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LOW LEVEL TRAFFIC MONITORING: RPAS CONCEPT OF OPERATION AND DEVELOPMENT OF A GROUND BASED SYSTEM

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Abstract

Large benefits are expected from operations of unmanned aircraft systems (also known as drones) in the lowest layer of the airspace. However, these operations raise a number of safety and security issues. A concept of operation for a safe organization of the low level drone traffic is first proposed. Next, a technological solution comprising onboard tracking devices, on ground receivers and user displays is described. Finally, the tests performed with the resulting system in simulation and in flight are presented.

1 Introduction

Large benefits are expected from operations of small drones (i.e. aircraft systems with no pilot on board) in the lowest layer of the airspace [1]. However these operations raise several safety and security issues and their benefits won't be fully achieved if these issues are not properly addressed. Several initiatives are thus underway worldwide to define appropriate frameworks for their safe and efficient integration in the air traffic, including UAS Traffic Management (UTM) in the United States of America [2] and U-Space in Europe [3][4]. Electronic registration, electronic identification and geofencing have been identified as foundational services of the U-space [3]. Tracking and monitoring are also identified as essential services and their definitions are now clarified [4]. These services will be progressively deployed and their use will be made mandatory by the European aviation authorities as they are recognized necessary to insure the safety of drone operations, to address security threats and to enforce privacy [5]. Several governments have indeed already mandated the carriage of electronic identification devices for small drones operating at very low level (VLL, i.e. between ground surface and 500 feet), with the aim to enforce compliance with existing flight restrictions (e.g. [6] in France, for drones weighting more than 800 grams). In order to fulfill these emerging requirements, a detailed and consistent concept of operation is still to be defined and technological solutions have to be developed and experimented on the field.

This paper thus presents a concept of operation and a technological solution for low level traffic tracking and monitoring, addressing both the safety and the security issues.

In a first section, we analyze the needs and issues associated to the VLL operations of Remote Piloted Aircraft Systems (RPAS). We then discuss the possible changes in the low level airspace structure and flight rules. In the next section, we describe a technological development based on onboard tracking devices and on ground receivers for use by the remote pilot or by an RPAS traffic manager. Finally, simulation trials and flight tests of this technological solution are reported.

2 Operational needs and issues

The operations of UAS at low level are expected not to affect the safety of other airspace users and of the overflown population. However, in flight conflicts of drones with manned aircraft are now frequently reported, highlighting the need to define how the low level airspace should be safely shared with manned aircraft (including medical, military and police aircraft and rotorcraft, general aviation and gliders). These operations may also impact the security of ground installations and solutions have to be found to enforce the existing flight restrictions.

Specific measures (airspace segregation, notices to airmen, no-drone zones) have been used up to now to avoid these issues at a strategic level. However, such accommodations are not sufficient to enable the routine operations of UAS at a large scale. A set of new functions will be required to this end, comprising electronic registration of the drone and of its owner under a unique registration number, flight preparation using shared web services, remote identification, tracking, monitoring and geofencing capabilities. These functions are indeed required to build a safe environment shared by the remote pilots, the UAS operators, and the other airspace users. As UAS traffic density is expected to increase rapidly, solutions have also to be found to solve the possible conflicts between unmanned aircraft while being compatible with the large number of unmanned aircraft foreseen in the short future (scalability issue).

Prior to technological solutions, some operational concepts regarding the organization of the RPAS traffic in the low level airspace could contribute to flight safety at the strategic level. These operational concepts are briefly presented in the next section - a detailed description is provided in [7] and [8] - before we address a possible technological solution to track and to monitor the traffic flying at low level.

3 Low level airspace structure and navigation principles

Currently the lower airspace is not structured. Flight safety may be improved by adopting rules similar to the ones existing at higher altitudes for VFR flights. In particular, most possible head-on conflicts may indeed be solved at a strategic level by organizing the traffic in vertical layers with appropriate buffers and by using a semi-circular rule similar to the rule already in force for manned aviation at higher altitudes (Fig. 1). In practice the application of this rule requires a careful consideration of vertical navigation performance and altitude references, taking into account the terrain elevation and the possible obstacles.

