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AI-Based Automated PCB Defect Detection and Sorting Using Edge Machine Vision

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Abstract: Printed Circuit Boards (PCBs) require proper inspection to ensure the quality and reliability of electronic products. Manual inspection can be time-consuming and may overlook small defects. This paper presents an AI-based PCB inspection and sorting system using edge machine vision. The system uses a Raspberry Pi, IR sensors, camera, conveyor belt, servo motor, and TFT display to automate PCB inspection. Images captured at the inspection stage are processed using OpenCV and YOLO classified AI model into four categories: Good PCB, Resistor Missing, IC Missing, and Broken PCB. Based on the classification, the servo motor automatically separates good and defective boards. The inspection results are displayed on the TFT screen, while all processing is performed locally on the Raspberry Pi without cloud connectivity. The prototype demonstrates an integrated approach to automated PCB defect detection and sorting.

Keywords: PCB inspection, defect detection, machine vision, edge AI, artificial intelligence, OpenCV, Raspberry Pi, automatic sorting, computer vision.

I. INTRODUCTION

Printed Circuit Boards (PCBs) are fundamental components of modern electronic systems and are widely used in consumer electronics, industrial equipment, automotive systems, communication devices, and control applications. The quality of a PCB directly influences the reliability and performance of the final electronic product. During manufacturing and assembly, defects such as missing components, damaged boards, open circuits, short circuits, and other visual abnormalities can occur. Therefore, early and accurate identification of PCB defects is essential for maintaining product quality and preventing defective boards from progressing to subsequent production stages [1], [2].

Conventional PCB inspection is often performed through manual visual examination, which requires continuous operator attention and can become time-consuming and inconsistent for large numbers of boards. Automated Optical Inspection (AOI) and computer-vision-based techniques have been developed to improve inspection accuracy and repeatability. Recent studies have demonstrated the use of deep-learning models for automated PCB defect detection, while image-alignment techniques have also been investigated for identifying missing and incorrect components. However, inspection performance can still be influenced by image quality, PCB positioning, computational requirements, and variations in inspection conditions [3], [4].

This work presents an AI-based automated PCB inspection and sorting system using edge machine vision. A Raspberry Pi is used as the central processing and control unit, integrating two IR sensors, A Raspberry Pi camera, conveyor mechanism, motor driver, servo motor, and TFT display. IR1 detects PCB entry, while IR2 positions the PCB for image acquisition. The captured image is processed using OpenCV and classified using an ONNX-based AI model. Based on the predicted PCB class, the Raspberry Pi controls the servo for automatic sorting and displays the inspection result on the TFT. The complete process is performed locally on the Raspberry Pi, providing an integrated PCB inspection solution [5]

II. LITERATURE REVIEW

1. Mohammed Kurian et al. [1] developed a real-time AI-based defect detection system for plastic bottle inspection using computer vision and weight sensing. Their study combined deep-learning techniques with weight

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measurement for automated quality inspection.

2. Huang et al. [2] proposed YOLOv8-BVC, a lightweight industrial defect detection model. Their study focused on improving defect detection efficiency while reducing computational complexity for industrial applications.
3. Ghany et al. [3] implemented the YOLOv8 algorithm on a Raspberry Pi for automated PCB quality inspection. Their study demonstrated the detection of PCB defects such as pad misalignment, open circuits, solder bridging and component misplacement.
4. Shourie et al. [4] developed Surface Crack Finder, a CNN-based approach for surface crack detection. Their study explored the application of convolutional neural networks for identifying surface defects through image-based inspection.
5. Parikh et al. [5] proposed M2U-InspectNet, a deep-learning framework for automated defect detection in industrial manufacturing. Their study utilized multi-scale vision transformers and self-supervised learning to improve defect localization, detection accuracy and real-time inspection performance.

