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The Untiring Eye: Automated Visual Inspection System for the Electronics Industry

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ABSTRACT

To address the increasing complexity of modern quality standards, this study presents the development of an automated vision-based inspection system designed for examining terminals in electronic components. The system is equipped with a stepper-motor-driven conveyor, a photo-sensor for distance measurement, positioning guides, a vision sensor for quality assessment, a pneumatic cylinder for product rejection, and a PLC for overall control. By integrating logical decision-making, the system reliably distinguishes between acceptable and defective products and directs the defective ones into a designated reject box. Operating at a throughput of 60 units per minute, the system demonstrated highly consistent performance, achieving 100% accuracy in both visual inspection and pneumatic ejection, as well as a 97.5% success rate in product positioning. These findings highlight the strong potential of automated inspection technologies to enhance both the efficiency and accuracy of electronic component manufacturing processes.

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INTRODUCTION

Traditional manual inspection methods demand significant resources, time, and skilled labor to ensure high-quality outcomes [1], [2]. Herlambang et al. [3] highlight the prevalence of manual inspection practices in assembly areas, especially for tasks like dimensional and geometric measurement. These methods often involve direct physical contact, leading to prolonged inspection times and the risk of human error. To address these limitations, this study

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proposes an intelligent vision system that leverages machine vision and programmable logic control to automate defect detection and sorting processes in terminal products.

Existing literature increasingly underscores the growing benefits of machine vision technologies across various fields. In agriculture, for example, machine vision has proven effective for evaluating musk grafting seedlings, achieving a 98% success rate at a processing rate of one seedling every 15 minutes [4]. Multivariate analysis combined with machine vision has also supported reliable rice seed variety identification, with reported accuracy levels exceeding 83% [5]. Within the soft drink industry, automatic vision checks utilizing a Raspberry Pi controller have effectively detected color classification and level variations [6]. Similar applications have been implemented in bottle manufacturing, where automatic visual inspections identify defects and pinpoint their locations. These inspections encompass bottle bottom, mouth, and wall assessments, employing the edge points double classifying method and least-squares fitting algorithm [7].

This study demonstrates the feasibility of employing automated visual inspection to identify color and dent defects on sandwich panel components, utilizing affordable equipment and eliminating the need for human intervention [8]. Within the electronics industry, machine vision has been successfully implemented to enhance automation levels and expedite product changeover processes [9]. Within steel plate manufacturing, an automated vision platform has been developed to evaluate cutting performance through the detection of defect sites and thermally degraded fracture areas [10]. A fully automated, non-contact inspection system for testing 608ZZ bearings has been realized through the integration of electro-mechanical components [11]. While existing studies have successfully demonstrated the application of automated visual inspection for detecting defects on larger-scale components, such as sandwich panels, electronics, and steel plates, limited research has addressed the challenges of inspecting smaller-sized objects with high-speed requirements and random positioning. Furthermore, the identification of specific defect types within terminal products using automated inspection technology remains a relatively unexplored area.

This study presents an intelligent product inspection system capable of automatically identifying and classifying terminal product defects without requiring manual intervention or precise product positioning. The system integrates mechanical architecture, photonic sensing modules, computer-driven processing, and PLC coordination to analyze vision-system outputs and perform defect classification. The identified defects are automatically sorted through a process that leverages the programmable logic controller to interpret and compare positional data transmitted by the vision system.

RESEARCH METHOD

2.1 Object of Inspection and Defect Classification Framework

This study centers on Indonesian manufacturers of electronic components, with a particular emphasis on terminal products that facilitate the transmission of electrical pathways and signals within electronic devices. These terminals, which are small and highly precise, are susceptible to subtle imperfections that could compromise overall product performance. With dimensions of 1 mm in thickness, 9.5 mm in length, and 6.8 mm in diameter, the terminals are produced using a specialized vinyl-based insulating material. The identification of these defects, often overlooked in quality assessments, serves as a critical input for the development of an automated vision inspection system. This study focuses on enhancing product quality control within the production department by accurately identifying and classifying product defects. Traditional inspection methods often prove inadequate for detecting and categorizing the diverse range of macroscopic defects that can occur in products. These methods are time-consuming, subjective, and unable to provide the structured and precise classification required for effective quality management [12], [13], [14], [15]. To mitigate these shortcomings, the study proposes an automated vision-based inspection framework capable of reliably

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identifying and classifying defects, contributing to the creation of a unified production database.

