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CLASSIFICATION AND DETECTION OF DEFECTS IN TUBULAR PRODUCTS USING MACHINE VISION

Inspection is a critical component of a production management system, involving the measurement and inspection of products to ensure that they meet required specifications and performance. Quality control standards are usually dictated by quality assurance approaches such as ISO 9001. These approaches define protocols for the manufacturing process, and quality control ensures that the required tasks are performed. In a manufacturing environment, businesses can perform various types of quality control, including material inspection, in-process inspection, and final inspection. By performing these checks, you can ensure that quality control is on the right track, resulting in lower costs and increased efficiency. Implementing quality control best practices can improve quality control. The key ingredients for success in building a quality control system are automation, inspection, and tracking.

Non-automated visual inspection, which is still used in many enterprises, has a number of disadvantages, namely subjectivity and low reliability, as well as low performance on complex products with fine topology. According to the operators, inspection of complex products using simple optical devices is very stressful on their eyes, which is probably a danger to their health.

The growing interest in computer vision technology is due to the non-contact method of control, high accuracy and productivity, at a relatively low cost

The paper considers the problem of controlling the output characteristics of finished products, which is proposed to be solved using computer vision methods, and proposes a mathematical description of one type of defect using the Hough transform, which is successfully used to describe and detect objects of round shape.

Also, the paper analyses the most typical defects for the object of control of a tubular body and proposes a classification of these defects by grades for further use in training a neural network.

Key words: *product defect, quality management, automated production, quality control, machine vision, neural networks.*

Formulation of the problem. One of the most important aspects of product quality management in the instrumentation industry is testing and all types of control. Specialised research laboratories and technical facilities allow us to test and inspect products for compliance with specifications and standards. This includes testing at least for reliability, accuracy, and other characteristics. Automation of quality management processes is also becoming more and more practical in the instrumentation industry. The use of special software for monitoring and analysing data helps to reduce the human factor, increase productivity and improve the accuracy of quality control. Modern technologies, such as machine learning and the Internet of Things (IoT), also have applications in quality management in instrumentation. For example, IoT devices can collect data on the operation of devices in real time, and machine learning algorithms can predict potential failures and perform preventive maintenance [1].

The use of computer vision techniques is rapidly expanding to cover all spectrums of production technology. The task to be solved includes the initial quality control of tubular products, which are naturally occurring objects and include a variety of criteria for control, which greatly complicates the task of initial quality control. Defects such as stains and microcracks are not critical to the functionality of the object of study, but directly affect the appearance of the product and the quality control process. The main classification is based on the shape, size, type of defect and its location.

To assess the external condition of product elements, either visual inspection of the structure or analysis of images taken with digital cameras is usually used. Non-automated visual inspection, which is still used at many enterprises, has a number of disadvantages that prevent its use in modern conditions [2]. The main negative aspects in this case are subjectivity and low reliability, as well as low performance on complex products with a thin topology. According to the operators, inspection of complex products using simple optical devices refines their vision too much, which is probably dangerous for their health [3].

Analysis of recent research and publications. Today, significant experience has already been gained in the use of machine vision to solve various problems in production processes, the results of which are presented in the works of domestic and foreign researchers. For example, Nandini et al. in [4] extensively discuss the application of machine vision technologies in various industries, such as the food industry, textile industry, and printed circuit board industry. The team of researchers proposes to improve the methods of output quality control by analysing images of finished products. Their research demonstrates an improvement in results compared to manual inspection of products.

Paper [5] presents a comprehensive view and the important role of computer vision as a key advanced technology in the materialisation of various global visions of a new generation of ICT solutions in manufacturing and industry in general. The authors position visual computing as a key role for Industrie 4.0 and provide a general and broad overview with specific directions and scenarios for future research. The visual computing research community will have exciting new areas of research to address the challenges of the next industrial revolution.

The authors' research [6] demonstrates the positive impact of the introduction of continuous quality control, technologies and approaches used in Industry 4.0. They argue that it is important to conduct further applied research, not to stop at the results obtained, in order to obtain statistical data that can be processed in real time.

In article [7], the authors demonstrated the tendency of transition from manual visual inspection to computer vision. The advantage of machine vision as a non-destructive method is given. It was used for external determination and showed an increase in product quality and its efficiency, objectivity, consistency and reliability. Machine vision systems used to measure size, shape and colour are described, including improvements in cameras, lighting settings, image processing and analysis methods, and experimental results. In addition, the advantages and disadvantages of machine vision systems are outlined with recommendations for future developments.