III. PROPOSED SYSTEM ARCHITECTURE

The proposed system is designed to inspect PCBs and separate good and defective boards automatically. The system is built around a Raspberry Pi, which controls all the inspection and sorting operations. It is connected to two IR sensors, a conveyor belt, a camera, a motor driver, a servo motor, and a TFT display.

When a PCB enters the conveyor, IR1 detects it. IR2 detects the board at the inspection point and stops the conveyor. The camera then takes a picture of the PCB. OpenCV processes the image, and the ONNX-based AI model checks for defects. Based on the result, the Raspberry Pi controls the servo motor to send the PCB to either the good or defective section. The inspection result is also shown on the TFT display. The overall system is shown in Fig. 2.1.

A. Block Diagram

The system consists of six main units: PCB detection and positioning, image acquisition, processing and AI classification, conveyor motor control, sorting mechanism and visual monitoring. The IR sensors detect the PCB and identify its position on the conveyor belt. The Raspberry Pi camera captures the PCB image, which is processed using OpenCV and evaluated by the ONNX-based AI model to classify the board as good or defective. The conveyor motor is controlled using an L298N motor driver, while a servo motor performs automatic sorting based on the classification result. The TFT display presents the inspection status and classification results.

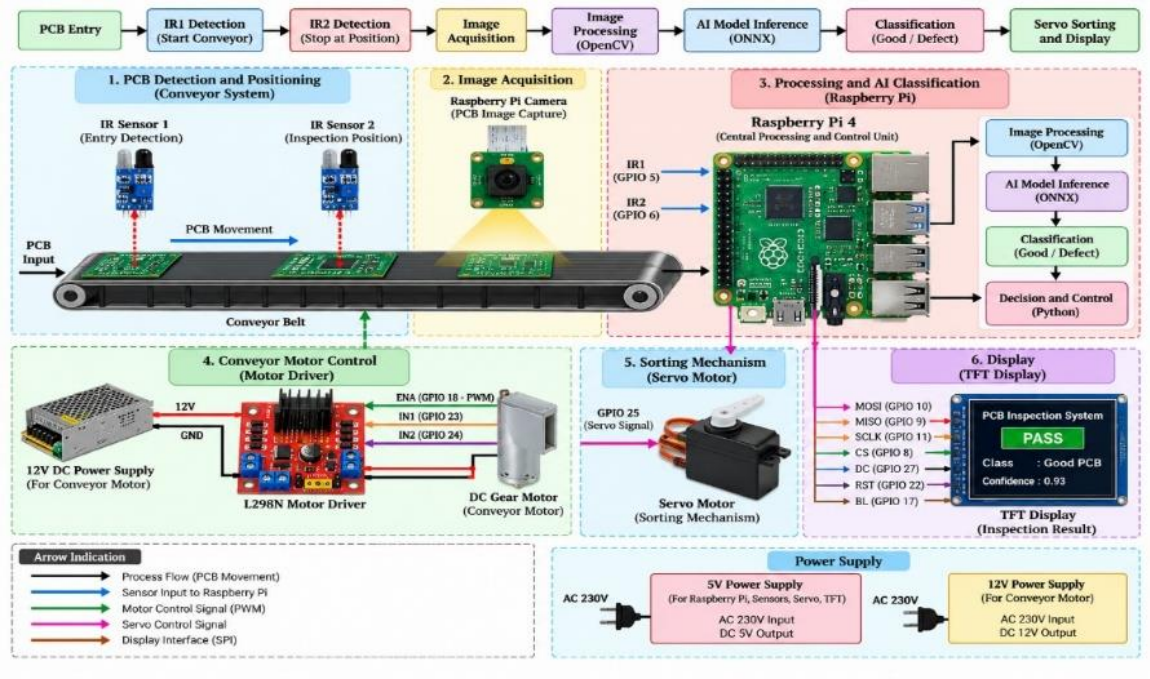

Fig. 3 1. Block diagram of the proposed motor condition-monitoring system.

