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Interception and Detection of Drones Using RF-based Dataset of Drones

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The usage of Unmanned Aerial Vehicles (UAVs) is accessible for different applications to a wide range of users. However, this wide range of users raises a great concern about the threat (passive or active threats) of malicious actors who can use UAVs for criminal activities. The detection of UAVs is considered to be the first step in the process of UAVs countering (c-UAV). Nowadays, the c-UAV applications offer systems that include different sensors such as electro-optical, thermal, acoustic, radar and radio frequency sensors. Information gathered by these sensors can be fused in order to increase the reliability of threat's detection, classification and identification. It is necessary to have datasets from the different sensors in order to develop methods and algorithms for detection and classification of UAVs. This paper presents a dataset of communication signals between the drone and the control station that is used in the process of detection and classification.

Key words: **dataset, detection, Unmanned Aerial Vehicle, RF sensor.**

Introduction

DEVELOPMENT of Unmanned Aerial Vehicles (UAV) technology in recent years has caused the increase of drones popularity. Nowadays, drones are more compact in size, easier to operate, cheaper and widely available for anyone. Therefore drones are also used for malicious activities such as harming targeted individuals or the public at events or attacking military installation such as bases [1], [2] and [3]. In open literature there is now lot of research on the application of drone detection using different technologies such as the interception of communications signal by radio frequency (RF) sensors, active or passive radar such as a GSM passive coherent location system and a digital TV based bi-static radar, electro-optical cameras, thermal cameras and acoustic sensors [4].

Counter UAV solutions usually offer systems that include multiple integrated sensors for detecting the threat. The basic sensor in that system is radar and/or electro-optical/thermal (EO-IR) sensors and less commonly RF sensors and acoustic [5]. Every of these sensors have some weaknesses and strengthens.

In this paper the possibility of using RF sensors for interception of communications links used by UAVs, detection and classification of drones was examined. In order to consider that possibility, large amount of drone RF signals were required. Most drones use ISM 2.4 and ISM 5.8 band for communication between drone and the control station (the operator's controller.). This is an uncontrolled frequency band where most wireless internet and other WLAN can be found. There is a possibility to detect the signal that is being broadcasted by the drone by signal surveillance.

Due to various reasons such as privacy, there were no public drone RF data available for this application in literature. Therefore, we have created our RF based dataset.

This paper consists of four parts. Introduction is given in Section I. Drones under analysis and used detection system are explained in Section II. Obtained results are given and in Section III and analysis of drone RF database is presented in Section IV. Conclusions are given in Section V.

Experimental setup

Acquisition equipment used in this analysis, drones specifications and examined operational modes are explained in this Section.

It is known that testing various drones means differnecing various working principles regarding frequency, mode etc. Each of tested drones manifests in a different RF signal so afterwards, it can be recognized among many others regardig to these specifications [6]. The main purpose of this paper is contribution to a world wide drones database so further is given a list of droes used in this testing:

- DJI Phantom IV
- DJI Mavic 2 Zoom
- DJI Mavic 2 Enterprise.

As can be seen in Fig. 1., each drone is paired with a

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specific remote controler. Remotes for Phantom and Zoom 2 can optionally been connected to a smartphone provided with free mobile applications "DJI GO 4" through which they could be operated [7]. As far for Mavic 2 Enterprise, there is no option for a mobile phone because the application is already installed on the control station so there are varios combinations of testing theese drones in simultanious operation [8].

Figure 1. Experimental setup and drones under analysis

Table 1. Drone specification

UAV type	DJI Phantom IV	Mavic 2 Zoom	Mavic 2 Enter-prise
Total weight	1380 g	905 g	899g
Diagonal size	350 mm	354 mm	354 mm
Work autonomy	28 min	31 min	31 min
Range (remote)	5 km	8 km	8 km
Operating Fre-quency (GHz)	2.400 - 2.483	2.400 - 2.483 5.725 - 5.850	2.400 - 2.483 5.725 - 5.850

Listed drones are in commercial use and as they vary in size, price and specifications also cause variations in capability and offered tehnology. Drone specification is shown in Table 1 [7] and [8].

