Detection And Protection Against Unwanted Small UAVs

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Abstract—**The market for small Unmanned Aerial Vehicles (UAVs) is growing fast. Based on increasing reliability, accessibility and decreasing operational restraints these systems become more and more used in different areas of application. Besides the benefits of this development, an increasing number of more or less hazardous incidents with small UAVs can be noticed. Accidents or the misuse of these technologies do lead to dangerous situations – from simple mishaps over illegal activities like spying or drug transportation up to the possibilities of terroristic actions. To deal with this development a concept of a new Low Altitude Air Surveillance Control (LASC) system is developed. Based on heterogeneous, distributed multi-sensor networks embedded into a capable and application oriented modular, adaptable and scalable backend system, the LASC concept addresses detection, localization, tracking and classification or identification of small UAVs providing interactive threat and risk assessment as well as suggestions for adequate counter measures.**

Keywords-UAV; air surveillance; multi-sensor network; threat protection; modular.

I. INTRODUCTION

Small Unmanned Aerial Vehicles (UAVs) are an emerging technology with a great potential to disruptively change our lives. They have by far exceed the capabilities of the niche products of remote controlled models with their ability in terms of payloads, flight duration and ranges, auto pilot capabilities, automated collision protection and video transmission capabilities. Leveraged with new technologies (e. g. high capacity battery packs, low energy consuming motors and small-sized high computing power) the small UAVs have started exceeding entertainment domain while entering more and more applications [1][2][3] (surveillance, reconnaissance and rescue, video production, logistics, etc.). This development has been boosted by a constantly rising commercial market for UAVs providing broad accessibility and diversity at a low cost scale.

As always, each technology comes along with drawbacks and potential for abuse and this is in particular true for small UAVs. With their inherent risk of crashing causing damage and harm to people, each business application has to be assessed seriously in terms of security issues and constraints. Furthermore, with the broad availability and low cost aspect of UAVs, a common and unforeseeable use of this technology is expected in the private sector. This will in turn demand for new legal laws, rules and enforcement technologies [4][5] to keep the low altitude air space save and controlled.

In this article, detection technologies for small UAVs are described in Section II, as well as the concept of a new Low Altitude Air Surveillance Control (LASC) system in Section III. The paper is closed with a final discussion in Section IV.

II. DETECTION TECHNOLOGIES FOR SMALL UAVS

Taking the established national and international airspace control as an archetype, the simplest solution for detecting and identifying a small UAV would be the mandatory introduction of a standardized identification friend or foe (IFF) system deployed in all UAVs. If this IFF provides the capability to broadcasts the current position, altitude, heading and speed together with a unique identifier, the integration of these systems into the lower airspace would be easy. But the standard IFF systems are not applicable on board of small UAVs, and the number of small UAVs is growing rapidly. Moreover, such a technology can only be a part of the solution as it provides no functionalities to deal with illegal activities. To establish a safe and secure lower airspace, additional technologies that do not rely on the cooperation of the traffic are of major importance.

Small, relatively slow and low flying UAVs as we know them today can be either detected by searching their electronic, acoustic, thermal or visual signature or by using active sensors like radar or lidar to search for anomalies that might be operating UAVs.

Video based airspace surveillance within the optical as well as the infrared spectrum is a promising approach. Existing commercial solutions rely mostly on easy change detection algorithms and basic data fusion [6]. Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (IOSB) has done comprehensive research on robust computer vision algorithms allowing the detection and primary classification of different flying objects in real time [7]. But this approach comes with challenging requirements – especially for urban areas. The whole complicated low altitude airspace need to be continuously observed without knowing the number, the size and the distance of a small UAV to be safe detected and separated from other eventually moving objects.

Sound pattern emitted by UAVs are also representing a promising source for detection and classification. Microphones combined with digital signal processing using matched digital filters adjusted to the characteristic sound frequency spectrum can unveil an approaching UAV [6]. The approach vector can be identified by the alignment of directional microphones and lead to distance estimation by signal strength or triangulation.

