Guest Editorial
Special Section on Aerial Swarm Robotics

I. Introduction

AERIAL robotics has been one of the most active areas of research within the robotics community, and recently there have been many reports of promising results in aerial swarm systems. This is partly due to the commoditization of multicopter platforms, and communication, sensing, and processing hardware that has substantially lowered the barriers to entry to the field of aerial swarm robotics.

Aerial swarms differ from swarms of ground-based vehicles in two major respects: Aerial robots or unmanned aerial vehicles (UAVs) operate in a three-dimensional space, and the dynamics of individual vehicles add an extra layer of complexity to the problems of path planning and trajectory design. Furthermore, the success of aerial swarms is predicated on the distributed and synergistic capabilities of individual and cooperative control, estimation, and decision making of aerial robots with limited resources, such as modest onboard computation and sensing capabilities and size, weight, and power constraints.

This special section, starting with the survey paper, presents recent advances in aerial swarm robotics, and aims to put together a cohesive set of research goals and visions toward realizing fully autonomous aerial swarm systems. One objective is to emphasize the three-way tradeoff among computational efficiency for large-scale swarms, stability, and robustness under uncertainty, and the optimal system performance.

II. Guide to the Special Issue

The survey paper by the guest editors reviews the state of the art of theoretical tools and technologies that allow the individual members of the swarm to communicate and allocate tasks amongst themselves, plan their trajectories, and coordinate their flight in such a way that the overall objectives of the swarm are achieved efficiently and autonomously. Such swarm algorithms, often organized in a hierarchical fashion, endow the swarm with autonomy at every level, and the role of a human operator can be reduced, in principle, to interactions at a higher level without direct intervention. The survey includes reviews in dynamic modeling and conditions for stability and controllability that are essential in order to achieve cooperative flight and distributed sensing. The main sections of the paper focus on major results in aerial swarm robotics covering trajectory generation, task allocation, adversarial control, distributed sensing, monitoring, and mapping.

The paper by Hönig *et al.* presents a method of computing safe and smooth trajectories for hundreds of aerial robots flying in a dense obstacle-rich environment, combining graph-based planners and trajectory optimization. The proposed method is hierarchical, and follow three stages. In the first stage, sparse roadmaps are generated and annotated with information about collisions. In the second stage, a discrete schedule is obtained for each UAV using one of two planners, depending on whether or not the assigned goals can be exchanged between UAVs. Finally, the schedule is refined using an iterative procedure to yield a smooth trajectory for each UAV and represented using a concatenation of Bézier curves. The paper reports results from flight test experiments involving 32 quadrotors.

The paper by Liu *et al.* presents a distributed formation control algorithm for a group of aerial robots. The complete distributed control framework is implemented with the combination of a fast model predictive control method executed at 50 Hz on low-power computers onboard multirotor UAVs and validated via a series of hardware-in-the-loop simulations and real-robot experiments. The authors also carried out hardware-in-the-loop simulations using up to six onboard computers to achieve spherical formations and a formation moving through obstacles.

The paper by Trotta *et al.* proposes deployment strategies that allow a swarm of UAVs to maximize the coverage of a target area, and simultaneously guarantee continuous service. The combined problem of optimizing the positioning of the UAVs for coverage and scheduling the charging operations is first solved using a centralized approach, which assumes global (all-to-all) communication. Next, a distributed, game-theoretic scheduling strategy is proposed as a computationally efficient alternative to the centralized solution. A key result of the paper is that the distributed deployment, using only 1-hop messaging, approximates the performance of the centralized optimum solution with a predictable bound. This performance matching persists even as the number of UAVs in the system is increased.

The paper by Paranjape *et al.* explores the use of aerial robots to protect an airspace, such as around an airport, from intrusion by a flock of birds. The paper falls under the umbrella of adversarial control of swarms. Using a combination of reduced-order flocking dynamics modeling, heuristics, mathematical analysis, and experimental system identification the paper demonstrates

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via experimentation and simulation the ability of a real-world aerial robot to successfully steer a flock of birds in a desired direction while maintaining cohesion within the flock. The paper offers a key first step toward a system that, if implemented broadly, could have a significant economic impact by preventing thousands of bird strikes from causing hundreds of millions of dollars annually in damage to aircraft.

The paper by Zhou and Schwager presents a single operator control method, and an experimental demonstration, for a swarm of quadrotors with a built-in collision-free capability against other quadrotors and static obstacles. The paper expands on the use of the virtual structure concept for planning complex trajectories. The same concept allows a human operator to fly the swarm as if it were a single rigid body, and switch between a suite of predefined formations. Trajectory generation is accomplished by combining the virtual structure concept with potential fields for collision avoidance, and differential flatness-based feedback control for tracking. The method is demonstrated in hardware experiments featuring quadrotors flying preplanned trajectories as well as those commanded by a human operator.

III. Acknowledgment

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