Exploiting Heterogeneity in Networks of Aerial and Ground Robotic Agents

by

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Abstract

By taking advantage of complementary communication technologies, distinct sensing functionalities and different motion dynamics present in a heterogeneous multi-robotic network, it is possible to accomplish a main mission objective by assigning specialized sub-tasks to specific members of the robotic system. An adequate selection of the team members and an effective coordination are some of the challenges to fully exploit the unique capabilities that these types of systems can offer. Motivated by real world applications, we focus on a multi-robotic network made by aerial and ground agents which has the potential to provide critical support to human teams in complex environments. For instance, aerial robotic relays are capable of transporting small ground mobile sensors and also of expanding the communication capabilities of the whole system.
In the first part of this dissertation, we extend the work on manipulation of cable-suspended loads using flying robots by solving the problem of lifting the cable-suspended load from the ground before proceeding to transport it. The suspended load-quadrotor system experiences switching conditions during this critical maneuver. Thus, we define a hybrid system and show that it is differentially-flat. This property facilitates the design of a nonlinear controller which tracks a trajectory generated based on waypoints associated with the discrete states of the hybrid system. In addition, we address the case of not knowing the payload mass by combining a least-squares estimation method with the designed controller.

Second, we focus on the coordination of a heterogeneous team formed by a group of ground mobile sensors and a flying communication router which is deployed to sense areas of interest in a cluttered environment. Using potential field methods, we propose a controller for the coordinated mobility of the team to guarantee inter-robot and obstacle collision avoidance as well as connectivity maintenance among the ground agents while the main goal of sensing is carried out. For the case of the aerial communications relays, we combine antenna diversity with reinforcement learning to dynamically re-locate them so that the received signal strength is maintained above a desired threshold.

Motivated by the recent use of optical wireless communications as the perfect complement for radio frequency, we envision the implementation of an optical link between micro-scale aerial and ground robots. This type of link requires maintaining an adequate relative transmitter-receiver position for reliable communications. In the third part of this proposal, we tackle this problem. Based on the link model, we define a connectivity cone where a minimum transmission rate is guaranteed if the transmitter stays within. For example, the aerial robot has to track the ground vehicle to stay inside this cone. The control must be robust to noisy measurements. Thus, we use particle filters to obtain a better estimation of the receiver position and we design a control algorithm for the flying robot to enhance the transmission rate.
Also, we consider the problem of pairing a ground sensor with an aerial vehicle, both equipped with a hybrid radio-frequency/optical wireless communication system. A challenge in this case is positioning the flying robot within optical range when the sensor location is unknown. Thus, we take advantage of the hybrid communication scheme by developing a control strategy that uses the radio signal to guide the aerial platform to the sensor node. Once the optical-based signal strength has achieved a certain threshold, the robot hovers within optical range.

Finally, we investigate the problem of building an alliance of agents with different skills in order to satisfy the requirements imposed by a given mission. We find this alliance, known also as a coalition, by using a bipartite graph which represents the relation between agent capabilities and required resources for task execution. The total capabilities of the formed coalition can satisfy the task resource requirements. Also, we study the heterogeneity of the generated coalition to analyze how it is affected for instance by the amount of resources present in the agents.