HỌC VIỆN KỸ THUẬT QUÂN SỰ
Military Technical Academy

Review of AI Applications in Electronics-Telecommunications

Presenter: Ph.D Thi Nga Dao

Faculty of Radio-Electronic Engineering, Le Quy Don Technical University

MTA
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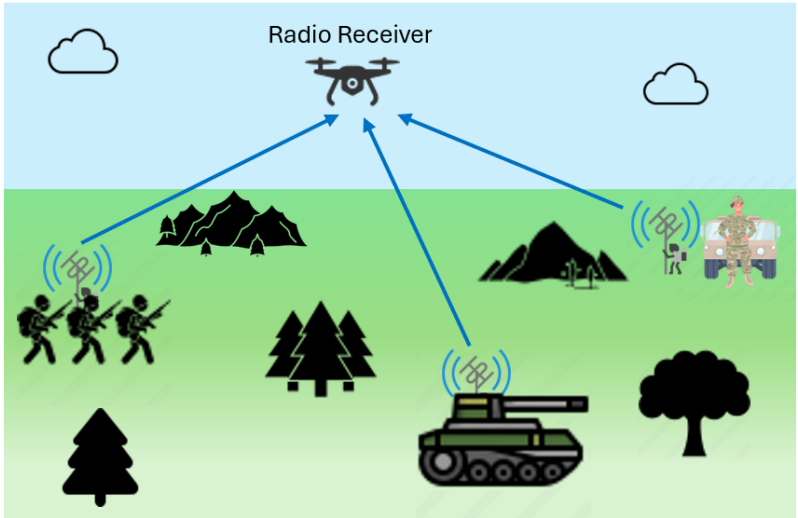
Contents

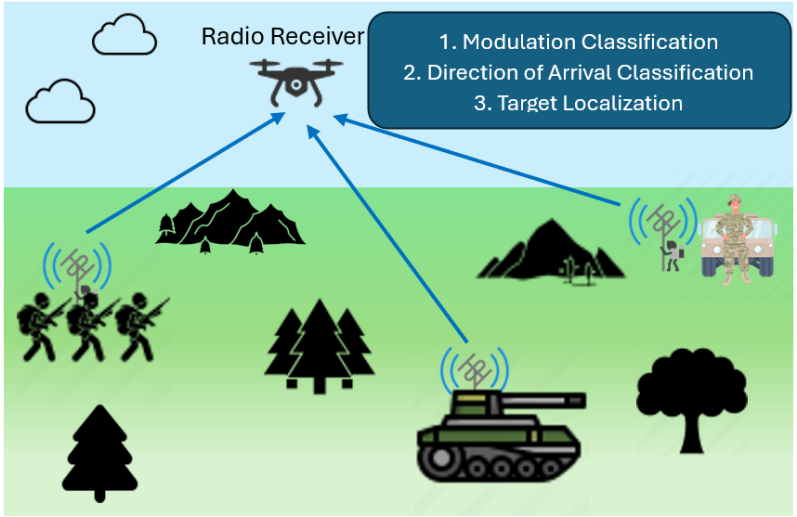
AI applications in Electronics-Communication

1. **Electronic Warfare**: Signal modulation classification, direction-of-arrival estimation, target localization
2. **Communication system**: Modulation and demodulation, channel estimation, resource allocation such as time and spectrum, adaptive beamforming in MIMO
3. **Electronics**: Automated quality control (PCB defects detection), human-machine interaction, smart health monitoring
4. **Chip design**: Automation of circuit design and layout optimization, optimization of power, speed, area in chip design

Electronic Warfare (EW)



AI Applications in Electronic Warfare (EW)



Automatic Modulation Classification (AMC)

