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Non-Destructive Testing of Printed Circuit Boards Using Ultrasonic Imaging and CNNs

Venkatesh D
Department of ECE
PSG Institute of Technology and Applied Research
Tamilnadu, India
venkateshd@psgitech.ac.in

Surya R
Department of ECE
PSG Institute of Technology and Applied Research
Tamilnadu, India
23l216@psgitech.ac.in

Thiru Murugan A
Department of ECE
PSG Institute of Technology and Applied Research
Tamilnadu, India
23l219@psgitech.ac.in

Parishith A I
Department of ECE
PSG Institute of Technology and Applied Research
Tamilnadu, India
23l168@psgitech.ac.in

Thanwanth V G
Department of ECE
PSG Institute of Technology and Applied Research
Tamilnadu, India
23l205@psgitech.ac.in

***Abstract*- A novel non-destructive testing (NDT) system for detecting structural defects in Printed Circuit Boards (PCBs) using real-time B-scan imaging by air-coupled ultrasonic transducers and integrating deep learning is proposed in this article. Traditional inspection methods like visual inspection and X-ray inspection are likely to miss hidden defects, especially in multilayer PCBs. To bridge these gaps, we introduce a contactless inspection method with high-frequency air-coupled ultrasonic transducers for B-scan imaging and a convolutional neural network (CNN) for the classification of defects. Air-coupled transducers facilitate non-contact testing, minimizing handling risks and placing the system in a position for inline production testing. Noise reduction and contrast enhancement are preprocessing techniques used to enhance image quality. The CNN model is pretrained from B-scan images for detection of common PCB defects such as solder voids, delamination, trace breaks, and short circuits. The system has a classification accuracy of 96% in a specific dataset. The improved model is executed on an embedded edge AI device for the intent of real-time low-latency fault detection. Comparisons against benchmark performance indicate that this technique is faster, more accurate, and more suitable to use in automated manufacturing than current techniques of inspection. The applicability of the integration of air-coupled ultrasonic B-scan imaging and AI in providing sophisticated, noncontact PCB inspection is proven by this research.**

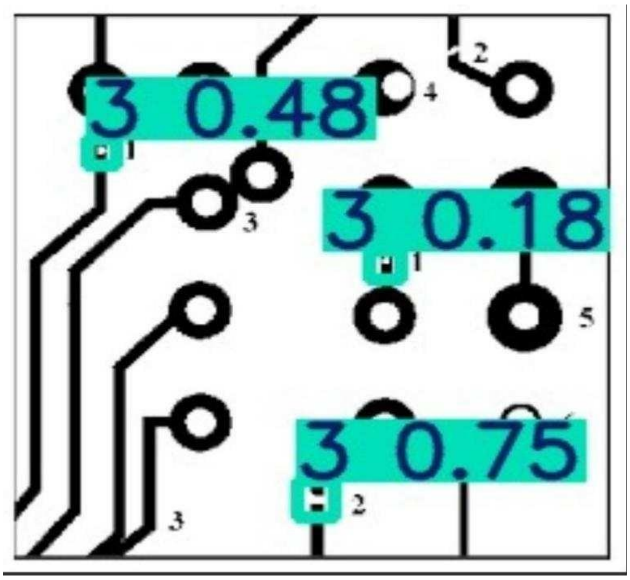
Keywords—PCB, Ultrasonic Imaging, Deep Learning, CNN, Non-Destructive Testing, Defect Detection

I. INTRODUCTION

Expansion in the intricacy and diminishing dimensions of electronic products in industries like aerospace, medical diagnostics, consumer electronics, industrial automation has focused more importance on aggressive, high-resolving inspection techniques to validate the structural integrity of Printed Circuit Boards (PCBs). PCBs are the building platform in electronic systems, offering interconnection between important constituents by way of complex conductive channels and multilayer configurations. With high-density, multi-layer PCBs now the standard in modern electronics, traditional inspection techniques are under greater pressure to detect subsurface and microstructure defects that can compromise device reliability. This work presents the design of a low-power, filter-based NS SAR ADC that addresses these issues. The proposed architecture uses innovative methods to advance resolution, reduce power, and enhance PVT robustness. The emphasis is placed majorly on optimizing the noise-shaping loop, minimizing nonlinearity and power dissipation, which will make the design suitable for low-power next-generation products. The faults like delamination, via crack, solder voids, and internal shorts might not be detectable by standard surface-based inspection technologies like visual inspection or Automated Optical Inspection (AOI).

While superior coverage is provided by In-Circuit Testing (ICT) and X-ray inspection, they are generally constrained in resolution, expense, or the capability to detect internal faults without human oversight. These constraints necessitate smarter, non-contact test systems that are able to test real time with little setup and no contact with sensitive electronic assemblies. To address these issues, in this article, an aircoupled ultrasonic imaging system with deep learning enhancement is presented for non-destructive defect inspection of PCBs. Unlike the traditional ultrasonic methods with liquid or gel coupling mediums, the system is designed on an air-coupled transducer, which does not require contact-based coupling and is more suitable in automated inline inspection conditions.

The ultrasonic waves propagate through the air gap between the layers of the PCB and reflect according to the internal status and defect condition. The reflection is detected as B-



These classes were categorized in the dataset and used during training the model to enable the YOLOv5 model to learn to detect and classify different forms of PCB defects. The number of samples per class also indicates a reasonably balanced dataset, promoting model robustness and generalizability against different kinds of defects.

V. CONCLUSION

This paper presents a strong and efficient non-destructive testing (NDT) technique for Printed Circuit Boards (PCBs) by integrating ultrasonic imaging with deep learning-based classification to improve inspection accuracy and reliability. The system overcomes the limitations of traditional methods with the ability to detect subsurface and microstructure flaws like delamination, solder voids, short circuits, and ruptured traces. Using ultrasonic B-scan imagery and a Convolutional Neural Network (CNN), the system can obtain 96% classification accuracy in showing competence in single-layer as well as multilayer PCB constructs. To validate its applicability in the real world, the model is executed on an embedded platform for real-time fault detection, showcasing its viability for use in automated electronic manufacturing plants. Comparison shows that the new method is superior to conventional inspection techniques in terms of detection accuracy, flexibility, and processing time.

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