1. Tomasz KRASZEWSKI[1], 2. Anna PIWOWAR[1,2] 3. Renata FRĄCZEK[1,2], 4. Piotr ŚWISZCZ[1] 5, Łukasz BIS[1]

Centrum Badawczo – Rozwojowe GLOKOR Sp. z o.o. (1),
Politechnika Śląska, Wydział Elektryczny (2)
ORCID: 1. 0000-0003-2208-8536; 2. 0000-0002-5578-3757; 3. 0000-0002-8121-7417; 5. 0000-0002-1692-887X

doi:10.15199/48.2022.11.55

Visual defect detection methods overview

Streszczenie. *Artykuł stanowi część prac związanych z opracowaniem linii do automatycznej identyfikacji wad na elementach obrabianych z opracowaniem technologii ich usuwania strumieniową obróbką ścierną na stanowiskach zrobotyzowanych w warunkach przemysłowych. W artykule dokonano przeglądu metod wizyjnej detekcji wad obejmujące układy budowane w oparciu o czujniki wizyjne, systemy laserowe, w tym systemy światła strukturalnego. Opisane metody detekcji wizyjnej uzupełniono przykładami testów i doświadczeń z wykorzystaniem wybranych urządzeń.*

Abstract*. The article is a part of research related to developing a line which automatically identifies defects of workpieces together with technology of their elimination with the aid of stream abrasive treatment at automated stations in industrial conditions. The article presents an overview of visual defect detection methods, including systems based on vision sensors, laser systems, including structured light systems, photogrammetry, and thermal imaging systems. The described methods have been supplemented with examples of tests and experiments involving selected devices. (****Przegląd metod wizyjnej detekcji wad****).*

Słowa kluczowe: defect detection, vision systems, vision sensors, structured light
Keywords: identyfikacja wad, systemy wizyjne, czujniki wizyjne, światło strukturalne

Introduction

The article is associated with a project of research and development works which aims at creating an innovative solution in the form of a production line enabling automatic defect detection of elements undergoing the cleaning process based on stream abrasive treatment. It is the first step in developing the technology of visual defect detection, one part of a production process. The vision system is to visualize the physical features of an element under scrutiny in order to conduct measurements and control its quality. The data collected by the database automatically determine the subsequent step of the process, providing precise information concerning the localization of a defect together with a suggested elimination method. It is assumed that the system will consist of vision devices and a system of image acquisition and processing, by combining acquisition and processing processes with software allowing to make the steps of control, measurement and production processes automatic. Vision systems conducting quality control are used in the production process as well as for warehouse management. They enable to automatically inspect products moving through production lines. The systems are based on high quality cameras and software, which perform a constant 2D or 3D image analysis. The obtained image is compared to the reference and deviation values. Integrating vision systems with measurement and industrial automatics systems supports quality management processes and facilitates:

- automation of quality control processes,
- constant verification of products on production lines,
- limiting the complaint-related costs,
- shape, measurement and color verification,
- element localization control,
- presenting data related to inspection results.

The work is considered as an overview of image capturing methods and appropriate image processing methods, becoming an essential database for the selection of an optimal technique in order to attain a desired goal. Various technologies (based on vision sensors, lasers and structured light systems) were analyzed with respect to their properties and potential application for defect detection under defined conditions. The selected system should most of all ensure reliability and prevent an element with defects from being accepted. Furthermore, high level of reliability is required. As far as the selection of a recommended visual method, its high speed of operation is an essential feature. Defect detection and localization system must not negatively influence on the production rate. From the point of view of the selection of visual methods, high operation speed is a significant feature. It is particularly important due to the overall process of detecting and removing defects, in which devices will be used to perform repeated measurements and introducing inertia in the production process. Due to the fact, an appropriate image analysis system should be selected to decrease delays associated with its application as much as possible and not to cause additional process extension.

