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Research Article

PCB Inspection System Using Image Processing in Matlab

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ABSTRACT

In Existing method where engineers or technicians visually examine PCBs for defects such as missing components, misalignments, soldering issues, and short circuits. This process requires skilled professionals to carefully inspect each board under magnification or with the naked eye. This project presents an PCB defect detection system using MATLAB's image processing capabilities. The proposed method loads a reference and an inspection image, aligns them using affine transformation, and applies Gaussian filtering and adaptive histogram equalization for enhancement. After binarization, an XOR operation detects defects, which are refined through morphological filtering. Valid defects are classified based on area, eccentricity, and solidity. The system visually marks defects on the PCB and generates a processed image with bounding boxes. The approach improves defect detection accuracy while reducing manual inspection efforts, making it suitable for industrial applications.

Keywords: Anomalies Optical Inspection (AOI), PCB Defect Detection, Affine Transformation.

1.INTRODUCTION

Bare printed circuit board is a PCB without any placement of electronic components. In order to reduce cost spent on manufacturing caused by defected bare PCB, the bare PCB must be check firstly. Printed circuit board (PCB) is a mechanical platform of conductive and non-conductive layers on which electronic components are electrically connected. Glass fibers and epoxy is used to form non-conductive layer of the PCB and copper, nickel, aluminum, chrome and other certain metals are used form the conductive layer of the PCB. Fabrication of PCB is a multilevel process inhibiting several multidisciplinary processes. Etching is one such process in the PCB fabrication wherein unwanted metallic portion occurring in places other than the designed pattern is removed. If the PCB defects are still present in the final etching inspection process, PCBs are considered as the scrap and can be thrown out from process. The 70% of the PCB fabrication cost is utilized for etching process, so we mainly focus on ethching process. We detect fault and classify them based on overetch, underetch or both. We using subtraction method to detect fault by comparing template PCB and real time PCB.

PCB inspection using image processing in MATLAB involves acquiring images of the PCB, applying filters to remove noise, detecting defects such as cracks, scratches, and missing components using techniques like thresholding, edge detection, and morphological operations, and classifying defects using machine learning algorithms. MATLAB provides an ideal platform for rapid prototyping and development of PCB inspection algorithms, with extensive toolbox support for image processing, machine learning, and computer vision, enabling accurate and efficient inspection of PCBs Banking is one of the widely known area where OCR is used for automatic processing

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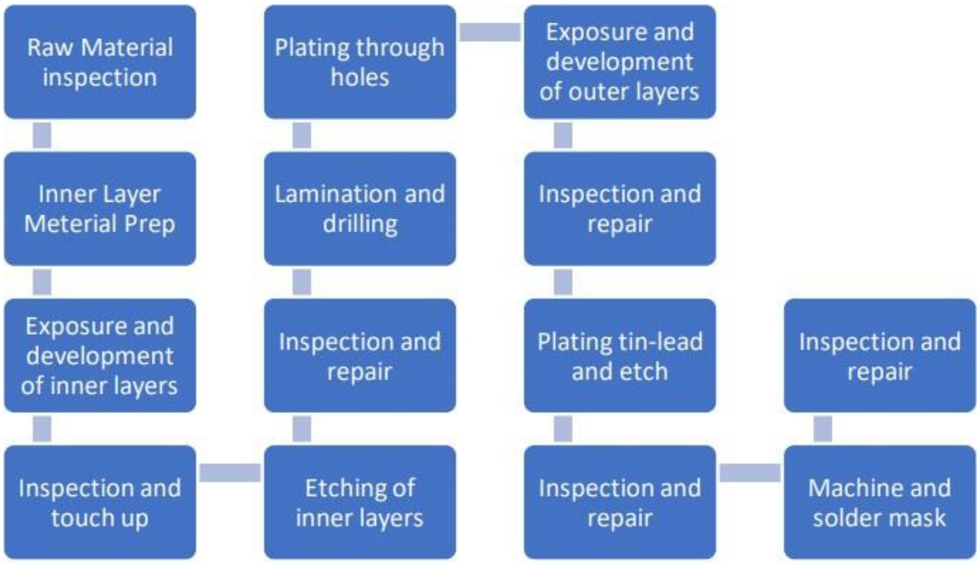

Fig.1.1: Printed Circuit Board Manufacturing Flow Diagram

In the Fig. 1.1, shows Imperfections on PCB can be categorized into two sectors, Cosmetic defects and Functional defects. It is critical to identify both of these deformities to produce a PCB with a 100% quality confirmation. Functional defects are considered to be fatal issues, which means the PCB does not attend the objective they are designed for; conductor breaking and short-circuit are some of the defects in this category. Cosmetic defects are imperfections that compromise the appearance of the PCB, for example, pinhole, breakout, over-etch, and under-etch. Cosmetic defects won't pose an immediate threat to the operation of the PCB but can jeopardize the performance of it in the long run due to abnormal heat dissipation and distribution of current.

