Automated Component Detection and Connectivity Analysis in Circuit Schematics

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Subject Area
Artificial Intelligence, Image Processing and Computer Vision

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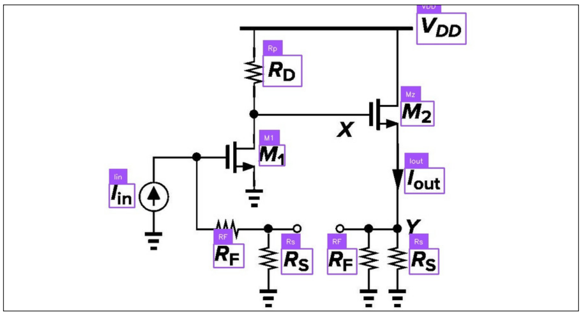
Problem: The automated transformation of schematic images into netlists has long been an active area of research. Project documentation requires the manual labor of trained individuals and is cost-inefficient. Large Language Models can automate portions of this work, however, they still struggle with image recognition, particularly in highly specialized tasks. Existing papers that propose solutions to this problem limit themselves to specific types of schematics. They typically operate on hand-drawn or digital schematics and are limited to a fixed set of component types.
In this thesis, a processing pipeline capable of transforming diverse schematic images into netlists is proposed. This pipeline is not restricted to specific component sets, thereby aiding Large Language Models in automated documentation.

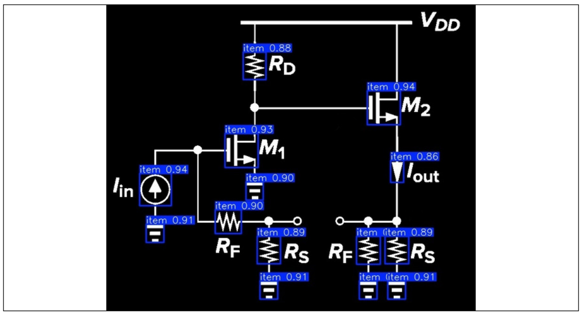
Approach: This pipeline is divided into three main stages. Component detection is performed using a YOLOv8 model trained on datasets of varying complexity, ranging from hand-drawn sketches to complex digital schematics.
Connectivity analysis, based on classical computer vision and statistical machine learning, uses rule-based algorithms and Canny edge detection to decompose and rebuild the schematic, identifying nodes, terminals, and crossings.
For annotation detection and recognition, the EasyOCR library is used, with proximity-based algorithms and text processing implemented to associate the extracted annotations with their corresponding components.

Result: With single-component detection, an F1-score and mAP@50 exceeding 99% are achieved on a test set comprising three different types of schematics. The mAP@50–95 score exceeds 95% for digital schematics and remains above 80% for hand-drawn inputs.
The developed algorithm for connectivity analysis is scale-invariant and generalizes effectively across different schematic types, offering a reliable and robust method for analyzing connections.
For the EasyOCR pipeline, two evaluation procedures were implemented to assess detection and recognition separately.
For hand-drawn schematics, text detection achieved a recall of 0.964 and a precision of 0.928. On complex digital schematics, it reached a recall of 0.889 and a precision of 0.737.
For recognition, both full-label accuracy and character-level accuracy within each ground-truth bounding box were evaluated. Full-label recognition yielded an F1-score of 0.3066 on hand-drawn schematics and 0.9269 on digital schematics.
Character-level recognition achieved an F1-score of 0.5429 on hand-drawn schematics and 0.9269 on digital schematics.
The proposed pipeline is ready for practical deployment and already delivers tangible value by converting schematic images into text-based netlists. Building on this foundation, several promising directions to further enhance accuracy, robustness, and computational efficiency are outlined, including the integration of deep learning and graph-based methods for deeper electrical analysis.

Text Detection and Recognition
AMSNet: https://arxiv.org/html/2405.09045v1#bib



Component Detection
AMSNet: https://arxiv.org/html/2405.09045v1#bib



Connectivity Analysis
AMSNet: https://arxiv.org/html/2405.09045v1#bib