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B. Working Flow

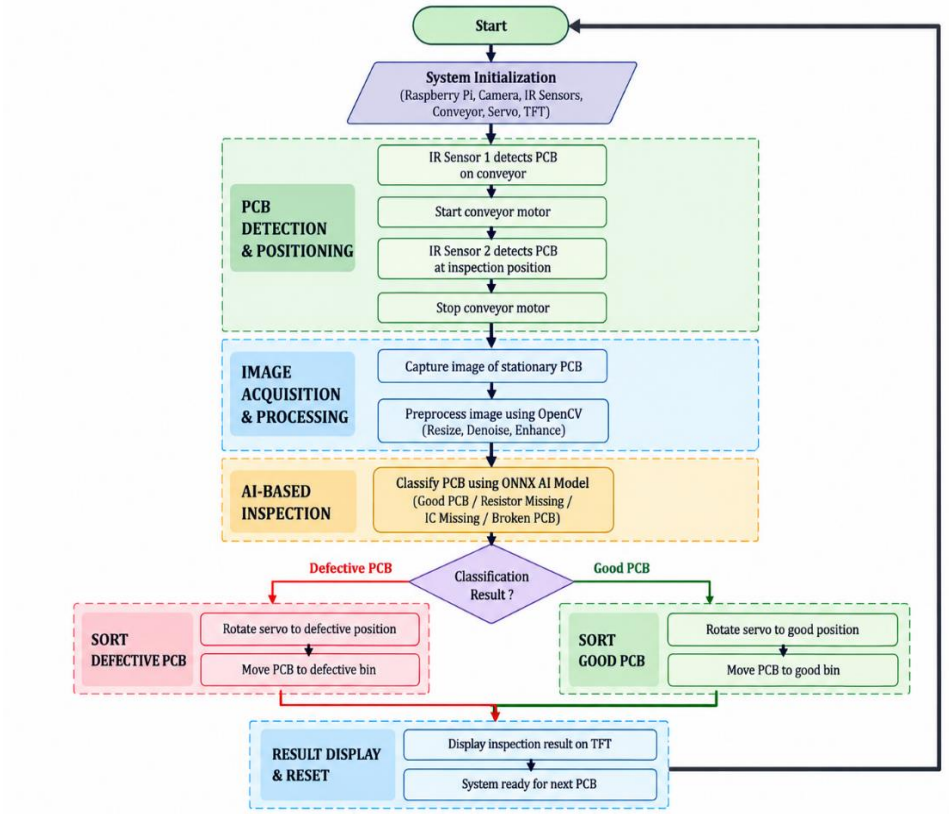

Fig. 3 2: Operational flowchart illustrating the complete workflow of automated PCB

Defect detection, classification and sorting system.

Initially, the Raspberry Pi, camera, IR sensors, conveyor motor and servo motor are initialized. When a PCB is placed on the conveyor, the first IR sensor detects it and starts the conveyor belt. The second IR sensor detects the PCB at the inspection position and stops the motor. The camera then captures an image of the stationary PCB, which is processed using OpenCV before being passed to the YOLO model. The model identifies the PCB condition as GOOD or DEFECTIVE by checking for missing resistors, missing ICs or broken PCBs. Based on the classification result, the servo motor rotates to the required position and moves the PCB into the corresponding good or defective bin. Finally, the inspection result is displayed on the TFT screen, and the system becomes ready to inspect the next PCB. This process repeats for each PCB placed on the conveyor.