2. LITERATURESURVEY

Printed Circuit Board (PCB) defect detection has been an active area of research due to its importance in quality control for electronics manufacturing. Various approaches utilizing image processing, mathematical morphology, machine vision, and artificial intelligence have been developed. Below is a literature survey summarizing key contributions from different studies.

Indera Putera et.al., [1] explored the use of mathematical morphology combined with MATLAB-based image processing tools for detecting PCB defects and demonstrated effective segmentation techniques that enhance defect visualization.

Heriansyah et.al., [2] introduced segmentation methods for PCB images by applying mathematical morphology and windowing techniques and focused on improving pattern recognition for PCB defect classification and the approach enhances defect identification by reducing complex background variations.

Khalid, [3] discussed an image processing approach for classifying different PCB defects and presented feature extraction methods for defect identification and used a combination of edge detection and blob analysis to improve classification accuracy.

Heriansyah, [4] explored neural network-based classification for PCB defects and highlighted the advantages of machine learning in improving defect detection accuracy and the study demonstrates the use of supervised learning techniques for enhancing detection performance.

Wu et.al., [5] examined machine vision applications in automated PCB inspection and emphasized image processing techniques and real-time defect identification and utilized template matching and morphological processing for robust defect detection.

Moganti et.al., [6] provided a comprehensive survey on PCB inspection methodologies and reviewed existing techniques and their effectiveness in automated PCB inspection and discussed feature extraction, defect

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classification, and comparison of algorithms and identified limitations in traditional inspection techniques and suggests improvements.

Taniguchi et.al., [7] investigated the use of eddy-current techniques combined with image processing for defect detection and focused on non-destructive testing methods and enhanced defect identification through hybrid sensor and vision-based techniques.

Chomsuan et.al., [8] developed a PCB inspection system integrating eddy-current testing with a specialized sensor and enhanced detection precision for surface and subsurface defects and incorporates machine learning to classify detected anomalies.

Guo et.al., [9] studied machine vision applications for automated PCB defect inspection and demonstrated improvements in defect detection through advanced imaging techniques and used adaptive thresholding and deep learning models to improve defect detection rates.

Wu et.al., [10] explored automated visual inspection techniques for surface-mounted components and focused on quality assurance in PCB assembly and implemented feature-based recognition techniques to minimize false positives.

Duan et.al., [11] presented an optical inspection method for detecting drill bit defects in PCB manufacturing and utilized pattern classification techniques to improve defect recognition and developed an AI-assisted classification model for micro-drill bit quality assessment.

Opera et.al., [12] investigated methods to identify misplaced drill holes using image analysis and enhanced accuracy in PCB defect localization and employed contour analysis and probabilistic modelling for improved precision.

Ercal et.al., [13] discussed various algorithms used in automatic PCB inspection, including image processing and machine vision techniques and compared different defect detection methods such as reference comparison, design-rule verification, and hybrid approaches and highlighted the role of artificial intelligence in improving detection accuracy.

Taha et.al., [14] provided a survey on automatic optical inspection (AOI) techniques in PCB manufacturing and discussed the advantages of AOI over manual inspection methods and analysed different optical inspection technologies, including pattern matching and machine learning-based approaches and reviewed emerging trends in AI-driven inspection techniques.

Benedek, [15] proposed a novel hierarchical marked point process-based approach for detecting soldering defects and utilized a probabilistic framework to enhance defect identification and demonstrates improved defect classification accuracy compared to traditional image processing techniques.

Kobayashi et.al., [16] introduced a hybrid method combining shape measurement and feature extraction for detecting defects in complex PCB patterns and focused on improving accuracy in identifying intricate defect patterns and incorporates machine learning techniques for better classification and localization of defects.

Chen et.al., [17] presented a smart machine vision system for PCB defect detection and utilized advanced image processing techniques to enhance defect identification and employed intelligent algorithms for pattern recognition and automated defect classification and demonstrated improvements in accuracy and efficiency for industrial PCB inspection.

Tsai et.al., [18] proposed a non-referential, self-compared defect inspection method for bond pads with deformed shapes and focuses on detecting shape deformations without requiring a reference image and used statistical shape analysis and adaptive thresholding techniques to improve accuracy and demonstrates effectiveness in identifying defects in complex PCB structures.

