Droneilliance and Detection Dynamics: A Review of Radar Techniques and Trends

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***Abstract*—Due to the increased threats these devices offer, the development of radars in detecting miniature drones has become of greatest priority. This is due to their demonstrated ability in automotive and military applications, as well as in low-light, noisy, blurry, or misty settings. This paper will present the advantages of using radar technology for drone detection as well as its problems and some solutions.**

***Index Terms*—Anti-drone, artificial intelligence, drone detection, Radar, security.**

I. Introduction

The development of drone detection radars has become crucial given the quickly expanding drone market in order to stop things like unauthorized imaging and recording in prohibited areas, illegal surveillance, air collisions, terrorist assaults, and drug smuggling [1]. In addition to other tools like RF sensors and cameras, a comprehensive anti-drone solution typically incorporates drone surveillance radar. The fusion of different detection techniques in a hybrid system to counter malicious UAVs will undoubtedly yield a lesser possibility to have false positive alerts guarantee exhaustive threat prevention. This short review examines drone detection techniques with a focus on the progressive deployment of radar technology for countering drone invasion.

II. Droneillance and Defense Technologies

Several techniques and technologies are used in drone defense systems otherwise called anti-drone systems. These techniques range from acoustic, video/optical, thermal, radio frequency (RF), radar, and most recently, sniffing technique [2]. Each of these techniques has underlying technological strengths and limitations which are summarized in Table I. The operational principle of each technique differs considerably. For instance, RF techniques work by using RF sensors to passively listen to the RF spectrum where drones and their controllers communicate which is usually interfered with by surrounding noise.

A. Radar Technology for Drone Detection

Radar technology is massively deployed for drone detection due to its enhanced spatial coverage both in the distance, speed/velocity, direction/angle, and altitude of the target [3] with increased observational capabilities for 24-hour operations, despite interference from unfavorable weather conditions like rain, fog, and darkness. This is in contrast to optical, infrared, and rf detection, confirming its capability in automotive and military applications. Additionally, radar devices provide early drone detection and warning of oncoming hazards with a highly accurate estimation of the attack's position and dynamics. Unlike RF scanners, radar weighs the time of flight of the reflected signal whereas RF demodulates the signals.

Fig. 1 illustrates how radar is used to detect drones. Simply put, the radar sends radio waves through the transmitter and receives them back through the receiver to detect drones. The reflected signals are evaluated and compared with a database threshold value for drone characterization. Similar to how radars are deployed to find birds, the recorded signatures in the database can be used to filter out non-dronelike objects and identify what type of drone the radar is detecting. Due to this signal processing, which significantly raises detection efficiency, fewer false positives are conceivable in radar-based drone detection. Advanced technologies like machine learning and deep learning (DL) models can improve drone radar detection and minimize false positives [4].

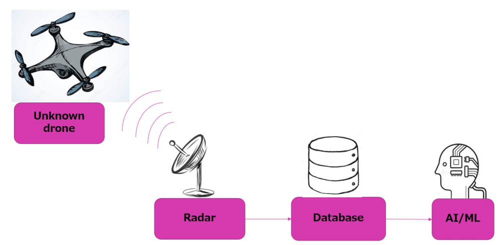

Fig. 1. The usage of usage radar technology to detect drones

To detect objects, radar systems use short radio wave pulses. After interacting with an object, this signal returns to the radar antenna. To calculate the object's size and speed, the radar then amplifies the signal that was reflected. To find and locate aircraft with a high radar cross section (RCS) in the sky, not at low altitudes, air surveillance radars (ASRs) are primarily designed to find and locate aircraft with a high radar cross section (RCS). Additionally, it is difficult to locate drones with high-range resolution radar profiles (HRRPs) since the sub-centimeter resolution is required to capture the longitudinal structure of objects that are shorter than 100 cm in length. As a result, the great majority of radar systems used to find and identify birds and drones have a low range profile [5]. Leakage, also known as unwanted power flux from the transmitter to the receiver, is a major issue with frequency-modulated continuous-wave (FMCW) radars [6]. Several innovative attempts to address leakage problems in radar detection techniques have been carried out in contemporary times.