Communication detection of UAVs is very promisingly and partially already in application [8]. Every remote controlled UAV needs up-/downlink to the ground control station. Control commands are sent to the UAV and sensor data like position, system state and in particular the payload data (video signals in most cases) are sent back. If the typical frequency bands are monitored, characteristic communication can be identified and transmission can be extracted. The information can be used to do a rough classification of the UAVs type. In conjunction with triangulation capabilities of cooperating sensors, position and heading of a detected UAV can be determined as well. But these technologies will fail if the UAV is operating autonomously. More sophisticated technologies detecting the electromagnetic background radiation emitted by the electronic equipment of the UAV could provide a promising approach, but such systems do not exist.

Radar technology is always tailored to its application scene (e.g., detection range, size of object, material, etc.). It is insensitive to environmental conditions (poor visibility, no light at night time, rain, fog, etc.) and therefore applicable in almost any environmental situation. Long range air surveillance radar operating at 1 to 2GHz (L-Band) for range <400km and large objects (>10m) are not suitable for the LASC system as UAV’s small size, its low EM-wave reflecting composite material and low flying altitudes.

More suitable radar technologies are found in the K- and Ka-Band with frequencies between 20 and 40 GHz as far as in the W-Band (60 - 120 GHz). But a robust detection and recognition of small UAVs with radar are still a topic of research. Applied in urban areas, reflection by infrastructures and building are representing the major challenge for development of appropriate radar surveillance systems. In addition, a usage of many radar systems in urban areas can be problematic because of their radiation. Lidar seems to be a promising solution as it can provide a comprehensive three dimensional image of the surroundings allowing to precisely locate and in some cases to identify an airborne object, but the range of these sensors is too short.

III. LOW ALTITUDE AIR SURVELLANCE AND CONTROL CONCEPT

Most approaches or commercial available systems rely on a single sensor technology. Derived from the possible detection methods these systems are developed with the aim to get the best possible solution based on the capabilities of the selected single sensor type - in the best case aligned with an additional secondary sensor for a better detection rate. But all sensor technologies do have their advantages and disadvantages and a capable sensor can totally fail or become unsuitable if the situation changes.

The protection concept is normally centralized and focusing on the single sensor system itself. But systems for UAV detection and defence require solutions covering different spotting directions which often cannot be covered by a single deployed sensor. A multiple application of a sensor is not suitable if the technology is not using a control centre that is logically linked to the sensor system.

Additionally, the detecting is not sufficient if no adequate countermeasures are timely provided. On the other hand, some countermeasures can be unsuitable and even dangerous if a detected UAV is not classified or identified.

To cope with these aspects, the new LASC system concept was developed in a joint project between AToS SE and Fraunhofer IOSB.

The air space beyond the 500m is already been in control by conventional air traffic control mostly based on long-range radar technologies, so the major objective of a LASC system is the monitoring of the today uncontrolled air space below 500m with a special focus on urban areas. In order to guarantee seamless information exchange (e.g., some UAVs may enter the high altitude air space and endanger the air traffic), LASC system must be integrated into conventional air traffic control.

The common workflow of LASC is shown in Figure 1. The LASC system continuously monitors the air space with multiple sensors. Once a sensor detects a flying object, the system will try to locate it (e.g., by triangulation of signals from many sensors) and ensure tracking by orchestrating multiple sensors. Once the location and tracking is established, the backend system of LASC will carry out the (possible interactive) classification and if applicable the identification of the detected object. Once this is executed, the LASC backend system starts the evaluation of the drone’s authorization to fly through the current air space corridor. If no authorization is given, system will prepare reaction options considering the current situation, estimated threat classification and risk assessment (disturbing, illegal or endangering). The LASC system provides decision support to a human operator who is in charge of selecting and initiating the counter measures. All activities that do not need necessarily the interaction with the operator must be automated to a high degree in order to guarantee a real time execution and to enable high scalability in terms of multiple events.

