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Information and measuring system for geometric and motion parameters determination of industrial products by their video images

The article presents the information and measuring system for geometric and motion parameters determination of industrial products, for example, at a stone processing or machine-building enterprise. The proposed system allows automating measuring geometric parameters and quality control processes. The additional determination of product motion parameters allows compensation of dynamic errors in the video measurement data using software and algorithms. A distinctive feature of the proposed system for measuring geometric and motion parameters of objects is the use of non-contact measurements. Modern hardware and software such as a digital video camera and a computing module (personal computer); Python programming language with the OpenCV image processing library are used to build the system ensuring the measurement of geometric and motion parameters of products. The developed system is calibrated by the video images of objects with the given geometric dimensions before starting the operation. The information and measurement system operates in two measurement modes: manual and automatic. Measurements performed in the manual mode are more accurate than in the automatic mode. In addition, in the automatic mode, the software is supplied with video image normalisation and segmentation thresholding functions for more accurate measurements. A series of measurements have been made in manual and automatic modes. The nominal dimensions of the industrial product are 60.00 mm long and 75.00 mm wide, which is manufactured with a high accuracy class of these dimensions. The confidence intervals of the measurement results are as follows: for the manual mode: length is 59.68 ±0.46 mm, width is 74.78 ±0.54 mm; for the automatic mode: the length is 60.60 ±0.15 mm, the width is 74.95 ±0.13 mm. The proposed system provides an error of (0.13–0.54) mm when measuring the geometric parameters of industrial products, which may be sufficient for routine inspection, but insufficient for use in precision measurements. The main way to improve the accuracy to the requirements of precision measurements is to use a more advanced digital camera, software and algorithmic procedures for approximating and smoothing the contours of objects and motion parameters. Meanwhile, the main advantage of the developed system is the automation of the processes of measuring and controlling the industrial products geometric and motion parameters.

Keywords**:** *machine vision; information and measuring system; video image; geometric parameters; motion parameters; digital camera.*

Topicality. Automation of processes in production is the main guarantee for the continuous development of production, including the automation of measurements in the process of industrial products quality control. Measuring the geometric parameters of products, parts of products, components, etc. is a routine operation at every enterprise in our country and worldwide. For example, it can measure geometric and motion parameters of industrial products at stone processing and machine-building enterprises.

To obtain the geometric parameters of objects, a lot of measurement methods can be used, both manual with direct human intervention and fully automated.

To develop information and measurement systems nowadays, it is necessary to ensure simplicity of design, transfer of most operations from humans to the hardware and software complex of the information and measurement system, not forgetting the availability and cost of such a system components in an unstable economic situation.

To improve the accuracy of measurements, it is necessary to focus on software and algorithmic measurement methods using machine vision technologies, providing the automated system with the necessary amount of information. Another effective method to improve the accuracy of geometric parameters determinination is to measure the motion parameters of industrial products and use software and algorithmic compensation for dynamic errors in video images.

Analysis of recent research and publications which the authors rely on. Methods of video image processing are discussed in [1–3]. The principles of computer vision systems are revealed in [1–4]. The device for measuring geometric parameters is proposed in the utility model patents «Method for determining the geometric parameters of moving measurement objects» [5, 6]. These patents indicate the fundamental possibility of determining the motion parameters and compensating for dynamic errors in measurement information. The article consider improving the accuracy of geometric quantities measurement, theoretical estimation of the accuracy of these measurements, and algorithmic compensation of dynamic errors in video images with data on the geometric parameters of objects [7–9].

The principles of working with the Python programming language and the OpenCV machine vision library are discovered in [10–13]. For comparative analysis, the devices manufactured by Keyence have been also considered using the official documentation available on their resources [14].

The purpose of the article is to develop an information and measurement system for geometric and motion parameters determination of industrial products at stone processing and machine-building enterprises from their video images, as well as to evaluate the metrological characteristics of this system.

