COMETa 2024
7th INTERNATIONAL SCIENTIFIC CONFERENCE
14th - 16th November 2024
Jahorina, B&H, Republic of Srpska
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

APPLICATION OF ROBOTICS SYSTEMS FOR QUALITY INSPECTION IN INDUSTRY

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Abstract: Quality inspection (QI) is one of the key segments of modern industrial processes and has crucial role in meeting high standards and product expectations. Advanced QI systems and practices enable companies to create products that are safe, reliable and compliant with specifications, thereby improving their position on market and ensure customer confidence. The rapid development of technology results in dynamic changes in the QI segment. Trends in the application of principles and tools of Industries 4.0 stand out in particular in this area, with huge potential for further significant implementation. One of the trends is the introduction of robotics and collaborative robotics which, along with machine vision systems, represents indispensable and reliable tools in modern industrial QI. Their implementation in industrial practice contributes to the improvement of efficiency, speed and precision of QI processes, creating conditions for high quality products which meet the requirements of today's market.

Key words: robotic, quality inspection, Industry 4.0

1 INTRODUCTION

Contemporary organizations are increasingly focused on the production of personalized products and much less on mass production. Special emphasis is placed on the ever-increasing degree of adaptation to the needs and demands of customers through the production of small series of products to order. Quality is one of the most important factors in any manufacturing organization, as it directly affects customer satisfaction, market competitiveness and long-term success of the organization. Therefore, in modern industrial systems, there is a strong need to develop advanced

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systems for timely detection and correction of irregularities, in order to improve the quality of the final product and reduce costs due to complaints and additional product modifications. Automating manual visual inspection processes through machine vision-based robotic systems can significantly speed up work cycles and increase productivity, providing greater precision and reliability in quality control.

Quality management is a comprehensive approach aimed at ensuring product reliability and compliance with customer requirements. Within this system, various methodologies and tools are applied in order to achieve high quality standards. Quality management is the responsibility of all employees at all levels of management.

Quality control, as a management process, refers to monitoring progress in achieving goals and taking corrective actions when they are not achieved. Quality control plays a significant role in meeting high standards and customer expectations. It ensures that products meet specific market requirements, which is essential for maintaining competitive advantage and increasing customer loyalty. Quality 4.0 brings a revolution in quality control. The focus is on predictive control and connecting data obtained through sensors with decision-making algorithms in order to eliminate irregularities, anomalies, non-conformities and maintain a high level of product compliance with quality standards. The application of Industry 4.0 digital technologies such as artificial intelligence, machine learning, the Internet of Things, cloud computing and Big Data plays a key role in ensuring consistency, efficiency and accuracy. These technologies enable faster and more accurate detection of irregularities, which results in an increase in the quality of final products and a reduction in costs.

The motivation for writing the paper stems from the fact that insufficient attention has been paid to researching the possibility of applying robots in the quality control segment. A review of literature sources concluded that quality control within the framework of human-robot cooperation is particularly neglected. Although robotics offers the potential to improve the efficiency and reliability of inspections, previous research has not focused enough on application of robotics in quality inspection. Therefore, there is a need for further research into this aspect, in order to better understand the possibilities of applying robots and collaborative robots in quality control.

Manual inspections, performed by operators, include product reviews to detect possible defects or non-compliance with quality standards. Although this process can be effective in certain cases, it is often time-consuming and quite expensive. Also, there are often delays in implementing corrective measures. These methods typically require more time to analyze the data and apply appropriate actions, which can result in longer troubleshooting cycles and increased costs. In addition, manual inspections can lead to greater variations in the accuracy and consistency of results because they depend on the human factor. This inconsistency can significantly affect product quality and process efficiency, indicating the need to introduce automation and advanced inspection methods in modern industrial systems to increase reliability and reduce costs.

The main goal of this scientific research paper is to indicate the possibilities of applying robotics in quality inspection of final products. The paper presents a case study in which robot equipped with machine vision systems inspect products in real time, which significantly increases the reliability of the QI and highlights the benefits of applying robotics in quality control from the aspect of identifying defects and irregularities that could affect the functionality of final products, reducing the cost of claims and increasing the efficiency of the production process.

