The influence of properties of a measured object on the surface digitalization performed by a laser scanner integrated with measuring arm

Michał Rak, Adam Woźniak

Institute of Metrology and Biomedical Engineering, Warsaw University of Technology

Abstract: Examining the influence of properties of the measured object on the surface digitization is a purpose of this article. Properties of an object are understood by the surface condition – its roughness, curvature and reflectivity, as well as the material composition of the measured object. A surface roughness was the first studied parameter. Tests were performed on standards of a roughness. It was checked how the roughness profile's height affects the accuracy of collected points. Measurements were performed for both reflective and scattering surfaces. It was also examined whether the scanning direction, perpendicular or parallel to the roughness profile affects the result significantly. The second part of the study was based on measurements of balls. For researches ceramic balls were chosen due to the accuracy of their making. In this case finding balls made of a material that allows the measurement by laser triangulation method was the crucial purpose. After a selection of a suitable material it was tested how the radius of the curvature affects the surface digitization. Three parameters were taken into account. These parameters were: sphericity, stability of determination the position of the centre of the fixed ball and accuracy in determination of the diameter with respect to the nominal. All measurements were studied with a portable measuring arm Metris-Nikon model MCA II fitted with a MMC80 laser scanner.

Keywords: 3D digitalization, laser scanning, roughness, laser triangulation

1. Introduction

The idea of coordinate measurements was founded in the seventies of the 20th century, but only progress of computer technology has allowed the full development [1]. In contrast to the classic metrology, coordinate measuring technique relies on computer processing of information from measurement and enables to obtain high accuracy in the short time. A characteristic property of the coordinate technique is the determination of dimensions of spatially shaped elements on the basis of coordinate values. The main device working in coordinate technique is Coordinate Measuring Machine (CMM). Its moving parts can move in three perpendicular directions. Another example of device working in the coordinate technique is Coordinate Measuring Arms called also portable CMM's. Their construction is much simpler than in case of Coordinate Measuring Machines. In contrast to the CMM in Measuring Arms during measurement angle coordinates from rotary encoders are obtained. Then using calculation procedure coordinates of points are transformed into the Cartesian system.

Points can be collected in a contact way. In this case high accuracy coordinates are obtained. Main disadvantages of this approach are the small number of measurement points and the long measuring time. Especially in industry faster and more thorough and complete inspection of machined parts in order to shorten development and production time of products are requested. An attractive solution is applying optical methods where data on the entire object in a short time is gathered. Optical methods include [2]: triangulation, ranging, interferometry, structured lighting and image analysis. To perform the research presented in this article laser triangulation method was used.

2. Laser triangulation

Compared to other optical measuring methods, higher precision and lower costs characterize laser triangulation [3]. Its working principle is as follows: a laser beam is aimed in the direction of the measured surface, producing a spot or a stripe. The spot/stripe is imaged on a detector at a position dependent on the distance of the measured area from the source of the laser. There are some factors affecting the measurement accuracy [4]:

1. Laser scanning depth,
2. Projected angle,
3. Environment effects,
4. Operation error,
5. Data processing.

The first factor was widely analyzed by Vukašinović et al. [5]. He concluded that at a closer distance from the laser scanner to the measured surface obtained resolution is higher.

A significant factor influencing the result of measurement is the projection angle. Demkin et al. [6] consider that to reduce significantly the deformation of the resulting cloud of points, caused by the surface properties, it is necessary to keep the triangulation plane orthogonally to the measured surface. The influence of incident angle was also noticed by Van Gestel et al. [7]. They showed that for measurements of the sphere from only one direction unstable results were obtained. Extensive studies of the impact of projected angle were made by Vukašinović et al. [5]. They measured the intensity of surface reflection. It was indicated that at incidence angle over 60° the intensity is equal to zero.

As environment effects mainly ambient light and temperature changes are taken. Blanco et al. [8] noted that the best results were obtained in the absence of external light but this condition is inappropriate for most laboratory tasks. The use of mercury vapour lamps is therefore recommended. In their paper the effect of temperature on results was also presented. Thermal distortion of laser head internal geometry causes that within one hour, variation of achieving results is 10 µm. Vukašinović et al. [9] paid attention to the appropriate data processing. Only a central part of point clouds should be used, what is connected with the measurement angle and the distance.