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3. DESIGN METHODOLOGY:

PCB Defect Detection System: Process Description

1. Image Acquisition

Image acquisition captures digital images of printed circuit boards (PCBs) to establish the foundation for downstream analysis and ensure overall detection accuracy.

Hardware Components

- **High-Resolution Cameras:** Industrial-grade cameras (5–20 MP) capture detailed board images.
- **Uniform Lighting Systems:** LED arrays or ring lights provide consistent illumination to minimize shadows and reflections.
- **Positioning Mechanisms:** Precision stages or conveyor systems ensure reproducible board positioning.
- **Optical Systems:** Lenses with appropriate focal lengths and minimal distortion capture the entire PCB or specific regions.

Acquisition Parameters & Process

- **Parameters:** Resolution is set at 50–100 µm per pixel. Calibrated exposure control maintains detail across dark and bright areas. Grayscale images are preferred to save processing power, though multiple angles can be used for height defects.
- **Process Sequence:** 1. The PCB enters the imaging area via manual or automated conveyance. 2. The system positions the PCB precisely under the camera, verifying and adjusting lighting. 3. Reference position markers (fiducials) are identified for alignment. 4. Inspection and reference (known good) images are captured and transferred to the processing system.

Quality Assurance Measures

- Regular camera calibration and lighting condition monitoring maintain uniformity across inspections.
- Board reference markers enable accurate registration, while automated quality metrics validate images before processing

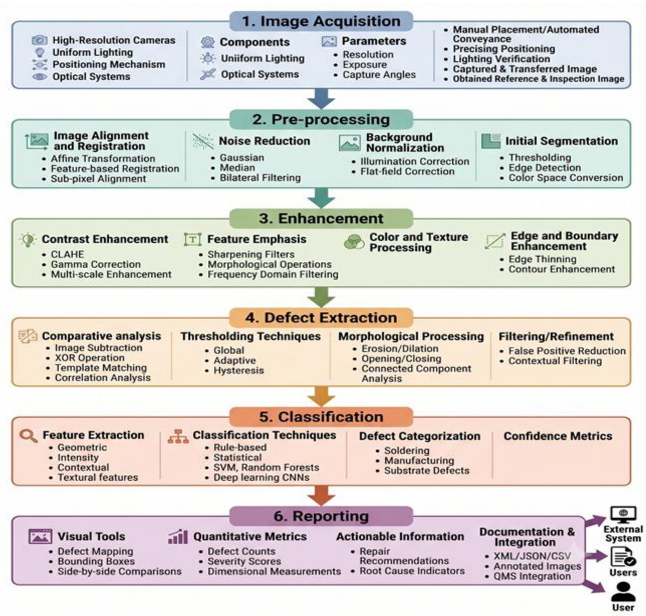

Fig.1.2: Proposed Work Block Diagram

2. Pre-processing

Pre-processing transforms raw images into a standardized format optimized for analysis by addressing alignment differences, noise, and inconsistent illumination.

Image Alignment, Registration & Noise Reduction

- **Alignment:** Affine transformations correct translation, rotation, and scaling differences. Feature-based registration uses fiducial markers or board edges to align images alongside geometric and sub-pixel corrections.
- **Noise Reduction:** Gaussian, median, and bilateral filtering reduce random or "salt and pepper" noise while preserving critical edges. Temporal averaging is used if multiple images are available.

Background Normalization & Initial Segmentation

- **Normalization:** Illumination and flat-field corrections compensate for uneven lighting, while background subtraction highlights anomalies.
- **Segmentation:** Thresholding, edge detection, and color space conversions (e.g., RGB to HSV/Lab) separate features from the background to isolate the Region of Interest (ROI).

Implementation Considerations

- System throughput is maintained via parallel processing, hardware acceleration, and optimized pipeline architectures.
- Efficient memory management handles high-resolution images, and automated quality metrics guarantee standardization.

3. ENHANCEMENT

Image enhancement improves the visibility and detectability of potential defects by optimizing contrast, emphasizing relevant features, and suppressing background noise.

Contrast and Feature Emphasis

- **Contrast:** Techniques include Contrast Limited Adaptive Histogram Equalization (CLAHE), gamma correction, and multi-scale enhancement to optimize local details without over-amplifying noise.
- **Feature Emphasis:** Sharpening filters (unsharp masking), high-pass filtering, morphological operations, and frequency domain filtering emphasize high-frequency components and shapes associated with defects.

Edge, Boundary & Adaptive Processing

- **Edge Processing:** Operators like Sobel or Canny highlight component boundaries. Edge thinning reduces width to single-pixel precision, and contour/junction detection highlights feature outlines.
- **Adaptive Enhancement:** Content-aware and reference-guided processing dynamically adjust parameters based on regional board characteristics, targeting defect-specific features.