Presentation of the main material. The following algorithm is always the basis of video measurement methods:

1. Acquisition of a video image;
2. Conversion of a video image into digital form;
3. Conversion of a video image into grey scale;
4. Removing noise;
5. Determining the boundaries of the object;
6. Determining the coordinates of key points of the object;
7. Calibration of the system relative to the known dimensions of another object;
8. Calculation of geometric and motion parameters in pixels of the video image and their conversion to mm and mm/s^2;
9. Software and algorithmic compensation of errors, including dynamic ones;
10. Output of geometric parameters of the measurement object to the user of the information and measuring system.

Digital images generated by a machine vision system record the ratio of the size of target objects in pixels. To obtain the object's true size in units convenient for further processing, it is necessary to establish a connection between the position of the pixels in the image and the position of each point in the real world. The block diagram of technical means of information and measurement systems for measuring geometric and motion parameters is shown in figure 1 [5, 6].

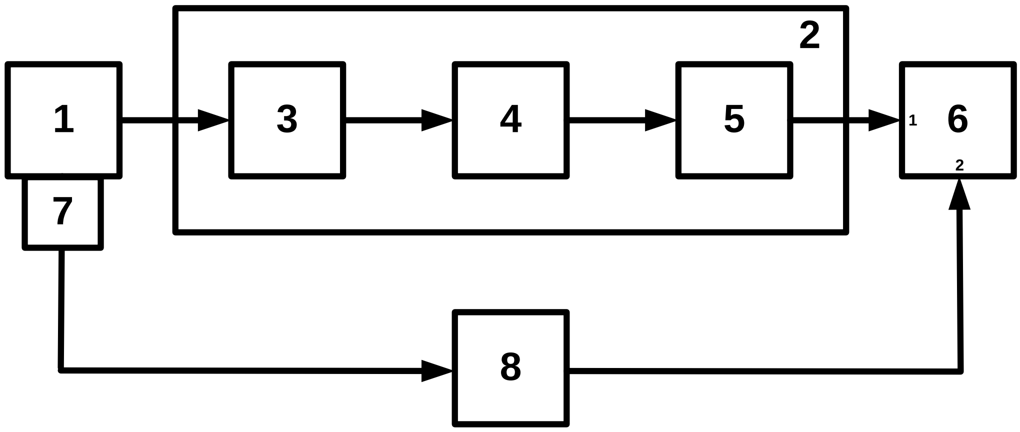


Fig. 1. Block diagram of the information and measuring technical means to measure geometric and movement of objects parameters

The components of the device are as follows:

1 – object of measurement;
2 – video image formation device;
3 – optical system;
4 – light-to-signal converter;
5 – analogue-to-digital converter.
6 – electronic computer system;
7 – accelerometer;
8 – integrator.

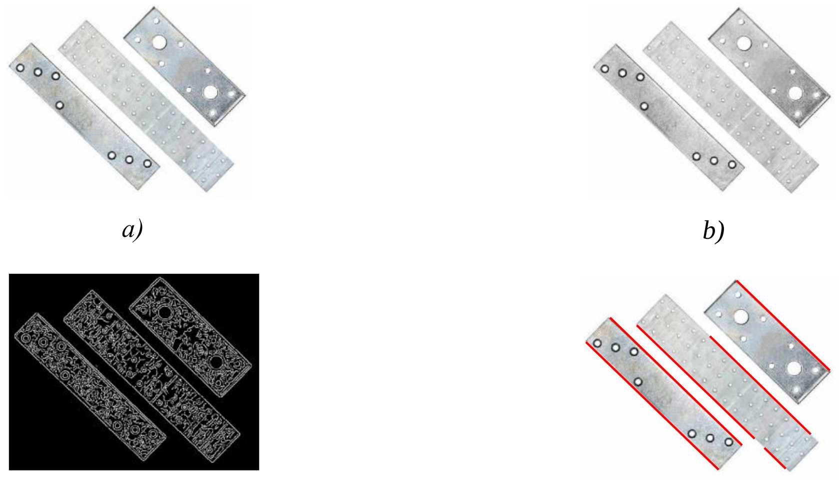
Precision measurements of geometric parameters of industrial products are performed in the following way: an accelerometer is initially fixed on the object of measurement and connected to a digital computer through an integrator. Afterwards, simultaneously with the formation of a video image of the object of measurement, conversion of this video image into digital form and its input into a digital electronic computer system**,** selection of the measurement object and its contours (edges) on its video image determine geometric parameters and define the movement parameters of the measurement object using an accelerometer and integrator. These parameters are entered into the electronic computer system, after which the error arising from the movement of the measurement object relative to the video image formation device is compensated in the video image of the measurement object for the areas containing the contour of the measurement object, taking into account the results of determining the parameters of the measurement object movement [5, 6].

