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Editorial

Autonomous Control of Unmanned Aerial Vehicles

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Received: 12 April 2019; Accepted: 15 April 2019; Published: 22 April 2019

1. Introduction

Unmanned aerial vehicles (UAVs) are being increasingly used in different applications in both military and civilian domains. These applications include, for example, surveillance, reconnaissance, remote sensing, target acquisition, border patrol, infrastructure monitoring, aerial imaging, industrial inspection, and emergency medical aid.

Vehicles that can be considered autonomous must be able to make decisions and react to events without direct intervention by humans [1]. There are some fundamental aspects that are common to all autonomous vehicles. These aspects include the abilities of sensing and perceiving the environment, analyzing the sensed information, communicating, planning and decision making, as well as acting using control algorithms and actuators.

Although some UAVs are becoming able to perform increasingly complex autonomous maneuvers, most UAVs are not fully autonomous; instead, they are mostly operated remotely by humans [2]. To make UAVs fully autonomous, many technological and algorithmic developments are still needed. For instance, UAVs will need to improve their sensing of obstacles and subsequent avoidance. This becomes particularly important as autonomous UAVs start to operate in a civil air space that is used by other aircraft.

Operating unmanned flying vehicles is useful yet it can be challenging when the vehicle interacts with the environment [3]. This interaction could be, for instance, in the form of landing on ground or landing pads, docking into a station, approaching terrain for inspection, or approaching another aircraft for refueling purposes. Such tasks can often be solved when the vehicle is remotely piloted, especially when the pilot has a first-person view of the environment. However, human control may not always be possible, for instance due to the unavailability of a suitable data link, or because of the precision and/or speed that is required for the maneuver, which may be outside human capabilities. Thus, it is important to find effective and flexible strategies to enable vehicles to perform such tasks autonomously.

Well-developed features of autonomous UAV control include, for instance, stability enhancement and waypoint flight [4]. However, new developments in the design of UAVs and the emergence of new application areas demand robust and adaptive control techniques for different flight conditions, aggressive maneuvering flight, robust disturbance rejection, obstacle avoidance, fault tolerance, formation flying, and the use of new sensing and perception paradigms, such as computer vision. Even when the vehicle performs tasks autonomously, the efficiency and reliability of the communication link to the ground station or other aerial vehicles is important, as the autonomous UAV may need to send information about itself or its environment to the ground station or other vehicles, or it may need to receive updated mission parameters from the ground station, or information from other vehicles. To achieve all the ambitious requirements that autonomous operation brings about, systematic and innovative methods for planning, navigation, decision making, control, sensing and communications are needed.

The aim of this Special Issue is to bring together researchers and practitioners in the field of unmanned aerial systems, with a common interest in their autonomy. The contributions that are part of this special Special Issue present key challenges associated with autonomous control of unmanned aerial vehicles, propose solution methodologies to address such challenges, analyse the proposed methodologies and evaluate their performance.

2. The Present Special Issue

This special issue consists of thirteen selected articles covering different aspects of autonomous aerial vehicles, including 3D path planning with obstacle avoidance, visual control of near ground maneuvers, visual inspection, vision-based safe emergency landing, control strategies for robust disturbance rejection, efficient communication links, autonomous decision making in automated air confrontation systems, remote sensing using multi-UAV systems, ground vehicle detection, and novel autonomous UAV designs, such as flying wings and coaxial rotor UAVs.

The ability to plan colision-free paths in complex environments is an important element of UAV autonomy. In [5], Samaniego and co-workers present a computationally efficient method for 3D path planning of UAVs using an adaptive discrete mesh. The proposed method explores and decomposes the 3D environment under a recursive reward cost paradigm, resulting in an efficient and simple 3D path detection. Their algorithm saves computational time and memory compared with classical techniques.

