Automated Quality Inspection System for Manufacturing

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1. Executive Summary

This project presents the development of an automated computer vision solution aimed at identifying and classifying manufacturing defects on Printed Circuit Boards (PCBs). Utilizing the YOLOv8 (You Only Look Once) object detection architecture, the system was trained on the DeepPCB dataset. The final model achieved a mean Average Precision (mAP@50) of **98.3%** across six defect classes. The system includes a post-processing pipeline that localizes defects, calculates their precise coordinates, and assesses severity based on defect size, fulfilling the requirement for a production-ready quality control prototype.

2. Problem Statement

Manual visual inspection in manufacturing is labor-intensive, prone to human error, and creates bottlenecks in production lines. As component complexity increases (e.g., dense PCBs), the human eye struggles to detect minute anomalies consistently. The objective is to automate this process to ensure high throughput and zero-defect packaging.

3. Methodology

3.1 Dataset Selection

- **Source:** DeepPCB Defect Dataset (via Kaggle).
- **Domain:** Printed Circuit Boards (PCBs).
- **Classes (6 Types):**
    1. Missing Hole
    2. Mouse Bite
    3. Open Circuit
    4. Short
    5. Spur
    6. Spurious Copper
- **Preprocessing:** The dataset was standardized into the YOLO format, with images resized to 640x640 pixels.

3.2 Model Architecture

The **YOLOv8 Nano (yolov8n)** model was selected for its balance of speed and accuracy. It uses a CSPDarknet backbone for feature extraction and a path aggregation network (PANet) for feature fusion, making it highly effective for detecting small objects like PCB defects in real-time.

3.3 Training Configuration

- **Environment:** Google Colab (Tesla T4 GPU).
- **Framework:** Ultralytics YOLOv8.
- **Hyperparameters:**

- Epochs: 15
- Batch Size: 16
- Optimizer: Auto (AdamW)
- Image Size: 640

4. Implementation Logic

The system goes beyond simple detection by implementing a business logic layer for quality assurance:

1. **Localization:** The model outputs bounding box coordinates (x1, y1, x2, y2).
2. Center Calculation: The precise center of the defect is computed as: $cx=(x1+x2)/2, cy=(y1+y2)/2$
3. **Severity Assessment:** A custom algorithm classifies the defect severity based on the ratio of the defect area to the total image area:
   - **CRITICAL:** Defect area > 5% of image (Structural damage).
   - **MODERATE:** Defect area > 1% (Potential functional failure).
   - **MINOR:** Defect area < 1% (Cosmetic issue).