An overview of optical methods was enriched with research consisting in conducting experiments involving various visual defect detection systems. The performed tests were to identify appropriate tools for the vision system, determine image processing parameters and preliminary development of algorithms enabling the achievement of target processing efficiencies. The test object with various kind of defects underwent tests (fig. 1).

Fig.1. Test object

The obtained results will be subjected to comparative analysis and an optimal measurement method will selected.

Vision sensors

Vision sensors (alternatively called optical sensors) are relatively simple in construction vision technique devices [1]. They consist of an image processing system, optical elements, an illuminator and input-output systems (fig. 2). Depending on the type, version and manufacturer, lenses and lighting are built into the sensor or require additional installation. Control software verifying given parameters of the tested objects can be stored in the device memory. These requirements can be activated depending on the object research needs. The construction of sensor casing is durable, which enables its use in difficult conditions (increased working temperature, the presence of dust and moist).

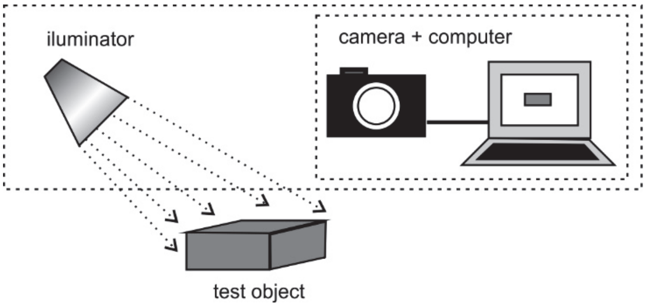


Fig.2. System with vision sensor

The research used a LED white light optical sensor with a scanning speed of 50 fps (frames per second) and a working distance of 400 - 500 mm. The camera was working in a black and white mode.

a)

b)

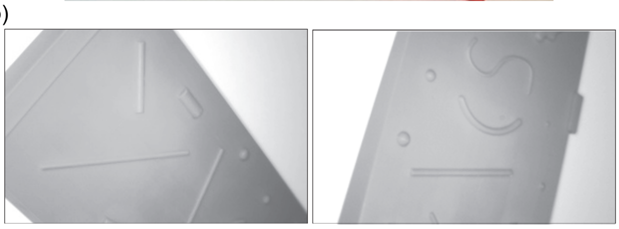


Fig.3. Testing with the use of an optical sensor (a) test stand (b) selected test results

A disadvantage of this device was the need to manually adjust the focus. Its advantages include:

- the ability to adjust the accuracy of determining properties, such as the surface of the object (number of pixels), external and internal dimensions of irregularly shaped samples, the number of holes, the content of holes,
- the ability to set the grayscale value and use it for further image analysis
- the ability to export and import an unlimited number of reference objects.

The tested cameras with floodlight and the obtained images were used in further research for photogrammetric method testing.

Laser sensors

Systems based on laser sensors the distance between points hit by the light emitted by the laser and the device using the reflected wave, recorded by the optical sensor. Laser systems collect 3D information from scanned objects by trigonometric triangulation, in which the transmitter (light emitter), the laser light projection point and the receiver (optical sensor) form a triangle. The concept of laser sensor operation is presented in Fig. 4.

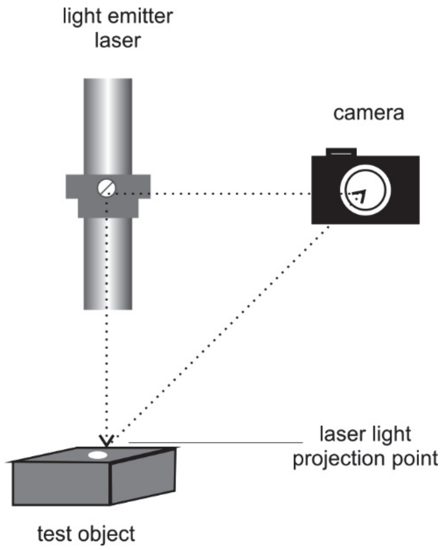


Fig.4. System with a laser sensor

In order to obtain complete imaging, at least three scans of the object are required. This process allows to precisely position points on a three-axis frame of reference.

