Introduction to PCB Defect Detection

What are PCBs?

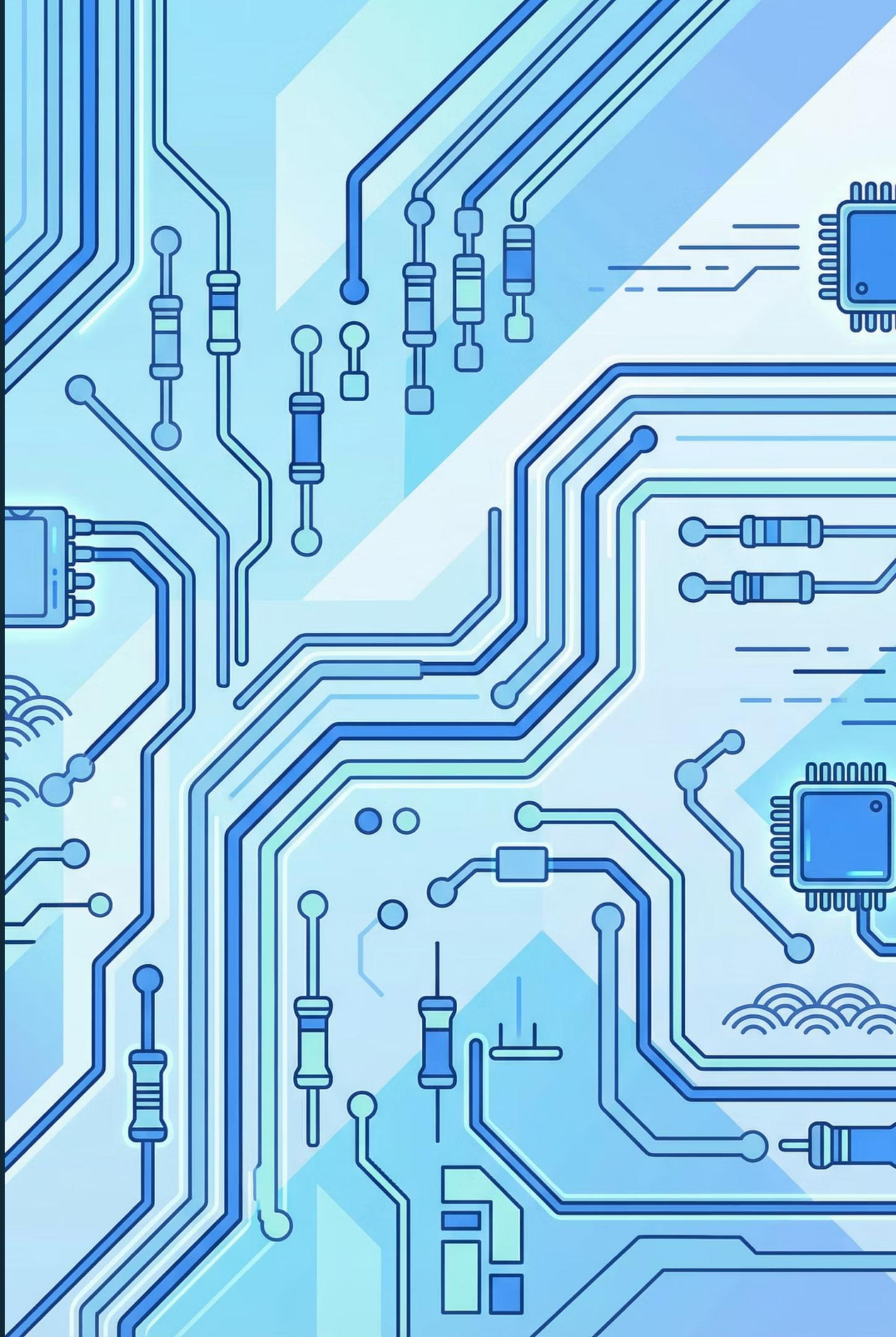
Printed Circuit Boards (PCBs) are the fundamental building blocks of modern electronic devices, providing the electrical connections that enable components to function.

- Essential in **mobile phones, medical devices, cars, industrial machinery, and aerospace applications**.

