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Comparative analysis of methods to detect radio-controlled commercial UAVs

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Abstract. In the last few years we have witnessed an increase in adoption of UAVs (unmanned aerial vehicles) in many fields. Although they have useful applications, they can also pose a security threat for both the civilian and military domains. This paper presents a comparative multiple-criteria analysis of existing detection methods and possible countermeasures against commercially available UAVs, with a focus on the radio communications. Based on an objective function, a hierarchy between the studied methods will be made, in order to establish the optimal solution.

1. Introduction

In recent years the use of radio-controlled unmanned aerial vehicles has increased considerably in the domestic and commercial domains and their market continues to grow. Their applications vary from aerial imaging, search and rescue or racing competitions to package deliveries.

Because of their low cost, anyone could afford to buy one no matter what the end use would be. UAVs can be acquired in many configurations like RTF (ready to fly) or BTF (bind to fly), which can be setup and flown with little or no experience. This opens up an opportunity for users that do not poses knowledge related to aviation or piloting of an aerial vehicle, to use a drone as a tool for their end goal. Without realizing, users are transforming a toy in a threat for any aircraft they could encounter in the airspace and common radar systems are not able to detect them because of the low observability of small UAVs.

Aside from this, drones are also used for illegal activities, like spying (audio or video surveillance), terrorist attacks (using weapons or toxic substances) or drug trafficking. This is a matter of concern for civilian domain, but also for the military, because of possible security breaches.

The lack of a strong legislation regarding remote-piloted aircrafts has led to an interest in finding a counter-UAV solution capable of detecting, identifying and neutralizing a variety of small-scale UAVs. A series of studies regarding the issue of detecting and countering of small unmanned aerial systems (UAS) have been conducted as part of the NATO Industrial Advisory Groups, which have been taking place from 2013 to 2017. One of these studies, SG-170 “The Engagement of Low, Slow and Small Aerial targets by GBAD (ground based aerial defense)”, concluded the following:

- new tactics and technologies are needed to effectively counter the threats;
- a single sensor solution is not enough for tracking or identification of UAVs;
- for best results a mix of sensors must be used. [1]

DARPA (Defense Advanced Research Projects Agency) has released in 2016 a public request for identifying new methods and approaches for fast detection, identification and neutralization of small UAS. A Mobile Force Protection program has been initiated by DARPA with the goal of integrating the best solutions received as a response, in order to develop a layered system capable of defending ground or naval convoys on the move. In 2017, three teams, led by Dynetics Inc., Saab Defense and Security USA, have been selected to work on the first out of three phases of the program. [2]

Figure 1. Examples of commercially available UAVs (multicopters, fixed-wing)

UAVs can be fixed or rotary-wing systems. The choice of detection sensors is also influenced by their type and configuration. Of interest for this paper are the drones classified by NATO as “micro” or “mini”.

Table 1. UAV classification by NATO

Type of UAV	Range	Altitude	Weight	Payload
Micro	5 km	100 m	< 2 kg	< 0.5 kg
Mini	25 km	1000 m	2 – 20 kg	< 10 kg
Small	100 km	1500 m	<150 kg	< 50 kg

2. Methods of detection

In order to detect an UAV, multiple passive or active techniques can be applied, each with their own advantages and disadvantages. Current available systems operate based on the following domains:

- visible or infrared;
- acoustic;
- radio (passive detection of emissions or active radar systems).

2.1. Visible/IR spectrum detection

Video tracking has the advantages of large availability of solutions on the market and reduced cost for the equipment. Detection is done in two steps: first, detecting the objects and then classifying them in order to separate the UAVs from other objects. Visual spectrum monitoring has medium results during the day, mainly because of the big rate of false positives from recognizing birds or other elements in the images as drones. [3,4] At night an auxiliary source of illumination would be required. Also they are greatly influenced by the weather conditions. To counter these difficulties thermal cameras could be used, although they are not very efficient because of the small thermal signature of the UAVs. Generally, a visual detection system would give good results for distances up to 200 meters. Farther than that, the accuracy depends on the type of environment in which it flies. [5]

Active systems are based on laser scanning technology called LIDAR, which allow measuring the distance to the drone, even on the order of kilometers. They are very little influenced by the weather conditions and have good results both during the day and night. As disadvantages, they require complex algorithms for separating objects, require a long period of time for scanning and have a high cost.

2.2. *Acoustic detection*

Most of the commercialized drones are equipped with brushless or brushed motors which make a characteristic noise. Acoustic sensors are cheap to acquire but are unable to provide a precise location of an UAV. The accuracy is affected by the surrounding noise and wind, having a high rate of false alarms. Microphone arrays can be used in combination with cameras in order to provide a faster detection time and reduce the number of false detections. [6]

2.3. Active radar detection

Because of the materials of which the drones are usually made and their reduced size, they have a very low radar cross-section, making it almost impossible for standard systems to detect them. Recently, new radars based on Doppler effect have been developed specifically for these kind of aircrafts. [7] Most of the reflectivity of the drones is generated by the batteries, cameras or motors and less from the fuselage or propellers, which are usually made of plastic. This technique has the advantage of being able to detect a vast majority of aerial vehicles from a long range. Better results are obtained for higher frequencies of the used radio waves. [8]

2.4. Passive radio detection

Another method for long range detection of UAVs is based on monitoring the radio communications. Generally, there are two communications channels between drone and operator:

- command (from operator to drone) and telemetry (from drone to operator) link;
- video feed (from drone to operator).

