Hybrid formation control of the Unmanned Aerial Vehicles

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ABSTRACT

An essential issue in the formation control of Unmanned Aerial Vehicles (UAVs) is to design a reliable controller in their path planner level to handle all interactions between the continuous dynamics of the system and inherent discrete nature of the decision making unit, which has been embedded to coordinate the control submodules. In this paper, we have proposed a new approach of hybrid supervisory control of UAVs for a two-dimensional leader follower formation scenario. The approach is able to comprehensively capture internal relations between the path planner dynamics and the decision making unit of the UAVs. To design such a hybrid supervisory controller for the formation problem, we have introduced a new method of abstraction, based on polar partitioning of the state space. Furthermore, we have utilized the properties of multi-affine vector fields over the polar partitioned space. Within this framework, we design a modular decentralized supervisor in the path planner level of the UAVs to achieve two major goals: first, reaching the formation and second, keeping the formation. In addition, an inter-collision avoidance mechanism has been considered in the controller structure. The approach is robust against uncertainty in the initial state of the system, in the sense that it can bring the follower UAV to the desired position, starting from any arbitrary initial position inside the control horizon. Moreover, the velocity bounds are applied through the design procedure so that the generated velocity references can be given to the lower level of the control hierarchy, as the references to be followed.

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1. Introduction

Formation control of cooperative multi-robot systems [1,2], is a rapidly growing area that aims at reaching and keeping a particular form of movement and has numerous applications in ground and aerial robotics. Cooperative control in general and formation control in particular, provide a framework for analysis and design of the team behavior of several autonomous vehicles. A team of robots, taking a cooperative structure, is more robust against the failures in the agents or in the communication links. Moreover, using several simpler robots instead of a complex one, results in a more powerful and flexible structure and could leverage the team efficiency [3].

In the area of the aerial robotics, formation control of the Unmanned Aerial Vehicles (UAVs) has aroused a challenging hot research area and has attracted both academic and military communities [4,5]. This is due to the fact that UAVs are not subject to the limitations of the ground robots like movement constraints and vision range limitations and therefore, they are quite fit solutions for missions such as terrain and utilities inspection [6], search and coverage [7], search and rescue [8], disaster monitoring [9], aerial mapping [10], traffic monitoring [11], reconnaissance mission [12], and surveillance [13].

A typical formation control scenario consists of several parts, including: reaching the formation, keeping the formation, and inter-collision avoidance. Starting from an initial state, the UAVs should achieve the desired formation within a finite time (reaching the formation). Then, they should be able to maintain the achieved formation, while the whole structure needs to track a certain trajectory (keeping the formation). Meanwhile, in all of the previous steps, the collision between the agents should be prevented (inter-collision avoidance). Definitely, this interacting control structure imposes lots of switching between the control submodules and hence, a decision making unit should be embedded in the control architecture to support this complicated orchestra. The existing formation control strategies, mainly focus on the keeping formation problem in which the formation problem could be reduced to the design of a controller for a system, which has been slightly deviated from the desired configuration [14–16]. There are also some methods that focus on the reaching the formation such as those are based on MILP programming, navigation function and potential field approaches [17–20]. These approaches usually suffer...