JOINT COMMUNICATION AND SENSING AT ELF USING AI ENABLED RADIO RECEIVERS

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1 INTRODUCTION AND PROBLEM STATEMENT

MicroUAS utilization has raised significant security and privacy concerns. Drones acts of terrorism through the delivery of explosive devices, unauthorized surveillance of individuals or chemical agents. Existing drone detection methods (radar, and radio frequency (RF) technologies, exhibit limitations as a third party can detect the location of the drone detection system.

2 OBJECTIVE

- The primary objective of the project is to use **passive sensing**-based techniques to **detect drones**, with a special focus on analyzing extremely low-frequency (ELF) signals emitted by drone motors during their rotation.

3 METHODOLOGY

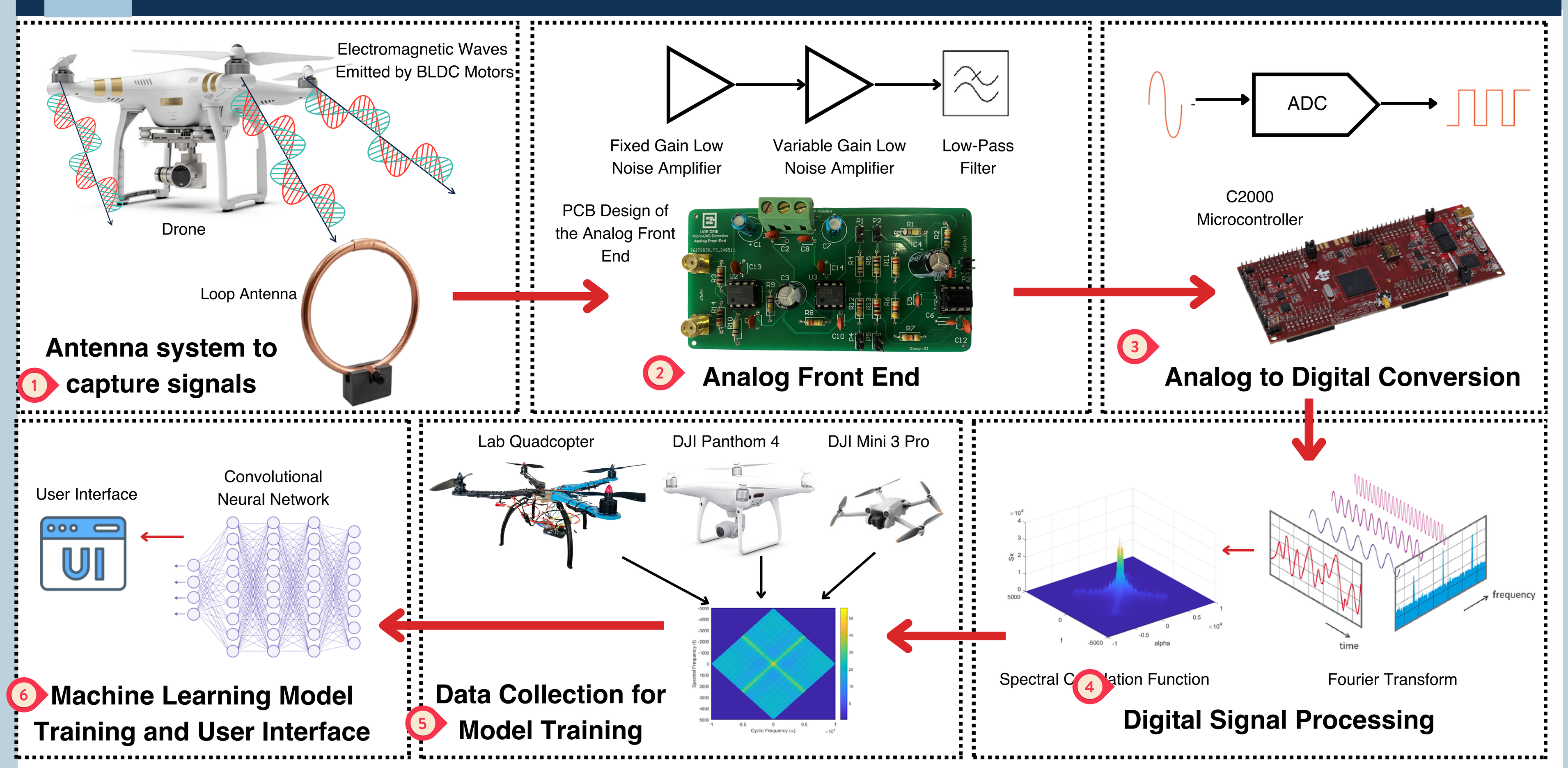

Figure 1 : Complete System Architecture

4 ANTENNA DESIGN

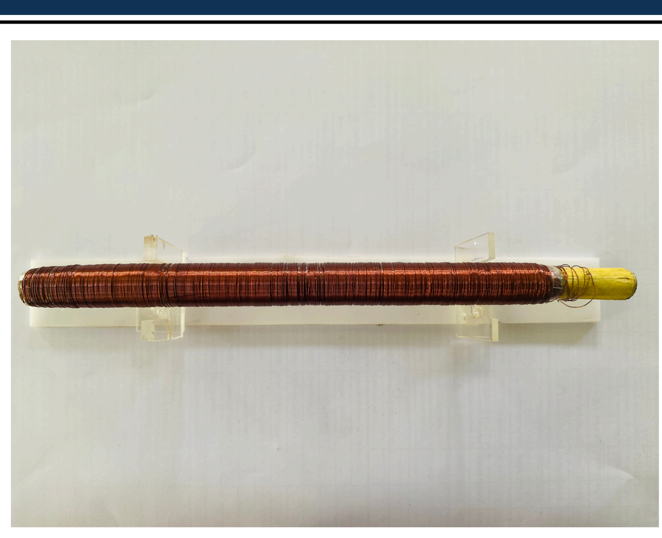

Figure 2: Ferrite Rod Antenna

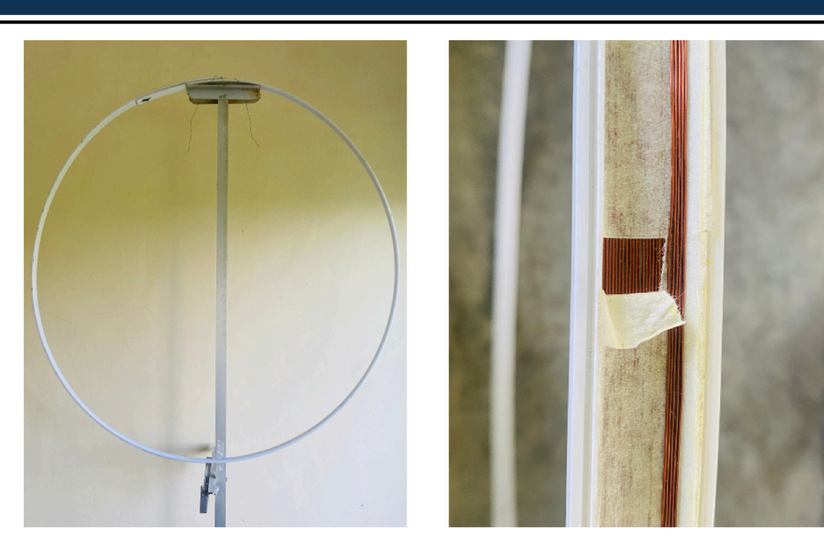

Figure 3: Circular loop Antenna

- 20cm length ferrite rods
- 36 AWG copper wire
- 1000 turns 10 layers - 10,000 Turns