The ability of some vehicles to transition from hover to lift-based forward flight and vice-versa brings the possibility for an autonomous flying vehicle to perform complex missions where the two different flight modes are needed. The work by Garcia-Nieto et al. [6] presents the design, implementation, harware-in-the-loop simulation and prototype testing of a control system that allows an unmanned flying-wing to perform vertical take-off and landing (VTOL) maneuvers using two tilting rotors. This work is considered by the authors as a first step towards the development of an autonomous flying-wing with VTOL capabilities.

Complex near-ground maneuvers, such as landing and capturing moving pray, are performed by flying animals with ease. These animals perform such maneuvres by exclusively using the information from their vision and vestibular system. It has been suggested that flying insects and birds use a particular visual strategy described by Tau theory to perform maneoeuvres that involve closing gaps with objects. Inspired by flying animals, the article by Armendariz and co-authors [7] describes and evaluates a visual approach that uses optic flow and Tau theory to perform autonomous near-ground manoeuvres involving vertical and horizontal motion relative to a moving target, without knowledge of height and velocity of the flying vehicle or the velocity of the target.

A coaxial rotor UAV uses a pair of coaxial reversing rotors which compensate for each other's torque, instead of balancing the yaw moment of the aircraft with a tail rotor. Therefore, a coaxial rotor aircraft has a compact structure, a small radial size, and a higher power efficiency. In their contribution, Li and co-authors [8] propose a decoupling algorithm to improve the reliability of the attitude control for the longitudinal motion stability of a coaxial rotor UAV. Based on a dynamic model that describes the vehicle's longitudinal motion, an under-actuated controller is designed using the fuzzy sliding-mode approach. The study provides simulation results showing that the position and attitude performance of the coaxial rotor UAV can be improved with the proposed control methods.

Visual inspection of aircraft is another application area where autonomous aerial systems are being used. The work by Papa and Ponte [9] describes the preliminary design of a general visual inspection system onboard a commercial quadrotor UAV. A high-definition camera is used to detect visual damage on the inspected aircraft caused by hail or lightning strikes, which are among the most dangerous threats for the airframe. Preliminary experimental results obtained from initial test flights are given, showing the performance of the ultrasonic distance keeping system and of the image acquisition/processing module for damage detection.

Because of their nature, autonomous flying vehicles must be able to reject disturbances in a robust manner. The article by Song et al. [10] presents a fixed-time active disturbance rejection control approach for the attitude control problem of a quadrotor UAV. The authors consider the presence of dynamic wind, mass eccentricity and actuator faults. The work is based on the feedback linearisation technique, along with a sliding mode feedback law and an extended state observer. The work provides mathematical proofs of convergence of the proposed extended state observer and feedback laws, along with simulation and experimental results that demonstrate the robustness and capabilities of the proposed control approach.

The efficiency of the communication link between a UAV and the groud control station is a key aspect in military applications, delivery services as well as search and rescue operations. In their contribution, Atoev et al. [11] investigate the single-carrier frequency division multiplexing modulation technique as a means to achieve high efficiency in the communications link between the UAV and the ground control station. The authors provide experimental results and compare the performance of their proposed approach with a commonly used modulation method.

The demand for autonomous decision-making algorithms to support automated air confrontation systems is growing. The work by Zhang et al. [12] addresses such demand by presenting the development of a super-horizon air confrontation training environment. The authors employ computational intelligence approaches, including reinforcement learning and neural networks, to create a self-learning air confrontation maneouver decision making system, which is tested by means of complex simulations of different air confrontation situations.

Agricultural applications of UAVs have mainly focused on a few areas, such as pest control and crop monitoring. However, agricultural UAVs are expected to be used for many other useful purposes such as field surveys, sowing, spraying, and remote sensing. In their article, Ju and Son [13] describe the development of a multi-UAV system for remote sensing in agriculture using a distributed swarm control algorithm. The authors show through their extensive experimental work and thorough analysis that their developed agricultural multi-UAV system solves the problem of battery shortage and reduces working time and control effort.