Vukašinović et al. [5] divide the reflection from a real surface into two components: specular and diffuse. Their ratio depends on surface properties, which includes: chemical composition, microstructure and roughness. Research of different materials (aluminium, stainless steel, low alloy steel, cooper alloy, necuron and arnite), i.e. with different composition and different properties of the surface were performed by Blanco et al. [8]. They noted that when stainless steel is digitized, the spatial position of the point cloud is less affected than in case of necuron. On the other hand necuron gives a good repeatability for the light influence and low steel carbon or coopers alloy not.

In the literature, the influence of surface color on measured results was widely discussed. Vukašinović et al. [5] made a spectral analysis for the different surface color using a laser diode of wavelength of 675 nm. The highest relative intensity was for white – 100 % and red surface – 87 %, and the lowest was for green and blue – 23 % and 7 %, respectively. Higher intensity associates obviously with a larger number of points collected from the surface. Vukašinović et al. [10] choose red instead of white surfaces. They justify this by the fact that red surface reflects only this part of red light which is between 600 nm and 700 nm and absorbs the energy of the most of the other spectral field. Vukašinović [9] determines the surface color as the factor most strongly influencing the result (in comparison to incident angle and distance).

Another important factor discussed by Lombardo et al. [11] is reflectivity of scanned surface. It cause that not all the light sent by the laser finds its way onto the detector what obviously is a limitation. A surface that is too reflective must be prepared for the measurement, for example through spraying a washable coat. The influence of the measured surface on results was also brought up by Martínez et al. [3] whom recommend that the surface should neither be specular, very shiny nor dark. A similar problem is also with transparent surfaces [8]. Vukašinović et al. [5] demonstrated that although covering the surface with white chalk powder increasing the intensity over the entire range of incident angle it does not increase this range.

In this article influence of properties of the measured object on the surface digitization were examined. Verified factors were surface's roughness, curvature and reflectivity, as well as the chemical composition of the measured object.

3. Experiment

3.1. Measuring equipment

Studies were performed on a coordinate measuring arm model MCA II made by Metris-Nikon. This is a 7-axis arm with a spatial accuracy, according to the ASME B89.4.22-2004 [12] standard, of 40 µm. This and other parameters of the arm are given in tab. 1.

The arm is equipped with a laser scanner head METRIS – NIKON model MMC80 with characteristics presented in tab. 2.

Point clouds were collected using the scanner manufacturer's software package called Focus Handheld. Points associated with the fixation elements were removed before further processing.

Tab. 1. Main parameters of the arm METRIS – NIKON model MCA II

Tab. 1. Główne parametry ramienia METRIS – NIKON model MCA II

Kinematic topology	**Measuring range**	**Accuracy according to the B test**	**Accuracy according to the C test**
7 rotary axes	2.4 m	± 0.028 mm	± 0.040 mm

Tab. 2. Parameters of the scanner MMC80 METRIS-NIKON

Tab. 2. Parametry skanera MMC80 METRIS-NIKON

Stripe width (Y)	80 mm
Measuring range (Z)	100 mm
Accuracy (1σ)	17 µm
Points per stripe	800
Maximum speed of scanning (stripes per second)	30
Maximal number of scanned points per second	24 000 p/s

Tab. 3. Main parameters of the profilometer Taylor Hobson model Talysurf PGI 830

Tab. 3. Główne parametry profilometru Taylor Hobson model Talysurf PGI 830

Product code	PGI 830
Gauge range	8 mm
Gauge resolution	0.8 nm
Horizontal traverse	200 mm
Horizontal straightness	0.35 µm over 200 mm
Vertical traverse	450 mm
System noise	2 nm
Isolation cabinet	Standard

Measurements of standards of roughness were performed on profilometer Talysurf PGI 830 made by Talor Hobson. Parameters of the Talysurf were given in tab. 3.

3.2. Test parts

Standards of roughness and ceramic balls were selected as elements for the tests. Example test parts are shown in fig. 1.

