DOI 10.4467/21995923GP.16.007.5483 GEOINFORMATICA POLONICA
15: 2016

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THE IMPACT OF THE ORIENTATION ERROR OF SCANS TO THE CHANGE OF THE LENGTH OF THE COMPONENT OF SITUATION ERROR IN THE CLOUD OF POINTS

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Keywords: laser scanning, reference signals, positioning geodetic instruments

Abstract

At present, the market of geodetic equipment was enriched by the large group of scanning instruments, which are massively used in the process of inventory and monitoring of various engineering constructions. There is more and more interest in this type of technology, because it is limiting the role of users, speeding up the measurement and allows higher amount of data that can be used in the individual stand. In Poland, new geodetic regulations define the conditions of applying this type of measurement sets in basic works of geodetic services. Nowadays, properly processed data can make the element of geodetic resource. It is common to apply laser scanning in inventory for a very large number of objects on the surface and underground. These objects have often a complicated geometry and are difficult to reach, so there are no possibilities to carry out the measurement, according to commonly accepted principles, looking for optimal measurement solutions guaranteeing adequate accuracy. The results of detail tests of geodetic technologies (carried out worldwide by the scientific and research centres), allow the conclusions about the possibility to apply them in a specific field situation or specific geometry of the object. In the article, the usefulness and accuracy of reference signals applied in the transformation of the clouds of reference signals point and the impact of the inaccuracy in recognizing the centre of the signal (as fully automatic process) to the value of the scan rotation and the change of values of the measured length due to the title of twisting the reflecting plane.

WPŁYW BŁĘDU ORIENTACJI SKANÓW NA ZMIANĘ DŁUGOŚCI JAKO SKŁADOWEJ BŁĘDU POŁOŻENIA PUNKTU W CHMURZE

Słowa kluczowe: skaning laserowy, sygnały referencyjne, pozycjonowanie instrumentów geodezyjnych

Abstrakt

W chwili obecnej rynek sprzętu geodezyjnego uzupełniła bardzo liczna grupa instrumentów skanujących, które wykorzystuje się masowo z racji ograniczenia do minimum roli użytkownika oraz szybkości i ilości danych we wszelkiego rodzaju pracach inwentaryzacyjnych oraz monitoringu geodezyjnym na całym świecie. Także w Polsce nowe przepisy geodezyjne określają warunki stosowalności tego typu zestawów pomiarowych w podstawowych pracach służb geodezyjnych. Dziś odpowiednio przetworzone dane mogą stanowić element zasobu geodezyjnego. Powszechność stosowania skaningu laserowego w pracach inwentaryzacyjnych ogromnej liczby obiektów powierzchniowych i podziemnych, często o skomplikowanej geometrii i trudnodostępnych oraz braku możliwości realizacji pomiaru według przyjętych powszechnie zasad, wymusza szukanie optymalnych rozwiązań pomiarowych gwarantujących wykonanie roboty z należytą dokładnością. Szereg prowadzonych na świecie przez placówki naukowo – badawcze szczegółowych testów technologii geodezyjnych, pozwala wnioskować o możliwości zastosowania ich w określonej sytuacji terenowej lub geometrii obiektu. W artykule przeanalizowano przydatność i dokładność dotychczas stosowanych do transformacji chmur punktów sygnałów referencyjnych oraz wpływ niedokładności rozpoznania środka sygnału (jako procesu w pełni automatycznego) na wielkość skręcenia skanu oraz zmianę wartości mierzonej długości z tytułu skręcenia płaszczyzny odbijającej.

1. INTRODUCTION

An immense progress in the development of measurement techniques with the application of laser telemeters, which took place especially within the last decade, brought many scanning total stations and laser scanners to many geodetic companies. Such a process results from the decrease of the need for a lot of information on the surface of the earth and selected elements of infrastructure, including information on geometry of the inventoried objects or their control from the point of view of users' safety. It also results from constantly changing requirements and strictness of regulations connected with the documentation of existing objects or newly constructed objects and the dynamics of the processes affecting the buildings during their exploitation.

Application of the defined measurement technology in a strictly defined range of geodetic measurements requires the accuracy assessment and has a key role to achieve precision, required by the rules of getting spatial data (Tsakiri M. et al., 2015). A relatively new technology of laser scanning and reserved by producers constructions of scanning instruments and their software, make surveyors create separate calibration models and standardization procedures of testing instruments allowing identification of the sources of measurement errors, and – more precisely – components of the situation error of point m_P in the cloud. Typical measurement instruments widely applied in inventory and implementation works equipped in protractor and telemeter modules are, in the framework of harmonization of the Polish legal system and the legal system of the European Union (according to the Law on „Standardization ….” of 3rd April 1993), subdued to metrological control (Pawłowski W., Abbas S., 2009).

In case of scanning instruments, characterized by a high degree of automation of measurement procedures, no international test procedures unifying control of this type of instruments have been implemented so far.

Thus the controlling of these instruments is carried out based on individual test bases to get detail information on real accuracy of a studied instrument or its selected parameters. The study fields made this way refer both to field bases of certain geometric constructions, as well as laboratory bases using other measurement instruments (patterns).

A basic accuracy criterion of all kinds of geodetic measurements is mean situation error of point m_P. Its value consists of many elementary errors. In the case of scanning instruments equipped in stepping errors, responsible for angular deviation of the telescope (total stations) or reflector (scanners) and systems of compensators (Lichti D.D., 2010), angular metricity of grid is guaranteed in all the planes of the measurement. The value of situation error of the point in the cloud is shaped by the following factors:

- **external** – related with:
  - accuracy and geometry of the control line;
  - accuracy of marking the situation of reference signals;
  - preparation actions (centring of the instrument and signals over the points of the control line), causing the rotation of the whole spatial system of the scan and „fuzziness" of the model at the stage of connecting individual points of the cloud;
- **internal,** connected with the accuracy of the applied measurement technology, i.e.:
  - protractor module (of the stepping motor) responsible for the metricity of the angular grid;
  - telemeter module (system of emitter–receiver telemeter responsible for marking the distance to the measured surface), the precision of which depends on the kind of the applied telemeter (phase, impulse, triangulation), the angle of the dispersion of the laser beam and the possibility of computer data filtration;
  - type of the reference signal and methods of the identification of the geometric centre of the scanning instrument;
  - type of the scanned surfaces (colour, roughness etc.) and their spatial distribution, able to cause the phenomenon of multiple reflections and cause the fluctuation of the light impulse modifying its real length.

The article presents the applied so far in scanning types of reference signals and ways of the identification of their geometrical centres by the scanning instruments. In the world literature referring to the terrestrial laser scanning, much attention was paid to the analyses of distance measurement error (Alkan R.M., Karsidag G., 2012; Lenda G., Marmol U., 2010; Hess K. et al. 2015), as the basic component of the point situation error in the cloud. The objective of this article is to pay attention to another important element of this error – the measurement error of direction towards the reference point, which is often neglected in the literature. This error can significantly dilute the scans combined to one another, causing serious deformation of point models and problems in correct interpretation of surveyed areas. The analysis of reference direction error was caused using an example of two selected scanning instruments representing two types of such devices, i.e.: total station VX and GX scanner by Trimble. Both have been available on the Polish market for several years.