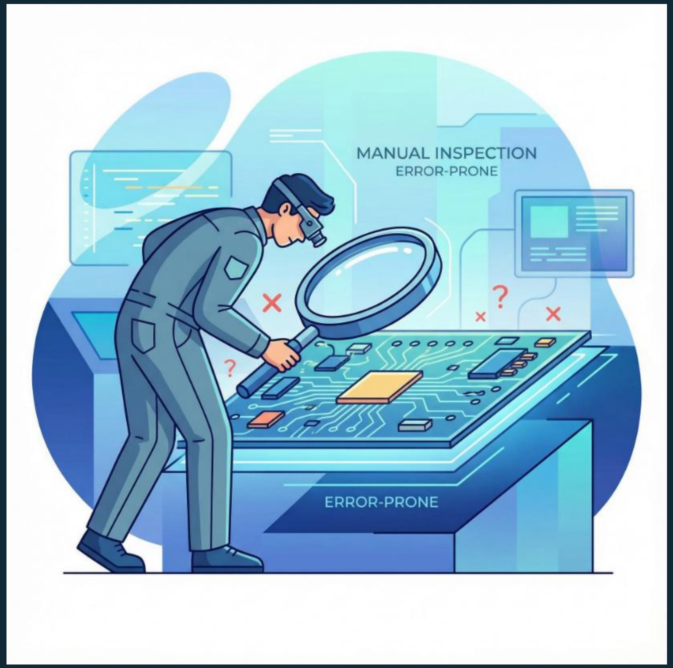
Why are PCB Defects Critical?

Even minute imperfections can lead to catastrophic system failures and significant operational risks.

- Defects cause **short circuits, open circuits, overheating, device malfunctions**, or complete operational failure.



The Problem We Are Solving: Enhancing PCB Quality Control



Current Manufacturing Challenges

Traditional manual inspection methods are:

- **Slow:** Inefficient for high-volume production.
- **Error-Prone:** Susceptible to human fatigue and oversight.
- **Costly:** High labor expenses at scale.

Traditional rule-based machine vision struggles with:

- **Irregular defects:** Inconsistent patterns are hard to define by rules.
- **Varying conditions:** Lighting and PCB layouts create inconsistencies.

Our Goal: Automated, Real-time PCB Quality Control

To develop an advanced system that:

- Compares a test PCB against a **golden reference standard**.
- Precisely **detects defective regions** on the board.
- Accurately **classifies defect types** using deep learning.
- Generates **annotated results and comprehensive analytics**.

This system ensures **fast, reliable, and real-time PCB quality control**, transforming manufacturing efficiency.

Industry Relevance: The Impact of Automated PCB Inspection

1

Ubiquitous Integration

PCBs are integral to virtually **every electronic product**, driving exceptionally high production volumes globally.