If an UAV doesn't provide a telemetry or video down-link to the operator, then with this method only the origin of the remote commands can be established. Complete autonomous drones, that fly on a preset path without communicating can't be detected. Each manufacturer can use different frequency bands, but the most utilized ones are the UHF 2.4 GHz and 5.8 GHz bands.

The process of identifying an UAV based on the RC (radio-control) communications can be divided in several steps:

- detection of RC links on the monitored spectrum;
- separation of the RC link from other communications;
- analysis of the parameters of the extracted channel;
- classification of the drone;
- localization of the emitter and/or receiver.

For listening to the communications, a radio spectrum analyzer with a high range of operating frequencies can be used coupled with a log-periodic antenna (or array of antennas). This ensures that a large section of the spectrum is monitored, taking into consideration other VHF or UHF bands that are used. Most of the RC protocols are based on a combination of two spreading techniques, DSSS (direct-sequence spread spectrum) and FHSS (frequency-hoping spread spectrum), which makes them harder to detect. Software-defined radio receivers can be powerful enough to detect and store the communications for further analysis and classification. A machine learning algorithm can also be added in order to more easily recognize the drone.

This method not only that it gives the possibility to timely detect an UAV as soon as it is turned on, but also allows to precisely localize it and/or the operator, depending on the type of communications it uses. A multilateration technique based on an array of spatially separated receivers and synchronized using the GPS timing can be employed for position estimation. [9]

3. Available commercial solutions

For a better understanding of the use cases of these methods and possible combinations that could increase the rate of success, several already available solutions will be analyzed.

One of the most powerful product is the *AUDS Anti-UAV Defense System*, offered by Blighter Surveillance Systems, a UK-based electronic-scanning radar and sensor solution provider. The system combines radar detection with electro-optic tracking and RF jamming. The radar is capable of detecting a small UAV from 10 km away and with a minimum radar cross section of 0.01 m^2. The electro-optic tracker uses both a color and thermal camera. After the target is locked, intelligent RF inhibition can be activated for disrupting the communications. This represents the perfect example for combining multiple sensors for a higher success rate.

Other systems based on single-sensor solution are:

- *Torrey Pines Logic Beam 220* active optical system, capable of detecting cameras and scopes from a maximum range of 2.5 km, on all-weather conditions;
- *DroneShield WideAlert* UAV acoustic detection module, with 180° coverage and range of up to 200 meters.

Figure 2. Counter-UAV systems (from left to right: AUDS, Beam 220 and WideAlert)

Another commercial solution is the *Drone Detection System* developed by the German company Aaronia AG. It is a radio-frequency emissions monitoring system, covering a frequency range from 20 MHz to 20 GHz. Apart from its detection functions it also has jamming capabilities. For both detecting and jamming communications, the system uses an array of log-periodic antennas, called IsoLOG 3D. The system can be deployed as mobile or fixed command center and has a detection range of 1 km. The software provided with it is capable of analyzing any type of communications and automatically localizing an UAV entering the supervised area.

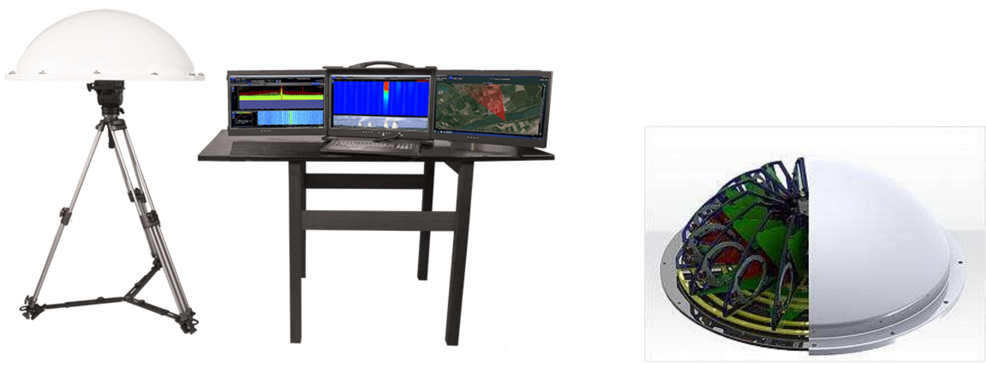

Figure 3. Aaronia Drone Detection System and IsoLOG antenna section

4. Conclusions

It is clear that no single-sensor solution is enough for detection of small class UAVs and that a combination of methods should be used for a high efficiency. After analyzing some of the most used detection methods and their applications, a hierarchy can be established between them based on several features like cost of equipment, probability of target detection (considering both false positives and false negatives), maximum detection range and the influence of environment or other factors on the accuracy of the results. Every studied method will be graded from 1 to 5 for each feature and the sum of received grades will represent each method’s total score.

Table 2. Classification of detection methods

Detection method	Cost	Rate of detection	Range	External influence	TOTAL
Visual	5	2	3	2	12
Infrared	5	3	4	2	14
Acoustic	5	1	2	1	9
Active radar	4	4	5	4	17
Passive radio	4	5	5	4	18

From the table results that the most accurate methods are those based on radio communications monitoring, active radar systems, and thermal tracking. Many manufacturers choose to combine an expensive, high accuracy device with a cheaper, lower accuracy one. This gives them the possibility to provide a system with better capabilities, while maintaining lower costs. While developing a system that tries to accomplish detection of small UAVs, it should be considered the utilization of passive radio monitoring equipment or an active radar, as they provide the best results as independent solutions.

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