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Anti-drone system with multiple surveillance technologies

[1]Anjali Nawalagatti [2]Arun. S. Tigadi
Student Dept of E and C KLE Dr. MSSCET, Belagavi Karnataka, India
Assistant Professor Dept of E and C KLE Dr. MSSCET, Belagavi Karnataka, India
Corresponding Author: Anjali Nawalagatti

Abstract— *UAVs (Unmanned aerial vehicle), also known as drones, play major role in progress of smart cities. UAVs, in future, can be used in many ways, for example, to deliver goods and merchandise, serving as mobile hotspots for broadband wireless access and to maintain surveillance and security. The goal of this survey article is to study various potential cyber and physical threats that may arise from the use of UAVs and also to review various ways to detect, track and prohibit malicious drones. Due to low price and ease of use, drones have been widely utilized in many applications. The use of UAVs poses great threat to public security and personal privacy, for example, an attacker might strap explosives or other dangerous materials to a drone to carry out an attack. Criminals can use drones to smuggle illicit materials across the border. An operator can control the drone carrying a high-fidelity camera to fly over walls and spy inhabitants' private information. Some drone manufacturers have embedded geofencing software into their drones to prevent them from flying over security-sensitive areas. However, it is unrealistic for geofencing to cover every place and every drone. Therefore it is necessary to deploy an anti-drone system in security-sensitive area as well as geofencing-free area. This anti-drone system is able to detect the drone at the time it flies into the sensitive area and estimate its location for drone defence. Anti-drone system can be jamming, hunting or control of the detected ones. Many technologies like radar surveillance, audio surveillance, video surveillance, radio frequency (RF) surveillance have potential for drone detection and localization. Nowadays, almost every company that deals with autonomous flight of drones claims the use of artificial intelligence and machine learning.*

Index terms: *surveillance technologies, orelia-drone detector, drone detector, dedrone, ARDRONIS, drone-shield, ADS-ZJU.*

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I. Introduction

An unmanned aerial vehicle (UAV), commonly known as a drone is an aircraft without human pilot onboard. The flight of UAVs may operate with various degrees of autonomy either under remote control by a human operator or autonomously by onboard computers. Compared to manned aircrafts UAVs were originally used for missions where it was impossible for humans to reach. UAVs were originated mainly for military applications but their use is rapidly expanding to commercial, scientific, recreational, agricultural purposes. Civilian UAVs now vastly outnumber military UAVs.

The potential benefits and advantages do not come without their share of risks and challenges. Some of the challenges include data theft, loss of control, collisions, limited battery power, untrained operators. Sensitive data of military base can be sent to another military with the help of UAVs. One can hack the drone to use it for malicious act. The biggest safety threat from drones is potential collision with airplanes. Because of the hardened materials on many of them and the velocity at which they move, can take down a passenger plane. The use of UAVs poses great threat to public security and personnel privacy. Therefore it is necessary to deploy an anti-drone system in security sensitive areas.

Anti-drone system is a scalable system which provides the maximum protection of areas. Due to drones' small size and low flying speed at low altitude, drone surveillance is a challenging task and many technologies like radar surveillance, audio surveillance, video surveillance, radio frequency (RF) surveillance have potential for drone detection and localization. Anti-drone systems have been developed based on one or several of these technologies. Nowadays almost every company that deals with autonomous flight of drones claims the use of artificial intelligence and machine learning. Drones have two parts: the aircraft and a control system. Sophisticated drones are equipped with the state of the art technology that uses artificial intelligence. Ex: Construction companies use AI drones to scan and map the terrain of building sites.

II. Literature survey

1. A review on cyber security vulnerabilities for unmanned aerial vehicles", by C. G. Leela Krishna and Robin. R. Murphy. Published in 2017 IEEE international symposium on safety, security and rescue robotics (SSRR). This paper surveys the scientific and trade literature on cyber security for unmanned aerial vehicles (UAV), concentrating on actual and simulated attacks, and the implications for small UAVs.
2. "Security Of Unmanned Aerial Vehicles: A Literature Review And Research Directions", by Caleb, Nanchen Nimyel , Alfred, Nanpak Albert , Odumu, Proc. IEEE trans.Issue-10, pp-106-109. : Unmanned Aerial Systems (UAS)- air vehicles equipped with sensors and software that enable the craft to fly without a human pilot on board.
3. "Compressed Sensing Technologies and Challenges for Aerospace and Defense RF Source Localization", by Pasquale Daponte, Luca de vito, Franscisco picariello published in 2018 5th IEEE international workshop on Metrology for aerospace (MetroAeroSpace). The paper presents an overview of technologies and challenges regarding the adoption of Compressed Sensing (CS) framework for ideation of novel instrumentation systems, that could be used for the next generation of radio frequency (RF) source localization and tracking.
4. "Security, Privacy, and Safety Aspects of Civilian Drones", by Riham Altawy and Amr. M. Youssef in vol.1 issue.2 Feb.2017 art.no.7 Proc. IEEE. Trans NY,USA. The market for civilian unmanned aerial vehicles, also known as drones, is expanding rapidly as new applications are emerging to incorporate the use of civilian drones in our daily lives.

