[DATASET DESCRIPTION]
SINGLE AND MULTIPLE DRONES DETECTION AND IDENTIFICATION USING RF BASED DEEP LEARNING ALGORITHM

Introduction

In recent years, unmanned aerial systems, especially drones have gone through remarkable improvement and expansion. Due to the low price and ease of use, drones have been widely utilized in many application and scenarios, which potentially pose great threats. To diminish threats to public security and personal privacy, it is necessary to deploy an effective and affordable anti drone (ADRO) system in the sensitive area to detect, localize, identify, and defend against the intruding malicious drones. These ADRO systems are usually a set of very different types of sensors, with the very difficult task of finding and locating targets in complex environment (drones are small in size, very agile, and they can operate at relatively low altitudes). The use of these sensors requires the symbiosis of different technologies (fusion of radar, audio, video, and / or radio frequency surveillance technologies).

For the research and development purposes of new ADRO systems, it is necessary to have verified and tested database. To the best of our knowledge, there is only one database with a radio-frequency signals from drones and flight (operational) control which is described in detailed in [1]. Therefore, at Military Academy, University of Defence in Belgrade and Military Technical Institute, extensive experiments with various scenarios were carried out in order to obtain a new RF database [2].

Database Description

This RF database (VTI_DroneSET_FFT) was obtained using Tektronix Real Time Spectrum Analyzer, two receiving antennas (for two separate ISM bands) with corresponding cables and connectors were used. The Real Time Spectrum Analyzer an instantaneously record bandwidth of 110 MHz within 2.4 or 5.8 GHz ISM bands and to save records directly in a *.mat format that is suitable for loading and analyzing in the MatLab application. It is important to notice that the acquisition length of each signal was 450 ms and the sampling frequency was 150 MSample/s for instantaneous bandwidth of 110 MHz, which produce *.mat file of around 500 MB for every RF signal from the experiment. Each saved file contains all this additional and useful information that can be used after importing into the MatLab application. For the equipment under test (EUT), three different drones (DJI Phantom IV, DJI Mavic Zoom and DJI Mavic 2 Enterprise) were used with a flight controller that sends and receives RF commands to and from drones in order to change the flight (operational) mode.

Data acquisition for each drone separately with four distinctive flight (operational) modes was performed during all experiments. In order to analyze the whole radio traffic, each experiment was organized in five steps:

- EUT is off. Drone is turned off. RF background (ambient) is recorded. For the sake of more genuine approach, random Wi-Fi and Bluetooth radio-communications at the beginning of experiment were induced.
- EUT is on and performing connecting procedure with flight controller. Drone is turned on by operator. Drone is connecting to flight controller. Recording is performed until drone is connected to flight controller.
- EUT is hovering. Operator lifts off the drone and puts it in a state of hovering (drone is flying without changing altitude and position, i.e. operator do not issue any commands). Recording is performed while drone is hovering (maintain height and position) independently without any operator command.

- EUT is flying. Operator issue some basic commands while drone is moving left, right, down and up. Recording is performed while drone is flying (drone is changing altitude and position all the time) by the commands from operator.
- EUT is flying and recording video. Operator enables video recording on drone and issues some basic commands while drone is moving left, right, down and up. Recording is performed while drone is flying and recording video to the flight controller.

This step by step procedure was done for all drones and encompasses one experiment. Total of 3 experiments were realized, one with single drone, one with two drones and one with three drones, which produced 25 recordings (15 recordings for the first experiment, 5 recordings for the second and 5 recordings third experiments) in 2.4 GHz ISM band and repeat all these for 5.8 GHz ISM band, which counts 50 recordings in total. In addition, it should be pointed out that each experiment was conducted in laboratory (indoor) conditions where RF background recording was firstly executed before four flight modes.

To prepare DNN input data and to create new RF drone database, a Binary Unique Identifier (BUI) was used for data notation. The good practice was followed and created the new RF drone database using suggested parameters such as number of experiments (E), total number of drones (D), and total number of flight modes, including RF background (F). Finally, new database was finished by using E = 3, D = 3 and F = 5. Detailed explanation regarding BUI usage was presented in Table 1.

Table 1. Specification of VTI_DroneSET_FFT database.

Experiment Name	**Experiment Name BUI**	**Drone Name**	**Drone Name BUI**	**Flight mode Name**	**Flight mode Name BUI**	**FINAL (RF SIGNAL) BUI**
	$E = 3 < 2^2$		**$D = 3 < 2^2$**		**$F = 5 < 2^3$**	
One drone	01	DJI Phantom IV	00	RF background Connecting Hovering Flying Flying and Recording	000 001 010 011 100	0100000 0100001 0100010 0100011 0100100
		DJI Mavic Zoom	01	RF background Connecting Hovering Flying Flying and Recording	000 001 010 011 100	0101000 0101001 0101010 0101011 0101100
		DJI Mavic 2 Enterprise	10	RF background Connecting Hovering Flying Flying and Recording	000 001 010 011 100	0110000 0110001 0110010 0110011 0110100
Two drones	10	-	00	RF background Connecting Hovering Flying Flying and Recording	000 001 010 011 100	1000000 1000001 1000010 1000011 1000100
Three drones	11	-	00	RF background Connecting Hovering Flying Flying and Recording	000 001 010 011 100	1100000 1100001 1100010 1100011 1100100

VTI_DroneSET_FFT database is organized in several folders which are shown in Figure 1.