IV. WORKING PRINCIPLE

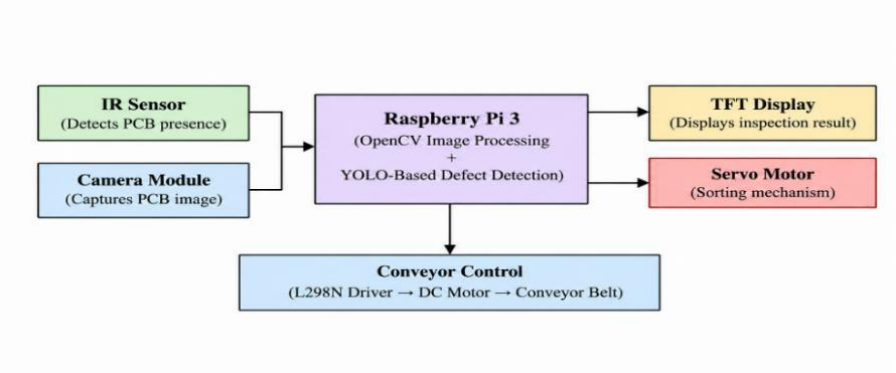

Fig. 3 3: Working principle of the proposed AI-based defect detection system.

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The system starts when the IR sensor detects a PCB on the conveyor belt. The Raspberry Pi 3 then stops the conveyor and triggers the camera to capture the PCB image. OpenCV processes the image, while the YOLO-based model checks for defects and classifies the board. The inspection result is shown on the TFT display. Based on the classification, the servo motor automatically moves the PCB to the appropriate section. The L298N driver controls the DC motor and conveyor movement throughout the inspection process.

V. HARDWARE IMPLEMENTATION

The proposed PCB inspection system consists of a Raspberry Pi, camera, IR sensors, conveyor belt, DC motor, motor drivers, servo motor, TFT display, and SMPS power supply. These components work together to detect, inspect, classify, and sort PCBs automatically.

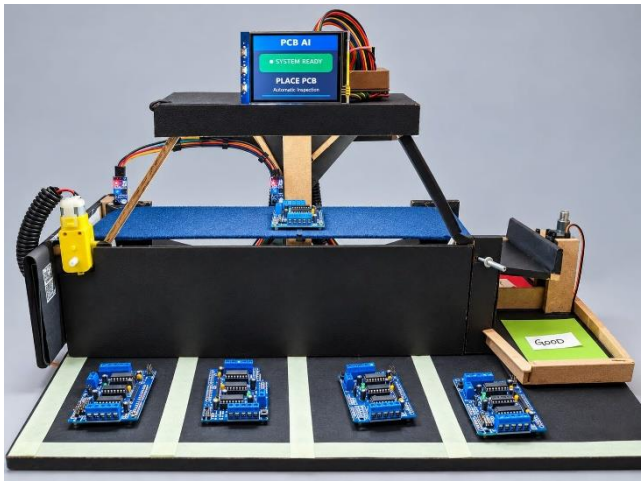

Fig. 4 1 Developed prototype of the proposed AI-Based PCB Defect Detection and sorting using Machine vision

A. Raspberry Pi 3: The Raspberry Pi 3 is the main controller. It manages the sensors, camera, motor, servo, TFT display, and AI-based PCB inspection.

B. Raspberry Pi Camera Module 3: The camera is placed above the conveyor with light illuminated to capture PCB images at the inspection point and send them to the Raspberry Pi.

C. IR Sensors: Two IR sensors detect the PCB at the entry to start conveyor and inspection points to stop conveyor belt and capture image. Their signals control conveyor movement and image capture.

D. Conveyor Belt and DC Motor: The conveyor moves PCBs through the inspection area using a DC motor.

E. L298N Motor Driver: The L298N controls the conveyor motor based on signals from the Raspberry Pi.

F. Metal Servo Motor: The servo motor separates good and defective PCBs based on the classification result.

G. TFT Display: The TFT display shows the PCB classification and inspection status.

H. L293D Arduino Module: The L293D module provides motor control through electrical signals from the controller.

I. SMPS Power Supply: The SMPS supplies power to the Raspberry Pi and other system components. Proper power distribution ensures reliable operation.

A. Overall Hardware Integration

The IR sensors detect the PCB, the camera captures its image, and the Raspberry Pi identifies defects. The servo sorts the board, while the TFT displays the result.

