Challenge: Machine Learning for Drone Identification

The identification of drones using sensors is an increasingly important problem in practice due to the widespread availability of highly capable drones. Radar is a long-range active sensor that can detect drones at longer ranges, as compared to optical sensors. Therefore, it is of interest to investigate if radars can be used to identify drones.

In this challenge, you will model the return radar signal, simulate radar returns from drones as a function of radar parameters and drone characteristics, and investigate the feasibility of using machine learning to classify drones.

1 Implement Time-Domain Radar Return Signals from Drones

The received radar signal from the drone being illuminated by the radar is given by

$$\psi(t) = A_r e^{j\left(2\pi f_c t - \frac{4\pi}{\lambda}(R+V_{rad}t)\right)} \sum_{n=0}^{N-1} e^{-j\frac{4\pi}{\lambda}\left(\frac{L_1+L_2}{2}\cos(\theta)\sin\left[2\pi f_{\mathrm{rot}}t+\frac{2\pi n}{N}\right]\right)} \mathrm{sinc}\left(\frac{4\pi}{\lambda}\frac{(L_2-L_1)}{2}\cos(\theta)\sin\left(2\pi\left[f_{\mathrm{rot}}t+\frac{n}{N}\right]\right)\right),$$

where

A_r is a real, scale factor,

L_1 is the distance of the blade roots from the centre of rotation,

L_2 is the distance of the blade tips from the center of rotation,

N is the number of blades,

R is the range of the center of rotation,

$V_{\mathbf{rad}}$ is the radial velocity of the center of rotation with respect to the radar,

λ the wavelength of the transmitted signal,

θ angle between the plane of rotation and the line of sight from the radar to the center of rotation,

f_c the transmitted frequency,

$f_{\mathbf{rot}}$ the frequency of rotation,

t is the time.

The drone propeller characteristics are N, L_1 and L_2, and f_{rot}. The radar-dependent quantities are λ, θ and f_s.

In this task, you will

- Implement the model a high-level programming language, such as python.
- Plot the time domain signal for representative values.
- Plot short-window and long-window short-time Fourier transforms (STFT) for representative values.

2 Simulate Radar Returns from Drones

The received radar signals from a drones is given by $\psi(t) + \mathbf{n}$, where $\mathbf{n}$ is random noise modelled by the Gaussian distribution with variance σ^2. The signal-to-noise ration (SNR) is defined as $\left(\frac{A_r^2}{\sigma^2}\right)$, and the SNR in decibels is given by $10 \log_{10} \left(\frac{A^2}{\sigma^2}\right)$. Choose two different radar operating frequencies (e.g., X-band (10 GHz) and W-band (94 GHz)) and three different SNRs (e.g., 10 dB, 5 dB, and 0 dB).

In this task, you will

- Simulate time series for returned radar signals for some representative values.
- Plot the STFTs.

3 Prepare Data Sets for application of ML techniques

In this task, you will

- Choose four different types of commercially available drones for simulation and verification.
- Generate simulated data sets for three different SNRs, such as 10 dB, 5 dB, 0 dB and for a low-frequency and high-frequency radar (X-band and W-band).

4 Apply Machine Learning Techniques to Identification of Drones

In this task, you will

- Generate confusion matrices for each of the SNRs for two different radar frequencies and four types of drones.
- Evaluate performance using metrics such as precision, recall, and ROC curves.

Any computer language and machine learning library may be used. It is suggested that python be used, as it has a rich set of powerful ML libraries such as `scikit-learn`, `tensorflow`, `keras`, `pytorch`, and `fastai`.

5 Submission

Summarize the explanatory notes and code and results in a Jupyter notebook, and upload the notebook and the code/library onto GitHub and provide your Github username.

6 BONUS

- Expand the set of drones and set of radar frequencies all the way to THz.
- Extend analysis to to multi-propellor drones.
- Utilize GPUs to speed up computation.

References

[1] Peter Klaer, Andi Huang, Pascale Sévigny, Sreeraman Rajan, Shashank Pant, Prakash Patnaik, and Bhashyam Balaji. An investigation of rotary drone HERM line spectrum under manoeuvering conditions. *Sensors*, 20(20):5940, Oct 2020.

[2] J. Markow and A. Balleri. Examination of drone micro-doppler and JEM/HERM signatures. In *2020 IEEE Radar Conference (RadarConf20)*, pages 1–6, Sep. 2020.