The received image is first processed during the measurement, and the number of pixels in the image coordinate system is counted and expressed as P. It is compared with the actual length of the reference standard L_{et} (K_m – scaling factor) and its number of pixels P_{et} to obtain the actual size S of the object in mm. It is expressed by the following formula (1):

$$S = P \times K_m = P \times \frac{L_{et}}{P_{et}}, \tag{1}$$

To determine the geometric parameters by a video image using the algorithm mentioned above, it is neccessary to perform the following steps on this image (fig. 2):

– prepare the image for further processing by converting it into a grayscale image;
– to determine the edges of the object, it is convenient to use the Kenny operator to determine the edges of the object [3];
– to use the Hough algorithm to detect straight lines [3];
– to compensate for dynamic errors or other procedures for approximating the edges of industrial products;
– to determine the geometric and motion parameters of products.



a) *b)*

c) *d)*

Fig. 2. An example of detecting contours and lines in a video image of industrial products: a) original video image; b) grayscale image; c) image after applying the Kenny operator; d) image after applying the Hough algorithm

The Kenny operator and the Hough algorithm have beemockn used because they are already implemented in most machine vision libraries such as OpenCV and Mathworks Image Processing Toolbox. On the hardware side, a Logitech C270 general-purpose camera has been applied to create the mock-up (fig. 3). It provides a video stream of up to 30 frames per second with 720 lines of progressive scan (30fps x 720p). This decision is justified solely by price and availability, as industrial-grade cameras are quite expensive, and using them in an instrumentation and measurement layout is problematic.

Fig. 3. Logitech C270 camcorder

General specifications:
- maximum resolution: 720p/30fps;
- number of megapixels: 0.9;
- focus type: fixed focus;
- type: plastic lens;
- diagonal field of view: 55 degrees;
- overall dimensions: 73x32x67 mm.

The research uses a conventional personal computer as a computing module.

The main working program of the information and measurement system under development has been written using the Python programming language and the OpenCV library for machine vision and image processing. Python has been selected as a tool that allows you to quickly create a readable working programme, easily edited and run on any device with a built-in interpreter or installed on this device. OpenCV has been chosen because it is the most common library used for machine vision, and it already implements all the algorithms required for the further operation of the information and measurement system. Another huge advantage is the openness of this library and the ability to edit its program code. An example of a working window of a functioning programme for an information and measuring system is exposed in figure 4.

