INDUSTRY 4.0: INTELLIGENT QUALITY CONTROL AND SURFACE DEFECT DETECTION

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ABSTRACT

Quality Control (QC) has recently emerged as a significant global trend among manufacturers, adopting intelligent manufacturing practices in view of Industry 4.0 requirements. Intelligent manufacturing is the process of enhancing production through the use of cutting-edge technologies, sensor integration, analytics, and the Internet of Things (IoT). The proposed paper mainly focuses on the study of the scope and the evolution of quality control techniques from conventional practices to intelligent approaches along with the state of art technologies in place. The challenges faced in building intelligent QC systems, in terms of security, system integration, Interoperability, and Human-robot collaboration, are highlighted. Surface defect detection has evolved as a critical QC application in modern manufacturing setups to ensure high-quality products with high market demand. Further, the recent trends and issues involved in surface defect detection using intelligent QC techniques are discussed. The methodology of implementing surface defect detection on cement wall surfaces using the Haar Cascade Classifier is discussed.

KEYWORDS

Quality Control, Industry 4.0, Internet of Things, Intelligent manufacturing, Interoperability, cutting-edge technologies, analytics, surface defect detection.

1. INTRODUCTION

Industrial societies are increasingly interested in intelligent manufacturing, especially with the advent of Industry 4.0, which calls for the majority of industrial tasks to be performed by robots with intelligence. It expressly indicates that the production systems will be fully connected and all production processes, including quality control and administration, can be made as intelligent as possible to run with the least amount of human involvement. Interoperability is a well-known necessity for the quick transformation of industry-specific processes. Hence it calls for integrating quality functions with other manufacturing operations to maintain intelligent collaboration so that quality-related knowledge may be shared with other manufacturing processes. On the other hand, the integration of manufacturing processes has ensured better performance.

Quality Control (QC) refers to a policy or set of practices created to satisfy a client's or customer's requirements or to fulfil a defined group of quality standards for a manufactured product or service [1]. It plays a significant role in maintaining and improving the quality of manufactured products. It involves testing the products to determine that they meet the necessary specifications. Testing is done to determine whether corrective measures are needed in finetuning the manufacturing processes to meet customer demands. QC ensures additional benefits such as reduced inspection and production costs, minimization of variations, and cost-effective use of resources. The process inspires employees to create high-quality goods leading to greater customer satisfaction [2]. Establishing customer-acceptable quality standards, finding defects or variations in the raw materials and manufacturing processes, ensuring smooth and uninterrupted production, assessing the degree of quality deviation in a product during the manufacturing process, thoroughly examining the contributing factors and thus achieving the objectives of quality control [3]. Some of the applications in that quality control are involved include preserving the quality of processes, products, and services, alerting for process abnormalities and fault detection, predicting the behaviour of machines, devices, and respective equipment in terms of the expected yield, machine maintenance and condition monitoring. Thus these practices ensure the effectiveness of the entire supply chain, starting from suppliers to customers [4]. The stepwise processes involved in quality control, starting from the inspection of manufactured products to meet the specified requirements up to the decision of acceptance/ rejection, are shown in Figure 1.

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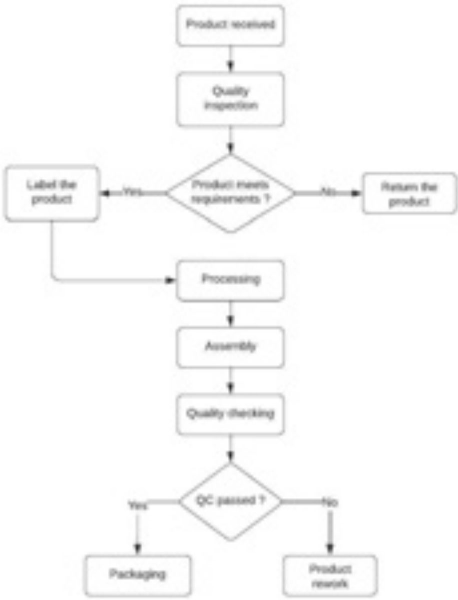

Figure 1. Quality control flowchart.

2. STATE-OF-THE-ART TECHNOLOGIES FOR QUALITY CONTROL

Production development is still guided by scientific management theory and has evolved from manually operated systems in Industry1.0 (I1.0) to intelligent systems in Industry4.0(I4.0). This strategy starts the management concept's scientific and technological growth. Control charts use graphical representations to determine whether the manufacturing processes or final products meet the intended specifications. Economic statistics defines econometrics as a field that helps to monitor and promote the economic factors influencing the quality of products. The Taguchi methods determine the ideal cost of quality throughout a product's life and emphasize product design and development in reducing defects in the manufactured products.

