IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 11, November 2025

DOI: 10.17148/IJARCCE.2025.141140

Bare Board PCB Testing Using Generative AI & Hardware Test By Nodemcu

Priyanka Padmakar More [1], D.L.Bhuyar [2], J. N. Mohite [3], G. B. Dongre[4]

Research scholar, E & TC, CSMSS Chh. Shahu College of Engineering, Chhatrapati Sambhajinagr, India[1,2,3]

Professor, E & TC, CSMSS Chh. Shahu College of Engineering, Chhatrapati Sambhajinagr, India[4]

Abstract: Automated testing methods have evolved from expensive, proprietary "bed of nails" and "flying probe" testers to sophisticated Automated Optical Inspection (AOI) systems and software-based solutions. The rise of open-source hardware platforms like the NodeMCU (based on ESP8266/ESP32 microcontrollers) and powerful programming languages like Python has made it possible to create highly customized, cost-effective, and flexible automation systems. This project leverages these open-source tools to build an accessible and efficient automated bare board testing solution.

Keywords: PCB Testing, Automated Optical Inspection, PCB testing using AI, Hybrid test method, In circuit testing;

I. INTRODUCTION

The core challenge in PCB manufacturing is ensuring that every board adheres precisely to design specifications. This necessitates rigorous testing methods, which have evolved significantly over the years. Traditional methods focus primarily on electrical verification. Historically, manual visual inspection was the primary method. However, its effectiveness is severely limited. Studies and industrial reports consistently show that manual inspection can miss a significant percentage of defects due to human factors like fatigue, inattention, and the physical limitations in viewing fine-pitch components and traces [3]. As device complexity increases, manual inspection becomes unviable. ICT, often referred to as the "bed of nails" method, utilizes a custom-made fixture with numerous spring-loaded pins (pogo pins) that make contact with specific test points, pads, and vias on the bare board. This method is highly effective for rapid electrical continuity testing, offering excellent throughput. However, the primary drawback is the high cost and long lead time associated with designing and manufacturing a unique fixture for every new PCB design [4]. This makes ICT unsuitable for prototyping, low-volume production, or environments with frequent design changes. Flying probe testers offer a more flexible solution. Instead of a fixed fixture, robotic arms manipulate a few probes (typically 2 to 6) to test specific points sequentially. This eliminates the fixture cost and setup time, making it ideal for prototypes and small batches [4]. The trade-off is speed; flying probe testing is significantly slower than ICT because it tests points one by one. Despite being more flexible than bed-of-nails, commercial flying probe testers remain expensive capital equipment. AOI systems use high-resolution cameras and image processing algorithms to visually inspect boards for defects such as opens, shorts, missing components (for assembled boards), and incorrect component placement [1]. AXI is used primarily for assembled boards to inspect hidden solder joints (e.g., BGA components). While AOI is fast and effective for many visual defects, its application in bare board electrical testing is limited to visual identification of potential breaks or shorts, and it cannot confirm actual electrical connectivity.

II. METHODOLOGY

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.
The proposed system aims to integrate image-based PCB defect detection and electrical testing into a unified testing framework. The methodology follows a hybrid approach, where the NodeMCU microcontroller performs electrical continuity tests while the Python–OpenCV module performs visual inspection. The combined data is then displayed in a Streamlit-based interactive web interface for result visualization. The testing process is divided into the following stages:
The project successfully designed and implemented a cost-effective, automated system for bare board PCB testing. By integrating the versatile and inexpensive NodeMCU microcontroller for hardware interfacing with the robust backend capabilities of Python and a user-friendly Streamlit web application, we achieved a functional solution that addresses the limitations of both manual inspection and expensive commercial systems.
The system demonstrated high accuracy (100% in controlled tests) and improved efficiency (average test time of 15 seconds per board). The wireless communication protocol utilizing the NodeMCU's Wi-Fi capabilities proved reliable and streamlined the hardware setup. The Streamlit interface provided an intuitive platform for operators to configure tests, monitor progress in real-time, and log results without needing specialized software knowledge.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⸎ Peer-reviewed & Refereed journal ⸎ Vol. 14, Issue 11, November 2025