2. THE REVIEW OF THE TYPES OF REFERENCE SIGNALS APPLIED IN POSITIONING AND ORIENTATION OF SCANNING INSTRUMENTS

Seeking new solutions in the photogrammetry, commonly applied in the inventory of historical objects in 1990s, had impact on the implementation and development of scanning instruments. The result of such demand was the release into the market a range of imaging and panoramic laser scanners. Their dimension and weight did not allow putting scanning heads on classical tribrachs by Zeiss and Wild or geodetic tripods. They are usually fixed on special tripods equipped with w „spiders" made automatic scanning from the free stands in the reference to shield signals, signalling shields or typical geodetic signals. A part of them could be put in the main rotation axis of the instrument of geodetic signals, allowing the determination of precise spatial co-ordinates of the scanning head. The recognition during the scanning geodetic reflectors or characteristic reference shields (of the previously marked co-ordinates), characterized by high reflectivity coefficient (intensity of the reflection of the signal), was possible due to the transformation of a single scan to the superior system.

Many models of scanners the orientation of which is based on directions resultant to the detected geodetic prisms (e.g., panoramic scanner Callidus by Callidus Precisions Systems GmbH of Halle), were equipped in modern software, analysing the power of return signals reflecting from strongly reflecting surfaces. A specific structure of a classical geodetic signal (figure 1), pro-

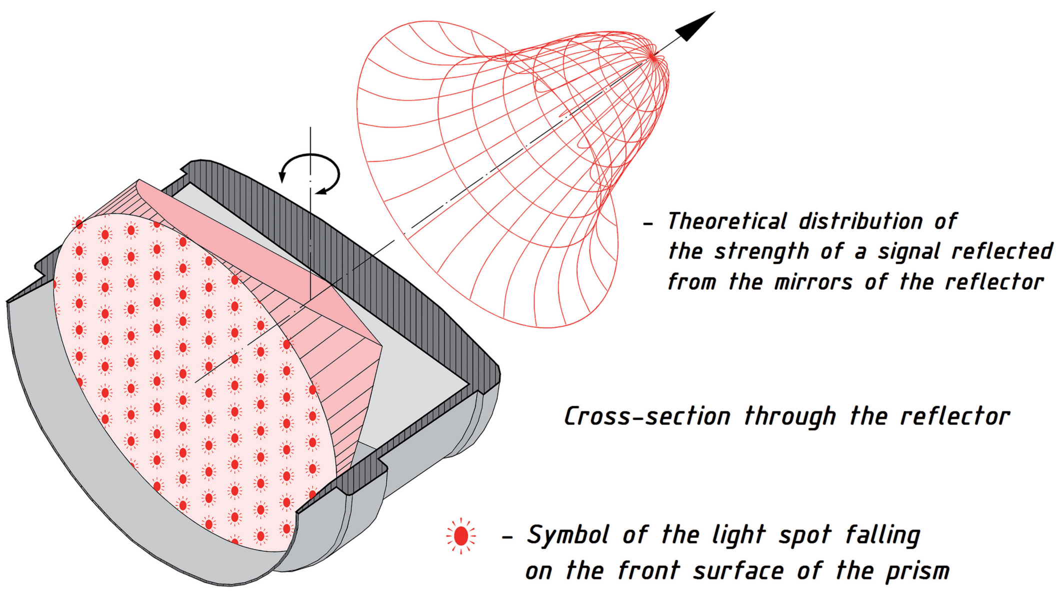

Fig. 1. Scheme of the recognition of the geometric centre of the geodetic signal identical with the radiometric centre based on the set of the points of the cloud, projected on the background surface, using a panoramic scanner Callidus CP3200 as an example

Rys. 1. Schemat rozpoznania środka geometrycznego sygnału geodezyjnego tożsamego z centrum radiometrycznym na podstawie zbioru punktów chmury odwzorowanej na tle szklanej powierzchni na przykładzie skanera panoramicznego Callidus CP3200 vides significant information about the characteristic and distribution of the strength of the signal reflected from a concrete impulse sent by the instrument in the direction of the signal. Its regular covering by a grid of light (infra-red) impulses, allows precise estimation of the position of its centre (the graph of the signal strength resembles the Gauss distribution in 3D space – Gawałkiewicz R., 2006). Usually this is based on the method of the estimation of the radiometric centre of all the reflections possible to be registered in terms of their intensity. Vector $\vec{v}$, defined as the direction resultant to the prism centre (the radiometric centre, identical with the direction compliant to the geometric centre of the signal), attached in the centre of the scanning head, is defined from the relationship (Lichti D., et al. 2001):

$$\vec{V} = \frac{\sum_{i=1}^{n} E_i \cdot \vec{V}_i}{\sum_{i=1}^{n} E_i} \quad (3)$$

where:

$\vec{v}$ – 3D radiometric centre of the target (prism);

$\vec{v}_i$ – vector (X,Y,H) for the individual scanning point i of the prism;

E_i – quantified energy of return signal from a single scanning point.

The above rule, applied in Callidus, is based on the assumption that the strongest signal should return from the centre of the reflecting prism. However, the rotation of the prism (depending on its construction) can cause that this relation is not fulfilled (Geodimeter prisms). Using the values of real errors, the accuracy characteristic error orientation $m_{k(scan)}$ for several selected base lengths, which is graphically presented in figure 2 (Gawałkiewicz R., 2006).

Today point sets in the form of cloud obtained from the land (TLS technology) and air (ALS technology), become valuable source of information on the environment and are commonly used by a wide group of users. The demand for this kind of information, including: construction, geology, mining, archaeology, architecture, conservation of historic monuments, environmental protection, etc., caused that scanning technology is used not only by geodetic services. Thus, modern solutions in laser scanning (equipment with scanning sets and software to process data), contain all the elements allowing independent retrieval of special data in the area and the generation of final effects of post-processing in the form of 3D models, without the necessity of using classical instruments or the geodetic control line. The propagation of laser scanning technology and making them available to specialists of other

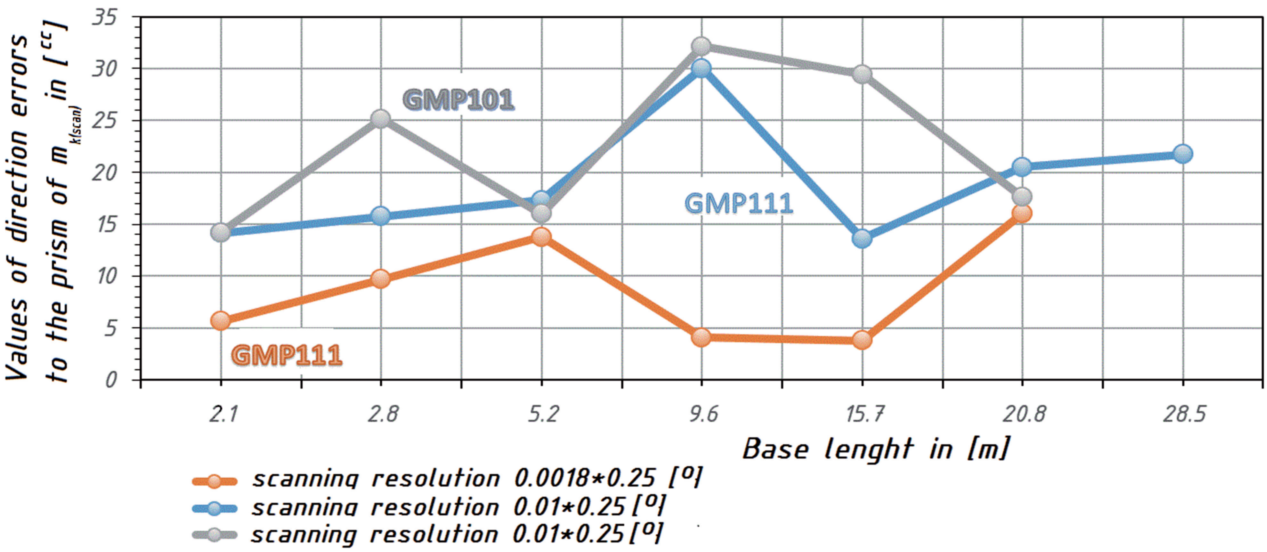

Fig. 2. The graph of the values of errors in the directions to prisms GMP 101 and GMP 111 Leica for the selected resolution of scanning and base lengths obtained by the panoramic scanner Callidus CP3200