An interesting type of laser sensor is a so-called profilometer - is a laser sensor using the phenomenon of electromagnetic wave interference. The profilometer emits a light beam divided into a measuring beam and a reference beam. The reference beam is emitted in a known and defined direction. The measuring beam, when directed at an element of a tested object, is reflected and interferes with the reference beam. The detector collects data concerning the height across the entire width of the laser beam, records the interference fringes from which obtains information about the height of the sample surface at a given point. The next measurement points provide information about changes in this altitude. Owing to this, the profilometer is perfect for measuring surface geometry, its waviness and layer thickness. Apart from the data concerning attitude, the tested profile sensor also records intensity data, which increases the accuracy and reliability of measurements. The mentioned properties make it possible not only for the laser sensors to be used not only for measuring the distance from the element under scrutiny, but also to detect the geometric profile of the analyzed detail, which enables the detection of various shapes of objects, gaps and scratches as well as contour control. The principle of profilometer-supported measurement is as follows: first, the sensor emits a linear laser beam and illuminates the surface of the tested object.

The cylindrical lens emits a parallel beam of light and reduces the scattering of light reflected on the surface of the object, which allows to obtain a precise reflection of light from any shape or surface and to register the reflected light. Then, the reflected light is registered by the CMOS matrix sensor, creating a surface profile. The measurement results are collected with high resolution (up to 3200 points/profile), which gives very good results in image recording in case of changing reflectance. In the next step, a profile of a model is created, aimed to be used in the subsequent defect identification process. The profilometer head works with a profiling controller compatible with various programming languages. In order to conduct the tests, a profilometer with a blue semiconductor laser (wavelength λ = 405 nm and power P = 10mW) as the light source was used. The results of the profilometer tests are shown in Fig. 4.

a)

b)

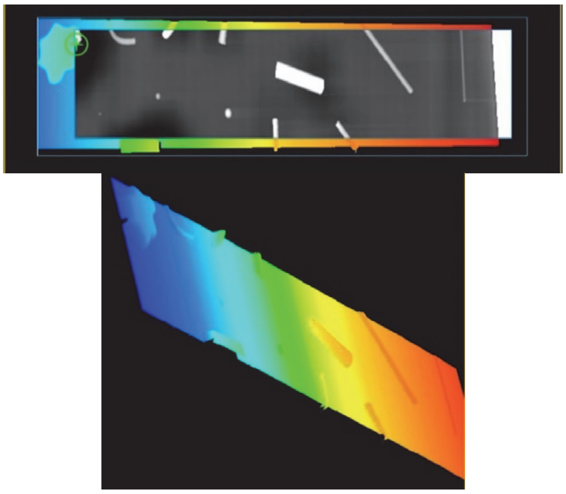


Fig.5. Tests with a laser sensor – profilometer (a) test stand (b) selected test results

Tests of such a type of device have shown the possibility to accurately map the shape and measure the smallest details (defects) of the tested object. The drawback of this technology is the influence of the properties of the tested surface on the scanning quality – it is a challenge to provide an image of bright and transparent surfaces.

Structured light systems

Structured light systems use the measurement method consisting in the distribution of lines and geometric patterns on the tested object, analysis of deformation of the displayed patterns and 3D structure generation of the tested object. The operation principle is also based on trigonometric triangulation [2], [3], however, the process itself is slightly different. The source of light (e.g. an LCD projector) projects a light pattern on the tested object, and a vision sensor (or more frequently - several cameras shifted in relation to the projector), examines the shape of the light pattern and calculates the distance from all points of the field of vision. Noise in the light bands caused by height differences recognize the third dimension by triangulation.