Acquisition equipment shown in Fig.1 consists of one Real Time Spectrum Analyzer and two receiving antennas (one for 2.4 GHz and one for 5.8 GHz) with belonging cables and connectors. Interception is performed in both frequency band, 2.4 GHz and 5.8 GHz but not simultaneously. Experimental setup on the Real Time Analyzer included the central frequency at 2.4 GHz (drone operational frequency) with the bandwith of 100 MHz that was wide enough to cover all drone emissions. The acquisition length of the signal was 450 ms and a sampling frequency of 150 MSample/s. Raw RF samples are recorded at real-time analyzer. After recording, raw RF samples are transferred to desktop computers. Data processing are performed by programs that have been designed in MATLAB software package. In this programs basic time-frequency analysis has been performed.

In order to cover as many RF activities as possilbe, acquisition was realized in five different operational modes:

- Drone on, only the dron is turned on, with no remote station or any actions included,
- Connection, when the remote control station is also turned on and the connection between starts to flow,
- Hovering, only take off and no other actions included,
- Flying, includes movement to the side, up an down and also circling around,
- Video, includes video streaming and recording throught an installed application, including flying.

Each drone was analyzed separately, in all mentioned operational modes, but in odrer to differ their characteristics, more suppositions were made. The acquisition was realized with dwo and all drones combined in order to determinate all differences. Most drones have capability of working in two different bands or in both simultaniously. There exist an option in the application of chosing which frequency distribution type will be used. When turned on, drone is set up to a lower frequency band, by default [7], [8].

Obtained results

The first measurement taken was the one with no drone activities included, only the environement taken into consideration. It was not posible at the moment to idealize examinating conditions. RF spectrogram of environemental activities in lower frequency band is shown in Fig. 2. As presented, there are no major activities that can be taken into consideration as a possible threat to valuable assesment on drone activities.

Mean value of the signal power (refers to the different operational modes) in spectrograms below for Zoom 2 takes values from -100 to -65 [dB], for Enterprise from -85 to -55 [dB], in case of Phantom IV from -90 to -47 [dB] and for all drones included from -86 to -49 [dB].

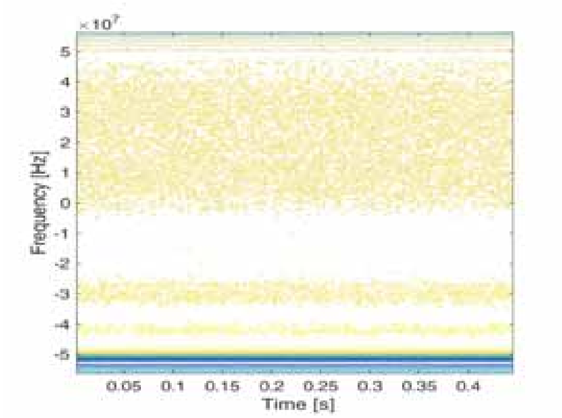

Figure 2. Spectrogram of RF background activities

As mentioned, acquisition was realized in few different operational modes. The results for lower frequency band (central frequency set to 2.4 GHz) given in spectrograms are presented below.

Mavic 2 Zoom

Obtained and processed results for Mavic 2 Zoom are shown in Fig.3 to Fig.7.

