Unsupervised Learning-Based Defect Detection in PCB Circuit Images for Automated Quality Inspection

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***Abstract*— Printed Circuit Boards (PCBs) are fundamental components in modern electronic devices, and their quality directly affects product reliability. Conventional inspection processes often rely on supervised learning models that require a large amount of annotated defect data. However, collecting and labeling defect samples is costly and impractical due to the diverse and unpredictable nature of PCB defects. In this study, we propose an unsupervised learning-based defect detection framework that leverages PCB circuit images for automated quality inspection. The approach employs convolutional autoencoders to learn standard pattern representations without requiring labeled defect data. Anomalous regions are detected by reconstruction error analysis, and statistical thresholds are applied to classify pass/fail conditions. To evaluate the effectiveness, experiments were conducted on a dataset of PCB circuit images, including both standard and defective samples. The proposed method demonstrated high detection accuracy with minimal false positives, outperforming baseline thresholding and clustering-based approaches. Moreover, the framework showed robustness to varying defect types such as missing tracks, misalignments, and surface contamination. These results suggest that unsupervised learning can serve as a practical alternative to traditional supervised inspection methods in PCB manufacturing. The proposed method reduces dependency on labeled datasets, enhances adaptability to new defect patterns, and contributes to the realization of intelligent and automated quality inspection systems in smart manufacturing environments.**

***Keyword*— Anomaly Detection, Unsupervised Learning, PCB Circuit Images, Smart Manufacturing, Quality Inspection**

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