Concept for a Software Defined Radio Based System for Detection, Classification and Analysis of Radio Signals from Civilian Unmanned Aerial Systems

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Abstract

The recent advances in the field of civilian Unmanned Aerial Systems have enabled a wide range of applications and facilitated their wide spread use. However, these systems can also pose a threat to the civilian population. As part of a research project to counter these threats, a Software Defined Radio based system for detection, classification and analysis of radio signals from civilan drones is proposed in this paper. A short look at related work, focusing on the application of machine learning techniques for the classification of radio signals is presented and a concept for the implementation of detection and classification system is proposed.

1 Introduction

Civilian Unmanned Aerial Systems (UASs) offer a wide range of useful commercial and recreational applications and are becoming a common sight in the skies. However, they can also pose a threat for the civilian population. These danger can range from accidents to the usage of UAS for crimes or even acts of terrorism. To counter these threats and to assist authorities in handling such dangerous situations is the reason why the ArGUS research project was started. Its goal is to create an assistance system, which can help the user (e.g. police or other authorities) to obtain a clear and full picture of the situation and provide them with the best suited option to counter the threat.

For the detection of UAS a multi-sensor approach is chosen. Radar is used as primary technology for the detection and tracking of inbound Unmanned Aerial Vehicles (UAVs). Acoustic and optical (video and infrared) sensors used for verification. Additionally, a Radio Frequency (RF) based system for detection and signal analysis is planed. The concept for this system is the scope of this paper.

The inputs from the sensors are fed to the Flight Intelligence Platform. Here the movement of the drone is analyzed. Also a classification, using an internal UAV register, is performed. By analyzing these information together with additional scenery data, such as possible targets in the area, a comprehensive situation analysis and risk assessment is performed. The assistance system then generates recommendations whether action should be taken and which countermeasures are best suited for the given case. The ArGUS system will present this information to the user (probably a police officer), who then makes the final decision.

Various scenarios are considered both theoretically and in real life tests. This includes violations of no-fly zones at civilian airports or drone attacks at major event locations, such as sport stadiums. The project also takes legal, ethical and social implications into account. An overview of the planned ArGUS system is illustrated in Figure 1.

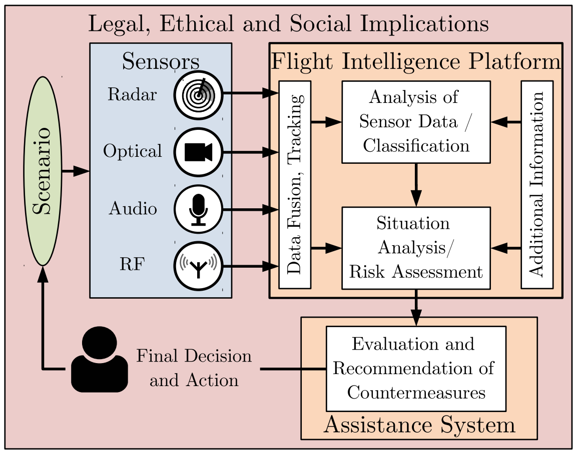

Figure 1. ArGUS system overview

In this paper a concept for radio frequency analysis using a Software Defined Radio (SDR) system is presented. A special focus is hereby on the machine learning based approach for the classification of the detected radio signal. In the following sections of this paper a short view at other relevant work is given. This is followed by the proposed concept and a conclusion.

2 Related Work

In this section a short look at relevant work concerning the application of machine learning algorithms is presented. This is by no means meant to give a full overview at the state of the art in this field. It rather serves to demonstrate the viability of the necessary tools and algorithms for the proposed concept.

For the application of machine learning algorithms to classification tasks in radio systems different approaches have been presented. Possible input for the machine learning can hereby either be the raw in-phase and quadrature (I/Q) data or preprocessed data such as a power spectrum or a Spectral Correlation Density (SCD) [1].

The possibility of using the Spectral Correlation Density and neural networks for signal classification is presented by [2]. An exemplary implementation of such a system, that is based on Software Defined Radio is shown in [3]. For the classification of various modulation schemes, an artificial neural network, in form of a Feed Froward Multi-Layer Perception Network with back propagation is used.