Quality costs involve a model that tracks the quality costs and is used to keep tabs on quality management's outcomes. The systems theory is used to model corporate systems through hierarchical breakdown and feedback. The primary organizational innovation paradigm for quality improvement in Japanese corporations was Quality circles, a collection of goals representing the best worldwide practices as a benchmarking model for building products and processes. A "flat" organizational structure with a specific position for quality management is the foundation of the lean system, an organizational, technical system then established in Japan. The material, process, and information flow from raw materials to goods delivered to customers are optimized and synchronized by the Quality Management supply chain model, which optimizes inventory and lowers the costs associated with product life. The concept of digital quality for intelligent systems has been improved by virtual quality using simulation models for the intelligent model quality of the integrated management system [5].

3. QUALITY CONTROL SYSTEMS WITH INTELLIGENCE

Industry 4.0, which calls for most industrial tasks to be performed by robots with intelligence, has made intelligent manufacturing popular with industrial societies. Setting up knowledge-intensive tasks to ensure quality and continual improvement is the fundamental prerequisite for developing intelligence in quality control. This calls for systematic performance monitoring and evaluation. Computer vision technology is mainly used to replace human eyes because many manufactured products' dimensions and surface characteristics dictate their quality. It is well known that automated machine vision systems can evaluate geometric and surface features to judge product quality and apply statistical analysis methods. Artificial intelligence can be used in industrial system design to ensure such capabilities. The manufacturers may require the use of lean manufacturing techniques and sophisticated machinery. To maintain proactive management of equipment, processes, services, and goods, they must increase predicted output while increasing the productivity and efficiency of their manufacturing hardware. Intelligent machinery should be able to process massive data collected from various sensors and use artificial intelligence and machine learning techniques. Utilizing cutting-edge manufacturing technologies is necessary to create intelligent systems that can be reconfigurable, interoperable, and reusable and cut down on potential wastes like scraps, overtime, and expenditures. AI-enhanced sensors, big data analytics-based decision support systems, and improved materials should be integrated throughout the industrial life cycle and serve as its drivers. A manufacturing system can predict and comprehend critical events and solve problems instantly before they result in any hazardous and dangerous situations or wastes, given the ability to process real-time data collected from the machines and conduct intelligent analysis over those through AI technologies. Thus it allows manufacturing systems to perform preventative maintenance and create fully functional manufacturing suits [4].

To provide the resources and capabilities required for satisfying standards and continuously enhancing the efficiency of the quality system, intelligent quality requires management commitment. The objective of the design of the manufacturing chain should be to maintain a constant and sustained level of quality for operations and services across the entire organization, with a high degree of integration. Another part of intelligent quality focuses on utilizing a knowledge-driven strategy rather than a conventional data-driven one. The system needs the appropriate operational and quality knowledge to establish the necessary level of intelligence. Methodologies and techniques are required to extract knowledge from the data that is currently accessible to produce self-behaviour with the desired quality function, as shown in Figure 2 [4].

Figure 2. Robot manipulators for intelligent quality control.

Source: https://www.therobotreport.com/top-5-countries-using-industrial-robots-2018/.

4. CHALLENGES IN INTELLIGENT QUALITY CONTROL

- ❖ Security Issues in Smart Manufacturing

An intelligent manufacturing system uses an integrated network to share information between manufacturing or machining units and end users using the internet. A globally unique identity and end-to-end data encryption are required for internet-based information sharing to ensure data and information security throughout the system. Therefore, every network node must be secured against outside threats and data exploitation [6].

- ❖ System Integration

Integrating new and existing technology equipment is a hurdle in developing an intelligent manufacturing system. A better communication system is also necessary for machine-to-machine communication and system interconnectivity. IPv6 connectivity is needed for the most modern production systems to enable more devices to be linked concurrently [6].

- ❖ Interoperability

The capacity of several systems to comprehend and utilize one another's features independently using proper synchronization of the communication protocols and standards is known as Interoperability. The differences in transmission bandwidth, communication method, operational frequency, hardware capabilities, etc., limit the system's compatibility.

- ❖ Safety in Human-Robot Collaboration

Any instructions given in a human language should be converted into machine language by the multilingual intelligent manufacturing systems for performing the appropriate action. The instructions can be in verbal or text form of input from the operator.

- ❖ Multilingualism

Financial Analysis and return on investment (ROI) should be thoroughly examined for an existing manufacturing system before transitioning to other advanced technologies. The increased expenditure necessary compared to production losses during an upgrade and the time needed to recover the investment's return [6].