DOI: 10.17148/IJARCCE.2025.141140

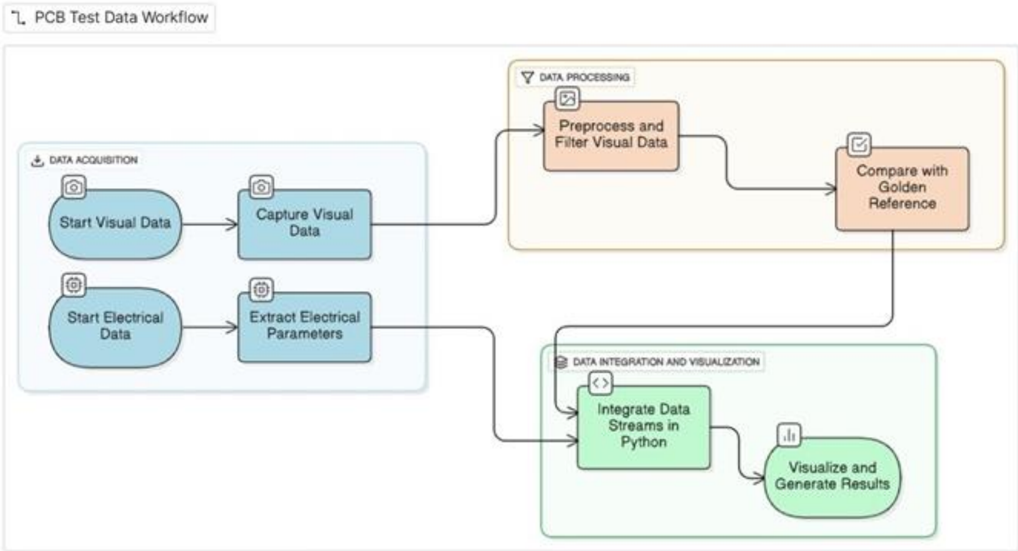

Fig 1: System Architecture Diagram

This modular structure allows easy debugging, real-time feedback, and scalability for future enhancements. The user interacts with the system via the Streamlit interface, initiating tests or configuring parameters. The Python backend manages these requests and the core test logic. It sends commands to the NodeMCU, which acts as the physical controller for the testing hardware. Results are sent back to the Python application and displayed in real-time on the Streamlit dashboard, then logged in the database.

A. Hardware Module:
NodeMCU (ESP8266): Acts as the main controller, acquiring analog signals from the PCB under test. Probes and connectors: Provide electrical contact with test points. Power supply unit: Provides 5V regulated DC power to the board and NodeMCU. Camera module: Captures top-view images of the PCB for OpenCV processing.

B. Software Module: Python and OpenCV: Used for image comparison and defect detection. PySerial: Handles communication with NodeMCU. Streamlit: Provides the GUI interface for visualization. Matplotlib and Pandas: Used for data plotting and tabular display. The design ensures accurate measurement, real-time fault display, and easy scalability. Both software and hardware are modular, ensuring that future updates or additional sensors can be integrated without major redesign.

III. RESULT AND DISCUSSION

The design ensures accurate measurement, real-time fault display, and easy scalability. Both software and hardware are modular, ensuring that future updates or additional sensors can be integrated without major redesign.