2

Market Value & Costs

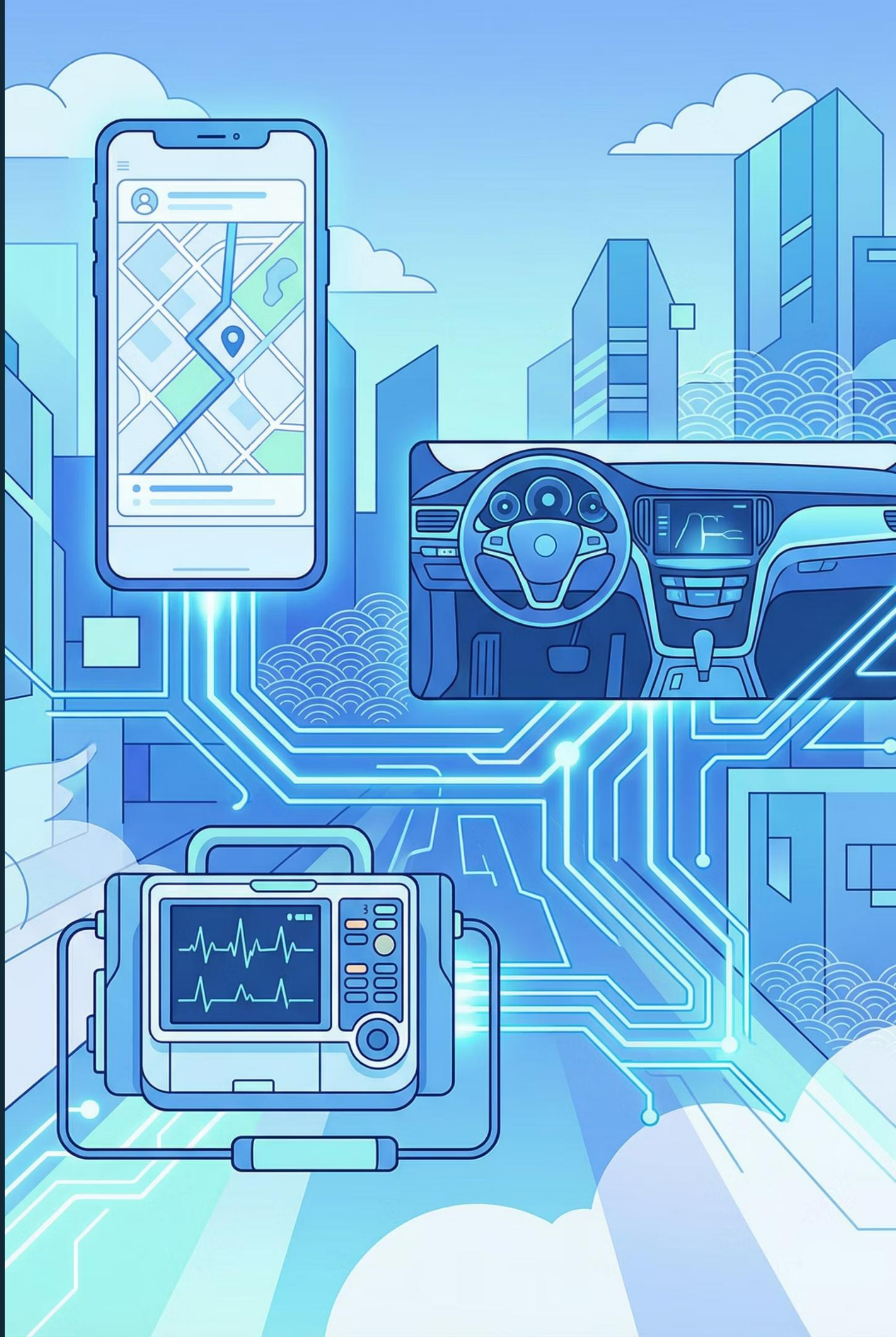
The global PCB industry is valued at **over $80 billion**. Even a **1% defect rate** can cost manufacturers millions annually.

3

Automated Inspection Benefits

Significantly **reduces scrap, prevents costly product recalls**, and **improves safety** in critical sectors like automotive, aerospace, and medical.

This project delivers a **scalable quality control solution** by integrating Computer Vision, Deep Learning, and Web deployment for versatile application across any production line.