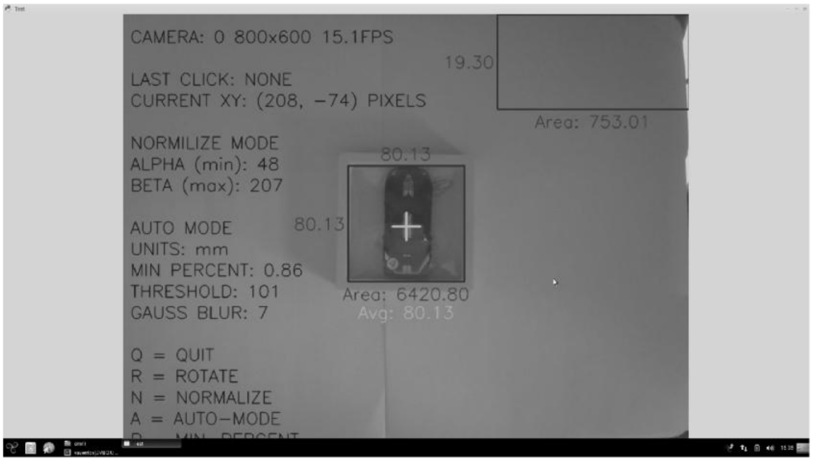
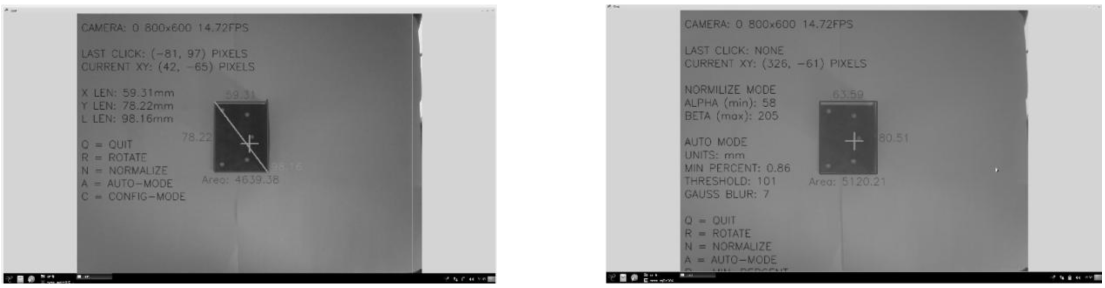


Fig. 4. Demonstration of the program functioning

The created program provides measurements in both manual and automatic mode. Measurements performed using the manual mode are more accurate than in the automatic mode. An example of the program window in manual and automatic mode is shown in figure 5.



(a) *(б)*

Fig. 5. Example of the program operation in manual (a) and automatic (b) mode

The program first and foremost checks for the presence of a camera at the input, by default, the address of the external device (video camera) is 0. If the program does not find the camera at address 0, it automatically searches the other 254 addresses at which it can be located. After initialising the camera, the software starts in manual mode. Using a computer mouse, the measurement object is selected, in our case it is an industrial product, and the dimensions are set according to the calibration and scale factor of the device.

When the calibration mode is selected, stripes appear along the diagonals of the screen, along which a ruler should be placed on the working field and put control points every 5 millimetres. After that, the device setup process is complete.

In automatic mode, the OpenCV machine vision library searches for the measurement object and marks it with a rectangle. With each selection, the function of drawing lines and dimensions on the screen and auxiliary information is activated. The information displayed on the screen is the final result of the measurement. To close the programme, press the corresponding key. In addition, image normalisation and thresholding buttons have been added in automatic mode for more accurate detection.

The developed programme functions in the following way: the input is the original video stream which is converted into a grayscale image. The Kenny edge / contour detection algorithm is used to detect the edges of the industrial products that hit the lens, and immediately after that, the Hough algorithm is used to convert the points found by the previous algorithm into lines. The length of the line is measured in pixels and converted to the usual units of measurement, i.e. in mm, by the standard against which the information and measurement system has been calibrated.

A series of measurements have been carried out using this program, which are presented in Table 1.

Table 1

Results of measurements of geometric parameters in the current model of the information and measuring system

№ measurement	Manual mode		Automatic mode	
	length, mm	width, mm	length, mm	width, mm
1	59,81	73,94	60,10	74,95
2	59,21	74,50	60,05	74,92
3	60,21	75,01	59,98	75,01
4	59,70	74,65	60,01	75,01
5	60,10	74,98	60,05	74,91
6	59,23	75,02	60,10	74,98
7	60,05	73,85	60,08	74,96
8	60,10	75,10	60,12	74,96
9	59,10	75,85	60,02	74,95
10	59,35	74,95	60,05	74,93

The nominal dimensions of the product are the following: the length is 60.00 mm, the width is 75.00 mm. Industrial products are manufactured with a high accuracy class for these dimensions. The errors are calculated using Student's coefficients for the number of degrees of freedom k = 9. The results of the calculations are presented in table 2.