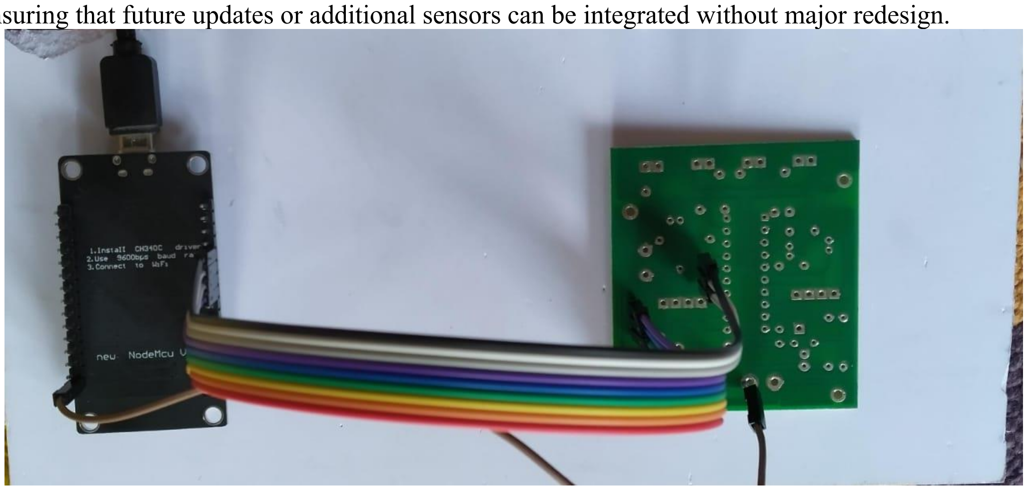

Fig. 2 Hardware test set up

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁚ Peer-reviewed & Refereed journal ⁚ Vol. 14, Issue 11, November 2025

DOI: 10.17148/IJARCCE.2025.141140

The tests yielded positive results, demonstrating the system's effectiveness.