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VI. SOFTWARE AND MACHINE LEARNING MODEL DEVELOPMENT

The software is developed using Python, OpenCV, and an YOLO model. Python connects and controls the camera, sensors, conveyor, servo motor, and TFT display. OpenCV is used to process the captured PCB images, while the AI model identifies the PCB condition. The Raspberry Pi performs the complete inspection and sorting process locally, without requiring an internet connection.

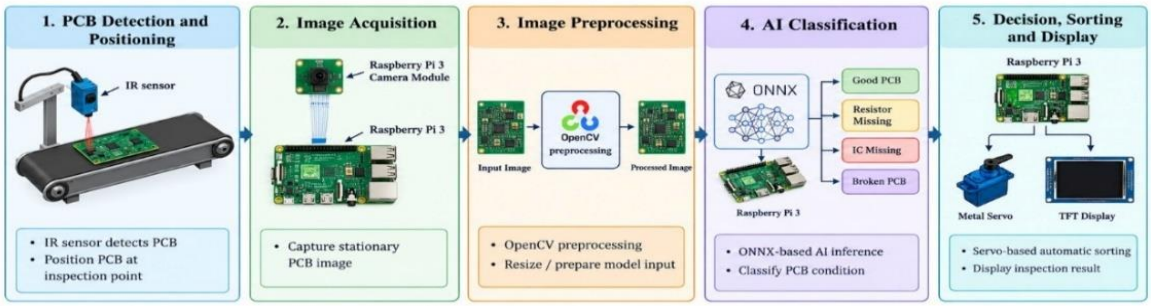

Fig. 5 1: Five Stage Pipeline of Automated PCB inspection and sorting system

A. Software Environment: The system is programmed using Python on the Raspberry Pi 3. Python controls the camera, IR sensors, conveyor motor, servo motor and TFT display. OpenCV is used for image processing, and the ONNX model is used for PCB defect classification.

B. Image Acquisition and Preprocessing: When the PCB reaches the inspection point, the IR sensor detects its position and stops the conveyor. The camera captures the PCB image, which is resized and processed using OpenCV before being given to the AI model.

C. AI Model and ONNX Inference: The trained model is converted into ONNX format and deployed on the Raspberry Pi. It examines the PCB image and identifies four conditions: Good PCB, Resistor Missing, IC Missing and Broken PCB. The model runs locally without requiring an internet connection or external server.

D. Classification and Sorting: The Python program receives the model output and decides the sorting position based on the detected PCB condition. The servo motor moves the PCB into the corresponding good or defective bin. The inspection result is also displayed on the TFT screen.

VII. RESULTS AND DISCUSSIONS

The developed AI-based automated PCB inspection and sorting system was experimentally evaluated to verify its ability to detect PCB conditions, perform image-based classification, display the inspection result, and automatically separate good and defective boards. The complete operation was carried out using a Raspberry Pi 3 as the central processing and control unit, with the conveyor mechanism, IR sensors, camera module, AI model, TFT display, and metal servo integrated into a single inspection system. The experimental results demonstrate the complete sequence from PCB placement and image acquisition to classification and physical sorting.

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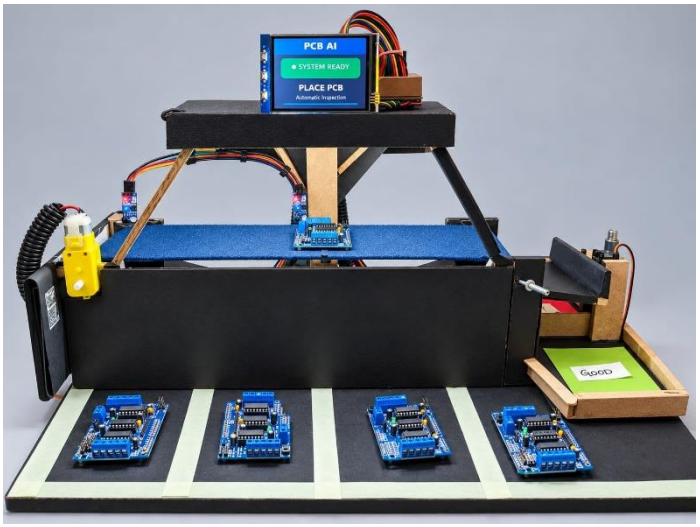

