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Research Directions of Unmanned Aerial Vehicles

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Abstract

Unmanned aerial vehicles are undergoing an extensive transformation in these days. Along with the penetration of large-scale military systems that require considerable logistics, commercial applications are also becoming widespread. These vehicles are equipped with a number of microelectronics- and mobile web-based tools. The major obstacle ahead is the safe integration of these vehicles into the airspace, which is both a legal and a technical challenge. The technical steps towards these goals are highlighted in the article.

Keywords: unmanned aerial vehicles, integration into the common airspace, communication systems, human-machine interaction, navigation systems, sensor fusion

Introduction

Unmanned aerial vehicles or, more commonly, drones have undergone a significant transformation in the past decade. In addition to their deployment in large and expensive military systems, the development of microelectronics and computing allowed for the civilian and recreational use of these small-size vehicles. Today, the two fields are starkly distinguished, because military UAVs fly long distances in restricted airspaces under constant remote control, while in civilian use, the flight of small vehicles is only permitted within visual range, and mostly for taking aerial photos.

Figure 1
Launch of a senseFly eBee aircraft

Source: sensefly.com

Figure 2
Global Hawk and Predator military UAVs, and an F-16 fighter jet

Source: http://web.ipmsusa3.org/content/rq-4b-global-hawk

In the future, the gap between complex and expensive military systems and cheap, simple and small-size civilian UAVs will disappear. What is uncertain is the time when it will actually happen as, in addition to addressing legislation issues, a lot of technical problems need to be resolved. Because the UAV industry does not currently have a significant market due to the above mentioned lack of legislation, most commonly the products of spin-off companies that draw on the findings of direct research appear in the applications. The expenditure on research exceeds 30% of the total costs. The economic potential, however, is clearly marked by the projections indicating that in the next ten years the total amount of UAV sales will represent a 91-billion dollar global market, which exceed the GDP of Hungary in 2003. The key to significant progress is to integrate drones into the common airspace, because there are already operational experimental systems for various fields of application (agriculture, cartography, environment perception, telecommunication, etc.), but they cannot be used on a regular basis on account of airspace restrictions.

Research challenges

The current major research areas can be divided into four large groups:

1. communication,
2. activities conducted in airspace,
3. unmanned aerial vehicle and its systems,
4. human-machine relationship.

In the following we will elaborate on the research needs of the four key areas.

Communication technology

Communication technology is an integral part of all UAS systems (unmanned aerial systems) because not only uninterrupted communication must be maintained between the pilot/operator and the vehicle in order to control the aircraft, but sensor data must also be downlinked to the ground personnel for decision support.

Figure 1

Complex communication system supplied by L-3 Communications for the satellite and radio links of large UAVs

Source: www.l3t.com

- *The impact of UAS systems on the communication requirements of the next generation (NextGen, Sesar) air traffic control systems:* The communication channels of air traffic control systems currently in operation or being designed are not prepared to meet the increased requirements imposed by UAVs in terms of either capacity or heterogeneity. Research issues also cover the problems related to the accurate prediction of capacity and performance requirements and to the integration of UAVs into the existing, voice-based air traffic control systems.
- *Allocation of a suitable frequency spectrum for UAV control:* For both military and civilian vehicles a redundant and encrypted channel which is protected against interference and capable of preventing unauthorized access to the entire system should be provided. Related research topics include selecting terrestrial radio frequency bands and allocating them in international agreements, standardizing satellite data transmission channels in the same way, and checking availability and vulnerability in a verifiable manner.
- *Determining the power requirements of the telemetry system of UAS control:* Based on communications standards and reliability requirements a scalable systems should be created to ensure that the data connection will be operational between the terrestrial control system and the aerial vehicle even if certain components fail. Another research topic includes development of a clear-cut design methodology that takes reliability into account and determines compliance of the control system with the applicable requirements in regard to systems designed for various uses: such compliance must be demonstrated through a high number of simulations and demo flights. In this context the amount and quality of telemetry data are a key consideration. Research topics also include the determination of what data is absolutely necessary for vehicle control and what data can be regarded simply as a source of extra information.

Airspace use

The second large group includes airspace use, which poses a significant challenge to the representatives of legislation as well as the members of the research community since the common airspace is expansive and the movement of a large number of vehicles is difficult to calculate.