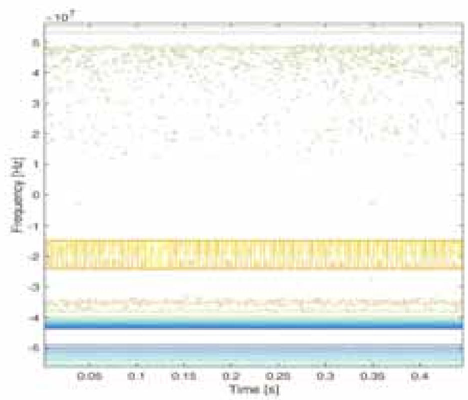

Figure 3. Spectrogram of the Mavic 2 Zoom during drone on mode

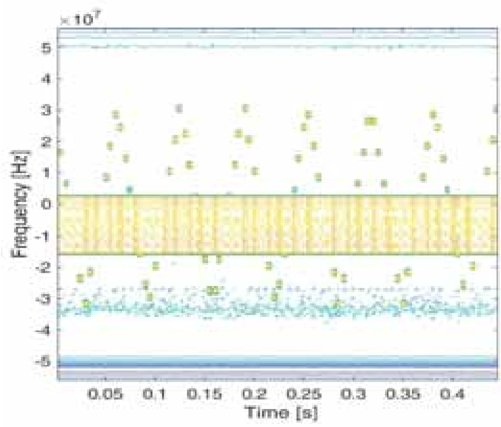

Figure 4. Spectrogram of the Mavic 2 Zoom activities during connection

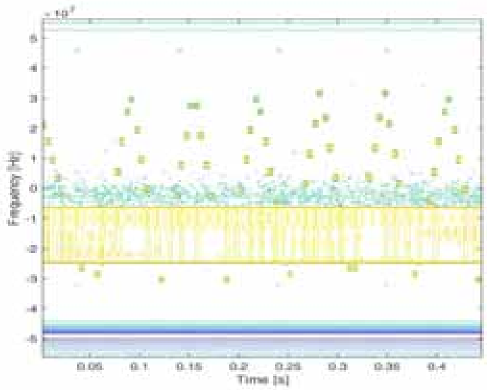

Figure 5. Spectrogram of the Mavic 2 Zoom during hovering mode

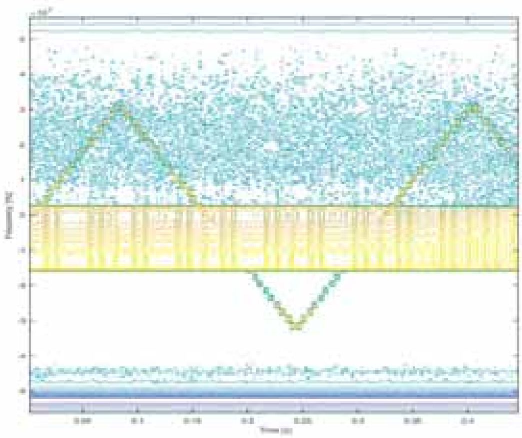

Figure 6. Spectrogram of the Mavic 2 Zoom during flying mode

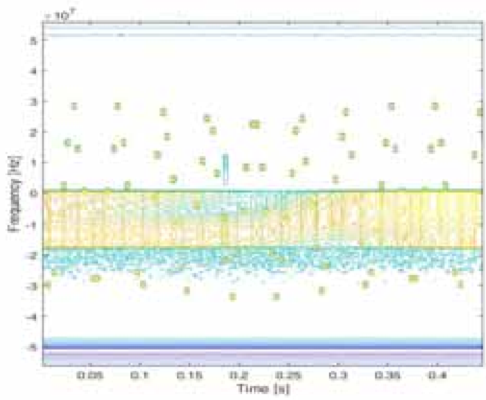

Figure 7. Spectrogram of the Mavic 2 Zoom during video transmission

Mavic 2 Enterprise

Obtained and processed results for Mavic 2 Enterprise are shown in Fig.8. to Fig.12.