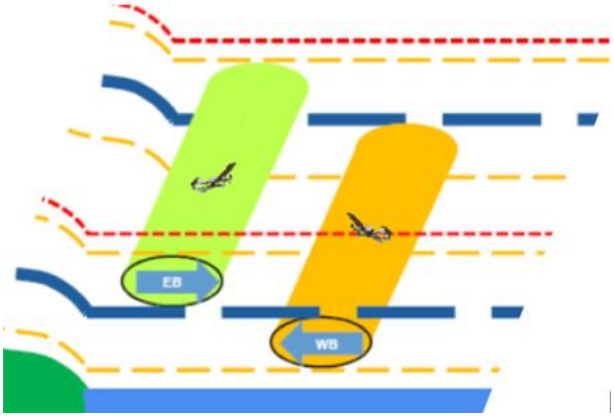

Fig. 1: Illustration of vertical layers and semi-circular rule.

This rule is used for point to point flights whereas stationary missions require a temporary reservation of a volume having a thickness being the addition of the eastbound and westbound layers (Fig. 2). These volumes of activity have to be declared some time before the flight in order to be avoided by other airspace users.

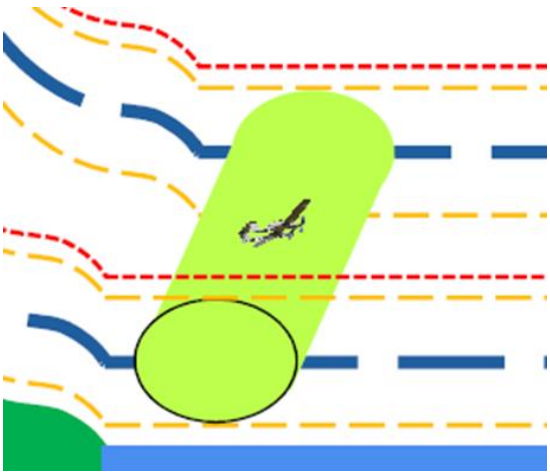

Fig. 2: Large flight zone for aerial work.

These traffic organizational features may be complemented by a strategic de-confliction system, providing each unmanned aircraft with a conflict-free 4D contract before take-off. The execution of the 4D contracts is then self-monitored and may be dynamically updated locally if a deviation occurs [9]. Such a concept was showed promising for future highly automated air traffic management and may be adapted for UAS traffic management despite the low flying speed of RPAS (higher sensitivity to variations in wind speed and direction) and their continuously variable pressure altitude necessary to maintain a constant height above ground. Research work is underway in order to adapt the concept and to address the associated issues, including 4D navigation performances, robustness to weather conditions, use of dynamic geofencing and scalability.

4 Toward a technological solution

4.1 Overview and working principles

Electronic identification, tracking and monitoring are fundamental to any UTM system. Monitoring has been recently defined as “a service that is based on a track coming from a tracking service and can warn the drone pilot of different kinds of problems or potential problems.” [10]. Among these potential problems, conflicts with the surrounding traffic are probably the most critical. In the case of small drones operating at low level, these conflicts can be appropriately tackled by a ground based system (rather than by an onboard detect and avoid system). A system tailored for traffic monitoring during RPAS operations at low level has thus been developed for the purpose of research and demonstration.

This system makes use of onboard identification and tracking devices and is based on a network of ground receivers. It includes a human-machine interface (HMI) for use by the remote pilot or by an ‘RPAS traffic manager’ who could further assist the remote pilots operating a fleet of drones. Note that this new role still has to be precisely defined.

The resulting system thus comprises an onboard segment and a ground segment; it performs traffic detection and conflict assessment and it provides assistance to the user in the conflict resolution task (Fig. 3).

