Thesis subject:

Multi-Robots Exploration Strategies using Active Visual SLAM and Distributed Control Architectures

PhD Advisors:

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Context of the thesis:

The thesis is part of the project activities of the Laboratory of Excellence (LABEX) at the Université de Technologie de Compiègne (UTC) in France on the Control of Technological Systems of Systems (MS2T) (http://www.labexms2t.fr). Specifically, the thesis belongs to the research activities planned in the context of the Challenge Team DIVINA (DIstributed cooperative VIsual Navigation for multi-uAv systems). It is also part of the ROBOTEX Equipment of Excellence Project in the topic of mobile robotics with an application on perception/navigation for multi-UAV systems.

PhD thesis description:

Nowadays robotic vehicles are used in a wide range of applications and scenarios, with significant improvements over past solutions. Empowered by fast technological and theoretical advances, a trend shift is occurring to the use of large scale, distributed formations of robots. Indeed, multi-robot systems are now recognized as a superior answer to many problems, taking advantage of important unique features such as flexible distributed sensing and intervention abilities, complementary heterogeneity, robustness to individual failures through redundancy, scalability in time and space, smaller deployment times, reduced operational costs and improved performances.

In more details, a key capability in multi-robot autonomous systems is to perform fast exploration and mapping in totally or partially unknown and GPS-denied environments. By sharing information between the robots, the performances of individual agents can be significantly improved, allowing for cooperatively performing complicated tasks in different domains including surveillance, search and rescue in dangerous or inaccessible areas, firefighting, etc.

To build a map of an unknown environment, a robot has to perform the so-called Simultaneous Localization and Mapping (SLAM). In passive SLAM algorithms, a remote entity controls the robot, and the SLAM algorithm is not involved in control actions. On the other hand, in active SLAM, the robot actively explores its environment in the pursuit of an accurate map, and the SLAM algorithm participates in the control actions. Active SLAM methods tend to yield more accurate maps in shorter time, but they constrain the robot motion. In scenarios where time is critical, the use of multiple robots allows to speed up the exploration and to take advantage of the existence of distributed sensors to improve the mapping process. Each robot explores a different but connected area. The global map is built by merging local maps built by the individual robots.

Formation control is a fundamental group behaviour required by robot teams engaged in tasks within spatial domains and so has to be considered for active SLAM by using multi-robot systems as well. Simply speaking, formation control refers to the problem of controlling the robots such that they accomplish a specific task or reach a final objective while maintaining a collision-free flocking. Many systems in nature exhibit stable formation behaviours e.g., swarms, schools, and flocks. In these highly robust systems, individuals follow distant leaders without colliding with neighbours. Thus, a coordinated grouping behaviour emerges by composing individual control actions and sensor information in a distributed control architecture. We have already developed various control algorithms for self-organization and collision avoidance, and experimentally verified their performance on a group of UAVs (quadrotors). A number of these algorithms operate hierarchically by using a leader-follower formation structure while the others have been designed to be completely decentralized. These earlier research works have been developed within the context of PhD students participating in the Labex MS2T Program. This new research activity will extend these works by including active SLAM within the control architecture, and by taking into account the objective of the construction of a global map. It will also propose novel exploration strategies to allow the fleet to achieve the objective of complete exploration in optimal time and energy consumption while maintaining its self-organization capability.

In summary, the goal of this thesis is to propose new algorithms beyond the state-of-the-art for allowing a multi-robot system to efficiently explore a totally or partially unknown area using on-board vision-based sensing through distributed control under local communications constraints.

Micro-UAVs equipped with either quad or octo-rotors will be the target robotic platform to test and implement the algorithms. Since many multi-robot platforms rely on indoor visual tracking systems and/or heavily use GPS-enabled environments, one of the challenges will be to operate the UAV fleet in outside conditions within unstructured and unknown environments.

Scientific challenges will be on:

- Design of distributed control strategies that use visual feedback for a multi-UAV systems formation performing a cooperative task while maintaining a collision-free flocking.
- Discrete graph theoretical tools exploitation for cooperatively estimating localization, mapping and robots' relative poses under topological and communications constraints.
- Bio-inspired and novel computational decision-making approaches for exploration strategies.
- System-of-Systems design to handle scalability, heterogeneity, and to predict emergent behaviours.

Keywords: Multi-robot systems, Distributed Control, Visual SLAM, Swarm Robotics, System-of-Systems design.

Candidate's profile:

Advanced knowledge required in the field of Robotics, Computer Vision, Estimation and Control Theory, Distributed Algorithms, and an advanced level in programming in Matlab, C/C++ and ROS middleware. Scientific curiosity, large autonomy and ability to work independently are also expected.

Documents required to apply:

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- Curriculum vitae
- Motivation letter
- At least two references and/or recommendation letters
- A statement of research experience and interests

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