In many solutions, the illuminator emits structured light from several light sources, which allows to reduce distortions and increase measurement accuracy. Furthermore, high-accuracy optical sensors enable to recognize colors. A system involving structured light is shown in Fig. 6.

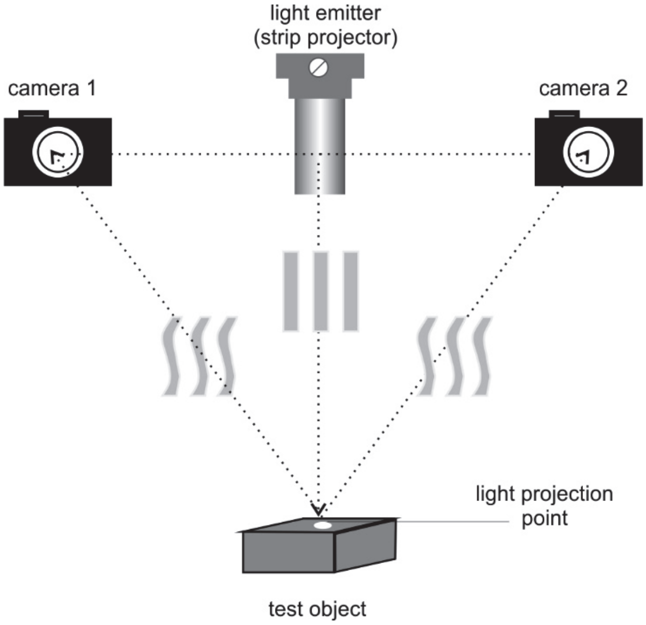
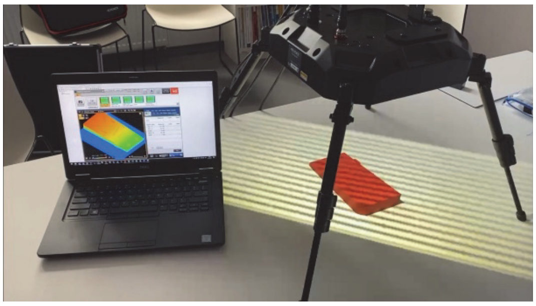


Fig.6. Structured light system

Structured light can be white, blue or green, whereas a pattern is usually stripes or a matrix of dots. The test sample underwent tests using several devices differing in the type of light source emitted by the projector.

a)



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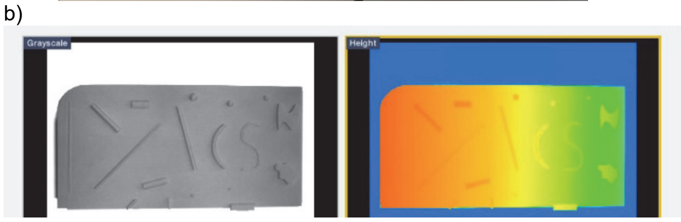


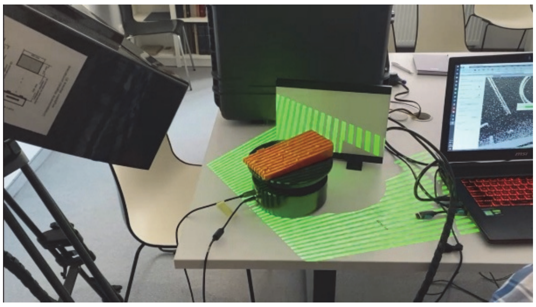
Fig.7. Testing with white structured light (a) test stand (b) selected test results

Figure 7 shows the results of system testing with structural white light emitted by several sources. The tests carried out with this method were not satisfactory. Complicated calibration of the head with floodlights and a camera together with low range of the measurement depth were considered their biggest drawback. Figure 8 shows measurements of a test sample with a green structured light. The measurement was made using two monochrome detectors with narrowband green LED light with a

wavelength of λ=520 nm and filters eliminating the impact of lighting changes on the imaging results.
The obtained scans are better than the methods using white light, whereas the disadvantage of this solution was the long scanning time and the necessity to dull the object.