Table 2

Measurement errors of geometric parameters in the current model of the information and measurement system

№ measurement	Error	Manual mode		Automatic mode	
		length	width	length	width
1	Average value, mm	59,68	74,78	60,60	74,95
2	Dispersion, mm^2	0,4290	0,5861	0,0445	0,0343
3	RMS error value of a single measurement of geometric parameters, mm	0,6550	0,7656	0,2110	0,1851
4	Relative rms error, %	0,0109	0,0102	0,0035	0,0025
5	RMS error value of the result of averaging a series of measurements, mm	0,2071	0,2421	0,0667	0,0585
6	Confidence limits of measurement error of geometric parameters, mm (Pdov = 0.95)	0,46	0,54	0,15	0,13

The confidence intervals of the random error are given as follows: for the manual mode, the length is 59.68 ±0.46 mm, the width is 74.78 ±0.54 mm; for the automatic mode, the length is 60.60 ±0.15 mm, the width is 74.95 ±0.13 mm. It can be disputed that the divergence of the information and measuring system provides an accuracy of about (0.13–0.54) mm, which may be sufficient for routine inspection of industrial products.

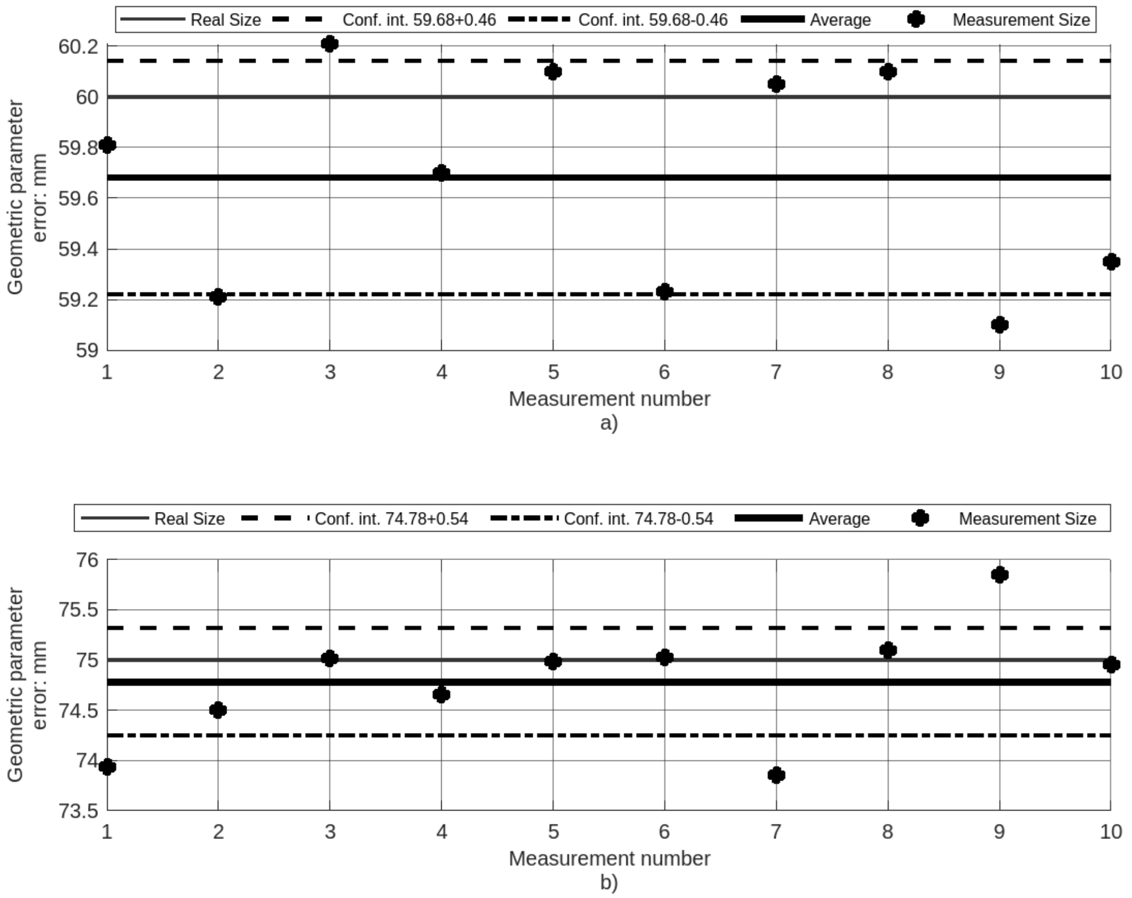


Fig. 6. Scatter plot of random errors in the manual mode: a) width; b) length

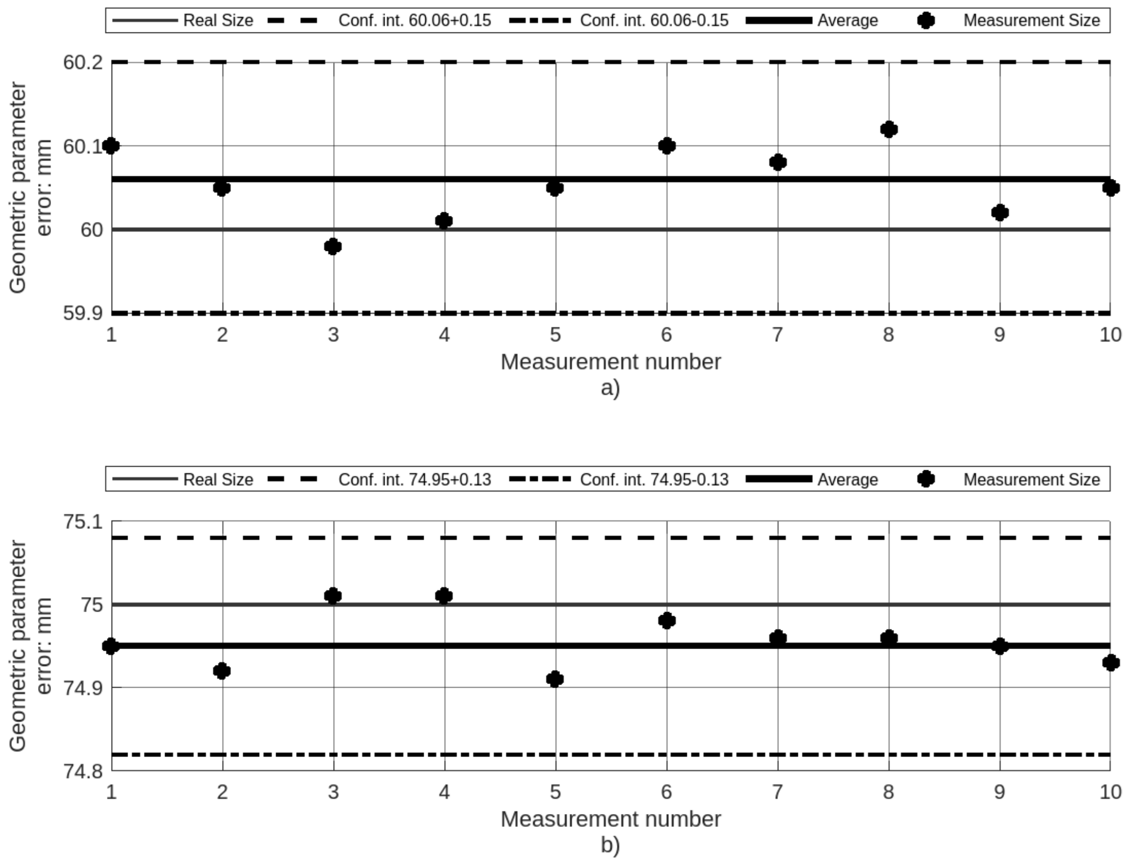


Fig. 7. Scatter diagram of random errors of the automatic mode: a) width; b) length

