Ph.D. Project:

Innovative control and optimization methods for managing missions of drone fleets powered by solar energy

Location:

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Context of the study:

Unmanned Aerial Vehicles (UAVs) can be defined as devices used for flight in the air that have no on-board pilot. These devices are sometimes referred to as drones, which are programmed for autonomous flight, and Remotely Piloted Vehicles (RPVs), which are flown remotely by a ground control operator [CG10]. Recently, discussions about UAVs have used the term Unmanned Aircraft Systems (UASs) to reflect the fact that in addition to the unmanned aircrafts, a complete UAS includes multiple pieces of ancillary equipment, such as vehicle control equipment, communications systems, and potentially even launch and recovery platforms. The versatility of these systems is one of the strongest drivers in the rapid development of these technologies, where the identification of new potential uses leads to the adaptation of the systems [FW12].

Fleets of drones are powerful autonomous and collaborative systems that can accomplish given missions such as surveillance, monitoring, target tracking and simultaneously support multimedia communications and provide them with high levels of Quality of Service (QoS) [OA18]. In fact, drones are usually equipped with communications facilities (such as WiFi and Bluetooth cards for medium- and short-range communications, and 3G-4G antennas for long range communications) that allow them to communicate for exchanging position information or control information (cooperative systems). These communication technologies have usually problems when sending information between drones, perturbing the whole fleet system and sometimes producing loss of data or sketchy information in each drone. This may increase the instability of the system, crashing the drones and compromising the success of the mission.

Another major issue is represented by the low autonomy of drone batteries, which typically allow a drone to fly for a few tens of minutes and then require to return to a station for recharging. This can severely limit the action of drones, especially in critical missions like exploration during natural disasters and mobile connectivity coverage in 5G telecommunications networks (e.g., [CD19, CD20, OA18]). As a remedy, drones and, more in general UAVs, have started to be equipped with solar cells that allow recharging while flying. However, the angle by which the drone receives solar beams on the cells may greatly influence the amount of energy received. Therefore, as discussed in recent works like [HGL19], it is really important to control the flight of the drone so to offer the best angle for recharging. This leads to new complex control problems that should be suitably integrated with optimization models and algorithms for planning the missions of the drones.

Ph.D. Thesis project:

To guarantee successful missions of a fleet of drones, it is necessary that the drones can know (almost) perfectly their respective location in a dynamic and active scenario, so to also have the possibility of exposing the solar cell to the sun according to the best recharging angle allowed by the current flight conditions. Errors in communications lead to nonlinear uncertainties in information available to each drone and to the fleet of drones as a whole, thus making their positioning not accurate as it would be desirable. This problem has been shortly addressed in the drone community, however it represents a crucial challenge when working in flight collaboration or formation of a fleet of drones.

In this Ph.D. Thesis, we propose to study how location uncertainty may degrade the performance of each drone and of the fleet of the drones as a whole and how (Robust) Optimization models and algorithms could be adopted to tackle it.

Specifically, the Ph.D. will be aimed at:

1. developing new network-aware algorithms of movement for accomplishing the drone missions and/or extending the network coverage by leveraging our experience with controlled mobility in wireless networks [CM17, CD19, CD20];
2. studying from a theoretical and applied point of view the impact of control and optimization methods on improving the energy generation of solar cells installed on the drones;
3. designing a new control-communication architecture based on quaternions [AC19, OS18] and 5G wireless technology communications for a fleet of drones;
4. by exploiting the architecture and algorithms developed in points 1 and 2, developing a new mathematical optimization model and solution algorithms for managing drones services in the context of a very important emerging technology: providing mobile communications services by drone-based 5G networks, taking into account the data uncertainty of the system through a Robust Optimization paradigm [BS04,BB14];
5. validating the proposed models and algorithms in real time in the aerial platforms maintained in the Laboratory Heudiasyc.

The Ph.D. Student will closely work with both supervisors, also profiting from the expertise of other members of the SCOP and SyRI Research Teams. Moreover, there will be the possibility of collaborating with senior professors and researchers of other universities, such as:

1) Prof. L. Chiaraviglio, Department of Electronic Engineering, University of Rome Tor Vergata (Rome, Italy)

2) Prof. Enrico Natalizio, Lorraine Research Laboratory in Computer Science and its Applications (LORIA, UMR 7503) and Universite de Lorraine (Nancy, France)

The Supervisors will also encourage the Ph.D. Student to make a research visit of at least 6 month in a foreign research group, possibly after the end of the second year.

Candidate's profile:

- knowledge of Control and Optimization Theory and Applications;
- good programming skills (C++, Java or Python; knowledge of Matlab is appreciated);
- proficiency in English;
- good communications skills;
- knowledge of Robotics, in particular aerial vehicles, is strongly appreciated.

Documents required to apply:

Please send to pedro.castillo@hds.utc.fr and d.andreagiovanni@hds.utc.fr

- a curriculum vitae
- a motivation letter
- at least two references and/or recommendation letters
- a statement of research interests and experience (if any)

Essential References:

- [AC19] H. Abaunza, P. Castillo, R. Lozano, "Quaternion Modeling and Control Approaches", Handbook of Unmanned Aerial Vehicles, Second Edition, edited by K.P. Valavanis and G.J. Vachtsevanos, 2019.
- [AS18] F. Oliva-Palomo, A. Sanchez-Orta, P. Castillo, H. Alazki, "Nonlinear ellipsoid based attitude control for aggressive trajectories in a quadrotor: Closed-loop multi-flips implementation", Control Engineering Practice 77, 150-161, 2018.
- [BB14] T. Bauschert, C. Büsing, F. D'Andreagiovanni, A. Koster, M. Kutschka, "Network planning under demand uncertainty with robust optimization", IEEE Communications Magazine 52 (2), 178-185, 2014

- [BS04] D. Bertsimas, M. Sim, “The Price of Robustness”, Operations Research 52(1), 35-53, 2004.
- [CM17] P. Castillo, L.-E. Munoz, and P. Garcia, Indoor Navigation Strategies for Aerial Autonomous Systems, Elsevier, Feb. 2017 ISBN : 9780128051894.
- [CG10] H. Chad, J. Gertler, “Homeland Security: Unmanned Aerial Vehicles and Border Surveillance,” Congressional Research Service, 1-6, 2010.
- [CD19] L. Chiaraviglio, F. D'Andreagiovanni, R. Choo, F. Cuomo, S. Colonnese, “Joint Optimization of Area Throughput and Grid-Connected Microgeneration in UAV-Based Mobile Networks”, IEEE Access 7, 69545-69558, 2019.
- [CD20] L. Chiaraviglio, F. D'Andreagiovanni, W. Liu, J. Gutierrez, N. Blefari-Melazzi, K. Raymond Choo, M. Alouini, “Multi-Area Throughput and Energy Optimization of UAV-aided Cellular Networks Powered by Solar Panels and Grid”, IEEE Transactions on Mobile Computing, early access, 2020.
- [FW12] R. L. Finn, D.Wright, “Unmanned aircraft systems: Surveillance, ethics and privacy in civil applications,” Computer Law and Security Review 28(2), 184-194, 2012.
- [HGL19] J.L. Hernandez-Toral, I. González-Hernández, R. Lozano, “Sun Tracking Technique Applied to a Solar Unmanned Aerial Vehicle”, *Drones 3*, 51, 2019.
- [OA18] A. Otto, N. Agatz, J. Campbell, B. Golden, E. Pesch, “Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey”. Networks, 1-48, 2018.