Fig. 6 1 System ready for PCB placement and inspection

A. System Initialization and PCB Placement

The Fig 6.1 The system initializes the inspection components and displays the **"PLACE PCB"** prompt on the TFT screen. This indicates that the system is ready to receive a PCB for inspection. Once the PCB is placed on the conveyor, the IR sensor detects its presence and initiates the inspection sequence.

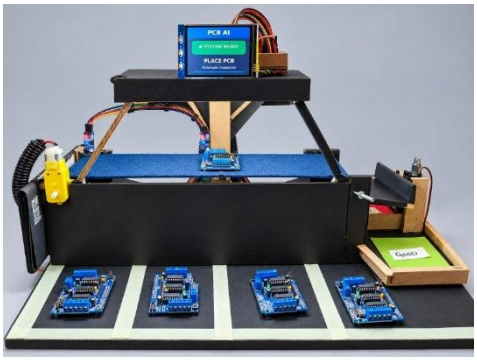

Fig 6.2 System ready for PCB placement and inspection

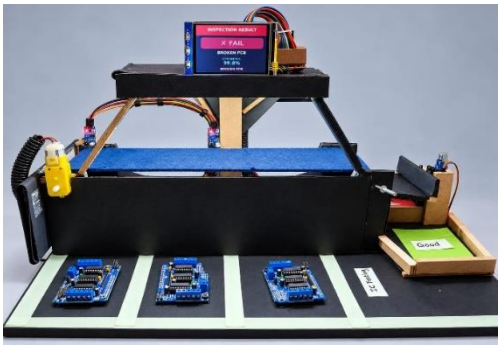

Fig 6.3. ***Experimental results showing, system initialization, (b) PCB image capture, (c) Good PCB, (d) IC Missing, (e) Resistor Missing, (f) Broken PCB***

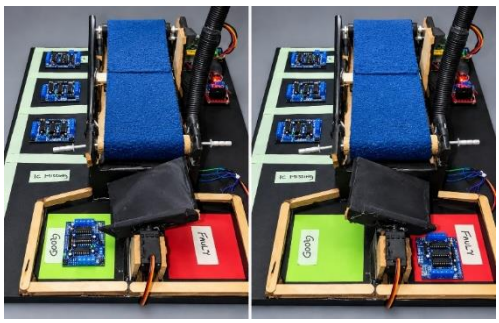

Fig 6.4 Servo-controlled sorting of inspected PCBs into Good and Faulty sections based on AI classification.

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TABLE I SYSTEM DECISION RULES FOR AUTOMATED PCB SORTING

Class	**PCB Condition**	**Sorting Action**
Good PCB	PCB is identified as acceptable with no targeted defect	Servo moves to the **Good PCB position**
Resistor Missing	PCB is identified as having a missing resistor	Servo moves to the **Resistor Missing position**
IC Missing	PCB is identified as having a missing IC	Servo moves to the **IC Missing position**
Broken PCB	PCB is identified as physicallydamaged/broken	Servo moves to the **Broken PCB position**

VIII. CONCLUSION

The proposed AI-based automated PCB defect detection and sorting system successfully integrates edge-based machine vision, AI classification, and automated mechanical sorting into a single offline platform. Using Raspberry Pi 3, the system identifies Good, IC Missing, Resistor Missing, and Broken PCB conditions and provides real-time results through the TFT display, while the servo mechanism automatically separates boards into Good and Defective categories. The key significance of the proposed system lies in its local edge-AI operation and direct integration of intelligent inspection with physical sorting, eliminating the need for cloud connectivity and reducing manual inspection effort. Thus, the system provides a compact, cost-effective, and practical approach for automated PCB quality inspection and sorting in small-scale manufacturing environments

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