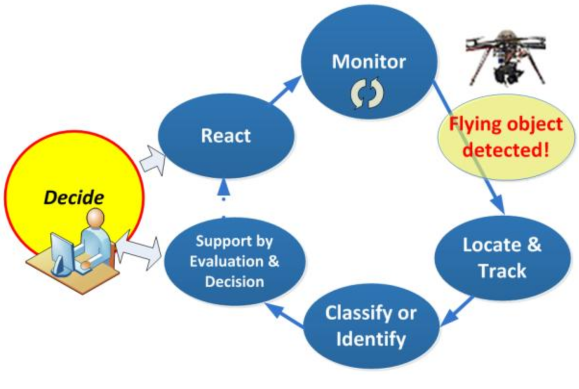

Figure 1. Common workflow of the LASC system

Depending on the application, the area of the surveillance is scalable by adding further sensor- and counter measure devices to the LASC systems or new sub-systems. Distributed LASC system can contain both mobile and stationary LASC sub-systems. This modular approach provides a broad field of application ranging from a single building to an entire suburb air surveillance. Therefore, a multimodal sensor network based on the technology stack recapitalized in chapter II must cover a certain part of the controlled air space providing day- and night time operations and coping with bad visibility conditions.

The next step after UAV detection is its classification based on sensor signal evaluation and its identification by IFF signals broadcasted by the UAV (if available). Once identified, the LASC system needs to reconcile the information with a LASC central UAV flight register to see if the UAV's flight is registered/allowed and further information is given covering payload, mission, flight path, destination and operator. If the UAV is registered, its flight register record must be updated by current position, altitude, speed and time stamp for consistent tracking. If there is no suitable record found in the LASC register, a new one must be created with all available information (e.g., ID with current position, altitude, speed and time stamp). In order to approve UAV flight authorization, its position must be mapped to pre-defined air space corridors, which will show permanent or temporarily valid restrictions or prohibitions. This is essential because different UAVs may have different air space transit rights (e.g., police UAV may enter the corridor which it prohibited for other participants). The last step of monitoring flight operations is the continuous tracking and updating the LASC register's records. Once a UAV is leaving the observation area of a sensor or a LASC system, it might enter another one. The hand-over of such tracking must be supported by the LASC intelligence, which provides analysing and predictions of flight path and identification of sensors which might detect the UAV soon.

The second objective of the LASC system is the downstream air space regulation enforcement for unauthorized UAV. Therefore, the violation of the air space must be unveiled, which must trigger a threat and risk analysis to determine suitable reaction. Based on the classification of risks and the availability of interception capabilities in reach, the LASC decision support must provide human operators with suitable enforcement and interception solutions. As the interception is near always related to potential collateral risks [9], it always needs to be initiated and controlled by a human operator. Therefore, the operator needs access to the sensors (e.g., video/IR camera) of the LASC system to leverage assessment of the situation and to gain a reliable decision base. A usage of geo-referenced situational awareness (e.g., showing locations of and distances to critical infrastructures in reach) facilitates the work of the operator considerably. All this needs to be integrated into the control centre of the LASC system to ensure a convenient use even in dangerous situations.

The major challenge of the LASC interception operation is the avoidance of collateral damages. Military interception solutions for low-altitude flying objects (e.g., lasers, shells or rocket defence systems) are not acceptable in urban areas. The "soft" interception techniques (like communication based mission distortion and interruption) need to be researched and integrated into the LASC solution. Another challenge is real time ability. In case of an abuse, the UAV might take off near its destination reducing reaction time drastically down to seconds. Therefore, most LASC system functionalities must be automated by delivering alerts and decision support to the operator within few seconds.

The common system design and major building blocks for a LASC system providing comprehensive monitoring, intelligence and interception functionalities are depicted in Figure 2.

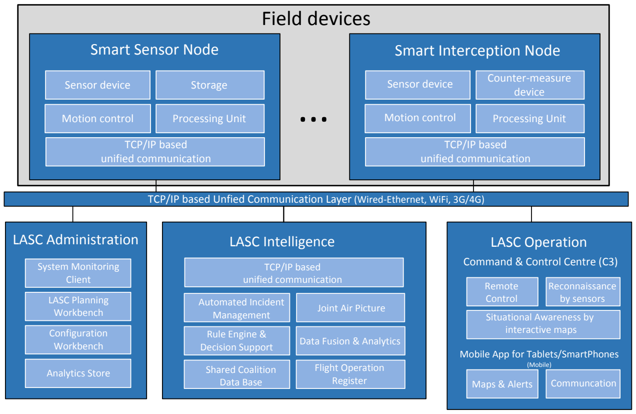

Figure 2. System concept with major building blocks

A field device of the LASC system contains the distributed network of smart sensor and interception nodes. The appropriate choice of the technology used by the nodes is strongly depending on the application and the environmental constraints (free space and the line of sight, electromagnetic or acoustic disturbances, realistic estimation of possible hazards, etc.). So deploying various sensors and interception technologies in a multimodal approach must be considered because different technologies can cooperate and extend their capabilities among each other during a parallel operation.