- ❖ Surface defect detection

The large and complicated curved-surface components present a challenge for inspection since it is challenging to assure shape accuracy using conventional inspection techniques, which is crucial to these components' functional performance [7]. The manual inspection methodology's accuracy for inspecting these components falls short of expectations. Thus it calls for the requirement of an inspection system that uses mobile manipulators to measure huge components with complicated curved surfaces in three dimensions accurately and automatically [8]. Surface defects are the lines or planes that divide a substance into sections, each having a distinct orientation but the same crystalline structure. Surface defects are often caused by surface finishing techniques like embossing, weather-related degradation, or environmental stress cracking [9]. Defects may also be produced when metals are used and treated for industrial reasons.

The aircraft and automotive industries reject any material with manufacturing defects since even a tiny defect in a finished product could result in a catastrophe. Steel rolling processes cannot do real-time inline surface flaw checking without automatic machine vision technology. Some spots may go unnoticed, costing production time and causing significant financial losses. Modern methods for finding surface defects include eddy current testing, electrical resistance testing, flux leakage testing, magnetic testing, thermographic testing, radiographic testing, resonant testing, ultrasonic testing, penetrant testing, and visual testing. A successful surface defect detection would ultimately identify all the surface defects on the product's surface, eliminate products with defective surfaces, and help repair the faulty surfaces. Automated visual inspection techniques for surface defect detection can help intelligent quality control automatically inspect each printed circuit board assembly and update measurements and observations without human interaction [10-13].

5. METHODOLOGY OF IMPLEMENTATION OF SURFACE DEFECT DETECTION

Here the process of implementation of intelligent Surface defect detection is presented further. Due to its high inference speed, the object detection model was trained using the Haar Cascade algorithm. This algorithm uses a set of 1000 images for training and uses Haar features that traverse through the entire image to detect a location of defects, namely, spalling, cracks, uneven surfaces, and holes. The samples of test images for defect detection are shown in figure 3.

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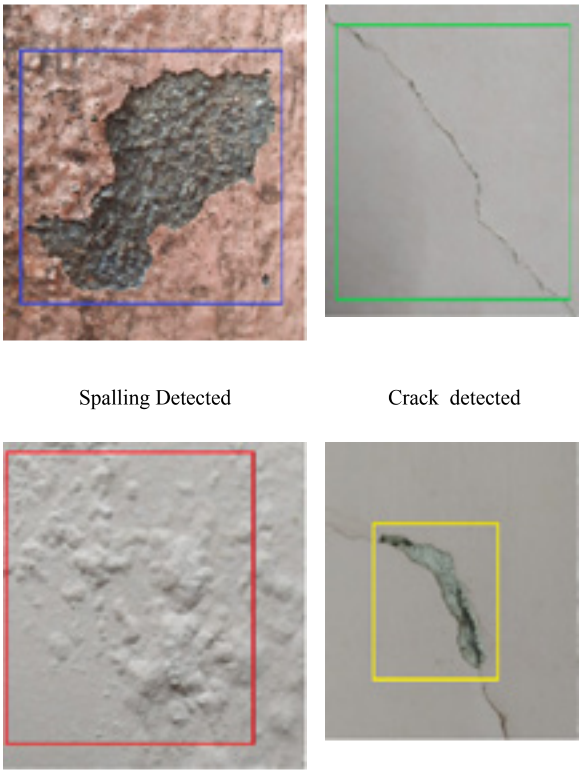
The experimentation results show that the Haar Cascade classifier is superior to other classifiers based on deep learning models in terms of higher inference speed. But the classifier suffers from some drawbacks, namely, low accuracy, false positives detection, and difficulty in training using custom datasets. The performance of the Haar Cascade classifier is evaluated in terms of inference time and accuracy of classification. As attaining accuracy in surface defect detection is crucial, autonomous quality inspection systems must adopt deep learning algorithms, namely, YOLO, Fast R-CNN, Faster R-CNN, etc., for better accuracy.



Spalling Detected

Crack detected

Residual surface detected

Hole detected

Figure 3. Surface defects detected.

6. CONCLUSIONS

The paper focuses on the study of quality control techniques, the evolution and processes involved and the state of art technologies in use. A review of challenges in intelligent quality control is explicitly done on surface defect detection. Further, the methodology and results of implementing surface defect detection using the Haar Cascade classifier on cement walls are presented. The performance of the Haar Cascade classifier is evaluated in terms of inference time and accuracy of classification. Further, it is proposed to analyze the surface defect detection performance using AI-based classifiers.

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