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# Restitution of 3D scenery with coherent and structured light scanner technologies

**Abstract**

In the paper, there is presented the comparison of the quality of three-dimensional object measurement by scanning devices using a coherent light beam and a structured light field. Several selected issues from the fringe pattern analysis, as well as the characteristics of terrestrial laser scanning are also presented. The comparative analysis was performed to scan a crankshaft in order to assess the measurement accuracy of both scanners. By applying the appropriate software for the resulting point clouds we created a three-dimensional model of the crankshaft and made adequate comparative measures.

**Keywords**: 3D scenery restitution, coherent light scanner, a structured light scanner, point clouds.

## 1. Instrduction

Optical methods for measuring the shape are a tool for describing the surface of 3D objects. On the basis of the measurement techniques that used, these methods allow for achievement of high resolution of the scanned scene to provide an adjustable range of its volume. There are various techniques of measuring distances as well as research of macro and microstructure of the tested object (field and point measurement methods). Point measurement methods where we can distinguish photogrammetry and laser triangulation have minor flaws, e.g. the limited number of points which should be processed at the time of automatic processing of the collected data, and too large amount of time devoted for their processing. Field measurement methods, in turn, involve a much larger group of optical shape test methods. The one of the most important advantages is delivering the information about the object shape from the whole area of the image at the same time. The methods of measurement may use, e.g. the analysis of the intensity of a striped field which is projected onto the top layer of the tested object.

## 2. Specialized scanning devices

Scanners are quite a large and diverse group of devices which can be divided into contact and contactless 3D scanners. Contact devices are characterized by the measurement which is made with a measuring head, placed on the precision arm which has a considerable range of motion. The accuracy of the obtained measurement is in the range of 0.25 mm to 0.005 mm. The measurement is limited to the data acquisition which is done by collecting points in the characteristic areas. The scanners have certain limitations, as the size of the scanned object and the inability to use them, e.g. in the field of criminology. However, a simple construction and lack of complicated software are the advantages. Measurement with contactless scanners, in turn, is made by directing a laser beam or structured light to the object, and next carrying out the analysis of the recorded image or images. Here a group of optical scanners can be distinguished as they have a higher measuring accuracy and operating speed. Lasers and stripe scanners are the most commonly used measurement devices. The line distortion technique is used in the form of a beam of light illuminating the scanned object is used in them. A fundamental difference between the techniques of scanning the object with a laser beam and with structured light is that in the case of the former, during one sequence, only one stripe of data occurs, while in the case of the latter, which uses structured light, appears a whole set of stripes including the measurement data.

## 3. Characteristics of the terrestrial laser scanning

Laser scanners are built mainly from a source of rays (laser), which is a data bearer and a movable mirror directing a beam in a desired direction (Fig. 1).

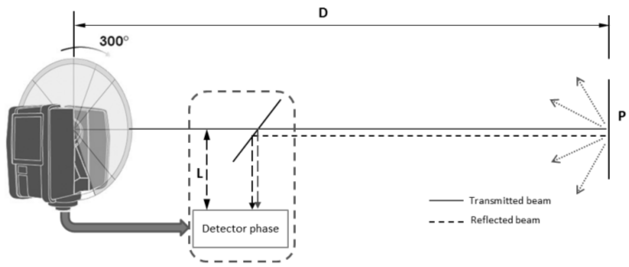


Fig. 1. Distance measurement at time *t*

The laser beam that is divergent, and its diameter increases together with increase in the distance, affects the resolution and the measurement accuracy. The pole coordinates are converted to Cartesian, and the point coordinates are calculated according to the formula:

$$x = D\cos\theta\,\cos\alpha \tag{1}$$

$$y = D\cos\theta\,\sin\alpha \tag{2}$$

$$z = D\cos\theta \tag{3}$$

Next to the coordinates, another value that corresponds to the signal intensity returning to the scanner is recorded. This intensity depends on the material (type, color, roughness) from which the beam is reflected. Laser scanners can have different systems of distance calculation, the so-called electrical system (pulse or phase) and optical (triangulation). The phase system, used in the research phase, involves the measurement of the phase difference between the sent and received signal (Fig.2). This is possible thanks to the sinusoidal form of the laser light. The distance can be described by the relationship:

$$d = \frac{N\lambda + \varphi}{2} \tag{4}$$

where: $\lambda$ – wavelength, $\varphi$ – phase shifting, $N$ – multiple wave-length.