Standards of roughness were divided into scattering and reflective (both can be seen in fig. 1.) For both groups four standards with different parameters of roughness were chosen. Based on the Ra parameter effort has been made to choose a similar sample of reflective and scattering surfaces. Selected samples were presented in tab. 4.

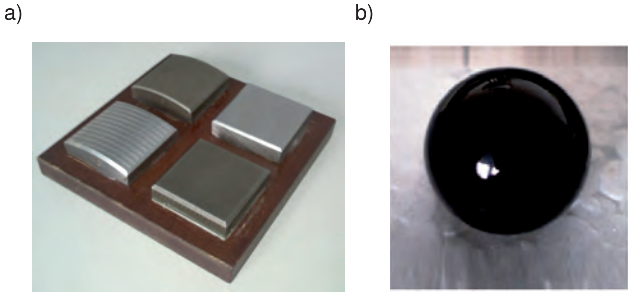

Fig. 1. Test parts: a) standard of roughness, b) ceramic ball

Rys. 1. Elementy pomiarowe: a) wzorzec chropowatości, b) kula ceramiczna

Tab. 4. Selected samples of standards of roughness

Tab. 4. Wybrane próbki wzorców chropowatości

Reflective	Scattering
Ra, µm	Ra, µm
33.0	26.7
9.1	9.4
4.7	5.1
0.9	1.4

Measurements were performed in the perpendicular and parallel direction to the surface roughness profile. For each direction for each surface a series of 10 measurements were performed. For obtained point clouds sections perpendicular to roughness profile were measured and their straightness was determined. From ten values of straightness for section their averages and standard deviations were calculated.

For balls tests finding a material that allows the measurement by laser triangulation method was a first goal. Four materials were tested: silicon nitride (Si_3N_4), tungsten carbide (WC), zirconium oxide (ZrO_2) and aluminium oxide (Al_2O_3). Subsequently it was tested how the radius of the curvature affects the surface digitization. Three parameters were taken into account: sphericity, stability of determination the position of the centre of the fixed ball and accuracy in determination of the diameter with respect to the nominal.

4. Results

For all select standards a comparison of average values and standard deviations of straightness of sections for both perpendicular and parallel strategies was presented in tab. 5 (a – for reflective surfaces, b – for scattering surfaces).

Results were presented in graphs. Straightness for reflective and scattering surfaces and standard deviations were shown in fig. 2a, b and c, respectively.

Tab. 5a. Straightness of sections from reflective surfaces

Tab. 5a. Prostoliniowość przekrojów z powierzchni refleksyjnych

reflective				
	perpendicular		parallel	
Ra, µm	straightness, µm	standard deviation, µm	straightness, µm	standard deviation, µm
33.0	233.8	34.6	225.9	37.7
9.1	64.8	13.5	163.3	83.8
4.7	79.2	28.6	80.3	274.5
0.9	81.5	45.0	104.9	42.4

Tab. 5b. Straightness of sections from scattering surfaces

Tab. 5b. Prostoliniowość przekrojów z powierzchni rozpraszających

scattering				
	perpendicular		parallel	
Ra, µm	straightness, µm	standard deviation, µm	straightness, µm	standard deviation, µm
26.7	122.9	17.5	95.6	5.9
9.4	73.4	17.0	44.4	6.3
5.1	71.7	9.8	51.9	7.9
1.4	55.6	5.7	43.3	5.8