For visual product inspection tasks, the use of deep learning solutions is increasingly being adopted. However, new data and product-specific considerations are still required to solve each specific problem. Study [8] proposes a method inspired by class activation maps (CAM) to improve deep neural network-based image classification algorithms. image classification algorithms by creating an attention map that marks the defective area.

As can be seen from the above examples of research by scientists, computer vision technology is an important feature of modern production in ensuring product quality, as such systems can check for defects faster and more accurately than humans.

Purpose and task statement. The aim of the study is to analyse and classify defects in tubular products and, on its basis, to develop a set of product quality criteria for further processing by a machine vision system that will allow detecting product defects with a given probability and sorting them according to the proposed classes.

Presentation of the main research material. Computer vision methods for outbound quality control are widely used due to their efficiency and objective results compared to human inspection. But, on the other hand, in some cases, a major drawback is that the development of such systems is time-consuming. Hence the desire to find new, fast and reliable solutions [9].

For quality control of tubular products, the advantage is that the body can be viewed on the basis of a cylinder and divided into independent zones, allowing for parallel output inspection. One of these zones is the end part. The main task is to correctly identify and classify defects.

Thus, when classifying defects by shape, three main cases are distinguished (Fig. 1): a) defects of regular shape, oval, close to cylindrical or spherical, without sharp edges; b) defects of lentil shape, with sharp edges; c) defects of arbitrary, indefinite shape, with sharp edges – cracks, tears, foreign inclusions Fig. 1.

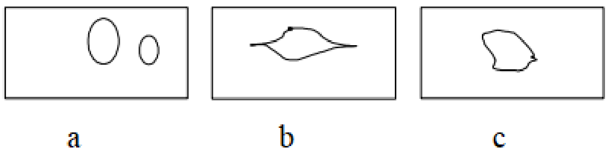


Fig. 1. Classification of defects by shape: a – regular shape; b – lentil-like shape with sharp edges; c – arbitrary, indefinite shape with sharp edges

When classifying defects by location, four cases are distinguished Fig. 2: a – surface defects located on the surface of a material, semi-finished product or article – cracks, dents, foreign inclusions; b – sub-surface defects – defects located under the surface of the controlled article, but near the surface itself; c – volumetric defects – defects located inside the article. For example, the presence of phosphide and nitride inclusions and layers can lead to the formation of defects of the fourth type – through defects.

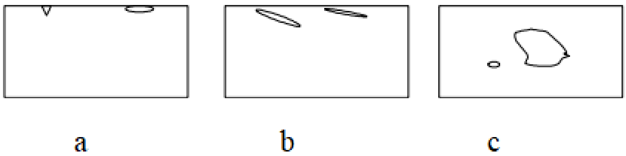


Fig. 2. Classification of defects by position in the controlled object: a – surface; b – sub-surface; c – volumetric

According to the shape of the cross-section, through defects are round (pores, slag inclusions) and slit-shaped (cracks, structural defects, discontinuities in the location of oxide and other inclusions and layers). According to the size of the effective diameter or width of the opening (for cracks and crevices), through defects are divided into ordinary (> 0.5 mm), microcapillary (0.5 … 4 2 10 mm) and microcapillary (< 4 2 10- × mm) defects [10].

As an object of control, let's consider a beverage tube, which is a complex-shaped product for initial inspection by computer vision. It has several surfaces, which can be considered as a side surface, which takes the form of a rectangle when expanded, and an end face, which takes the form of an isosceles trapezoid when expanded Fig. 3.

Fig. 3. Object of control reed tube

In this paper, we will consider the end part of a reed tube, which is geometrically characterised by the inner and outer diameters; among the permissible defects, we can distinguish an end crack and a neoplasm in the middle of the product Fig. 4.

As a first step, according to the Hough transform technique, which is the most suitable and widely used method among the methods for detecting round

Fig. 4. End part of the reed tube

shapes, we determine the centre of the tube to determine the inner and outer diameters, which will also give an understanding of the still unknown coordinates of the product centre (x0, y0), as well as the outer and inner diameters as r1 and r2, respectively.

Using the circular Hough transform method again, but reducing the search area, we check the product for neoplasms, since they are mostly not dense and have a gap, so we can distinguish among them a circle using the Hough transform Fig. 5.

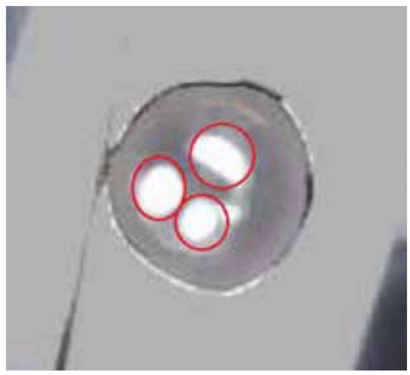


Fig. 5. End part of a reed tube with a defect

The detection of neoplasms is performed in the plane bounded by the radius $_{r2}$ found at the previous stage. After the Hough inspection operations, the reed tube is checked in several successive stages, and if at least one of them shows deviations from the specified parameters, this control object, i.e. the product, will be sorted or rejected.

