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Doctoral Program in Aerospace Engineering (37th Cycle)

Novel Technology Perspectives for Urban Air Mobility Applications

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Unmanned Aerial Vehicles (UAVs), commonly referred to as “drones,” are gaining momentum in a broad range of applications spanning from the civilian sector to the military sector. Package delivery, inspection, mapping, aerial photography, storm tracking, disaster management, surveillance, and monitoring represent just a few applications in which UAVs have been successfully employed over the last decade, and hundreds of diverse applications will be likely to be developed in the upcoming years. Furthermore, drones are foreseen to play a crucial role in the enabling of Urban Air Mobility (UAM) services in the smart cities of the next decades. When referring to UAM, the concept of a set of innovative transportation services for goods and people relying on the use of Vertical Take-off and Landing (VTOL) vehicles in urban environments comes into play. The innovations experienced in recent years regarding electrification, automation, Artificial Intelligence (AI), and, more in general, technology have opened up to new business models and scenarios such as the concept of on-demand air mobility. On the other hand, concerns about regulation, noise, safety, social acceptance, traffic management, as well as environmental and economic sustainability represent the main barriers to the deployment of scalable UAM services based on drones, helicopters, and other VTOL vehicles. There are also technical barriers that still need attention before reaching the point of complete feasibility of deployment of large-scale drone-based operations in an urban environment. Those are related to both low-level control (robust control, optimal control, turbulence modelling) and high-level control (fleet management, operations scheduling, path planning).

This thesis investigates novel software-based solutions for managing both low-level UAV control (i.e., system modelling, identification, and control) and high-level mission planning (i.e., task

scheduling and path planning) for enabling safe, robust, resilient, and efficient UAV-based UAM services.

In particular, the quadrotor UAV-based delivery case study is chosen as a proof of concept. As far as the part about low-level UAV control is concerned, this work focuses on the identification of Control-Equivalent Turbulence Input (CETI) models for rotary wing aircrafts such as helicopters and multi-rotor drones. An innovative simulation-based framework of CETI model identification exploiting a computationally efficient turbulence model is proposed and validated by means of a generic multi-rotor model implemented in MATLAB/Simulink® and the use of CIPHER®. Also, this thesis presents a set of system engineering tools for the future development of the drone digital twins by simulating a PMSM-Quadrotor UAV system with optimal PID gains tuning. An optimal vibrations-aware gains tuning algorithm has also been developed for a SMC-based framework controlling a quadrotor UAV elastically attached to its rigid body payload.

As far as the part high-level mission planning is concerned, a novel parcel pick-up and delivery Drone Delivery Problem (DDP) with charging hubs, is formulated. Two different approaches of combined task allocation and path planning based on different optimization methods are developed and compared to address the formulated DDP: market-based and evolutionary. A UAV configuration-free energy consumption model is optimized when allocating the delivery tasks while ensuring delivery time windows are met and recharging hubs are visited. Extensive Monte Carlo simulations in MATLAB and ROS (Robot Operating System) corroborate the validity of the proposed approaches even with lossy communication scenarios. The proposed combined market-based task allocation and risk-aware path planning strategy is also integrated with a drone's fleet management system developed by Telespazio Spa: T-DROMES.

Finally, the problem of enabling noise-contained operations with UAVs in urban environments is addressed. A combined Reinforcement Learning (RL) and acoustic ray tracing-based path planning framework is proposed (and implemented in MATLAB) with the aim of minimizing the total Sound Pressure Level (SPL) at ground level.

This doctoral thesis paves the way for the sustainable, scalable, safe, robust, efficient management and control of UAV-based applications in smart city context.