Enhanced radar detection of small remotely piloted aircraft in U-space scenario

Fausta Mattei[a*]

Department of Industrial Engineering, Università degli Studi di Napoli Federico II, Piazzale Tecchio 80, Naples, Italy

Dept. of Management, Information and Production Engineering, Università di Bergamo, Viale Marconi 5 Dalmine, Italy

[a]fausta.mattei@unina.it

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Abstract. Efficient and safe integration of Unmanned Aerial Systems, both civil and military ones, must be guaranteed in the airspace, which is expected to be threated by problems of collisions, loss of communications and congestion of the air traffic environment. One of the main issues is how to improve the identification of unmanned aircrafts in the low altitude airspace. The identification process, that includes detection, verification, and recognition phases, is affected by different problems such as the difficulty of distinguishing Unmanned Aircraft Vehicles from other small flying objects as birds, because of their similar Radar Cross Section (RCS). To improve this process, an enhancement of the RCS can be a solution. The purpose of my PhD is to find the best passive and active solution for the following assignment.

Introduction

Unmanned Aerial Systems (UASs), i.e. drones, have been recognized as one of the revolutionary advances in the recent technological evolution. The origin of UAS traces back to the military field, for operating in hostile or human-denied areas. They are typically employed for “Dull, Dirty and Dangerous” missions. Today, their technology is improving more and more and making these types of systems more attractive for several applications both in civilian and military domain, including surveillance, search and rescue, traffic and weather monitoring and others [1]. Their main features include improved transportability due to small size, low cost, and speed of implementation. The current level of safety they can provide has made this technology accessible to the general public.

In 2020, the global small UAV market was valued at US$ 411.8 million and is predicted to be more than US$ 1350.1 million by 2027 [2]. Therefore, a large number of projects started in the past years, such as Single European Sky ATM Research (SESAR) [3] and the American “Next Generation Air Transportation System” (NextGen ATS) [4], with the purpose to enable several standards and regulations to fulfil the operational needs of and the basic requirements for UAS Traffic Management [5].

In Europe, a relevant project is the SESAR 3 Joint Undertaking (SJU) [6] which is an institutional European Partnership between private and public sector partners set up to accelerate through research and innovation the delivery of the Digital European Sky. This project started in 2021 and will end in 2031, and it aims to develop all the architectures, services and regulations for the realization of a safe, smart, sustainable and well-connected UTM airspace. More specifically, the European Union has developed a U-Space project [7], that deals with the realization of a set of services to ensure a safe and efficient integration between air traffic of manned aircraft vehicles and air traffic of UAVs.

The "safety and security assessment" aspect is essential both under functional and operational aspects. In general, the challenges that affect the integration of U-Space in Urban Environment are [8]:

- Public acceptance;
- Safety metrics for VLL operation;
- Need for high fidelity updated obstacle data;
- Hyper-local weather events;
- Communication and GNSS occlusions;
- Air rules and airspace organization.

From an operational point of view, loss of communication, congestion problem and traffic collision are the main reasons for the lack of safety and must be reduced for an efficient and smarter UTM.

One of the first steps to enable the integration of unmanned aircraft in Urban Air Mobility (UAM), is to take care of surveillance systems to support UTM. Surveillance is the function that provides a continuous monitoring of trajectories of RPAS flying inside a volume of interest. It must guarantee three main features, such as[9]:

- Interoperability;
- Performance;
- Efficiency.

These three characteristics combined allow cooperative and non-cooperative surveillance systems to deliver a broader range of services and to operate within a wider range of environments.

A big challenge concerning drone surveillance systems is the identification process, which includes three phases: detection, classification, and recognition. Identification means that a small Remotely Piloted Aircraft is properly recognized as soon as a track is initialized after sensor detection. The drone's detection problem is more challenging in urban environments given the number of potential targets, multipath, and often low Signal-to-Noise Ratio (SNR). The problems of identification are multiples [10]:

- UAVs can be identified after a long time is passed from their initial detection when they fly at very short distances from surveillance sensors;
- Because of their small Radar Cross Section (RCS), they can be barely distinguished from other small flying objects such as birds;
- Their low-speed poses challenges when sensors are provided with special processing features such as Moving Target Indicator used to remove ground clutter.

A possible solution to improve the drone detection performance using radar sensors is to do Radar Cross Section RCS enhancement. It is the capability to improve the intensity of radar echo backscattered by a drone. The idea of the proposed PhD project is to evaluate the effect of passive and active solutions for RCS enhancement of a prototypical drone. Both passive and active solutions should be evaluated in light of the flight mission, and the impact on weight, endurance

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and range, and other parameters related to the safety and efficiency of flight. Passive systems refer to all the methods for radar cross section enhancement which modify the geometry of the drone, for example using corner reflectors on-board, whereas active systems are the ones that do not affect the geometry of the drone, but they can make the enhancement using antenna, sensors or hardware.

Building up a prototypical unit can be easily performed by using Software Defined Radio (SDR). The SDR is a radio communication system that employs reconfigurable software-based components for the processing and conversion of digital signals [11] Flexibility, reduced costs and versatility [12] make it a suitable system for an experimental test of active and passive radar cross section enhancement. It is possible to set the parameter of the hardware through software, also in real-time, on the basis of the available type of radar.

Methodology

The proposed activity can be summarized in a sequence of processing steps, as follows:

I. Identify and test passive solutions for RCS enhancement of a small drone;
II. Identify and test active solutions which are able for RCS enhancement of a small drone;
III. Build a prototype of a small multicopter drone implementing the proposed solution to accomplish a civil flight mission;
IV. Integrate the proposed active enhanced detectability solutions in the guidance control and navigation system to take advantage of the position, attitude and situational awareness of the drone;
V. Make a campaign of flight tests with the developed prototype and provide indications on the impact of the proposed solution on flight performance and safety and on the detection rates.