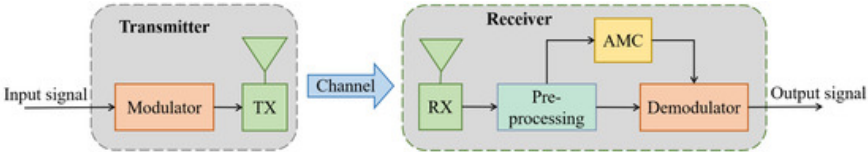
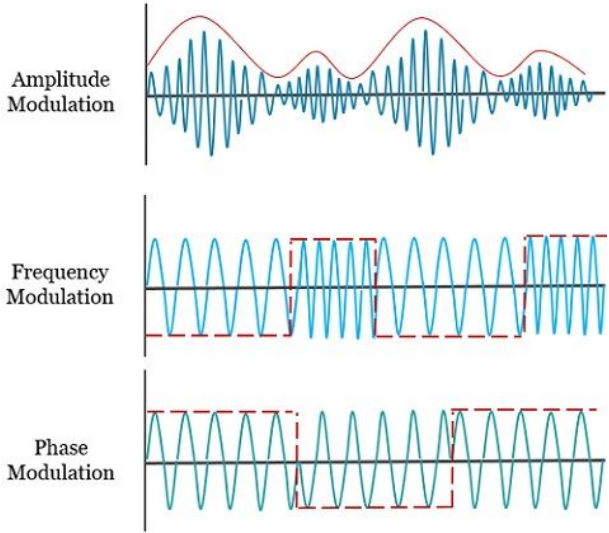


Figure: AMC in Radio Communications

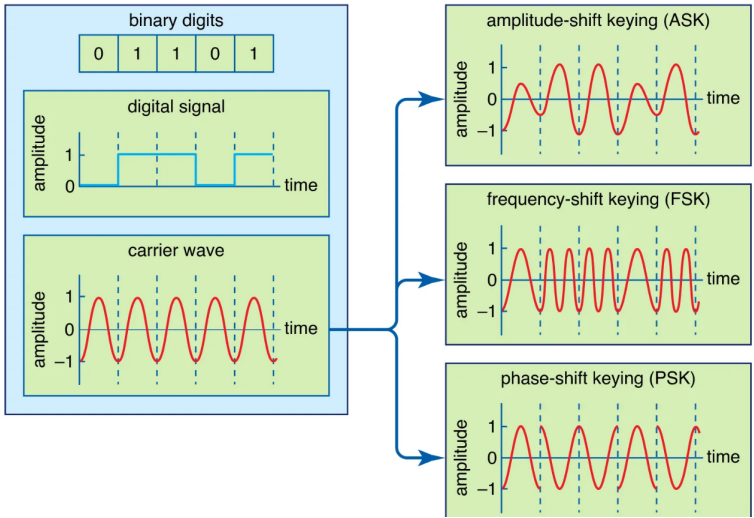
- Demodulation is an important block in radio receiver. We need to know modulation scheme of transmitter for accurate signal demodulation.
- Pre-processing techniques: Extract signal power, frequency, phase, amplitude, ...