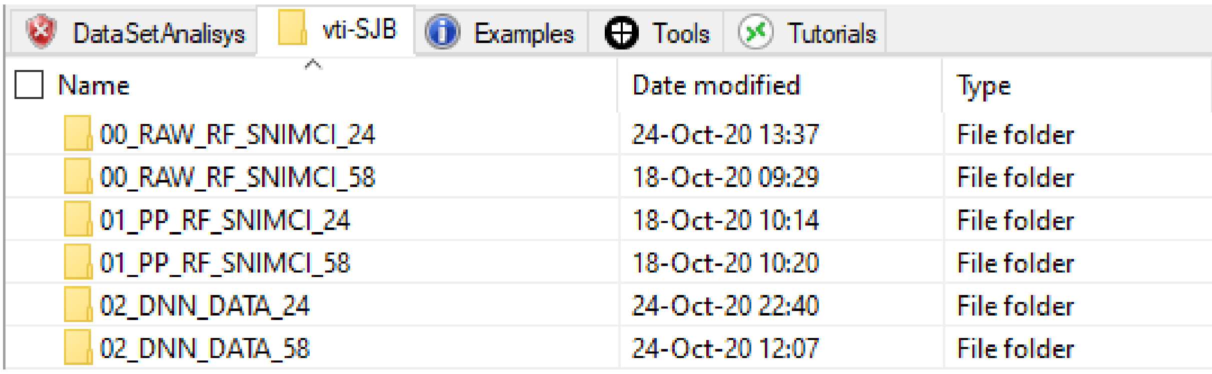

Figure 1. VTI_DroneSET_FFT database organization

Folders 00_RAW_RF_SNIMCI_24 and 00_RAW_RF_SNIMCI_58 are consists of raw data from Real Time Spectrum Analyzer. Total of 50 files are stored in both folders and named by BUI conventions explained in Table 1. These files are the most important part of the VTI_DroneSET_FFT database and our goal is to update regularly with new recordings (RF signals) from different drones.

Folders 01_PP_RF_SNIMCI_24 and 01_PP_RF_SNIMCI_58 are consists of pre – processed RF signals. In order to preprocess and prepare raw data, signal segmentation and simple calculation of the RF spectrum were performed for each segment of signals in both ISM bands. For this purposes, RF spectrum calculation was used MatLab embedded Fast Fourier Transform (FFT) function was used with 2048 frequency bins on zero mean (without DC component) RF segments of signals. The signal segmentation process was realized by dividing the whole signal into snapshots of data consisting of 100,000 samples. This number of samples was deliberately chosen because in that way it is possible to observe and analyze the largest hop that is detected from these three drones (DJI Phantom IV hop length is 6 ms and in this way it is possible to observe 6.7 ms). In addition, signal segmentation was performed to speed up signal preprocessing and to performed data augmentation because each segment of each signal was used as DNN input. Total of 50 files are stored in both folders and named by BUI conventions explained in Table 1.

Folders 02_DNN_DATA_24 and 02_DNN_DATA_58 are consists of input data for corresponding DNNs (preprocessed data with labels). Aggregation of the pre – processed and labeled data from all experiments was performed and stored in four matrices representing the RF spectrum (two matrices for 2.4 GHz and two matrices for 5.8 GHz). Total of 4 files are stored in both folders and named by following rules:

- 2.4 GHz input data:
  - File RF_Drone_Data_24GHz_1.csv representing 2.4 GHz input matrix for DNN No. 1, 2, 3 [2048 x 10050] consist only data from 1st experiment and
  - File RF_Drone_Data_24GHz_2.csv representing 2.4 GHz input matrix for DNN No. 4 [2048 x 16750] consist data from all experiments.
- 5.8 GHz input data:
  - File RF_Drone_Data_58GHz_1.csv representing 5.8 GHz input matrix for DNN No. 1, 2, 3 [2048 x 10050] consist only data from 1st experiment and
  - File RF_Drone_Data_58GHz_2.csv representing 5.8 GHz input matrix for DNN No. 4 [2048 x 16750] consist data from all experiments.

It is important to notice that input matrices for DNNs are consist of additional rows for labeling purposes, so final matrix's dimensions for DNN No. 1, 2, 3 are [2051 x 10050] and for DNN No. 4 [2051 x 16750].

Download Database

Please contact Boban Sazdic-Jotic (boban.sazdic.jotic@vs.rs) if you have any questions.

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We have decided to make the database available to the research community free of charge. If you use this database in your research, we kindly ask that you reference our work.

Please email Boban Sazdic-Jotic (boban.sazdic.jotic@vs.rs) for password request, briefly describing the intended use of the database and your affiliation.

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References

[1] **[dataset]** M.S. Allahham, M.F. Al-Sa’d, A. Al-Ali, A. Mohamed, T. Khattab, A. Erbad, M.H.D. Saria, M.F. Al-sa, DroneRF dataset : A dataset of drones for RF-based detection, classification and identification, Data Br. 26 (2019). https://doi.org/https://doi.org/10.1016/j.future.2019.05.007.

[2] **[dataset]** B.M. Sazdić-Jotić, I. Pokrajac, J. Bajčetić, B.P. Bondžulić, V. Joksimović, T. Šević, D. Obradović, VTI_DroneSET_FFT, Mendeley Data. (2020). https://doi.org/10.17632/s6tgnnp5n2.1.