The accuracy in laser scanning systems depends on the precision of determining distances and angles. It is conditioned by a number of parameters, among others, atmospheric conditions, surface roughness of the object, the capacity of particular materials for reflecting the light, distances between the object and the scanner, as well as its very quality and functions.

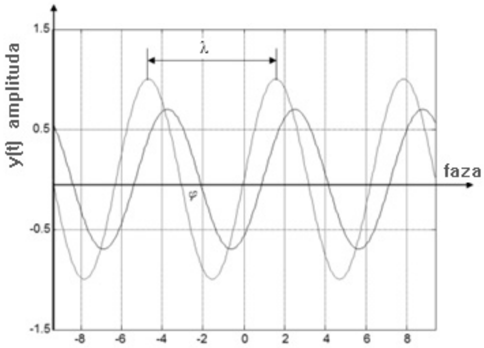


Fig. 2. Phase shifting of the reflected signal

## 4. Selected aspects of the fringe pattern analysis

The analysis of the stripe image is based on encoding the information about the tested process or object in the intensity setting $I(x, y)$ and applies to all interferometric methods. In most measurement systems, we have to deal with changes of the intensity in the space of sinusoidal character, hence the formula describing the analysis of the interferogram can be described as follows:

$$I(x,y) = a(x,y) + b(x,y)\cos[(\varphi(x,y))] \tag{5}$$

where: $a(x, y)$ - value of the light in the point, $b(x, y)$ - contrast in the point, $\varphi(x, y)$ - phase setting, $I(x, y)$ - value of the light in the point.

The analysis of the interferogram consists of two basic stages:

- calculation of the phase function modulating the intensity of an image,
- overscaling to the search physical magnitude $h(x, y)$ of phase.

The measured intensity setting $I(x, y)$ does not allow the phase restoration because the measured phase function is obscured by two unknown functions: $a(x, y)$ the background lightness and the interferogram contrast $b(x, y)$, so there is one equation with three unknown quantities. In contrast, the parity of cosine function causes the uncertainty of the phase sign $\cos(\varphi) = \cos(-\varphi)$, and the phase function periodicity is determined by mod(2π) causing the restriction of the result range. In the intensity methods, the value describing the image is defined as a function of lightness $I(x, y)$, on the basis of which the detection of axis lines (spine stripes of line) is performed. The frame of the contour map of the tested object create minima and maxima of light functions, found in the image. There are three groups of axial line detection methods. They are: thinning the edges of stripes, gradient and statistics and laplacian filters. In the group of phase methods, the essence of stripe image analysis and the main assumption is that the information about the object contour map is included in the phase extracted from the measured lightness function. Based on the method of a discrete phase change, it can be assumed that:

$$I(x,y) = a(x,y) + b(x,y)\cos[\varphi(x,y) + 2\pi f_0 x] \tag{6}$$

where: $2\pi f_0 x$ describes the vertical stripes coming from the diffraction net or generated by a suitable project device, the so called parasitic bands.

In relation to the presence of three unknowns, it is necessary to make at least three measurements in a discrete form taking into account the stepwise phase change in any of the measurements. The phase setting is calculated by taking the first sine and cosine of harmonics in the Fourier series. For calculations, the following relationships are used:

$$\alpha_1(x,y) = \sum_{n=0}^{k} I_n(x,y)\cos\left(\frac{2\pi n}{k+1}\right) \tag{7}$$

$$\beta_1(x,y) = \sum_{n=0}^{k} I_n(x,y)\sin\left(\frac{2\pi n}{k+1}\right) \tag{8}$$

where: $I_n(x, y)$ - lightness value in the point measured in the $n$-th measurement, $k$ – number of measurements with phase changes.