Example of Analog Modulated Signals

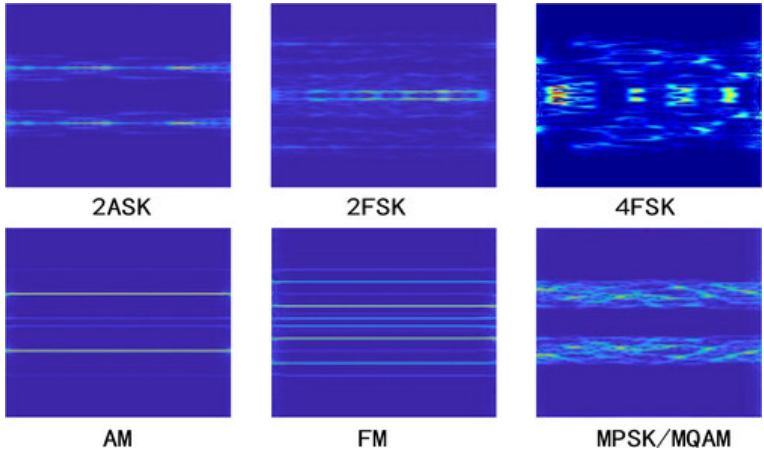


Types of Analog Modulation

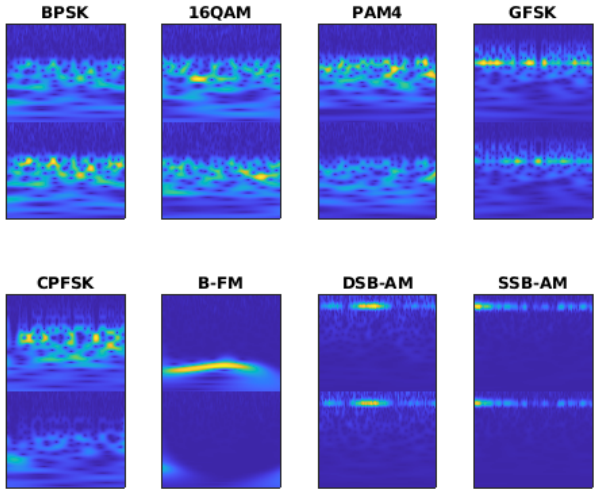
Example of Digital Modulated Signals



Time Frequency of Modulated Signal



Time Frequency of Modulated Signal



AMC Model

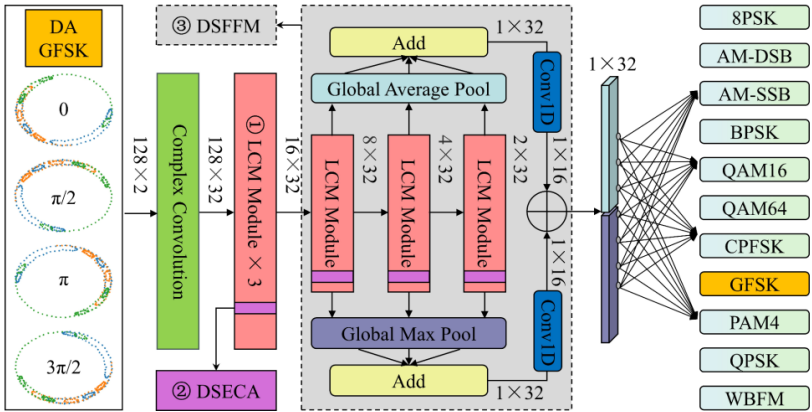
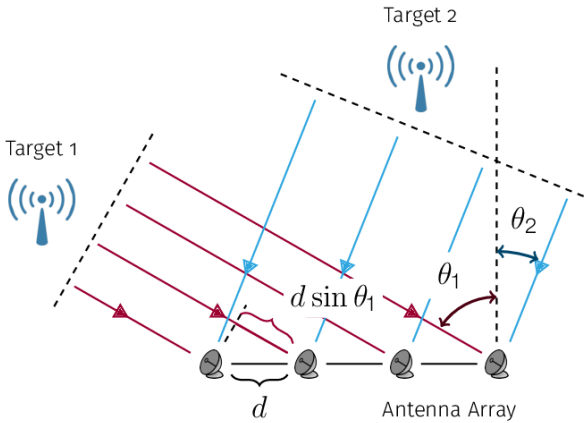


Figure: Lightweight Modulation Classification Model

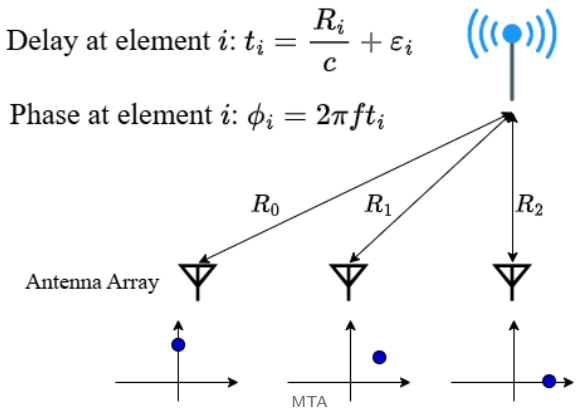
DoA Estimation

1. **Definition**: The process of determining the direction of electromagnetic waves.
2. **Input information**: Capture received signal multiple times at antenna array with M elements



DoA Estimation Intuition

- Due to different distances from target to antena elements, signal arrived at antena at different time or has different phase
- We need to sample received signal multiple times to address signal distortion (due to noise, fading)



