PCB Inspection System

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ABSTRACT

The AI-Based PCB Inspection and Status-Indication System is designed to provide an automated and low-cost approach for inspecting Printed Circuit Boards (PCBs) using computer vision, image processing, and Artificial Intelligence/Machine Learning techniques. Manual PCB inspection requires continuous visual checking and may be time-consuming and prone to human error. To address these limitations, the proposed system uses a camera to capture PCB images and processes them using Python-based image processing techniques. The system is divided into two major inspection modules: bare PCB inspection and assembled PCB inspection.

In the bare PCB inspection module, the captured image is processed to analyze copper tracks and conductive paths. Image preprocessing techniques such as grayscale conversion, filtering, thresholding, edge detection, and morphological operations are used to obtain useful information from the PCB image. The system aims to identify defects such as track cuts, open traces, short circuits, and missing conductive paths by comparing the observed PCB pattern with the expected pattern. Machine learning and lightweight deep-learning techniques can then be used to classify the inspected PCB condition.

The second module focuses on assembled PCB inspection. It checks important conditions such as the power-supply section and LED indicator. Visual information from the camera can be combined with electrical measurements to determine whether the assembled PCB satisfies the required conditions. After completing the inspection, the system generates a PASS or FAIL decision. The result can be communicated to a microcontroller through serial communication and indicated using a Green LED for PASS and a Red LED for FAIL, with an optional buzzer for fault indication.

***Key Words*:** Marine Security, Surveillance System, IoT, Multi-Sensor Fusion, ESP32, AI/ML, Object Detection, Computer Vision, USV, Real-Time Monitoring.

INTRODUCTION

Printed Circuit Boards (PCBs) are an important part of modern electronic systems because they provide electrical connections between different components. The quality of a PCB directly affects the reliability and performance of the final electronic product. During manufacturing and assembly, various defects may occur, such as broken tracks, open connections, unwanted shorts, missing conductive paths, power-supply faults, and LED-related problems.

Traditional PCB inspection is generally performed through manual visual checking or dedicated testing methods. Manual inspection can be time-consuming and depends on the operator's experience and attention. Small track breaks and unwanted connections between nearby tracks may be difficult to identify consistently. Therefore, an automated inspection method can help reduce manual effort and improve the consistency of PCB quality checking.

Recent developments in computer vision, image processing, and Artificial Intelligence/Machine Learning (AI/ML) provide useful methods for automating PCB inspection. A camera can capture the PCB image, while image-processing techniques can extract important information about tracks, paths, and components. Machine-learning and deep-learning techniques can further assist in classifying the inspected board condition.

The proposed AI-Based PCB Inspection & Status-Indication System is a low-cost prototype that uses a camera, Python, OpenCV, AI/ML techniques, and a microcontroller-based indication system. The system consists of two main modules. The first module performs bare PCB inspection to identify track cuts, open traces, short circuits, and missing conductive paths. The second module performs assembled PCB inspection by checking the power-supply section and LED indicator using visual and electrical information.

After inspection, the system produces a PASS or FAIL decision. The result can be transmitted to a microcontroller through serial communication and indicated using a Green LED for PASS and a Red LED for FAIL. An optional buzzer can provide an additional indication when a fault is detected. The system demonstrates the basic concept of an Automatic Optical Inspection (AOI) system and can be useful for educational laboratories, small-scale electronics applications, and PCB quality-control activities.

BASIC IDEA OF PROJECT

The basic idea of the proposed AI-Based PCB Inspection & Status-Indication System is to develop a low-cost automated system for inspecting bare and assembled PCBs using camera-based image processing and AI/ML techniques. The system aims to reduce manual inspection effort and provide a quick PASS/FAIL indication.

2.1 Automated PCB Inspection

- Manual PCB inspection requires continuous visual checking and can be time-consuming.
- A camera-based system can capture PCB images and process them automatically.
- The proposed system helps identify common PCB defects and reduces dependence on manual inspection.

2.2 Bare PCB Inspection
- Bare PCBs need to be checked for proper copper tracks and conductive paths.
- The system analyzes the captured PCB image to identify track cuts, open traces, shorts, and missing conductive paths.
- Image processing techniques are used to compare the observed PCB pattern with the expected pattern.

2.3 Assembled PCB Inspection
- Assembled PCBs require checking of important components and basic operating conditions.
- The proposed system checks the power-supply section and LED indicator of the assembled PCB.
- Visual inspection and electrical information are combined to determine the condition of the board.