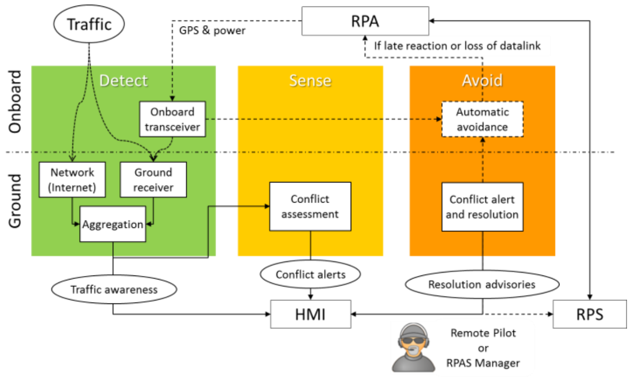

Fig. 3: Air-ground and human-system functional allocation of the traffic monitoring system.

Key assumptions for the development of this system are 1) mandatory equipment of unmanned aircraft with an electronic identification and tracking device and 2) operations in uncontrolled airspace, where conflict management is under the responsibility of the remote pilot.

Moreover, a fundamental consideration is that the unmanned aircraft should give way to manned aircraft. Indeed whereas remote pilots have to insure ‘see and avoid’ as pilots of any aircraft, it cannot be relied upon the pilots of manned aircraft to see a small drone (conspicuity issue). A conservative approach is thus adopted, meaning that remote pilots should have the means to remain well clear of manned aircraft, whatever is their priority according to the legacy rules of the air. As small drones are usually slower than manned aircraft, this approach poses severe requirements to the system regarding the detection range and the look-ahead time of the trajectory prediction.

Among the technologies available for surveillance and tracking, only a few already equips manned aircraft. Transponders (mode S/C) and transceivers (ADS-B) are used worldwide by commercial aviation. These devices are costly and their operating frequency would be congested if used by a large number of drones. FLARM (Flight Alarm) devices are another type of transceivers. These devices already equip more than 35.000 aircraft, gliders and general aviation, in the world, mainly in Europe. They broadcast the aircraft GNSS position, altitude and speed vector every second, together with a device identifier, using an encrypted radio protocol on the 868 MHz frequency band (in Europe). They also provide conflict warnings and assistance for traffic visual acquisition by the pilot. They are based on a concept patented by ONERA [11].

Our technological development is thus based on this technology and it encompasses 1) a miniaturized device for equipment of unmanned aircraft and 2) a network of specific ground receivers and 3) a processing unit, with HMIs dedicated to the potential users of the system: the remote pilot, an RPAS traffic manager or a security officer. The working principle and the components of this traffic monitoring system are illustrated on Fig. 4.

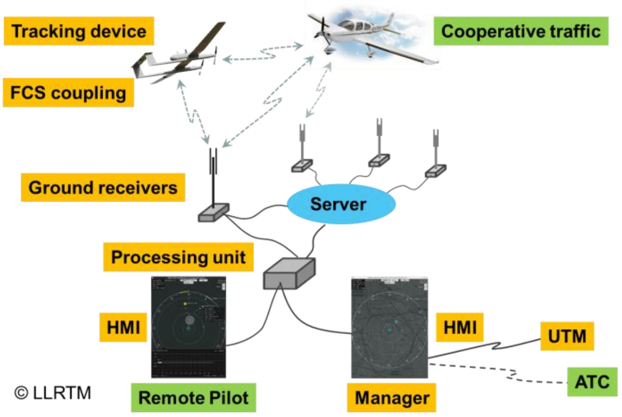

Fig. 4: Working principle and components of the traffic monitoring system.

Note that the system is able to detect all cooperative traffic, equipped either by ADS-B, transponders or FLARM. A capability to detect non cooperative traffic could also be added by connection to existing radar facilities where coverage is insured or by the addition of a dedicated ground surveillance radar when required locally.

The resulting system thus provides traffic awareness to the user; it also performs conflict assessment and alerting and it supports its user in the conflict resolution by displaying the conflict geometry and sectors in the horizontal and vertical dimensions.