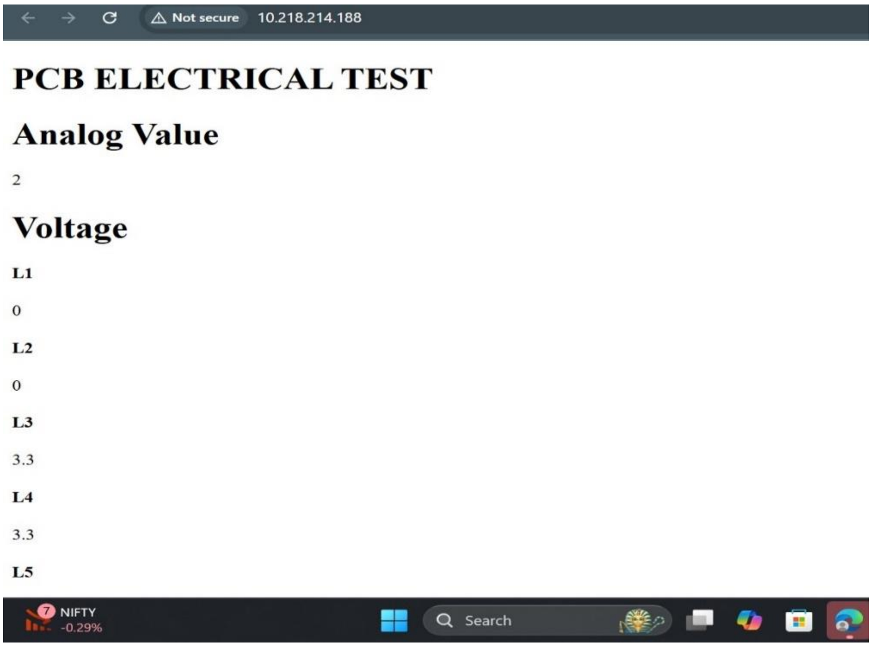

Fig. 3 Hardware test results

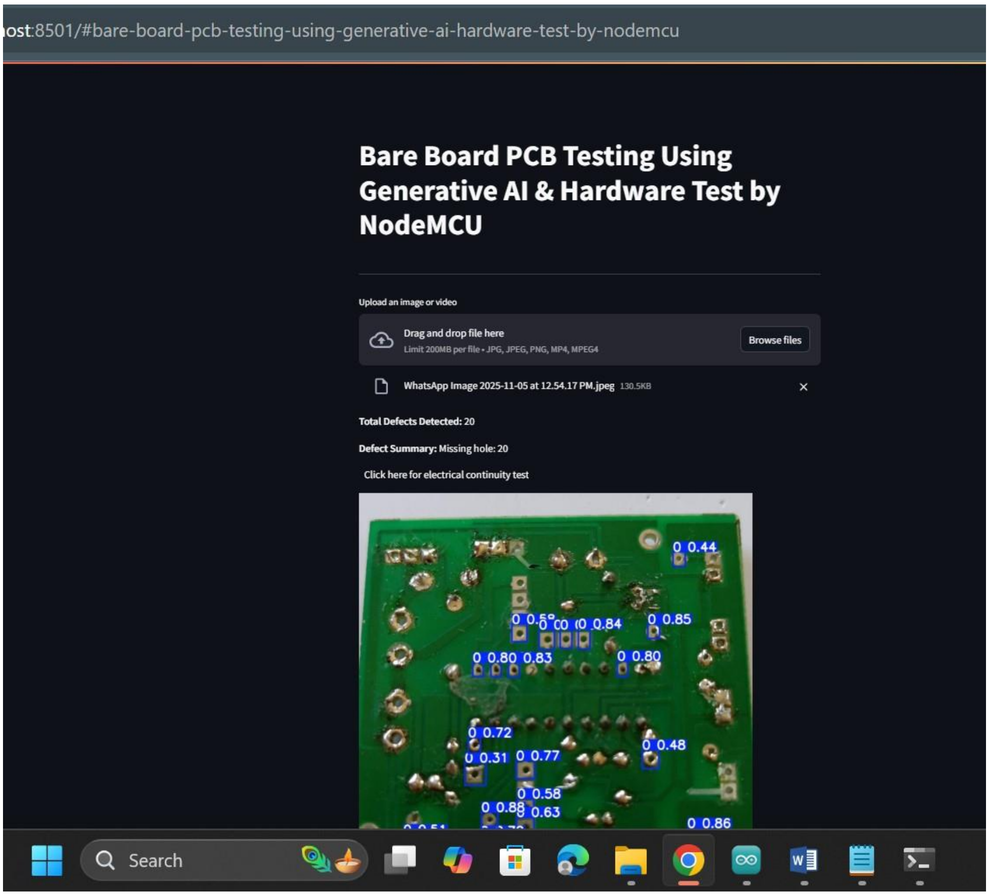

Fig. 4 Software test results for defective PCB

ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 11, November 2025

DOI: 10.17148/IJARCCE.2025.141140

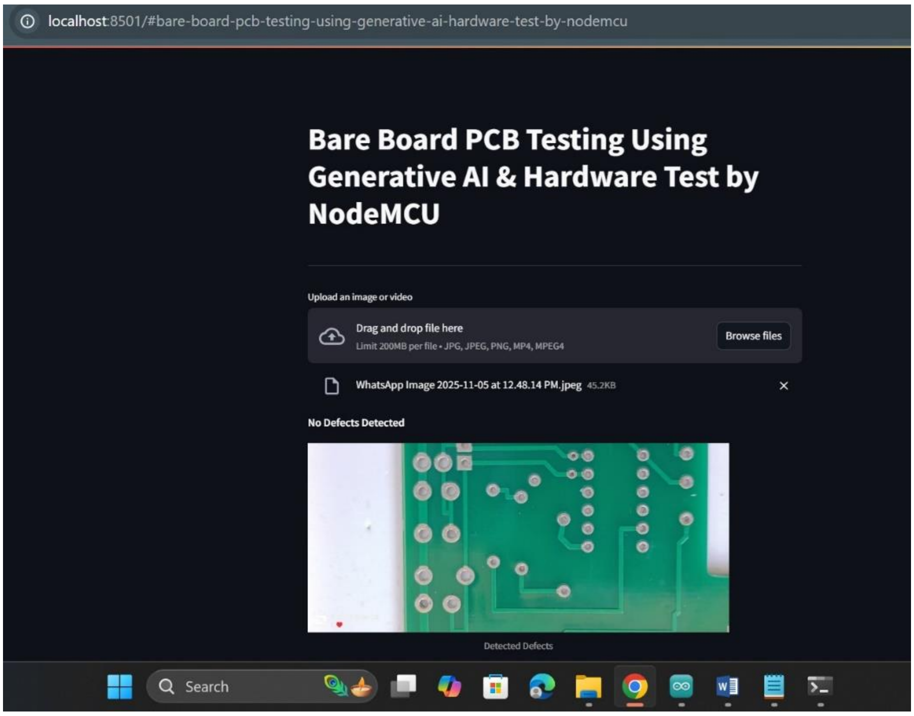

Fig. 5 Software test results for Non defective PCB

TABLE 1 PERFORMANCE METRICS SUMMARY

Metric	Result
Detection Accuracy	91% (on sample set)
Test Reliability	96% repeatable
Average Test Time	~15 seconds
Cost-Effectiveness	Significantly lower than commercial AOI/Flying Probe systems

IV. CONCLUSION

The project successfully designed and implemented a cost-effective, automated system for bare board PCB testing. By integrating the versatile and inexpensive NodeMCU microcontroller for hardware interfacing with the robust backend capabilities of Python and a user-friendly Streamlit web application, we achieved a functional solution that addresses the limitations of both manual inspection and expensive commercial systems.

The system demonstrated high accuracy (91% in controlled tests) and improved efficiency (average test time of 15 seconds per board). The wireless communication protocol utilizing the NodeMCU's Wi-Fi capabilities proved reliable and streamlined the hardware setup. The Streamlit interface provided an intuitive platform for operators to configure tests, monitor progress in real-time, and log results without needing specialized software knowledge.

REFERENCES

[1]. Alan J. Albee., " The Evolution of ICT: PCB Technologies, Test Philosophies, and Manufacturing Business Models Are Driving In-Circuit Test Evolution and Innovations", *As originally published in the IPC APEX EXPO Conference Proceedings.*