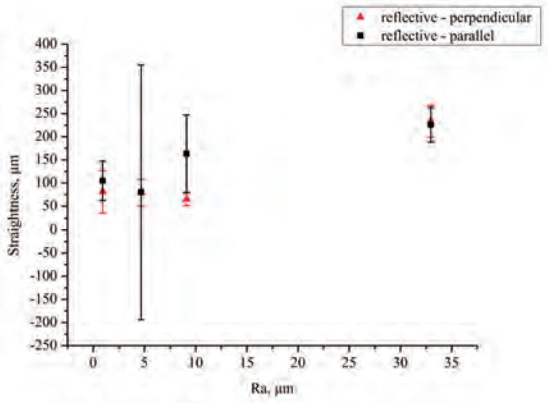

Fig. 2a. Straightness of sections for reflective surfaces

Rys. 2a. Odchyłka prostoliniowości przekrojów dla powierzchni refleksyjnych

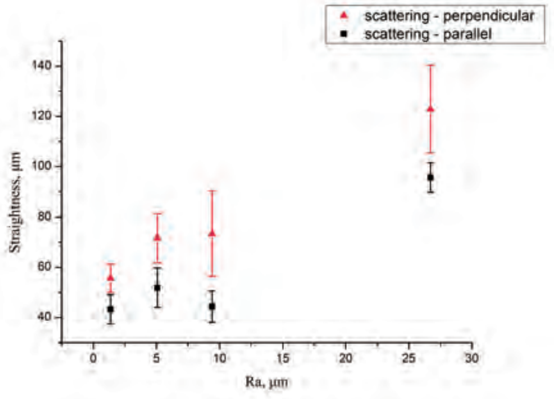

Fig. 2b. Straightness of sections for scattering surfaces

Rys. 2b. Odchyłka prostoliniowości przekrojów dla powierzchni rozpraszających

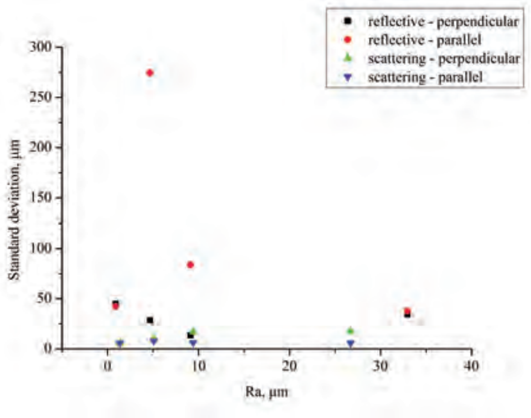

Fig. 2c. Standard deviations of straightness of sections

Rys. 2c. Odchylenia standardowe odchyłek prostoliniowości przekrojów

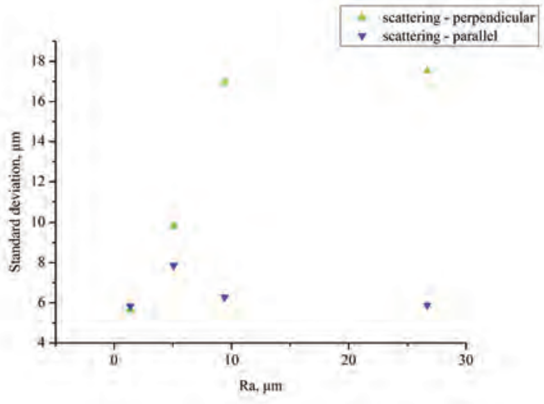

Fig. 2d. Standard deviations of straightness of sections for scattering surfaces

Rys. 2d. Odchylenia standardowe odchyłek prostoliniowości przekrojów dla powierzchni rozpraszających

The first thing, which should be noted, is that both the straightness of sections and standard deviations are almost in the whole range higher in case of reflective surfaces than for scattering. With increasing of roughness the stability of the straightness of the section determination increases. It may be due to the fact, that roughness makes the surface is no longer specular.

Another important issue is the effect of the scanning direction. For measurements of reflective surfaces both straightness and standard deviation are higher for measurements, which are parallel to surface roughness profile. For measurements of scattering surfaces, the situation is reversed. Curves of the straightness for scattering surfaces measurements are similar in shape but with higher values for perpendicular measurements. For the reflective surfaces a large the randomness of results reveals.

It can be concluded that in order to reduce the impact of the measured surface properties on the result part should be prepared for measurement, for example by applying an appropriate coating.

To illustrate the effect of the measuring direction, curves of the standard deviation only for scattering surfaces were shown. It was presented in fig. 2d.

It can be noticed that in measurements perpendicular to profile of roughness standard deviation increases with the size of roughness considerably faster and reaches almost three times higher values.