- 1m diameter loop made by plastic
- 26AWG copper wounded upto 300 turns

5 ANALOG FRONT END

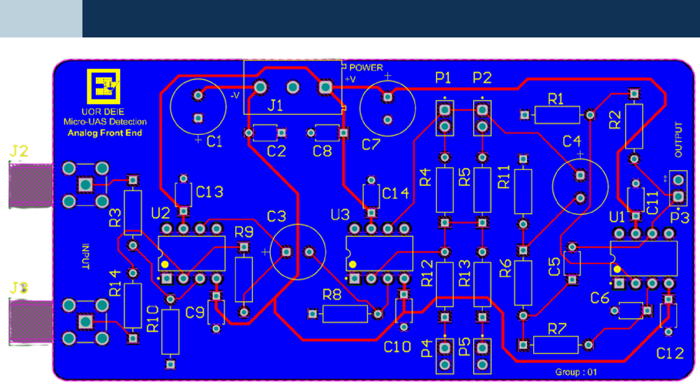

Figure 4: PCB layout Design using Altium

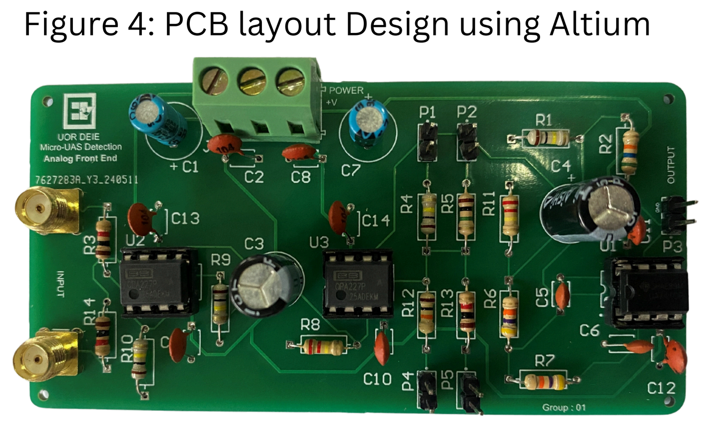

Figure 5: Analog Front-End

- **Amplifier Stages**: Two amplifier stages to process signals.
  - Stage 1: Fixed gain Amplifier of 100
  - Stage 2: Variable gain Amplifier varying from 10-1000
- **Filter**: A 2nd-order low-pass Butterworth filter with cutoff frequency 4kHz.
- **PCB Design**: Altium Designer, supporting multi-layer PCB design and 3D visualization.
- **Fabrication**: The PCB was fabricated by JLC-PCB in China for precision amplification and filtering. Soldered with the necessary components in the laboratory.

6 FOURIER TRANSFORM

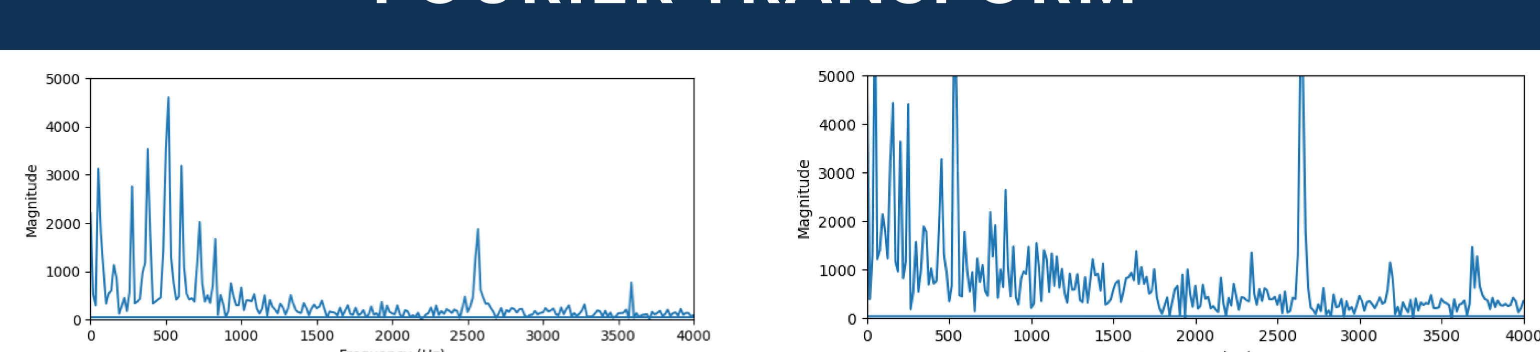

Figure 6: FFT Performance of Both Ferrite Rod and Circular Loop Antennas

- The loop antenna is able to capture signals with high power, ensuring that it can capture signals from a longer distance compared to the ferrite rod antenna.