2.4 AI-Based Defect Detection
- Detecting small PCB abnormalities manually can be difficult and may result in inspection errors.
- AI/ML techniques can assist in classifying PCB images and identifying defective conditions.
- The system uses image features and machine-learning/deep-learning approaches for automated inspection.

2.5 Image Processing
- The captured PCB image may contain noise and unwanted variations.
- Image preprocessing techniques such as grayscale conversion, filtering, thresholding, edge detection, and morphological operations can improve the inspection process.
- These operations help extract useful PCB track and component information from the image.

2.6 PASS/FAIL Status Indication
- After inspection, the system generates a final PASS or FAIL decision.
- A Green LED is used to indicate a satisfactory PCB, while a Red LED indicates a detected fault.
- An optional buzzer can also be used to provide an additional warning during a failure condition.

2.7 Low-Cost Development
- Industrial Automatic Optical Inspection (AOI) systems can require expensive equipment and infrastructure.
- The proposed prototype uses commonly available components such as a USB camera, computer/laptop, microcontroller, LEDs, and software tools.
- This makes the system suitable for academic laboratories and small-scale electronics applications.

2.8 Simple User Interface
- A simple software interface can display the captured image and inspection result.
- The interface can show whether the PCB has passed or failed the inspection.
- Inspection results can also be recorded for future reference.

2.9 Automated Result Logging
- Maintaining inspection records manually can be difficult when several PCBs are checked.
- The proposed system can store inspection decisions and related information in a log file or database.
- This can help in tracking defective boards and analyzing inspection history.

2.10 Educational and Industrial Application
- The system demonstrates the basic working principle of an Automatic Optical Inspection (AOI) system.
- It can be useful for PCB testing, teaching laboratories, small-scale electronics manufacturing, and repair/rework activities.
- The project also provides practical implementation of computer vision, AI/ML, Python, and microcontroller-based status indication.

LITERATURE REVIEW

3.1 Computer Vision-Based PCB Inspection
- Computer vision techniques can be used to examine PCB images and identify visual abnormalities.
- Camera-based inspection reduces the need for continuous manual checking of electronic boards.
- Image quality, illumination, camera position, and PCB surface condition can affect inspection results.
- The proposed project applies computer vision techniques for automated inspection of bare and assembled PCBs.

3.2 Image Processing for PCB Defect Detection
- Image preprocessing is an important step before analyzing PCB images.
- Operations such as grayscale conversion, Gaussian filtering, thresholding, edge detection, and morphological processing can help extract PCB patterns.
- These techniques can make track and conductive-path differences easier to identify.
- The proposed system uses image preprocessing to detect abnormalities in PCB track structures.

3.3 Machine Learning-Based Defect Classification
- Machine learning can be used to classify PCB images or extracted image features into different defect categories.
- Features such as contour information, shape characteristics, colour information, and texture can be used for classification.
- Algorithms such as Logistic Regression, SVM, Random Forest, and kNN can be considered for PCB defect classification.
- The proposed system combines image-based features with ML techniques for automated inspection.

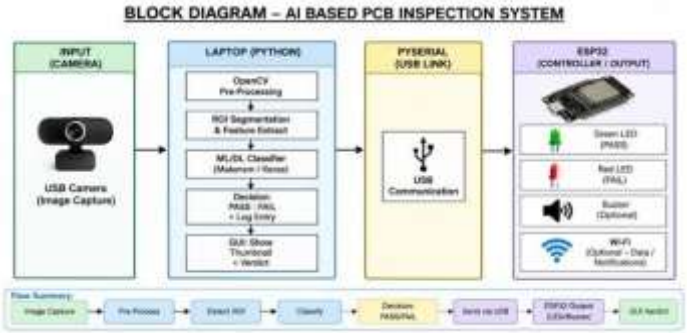
3.4 Deep Learning for PCB Inspection
- CNN-based methods can learn useful visual features directly from PCB images.
- Deep-learning approaches can support recognition of different PCB conditions when a suitable image dataset is available.
- Lightweight CNN architectures are useful when computational resources are limited; MobileNetV2 is one example designed with efficiency in mind.
- The proposed system considers a small CNN model for classifying PCB images and detecting defective conditions.

3.5 Automated Optical Inspection (AOI)
- Automatic Optical Inspection uses camera-based techniques to examine electronic assemblies.
- Automated inspection can provide consistent checking compared with repeated manual visual inspection.
- AOI concepts are useful for identifying PCB pattern abnormalities and supporting quality-control activities.