The phase function is calculated from:

$$\varphi(x,y) = \arctan\left(\frac{\beta_1(x,y)}{\alpha_1(x,y)}\right) \tag{9}$$

If you apply the amount of phase shifts determined by the value of 0,5π, for example, the simplified formula is obtained:

$$\varphi(x,y) = \arctan\left(\frac{I_4 - I_2}{I_1 - I_3}\right) \tag{10}$$

where: $I_1$, $I_2$, $I_3$, $I_4$, - lightness of the following images after the change of phase.

## 5. 3D object measurement and analysis

To compare two different 3D scanning techniques, there was used an automobile engine crankshaft, whose characteristic structure and size made it possible to see the essence of scanning with structured and consistent light beam. Before making measurements for each of the used devices, the measurement volumes and the suitable scanning parameters were selected, that is: the measurement distance was determined, the place of taking measurement, the measurement resolution, the scanning area. The scanned object was covered with a matting agent which significantly eliminated the unsafe effect of appearing the reflections on the shiny elements of objects.

Using the structured light scanner, a three-dimensional cloud of points reflecting the scanned model was obtained (Fig. 3).

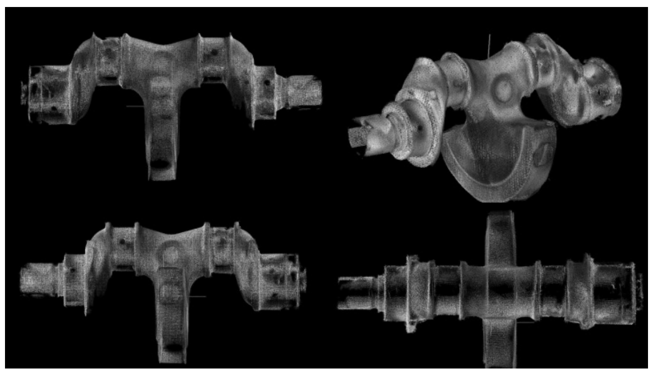

Fig. 3. 3D model of the object obtained with the use of the structured light scanner

To obtain a 3D model of the object with the use of a laser scanner (Fig. 4), there were made six measurements from different positions around the object using the reference points. The cloud of points was cleared out of redundant elements. The appropriate color scheme which is the exact reflection of the scanned objects was applied.

The environments used to connect point clouds have the ability to develop measurements of length between selected elements. In order to compare the accuracy of scanning techniques, measurements of the actual details of the tested object were taken, and next they were compared with the results obtained during the scanning process.

The measurement accuracy of the structured light scanner using SmartTech ranges from a few to several microns, whereas in the case of laser scanning the values are calculated to a millimeter. Hence, the results were rounded to two decimal places. The characteristic places on the engine shaft measured using the measurement tool in the Mesh3D and Faro SCENE as well as with calipers were compared. The results of the obtained measurements are presented in Table 1. Figs. 5 and 6 show the measured elements.