Rys. 2. Wykres wartości błędów kierunków do pryzmatów GMP 101 i GMP 111 Leica dla wybranych rozdzielczości skanowania i długości bazowych uzyskanych skanerem panoramicznym Callidus CP3200

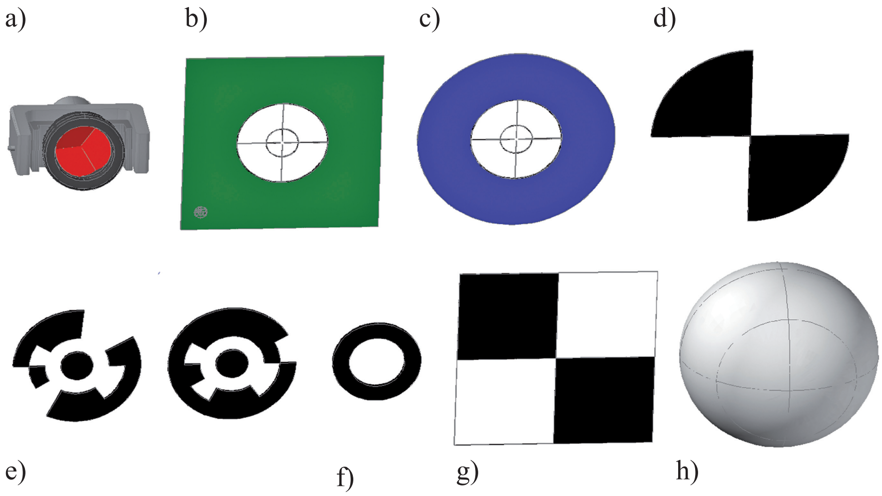

Fig. 3. Examples of reference signals (geodetic reflectors and target shields) used in the positioning of laser scanners and digital cameras and spatial orientation of scans (a – typical geodetic return signal, e.g.,: Leica, Topcon, Trimble, etc.; b – shield Mensi/Trimble; c – tarcza Leica; d- tarcza Z+F ProfiTarget; e – code shields RAD/CANON EOS20D; f – non-code shields RAD/CANON EOS20D; g – shield FARO/Trimble; h – spherical signal Leica/Trimble)

Rys. 3. Przykłady sygnałów referencyjnych (reflektorów geodezyjnych oraz tarczek celowniczych) używanych do pozycjonowania skanerów laserowych oraz kamer cyfrowych i orientacji przestrzennej skanów (a – typowy geodezyjny sygnał zwrotny, np.: Leica, Topcon, Trimble, itp.; b – tarcza Mensi/Trimble; c – tarcza Leica; d- tarcza Z+F ProfiTarget; e – tarczki kodowe RAD/CANON EOS20D; f – tarczki niekodowe RAD/CANON EOS20D; g – tarczka FARO/Trimble; h – sygnał sferyczny Leica/Trimble)

disciplines, forced the introduction of other geometric forms of reference signals, allowing the combination of scans obtained from different measurement stands. Thus the constructors and producers of laser scanners went away from the application of geodetic reference signals, as reference points, although, as the graph in figure 2, already 0.01× to 0.25 gives the high accuracy of the recognition of the reference directions in case of e.g., historical scanner Callidus. Nowadays the majority of signals make flat constructions (figure 3b–g) or spherical (figure 3h), relatively less expensive than geodetic reflectors.

Examples of reference signals commonly applied in positioning scanning instruments and the orientation of scans in the process of the transformation of the cloud of points to the superior systems, was illustrated in figure 3.

From the presented in figure 3 reference shields (positions: b, c, d, f, g), the way of automatic recognition of geometric centre was based on two measurement zones:

– the first is the field excellently absorbing light impulses (Mensi shield – green field, Leica shield – blue field, Z&F and Faro shield – black field); the colour of the field was adjusted to the kind of the telemeter system with the angle of wave length and the power of the laser;
– the second is the white field of a favourable reflection parameter, i.e. small coefficient of energy dispersion of light impulse, within which the field are projected by measurement points.

3. THE REVIEW OF THE WAYS OF POSITIONING AND ORIENTATION OF SCANNING INSTRUMENTS

Scanning instruments make a group of instruments the task of which is obtaining large sets of point data in the form of the point cloud, providing the simplest information on the geometry of the inventoried object. Laser scanning can be carried out from the following check points: free-stand, forced or localized over or under the points of the geodetic control line. The way of the selection of the method of spatial positioning of the scanner and the orientation of scans in space depends on factors such as:

– the construction of the tribrach of the scanner (possibility of fixing the instrument on a classical head of the geodetic tripod or the lack of such a possibility in case of an untypical tribrach or bed of the scanning head);
– the size of the instrument (large and heavy scanners, e.g., Callidus CP3200 or Cyrax 3D had their own, untypical tribrachs and tripods not allowing precise situation of the instrument over or under the point of the control line);
– the type of the documentation:
  • *architecture – construction,* usually not requiring reference to the points of the state control line, just precise combining of individual scans in the local system;
  • *geodetic–cartographic*, forced by the regulations on the transformation to the state spatial reference system;
– the type of the control line (ground points or wall points) and its availability to the direct use (centring the instrument over or under the point);
– the possibility of replacing the instrument and signal of the control line points, which reminds the method of three tripods (traverses);
– accessibility of the inventoried object and spatial limitation in the creation of a typical measurement model based on a classical measurement of the position of the scanning head and reference signals;
– repeatability of measurements and profitability of building forced check points (in the form of observation pillars) in the process of the monitoring of engineering objects (required permanent protection of check points);
– the size of the object and its geometric complexity forcing the increase of the number of measurement points to provide maximum cover of the inventoried details and other surfaces.

4. METHODS OF SCAN ORIENTATION ERROR $m_{k(skan)}$ ANALYSIS

Scan orientation error $m_{k(skan)}$ analysis was based on two typical and popular on the Polish market surveying scanning instruments by Trimble, i.e.: scanning total station VX Spatial Station and laser scanner GX. Basic parameters of both instruments were put in tables 1 and 2.