2 QUALITY CONTROL

Quality is the level to which a set of inherent characteristics meet the requirements, needs or expectations that are stated, in principle implied or mandatory [1]. Deming defines quality as the degree of reliability of meeting the needs of users at low costs [2]. According to [1], quality management is a set of coordinated activities for leading an organization in relation to quality and managing it in that sense. Quality management includes planning, quality control, quality improvement and quality assurance. During Industry 1.0, product quality control was performed by humans, which meant that errors were often discovered late, and corrective measures were introduced late and required large financial outlays. In the course of Industry 2.0, quality standards became more formalized, and some methods of statistical quality control were introduced, which enabled more systematic monitoring and control of processes and earlier identification of potential problems, but control still relied on human intervention and inspection. The introduction of digitization and automation during Industry 3.0 has significantly improved quality control. This period is associated with the beginning of the development of automated inspection, which reduces the dependence on manual control and enables the detection of defects during the production process itself, and not only at the end.

The fourth industrial revolution (Industry 4.0) implies the digital transformation of production systems through the connection of all elements of the factory in an integrated network. Advanced technologies of Industry 4.0 contribute to the automation and optimization of production processes [3]. The rapid development of new technologies conditions dynamic changes in the quality control segment as well, where the trends of the application of Industry 4.0 technologies in this area stand out. These trends have the potential to completely redefine the way quality control is organized and implemented. One of the biggest advantages of applying Industry 4.0 technologies in quality control is the possibility of predictive analysis. In smart work environments, through the analysis of large amounts of data and the application of machine learning algorithms, potential problems and irregularities can be predicted and measures taken before defects appear.

While Industry 4.0 is focused on digitalization and automation of processes, Industry 5.0 emphasizes human-robot collaboration, with robots taking over routine and monotonous tasks that require high precision, while humans focus on tasks that require creative thinking and decision-making.

Modern organizations pay special attention to improving the quality of final products. This is the result of the growing need to meet market demands and fulfill the expectations of customers, who demand products of a higher level of quality at acceptable prices. Organizations strive to integrate new methods and techniques to increase efficiency, minimize the possibility of defects and maintain consistent quality of final products.

Modern approaches to quality control involve automated inspection and the application of advanced technologies, such as robotics, artificial intelligence and machine vision, to detect irregularities and ensure compliance with legislation and standards. One of the more significant trends is the introduction of robotics and collaborative robotics, which together with machine vision systems play an important role in quality control in industrial plants. Robotic systems, thanks to the precision and ability to perform repetitive tasks, enable more accurate and reliable inspection at every stage of production. In this way, it contributes to maintaining high standards, reducing defects and increasing customer satisfaction.

3 IMPLEMENTATION OF ROBOTICS IN QUALITY INSPECTION

Although the application of robotics in production processes is linked to the third industrial revolution, the new production paradigm is characterized by the optimization of this technology through the evolution of traditional robots into intelligent robots that collaborate with people [3].

Unlike traditional control methods that rely on manual inspection, robotic systems are able to continuously perform inspection tasks with high accuracy and consistency. One of the key benefits is providing consistent and objective results. By integrating robotic systems and sensors, it is possible to monitor product quality in real time, which significantly reduces the risk of errors and increases the efficiency of the production process [4]. Data on the quality of final products is collected, analyzed and automatically processed at each step of the production process in order to determine irregularities, which significantly improves the efficiency and reliability of quality control.

Unlike humans who can make mistakes due to fatigue, machine vision enables precise and repeatable inspection, thus reducing the possibility of missing defects. With the help of cameras and sensors, robots can identify objects, recognize their characteristics such as size, shape, color, and orientation [5]. This level of precision is especially important in industries with high quality requirements, such as the automotive, electronics and pharmaceutical industries.

Unlike traditional industrial robots, collaborative robots are a special type of robots that are designed to work with humans in the same workspace, without physical barriers, which enables safe and efficient collaboration [6] and opens up new opportunities for improving efficiency of process [7]. The cobots are equipped with sensors, which allows them to react to the presence and interaction with people in real time.

Collaborative robots play an increasingly important role in quality control, enabling quick detection of defects. One of the key advantages of collaborative robots in quality control is their ability to perform precise control tasks in cooperation with operators, which enables greater efficiency in the detection of irregularities and defects in real time. Table 1. shows a comparative overview of the characteristics of industrial and collaborative robots.