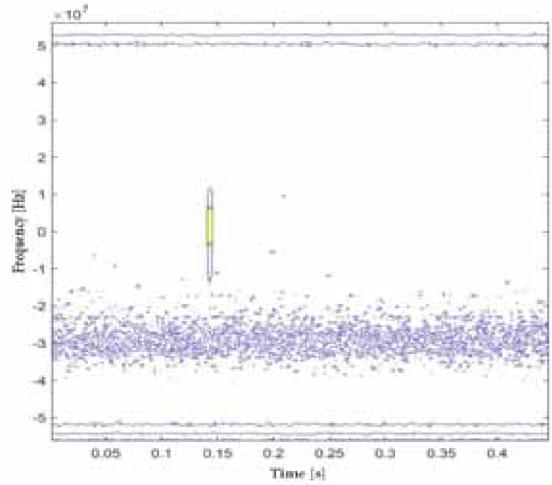

Figure 8. Spectrogram of the Mavic 2 Enterprise during drone on mode

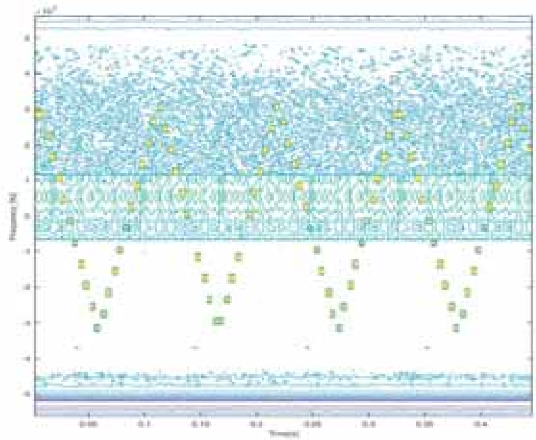

Figure 9. Spectrogram of the Mavic 2 Enterprise during connection

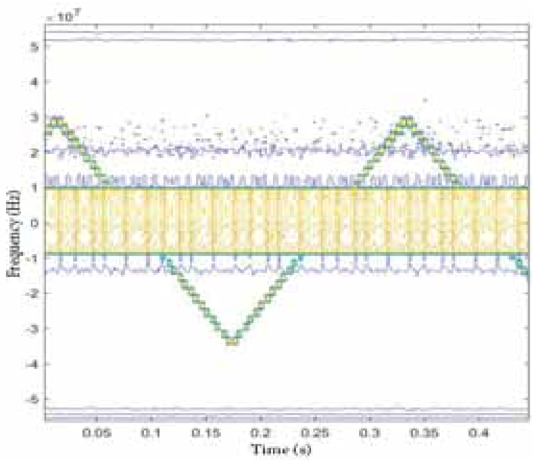

Figure 10. Spectrogram of the Mavic 2 Enterprise during hovering mode

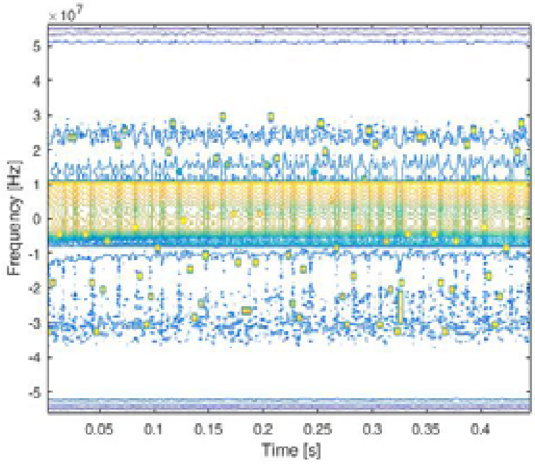

Figure 11. Spectrogram of the Mavic 2 Enterprise during flying mode

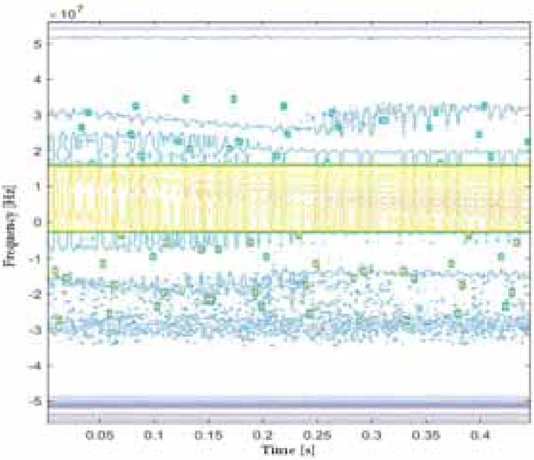

Figure 12. Spectrogram of the Mavic 2 Enterprise during video transmission

Phantom IV

Obtained and procesed results for Phantom IV are shown in Fig.13.

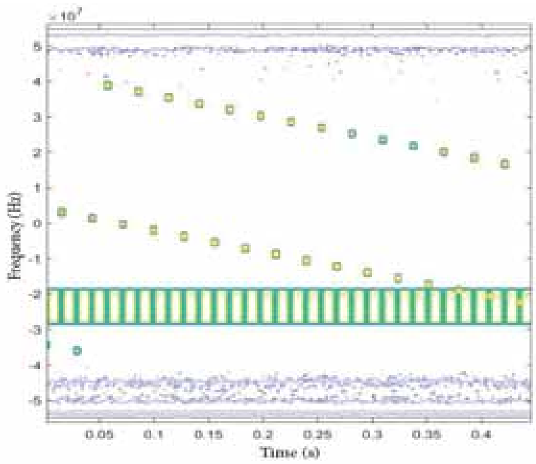

Figure 13. Spectrogram of the Phantom IV during all operational modes

Three drones

Obtained and procesed results for all three drones included are shown in Fig.14. to Fig.17.

