Aerial Robotics: a Bird's-Eye View

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After manufacturing, ground transportation and medicine, robotics has now made an incursion in the field of aerial applications. Several domains, such as mapping, shooting, monitoring of indoor and outdoor 3D environments, agriculture and traffic monitoring, surveillance of sensitive areas, structure inspection, handling and carrying of heavy loads, and physical interventions now seek to exploit what are commonly called "drones". While these unmanned aerial vehicles (whether called UAV, UAS, or RPAS) have reached a fair degree of maturity, as witnessed by their success in entirely new aerial missions (dangerous, long, tedious, etc.), their capabilities and their performance generally remain limited. These systems are still endowed with scant autonomy capabilities, in particular with regard to their capacity for sensing and interacting with their environment, and significant progress is expected in this direction. Other topics of practical importance concern energetic autonomy (*i.e.*, the capacity to fly longer), or avionic architecture in relation with security issues. Robotics will undoubtedly play a major role in replacing humans onboard these aerial vehicles. Robotics is one of the scientific fields of information science that relies on computer science, automatic control and signal and image processing. The involvement of several of these different aspects in the development of next generation unmanned aerial vehicles is discussed in the articles contained in this special issue.

Introduction

After manufacturing, ground transportation and medicine, robotics has now made an incursion in the field of aerial applications. Several domains, such as mapping, shooting, monitoring of indoor and outdoor 3D environments, agriculture and traffic monitoring, surveillance of sensitive areas, structure inspection, handling and carrying of heavy loads and physical interventions, now seek to exploit what are commonly called "drones". These Aerial Robotics systems can also be a flexible alternative to satellites and antennas for optimal network territory coverage. Today, their application potential is recognized as quite considerable.

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Robotics will undoubtedly play a major role in replacing humans onboard these aerial vehicles. Robotics is one of the scientific fields of information science that relies on computer science, automatic control and signal and image processing. It also draws on engineering for modeling at various levels of fidelity and for mechatronical design. It helps to address design and control systems problems, in order to develop a form of intelligence enabling very different tasks to be carried out autonomously (or with some human assistance) in highly dynamic environments.

The science and technology of Robotics, as such, cover a relatively wide range. They focus on aspects related to:

• Structural systems design;
• Control systems, computer architecture (hardware and software) for control;
• Perception (often multi-modal) of the environment, detection and information retrieval at various semantic levels;
• Localization and navigation in complex environments,
• Development of complex functions in autonomous forms and/or interaction with humans or other robotic agents;
• Planning of these functions for performing tasks/complex missions, their dynamic linking, the execution control and adaptation activities with "cognitive" artificial systems;
• Development of learning methods for the representation and solution of problems relating to particular tasks or missions, based on machine learning.

The involvement of several of these various aspects in the development of next generation unmanned aerial vehicles is discussed in the articles contained in this special issue.

Mechanical design and pre-sizing of unmanned aerial vehicles pre-sizing

Most mini-drones are rotary-wing aircraft, due to the ability of this family of systems to perform vertical take-off and landing. There is a very large variety of existing concepts and the development of new platforms is still an active research topic. Among the various possible objectives, obtaining a good trade-off between good hovering capacity and good energy efficiency in cruising flight for a given speed range, maximum weight, payload, dimension, etc., is a complex optimization problem that can involve multidisciplinary models. An article in this special issue discusses these various aspects and describes research projects conducted at Onera for rotary-wing aircraft design and pre-sizing.

Reactive control

Once a UAV (Unmanned Aerial Vehicle) has been built, the first step is to design low-level feedback control laws that ensure good flight stability. For VTOL (Vertical Take-Off and Landing) aircraft, this starts with attitude control, since these systems are inherently unstable. Higher level control objectives include, for example, velocity/position control based on GPS data, which is now part of the functionalities available on most commercial mini-drones. More recently, progress in the miniaturization, cost and energy consumption of micro-processors have made possible the on-board processing of complex sensory data, such as camera data. This opens the door to feedback control strategies based on exteroceptive sensors (cameras, laser scanners), which are very well suited to inspection applications. Several articles in this issue address these various topics from different viewpoints: modeling of strapdown IMU (Inertial Measurement Unit) measurements in relation with quadrotor UAV aerodynamics, design of attitude observers, design of non-linear feedback control laws to ensure stability over large flight envelopes and perturbation rejection, and vision-based control.

Planning and mapping

Reactive control may be sufficient for the remote operation of an aerial vehicle by a human pilot. To further increase the autonomy and envision fully autonomous flight in cluttered environments, a high level of perception and planning capability must be reached. First, the vehicle must be able to build a map of its environment and locate itself on this map. This is a major problem in robotics, usually referred to as the SLAM problem (Simultaneous Localization and Mapping). Once this map is available, planning strategies can be developed so as to ensure safe navigation in the environment. Results on visual SLAM conducted at Onera are presented in one paper in this special issue and planning issues are also covered in two articles. The first, which also describes research work conducted at Onera, addresses planning and training flight for a fleet of vehicles. The second describes research conducted at the University of Sidney on autonomous soaring, with the purpose of achieving long endurance flight. This article also discusses other means to achieve this goal.

Avionic architecture and security

A high level of autonomy can only be achieved via the use of many different sensors and the on-board processing of the associated sensory data. This leads to complex systems, at both the hardware and software levels. Such complexity is a challenge to the design of certified avionics, especially for small UAVs, which are subjected to very strong payload constraints. On the other hand, with the rapid increase in the number of UAVs operating close to inhabited areas, security demands will increase. Based on existing methods that were developed for commercial fixed-wing aircraft, work is being conducted in research labs to develop certified avionics architectures tailored to UAVs. An article in this special issue is dedicated to these aspects ■