To carry out these tasks, the following procedure is adopted for the research project:

- *First step*: State-of-the-art analysis. The aim is to identify all interesting projects on the detection of drones in an urban air mobility scenario, to find the most important systems (active and passive) that can fit the proposed objective of research and to study if their application is feasible.

- *Second step*: set up of requirements needed for the choice of the various system for the drone. The idea is to realize a prototype of a small drone from the beginning, so it is crucial to fix the most important requirements that must be satisfied such as endurance, payload weight, and radar specification. The specifications can be used to size the active and passive systems (*SDR and corner reflectors*).

- *Third step*: define the system architecture. After the requirement definition, it is possible to proceed with the choice of systems. Table 1 lists all the components needed for the experiments that must be conducted.

Table 1. System Architecture.

Drone Configuration		**Payload**		**Ground Control Systems**	
Object	*Quantity*	*Object*	*Quantity*	*Object*	*Quantity*
Autopilot [13]	1	Secondary battery	1	Radar [14]	1
Firmware	1	CPU Computer [15]	1	Remote controller	1
GPS receiver	1	SDR transceiver [16]	1	Computer	1
Inertial Measurement Unit (IMU)	1	Antenna	4		
ESC motor controller	6	Corner reflector	1		
Propellers	6				
Motor	1				
Primary battery	1				
Receiver	1				

- *Fourth step*: define system testing strategy. A set of Flight Test Cards can be filled to describe the proper realization of the experiments. For instance, assuming that 'open category' drones can fly within a maximum altitude of 120 [m] above ground, three different values of altitude are chosen to carry out the same manoeuvre. Then for each altitude, other three different values of speed are imposed, assuming that the maximum velocity allowed in the Urban Air Mobility is 5 [m/s]. For each test, there is a total of 9 acquisitions, as shown in Table 2.

Table 2. Types of tests acquisition.

Altitude [m]	**Speed**
60	• 60% of V_{MAX} • 75% of V_{MAX} • 90%of V_{MAX}
90	• 60% of V_{MAX} • 75% of V_{MAX} • 90% of V_{MAX}
120	• 60% of V_{MAX} • 75% of V_{MAX} • 90% of V_{MAX}

- *Fifth step*: test execution.

- *Sixth steps*: data processing and results analysis. The data acquired during the test must be processed using a processing software tool, such as Matlab^{TM}.

Results

As result, it is expected that the signal is amplified when come back to the radar and to find out which are the best conditions for this to happen. In previous work, a preliminary test campaign was carried out and the signal amplification by a commercial SDR system, i.e. HackRF One [17], was validated. It is possible to appreciate in Fig. 1 the peaks which represent the proper amplification of the received tone by the on-board SDR for six different cases, listed as follows:

Test1. Drone in a steady state mode on the ground, with an active rotor blade;
Test2. Post take-off phase;
Test3. Quickly movement up and down;
Test4. Quickly movement up and down;
Test5. 360° heading rotation in hovering around its vertical axis;
Test6. Data are acquired subsequentially to the rotation until the leading;

The weaker response is when the drone rotated 360°, because of the presence of the landing gear.

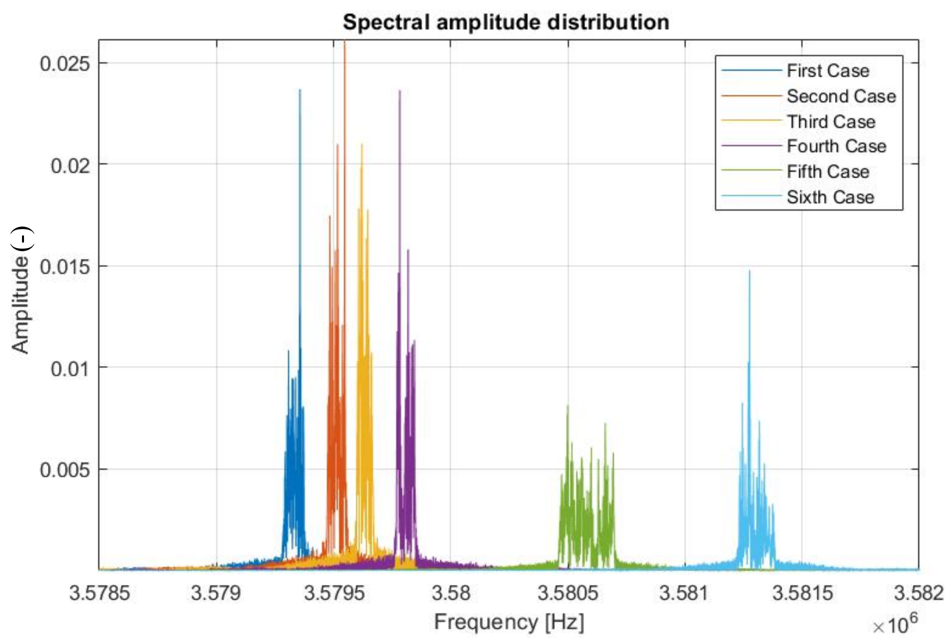

Fig. 1. Peaks of the signal amplified by the HackRF One for six different cases.

Conclusions

An optimization method for the surveillance of drones in the Urban Air Mobility is the Radar Cross Section enhancement. To carry out this task, both active (SDR) and passive (coating, phased antenna array, corner reflector, etc…) systems are investigated. Further activities will be mainly focused on the execution of several tests and simulations in order to assess the best solution to perform RCS enhancement.

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