An example of using raw I/Q data as input for Constitutional Neural Networks (CNNs) is presented in [4]. A focus hereby is using a "blind" approach ,which relies on naively learned features, as opposed to the common approach with expert feature based methods. As input, a windowed raw I/Q time series, in form of a two-dimensional vector is fed to the neural network. A comparable approach is commonly used for voice recognition. The used Constitutional Neural Network requires a comparable long time for training. However, the classification itself is fairly fast. This is an acceptable solution for the proposed UAS detection and classification system. Overall it is shown that a "blind" CNN used on a I/Q time series can be a viable option for modulation classification.

GNU Radio is a commonly used toolkit for interfacing the SDR hardware and signal processing [1, 3, 5]. For the implementation of the machine learning algorithms, tools like Keras and TensorFlow are common choices [1, 4].

3 Concept

ArGUS detection uses a radar sensor for the primary of inbound UAVs. Additionally, a RF based detection system is included. The advantage of such a system is that it offers the possibility to detect an UAS during the pairing process of the remote control and therefore, before the UAV even takes of. Thus it can grant the user additional time. Due to the short reaction times in real life scenarios, every additional second may be valuable in order to prevent an accident or attack. Besides the detection of UAS signals, the second goal of the proposed system is to obtain the information transmitted between the UAV and its base station. Especially telemetric or sensor data (e.g. video streams), which is transmitted from the UAV back to the ground station, may be a valuable input for the ArGUS systems.

Due to its high flexibility a Software Defined Radio based approach is chosen. Since almost all of the signal processing is performed in software, modifications can be easily implemented. Also generating or manipulating (e.g. simulation of channel effects) test data, is easily possible, as shown in [4]. This is a major advantage especially for a research project, where different approaches may be evaluated and compared. The concept for the proposed system is presented in the following.

3.1 Hardware setup

The hardware setup consists of a SDR front end and a workstation. As SDR system the Universal Software Radio Peripheral (USRP) X310 is chosen. It is operated with UBX daughterboards. This setup provides two separate channels. A dual 10 GB/s Ethernet interface is used to transfer the raw data from the USRP to the workstation, where the signal processing and machine learning tasks are performed. The main characteristics of this system are [6, 7]:

- frequency range 10 MHz...6 GHz
- bandwidth up to 160 MHz per channel
- sample rate up to 200 MS/s

The given frequency range allows to cover all the frequencies, which are typically used by UAS. The maximum bandwidth allows to monitor the complete Industrial, Scientific and Medical (ISM) band, either at 2.4 GHz or at 5.8 GHz.

3.2 Software setup

The software is implemented using GNU Radio, Tensorflow and Keras. A block diagram of the proposed system is illustrated in Figure 2.

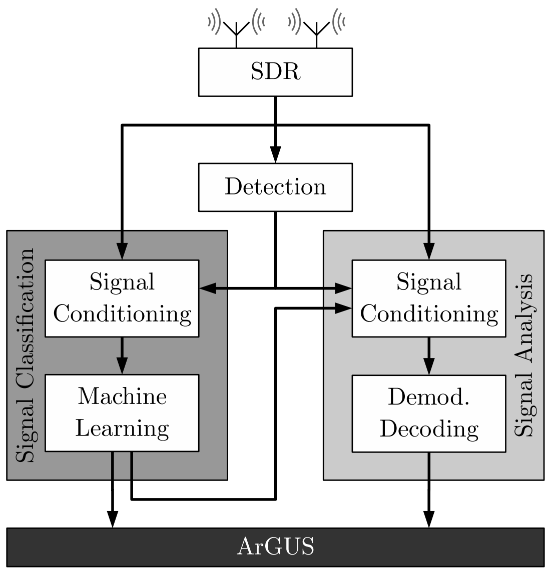

Figure 2. Block diagram of proposed SDR system

Signal Detection: The signal detection block, as shown in Figure 2 is implemented in GNU Radio. The functionality of the block relies on energy detection within the received spectrum. This approach is similar to the one used by the Gr-Inspector Toolbox [8]. The block is also capable of performing a bandwidth estimation for the detected signal. The majority of parameters used by this block are variable and can therefore be modified by the user. At the output, this block presents a list containing all detected signals and their parameters, such as center frequency or bandwidth. The results of the signal detection block are used to configure the signal conditioning blocks, for the signal classification and the signal analysis block respectively.

Classification of detected Signals: The heart of the classification process is a machine learning algorithm. The proposed system shall be evaluated with neural networks that use either a windowed I/Q time series or processed signals (such as power spectrum or Spectral Correlation Density). Before the raw data from the USRP is fed to the machine learning block it is passed through a so called signal conditioning block which performs the necessary operations to obtain a data set in the proper format, so that it may be fed to the neural network. This may contain filtering, but also tasks like windowing the I/Q time series or calculation of the SCD. Due to the modularity of the approach it's easily possible to switch between different approaches for the classification process.