7 SPECTRAL CORRELATION DENSITY

- Effectively extract and enhance ELF signals blended with noise.
- Spectral Correlation is characteristic to Cyclostationary signals.
- The Spectral Correlation Density (SCD) is implemented using FFT Accumulation Method (FAM) in MATLAB to reduce the computational complexity.

Comparison of SCF for different distances

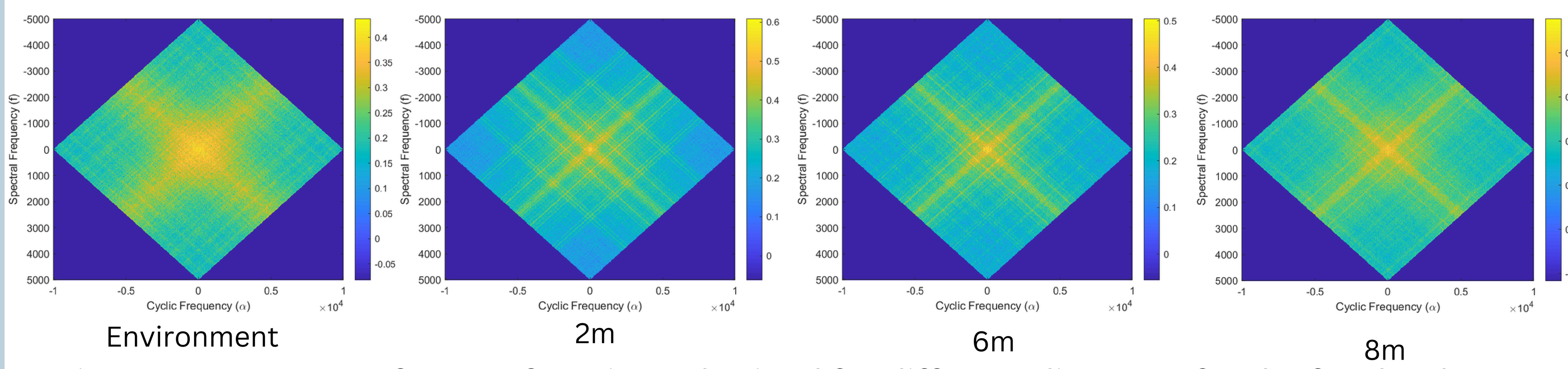

Figure 7: 2D patterns for SCD functions obtained for different distances for the faculty drone.

8 MACHINE LEARNING MODEL

Table 1 : Information about the dataset

Data Type	No. Data Points
Environmental	103,000,000
Faculty Drone	124,000,000
DJI Panthom 3 Pro	74,000,000
DJI Mini 3 Pro	88,000,000