Table 1. *Comparison of industrial and collaborative robots* [8]

Collaborative robots	**Conventional industry robots**
Simple programming	Programming is time-consuming
Lower weight of robot < 29kg	High weight of robot > 50kg
Embedded safety features	Lack of embedded safety features
Operation in the limited space	Large operation space
Lower weight of machined workpiece	Greater load capacity
Mobile	Immobile
External force sensors	Sensors of external forces are missing
Faster and simpler setting	High operation speed in operation
Flexibility of deployment	Universal usage in the limited space

One of the most significant advantages of collaborative robots in QI is flexibility. Flexibility is reflected in their ability to easily adapt to different production stages and product types. Collaborative robots can be quickly configured for new tasks, ie. they have the ability to automatically adjust the work parameters in real time and without the need for complicated reprogramming, they switch from one type of product to another, adjusting their control criteria in accordance with the specific requirements of each product. Thanks to advanced sensors and software solutions, these robots can analyze different product characteristics and adjust their activities according to quality requirements. This approach allows companies to optimize inspection and control without the need for large financial investments in the reorganization of production lines. Flexibility reduces the time for preparation and adaptation of production lines.

Contemporary trends in the application of robotics in quality control indicate that these technologies will significantly shape the future of industrial production. As robotic systems continue to evolve, they will become even more powerful and flexible tools for automated quality control.

Analyzing trends in the application of robotics in quality control, it was established that special attention is paid to [9,10,11]:

- Artificial intelligence integration - Artificial intelligence enables robotic systems to become "smarter", learn from data and adapt to different scenarios in real time. This significantly improves the ability to detect complex defects and enables predictive analysis, where robots can predict and prevent potential defects in the early stages of production.
- Applications of sensors and machine vision - The development of sensor systems and machine vision enables even more detailed and precise 3D scanning and inspection of parts, even those with complex geometry and hard-to-reach places. Sensors have the ability to detect even the smallest irregularities that may go unnoticed in traditional control methods. Optical scanning of millions of points within just a few minutes enables extremely detailed measurements and significantly shortens the time required for manual measurement techniques, while reducing the risk of human error.

The most efficient and flexible automated 3D inspection systems use robots. One example of the application of automated quality control systems is robotic three-dimensional quality control (3DQI), which combines hardware and software that enables precise 3D scanning, inspection and analysis of complex components, without affecting production speed. One of the key advantages of 3DQI is that it is used not only to control parts produced on site, but also to check and verify parts arriving from suppliers, thus ensuring compliance with quality standards at all levels of the production chain.

While standard 3D measurement systems often use fixed cameras with static points, which can limit the full visualization of components, robots in 3DQI systems can move around the object. In this way, it is possible to scan objects with complex geometry or irregular shapes, where multiple angles and measurement points need to be taken into account in order to obtain an accurate and complete image. In 3DQI systems, three-dimensional optical scanners position precisely defined points around the object being scanned. This makes it possible to obtain a complete and accurate 3D representation of the components in real time, thus ensuring a fast and accurate inspection.

Metrological tests that involve the use of a coordinate measuring machine often involve the analysis of only one part or product over a long period of time. This is a bottleneck in the production process, limiting the number of parts that can be inspected in a single lot, which directly reduces productivity and creates possible delivery delays.

Robotic quality control systems, both those based on classic industrial robots and those based on the cooperation of an operator and a collaborative robot, offer a number of advantages that are of key importance for modern industrial systems. These solutions transform the way product inspection, control or testing is carried out, enabling companies to improve their manufacturing processes through [11,12,13,14]:

- Increasing control efficiency: Robotic systems significantly speed up the quality control process, thanks to their ability to work at high speed and with extreme precision. Complex test protocols that require significant time when performed by humans can be performed much faster with robots. This contributes to shortening production time, eliminating bottlenecks in the production process and increasing productivity.
- Increased precision: Precision is measured in hundredths of a millimeter, making them an ideal solution for implementing demanding quality controls. This capability allows the detection of the smallest defects or irregularities, even those that are an order of magnitude smaller than the permitted tolerances. Thanks to this, robotic systems can detect potential problems and irregularities at an early stage, preventing these problems from causing defects.
- Consistency and objectivity of results: One of the main problems in traditional quality control is variability due to the human factor. Fatigue, loss of concentration or subjectivity can lead to unreliable results. Robotic quality control systems eliminate this type of variation, as they ensure objective results throughout the entire process, regardless of the length of the inspection. This significantly reduces the risk of defects and ensures that the results are always reliable and objective, thus improving the quality of the final products.
- Cost reduction: Precise quality control in the early stages of production allows identification of problems before major defects occur, which reduces the investment of resources, materials and time. A quick reaction to discovered defects prevents the production of larger quantities of defective products, thereby reducing scrap. Although the introduction of robotic systems involves initial costs, the return on investment is usually fast, especially if the systems are placed at critical points of the production process and adequate control protocols are applied.