Figure 2

Communication between UAV and other occupants of the airspace

Source: www.nasa.gov/centers/armstrong/news/FactSheets/FS-075-DFRC.html

- Standardization of vehicle separation steps as an integrated separation principle: In its current state, civil aviation has various systems and rules for implementing head-on collision prevention, self-separation and separation management (TCAS, air traffic control, airspace rules), which should be part of a consistent system in regard to UAVs. Another research topic deals with determining the degree of automation for various functions: what tasks can be delegated to the grounds personnel and in which situations the UAVs are expected to make independent decisions.
- *Evaluation of security risks posed by aircraft to the airspace:* A systematic analysis method based on theoretical grounds should be developed for the evaluation of problems arising from faults and failures and their consequences, which takes into account the airspace structure, the risk posed to persons in the vicinity of the incident, and the human-machine control connection. This would make it possible to determine the degree of risk posed by each UAV to human life and property, which would constitute the basis of authorizing flight in the various segments of the airspace.
- *Implementing the "See and Avoid" system:* Aboard every civilian aircraft, the pilot's vision complements the sensors of air traffic control and the aircraft, however, in unmanned aerial vehicles this capability must be substituted with other sensors (camera, radar, radio navigation devices, etc.), and sensor fusion should also be implemented to allow for making consistent decisions. In addition to meeting performance requirements imposed on these systems, the greatest challenge is the satisfactory theoretical demonstration of compliance to the authorities.

Figure 3

Aircraft "Sindy" of HAS ICSC used for performing "see and avoid" tests

Source: uav.sztaki.hu

- *Development of separation algorithms:* Automation of safe separation demands special care as theoretically proven algorithms that are also tailored for efficiency beyond tackling separation should be developed to handle every conceivable situation. It is important to note that these methods should be compatible with the current aviation standards, and the system should behave in an unambiguous and safely predictable way all the time so that an encounter with the vehicle does not confuse pilots or the air traffic control.

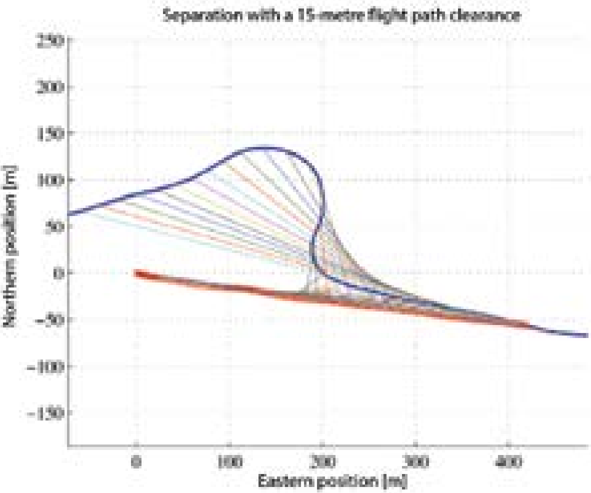

Figure 3

Aircraft "Sindy" of HAD ICSC, testing avoidance manoeuvres designed to achieve sufficient separation: own aircraft (blue), aircraft on collision course (red)

Source: uav.sztaki.hu

On-board systems of the aircraft

The on-board systems of the aircraft and its airframe – the most spectacular element of an UAS – are just components of an entire system, but they still pose serious challenges to research.

- *Aircraft state awareness and real-time mission control:* An aircraft often changes its trajectory and performs a number of different activities during its mission so it is necessary to be aware of its flight state in regard to all mission objectives and possibilities, which allows the vehicle or its operator to determine the upcoming tasks, and in case of malfunctions they can make a responsible decision on aborting mission and respond correctly to emergencies. In this area research involves development of on-board diagnostic and fault detection algorithms which can be used to predict various failure modes or investigate faults and failures that have already occurred.
- *Certification of airframe and avionics system:* Aircraft used in civil aviation are subject to a thorough and expensive procedure in which the aviation authorities attempt to cover every detail to confirm the reliability of the vehicle. However, this expensive and time-consuming procedure is not feasible in the case of UAVs due to the long lead time and the diversity of aerial vehicles. Research is underway in model-based certification procedures that would produce reliability statistics from a minimum number of flight tests, promoting the continued development of UAVs and contributing to the supply of data that are indispensable for their integration into the airspace. In civil aviation a stark distinction is made between hardware and software reliability, but in the case of UAVs, the application of analytical redundancy blurs the lines and, as a result, research in integrated software and hardware certification methods is also a significant task.
- *Supply of precise position and navigation data:* Unmanned aerial vehicles rely heavily on the GNSS global positioning system to establish their current position. In terms of availability this represents a significant problem as they are unable to use alternative methods to determine their position if the GPS/GNSS signals are jammed. There are multiple research projects that aim to develop cost-effective alternative positioning and navigation systems that are based on the fusion of data from multiple sensors. From conventional inertial devices through triangulation methods based on terrestrial wi-fi networks to solutions using visual data and laser scanning, several research areas show promising results.