Due to their small size, autonomous UAVs are often sensitive to environmental disturbances such as wind gust. The contribution by Shi et al. [14] deals with high precision attitude control for a quadrotor UAV subject to wind gust and actuator faults. Their control strategy is based on the online disturbance uncertainty estimation and attenuation method. The authors propose and analyse state observer and sliding mode control laws based on the super-twisting algorithm, which is used to mitigate the chattering effects that often occur in sliding mode control and estimation methods. The effectiveness of their approach is demonstrated by means of simulations and real-time experiments.

The presence of a slung load attached to an autonomous helicopter exerts a swing effect on the system which significantly changes the dynamics of the vehicle and can threaten the stability of the attitute control system. Aiming to address this problem, the work by Shi and co-workers [15] proposes a high precision disturbance compensation method for a quadrotor. The authors model the quadrotor-slung load system, representing the slung load as a disturbance, and propose a harmonic state observer, along with an attitude tracking controller based on backstepping. The control system is tested by means of simulations and real-time experiments, showing improvements in the robustness of a quadrotor subject to a slung load.

An important task for some autonomous aerial systems involves the detection of vehicles and other objects on the ground. The work by Liu et al. [16] presents a method for ground vehicle detection in aerial infrared images based on a convolutional neural network. The proposed method is able to detect both stationary and moving vehicles in real urban environments. As part of their research, the authors created and have publicly shared a database of aerial vehicle imagery that can be used for research in vehicle detection. Their tests demonstrate that the proposed method is effective and efficient in recognizing ground vehicles, and is suitable for real-time application.

A current area of research of clear importance to the operation of autonomous aerial vehicles is their safe landing and recovery. As most UAV navigation methods rely on global positioning system (GPS) signals, many drones cannot land properly in the absence of such signals. Given that with the use of vision and image recognition technology the position and posture of the UAV in three dimensions can be estimated, and the environment where the drone is located can be perceived, the contribution by Yang and co-workers [17] proposes a monocular autonomous landing system that utilizes vision-based simulteaneous localization and mapping (SLAM) algorithms for use in emergencies and in unstructured environments. Experiments carried out by the authors with multiple sets of real scenes are reported and demonstrate the effectiveness of their proposed methods.

3. Future Possibilities

The UAV market is growing at a fast pace and in 2017 it was expected to triple from the the annual value of $4 billion to $14 billion in 2027 [18]. Although the market is still dominated by military applications, commercial aapplications are increasing their market share, with commercial UAV production expected to grow from $4.1 billion worldwide in 2018 to $13.1 billion in 2027 [19]. Moreover, the size of UAV-based solutions and services has been estimated to have a potential value of over $127 billion [20].

With the demand for autonomous features in UAVs growing alongside the UAV market as a whole, it can only be expected that the future research activity in the area of autonomous control of unmanned aerial vehicles will be very active, with commercial R&D aimed at enriching the technological capabilities of products to better compete in a growing and demanding market, but also with universities supported by their own funds and by government funding agencies, which see great future potential in autonomous systems. In [20], market analysts have identified the following key areas for R&D in unmanned aerial vehicles: artificial intelligence, drone detection and avoidance technology, control and communications, image processing, and battery capacity. All of these key areas are fundamental to UAV autonomy and are reflected in different ways in the contributions that are part of this Special Issue.

Funding: This research received no external funding.

Acknowledgments: The Guest Editor and the Editor-in-Chief MDPI Electronics journal wish to thank all authors who submitted their excellent research work to this special issue. We are grateful to all reviewers who contributed evaluations and views of the merits and quality of the manuscripts, and provided valuable suggestions and comments to improve their quality and the overall scientific value. Special thanks go to the Editorial Board of MDPI Electronics journal for the opportunity to edit this special issue, and to the Electronics Editorial Office staff for the hard and attentive work in keeping a rigorous peer-review schedule and timely publication process.

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
UAV	Unmanned aerial vehicle
SLAM	Simultaneous localization and mapping
3D	Three-dimensional
VTOL	Vertical take-off and landing
R&D	Research and development

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