Table 1. Basic technical parameters of scanning total station Trimble VX Spatial Station
Tabela 1. Podstawowe parametry techniczne tachimetru skanującego VX Spatial Station Trimble'a

Parameter	Value
Range of distance measurement in reflectorless mode	2÷1300m
Accuracy of distance measurement in prism mode (standard deviation)	±3mm ±2ppm
Accuracy of distance measurement in reflectorless mode (standard deviation)	±3mm ±2ppm
Accuracy of distance measurement in scanning mode (standard deviation)	±3mm
Telemeter type, laser class, wave length and power	Impulse telemeter, class 1 (IEC 60825-1), λ = 870nm, power < 1mW
Maximal speed of scanning (mean speed)	Max. 15 points/second (5 points/second)
laser spot size (Hz × V)	4 × 8cm/100m
Mean error of point's situation in space $\mathbf{m_P}$	±10mm
Accuracy of angles' measurement	1" (3^{cc})
Driving gear / Alidade rotation speed	Electromagnetic / 115^{o}/second
Compensator / Range	Automatic two-axes / ±6'
Level / Accuracy	Electronic / 0.3"

Tabela 2. Podstawowe parametry techniczne skanera panoramicznego GX Trimble'a
Table 2. Basic technical parameters of the tested panoramic scanner GX Trimble

Parameter		Value
Range of distance measurement		150 ÷ 200m
		Up to 350m in OverScan technology
Accuracy of distance measurement in the range up to 100m		±7.0mm
Accuracy of marking point situation $\mathbf{m_P}$		±12mm / 100m
Telemeter type, laser class, wave length and power		Impulse telemeter, 3R (green) λ = 532nm, power 20mW
Scanning speed		Up to 5000 points/second
Laser spot size		Ø6mm/100m
Eyeshot while scanning – horizontal position		360°
Eyeshot while scanning – vertical position		60°
Scanning step:	horizontal position	200 000 lines in the range of 360° / 3.2mm
	vertical position	65 536 lines in the range of 60°
Electronic compass		No
Camera – resolution / zoom		768 × 576 pix / 5x

4.1. The analysis of the scan orientation error $\mathbf{m_{k(scan)}}$ at the application of a scanning total station

Scanning total stations and laser scanners are instruments automatically marking angular–linear (polar observations) to the inventoried surface. In case of scanners, generally the whole scanning process is carried out automatically. Only the establishment of scanning parameters, i.e. resolution, the range of the measurement, at the stage of the preparation of the instrument to the measurement is carried out with the user's participation. In case of total scanning stations, the process of automatic scanning must be predeceased by a wider range of preparation works connected with the reference of the instrument to the reference points of the coordinates and showing on the screen of the monitor the range of the scanning (camera image) and parameters of the scan. The transformation procedure of angular – linear measurements, including laser scanning data to the overriding system is simplified, if the observations are made from the points of the implementation control line, referring to signals put only on the neighbouring points of the grid. In such a case, the reference direction is affected by the following errors:

– targetting to the reference signal m_c, the value of which can be defined from the formula most often applied in literature (Pielok J., et al. 2011):

$$m_c = \pm \frac{\varpi''}{G} \tag{1}$$

where:

ω – the limit of point resolution, expressed in [''], which for average measurement conditions and a typical eye is ω = 60" (180^{cc});

G – increasing the telescope of the instrument (standard 30×);

The conclusion is that the value of this error is $m_c = \pm 2'' = \pm 6^{cc}$.

– centring the instrument e_i and signal e_s, of data with linear values the same as the values of ex-centres in the questions of eccentricity of the direction measurement; the influence of these errors to the value of the direction error depends on the length of the base side $d_{i\text{-}j}$ (reference);

Rotation angle ε of the direction $k_{i\text{-}j}$ resulting from linear values of instrument centring errors e_i and signal errors e_s is in eccentricity calculated as the amendment to the direction is expressed by the formula (Lazzarini T. et al., 1990; Jagielski A., 2007):

$$\varepsilon = \arcsin \frac{e_i \cdot \sin\alpha' + e_s \cdot \sin\beta'}{d_{i-j}} \quad (2)$$

where:

e_i – linear value of the error of centring the instrument (for optical verticals, taken as $e_i = 0.5$ mm);

e_s – linear value error of the error of centring the signal (for optical verticals, taken as $e_s = 0.5$ mm);

α' – the equivalent of the direction angle of the eccentricity of the stand in the initial point of the base section;

β' – equivalent of the direction angle of eccentricity of the target at the ending point of the base section;

d_{i-j} – real length of the base side.

The description of the situation is illustrated in figure 4.

The graph (figure 5) shows that the targeting error m_c towards the angle of the direction rotation ε, even in the situation of precise centring of the instrument and signals (assuming that: $e_i = e_s = \pm 0.5$ mm) gives the value

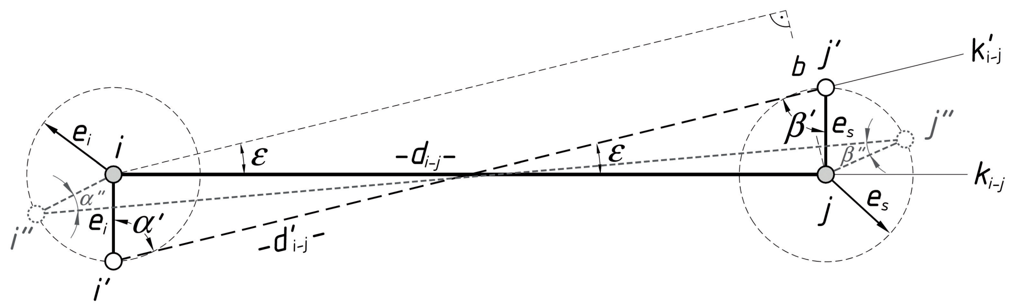

Fig. 4. The impact of linear values of the errors in centring of the instrument e_i and signal e_s on the value of the change in the base direction i-j

Rys. 4. Wpływ liniowych wartości błędów centrowania instrumentu e_i oraz sygnału e_s na wartość zmiany kierunku bazowego i-j

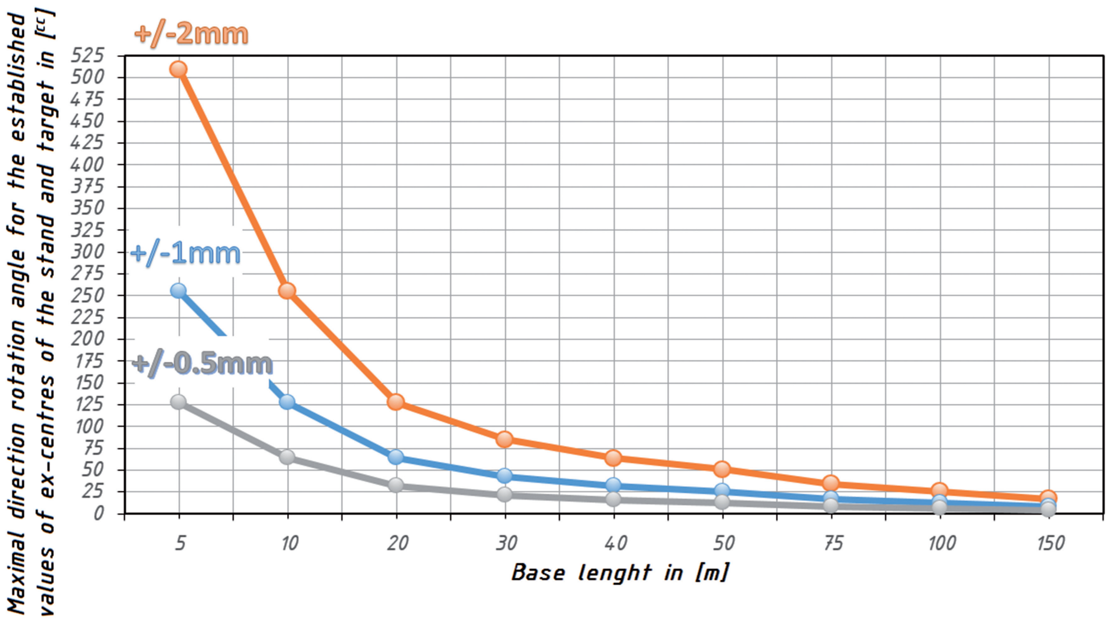

Fig. 5. The impact of the value of ex-centres of the stand of the instrument, its signal and the base length on the value of the direction rotation angle ε (error of reference direction)