4 CASE STUDY

Figure 1. shows the proposed robotic system for quality inspection. The system includes a conveyor for transferring parts, a frequency regulator for starting the conveyor, two photocells (one for detecting the passage of parts on the conveyor and the other for detecting the arrival of parts at the storage location), a camera for executing the product quality control process, a light tower for signaling and a SCARA robotic arm which has the role of product manipulation. Clicking on the start button starts the frequency controller and the robot controller program. The frequency regulator controls the movement of the conveyor. Until the operator places the product on the conveyor, the robot arm is idle and does not perform any activity.

The robotic system visually evaluates products and components using a camera and advanced algorithms to recognize shapes, colors, textures and other visual parameters. Combined with sensors and artificial intelligence algorithms, this system can automatically detect and analyze defects in real time, thus minimizing the possibility of human error and increasing the efficiency of the production process.

The integration of sensors, data processing systems and software enables precise checking of dimensions and other physical characteristics of components and parts in real time. Quality control takes place with the help of the SICK Inspector PIM60 camera. Using the Circle tool, the camera recognizes whether the incoming product is the correct and specified size. When the product to be measured passes the photocell located on the conveyor, its signal acts as the Trigger input of the camera, which signals the camera to take a picture of the product at a given moment, measure its dimensions, and set the result at the output depending on whether the product meets the predefined size parameters set in the camera or not. Based on the obtained result, a green light is lit on the light tower in case the camera has judged that the product is of satisfactory quality, or a red light in case the camera has judged that the product has irregularities.

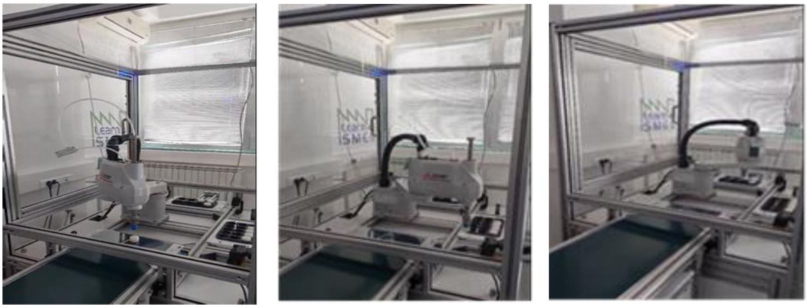

Figure 1. a, b, c *Robotic system for quality inspection*

After setting the results to the digital outputs (+24V), the outputs are connected to the input of the robot controller. The digital outputs of both photocells as well as the measurement results via the camera are set as inputs. The SCARA robot comes to the pick-up position and waits for a signal from the photocell at the pick-up position to pick up the product (Figure 1. a). If the camera determines that the product is of the correct dimensions, the SCARA robot transfers the part to the place provided for storing the correct parts (Figure 1. b). Otherwise, if the camera has detected that the part does not have the correct shape, the robotic arm deposits the part in the defective parts disposal area (Figure 1. c).

The proposed system enables automated quality control, with the ability to detect irregularities and potential problems in real time, contributing to improving the efficiency of the quality control process and ensuring the production of high quality products that meet market requirements.

5 CONCLUSION

Quality management is a key aspect of any manufacturing process, as it ensures that products meet established standards and customer expectations. The main goal of quality management is to reduce or completely eliminate irregularities and defects in production, which directly affects the increase in efficiency.

Quality 4.0 represents a new approach to quality management in the era of Industry 4.0, which implies the integration of digital technologies into all aspects of production processes. The application of artificial intelligence, the Internet of Things, big data and automated systems, such as robotic systems, is radically changing the way quality is managed in modern manufacturing environments. These technologies enable faster and more accurate data analysis, early detection of defects and continuous process improvement, thereby significantly increasing productivity and consistency.

In paper a case study of the application of robotics in QI was presented.The paper points out the benefits of applying proposed robotics system in quality control. The implementation of proposed robotic system in quality control significantly will contribute to the improvement of the quality of final products. Robots perform quality control with high accuracy, thus ensuring greater reliability and consistency in all stages of the process, eliminating variations and errors which is crucial for maintaining high quality standards. Automated control and inspection reduces the need for human intervention, will minimize the time required for quality control and contribute to reducing operating costs and improving the efficiency of production processes.

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