Dataset Used: Kaggle PCB Defects Dataset

Dataset Source

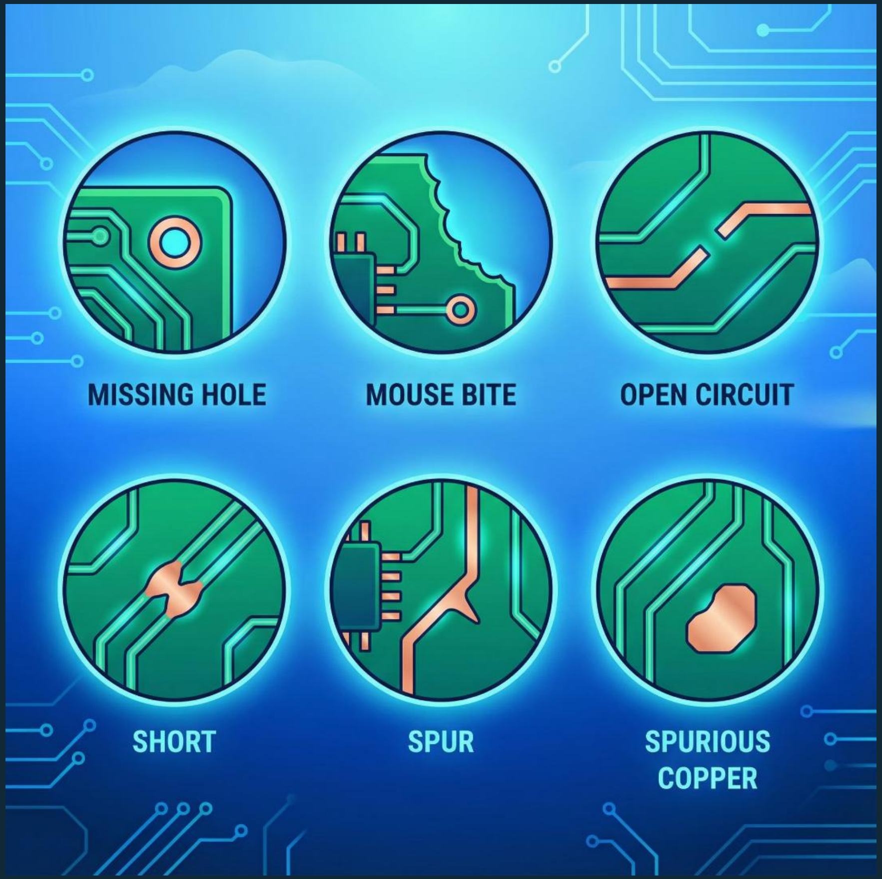
https://www.kaggle.com/datasets/akhatova/pcb-defects

Our project leverages the comprehensive **Kaggle PCB Defects Dataset**.

It includes:

- Golden PCB images (defect-free references)
- Corresponding defective PCB images

> This high-quality dataset is crucial for training robust supervised learning models capable of accurate defect detection.



Dataset Details

The dataset containing 1386 images with **six distinct defect types**:

- Missing Hole
- Mouse Bite
- Open Circuit
- Short
- Spur
- Spurious Copper

Preprocessing Pipeline: From Raw Images to Clean Defect Samples

We developed custom preprocessing scripts (e.g., B&W.py, image_subtraction.py, contour.py) to meticulously prepare the data.

Image Standardization

Convert RGB images to **Grayscale** and normalize their **size and orientation** for consistent analysis.

Image Subtraction

Utilize `cv2.absdiff()` to compare the test PCB against the golden reference, generating a binary map of actual defect regions.

Thresholding

Apply `cv2.threshold()` to isolate bright defect pixels from the background noise, enhancing defect visibility.

Contour Extraction

Employ `cv2.findContours()` to precisely locate defect boundaries. Filters applied for minimum area and ROI size.

ROI Cropping

Each detected defect region is cropped from the PCB and saved as an individual image, ready for classifier input.

This robust pipeline guarantees **clean, noise-free defect samples** essential for accurate model training.

Methods Used in This Project: A Comprehensive Approach

Computer Vision

- Grayscale conversion & Image subtraction.
- Thresholding & Contour-based ROI extraction.
- ORB feature matching for automatic golden PCB selection.