Rys. 5. Wpływ wielkości ekscentrów stanowiska instrumentu i sygnału oraz długości bazy na wartość kąta skręcenia kierunku ε (błąd kierunku nawiązania)

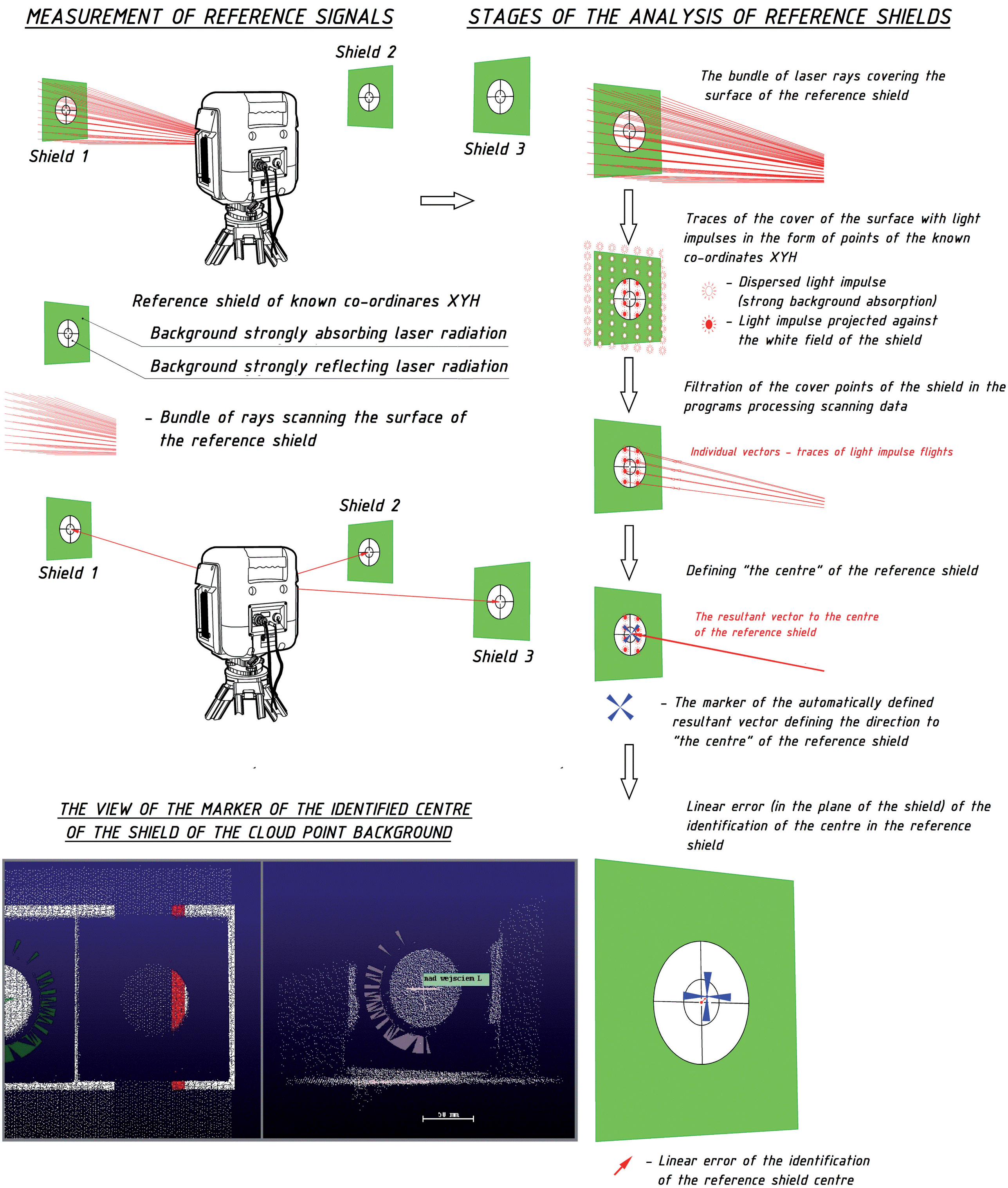

Fig. 6. The scheme of the identification of the centre of a typical target shield used in the positioning of the scanning head and transformation of scans, using the example of scanner GX Trimble

Rys. 6. Schemat rozpoznania środka typowej tarczki celowniczej służącej do pozycjonowania głowicy skanującej i transformacji skanów na przykładzie skanera GX Trimble smaller than values of ε, even in case of the length of base equalling 100 m.

Thus the set of vectors initiated in the centre of the telemeter system and final points projected within the white field; makes the base for defining the resultant vector of the direction of orientation. This means that the more points are projected within this zone, drawing this way a clear shape of the circle, the more accurately the central point shield could be marked. Previously, the coordinates are marked with classical geodetic techniques, including refrectorless measurement. The rule of the determination of the resultant vector to the reference shield was graphically illustrated in figure 6.

To measure the value of the error in the reference direction $m_{k(scan)}$ of the set: panoramic scanner GX Trimble and reference shields Mensi (as in figure 7), forced stands of the faculty test base were applied (localized on the roof of building C-4 AGH-UST, figure 7) of precisely marked horizontal co-ordinates XY at the application of precise total station TCA 2003 Leica. The base was so far used to determine the characteristics of the measurement errors of length to the target shields, including: total station TCR 303 Leica and scanner GX Trimble – in the framework: Maciaszek J., Gawałkiewicz R., 2007a and 2007b). This experiment was carried out based on scanning measurements made of two stands: 08 and 13 to reference shields T1, T2 and T3 distributed in one vertical plane (according to the scheme, as in figure 7).