2.2 Structural Configuration and Operational Principles of the Inspection System

This study presents an automated visual inspection system designed to enhance product quality control within a manufacturing process. The system interfaces with the main production unit, functioning at a rate of 60 units per minute and powered by an induction motor that drives a cam assembly. Since the built-in inspection mechanism of the primary machine struggles to detect particular defect types, the newly proposed solution remedies this by integrating a conveyor line and a vision sensor. To ensure accurate inspection, the system employs a product guide to maintain consistent product positioning prior to visual analysis. The vision sensor is strategically positioned at a distance of 145 mm from the detection object to capture optimal images of the products, which are then evaluated against predetermined quality standards. Defective products are automatically rejected through an ejection cylinder, while conforming products are directed to a designated container. As depicted in Figure 2, the automated visual inspection device measures 870 mm in length, 380 mm in width, and 530 mm in height. Conveyor motion is achieved through a stepper motor linked to a sprocket–chain assembly, and product monitoring is performed using a cam photosensor positioned parallel to the conveyor pulley to ensure accurate rejection decisions.

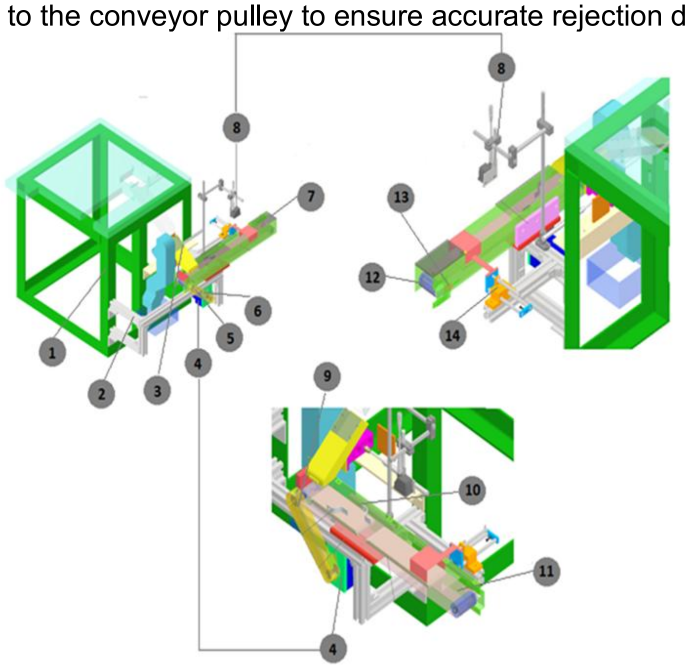

Figure. 1. Automatic vision system. (1) Main machine processes; (2) Aluminium frame automatic vision inspection; (3) Main machine shutter; (4) Stepping motor; (5) Sprocket; (6) Chain; (7) Cover conveyor; (8) Vision sensor; (9) Cover sprocket and chain; (10) Product guide; (11), Belt conveyor; (12), Pulley; (13) Slide cam; (14) Cylinder ejection

2.3 Requirements for detection and identification

To establish an effective intelligent inspection system, the system must maintain consistent product positioning and speed, accurately identify defects, and reliably determine product conformance to specifications. Key performance indicators include the ability to precisely direct products for optimal sensor detection, maintain central product positioning to prevent slippage, accommodate various product types, and ensure user-friendly operation and installation of the vision sensor. Additionally, the vision sensor must possess rapid processing capabilities that do not compromise the overall production speed and must be integrated with an automated sorting mechanism that eliminates the need for manual intervention. Given the

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diverse range of product defects, sizes, and operational requirements, a compact vision sensor comprising a sensor head, amplifier, connecting cables, and an intelligent monitor, as depicted in Figure 2, is essential for achieving these objectives.

