# Experimental Evaluation in Radio Frequency Machine Learning Datasets in Drone Detection

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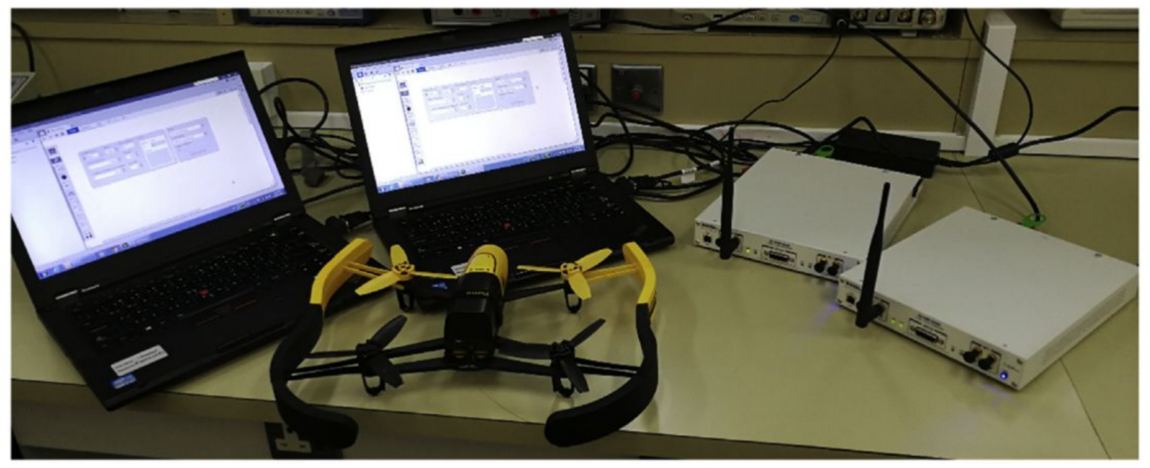
## Abstract

Machine learning (ML) is poised to revolutionize the field of radio frequency (RF) signal analysis by enhancing the detection and classification of drone signals. Accurate RF-based detection is essential for ensuring security and monitoring in diverse environments. With drones being used in various sectors, from logistics to surveillance, robust drone detection mechanisms are becoming critical. Utilizing datasets like CardRF[2] and the DroneRF[1] dataset, we aim to assess and validate classification techniques designed for RF signal detection. CardRF incorporates outdoor UAV/UAS drone signals and Bluetooth and Wi-Fi signals, while the Drone RF dataset focuses on signals from drone controllers. By replicating the classification models applied to DroneRF and implementing them on CardRF, we aim to determine the validity of these techniques across different datasets. This evaluation will aid in developing a robust, experimental data collection and classification framework, improving the detection accuracy of UAVs.

## DroneRF Experimental Setup



The DroneRF experimental setup consists of three key components:

1. **Drones**: A diverse selection of drones varying in size, capabilities, price, and technology.
2. **Flight Control**: A mobile phone or flight controller used to communicate with the drones and modify their flight modes.
3. **RF Sensing**: An RF receiver that captures the communication signals between the drones and the flight control module, processing and storing the RF data in a database. [1]

## DroneRF Hardware [1]

Parrot Bebop drone

Parrot AR 2.0 elite edition drone

DJI Phantom 3 standard drone

| Drone | Parrot Bebop | Parrot AR Drone | DJI Phantom 3 |
|---|---|---|---|
| Dimensions (cm) | 38×33×3.6 | 61×61×12.7 | 52×49×29 |
| Weight (g) | 400 | 420 | 1216 |
| Battery capacity (mAh) | 1200 | 1000 | 4480 |
| Max. range (m) | 250 | 50 | 1000 |
| Connectivity | WiFi (2.4 GHz and 5 GHz) | WiFi (2.4 GHz) | WiFi (2.4 GHz −2.483 GHz) +RF (5.725 GHz −5.825 GHz) |

## DroneRF Hardware continued [1]

NI USRP-2943R RF receiver

PCIe interface kit

| | |
|---|---|
| Number of channels | 2 |
| Frequency range | 1.2 GHz – 6 GHz |
| Frequency step | < 1 KHz |
| Grain range | 0 dB to 37.5 dB |
| Maximum instantaneous bandwidth | 40 MHz |
| Maximum I/Q sample rate | 200 MS/s |
| ADC resolution | 14 bit |

## DroneRF Data Collection Process

How the data was collected:

1. Turn on the drone that is under analysis and connect to it using a mobile phone or a flight controller.
2. In case the utility of a mobile phone as a controller, start the mobile application to control the drone and to change its flight mode.
3. Check the drone connectivity and operation by performing simple takeoff, hovering, and landing tests.
4. Turn on the RF receivers to intercept all RF activities and to transfer those to the laptops via the PCIe connectors.
5. Open the LabVIEW program on laptop, and select appropriate parameters.
6. Start the LabVIEW program to fetch, process and store RF data segments.
7. Stop the LabVIEW program when done with the experiment.
8. For a different flight mode, go back to step 6, and for different drones go back to step 1.