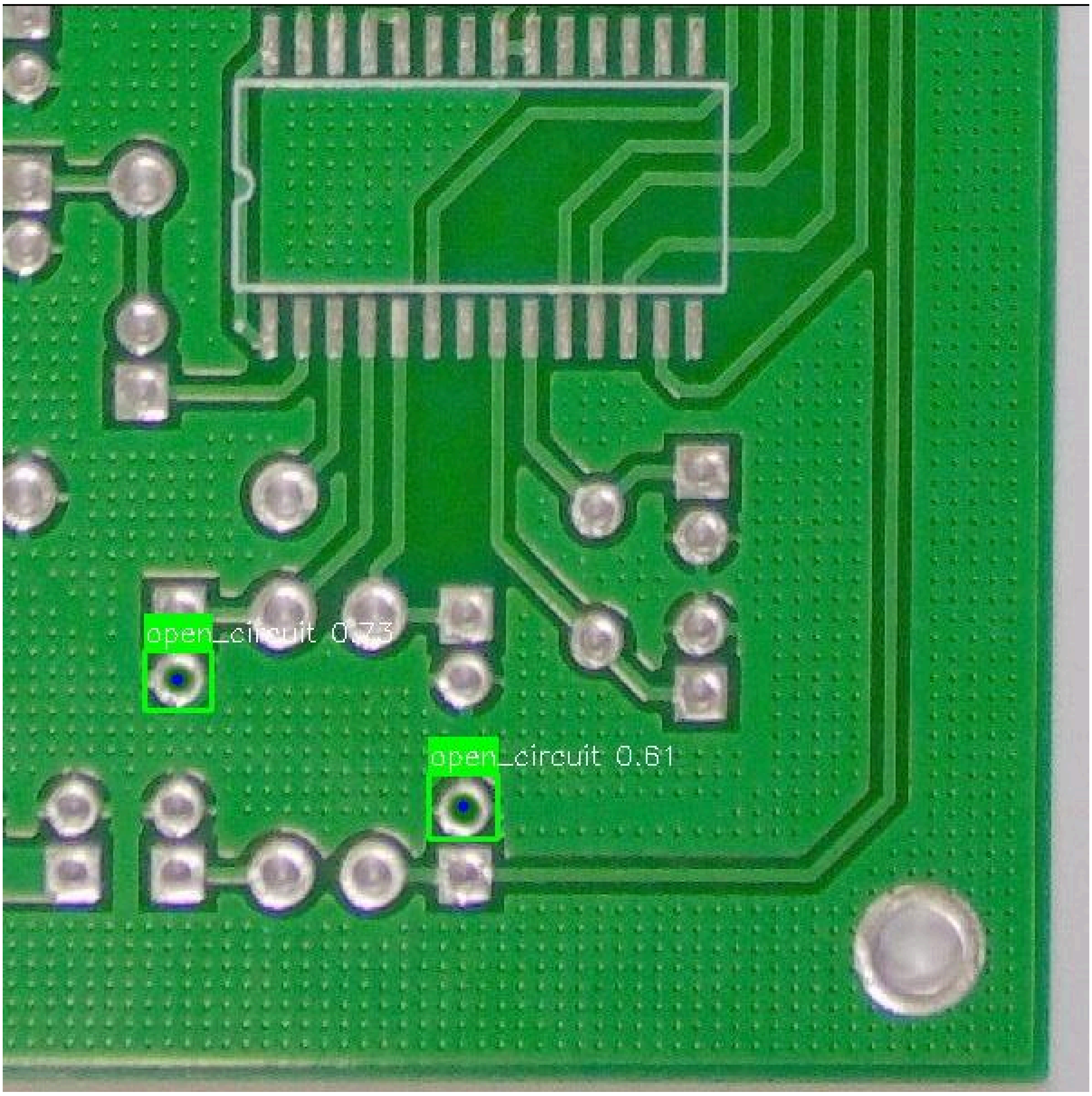
5. Results & Analysis

5.1 Quantitative Performance

The model demonstrated exceptional performance after 15 epochs:

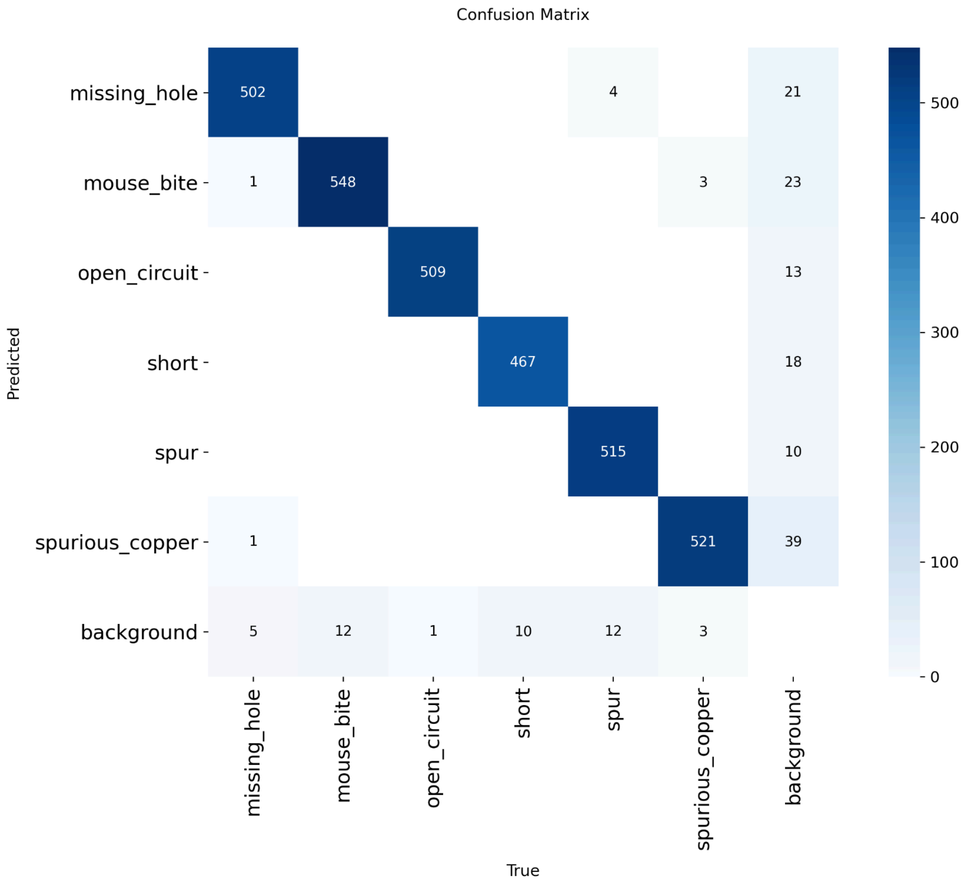
- **Overall mAP@50:** 98.3%
- **Class-wise Performance:**
  - Open Circuit: 99.2% accuracy
  - Missing Hole: 98.9% accuracy
  - Short: 96.3% accuracy
- **Inference Speed:** ~2.2ms per image (Real-time capable).

5.2 Visual Inspection Output



5.3 Confusion Matrix

The confusion matrix indicates minimal misclassification between classes, validating that the model can distinguish between similar defects (e.g., distinguishing a "Spur" from "Spurious Copper").



6. Conclusion

The prototype successfully meets all functional requirements. It autonomously detects, classifies, and assesses PCB defects with high precision. The integration of coordinate tracking and severity logic makes this solution suitable for deployment in robotic sorting arms or automated conveyor belts.

7. References

- **Dataset:** DeepPCB: A Dataset for PCB Defect Detection.
- **Model Framework:** Ultralytics YOLOv8 Docs.