NN-based DoA Estimation Model

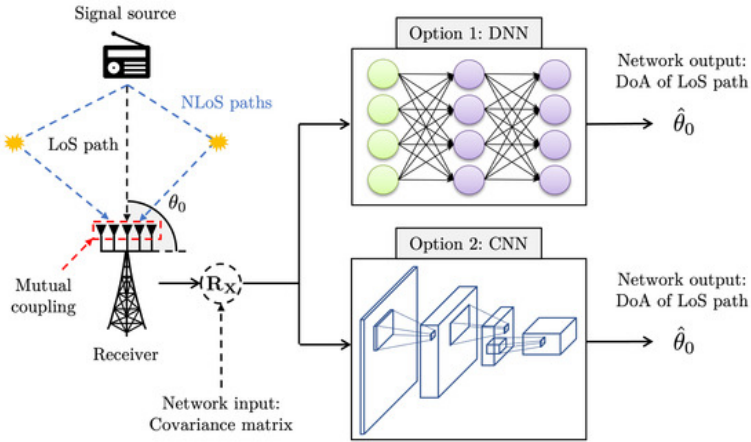
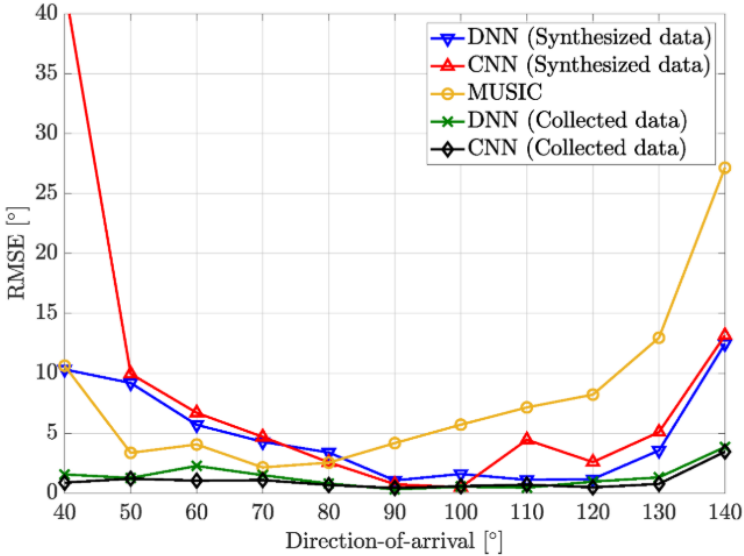


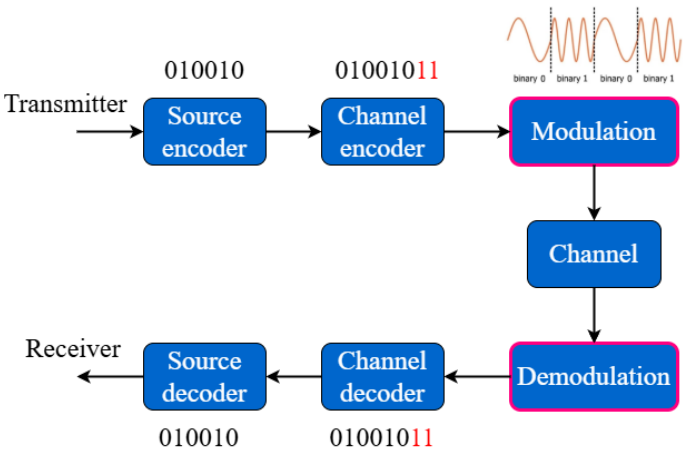
Figure: DoA Estimation Model [3]

NN-based DoA Estimation Result

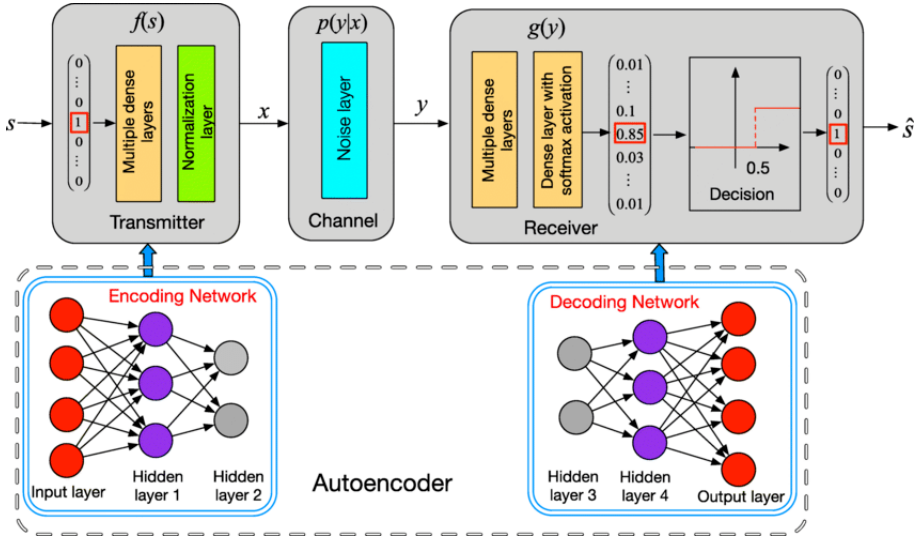


Digital Communication System

- Digital modulation: Process of encoding information signal into amplitude, phase, or frequency of RF transmitted signal (e.g., ASK, FSK, PSK, QAM)
- Limitation of traditional schemes: Weak security, not flexible



AE-based Model for Digital Modulation



AE-based Model for Digital Modulation (cont.)