The dataset was organized in 3 different levels:

First Level:

- Drones Off: RF background activities are recorded.
- Drones On: RF activities of the drones are recorded.

Second Level:

To train and evaluate the system's ability to identify drones, experiments are performed on three specific drones :

- Bebop
- AR
- Phantom

Third Level:

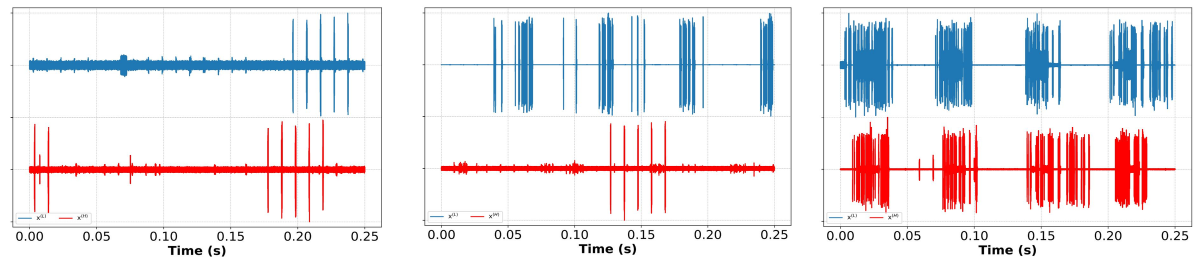
The system is further tested by explicitly controlling the drones' flight modes to evaluate its capability to identify flight modes of intruding drones.

The experiments include:

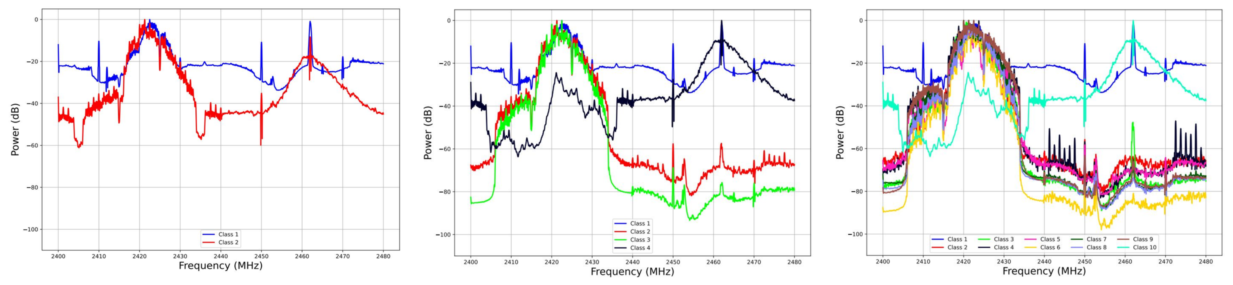
- On and connected to the controller.
- Hovering automatically without controller input at a preset altitude.
- Flying without video recording, ensuring no obstacles are hit.
- Flying with video recording, also ensuring no obstacles are hit to prevent warning signals. [1]

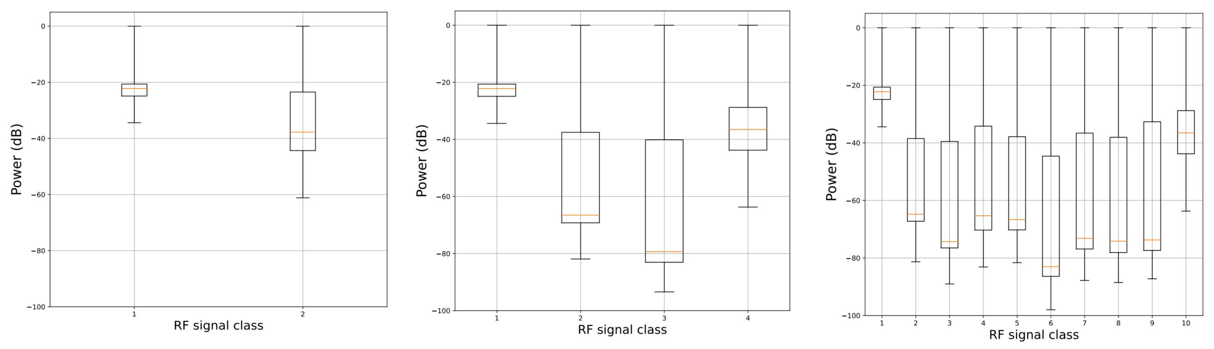
## DroneRF Demo

Taking the matlab code from DroneRF paper [1], we converted the them into Python and recreated these graphs:



x(L) and x(H) are plotted in blue and red respectively with normalized amplitudes from –1 to 1. First figure shows RF background activities, second figure shows Bebop RF signals when flying and video recording, and third figure shows Phantom RF signals when on and connected.





Top 3 graphs show the average power spectra of the acquired RF signals and the bottom 3 graphs show the boxplot of the computed spectra. For bottom left graph, class 1 is for RF background activities and class 2 is for the drones RF communications. In bottom middle graph, class 1 is for RF background activities and classes 2–4 are for the Bebop, AR and Phantom drones. In bottom right graph, class 1 is for RF background activities, classes 2–5 are for the Bebop 4 different flight modes, classes 6–9 are for the AR 4 different flight modes, and lastly, class 10 is for the Phantom single flight mode.