The second part of the study was performed using ceramic balls. The first task was to select a material with a chemical composition that the laser beams were neither scattered nor absorbed by the surface. Four materials were chosen: silicon nitride, tungsten carbide, zirconium oxide and aluminium oxide. A simple test was performed. It was checked whether the laser beam intersects with the real surface of the ball. Location of measuring point outside the ball demonstrates significant surface reflectivity, and gathering point inside the ball demonstrates absorptivity of material of which the ball was made. For balls of different materials measuring points were collected. On this basis their diameters were determined. Diameters were compared with nominal values. The comparison was presented in tab. 6.

Tab. 6. The comparison of diameters for different materials

Tab. 6. Porównanie średnic kul dla różnych materiałów

	silicon nitride	tungsten carbide	zirconium oxide	aluminium oxide
nominal diameter, mm	12.700	6.350	15.875	12.700
measured diameter, mm	12.765	7.910	15.451	12.417
measured-nominal, mm	0.065	1.560	–0.424	–0.283

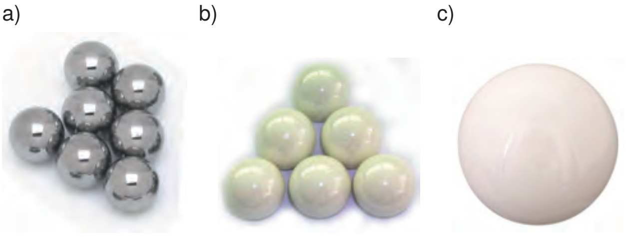

Fig. 3. Materials of balls: a) tungsten carbide, b) zirconium oxide, c) aluminium oxide

Rys. 3. Kule wykonane z różnych materiałów: a) węglik wolframu, b) tlenek cyrkonu, c) tlenek glinu

Comparing the difference between the measured and nominal diameter it can be seen that the best material is silicon nitride. Ball made of this material was presented in fig. 1b. Tungsten carbide has high reflective properties, while zirconium oxide and aluminium oxide absorb the laser beam. These materials were shown in fig. 3.

Further studies were performed on balls made of silicon nitride. Balls with a diameter ranging from 12 mm to 5 mm were studied.

The first tested parameter was sphericity. Its value for each diameter was shown in fig. 4.

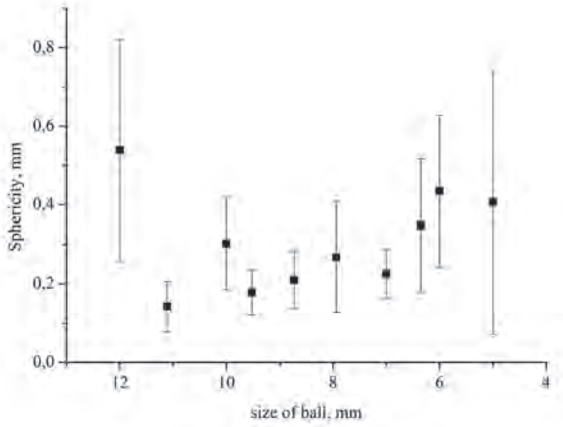

Fig. 4. Sphericity for different balls' sizes
Rys. 4. Odchyłka sferyczności dla różnych rozmiarów kul

The curve of sphericity as a function of balls diameter may indicate a negligible effect of the radius of curvature on values of sphericity. It is rather due to properties of surfaces, environmental conditions and errors of the measuring device.

A stability of determination the position of the centre of the fixed ball was a next checked parameter. Results were presented in fig. 5.

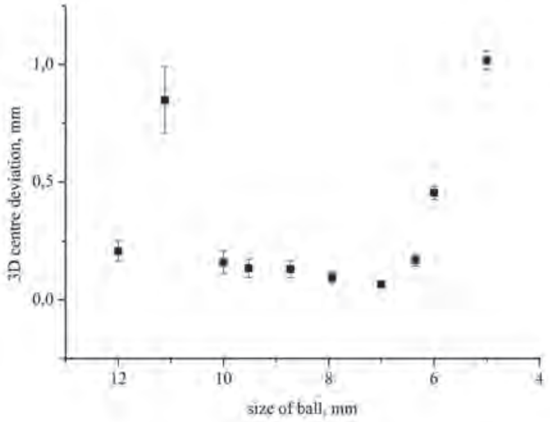

Fig. 5. Stability of positions of centres (3D centre deviations)
Rys. 5. Stabilność pozycji środków (odchylenia 3D środków)

It can be seen that apart from peak of the balls with a diameter of 7/16" (11.113 mm) the stability of determination centres of balls is maintained at a similar level up to the ball with a diameter of 7 mm. Subsequently a rapid increase is noticeable. This is due to the fact that in smaller balls percentage of random points and noise is much higher. From the smaller surface smaller number of points is collected so that each artifact is more significant.

