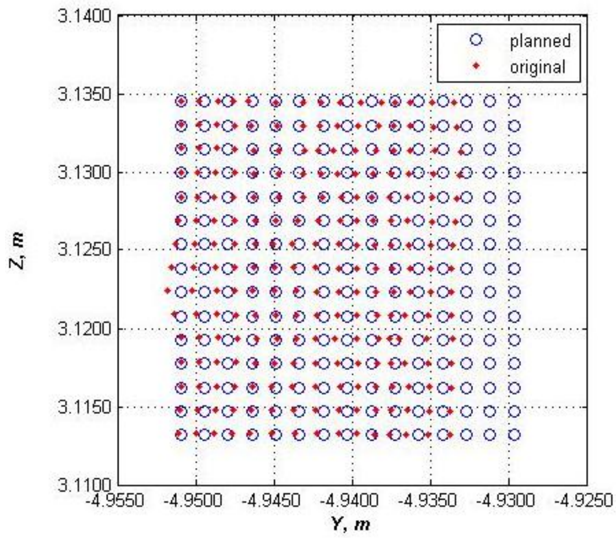

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Fig. 7. Distribution of the central fragment of the point cloud of the black side of the target in the planes YX (a) and YZ (b) with a scan distance of 10 m

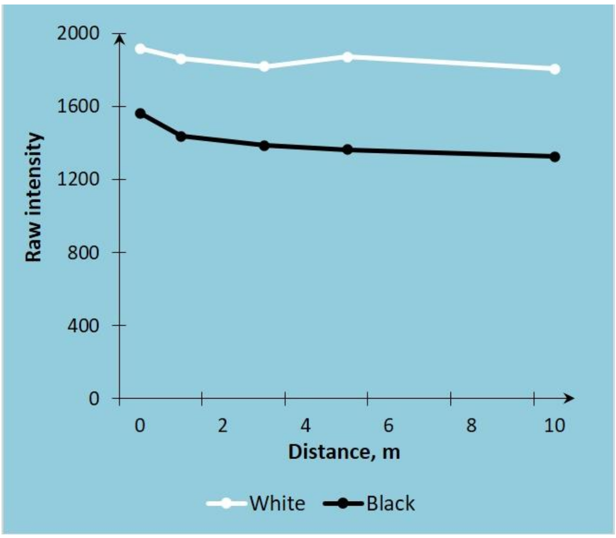

Fig. 8. Variation of intensity values with distance to scanning object

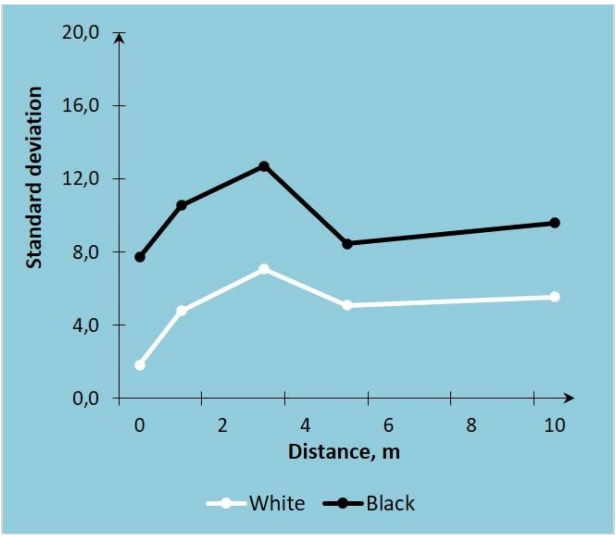

Fig. 9. Variation of standard deviation of intensity values with distance to scanned object

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ДОСЛІДЖЕННЯ ТОЧНОСТІ ХМАРИ ТОЧОК МЕТОДОМ НАЗЕМНОГО ЛАЗЕРНОГО СКАНУВАННЯ

Виконано експеримент, який полягав у дослідженні хмар точок, а саме їх щільності, інтервалу між точками, змін інтенсивності залежно від зміни відстані та кольору поверхні сканування. Для досліджень використано наземний лазерний сканер Faro Focus 3D S120. Як тестову марку обрано шліфовану скляну платівку розміром 30×30 см, яку було двічі покрито аерозолем із білою матовою фарбою з відбивною здатністю близько 80 % з однієї сторони марки та чорною матовою фарбою з відбивною здатністю близько 20 % з іншої сторони марки. Для виконання експериментальних робіт тестову марку встановлювали на підставку штатива за допомогою втулки, яка кріпиться до марки. Марку розташовували білою стороною на відстані 0,6 м від наземного лазерного сканера та виконували сканування. Потім марку обертали чорною стороною та повторювали сканування. Виміри повторювали на відстанях 1,5 м, 3 м, 5 м, 10 м. Загалом отримано 10 сканів. Значення інтенсивності експортовано з хмари точок за допомогою стандартного програмного забезпечення Faro SCENE. Для оцінювання результатів дослідження проаналізовано графіки розподілу хмар точок у площинах YX та YZ фрагментів білої та чорної сторін марок, інтенсивності відбитого лазерного випромінювання та стандартне відхилення значень інтенсивності. Подано та проаналізовано вплив якісно-кількісних характеристик об’єкта сканування на точність побудови хмар точок наземним лазерним сканером Faro Focus 3D S120.

Ключові слова: наземний лазерний сканер, хмара точок, відбиття, інтенсивність.

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