The first step is to pre-process the image and isolate all external factors. The second step is to transform the circle area into a plane, for which we denote the outer and inner diameters as r1 and r2, respectively.

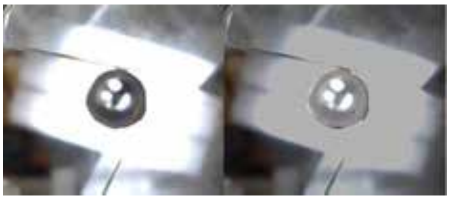
The next step is to expand the circle area to create a rectangular area to simplify information processing. The perimeter of the circle with radius r will be 2πr, since we have r1>r2, so 2πr1>2πr2. The area of our circle with diameters r1 and r2 in the expanded view will take the form of an isosceles trapezoid with aspect ratios of r1/r2. Working with the shape in this way, important pixels are lost, which affects the final result, so the best option is to solve the matrix as 2πr1 and add the missing pixels by duplicating the neighbouring ones. Note that the number of missing pixels is proportional to the ratio r1/r2.

Using the initial data, we unfold the circle to obtain a rectangular matrix with a height of r1-r2+1 and a length of 2πr1. The unwrapping process can be represented as a transformation from the polar coordinate system to the Cartesian coordinate system. Let's introduce new values (xc, yc) as the coordinates of the centre of the circle in Fig. 6. Each pixel in the

Fig. 6. End part of the reed tube with parameters

Table 1

Classification of the most typical defects of the object of control and their correspondence to the class

Type of defect	Type of defect	Type of defect	Type of defect
Pigmentation		Explicit, corrective; Insignificant; Superficial defect;	Chemical treatment 1 Grade, 2 Grade
Colour		Explicit, corrective; Insignificant; Superficial defect;	Chemical treatment 1 Grade, 2 Grade
Cutting defects (chipped ends)		Explicit, incorrigible; Critical; Superficial defect;	Waste
The presence of a film inside		Explicit, incorrigible; Minor defect; large-scale defect;	Mechanical modification
Cracks		Manifest, irreparable; Significant; Superficial defect;	Waste
Compliance with sealing parameters (product length L, outer diameter D, inner diameter d)		Explicit, corrective; Significant; Superficial defect;	1 Sort S 1 Sort M 1 Sort L 1 Sort XL 2 Sort S 2 Sort M 2 Sort L 2 Sort XL

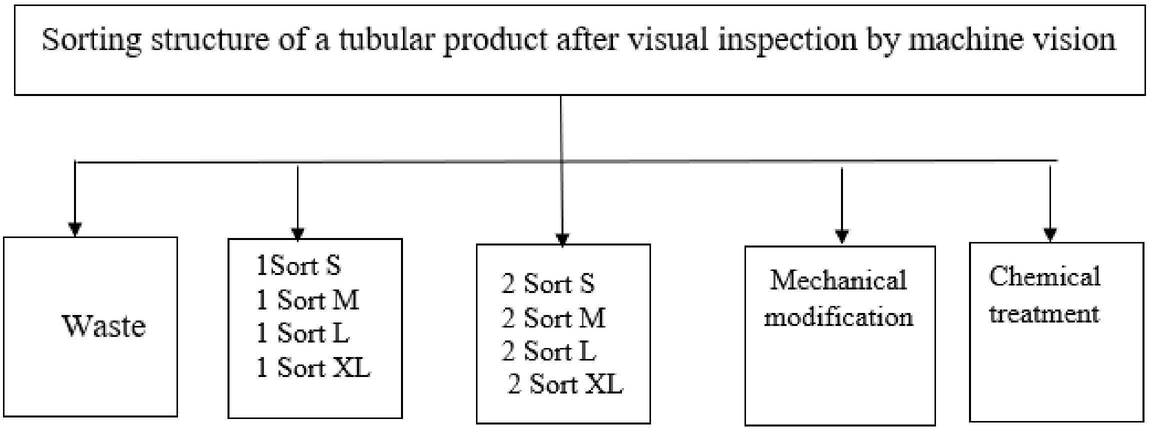


Fig. 7. Product sorting structure according to defect classes

polar coordinate system is represented by a radius r and an angle θ [11].