The network of ground receivers is connected to a server through the Internet. This network can be an existing public network. The Open Glider Network (OGN) in particular already consists of more than 700 receivers installed by flying clubs or individuals over the world. This network provides a global view of the FLARM equipped traffic in almost real time. A complementary private network can also be developed on demand, thus offering privacy, security and a guaranteed quality of service for use by institutions when required.

A network of receivers indeed offers several benefits: it improves the tracking robustness and its accuracy, through redundancy, and it provides an extended detection range, which is an essential requirement for operations beyond visual line of sight (BVLOS). Connection to the Internet is also an interesting capability, by providing a view of the traffic to the other airspace users or to authorities which may be distant from the UAS operation area.

4.2 Conflict detection

The design of any conflict detection system requires an objective definition of what is a conflict. Aircraft trajectories are deemed in conflict when the closest point of approach is predicted within a given period of time and within a pre-defined volume. The definitions of the time horizon and the conflict volume are still under discussion and they will most probably depend on the context of operation.

In our case, considering the applicability to operations at very low level in constrained environment (urban or in close proximity to ground infrastructures), a time horizon of 30 seconds was deemed necessary and the conflict volume was defined as a cylinder of 500 feet horizontal radius and 200 feet vertical height, so that a conflict is detected when the drone and an intruder aircraft are predicted to come closer than 500 feet horizontally and 100 feet vertically, within the next 30 seconds.

The value for this time horizon is relatively high, so that the remote pilot can be alerted of a possible conflict before the pilot of a manned intruder (traffic alerts of current FLARMs are delivered at less than 19 – 25 seconds before the possible collision [12]). The trajectory prediction thus has to be as reliable as possible in order to avoid nuisance alerts and maneuvers.

The size of our conflict volume is identical to the usual Near Mid-Air Collision (NMAC) volume[1] and small when compared to published separation minima –which are not directly applicable to small drones operation at VLL. Note that this conflict volume has to be understood as a system design parameter for the sake of pilot assistance, without necessarily reflecting regulatory requirements which in the case of RPAS VLL operations still have to be promulgated. Its dimensions can also be easily changed as the system and the regulation mature. In particular they could change in accordance with the definition of objective criteria regarding the application of the ‘remain well clear’ principle to small drones operating at low level.

As mentioned above, the quality of the trajectory prediction is essential for the usability of the system. Several factors may hinder this prediction:

- The measures provided by the tracking device are subject to uncertainty;
- Some measures may be missing due to, for instance, masking or low signal to noise ratio;
- The aircraft may maneuver within the time horizon.

We have thus implemented and tested several techniques to improve the prediction, including first or second order prediction algorithms and Kalman filtering, so that the prediction takes into account the aircraft maneuvering state and provides an estimation of the uncertainties regarding the conflict.

4.3 HMI design

The system provides assistance to its users through a human machine interface. Its graphical display is adapted for each user profile, being the remote pilot, the RPAS traffic manager or a security officer. We hereafter focus on some design choices regarding the remote pilot display and its traffic alerts.

Although using a graphical design inspired by 2D radar displays and traditionally used in manned aviation, several features of this display are adapted to the particular position of the remote pilot. These features include:

- Depiction of the ground receiver and remote pilot position, with a geographical map in the background (when desired). These elements are indeed required to facilitate the relative positioning.
- The frame of reference (center and orientation) which can be set by the user. Tests in the field have revealed that the user preferences indeed depend on his own education and training profile, and differ for instance between hobbyist and pilots with a background in manned aviation.

The primary objective of the display is to provide assistance to conflict avoidance. Even when no conflict is detected, the display supports the traffic awareness by showing the identification, the location and the relative speed of the traffic surrounding the drone. The display elements are sufficient for the pilot to anticipate a possible conflict, before an alert is emitted by the system. When a conflict is detected, the display delivers visual and auditory alerts. The first alert (“conflict”) occurs when the conflict is predicted in less than the time horizon (30 seconds). A second level alert (“avoid avoid") is emitted 12 seconds before conflict. The visual changes in the display are shown on Fig. 5.