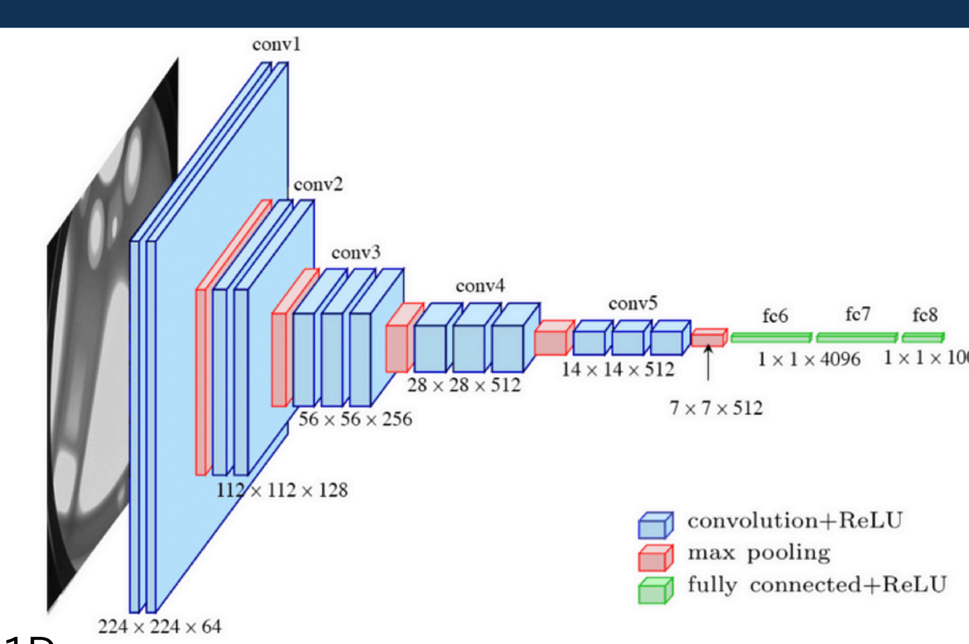

Figure 8 : VGG16 Model Architecture

- Excluding the Top Layer
- Adding Custom Layers
  - Flatten Layer: Converts the 3D output of the last convolutional block into 1D
  - Dense Layer: A fully connected layer with 1024 neurons and ReLU activation
  - Output Layer: A dense layer with one neuron

Results for Drone Detection

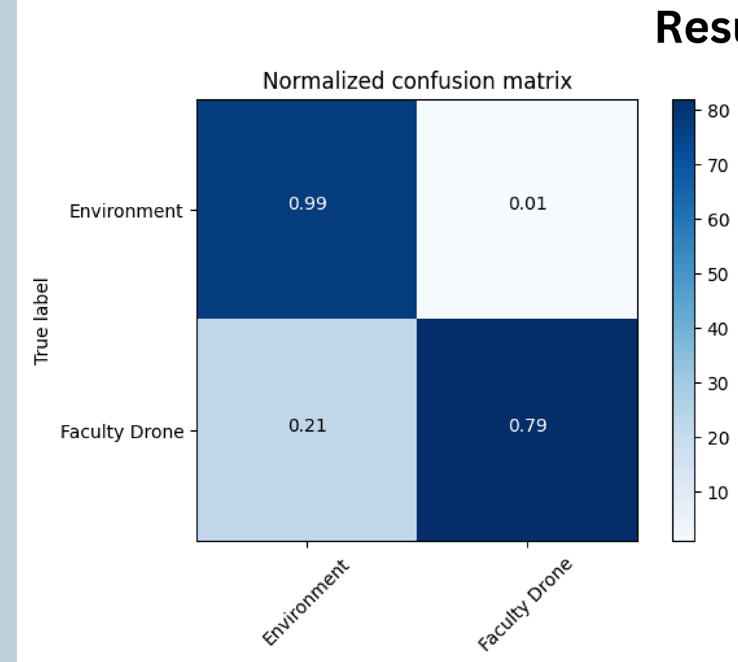

Figure 9 : Confusion matrix of Faculty Drone

- **VGG16, EfficientNetB0**, and a **Custom CNN** were evaluated on the "Faculty Drone" dataset. VGG16 outperformed with a **96% accuracy.**

Figure 1 : Performance Comparison for different AI models

Metric	VGG16	EfficientNetB0	Custom CNN
Accuracy	96%	65%	78%
Precision (Environment)	0.95	0.64	0.77
Recall (Environment)	0.94	0.67	0.79
Precision (Drone)	0.96	0.66	0.79
Recall (Drone)	0.97	0.62	0.77
Macro Average Precision	0.96	0.65	0.78
Macro Average Recall	0.95	0.65	0.78