The transition system can be represented as follows:

$$\begin{cases} x = x_c + r * \cos(\theta) \\ y = y_c + r * \sin(\theta) \end{cases}$$

where (x, y) are the Cartesian coordinates of the corresponding polar coordinates (r, θ).

Having analysed the object of control in accordance with the considered possible defects (Figs. 1, 2), we have developed a classification of the most typical product defects and introduced the concept of defect class Table 1.

Thus, according to the proposed classification of the most characteristic defects of the object of inspection and their compliance with the class, the sorting structure of a tubular product after visual inspection by means of machine vision can be presented as follows Fig. 7.

Based on the results of the classification in Table 1, the following criteria give us the following results:

Pigmentation is not a critical defect, therefore, depending on the percentage of contamination, it can be corrected by washing in a chemical solution and subsequently classified as grade 1 or 2.

Similarly, considering the colour of the object of control, we divide the products into grade 1 or 2.

If there is a cutting defect or a crack on a tubular product, it is rejected.

If there is a film in the middle, the product is assigned a separate grade, and all these products with a defect are sent for revision by mechanical and then chemical methods for better results and are re-inspected.

The last important defect is the conformity of geometric parameters; if there are any curved or bent products, they are rejected. At the same time, the diameters of the products are analysed and allocated to the appropriate size.

Conclusions. The paper considers the problems of controlling the output characteristics of finished products and proposes a classification and criteria for determining defects in the future using computer vision, namely the use of optical cameras will allow to obtain images that clearly show the colour gradient, geometric shape, and internal state of the objects under control. The most typical defects for a tubular product were analysed, which made it possible to classify them accordingly and select the most rational mathematical apparatus for their description.

The work has several directions for continuation, namely, it is necessary to implement a procedure for sorting tubular objects based on the proposed classes, i.e., detecting by a neural network the presence or absence of defects on them, colour and diameter according to the proposed classes of defects. It is also necessary to develop a segmentation method that will help, in addition to detecting the defect, to track its changes and parameters in the overall product quality management system.

It is planned that the developed system of output control by computer vision may be of interest to organisations and contribute to the automation of their output or intermediate quality control by computer vision, which will allow production to exercise full control over the conveyor production process and reduce the likelihood of rejects.

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Стельмах Н.В., Мастенко І.В. АНАЛІЗ ТА КЛАСИФІКАЦІЯ ВИЯВЛЕННЯ ДЕФЕКТІВ ВИРОБІВ ТРУБЧАСТОЇ ФОРМИ ЗАСОБАМИ МАШИННОГО ЗОРУ

Контроль є найважливішим компонентом системи управління виробництвом, що включає вимірювання та перевірки виробів, щоб переконатися, що вони відповідають необхідним специфікаціям та технічним характеристикам. Стандарти контролю якості зазвичай диктуються підходами до забезпечення якості, як-от ISO 9001. Ці підходи визначають протоколи для виробничого процесу, а контроль якості забезпечує виконання необхідних завдань. У виробничому середовищі підприємства можуть здійснювати різні види контролю якості, включаючи перевірку матеріалів, перевірку у процесі виробництва та остаточну перевірку. Виконуючи ці перевірки, можна переконатися, що контроль якості знаходиться на правильному шляху, що призводить до зниження витрат, підвищення ефективності. Впровадження найкращих практик контролю якості може покращити контроль якості. Головні складові успіху при формуванні системи контролю якості: автоматизація, огляд, відстеження.

Неавтоматизований візуальний контроль, який до цих пір використовується на багатьох підприємствах має ряд недоліків, а саме суб'єктивність і низька достовірність, а також мала продуктивність на складних виробах з тонкою топологією. Контроль складних виробів із застосуванням простих оптичних пристосувань, за словами операторів, дуже сильно напружує зір, що, напевно, становить небезпеку для їх здоров'я.

Зростаюча зацікавленість до технології комп'ютерного бачення зумовлена, безконтактним методом контролю, високою точністю та продуктивністю, за відносно низьку вартість

***В роботі розглянуто** проблематику контролю вихідних характеристик готової продукції, яку пропонується вирішити використанням методів комп'ютерного зору та запропоновано математичний опис одного з видів дефектів застосувавши перетворення Хафа, яке успішно використовується для опису та виявлення об'єктів круглої форми.*

Також в роботі проаналізовано найбільш типові дефекти для об'єкту контролю тіла трубчастої форми та запропоновано класифікацію цих дефектів по сортам для подальшого застосування при навчанні нейронної мережі.

***Ключові слова:** дефект виробу, керування якістю, автоматизоване виробництво, контроль якості, машинний зір, нейронні мережі.*