## CardRF Data Collection and Pre-processing

The CardRF dataset is collected as follows:

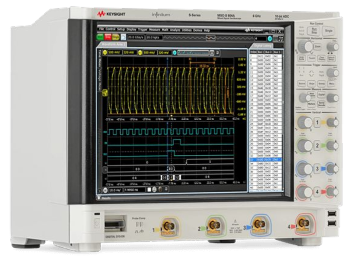
1. Signals captured from 2 Bluetooth devices, WiFi routers, and 6 UAV controllers. All signals are in 2.4 GHz.
2. Data collected in an outdoor, controlled environment, using a grid antenna.
3. Collected signal is passed through a 2.4 GHz band pass. Low-noise amplifier is used to amplify the band-passed signal.
4. Oscilloscope used to collect and monitor RF signal.
5. Trigger threshold for signal detection is set above the background noise level.
6. For CardRF, ⅔ of the collected signal is used as training data, while the rest is used for testing.

Collected CardRF data is then pre-processed as follows:

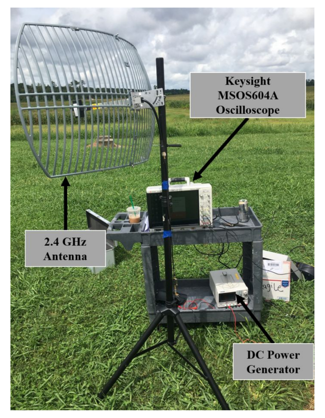
1. RF signals start point is determined by changepoint detection algorithm in MATLAB, removing noisy parts of the raw signal.
2. RF signal is then pre-processed using a single-level Haar wavelet decomposition (HWR).
3. HWR involves passing the raw signal through a set of low-pass and high-pass filters.
4. The down-sample of the low-pass (approximate coefficient) is then used for feature extraction.

## CardRF Hardware List

FMAM63007 low-noise amplifier



Keysight MSOS604A oscilloscope

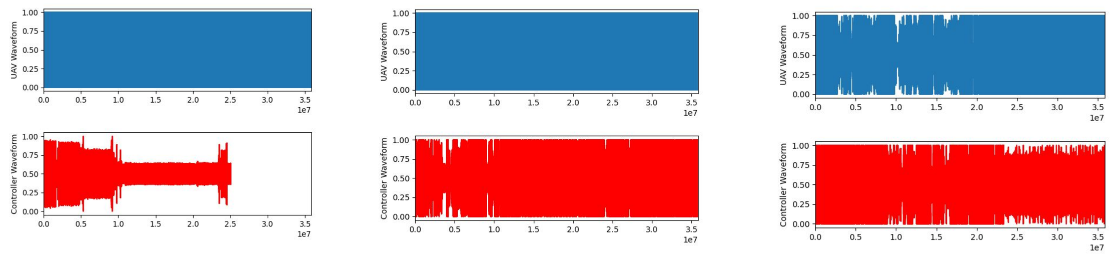


Hardware setup used by CardRF

- **Signal sources**: 2 Bluetooth devices, 2 WiFi routers, 6 UAV controllers (all devices are 2.4 GHz)
- **Collection antenna**: 24 dBi 2.4GHz grid parabolic antenna
- **Signal amplifier**: FMAM63007 low-noise amplifier (LMA)
- **Oscilloscope**: Keysight MSOS604A (6GHz bandwidth)

## CardRF Data Analysis (using DroneRF Demos)

Using the CardRF dataset, we performed data analysis using the same techniques demonstrated in the DroneRF dataset.
We created graphs of the normalized waveforms of each UAV signal and compared each of them with the normalized waveform of their corresponding controller signal. The graphs below represent the RF signals coming from a BeebeeRun drone and two DJI drones used in for data collection. The blue waveform represents the UAV signals, while the red waveform represents the controller signals.



## Conclusion and Future Work

Neither dataset utilizes RF chambers, which are typically employed to collect clean, noise-free signals. We would like to explore the implication and impact of this omission on data quality. Additionally, DroneRF relies on software-defined radio, while CardRF uses an oscilloscope. This variation in instrumentation raises questions about which dataset provides more accurate or useful data. Further research is needed to compare the performance of these two approaches and determine their suitability for specific RF applications.

## Citations

[1] "DroneRF Dataset: A Dataset of Drones for RF-Based Detection, Classification and Identification." Data in Brief, vol. 26, 1 Oct. 2019, p. 104313, www.sciencedirect.com/science/article/pii/S2352340919306675, https://doi.org/10.1016/j.dib.2019.104313.

[2] OLUSIJI MEDAIYESE. "Cardinal RF (CardRF): An Outdoor UAV/UAS/Drone RF Signals with Bluetooth and WiFi Signals Dataset." IEEE DataPort, 13 July 2022, ieee-dataport.org/documents/cardinal-rf-cardrf-outdoor-uavuasdrone-rf-signals-bluetooth-and-wifi-signals-dataset.