In the case of determining the differences between measured and nominal diameter situation is similar as in the case of sphericity. Correlation of errors of diameter determination and the size of balls was shown in fig. 6.

Higher ratio of the number of points collected outside the surface to those collected under surface results in the determination of a diameter of a ball higher than nominal value. The diameter of the ball does not affect on this. Sphericity, so also indirectly appropriate filtering can reduce the error of the diameter determination. Outlying points that adversely affect the result are then removed.

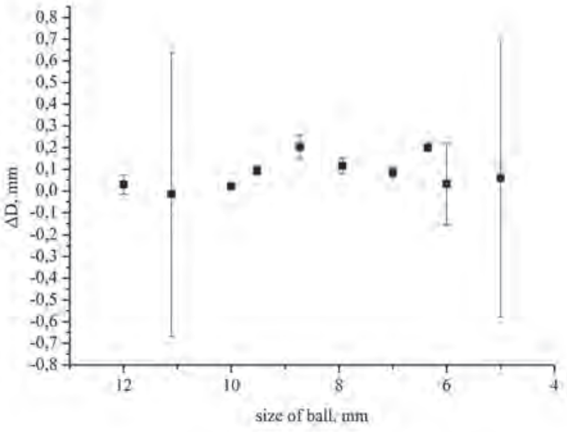

Fig. 6. Errors of determination the diameter of ball
Rys. 6. Błędy wyznaczenia średnicy kuli

5. Conclusion

We can conclude that the impact of properties of the measured surface is significant. Therefore its preparation for measurement is very important. During measurements of standards of roughness it was reported that reflectivity of surface causes a strong randomness of results. With increasing of roughness the stability of the straightness of the section determination increases. It may be due to the fact that roughness makes the surface is no longer specular. For scattering surfaces, for higher stability of results it is recommended to perform measurements in a parallel to the roughness direction.

During the research on balls a strong the influence of the material of which the part was made to the measurement results was proved. Depending on the chemical composition surface can absorb or reflect the laser beam. It was checked whether the laser beam intersects with the real surface of the ball.

It has also been shown that there is a negligible effect of the radius of curvature on values of sphericity. It is rather due to properties of surfaces, environmental conditions and errors of the measuring device.

If determination of position of feature is the main goal of measurement, features with small dimensions should not be selected. This is due to the fact that in smaller features percentage of random points and noise is higher.

In the case of determining the diameter of ball the situation is similar as in the case of sphericity. It is rather caused by properties of surfaces, environmental conditions, errors of the measuring device and other random factors.