Fig. 5: Display and alert symbology changes as the conflict gets closer.

Note that as explained in [7], the decision of when and how to react is intentionally left to the remote pilot. Indeed, it is the pilot’s responsibility to avoid the traffic and the set of possible avoidance maneuvers is generally very large (including vertical, speed or lateral

[1] An ‘NMAC’ is defined for ACAS as a situation where two aircraft simultaneoulsy come within 100 feet vertically and 500 feet horizontally [13] while FAA Order 8020.11D only specifies a ‘proximity of less than 500 feet to another aircraft’ or ‘where a report (..) states that a collision hazard existed’ [14].

dimensions) whereas several decision criteria for the choice of a maneuver may not be known by the system (e.g. terrain and obstacles, people on the ground, weather conditions, flight intent and maneuver feasibility).

5 Simulation and flight tests

5.1 HITL simulation and usability testing

Real-time simulation is widely used to verify and to evaluate the behavior of the system at the different stages of research and development. Additional software modules are then used to simulate the unmanned aircraft and the traffic trajectories, following scenarios which can be parameterized to reproduce various encounter conditions. Their outputs stimulate the system components, including the conflict assessment and resolution functions and the HMI. Controlled human-in-the-loop experiments are also performed in an iterative design approach in order to investigate the effects and the acceptability of design alternatives regarding the display, the human involvement and the interactions with the demonstrator in realistic settings.

When the HMI was deemed mature and before proceeding to flight tests, a usability test was performed with 11 volunteer participants with limited aeronautical experience and 2 military pilots. The test included attendance to 6 different encounter scenarios, which were frozen at various times before the conflict. The participants then had to answer questions regarding the specific situation, their understanding of the conflict and whether and how they would react. Eventually they also filled a usability questionnaire addressing the features of the HMI and they rated its usability using the System Usability Scale (SUS, Brooke 2011).

The SUS score was of 77.3 with a standard deviation of 13.3, thus ranging from good to excellent [15]. The results globally confirmed the usability of the display and revealed some differences in the preferences among the participants, which motivate the options left to the user with respect to the frame of reference and the zoom scale. Several possible minor improvements to the design were also identified, regarding mainly the consistency of the information provided about the drone and the intruders.

5.2 Flight tests

5.3 Preliminary tests focused on tracking and identification

Flight tests are performed since 2016 in order to validate the technological choices and to evaluate the potential of the concept and its possible improvements.

Preliminary tests involved the ground segment of the system, a multirotor drone and a very light aircraft playing the role of an intruder. Both were equipped with a FLARM device.

These tests were focused on signal acquisition and detection range. They confirmed the detection range was as expected of several nautical miles, although sensitive to terrain masking and antenna quality. HMI design assumptions regarding the preferred frame of reference and the need for attention getters were also validated.

A second set of tests focused on the system capabilities for the purpose of remote identification, using a dedicated variant of the HMI. These tests were conducted in March and July 2017 and demonstrations were performed to a large audience of safety and security authorities, including representatives of international bodies. Identification and tracking of two drones equipped with a miniaturized device using the FLARM technology were demonstrated at distances up to one kilometer. The connection of the system to a server providing a global view to national authorities was also demonstrated.

5.4 Flight tests involving conflict detection and resolution

The following tests took place in December 2017 with the support of a gliding training unit of the French Air Force. The tests actually addressed the use of the system for traffic monitoring, conflict detection and resolution. They involved a Jodel D-140R tow plane and a multirotor RPAS (Fig. 6). Both aircraft were following predefined trajectories in order to generate encounters in various configurations of relative speeds, altitudes and angles.

Fig. 6: A close encounter between the tow plane and the drone.