The Flight Intelligence Platform of the ArGUS system is notified once a signal is classified as UAS signal. The results from the classification are also fed back to parameterize the signal conditioning block for the signal analysis.

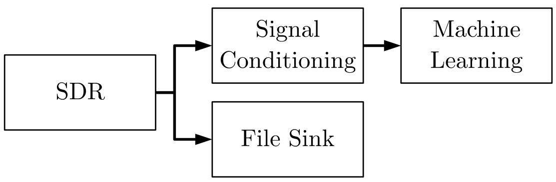

Figure 3. Simplified block diagram for acquiring test data

In order to generate the training data sets, the signals from different UAS systems have to be recorded with the SDR in a controlled environment (i.e. without interference from other signal sources). A simplified version of the presented flow graph can be used for acquiring training data for the machine learning algorithms. This is illustrated in Figure 3. The signal is received by the SDR system and is then passed to the signal conditioning block, which contains all necessary operations to get a usable set of training data. This may include filtering, down converting but also reformatting the data, so that it may be passed to the machine learning algorithm. Since different machine learning approaches shall be evaluated, the raw stream from the SDR is also passed to a file sink.

Signal Analysis: The final step of the concept is to further analyze signals, which are classified as UAS-borne. The goal is to obtain the information that's transmitted between the drone and the ground control station. The gathered information is provided to the Flight Intelligence Platform of the ArGUS system, where it presents a valuable source of information for the situation analysis and risk assessment. Of special interest may be telemetric or sensor data (e.g. video streams), as these can provide first hand information on the UAS and may allow the authorities to see the situation through the eyes of the drone's pilot. The signal analysis block as shown in Figure 2, contains the necessary functions to demodulate and decode the intercepted signals. It's implemented in GNU Radio.

There are cases, when it might not be possible to obtain the transmitted information. For example, when the radio link of the UAS is encrypted. The proposed SDR system is nevertheless an integral part of the ArGUS system. Ideally, it can provide early warning before other detection systems can alert the user.

4 Conclusion & Future Work

The necessary machine learning algorithms and software tools, which are required for this project already exist and there viability for signal classification has been shown in various publications.

After the full implementation of the proposed concept the following steps are necessary for its evaluation. Record signals from various UAS remote control and telemetry systems with the SDR setup and process them in order to generate training data sets for machine learning algorithms. The system can than be tested and evaluated under lab conditions and in real life scenarios. Existing data sets, as presented in [5] may also be used for the evaluation.

5 Acknowledgements

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References

[1] J. L. Ziegler, R. T. Arn, and W. Chambers. "Modulation Recognition with GNU Radio, Keras, and HackRF". In: *2017 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN)*. Baltimore, USA, 2017, pp. 1–3.

[2] A. Fehske, J. Gaeddert, and J. H. Reed. "A New Approach to Signal Classification Using Spectral Correlation and Neural Networks". In: *First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, DySPAN*. Baltimore, USA, 2005, pp. 144–150.

[3] T. O'Shea, T. Clancy, and H. Ebeid. "Practical Signal Detection and Classification in GNU Radio". In: *Proceedings of the SDR 07 Technical Conference and Product Exposition*. Denver, USA, 2007.

[4] T. J. O'Shea, J. Corgan, and T. C. Clancy. "Convolutional Radio Modulation Recognition Networks". In: *Engineering Applications of Neural Networks*. 17th International Conference EANN: Engineering Applications of Neural Networks. Aberdeen, UK, 2016, pp. 213–226.

[5] T. J. O'Shea and N. West. "Radio Machine Learning Dataset Generation with GNU Radio". In: *Proceedings of the 6th GNU Radio Conference*. Boulder, USA, 2016.

[6] *USRP X300 and X310 X Series*. Data Sheet. Ettus Research. URL: `https://www.ettus.com/content/files/X300_X310_Spec_Sheet.pdf` (visited on 01/2018).

[7] *UBX Daughterboard*. Data Sheet. Ettus Research. URL: `https://www.ettus.com/content/files/UBX_Data_Sheet.pdf` (visited on 01/2018).

[8] S. Mueller. "Overview of Gr-Inspector - A Signal Analysis Toolbox for GNU Radio". In: *Free and Open Source Software Developers' European Meeting, FOSDEM 2017*. Brussels, Belgium, 2017.