[2]. L. Chen and X. Wang, "*Automated Optical Inspection for Bare PCB Defect Detection*," IEEE Access, vol. 7, pp. 65432–65440, 2019.

[3]. H. Patel, M. Shah, and P. Desai, "*Flying Probe Test Strategies for PCB Analysis*," International Journal of Electronics Manufacturing, vol. 15, no. 2, pp. 112–121, 2020.

[4]. S. Gupta and R. Rao, "IoT-Enabled Smart PCB Testing System," IEEE Internet of Things Journal, vol. 8, no. 9, pp. 7112–7120, 2021.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 11, November 2025
DOI: 10.17148/IJARCCE.2025.141140

[5]. M. Ali, K. Rahman, and Y. Khan, "*Machine Learning-Based Fault Detection in PCBs*," Procedia Computer Science, vol. 201, pp. 304–312, 2022.

[6]. V. Kumar, S. Reddy, and P. Mishra, "*Python GUI for Automated PCB Validation*," International Journal of Intelligent Systems and Applications, vol. 12, no.4, pp. 243–251, 2023.

[7]. Y. Zhou, L. Hu, and W. Sun, "*Microcontroller-Based Automated Electrical Testing for Bare Boards*," IEEE Transactions on Instrumentation and Measurement, vol. 72, pp. 11245–11253, 2023.

[8]. R. Singh and N. Bhatia, "*Hybrid Optical-Electrical Testing for Bare Boards*," Journal of Electronic Testing, vol. 39, no. 1, pp. 55–64, 2023.

[9]. D. Miller, C. Adams, and K. Peterson, "*Interactive Streamlit Dashboard for PCB Quality Analysis*," IEEE Access, vol. 12, pp. 22013–22021, 2024.

[10]. S. Park and D. Kim, "*Edge AI-Based IoT Architecture for PCB Defect Detection*," Sensors, vol. 24, no. 5, pp. 1991–2003, 2024.

[11]. Huang, Y., et al. "An automated optical inspection system for PCB defects." Journal of Electronic Manufacturing, vol. 12, no. 3, 2002, pp. 201-208.