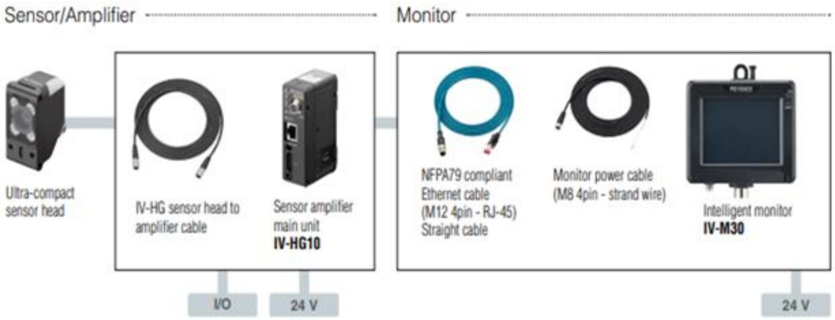

Figure. 2. Vision sensor configuration

2.4 Design of intelligent inspection system

This study presents an automated visual inspection (AVI) system designed to enhance product quality control within a manufacturing process. The AVI system, operating independently of the main machine's sensors, utilizes an electronic pneumatic system with a power supply ranging from 200V to 220V and an air source pressure of 0.5 MPa to 0.6 MPa. To ensure compatibility with the main machine's production rate of 50 units per minute, the AVI system is designed to operate at an equal or faster speed. Considering the lightweight nature of the products and the influence of gravitational forces, the system incorporates a shutter mechanism with a 30-degree inclination to minimize the impact of gravitational potential energy on product shape and quality. A conveyor belt with a length of 500 mm is driven by a stepper motor (Vexta Oriental Motor PK 266-02A) powered by a DC voltage source. The stepper motor is connected to the conveyor pulley through a sprocket and chain mechanism, with a safety cover sprocket installed to protect operators. The stepper motor driver (UDK 2120) is controlled by an AC voltage source of 100V and regulates the conveyor's rotational position. An antistatic conveyor belt is selected to prevent electrostatic discharge.

This study presents an automated visual inspection system designed to enhance product quality control. The system utilizes a vision sensor equipped with an LED light source and is positioned at a distance of 145 mm from the target object. The system is integrated into a machine operating at a speed regulated by a pneumatic system. To ensure optimal image acquisition, the camera resolution and field of view (FoV) are carefully configured based on the size of the detected object. The system is capable of identifying both structural and dimensional defects in products, with a focus on detecting defects as small as 0.38 mm. The inspection process involves image optimization, trigger activation, internal processing, result display, and image registration. Image analysis is conducted using specified tools and parameters, with an average processing time of 50 ms. The system's output includes the assignment of functions to corresponding output lines.

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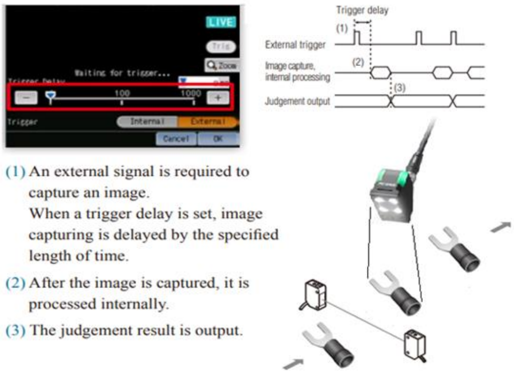

Figure. 3. External trigger mode selected

2.5 Control system design

The automated visual inspection (AVI) system incorporates an automatic ejection mechanism to segregate non-conforming products. The ejection system utilizes a pen-type cylinder supported by a bushing and shaft, ensuring precise translational movement. The cylinder specifications include an 80 mm stroke and a 12 mm diameter, capable of exerting an effective force of 67.8 Newtons. The total working load of the cylinder, including the supporting stainless-steel plate and product weight, is estimated to be around 1 kg, falling below the theoretical workload. The ejection system is designed in a U-shape configuration surrounding the conveyor.