TABLE I
NON-RADAR METHODOLOGIES FOR DRONE DETECTION

Technique	Prospects	Problems
Acoustic	Real time, longer range detection than other methods.	Inefficient in complex background and noise.
Vision/Optical	Low cost, less regulatory limitation	Weather dependent, shorter range, obstacle issues, cluttered env,
RF (radio frequency)	Obstacle free, can locate drone operator	Affected by noise interference, requires autonomous flight
Thermal	Slightly affected by weather, long-range detection	Low detection accuracy
Sniffing	Effective for toxic substance detection	Limited application

III. RESILIENT TECHNIQUES TO MITIGATE LEAKAGE PROBLEM

A. Convolutional Neural Network

Convolutional Neural Network (CNN) model is one noble method used to reduce the leakage issue. With its unique characteristics of extracting useful patterns from complex data features using convolution blocks, CNNs perform creditably as underlying models for solving leakage problems. For instance, a 32 filters, a depth concatenation layer CNN model (32DC) was applied on Real Doppler RAD-DAR Dataset and compared to several other networks such as SqueezeNet, LDA, SVM, ResNet-18, and KNN. The result proved that CNN had the best performance in terms of time and accuracy. However, since UAV radar datasets are almost nonexistent, optimization of this network before the application will improve its performance [3].

B. Stationary Point Concentration (SPC)

The stationary point concentration (SPC) technique was used to reduce the leakage by concentrating the phase noise of the leakage on a stationary point of a sinusoidal function. SPC improves the signal-to-noise ratio of small drones by lowering the noise floor and correcting their velocity and distance information (SNR). Additionally, it is feasible without additional hardware to utilize digital signal processing (DSP) based on strategic frequency planning and oversampling. The SPC approach, though, has significant drawbacks. Strategic frequency planning, one of the processes for putting the SPC technique into effect, limits the freedom in frequency planning, an important stage in the design of a radar system. Oversampling may also require the use of high-performance analog-to-digital converters (ADC) and memory, both of which may be pricey. The SPC technique is also restricted in the radar architecture it may be used to. The SPC method also has a limited radar design.

C. Advanced Stationary Point Concentration (A-SPC)

A-SPC approach introduces a quadrature demodulator and complex signal-based DSP to alleviate the inherent constraints of SPC. Quadrature imbalance can result in unwanted picture signals and false detections. A-SPC algorithms are capable of resolving quadrature imbalance. Additionally, the homodyne FMCW radar can be employed with the A-SPC technique, which does not call for oversampling or deliberate frequency selection. Finally, while A-SPC is still under investigation, there isn't much research that compares their findings to those of [7].

IV. OPEN RESEARCH ISSUES

As the risks associated with drone technologies increase, it has become imperative to create radars that can identify small drones. Drones are getting smarter and more advanced in terms of disguising and avoiding detection. For example, If a drone hovers in one place or moves slowly, radar cannot distinguish it from obstructions. Hence, there is increased smartness in disguising and avoiding detection. Also, radars are still confronted with difficulties in detection range, accurate classification, and appropriate mitigation strategies based on drone type and target characteristics. Therefore, intense research efforts directed in these areas will facilitate the building sophisticated and adaptive anti-drone systems with multifaceted functionalities.

V. CONCLUSION

Radars have seen frequent usage recently for drone detection due to their capabilities for early detection while providing several useful parameters about the upcoming drones under different circumstances. However, radars face some problems when it comes to differentiating between drones and birds, as well as leakage. This paper explored intrinsically some techniques that have been used to mitigate the leakage problem and some open issues for drone detection using radar technology.

ACKNOWLEDGMENT

This research work was supported by Priority Research Centers Program through NRF funded by MEST (2018R1A6A1A03024003), the Grand Information Technology Research Center support program (IITP-2022-2020-0-01612) supervised by the IITP by MSIT, Korea, and Industry-University-Research Institute platform cooperation RD funded Korea Ministry of SMEs and Startups in 2022.(S3311338).

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