Different surveillance technologies

a) Radar:

Radar is a useful tool for detecting and tracking of aircrafts. It also faces severe challenges in detecting and tracking drones since drones have a low radar cross-section and usually fly with low speed at low altitude. Even so, radar surveillance is promising in detecting and tracking drones. It has been verified that by analyzing the micro-Doppler signatures obtained by multistatic radar, the clutter/target discrimination can be improved which enables drone detection and tracking with high accuracy. A series of experiments showed that the detection range of radar hardly exceeds 3000 meters. Radar is one kind of active sensor which operates all day and night with high electromagnetic energy. Thus it might be inappropriate or even forbidden to deploy high-power radars in crowded urban areas.

b) Audio:

During the flight of drones, the sounds generated by the motors and fast rotating propellers can be utilized in detection, classification and localization of drones by a system equipped with acoustic sensors. Audio surveillance is sensitive to ambient noise and suffers from a limited detection range which depends on the drone type and testing environment.

c) Video:

An object can be detected based on its appearance features i.e. colors, contour lines, geometric forms or edges or its motion. Features across consecutive frames. Appearance feature based methods have great difficulty in distinguishing drones from other similar small objects. Motion based methods are easy they compare consecutive images, position and moving direction of moving object to recognize the object. Ex: A drone can be distinguished from birds by looking at the flight patterns, since a bird will fly in a more random pattern then a drone will. Such method might fail when the bird is gliding. Thus for drone detection, it is promising to combine both motion features and appearance features which would enable the detection with higher accuracy.

d) Radio frequency(RF):

The existing drones in the market or customized drones usually communicate with their controllers at some specific frequency bands. In practical environment, the existence of many other RF signals like wifi, which share same frequency band with the drones makes RF-based drone detection challenging. One simple way is to monitor a wide range of RF and take any transmitter of unknown RF signals as a drone. But this method will induce a high probability of false alarms since an unknown RF transmitter is not necessarily a drone. Identifying the media access control (MAC) address of a drone is also a feasible method. However, this method is possible only with those drones which are having open MAC addresses.

TABLE-I: Comparison of different surveillance technologies

Surveillance technology	Drone signature	Localization/ tracking method	Detection range	Challenges
Radar	Micro-Doppler	Doppler-based tracking, delay-based localization	<=3000m	Low radar cross-section, low speed and altitude
Audio	Time-frequency feature	DOA-based localization	40-300m	High ambient noise
Video	Appearance feature, motion feature	Mobile-based tracking	100-1000m	Occlusion indistinguishable small object
RF	Communication channel	RSS/DOA-based localization	<=1000m	Ambient RF noise, multipath non-line-of-sight

Different Anti-drone systems

There are already several commercial/ military anti-drone systems. Some of them are:

i. Orelia-drone detector:

Fig: Orelia-drone detector

- Orelia-drone detector is an audio-based detector and is able to detect both fixed-wing and rotary wing drones.
- Its detection range can reach 100m when the background noise is less than 40db.

ii. Drone detector (developed by dronelabs):

Fig: Drone detector

- Drone detector utilizes RF and audio surveillance for drone detection.
- Its detection range is 1km.

iii. Dedrone:

Fig: Dedrone

- Dedrone has several products including drone tracker, RF sensor and drone jammer etc.
- Drone tracker combines microphones, optical cameras and wifi sensors and it can detect drone within 500m.
- RF sensor can detect all drones connected through RF and wifi within 1km.
- Drone jammer transmits RF signals at multiple frequency bands via omni-directionl antennas to disrupt the drone communication.

iv. ARDRONIS:

Fig: ARDRONIS

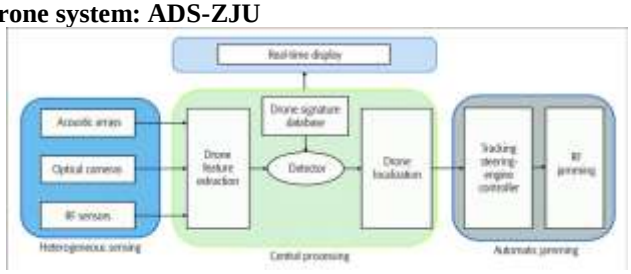
- ARDRONIS developed by Rohde and Schwarz is based on RF surveillance.
- For the drones using frequency-hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS) transmission systems, ARDRONIS builds an RF library for drone detection. The detection range of ARDRONIS can be up to 1km-2km, which depends on RF transmission power, radio condition and antenna gain.
- Apart from drone detection, ARDRONIS can realize localization of both the drone and its operator via direction finding.

v. Drone shield:

Fig: Drone shield

- Provides an integrated detection and defence solution.
- It utilizes radar, audio, video and RF surveillance for drone detection with nominal detection ranges: 1.5km for radar, 200m for audio, 600m for video and 1km for RF.

Implementation of anti-drone system: ADS-ZJU



ADS-ZJU is an anti-drone system which combines three surveillance technologies i.e. audio, video and RF. The above figure shows the architecture of ADS-ZJU which consists of four parts: heterogeneous sensing unit, central processing unit, automatic jamming unit and real-time display unit.

i. Heterogenous sensing unit: consists of 3 kinds of sensors. They are:
- Acoustic sensor: acoustic sensors with advanced detection technology are capable of sensing drones even if they are invisible to radars or lack radio-frequency links.
- Optical camera: it supports 360-degree horizontal rotation, -2 to 90 degree vertical rotation. It can achieve both automatic and manual focusing.
- RF sensor: the utilized RF sensor is one kind of software defined radio which has four independently tunable RX channels and can receive RF signals between 10MHz and 6GHz

Acoustic signals, video images and RF signals will be collected via these sensors and sent to central processing unit.

ii. Central processing unit: the central processing unit is the key part of ADS-ZJU it conducts drone feature extraction, drone detection and drone localization. Drone feature extraction: drone feature extraction is essential for drone detection. Drones' features are analyzed based on the received acoustic signals, video images and RF signals.
- Drone detection: the linear support vector machine (SVM) is utilized in drone detection.
- Drone localization: in case a drone is detected, location-related information will be extracted from the received acoustic signals, video images and RF signals for localization.

iii. Automatic jamming unit: RF jamming is used to defend against the drones which fly into the sensitive area. It consists of four parts:
- Two steering-engines: one can achieve 360-degree horizontal rotation and the other one can achieve 180-degree vertical rotation.
- Steering-engine controller
- A planar directional antenna whose antenna gain is 14Db.
- An RF signal generator which can generate RF signals.

iv. Real-time display unit: real-time display unit is a LCD which consists of four 46-inch sub screens to display the drone surveillance results.

Table-II: Comparison of anti-drone systems

System	Surveillance technology				Function		
	Radar	Audio	Video	RF	Detection	Localization	Defence
Orelia-drone detector	No	Yes	No	No	Yes	No	No
Drone detector	No	Yes	No	Yes	Yes	No	No
Dedrone	No	Yes	Yes	Yes	Yes	No	Yes
ARDRONIS	No	No	No	Yes	Yes	Yes	No
Drone shield	Yes	Yes	Yes	Yes	Yes	No	Yes
ADS-ZJU	No	Yes	Yes	Yes	Yes	Yes	Yes

III. Conclusion

In this article we discussed various advantages of drones and also studied in brief regarding the disadvantages or public threats caused due to malicious usage of drones. Due to these challenges it is necessary to deploy an anti-drone system in security-sensitive area. In this article gave a comprehensive review of four of the most widely used surveillance technologies in drone detection and localization i.e. radar surveillance, audio surveillance, video surveillance and radio frequency (RF) surveillance. Performances of these systems rely on the utilized technologies but an application varies with utilized technologies. We also gave a brief comparison on different surveillance technologies. Also summarized existing anti-drone systems with the brief comparison. Then we also summarized about implementation of anti-drone system called ADS-ZJU which combines three passive surveillance technologies.

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