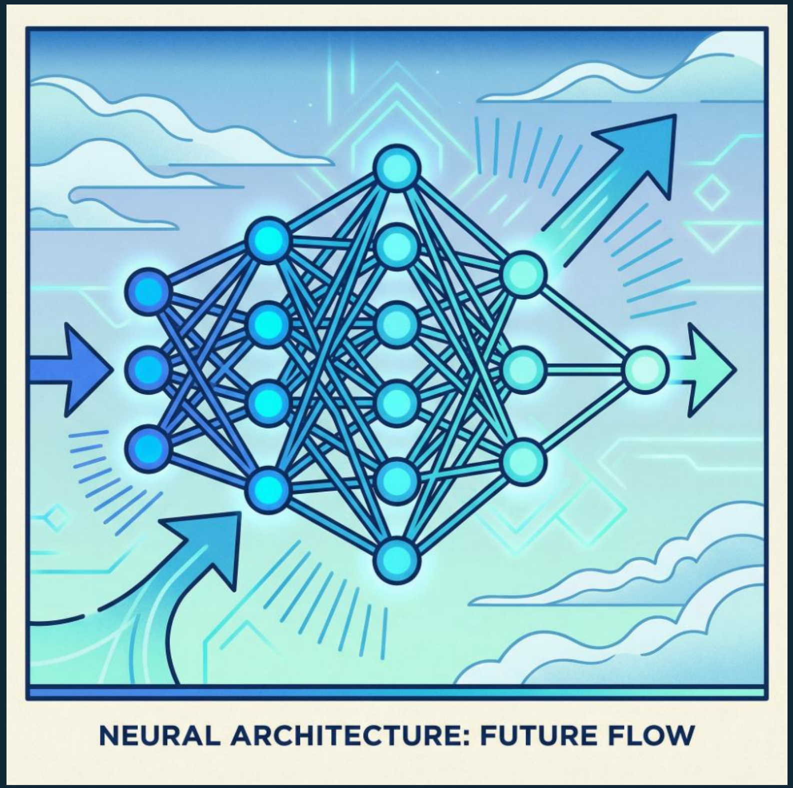
Deep Learning

- EfficientNet-B4 CNN classifier for high-accuracy defect detection.
- Trained on 128×128 ROI images for optimized performance.
- Softmax prediction for precise defect classification.

Backend & Frontend

- Flask REST API for robust server-side processing.
- HTML/CSS/JavaScript for an intuitive user interface.
- Real-time inference, annotated image generation, and downloadable logs.

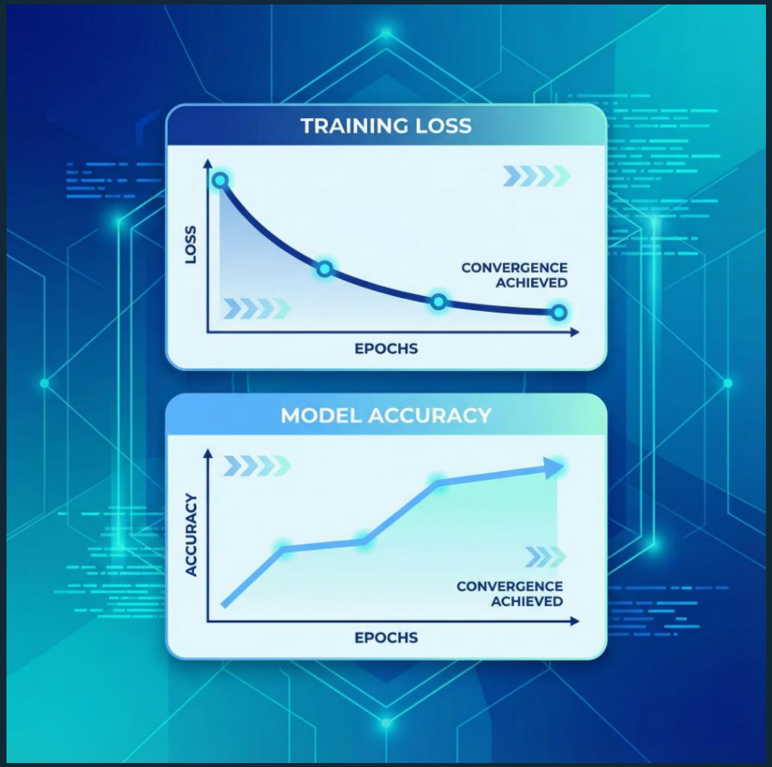
Model Selection: The Power of EfficientNet-B4



Why EfficientNet-B4?

EfficientNet-B4 was chosen for its optimal balance of accuracy and computational efficiency, making it ideal for deployment.

- **High Accuracy:** Excels with small, intricate images, crucial for PCB defects.
- **Efficient Architecture:** Designed for effective deployment without excessive resource demands.
- **Scalability:** Adapts well to varying complexities without overfitting.