- **Network architecture**: Usually a stacked AE model with multiple fully-connected layers in encoder and decoder blocks.
- **Data preparation:** Cover all generated symbols and include a lot of noise samples
- **Loss function**: can be mean squared error (MSE) or cross-entropy
- **Performance metric**: Bit-error-rate (BER) or Symbol-error-rate (SER) with different signal-to-noise ratios (SNR)
- **Network optimization**: Network complexity tends to increase when the number of bits per symbol increases.

Constellation of AE-based Modulation

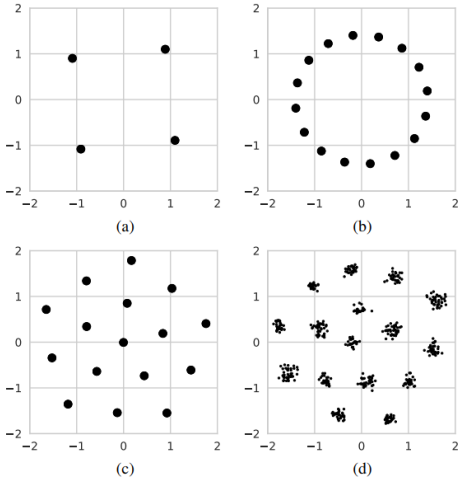


Figure 4: Constellations produced by autoencoders using parameters (n, k): (a) $(2, 2)$ (b) $(2, 4)$, (c) $(2, 4)$ with average power constraint, (d) $(7, 4)$ 2-dimensional t-SNE embedding of received symbols.

Performance of AE-based Modulation

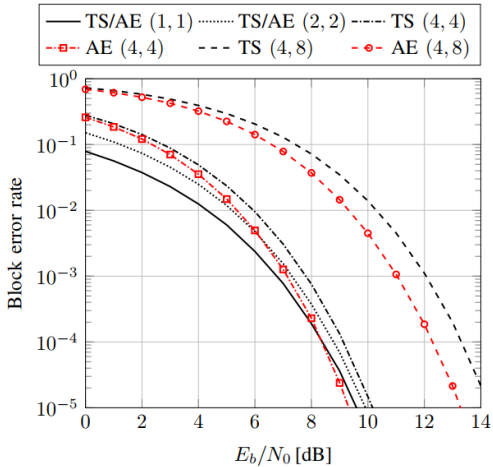
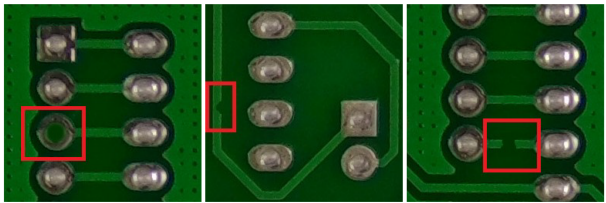


Figure 6: BLER versus E_b/N_0 for the two-user interference channel achieved by the autoencoder (AE) and $2^{2k/n}$-QAM time-sharing (TS) for different parameters (n, k)

PCB Defects Detection

- **Common PCB defects**: Missing hole, mouse bite, open circuit
- **Limitation of manual check**: Time consumption

