BAB VI
KESIMPULAN DAN SARAN

6.1 Kesimpulan

Penelitian ini berhasil merancang dan mengembangkan sistem klasifikasi kerusakan jalur PCB berbasis model YOLOv11 yang mampu mendeteksi lokasi sekaligus mengklasifikasikan enam jenis kerusakan, yaitu missing hole, mouse bite, open circuit, short, spur, dan spurious copper. Model dilatih menggunakan dataset hasil pengembangan dari dataset PCB Defects melalui proses *cropping* dan penyesuaian tingkat kecerahan sehingga jumlah data meningkat menjadi 12,326 citra. Berdasarkan hasil evaluasi menggunakan metrik Precision, Recall, mAP@50, dan mAP@50-95, model menunjukkan performa yang baik dalam melakukan deteksi dan klasifikasi kerusakan PCB serta mampu menghasilkan proses pembelajaran yang stabil selama pelatihan.

Selain menghasilkan model klasifikasi, penelitian ini juga berhasil mengembangkan mekanisme verifikasi berbasis analisis morfologi yang memanfaatkan proses segmentasi menggunakan U-Net, masking, skeletonization, serta rule-based analysis. Pendekatan tersebut memungkinkan sistem mengevaluasi kesesuaian hasil klasifikasi berdasarkan karakteristik geometris jalur PCB, seperti connected component, endpoint, junction, distance transform, dan hole detection. Dengan demikian, hasil klasifikasi tidak hanya bergantung pada karakteristik visual yang dipelajari oleh model *deep learning*, tetapi juga didukung oleh analisis struktur fisik jalur PCB sehingga proses pengambilan keputusan menjadi lebih konsisten dan mudah diinterpretasikan.

Seluruh komponen yang dikembangkan berhasil diintegrasikan ke dalam sebuah aplikasi menggunakan *framework* Streamlit sehingga membentuk alur kerja yang utuh, mulai dari proses unggah citra, deteksi menggunakan YOLOv11, segmentasi menggunakan U-Net, analisis morfologi, hingga proses verifikasi hasil klasifikasi. Berdasarkan hasil implementasi dan evaluasi bersama ahli, sistem mampu menjalankan fungsi yang dirancang sesuai dengan tujuan penelitian serta

menunjukkan potensi untuk digunakan sebagai alat bantu dalam proses inspeksi kerusakan PCB. Dengan demikian, penelitian ini memberikan kontribusi berupa pendekatan klasifikasi yang tidak hanya mengandalkan kemampuan *deep learning*, tetapi juga memanfaatkan pengetahuan mengenai karakteristik struktur jalur PCB untuk meningkatkan interpretabilitas dan keandalan hasil klasifikasi.

6.2 Saran

Penelitian selanjutnya dapat mengembangkan mekanisme *rule-based verification* yang lebih adaptif, misalnya dengan memanfaatkan metode *fuzzy logic*, *decision tree*, maupun pendekatan pembelajaran berbasis data sehingga proses penentuan aturan tidak hanya bergantung pada nilai ambang (*threshold*) yang ditentukan secara manual. Dalam pengembangan segmentasi, penggunaan metode segmentasi lain seperti DeepLabV3+, SegFormer, atau Transformer dapat dieksplorasi untuk meningkatkan kualitas representasi jalur PCB sehingga proses ekstraksi karakteristik morfologi menjadi lebih akurat. Hasil *rule* yang digunakan juga bisa dikembangkan di luar penelitian ini seperti penggunaan *graph analysis*, *graph neural network*, dan *topology analysis*.

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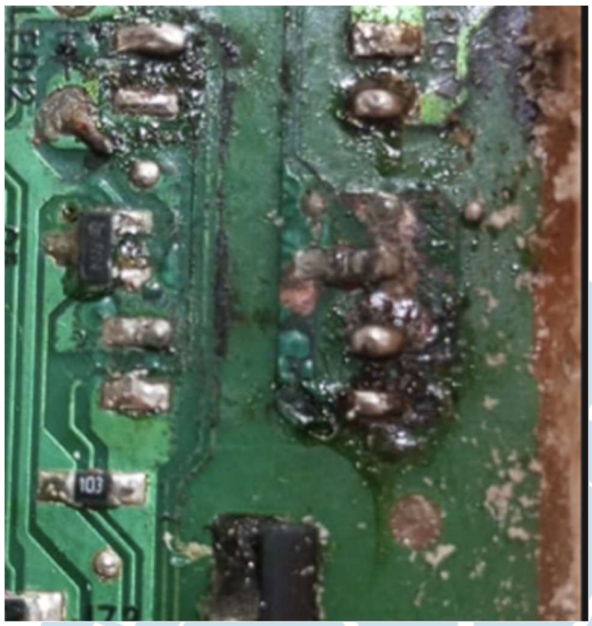
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LAMPIRAN

Lampiran 1 Tahap Wawancara dengan narasumber



Lampiran 2. Proses identifikasi jenis kerusakan – short



Lampiran 3. Proses identifikasi jenis kerusakan – open circuit