Smart sensor nodes are distributed on appropriate places across the observed area and equipped with data storage and processing units to pre-process sensor raw data using specific algorithms and embedded system technology. This will decrease the data volume to be transmitted to a ground station by far, as only derived data in case of an event needs to be transmitted. The derived information, analyzed data and detected events are provided via web services hosted in the sensor node and end-to-end secured (SSL, VPN) TCP/IP based communication channels. In addition, remote control and diagnose of components of each smart node is also enabled through the web services.

Smart interception nodes are also distributed across the observed area, placed stationary on buildings, infrastructures, balloons or mobile on vehicles (cars, UAVs, etc.) to provide appropriate interception capabilities. The interception nodes are based normally on the same subcomponents as the sensor nodes except that the data storage is replaced by a counter measure device. The sensor device, deployed in the interception node, in conjunction with a processing unit will enable automatic interception process preparation and support – it is especially important by multiple simultaneous threats.

Beside the field devices, the LASC system will contain three further major building blocks covering the domains administration, intelligence and operation.

The LASC administration block covers all kind of tools to configure, monitor and maintain the LASC system infrastructure and its components. It uses automated system monitoring and observation clients, which enable the survey of the operational state of sensor and interception nodes, allow load balancing of the intelligence platform and support the configuration of the intelligence itself (e.g., setup of analytics chains). Another important part of the LASC administration is the planning workbench, which provides simulation-based design support for arranging the sensor- and interception node network across a defined area in order to achieve a certain degree of air surveillance performance.

The LASC intelligence is the core block of the entire system. Its major task is the fusion of information from the sensor network and appropriate fast data analytics and complex event processing to provide a real time joint air picture (JAP) of the observed area. The JAP uses the georeferenced visualisation of all detected and tracked UAVs including all restricted and/or prohibited air areas. Utilizing a coalition shared database and the flight operation register, the LASC tries to identify a detected UAV automatically. If this fails, the LASC intelligence classifies the UAV and provides all available information (first of all video streams) for manual identification by a human operator using decision support tools. Once an air space violation is unveiled, an automated incident management provides available options for the operator to react appropriately to the incident. This incident manager utilizes a rule engine including pre-defined decision trees, risk assessments and potentially applicable counter measure nodes in reach. Once the LASC intelligence platform is deployed on virtualized server infrastructure, its service-orientated architecture provides enough performance to handle big amount of sensors (>1000), process their data in real time and provide all kind of information to multiple authorized operators.

The last building block presents the operation clients of the LASC system, which can be distinguished into stationary or deployable command and control centres (C3) and mobile apps supporting mobile access to the LASC intelligence information system. It can be developed, e.g., based on AMFIS ground control station [10]. All clients are connecting to the LASC intelligence platform via secured end-to-end encrypted (VPN, SSL) TCP/IP based communication channels and utilize its web service provision to access data and control. Once an incident is detected, alerts are shown or sent to operator and other responsible persons. The operator can request not only decision support from the LASC intelligence, but also real time video streams from optical sensors in the reach. All counter measure activities can be initiated and controlled by the C3 client software and are sent via the LASC intelligence control proxy to the selected interception node.

For mobile solutions, client apps running on smart phones and tablets are provided to inform responsible persons about incidents in the near environment and/or transmit instruction for further action.

IV. CONCLUSION

The LASC system concept includes multi-sensor detection, localization, tracking and classification or identification of small UAVs and their payloads integrated in a scalable distributed system. LASC system provides fast interactive threat and risk assessment as well as selection possibilities for adequate counter measures supported by a user-friendly interface.

The scalable architecture of the distributed LASC system has open interfaces wherever it is possible and includes data analysis and fusion modules, coalition shared database as well as interactive visualization and decision support components. The LASC system must be integrated into conventional air traffic control to prevent possible incidents because of intersecting air spaces.

In the next steps, major components of LASC as well as the system framework will be developed.

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