3.6 Bare PCB Track Analysis
- Bare PCB inspection mainly focuses on the correctness of copper tracks and conductive paths.
- Track breaks, open connections, short circuits, and missing paths can affect PCB operation

BLOCK DIAGRAM

BLOCK DIAGRAM DESCRIPTION



The block diagram shows the complete working flow of the AI-Based PCB Inspection System. The system has four main sections:

1. Input – USB Camera

The USB camera captures the image of the PCB.

The captured PCB image is given as input to the laptop.

Proper and controlled lighting is used to obtain better image quality and accurate inspection results.

2. Laptop – Python

The laptop performs the main image processing and AI operations.

a) OpenCV Pre-processing

The captured image is processed using OpenCV. operation such as grayscale conversion, Gaussian blur,morphological processing are performed.

These operations help to remove noise and identify the PCB tracks clearly.

b) ROI Segmentation & Feature Extraction

ROI (Region of Interest) refers to the important area of the PCB image that needs to be inspected.

The system identifies the relevant track and component regions.

Features are extracted from these regions for further classification.

c) ML/DL Classifier

Machine-learning/deep-learning techniques are used to classify the detected PCB condition.

The system can identify conditions such as clean PCB,track -cut, short circuit, PSU defect, or LED defect.

d) Decision – PASS/FAIL

After classification, the system generates a PASS or FAIL decision.

The inspection result and detected defect information can also be logged for future reference.

e) GUI

The GUI displays the PCB image or thumbnail along with the inspection result to the operator.

3. PySerial – USB Link

PySerial is used for communication between the python program and the microcontroller.

Python sends a character such as 'P' for PASS or 'F' for FAIL through USB-Serial communication.

4. ESP32 – Controller and Output

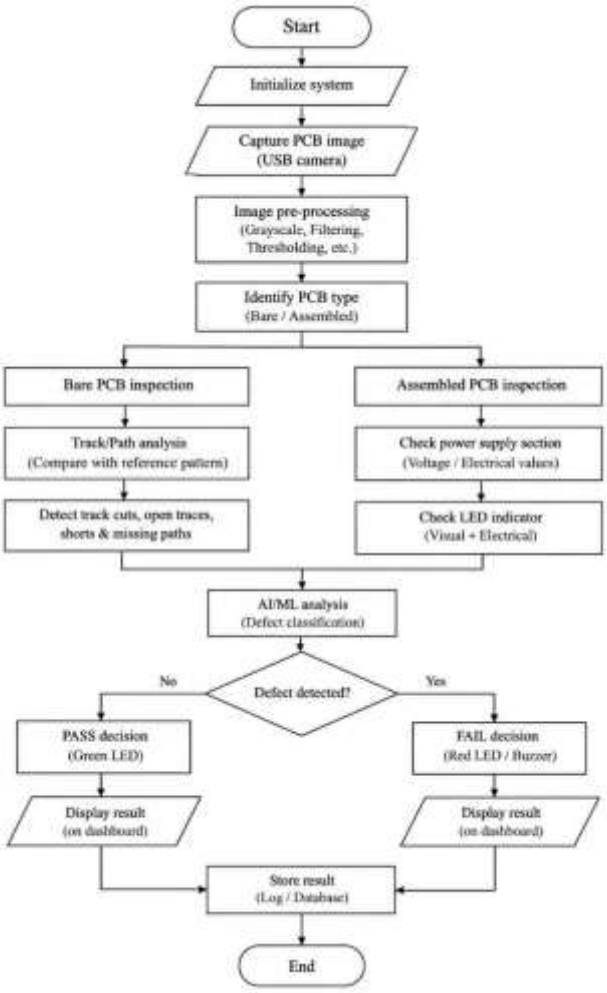
The ESP32 microcontroller receives the PASS/FAIL decision from the Python program.

If the result is PASS → Green LED is turned ON.

If the result is FAIL → Red LED is turned ON.

An optional buzzer can also be activated to indicate a fault condition

FLOWCHART



CONCLUSIONS

The AI-Based PCB Inspection and Status-Indication System provides a low-cost and automated approach for PCB quality inspection. The system uses a camera, Python, OpenCV and AI/ML techniques to inspect both bare and assembled PCBs.

The system can detect track cuts, open traces and short circuits on bare PCBs and verify the power-supply section and LED indicator on assembled PCBs. The final result is provided through a microcontroller-based Green LED for PASS and Red LED for FAIL, making the inspection result easy to understand.

Overall, the project demonstrates the basic workflow of an industrial Automatic Optical Inspection (AOI) system while keeping the implementation suitable for educational laboratories and small-scale electronics applications. The system can be further improved with multi-camera inspection, bottom-side inspection, 3D inspection and industrial system integration.,

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