A detailed safety analysis was performed and the tests procedures were approved prior to the flight tests. The roles of the personnel involved (flight crew, remote pilots, flight director and researchers) and the communication protocols between them were of course part of the safety assessment. The flight crew had to visually acquire the drone before coming close.

The tests consisted of forty four (44) encounters. Three conditions were used regarding the role of the remote pilot and the RPAS traffic manager:

1) The remote pilot used direct vision of the drone with support of the HMI;
2) The remote pilot used direct vision and was assisted for conflict avoidance by an RPAS traffic manager using only the HMI.
3) The remote pilot used only the HMI, with no direct vision of the drone. Safety was insured by an observer constantly looking at the drone.

The flight parameters of both aircraft were recorded on board and on the ground, together with the parameters of the system, including the traffic alerts and the resolution maneuver performed by the remote pilot, if any. A debriefing was also performed after the tests.

Fig. 7 shows the height of both aircraft (tow plane in orange color, drone in blue) as a function of time and the horizontal trajectories for one of the encounters. The figure also shows two alerts: a “conflict” alert (green square) occurring 24 seconds before the closest point of approach (CPA) and an “avoid” alert (red diamond shape) 16 seconds before CPA. The CPA itself is indicated (red star) with the values of the vertical and horizontal miss distances in meters. In this case the remote pilot successfully avoided the conflict by a descent maneuver, although the difference in the speeds of both aircraft is clearly visible.

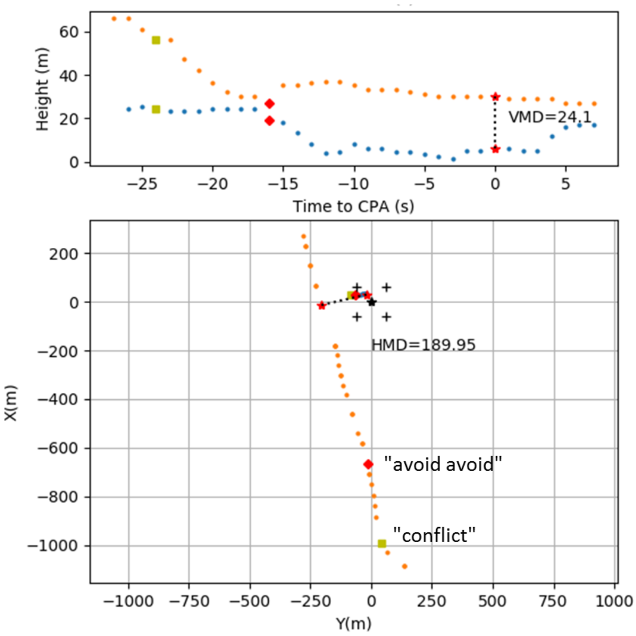

Fig. 7: Heights, trajectories and alerts during one encounter.

The results confirmed some previous findings. The flight crew was able to visually acquire the drone in these experimental conditions with a priori knowledge of its position, but also reported that it would have been very difficult in actual conditions. The remote pilots confirmed that it was hardly possible to understand the conflict geometry using direct vision, and that the system provided appropriate alerts and sufficient traffic awareness to give them a chance to react appropriately. Using the system while keeping the drone in sight was difficult (condition 1), whereas the support of an RPAS traffic manager (condition 2) was deemed very useful and efficient, of course involving team work. The use of the HMI alone (condition 3) was deemed acceptable providing an improved integration with the drone legacy system. This result paves the way for use in BVLOS operations, although further adaptation and investigation is required.

These findings were confirmed by the analyses performed afterwards, with the best results obtained in condition 2.

6 Conclusion and perspectives

Operational measures and technological developments are both required to enable the safe and secure VLL operations of small drones. This paper describes some possible solutions to reduce, to detect and to avoid the potential conflicts between the low level airspace users, including manned aircraft.

The flight tests confirmed the safety benefits provided by a ground based traffic monitoring system. Further work will focus on the use of this technological solution for BVLOS operations, by improving its reliability and extending the detection range. Strategies for semi-automated avoidance are also the subject of current research.

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