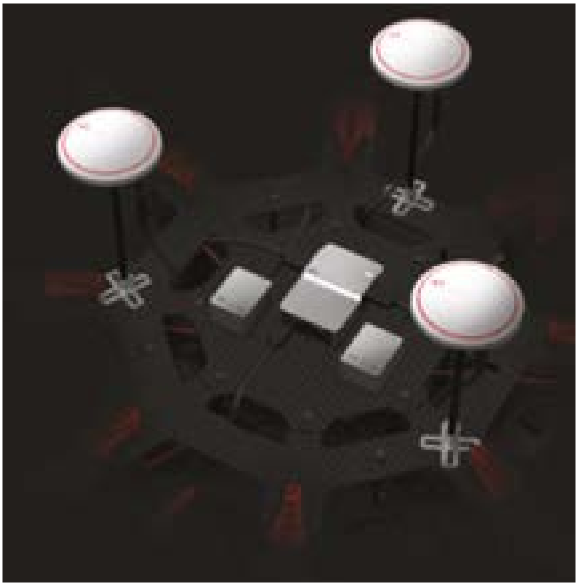

Figure 4

Triple-modular redundant flight control and navigation system available for DJI M600 multi-rotor drone

Source: www.dji.com/d-rtk/info

Human-machine integration

The fourth research area is human-machine integration, which is not exactly an engineering task: human factors and psychological considerations pose a serious challenge to the designers of future UAS systems.

- *Air traffic/airspace information display system:* Adapting UAVs to the familiar air traffic control systems is a serious challenge to air traffic controllers. It is unclear what information they can get and what instructions they can give to these vehicles the manoeuvrability of which is not known to them. Exploring human factors is an important research objective to reduce their workload stemming from the fact that air traffic is increasing and becoming significantly diverse.
- *Designing an efficient human-machine automation interface:* The problem with UAVs is that the ground control staff does not have the situation awareness of a pilot flying an aircraft, so they can only use information available to the ground control centre (GCS) to make decisions. However, the information available in the GCS is not always correct or the system does not provide information in the format that would be the most suitable for the ground controller. There are research projects all over the world that regroup and visualize these bits of information in a way that is the most efficient for the operator. Today it is humans who have the final say in matters of sudden emergencies, however, automated systems offer a wider selection of options to facilitate the process of decision making for the pilot.

Figure 4
UAV operator in a dedicated terrestrial control centre

Source: www.defenseindustrydaily.com/uav-ground-control-solutions-06175/

- *System-level interaction between terrestrial personnel and aerial vehicle:* In the future, a single pilot may control multiple semi-autonomous UAVs and manage high-level tasks for vehicles flying in formation. As a result, developing a user interface and a flow of information that are suitable for taking direct control of a single UAV in an emergency situation, in addition to visualizing and processing its high-level function specific controls is another serious challenge. In this context, handling division of labour between control centres at different geographical locations and implementing efficient and secure information exchange are also serious problems.

Figure 5
Multi-rotor aircraft flying in formation in an experiment conducted by the research team of ELTE Collmot

Source: https://hal.elte.hu/flocking

Conclusion

Unmanned aerial vehicles are a technology that shows considerable progress, and the new areas of applications that spring up every day make research extremely appealing in this field. As start-ups can develop competitive products for a fraction of the costs incurred in civil aviation, research projects may mature much earlier into actual products, which is also significant in regard to the national economy as aviation is traditionally regarded as a high-tech sector. There is significant domestic research and development potential in most of the above mentioned areas and Hungarian researchers produced achievements of global significance in several areas. Once satisfactory legislation is enacted, profit-oriented companies may also appear in the area of research and development, in addition to academic research institutions.

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