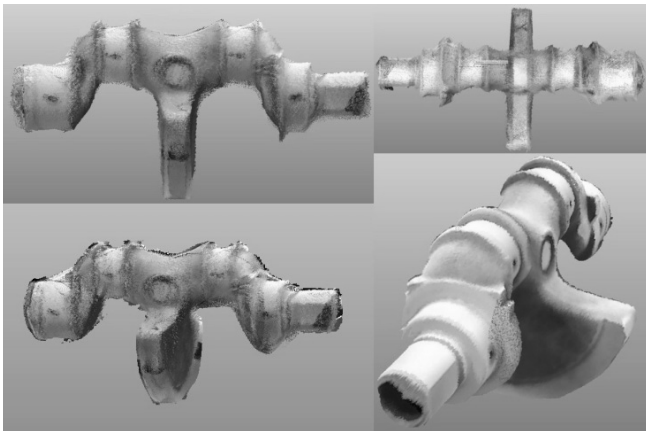

Fig. 4. 3D model of the object obtained with the use of the laser light scanner

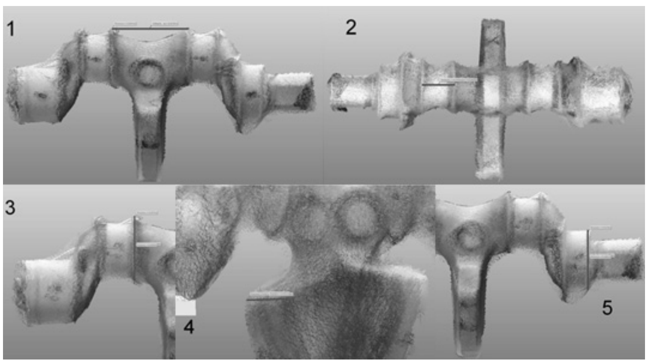


Fig. 5. Measurement of the crankshaft in the MESH 3D®

Tab. 1. Measurement results of the selected elements of the crankshaft

| Measurement | Measurement results, mm | | |
|---|---|---|---|
| | Caliper | Mesh3D® | Faro Scene ® |
| Distance between the main crankpins (no 1) | 71.95 | 71.87 | 73.00 |
| Width of the crankpin surface (no 2) | 30.10 | 30.24 | 30.00 |
| Diameter of the crankpin (no 3) | 54.05 | 54.16 | 53.00 |
| Width of the shaft counterweight (no 4) | 24.65 | 25.21 | 21.00 |
| Diameter of the main crankpin (no 5) | 50.85 | 50.78 | 51.00 |

The light of a laser scanner is designed primarily to measure large areas, such as structures of buildings or shapes of construction elements. These scanners are designed for visualization and documentation of 3D objects for CAD systems. Although appropriate parameters are set in the device settings, the scanner is not able to provide the mapping of an engine shaft as precisely as when making measurements with the use of a white light scanner. Thanks to the possibility of operating in two different resolution modes, which enables the optimization of the amount of downloaded data, the white light scanner can accurately copy a particular object.

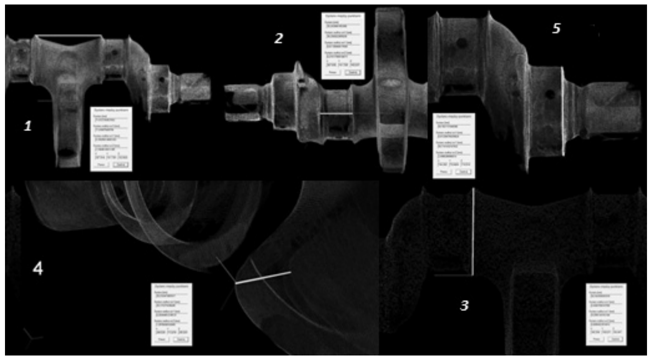


Fig. 6. Measurement of the crankshaft in the Faro Scene®

## 6. References

[1] Rychlik M.: Skanery – wrota do wirtualnego świata. Warszawa, 2007.
[2] Dybała M.: Integracja i spójność modeli w inżynierii odwrotnej: wybrane aspekty technicznych i medycznych zastosowań. Reverse Engineering, Wrocław, 2013.
[3] Patorski K., Kujawińska M., Sałbut L.: Interferometria laserowa z automatyczną analizą obrazu. Warszawa, 2005.
[4] Mokrzycki Wojciech S.: Wprowadzenie do przetwarzania informacji wizualne. Percepcja, akwizycja, wizualizacja. Warszawa, 2010.
[5] Gomółka Z.: Sieci neuronowe w analizie obrazów prążkowych. Rozprawa doktorska, Kraków, 2000.
[6] Inglot A.: Digitalizacja i wizualizacja 3d budynku z wykorzystaniem technologii skanowania 3D. Praca inżynierska, Rzeszów, 2015.
[7] Kawa Ł.: Digitalizacja wału korbowego silnika spalinowego z wykorzystaniem skanerów światła spójnego i strukturyzowanego. Praca inżynierska, Rzeszów, 2015.
[8] Foley J. D., Van Dam A., Feiner S. K.: Computer Graphics: Principles and Practice, 2013.
[9] Gortler S. J.: Foundations of 3D Computer Graphics. 2012.
[10] Vosselman G., Maas H.G: Airborne and Terrestrial Laser Scanning, 2010.
[11] Ferguson S.: Practical Algorithms for 3D Computer Graphics. Second Edition, 2014.

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