Drone Classification

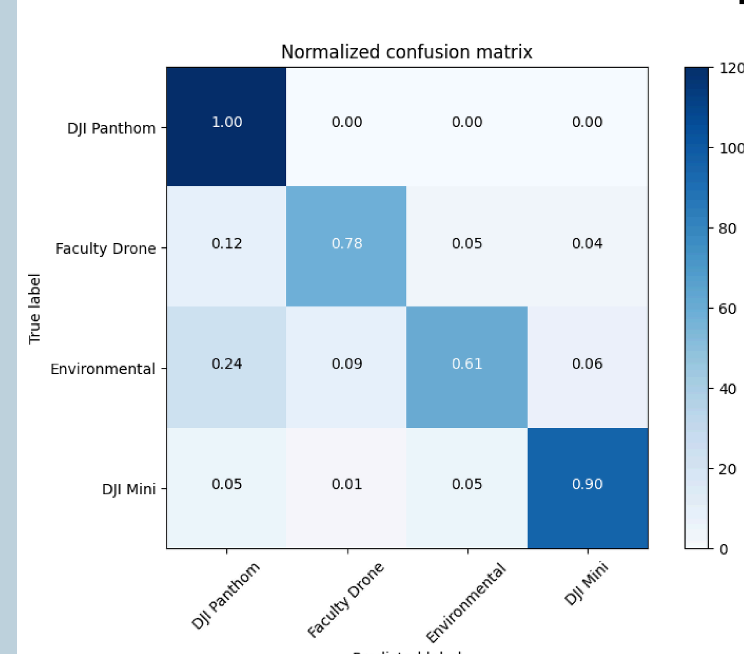

Figure 10 : Confusion matrix of Drone classification

Figure 1 : Performance Comparison for different drone types

Class	Precision	Recall	F1-Score	Support
Faculty Drone	0.76	1.00	0.86	120
DJI Panthom	0.85	0.78	0.82	74
DJI Mini	0.87	0.61	0.71	99
Environmental	0.91	0.90	0.91	107
Accuracy			0.83	
Macro Average	0.85	0.82	0.83	400
Weighted Average	0.85	0.83	0.83	400

- The Mini Drone shows significant confusion with Faculty and Panthom drones.
- The performance is greatly impacted with the size of the drone motor.

User Interface

- The predicted output, along with the accuracy score and the generated SCF plot, is displayed to the user through an interactive user interface. The start and stop buttons allow the user to control the model prediction process.

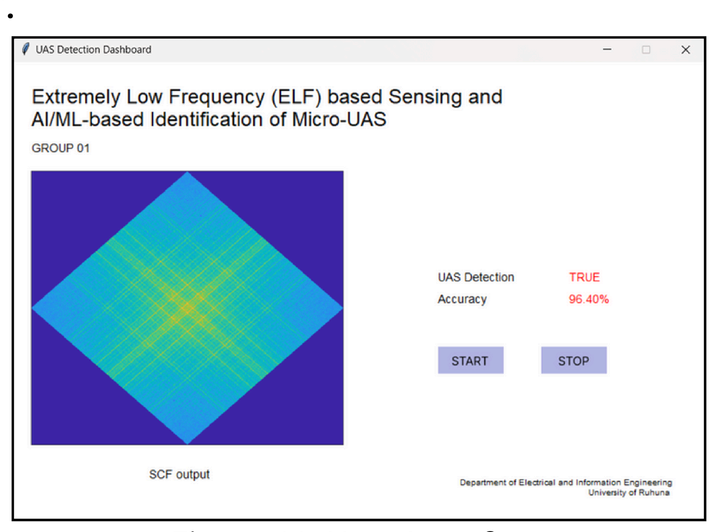

Figure 11: User Interface

CONCLUSION

- Spectral correlation and FFT are utilized to accurately identify drones from unique spectral signatures.
- Machine learning model achieves high accuracy in "drone" vs. "no drone" detection, confirming the effectiveness of passive sensing.
- The model can classify the drones based on the cyclostationary features emitted by BLDC motors.