The objective of the experiment was to find the relationship between the value of the dispersion of vertexes in n – samples, determining the points of the shield centres by the scanner (allowing the determination of the distance between the neighbouring shields in the indirect way), and the distance measured directly with precise measurement between their centres (distances HD_{T1-T2} and HD_{T2-T3} – figure 7). The knowledge of the co-ordinates of forced stands (stands: 08 and 13) and reference shields (T1, T2 and T3) precisely determined by the technique of precise angular-linear mea-

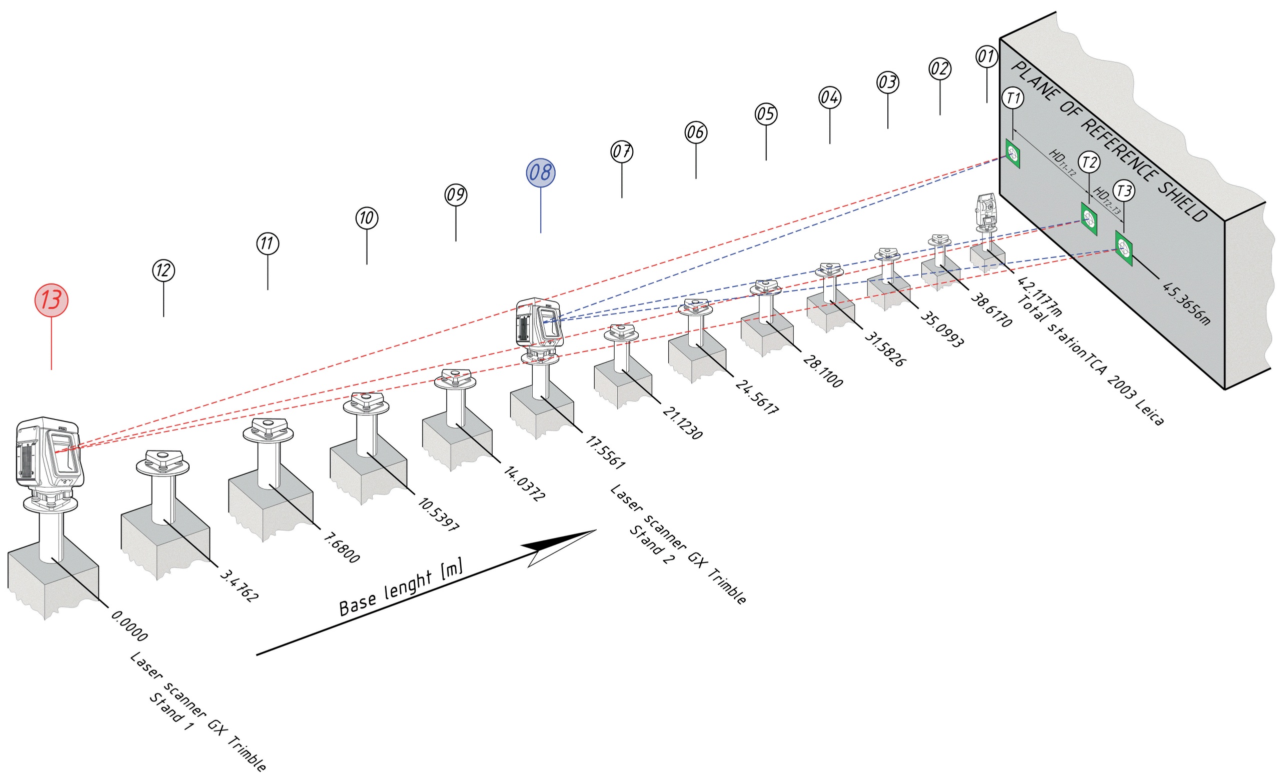

Fig. 7. The scheme of the distribution of the stands of scanner GX Trimble and tested reference shields in the experiment of the definition of the value of error $m_{k(scan)}$ (T1, T2, T3 – tested reference Mensi shields)

Rys. 7. Schemat rozmieszczenia stanowisk skanera GX Trimble oraz testowanych tarcz referencyjnych w eksperymencie określenia wielkości błędu $m_{k(skan)}$ (T1, T2, T3 – testowane tarczki referencyjne Mensi)

Table 3. The application of mean errors of the directions to reference shields $m_{k(scan)}$ with the application of scanner GX Trimble'a and reference Mensi shields
Tabela 3. Zestawienie średnich błędów kierunków do tarcz referencyjnych $m_{k(skan)}$ z wykorzystaniem skanera GX Trimble'a i tarcz referencyjnych Mensi

Studied parameter	Dispersion		Mean direction error $m_{k(scan)}$	
BASE	**T1-T2**	**T2-T3**	**T1-T2**	**T2-T3**
STAND 08	**27.0^{cc}**	**20.0^{cc}**	**±7.6^{cc}**	**±32.6^{cc}**
STAND 13	**13.4^{cc}**	**13.2^{cc}**	**±8.1^{cc}**	**±4.5^{cc}**

surements, allowed the definition of the direction errors $m_{k(scan)}$. The analysis of angle values obtained from scanning (distances of vertexes on shields), allowed the definition of the values of error $m_{k(scan)}$ for the studied distances 27,8095 m and 45,3656 m. Values of obtained errors $m_{k(scan)}$ were put in table 3.

The number of test stands (test distances) does not allow the conclusions referring to the impact of the change in the scanner–shield distance, in a wider measurement length, on the value of the error $m_{k(scan)}$. On the other hand it allows the conclusion that the obtained small values of direction errors guarantee high accuracy of the positioning of the scanner towards the reference signals and certain elasticity of the shape of the shield distribution grid in the full horizon, i.e. 360^{o}. It is particularly important in case of the limited working space and the necessity of the preservation of high data precision, e.g., during the inventory and monitoring of mining excavations, caves, urban underground areas, industrial objects, historical monuments, etc. Moreover, GX scanner, as the majority of the nowadays used instruments of this type, was equipped in two-axis compensators, responsible for correcting observations resulting from the inclination of the vertical rotation axis of the instrument. Due to the adaptation of classical Wild's heads in the base of the main body, it is possible to combine this set to work ith other instruments and signals and centring the scanner over or under the points of the control line, additionally facilitates the control of the data.

Regardless the type of the tested scanner (Callidus and GX) and the kind of the reference signal (geodetic reflector and 2D Mensi shield) for the accepted step of scanning for both instruments, equalling in the horizontal plane 0.0018^{o} (20^{cc}), the errors of the identification of the horizontal direction $m_{k(scan)}$ are on a very similar level. From the experiments carried out by Andriuskeviciute I. (2010), it can be concluded that the error of the direction to the reference shield Leica equals ±9.2^{cc} for scanner HDS 3000 Leica and ±57.3^{cc} for model HDS 4500 Leica.

Another, more often applied reference sign is a spherical signal of a defined diameter (white), defined in the offset of programs designed for joining individual scans. Such a signal, at the stage of joining neighbouring scans (overlapping), in case of works made in local systems does not have to have determined spatial co-ordinates. The points projected on its surface make base for fitting to the reference spherical surface, with the smallest squares method (with a small error). This sphere, mathematically defined in the main scan (base scan, referring to the points of the geodetic control line), actually it makes base adjusted to the neighbouring scan, provided the same signal is projected in the form of the point cloud. Spatial adjustment of two scans, based on spherical signs, requires the application of minimum 3 spheres projected on both scans, according to the rule of the construction grid of the spatial indentation. The studies (Kersten Th. et al. 2004) on the determination of the accuracy in the orientation of scans based on spherical signals, show that in case of scanner GS200 (predecessor GX), mean value of the translocation vector of the recognized signal ranging between 27 m and 2.6 mm, which means that calculating the angular discrepancy on the level of 43.3^{cc} despite symmetry of the target in every perspective.

4.2. The analysis of the impact of the orientation error of scan $m_{k(scan)}$ on the change of length

Situation error of the point in the cloud shapes the range of the components, which, in smaller are greater extent, have the impact on the value of the parameter.

In this article the impact of the orientation error of the scan to the change of the measured length.