4. DEFECT EXTRACTION

Defect extraction identifies and isolates anomalies by comparing the processed inspection image against a reference model.

Extraction Techniques

- **Comparative Analysis:** Employs pixel-by-pixel image subtraction, XOR operations on binary images, correlation analysis, and template matching against stored part models.

- **Thresholding & Morphology:** Global, adaptive, and hysteresis thresholding separate defect regions. Morphological operations (erosion, dilation, opening, closing) and Connected Component Analysis (CCA) smooth contours and label distinct anomalies.
- **Filtering & Refinement:** Potential defects are filtered by size, shape, and context relative to surrounding components to minimize false positives.

5. CLASSIFICATION

Classification categorizes detected anomalies into specific defect types or false alarms based on extracted features to provide feedback to manufacturing.

Feature Extraction & Classification Techniques

- **Features:** Extracted features include geometric properties (area, perimeter, eccentricity), intensity statistics, textural characteristics, and contextual position.
- **Techniques:** Utilizes rule-based decision trees, statistical classifiers (Bayesian), machine learning (SVM, Random Forests), and deep learning models like Convolutional Neural Networks (CNNs).

Defect Categorization & Refinement

- **Categories:** Classified into manufacturing (missing parts), soldering (bridges, insufficient solder), copper (opens, shorts), substrate (cracks, contamination), or component defects (wrong polarity).
- **Refinement:** Classifications are refined using ensemble methods, context-sensitive design data, and confidence metrics (probability scores, confusion matrices) paired with operator feedback learning.

6. REPORTING

Reporting communicates inspection results in a clear, actionable format to support defect remediation, process improvement, and quality documentation.

Visual and Quantitative Output

- **Visual:** Generates defect maps, color-coded bounding boxes, magnified anomaly views, and side-by-side reference comparisons.
- **Quantitative:** Logs defect counts by category, dimensional measurements, severity scores, and production batch trend analysis.

System Integration & Interactive Features

- **Actionable Data:** Outlines pass/fail decisions, priority rankings, repair recommendations, and precise coordinate logs for automated repair machinery.
- **Integration:** Exports structured data (XML, JSON, CSV) and annotated images to Quality Management Systems (QMS) and production control lines to maintain manufacturing traceability.
- **User Interface:** Interactive tools feature zoom/pan controls, defect filtering, manual verification logging, and historical batch comparisons.

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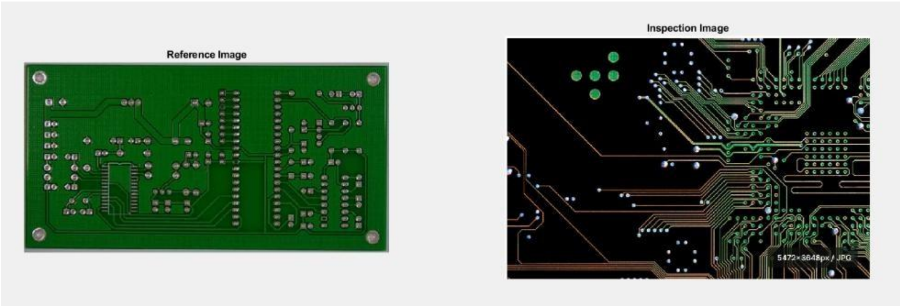
RESULTS:

Step 1: Load Reference Image and Inspection Image

Fig : **Reference Image and Inspection Image**



Step 2: Convert Images into Gray Scale

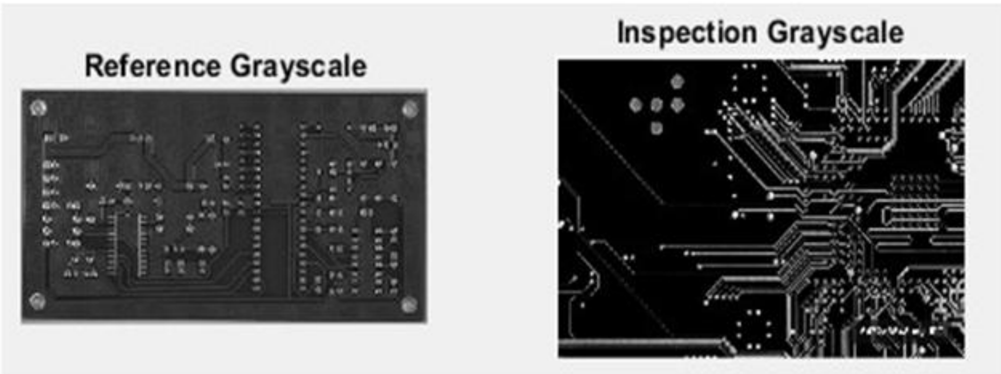
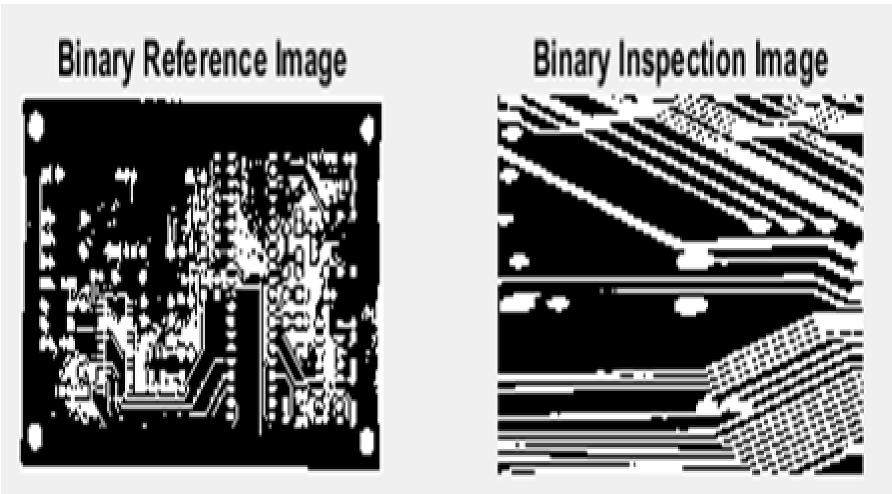


Fig : **Gray Scale Images**



Step 3: Convert Gray Scale Images into Binary Images

Fig :Binary Reference Image and Inspection Image

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Step 4: Difference Image (Detected Images)

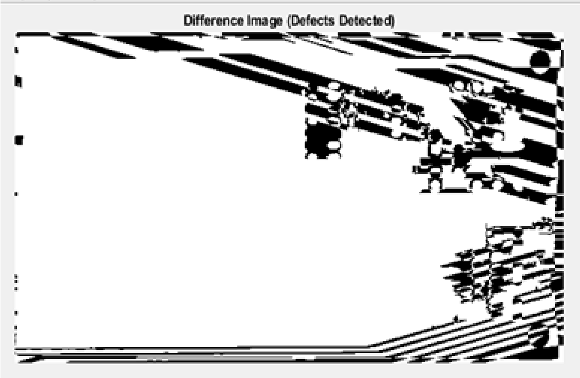
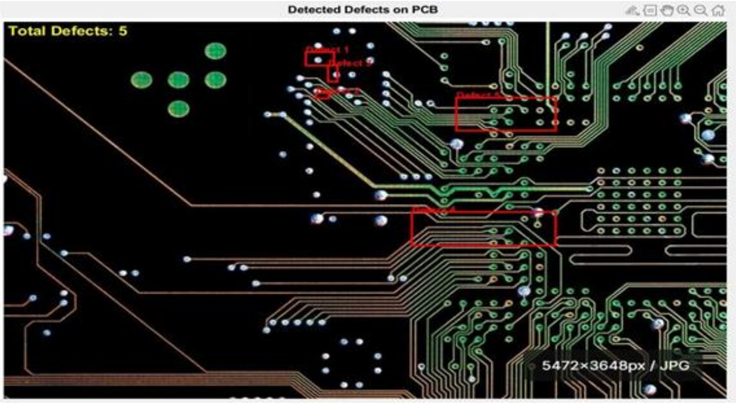


Fig : Difference Image

Step 5: Detected Defects On PCB



CONCLUSION:

This research presents a MATLAB-based PCB Inspection System that automates the detection of defects using image processing techniques such as filtering, binarization, and morphological operations. By comparing inspection images against reference images, the system accurately identifies and visually highlights defects, eliminating the inconsistencies and delays associated with manual inspection. The system proves robust under real-world challenges like lighting variations, noise, and misalignment, making it reliable for practical deployment. Its ability to integrate into live production lines further enhances manufacturing efficiency and reduces human effort. In summary, this system offers a scalable, accurate, and efficient approach to PCB quality control — making it a valuable tool for electronics manufacturing, quality assurance, and research applications.

FUTURE SCOPE:

.AI- Based Detection - Use deep Learning (CNNs) for better accuracy.

Real-Time Processing – Make the system faster with high-speed cameras.

Cloud Storage – Store and analyze data remotely.

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