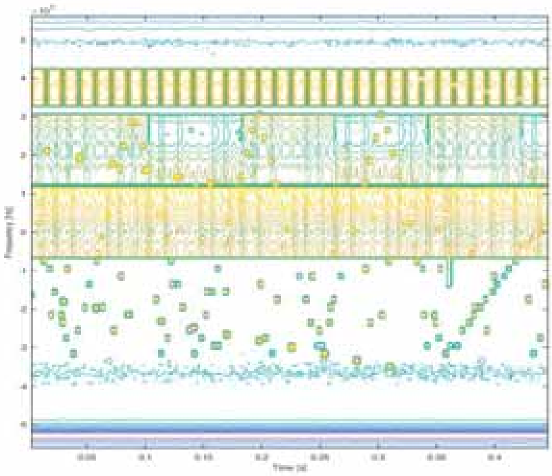

Figure 14. Spectrogram of all drones during connection

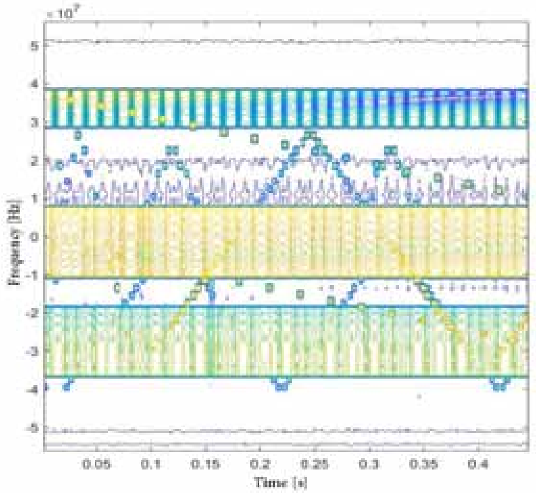

Figure 15. Spectrogram of all drones during hovering

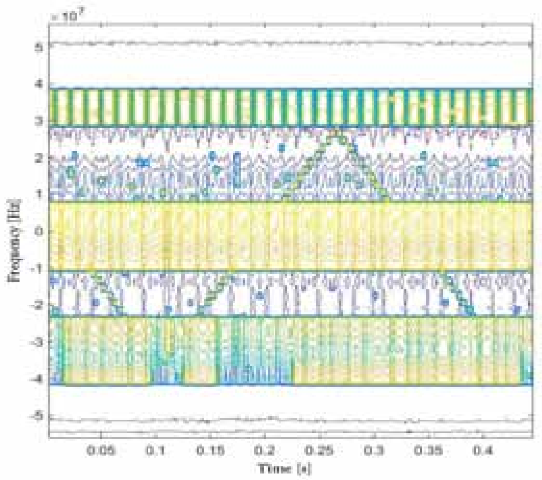

Figure 16. Spectrogram of all drones during flying

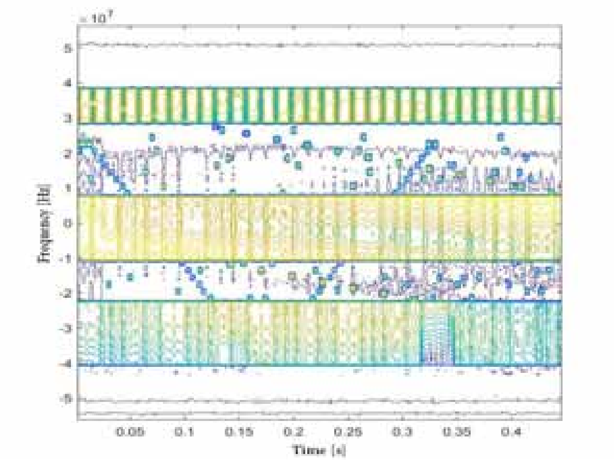

Figure 17. Spectrogram of all drones during video transmission

Drone database analysis

Based on time-frequency analysis of the recording raw RF samples can be obviously concluded that these three drones use the spread spectrum (SS) techniques based on frequency hopping (FH) for communication between drones and controllers. In this case the problem of drone controller detection is the same as the detection of FH emission. It can also be concluded that FH emissions are in these case similar to sweep signals. Based on time-frequency analysis, it is possible to estimate bandwidth of FH emissions, of the spectral bandwidth of the elementary narrowband frequency channel, the number of hopping channels, time between two hops, dwell time.

Phantom IV has the same principle of FH emission in all operational modes and the results which refer to all of them are given in Table 2.

Table 2. Phantom IV database

UAV type	Total channel number	Channel bandwidth [MHz]	Channel distance [MHz]	Hop duration [ms]	Δt [ms]
DJI Phantom IV	37	1.93	35	6	9

Parameter Δt is time between two hops, the value is calculated from the end of one hop to the next hop beginning. Actually, it represents non transmiting time. Channel distance refers to the frequency spacing between adjacent channels, not the whole bandwidth which is 75 MHz in case of Phantom IV. Channel distance is measured as the difference of two consecutive hops central frequencies. Total channel number refers to a different hops which occupy the same frequency. The number of hops exceeds the number of channels because of the hopping algorithm. In this case of Phantom IV, each hop has actually taken a different channel and these two parameters match. Dwell time refers to the period in which FH emission retains to the same hop (channel). Channel bandwidth is the difference between the upper and lower frequencies in a communication channel (hop).