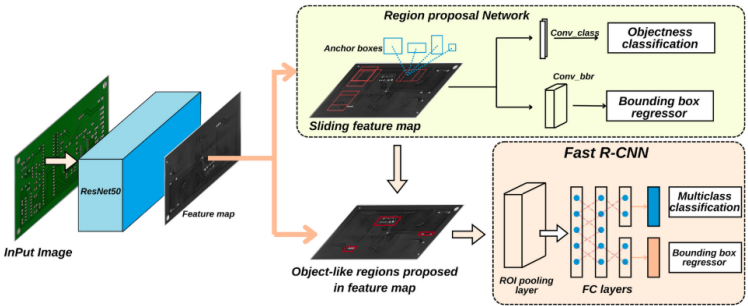


(a) Missing hole (b) Mouse bite (c) Open circuit

(d) Short (e) Spur (f) Spurious copper

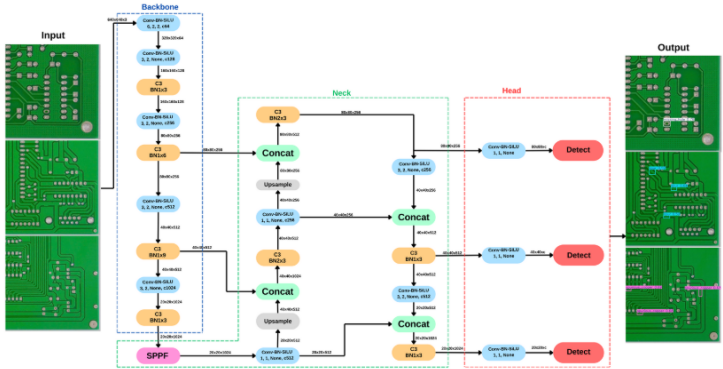
Faster R-CNN for Defects Detection

- **Stage 1**: Extraction of regions of interest (RoIs) with possible objects
- **Stage 2**: Object Classification and Box Refinement
- **Characteristics**: Accurate performance but slow processing time



YOLOv8 for Defects Detection

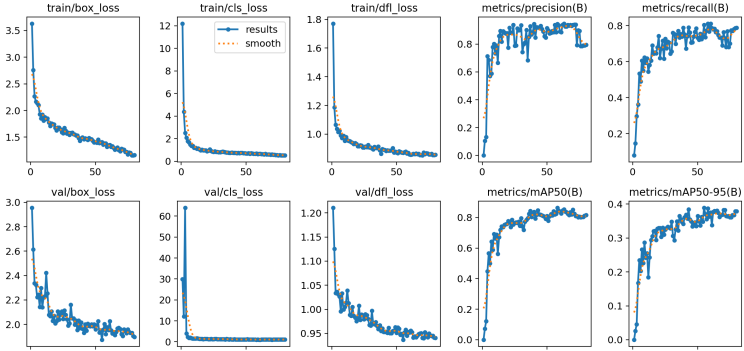
- **Main components**: Backbone, neck, and head
- **Characteristics**: Quick processing time but lower accuracy



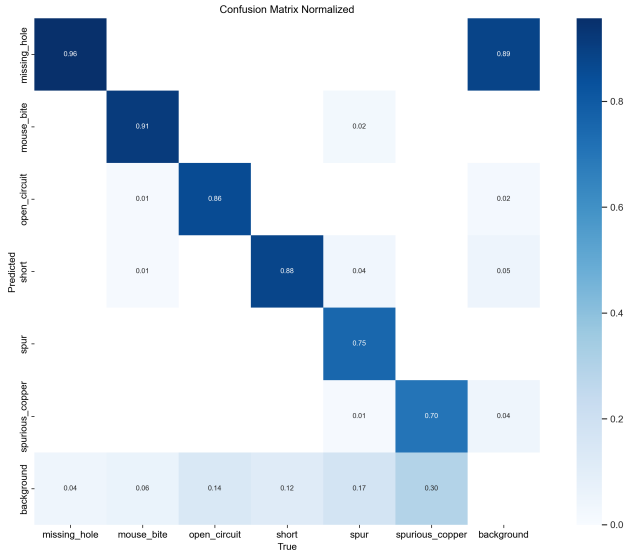
Training PCB Defects Detection based on DL

- **Data preparation**: Image resize, data augumentation, train-test split
- **Model selection**: Can be two-stage (e.g., Faster R-CNN) or one-stage (e.g., YOLO) model
- **Loss function**: Consists of loss for object *classification* and *localization*
- **Performance metrics**: Precision, recall, F1-score, mAP, accuracy, confusion matrix.
- **Performance evaluation**: Using an unknown PCB