The explanation of the impact of the error of scan orientation on the change of the measured length was based on a geometric construction fully projecting the studied situation and presented in figure 8. To give the example of the illustration of the impact of the orientation error $m_{k(scan)}$ on the cloud rotation value on the stand of the analysis, the measurements from the scanner Callidus CP3200: $m_{k(scan)} = \pm 32.8^{cc}$ (angle f in figure 8). It should be emphasized that, in case of scanners, the range of distances between the scanner and reference shields, usually does not exceed several dozens of meters. Thus, for the analysis of the impact of error $m_{k(scan)}$ on the change of linear values, the highest value, obtained by the panoramic scanner Callidus (orientation to geodetic prism) was accepted for the analysed error. This error results from the graph 4 for length 9.6 m, obtained for the typical resolution 0.01°×0.25° at the use of scanner Callidus CP3200 (Gawałkiewicz R., 2006). Using the similarity of the triangles building the presented in figure 7 geometry of the considered system, it is possible to define the length, depending the change of the reference direction, defined as $m_{k(scan)}$.

To carry out the analysis, it is necessary to put together the matrices ***A*** and ***L*** showing the system of linear equations $A \cdot x = L$, while matrix ***A*** is a square non-singular matrix. Thus, this system has only one solution. The application of Cramer's equation allows the calculation of the value of the angles of the geometry of the analysed system for the changeable values of angles α and ϕ ($m_{k(scan)}$) from the relation:

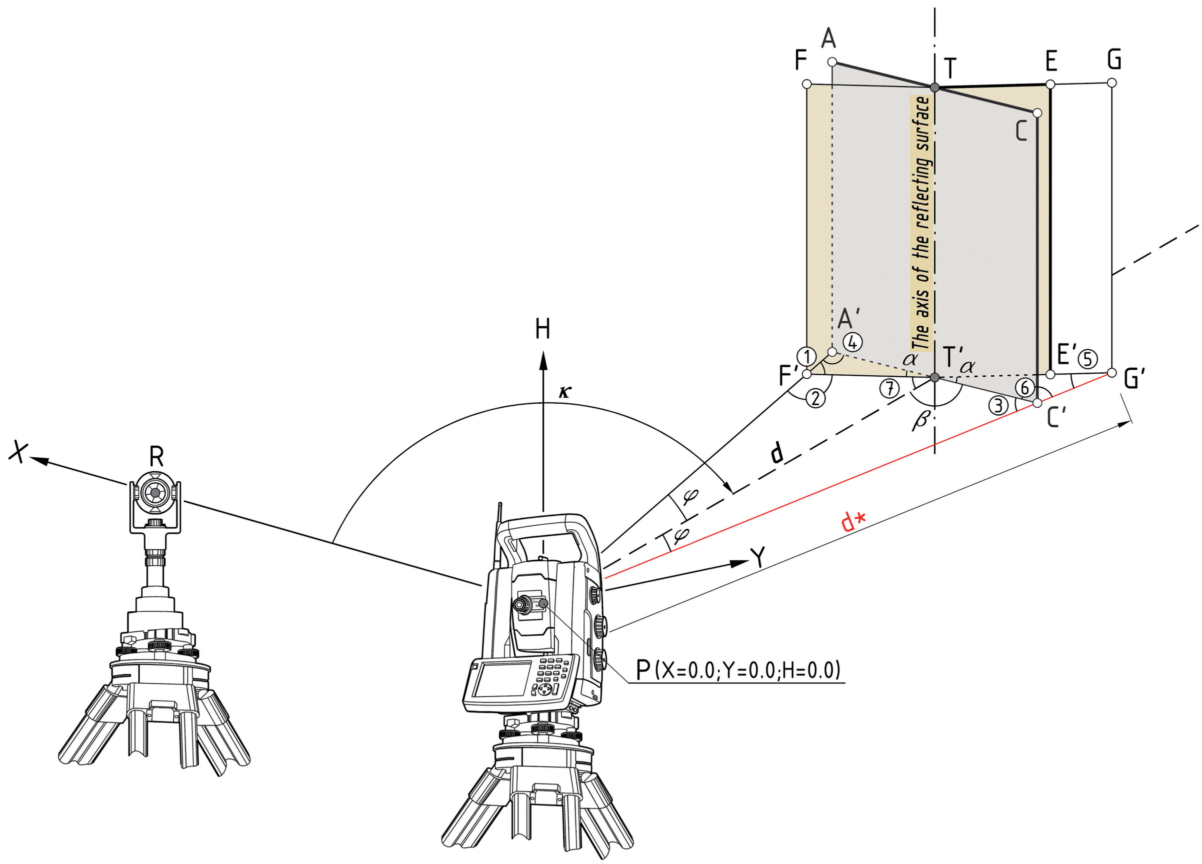

Fig. 8. The geometry of the system investigating the impact of the rotation of the scan on the determination of the length at different rotation angles of the reflecting plane (α - plane rotation angle; $\phi = m_{k(scan)}$ –orientation error of the scan towards the reflecting plane)

Rys. 8. Geometria układu rozpatrującego wpływ skręcenia skanu na wyznaczane długości przy różnych kątach skręcenia płaszczyzny odbijającej (α - kąt skręcenia płaszczyzny; $\phi = m_{k(skan)}$ – błąd orientacji skanu względem płaszczyzny odbijającej)

$$x = (x_1, x_2, ..., x_n)\ , \tag{4}$$

where:

$x_1, x_2, \ldots, x_n$ – the value of the sought angles of system (①÷⑦ – figure 2) expressed by formulae:

$$x_{(1)} = \frac{\det(L, a_2, a_3, ..., a_n)}{\det A} \tag{5}$$

$$\vdots$$

$$x_{(n)} = \frac{\det(a_1, a_2, a_3, ..., L)}{\det A}$$

The sought value of deformation Dd (presented in figure 8), depending on the value of the accepted $m_{k(scan)}$ is:

$$\Delta d = d - d^* = d - \left[\frac{\sin\beta \cdot \sin(5) + \sin\phi \cdot \sin\alpha}{\sin(3) \cdot \sin(5)}\right] \tag{6}$$

where:

d – real value;

d^* – deformed value loaded with error $m_{k(scan)}$;

(3), (5) – sought angles of the system (in figure 8 – marked: ③ and ⑤, respectively);

Based on the observation matrix ***A***, reflecting the system of triangles:

ΔABF – ΔBDF – ΔABD – ABC – ΔBCE – – ΔABE – ΔACD,

It is possible to determine angular values ①÷⑦ (figure 8). Marked in such a way angular values make