Conclusions and prospects for further research: An information-measuring system for geometric and motion parameters determinination of industrial products at stone processing and machine-building enterprises by their video images has been developed. For experimental studies, a working model of the information-measuring system has been created, which uses a webcam as sensors of the measuring channel, and the corresponding software has been generated. The geometric and motion parameters have been determined and dynamic errors have been compensated. The measurement results and their software and algorithmic processing results have been obtained using software based on the OpenCV and Python libraries. The data has been processed in Microsoft Excel and the errors have been calculated.

The geometric parameters of industrial product errors indicate that the information and measurement system works correctly. To reduce the magnitude of the error and to use the developed information and measurement system in industry, it is necessary to use higher-level cameras with telecentric lenses to eliminate the error caused by optical distortions, as well as to provide an appropriate level of illumination to remove shadows from the video image. Determining motion parameters and compensating for dynamic errors in the video measurement information is also recommended.

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Подчашинський Ю.О., Лугових О.О., Полянська А.С., Невмержицький В.С.

Інформаційно-вимірювальна система для визначення геометричних параметрів та параметрів руху промислових виробів за їх відеозображеннями

У статті представлено інформаційно-вимірювальну систему для визначення геометричних параметрів та параметрів руху промислових виробів, наприклад, на каменеобробному або машинобудівному підприємстві. Запропонована система дозволяє автоматизувати процеси вимірювання геометричних параметрів та процеси контролю якості. Додаткове визначення параметрів руху виробів дозволяє програмно-алгоритмічним шляхом компенсувати динамічні похибки вимірювальної відеоінформації. Відмінною рисою запропонованої системи вимірювання геометричних параметрів та параметрів руху об’єктів є використання безконтактних вимірювань. Для побудови системи вимірювання геометричних параметрів та параметрів руху виробів застосовуються сучасні технічні та програмні засоби: цифрова відеокамера та обчислювальний модуль (персональний комп’ютер); мова програмування Python з бібліотекою для обробки зображень OpenCV. Розроблена система перед початком роботи калібрується за відеозображеннями об’єктів з відомими геометричними розмірами. Інформаційно-вимірювальна система працює в двох режимах вимірювання: ручному та автоматичному. Вимірювання, виконані за допомогою ручного режиму, виходять більш точними, порівнянно з автоматичним режимом. Також при автоматичному режимі в програмному забезпеченні додано функції нормалізації відеозображення та виставлення порогу сегментації для більш точного детектування об’єктів. Було проведено серію вимірювань у ручному та автоматичному режимах. Номінальні значення розмірів промислового виробу: довжина 60,00 мм, ширина 75,00 мм, який виготовлено з високим класом точності цих розмірів. Довірчі інтервали результатів вимірювань дорівнюють: для ручного режиму – довжина 59,68 ±0,46 мм, ширина 74,78 ±0,54 мм; для автоматичного режиму довжина 60,60 ±0.15 мм, ширина 74,95 ±0.13 мм. Запропонована система при вимірюванні геометричних параметрів промислових виробів забезпечує похибку близько (0,13–0,54) мм, що може бути достатньо для поточного контролю, але не достатньо для використання в прецизійних вимірюваннях. Основним шляхом підвищення точності до вимог прецизійних вимірювань є застосування більш досконалої цифрової камери та програмно-алгоритмічних процедур апроксимації та згладжування контурів об’єктів та параметрів руху. При цьому основною перевагою розробленої системи є автоматизація процесів вимірювання та контролю геометричних параметрів та параметрів руху промислових виробів.

Ключові слова: машинний зір; інформаційно-вимірювальна система; відеозображення; геометричні параметри; параметри руху; цифрова камера.

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