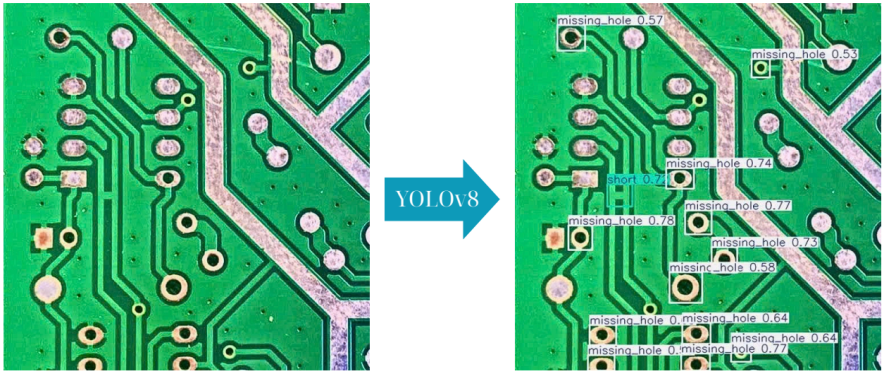
Results of DL-based PCB Defects Detection



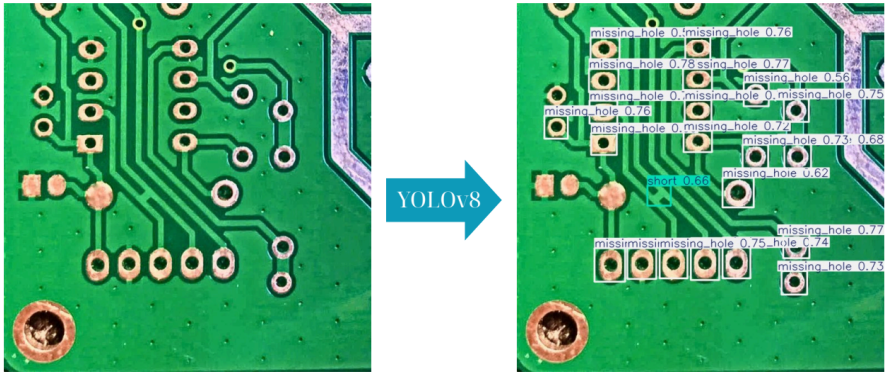
Results of DL-based PCB Defects Detection (cont.)



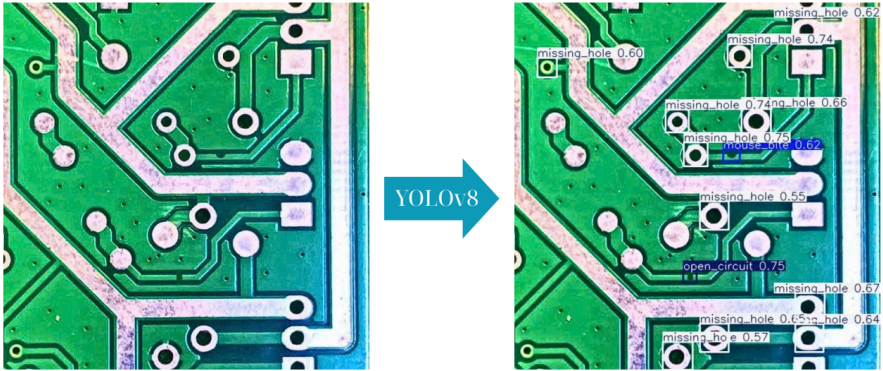
Visualization of DL-based PCB Defects Detection



Visualization of DL-based PCB Defects Detection (cont.)



Visualization of DL-based PCB Defects Detection (cont.)



Open Research Problems

1. Model complexity reduction: For usage in resource-constrained devices such as UAV. That means decrease in processing time.
2. Few-shot and zero-shot modulation classification: How to identify unseen modulation types from minimal data?
3. Explainability in modulation classification: Interpreting why a certain modulation is chosen.
4. Enhancing performance in low SNR conditions in communication system
5. Low-cost, high-accuracy DoA estimation with minimal antenna arrays
6. DoA estimation in non-line-of-sight (NLOS) environments:
7. Multimodal inspection for PCB defects: Combining X-ray, visual, and thermal imaging for robust defect detection.

References

1. Qian, L. *et. al* (2023). Research and implementation of modulation recognition based on cascaded feature fusion. IET Communications.
2. https://www.mathworks.com/help/deeplearning/ug/modulation classification-using-wavelet-analysis-on-nvidia-jetson.html
3. Chung, H. *et. al* (2022). Leveraging Deep Learning for Practical DoA Estimation: Experiments with Real Data Collected via USRP. Sensors, 22(19), 7578.