Training Details

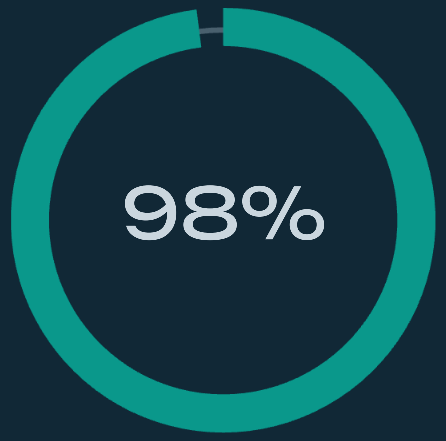
The model was rigorously trained using the following parameters:

- **Loss Function:** CrossEntropy for robust classification.
- **Optimizer:** Adam, known for its adaptive learning rate capabilities.
- **Batch Size:** 32, balancing memory and training speed.
- **Input Size:** 128×128 RGB images for detailed feature extraction.
- **Epochs:** 15–20, ensuring sufficient convergence without overfitting.

Classification Results: Exceptional Performance

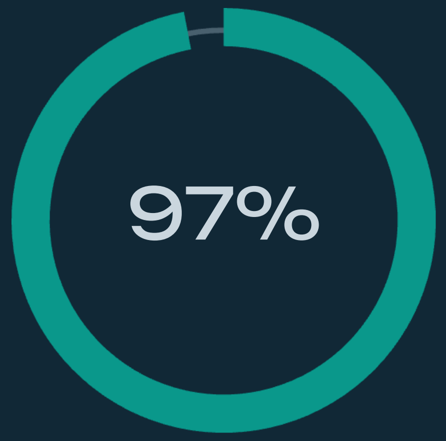
The EfficientNet-B4 model achieved outstanding results in defect classification, demonstrating its suitability for real-world applications.

Defect	Precision	Recall	F1-score
missing_hole	1.00	1.00	1.00
mouse_bite	0.99	0.99	0.99
open_circuit	0.96	0.97	0.96
short	1.00	0.97	0.99
spur	0.96	0.99	0.97
spurious_copper	0.97	0.97	0.97



Overall Accuracy

The model achieved an impressive 98% overall accuracy across all defect types.



Minimum F1-Score

Every classification class maintained an F1-score above 97%, indicating robust performance.

These results confirm the model's ability to **generalize extremely well** and its readiness for **reliable real-world deployment**.

End-to-End System Architecture: Key Stages

The complete system orchestrates a seamless flow from initial image input to a comprehensive, interactive web-based output.

Image Input

Users upload test PCBs, with automatic golden PCB selection via ORB matching for comparison.

Preprocessing Pipeline

Grayscale conversion, image subtraction, thresholding, and contour extraction isolate and crop defect regions (ROIs).

Defect Classification

Each cropped ROI is classified by the EfficientNet-B4 model, providing defect type and confidence scores.

Output Generation

Annotated PCB images are generated alongside detailed defect tables (bbox, center, confidence) and exported in various formats (Image, CSV, JSON).

Web Deployment

A Flask API handles inference, supported by an intuitive HTML/CSS/JS frontend for visualization and user interaction.

This structured approach ensures **accuracy, efficiency, and user accessibility** throughout the PCB defect detection process.

Frontend + Backend Overview: User-Friendly & High-Performance

Frontend (`index.html`)

Our intuitive web interface is designed for optimal user experience:

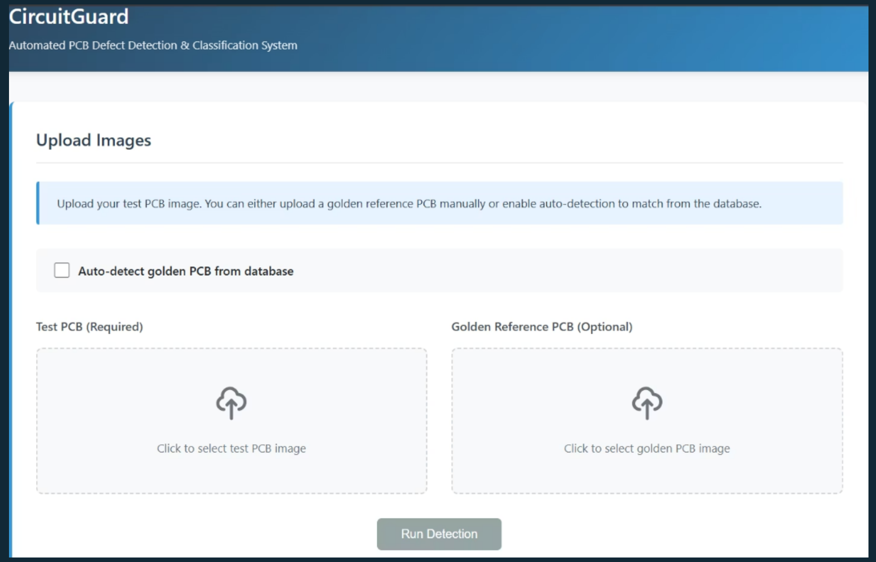
- **Clean UI:** Easy selection of PCBs for analysis.
- **Automatic Previews:** Instant visual feedback on uploaded images.
- **"Run Detection" Trigger:** Initiates the defect analysis process.