Bibliography

1. Ratajczyk E., *Coordinate measuring technique*, OWPW, Warsaw 2005 (in Polish).
2. Várady T., Martin R., Coxt J., *Reverse engineering of geometric models – an introduction.* “Computer-Aided Design”, Vol. 29, No. 4, 1997, 255–268.
3. Martínez S., Cuesta E., Barreiro J., Álvarez B., *Analysis of laser scanning and strategies for dimensional and geometrical control.* “The International Journal of Advanced Manufacturing Technology”, (2010) 46, 621–629.
4. Wang L., Ding H., Wang S., *Measurement Error Compensation Using Data Fusion Technique for Laser Scanner on AACMMs*, ICIRA 2010, Part II, LNAI6425, 2010, 576–586.
5. Vukašinović N., Bračun D., Možina J., Duhovnik J., *The influence of incident angle, object colour and distance on CNC laser scanning*, “The International Journal of Advanced Manufacturing Technology”, 9/1994, 56–64.
6. Demkin V.N., Stepanov V.A., *Measurement of surface roughness profile by a triangulation method*, “Measurement Techniques”, Vol. 51, No. 6, 2008.
7. Van Gestel N., Cuypers S., Bleys P., Kruth J.P., *A performance evaluation test for laser line scanners on CMMs*, “Optics and Lasers in Engineering”, vol. 47, 2009, 336–342.
8. Blanco D., Fernández P., Cuesta E., Mateos S., Beltrán N., *Influence of Surface Material on the Quality of Laser Triangulation Digitized Point Clouds for Reverse Engineering Tasks*, “Emerging Technologies & Factory Automation”, 2009. ETFA 2009. IEEE Conference.
9. Vukašinović N., Možina J., Duhovnik J., *Correlation between Incident Angle, Measurement Distance, Object Colour and the Number of Acquired Points at CNC Laser Scanning*, “Journal of Mechanical Engineering”, 58, 2012, 1, 23–28.
10. Vukašinović N., Korošec M., Duhovnik J., *The Influence of Surface Topology on the Accuracy of Laser Triangulation Scanning Results*, “Journal of Mechanical Engineering”, 56, 2010, 1, 23–30.
11. Lombardo V., Marzulli T., Pappalettere C., Sforza P., *A time-of-scan laser triangulation technique for distance measurements*, “Optics and Lasers in Engineering”, 39, 2003, 247–254.
12. ASME B89.4.22-2004 “Methods for Performance Evaluation of Articulated Arm Coordinate Measuring Machines”.

Wpływ właściwości mierzonego obiektu na proces digitalizacji powierzchni przeprowadzanej za pomocą skanera laserowego zintegrowanego z ramieniem pomiarowym

Streszczenie: W artykule przedstawiono wyniki badania wpływu właściwości mierzonego obiektu na proces digitalizacji powierzchni. Właściwości obiektu są rozumiane przez stan powierzchni – jej chropowatość, krzywiznę i refleksyjność, jak również skład materiałowy mierzonego obiektu. Pierwszym badanym parametrem była chropowatość powierzchni. Testy wykonano na wzorcach chropowatości. Sprawdzano, jak wysokość profilu chropowatości wpływa na dokładność zbieranych punktów. Pomiary wykonano dla powierzchni zarówno refleksyjnych i rozpraszających. Sprawdzano również, czy kierunek skanowania, prostopadły lub równoległy do profilu chropowatości wpływa znacząco na wynik. Druga część badań została wykonana na podstawie pomiarów kul. Do testów użyto kul, które zostały zbadane pod względem najlepszego materiału umożliwiającego pomiar na zasadzie triangulacji laserowej. Następnie sprawdzano, jak promień krzywizny wpływa na digitalizację powierzchni.
Wzięto pod uwagę trzy parametry. Tymi parametrami były: sferyczność, stabilność wyznaczenia pozycji środka unieruchomionej kuli i dokładność wyznaczenia średnicy w odniesieniu do wartości nominalnej. Wszystkie pomiary wykonano przy użyciu współrzędnościowego ramienia pomiarowego Metris-Nikon model MCA II wyposażonego w skaner laserowy MMC80.

Słowa kluczowe: digitalizacja 3D, skaning laserowy, chropowatość, triangulacja laserowa

Michał Rak, MSc

He received the MSc from Warsaw University of Technology in 2011. He is currently a PhD student in the Institute of Metrology and Biomedical Engineering, Faculty of Mechatronics, Warsaw University of Technology. Within the PhD he deals with the fusion of data from different measurement methods mainly optical and contact.

e-mail: M.Rak@mchtr.pw.edu.pl

Adam Woźniak, PhD, Prof. of WUT

He received the MSc (1998), PhD (2002), and DSc (2011) degrees from Warsaw University of Technology, Poland. From 2005 to 2006 he was a Visiting Professor with the Department of Mechanical Engineering, École Polytechnique de Montréal, Canada. He is currently a Professor with the Institute of Metrology and Biomedical Engineering, Faculty of Mechatronics, Warsaw University of Technology. His current research interests include dimensional metrology, especially coordinate measuring technique. He is the author of more than 80 papers in these areas.

e-mail: wozniaka@mchtr.pw.edu.pl