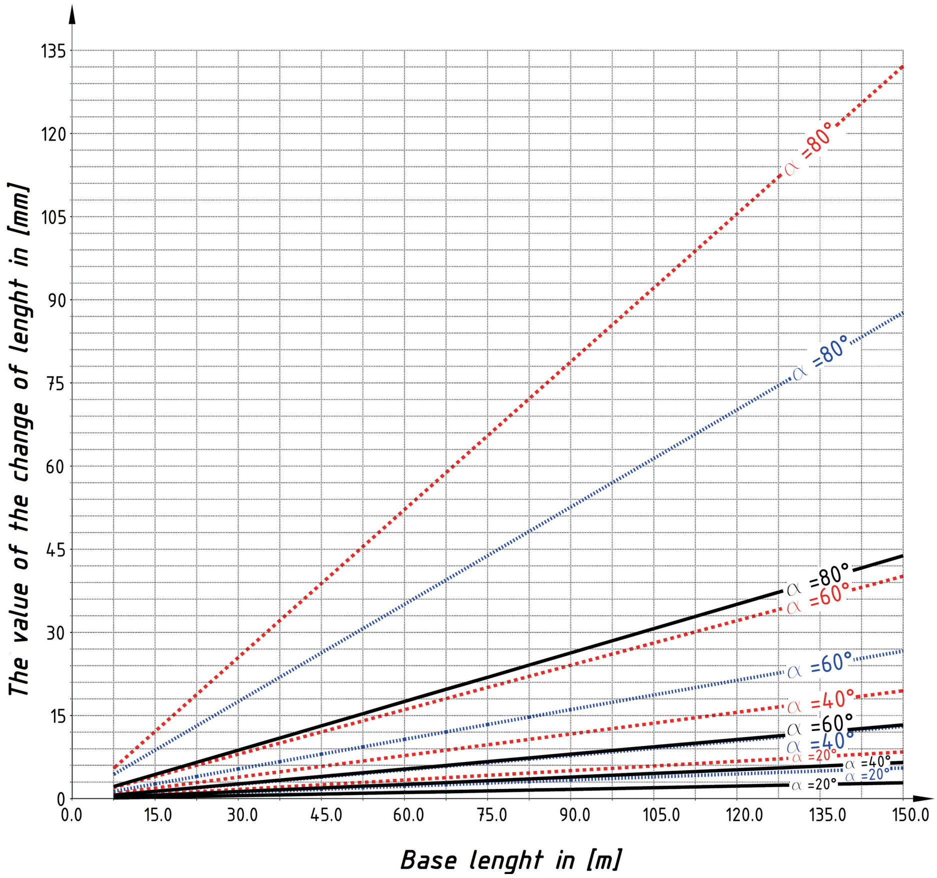

Fig. 9. Graphs of the measured length changes **Dd**, depending on the value of error $m_{k(scan)}$ (φ) and the rotation angle of the reflecting plane α. Value error $m_{k(scan)}$ was assumed as equal ±32,8^{cc}. The graph was made for: $\phi = m_{k(scan)}$ (black); $\phi = 2m_{k(scan)}$ (blue); $\phi = 3m_{k(scan)}$ (red)

Rys. 9. Wykresy zmian długości pomierzonych **Dd** w zależności od wielkości błędu $m_{k(skan)}$ (φ) oraz kąta skręcenia płaszczyzny odbijającej α. Wartość błędu $m_{k(skan)}$ przyjęto równą ±32.8^{cc}. Wykres sporządzono dla: $\phi = m_{k(skan)}$ (czarny); $\phi = 2 \cdot m_{k(skan)}$ (niebieski); $\phi = 3 \cdot m_{k(skan)}$ (czerwony) base to determine real length ***d****, the direction of which is loaded with the orientation error $m_{k(scan)}$ of the „point cloud" towards the reference prism or shield, which corresponds the theoretical value ***d***. The shape of observation matrix: ***A***, the determiner of which det***A*** = 1 and free expressions ***L*** takes the following form:

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 \end{bmatrix} - A \quad \text{and} \quad \begin{bmatrix} 200-\varphi \\ 200-\alpha \\ 200-\alpha-\varphi \\ 200-\beta-\varphi \\ 200-\alpha \\ 200-\alpha-\beta-\varphi \\ 200-2\varphi \end{bmatrix} = L$$

Based on the mentioned above analysis in a graphical way (figure 9) the impact of scan rotation, the created interpretation error of direction on the value of the change of the measured length to the surface, including the situation of a significant rotation towards the vector direction to the measured point (for the rotation angles a: 20°, 40°, 60°, 80°) were illustrated.

5. DISCUSSION AND CONCLUSIONS

The need for a large amount of detail and precise information on the surface of the terrain and environment in many areas of economy caused rapid development of scanning instruments. Additionally, this technology simplifies the exchange of data, both raw data and the ones processed in a strictly defined way, facilitating the co-operation of specialists of many branches of economy, at the stage of many documentation agreements. The abundance of scanning technology in the area of the inventory of the engineering objects, natural phenomena and their monitoring in time, requires verification and the identification of the sources of errors, which could possibly influence the final result and decrease the accuracy. Knowing the value of measurement errors and the causes of their formation, it is possible to make proper measurement models limiting their impact to final accuracy of the data. In case of measurements by total stations, carried out with the man's participation, there are many papers connected with the definition of the sources of errors and their impact on the obtained results. The technology of scanning, as the method of automated of semi-automated measurements (applying scanning total stations), with the use of concrete auxiliary elements (of a defined kind of reference signals), every time requires verification, applying to concrete range of the inventory works, so that accuracy requirements are fulfilled. It turns out that the first scanners (e.g., Callidus), based to the reference and positioning at the application of classical geodetic signals and theory of radiometric measurements provide high precision of the definition of the reference direction (especially scanning resolution 0.0018°), and the application of 3 signals of the known co-ordinates localized in the eyeshot of the scanner, provides the determination of the scanner position on the level ±0.2mm (Gawałkiewicz R., et al. 2004). Such a high accuracy is due to the quality of making reflectors and the possibility of very high accuracy of their positioning in space, towards the points of the geodetic control line. Present application of flat targeting shields or spherical signals in joining the cloud of points obtained from different observation, simplifies the measurement procedures, because it does not require auxiliary measurement instruments – total stations, levellers.

The determination of the values of the errors in reference directions can be highly significant for the accuracy of the geodetic documentation and architectonic construction object of a complicated geometry. This refers mainly to the inventory of gallery (historic) excavations, underground tourist routs, cellars, caves etc., where spatial limitations do not allow typical construction of regular rosettes based on a larger number of signals, or in the situation when it is necessary to make multi-stand traverse. This means that, for example, for a straight-line traverse of 5 equal sides (tested lengths, i.e.: 27.80 and 45.36m), assuming that the values of the direction errors presented in this article, for instruments VX and GX and length errors m_d, described in Gawałkiewicz R., (2008), the values of mean errors of the situation of the ending point m_P, are (table 4):

The presented above comparison shows that the situation error of the control line point, in case of the application laser scanner GX, decreases nearly three times with the growth of target lengths in the range of 27.80 – 45.36m.

The recognition of the accuracy of reference to a specific construction of a signal, can have a decisive impact on decision-making in the selection of the measurement set, so significant, in case of the observations carried out in the framework of geodetic monitoring of objects diffi-

Table 4. Mean point situation errors for the analysed scanning instruments
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Instrument	Base length	Mean error of:		Mean error of the situation of point m_P	
		direction m_k [^{cc}]	length m_d [mm]	average [mm]	maximal [mm]
VX	27.80m	±6.0	±3.0	±5.3	±7.4
GX		±32.6	±6.0	±13.1	±20.1
VX	45.36	±6.0	±3.0	±5.3	±7.4
GX		±8.1	±2.0	±5.0	±7.8

cult to reach. The lack of the knowledge of the errors in a definite measurement set in such situations, can limit the application of technology, due to the lack of the possibility of fulfilling accuracy criteria, according to the law, applicable for a given type of construction.

The article was financed within the grant *Badania Statutowe* 11.11.150.195.

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