Displays:

- **Annotated PCB:** Visual representation of detected defects.
- **Confidence Values:** Probability scores for each defect classification.
- **Defect Table:** Detailed list of detected issues.

Download Options:

- Annotated Image
- JSON Log
- CSV Report



Backend (Flask API)

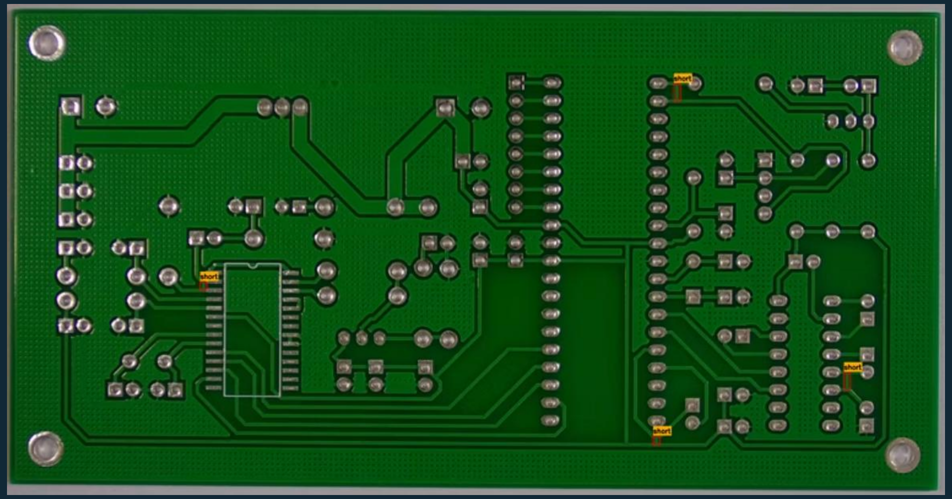
The powerful Flask REST API drives the entire detection pipeline:

- **Endpoint:** `/detect` for seamless communication.
- **Image Decoding:** Efficiently processes uploaded images.
- **Full Pipeline Execution:** Runs all preprocessing and classification steps.
- **Rapid Results:** Returns comprehensive results in **under 2 seconds**.

This integrated system provides a **fast, accurate, and user-friendly solution** for advanced PCB defect detection.

Final Output Examples

The system generates comprehensive, actionable outputs, enabling quick review and decision-making for quality control.



A detailed defect summary table provides critical information for each identified anomaly, streamlining the inspection process.

Defect Type	Centre (X, Y)	Confidence
short	(120, 345)	99.8%
short	(56, 890)	98.2%
short	(789, 123)	97.5%
short	(250, 600)	99.1%

Conclusion

Our project successfully delivers an advanced PCB defect detection system, combining cutting-edge technology with practical application.

Integrated Solution

Successfully built a complete, end-to-end system for automated PCB defect detection.

Outstanding Accuracy

Achieved an impressive 98% classification accuracy, ensuring reliable defect identification.

Key Technologies

- Image subtraction pipeline
- Auto golden PCB selection
- Deep learning classifier
- Full web deployment

Deployment Ready

Produces reliable, explainable inspection results, ready for integration into manufacturing workflows.

This system represents a significant step towards **enhancing quality control** and **optimizing production efficiency** in PCB manufacturing.