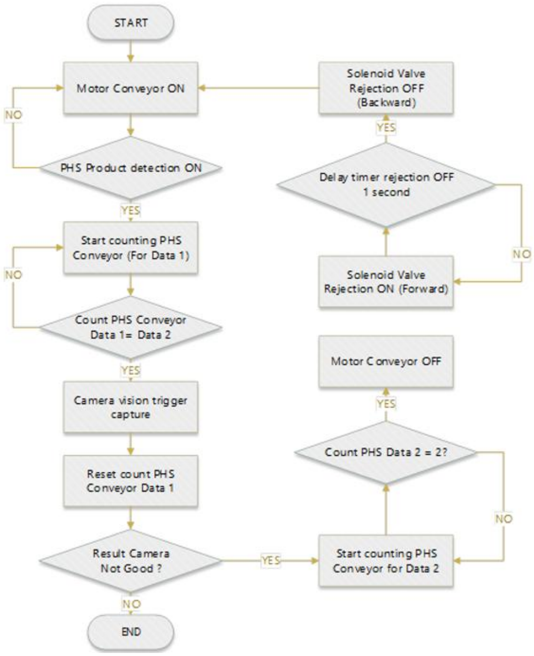

Figure. 4. Flow program chart

Upon detecting a non-compliant item, the AVI system energizes the ejection cylinder’s solenoid valve, diverting the product into the rejection bin and pausing system operation. The hardware configuration includes two Panasonic photo sensors—EX-15E and PM-T45 where PHS 1 identifies the product’s location on the conveyor, and PHS 2 determines the spacing relative to the vision camera to provide the trigger signal. Based on these inputs, the PLC evaluates conformity and operates the ejection cylinder when necessary. Conveyor motion is

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facilitated by stepper motors linked to sprocket and pulley mechanisms. The vision sensor is installed 145 mm above the belt, with an adjustable mount to fine-tune its field of view. The PLC selection, OMRON CP1HX40DT, is based on the system's input/output requirements and processing capabilities. The PLC offers a processing speed of under 0.16 microseconds, a program capacity of 20,000 steps, and NPN transistor-type outputs. Table 3 outlines the necessary hardware specifications, and Figure 8 illustrates the AVI system's process flowchart.

RESULT AND DISCUSSION

This study presents experimental results obtained from an offline evaluation of an automated visual inspection (AVI) system within a manufacturing environment. The initial phase involved collecting master product data to establish a baseline for comparison. The vision sensor setup, facilitated by autofocus and auto-brightness, ensured efficient and rapid image acquisition. The system's ability to accurately identify product defects and sort them into appropriate categories was assessed through a series of experiments. The evaluation encompassed product positioning, vision sensor performance, and cylinder ejection functionality. The results, as depicted in the confusion matrix (Figure 11), demonstrate the system's high accuracy in detecting defects and executing ejection processes. While the product positioning accuracy reached 97.5%, the overall system accuracy was an impressive 99.2%. These findings highlight the effectiveness of the AVI system in enhancing product quality control within the manufacturing process.

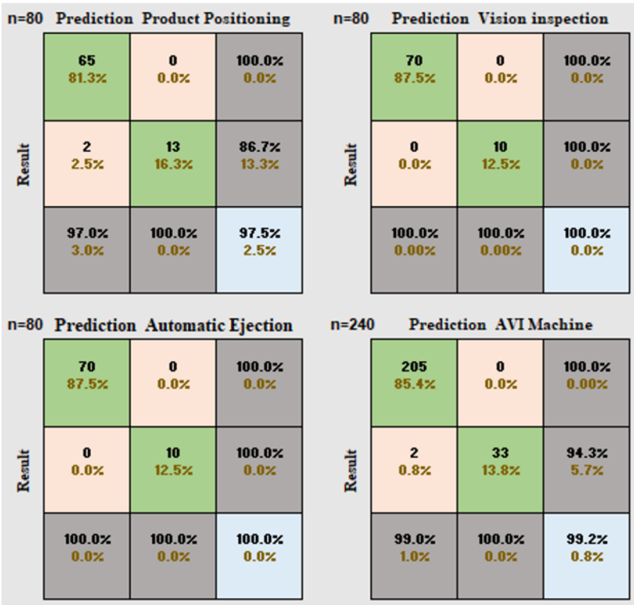

Figure. 5. Confusion matrix real time experiment

CONCLUSION

This study presents an automated visual inspection system aimed at improving quality control in electronic component manufacturing. The system leverages a combination of photo sensors, stepper motors, vision cameras, and PLC controllers to accurately identify and sort terminal products. A positioning guide ensures consistent product alignment, enabling the vision sensor to effectively distinguish between normal and defective items. One of the primary challenges encountered during this research was achieving precise product positioning. To address this, we implemented a robust positioning guide system that effectively aligns products, ensuring accurate inspection and sorting.

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Rigorous testing demonstrated the system's exceptional performance, achieving a 100% success rate in both vision sensor processing and sorting, a 97.5% accuracy in product positioning at a processing speed of 60 units per minute, and an overall system accuracy of 99.2%. The system's processing speed is compatible with the main production line, ensuring seamless integration. Future research endeavors will focus on expanding the system's capabilities to detect a wider range of defects, accommodate products with diverse sizes and shapes, and integrate robotic arms to enhance flexibility and versatility within electronic component manufacturing.

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