The results for Mavic 2 Zoom and Mavic 2 Enterprise are shown in Table 3. The results in tables are given as average values estimated trough processing and can vary in very small percentage. Unlike Phantom IV, these drones have specific RF activity for each operational mode. Both drones use the same working principle, as mentioned, but in different modes. There are overlaps, the same activity in two operational modes and specific values all modes have in common. In operational mode "Drone on" there is no detected activity that shoud be taken into consideration. In other modes, three types of FH emission are detected in communication with the controller. Based on results from Table 3., it can be concluded that the number of channels for different modes equal, also bandwidth and dwell time. As for other parameters, it is observed that the values of channel bandwidth and Δt are equal for the same drone. Channel distance parameter has the largest deviation. Comparing this parameter for both drones it could be seen that it is equal in Mavic 2 Zoom "Connection" and Mavic 2 Enterprise "Flying and Video" mode. Visually, it can be observed comparing Fig.4, 11. and 12. Conclusion is the same if compare Mavic 2 Zoom in "Hovering and Video" with Mavic 2 Enterprise in "Connection" mode (Figures 5, 7, and 9). FH emission is similar to sweep signals but only differs in channel distance which leads to different appliance of interception and jamming techniques. When all drones included, there is no change in RF activities, as can be seen in Fig.14. to Fig.17.

Table 3. Mavic 2 database

UAV type	Mavic 2 Zoom				Mavic 2 Enterprise			
Operational mode	Connection	Hovering	Flying	Video	Connection	Hovering	Flying	Video
Total channel number	32	32	32	32	32	32	32	32
Channel bandwidth [MHz]	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8
Channel distance [MHz]	12	4.5 9	2	12	5	2	12	12
	9			7.2			9	9
	3			3.5			3	3
Dwell time [ms]	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Δt [ms]	2.7	2.7	2.7	2.7	2	2	2	2
Total bandwidth [MHz]	64	64	64	64	64	64	64	64

Conclusion

In this paper the possibility of using RF sensors for interception of communications links used by UAVs, detection and classification of drones was examined. In order to consider that possibility, three present drones were used. Most drones use ISM 2.4 and ISM 5.8 band for communication between drone and the control station. In this paper, ISM 2.4 frequency band was presented. The main purpose of RF analysis is to detrminate elementary parameters of drones RF activity which implies, the transmission operatinal mode (is it frequency hoping, burst or continuous transmission), frequency band, number of channels and channel bandwidth. Based on time-frequency analysis of the recording raw RF samples can be obviously concluded that these three drones use the spread spectrum (SS) techniques based on frequency hopping (FH) for communication between drones and controllers so frequency hopping was the analyzed emmission and the estimated parametrs are given in the paper. In further work, higher frequency band (ISM 5.8) should be analized and also compared to the results estimated for ISM 2.4.

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Presretanje i detekcija besposadnih platformi koristeći RF bazu podataka

Upotreba besposadnih vazduhoplovnih platformi je u različitoj primeni dostupna širokom spektru korisnika. Naime, ovakva široka upotreba dovodi do razmatranja potencijalnih pretnji (pasivnih ili aktivnih) u vidu zlonamernih aktera koji bi platforme koristili za realizaciju nezakonitih aktivnosti. Prvi korak u suzbijanju ovakvih pretnji odnosno prvi korak u borbi protiv besposadnih platformi jeste njihova detekcija. U današnje vreme za ove aktivnosti prisutni su sistemi koji obuhvataju različite senzore kao što su elektooptički, termalni, akustički, radarski i radio-frekvencijski senzori. Informacije prikupljene sa ovih senzora se mogu objediniti u cilju povećanja pouzdanosti prilikom detekcije, klasifikacije i identifikovanja pretnji. Da bi se razvili algoritmi i metode za detekciju i klasifikaciju UAV, neophodno je imati bazu podataka prikupljenu sa različitih senzorskih sistema. U ovom radu predstavljena je baza podataka komunikacionih signala između besposadne platforme i kontrolne stanice koja se koristi u procesu detekcije i klasifikacije.

Ključne reči: **baza podataka, detekcija, besposadna vazduhoplovna platforma, RF senzor**