Another tested device was the blue structured light system (fig. 9). A scanner dedicated to automatic robotic systems was used.

a)



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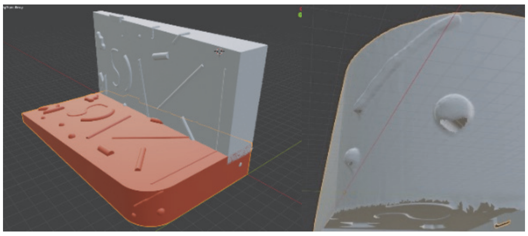

Fig.8. Testing with green structured light (a) test stand (b) selected test results

a)

b)

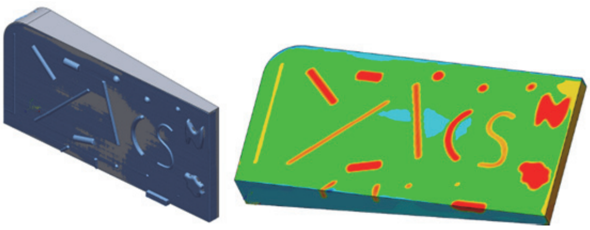

Fig.9. Testing with blue structured light (a) test stand (b) selected test results

As for all cases of using structured light, it can be stated that the advantages of this technique are speed and high accuracy, while shiny and black surfaces pose a problem due to the difficult analysis of the incident light.

Taking into account the obtained results, it can be inferred that the systems with blue structured light did best in case of the imaging of defects applied to the tested element. The obtained parameters and access to data should guarantee the possibility of obtaining a 3D model of an object with an accuracy of 0.1 mm in about 2 minutes.

Conclusions

Based on tests and the analysis of available technologies, various methods of 3D object scanning were tested. The best results are obtained when cameras with structured light are used, since they allow to achieve the assumed accuracy of mapping objects with an accuracy of 0.1 mm. For other technologies, mapping does not provide such possibilities or requires the use of much more complex calculations, the time of which significantly exceeds the assumed several minutes for computer data processing.
The analyzed technologies involved vision sensors, laser sensors and structured light cameras. Handheld 3D scanners proved to be the least effective solution to the assumed problem. In this case, there is no direct access to the database, the provided software does not allow for the process automation, and the processing of measurement data required a lengthy calculations time.

Laser profilometer is a satisfactory solution, nevertheless it is limited to one registration plane and about 7 cm of the measurement range, which creates additional problems in terms of generating the trajectory of the head movement.

Cameras with structured light are considered the best solution, since the built-in drivers allow to obtain a model of a point cloud or net with a satisfactory accuracy in a short time. However, the drawback is the risk of errors in registering light reflections from smooth and shiny surfaces, which may occur on scanned objects, as ultimately they are to be made of metal.

Acknowledgements
Research financed in the frame of the project „Prace badawczo-rozwojowe zmierzające do opracowania linii do automatycznej identyfikacji wad na elementach obrabianych z opracowaniem technologii ich usuwania strumieniową obróbką ścierną na stanowiskach zrobotyzowanych w warunkach przemysłowych", No.: POIR.04.01.04-00-0083/20

***Autorzy**: dr inż. Tomasz Kraszewski, dr inż. Piotr Świszcz, mgr MBA Łukasz Bis, Centrum Badawczo – Rozwojowe GLOKOR Sp. z o.o., ul. Górnych Wałów 27A, 44-100 Gliwice t.kraszewski@glokor.eu, p.swiszcz@glokor.eu, dr inż. Anna Piwowar, dr hab. Renata Frączek Politechnika Śląska Wydział Elektryczny, ul. Akademicka 10, 44-100 Gliwice e-mails:anna.piwowar@polsl.pl, renata.fraczek@polsl.pl*

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