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Feedback Formation Control of UAV Swarm with Multiple Implicit Leaders

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Abstract: UAV swarm is a typical application of multi-agent system and consists of a certain number of single- or multi-function UAVs. This paper mainly focuses on the motion consensus and formation control of UAV swarm. A novel formation control algorithm suitable for both leaders and followers is designed, in which leaders are implicitly integrated into the swarm and can be influenced by navigational feedback from their flockmates. Theoretical analysis shows that the system is asymptotically stable and can converge to the desired formation without collision among vehicles. Numerical simulations are performed to illustrate the theoretical results and verify the velocity and trajectory tracking abilities of the algorithm. Results reveal that the proposed algorithm guarantees a swarm of UAVs to fly with predefined formation and track scheduled trajectory. Furthermore, the novel algorithm can reduce the communication consumption and enhance the adaptability and scalability of the system.

Keywords: UAV swarm, motion consensus, formation control, multi-agent system, implicit leaders

1. Introduction

The unmanned aerial vehicles swarm will significantly expand the application areas and open up new possibilities for UAVs [1, 2]. It is more effective, flexible, robust and reliable than single vehicles. The deployment of UAV swarm brings a lot of advantages in surveillance and reconnaissance, traffic monitoring and management, fire detection and suppression. A swarm of UAVs may constitute a much more effective system than a single vehicle, and the formation control is a critical step of attempting to the cooperation among UAVs [3]. Extensive research has been conducted on the formation control of UAV swarm to fulfill cooperative missions [4-6]. One can see from [7, 8] that self-organization and automation based on limited information and simple rules is essential and critical feature of the UAV swarm, which means the formation control is decentralized and does not need traditional remote control center or ground control station [9, 10]. In general, a formation control problem is to find a distributed coordination scheme to enable UAVs to reach and maintain some desired, possibly time-varying formation or group configuration [11].

Over the last few years, many formation control algorithms have been put forward in robotics and control communities, which can be classified into three typical types, i.e., leader-follower based strategy [12, 13], virtual structure based approach [8] and behavior based method [14]. Among these approaches, the leader-follower based approach is the most popular and has been studied extensively in multi-agent formation control problems due to its convenience and ease of analysis and implementation [15-17]. In this architecture, some individuals in the swarm are informed of the global trajectory information and thus designated as leaders, while the uninformed ones are designated as followers [18, 19]. In the existing literature, the leaders are explicit and highlighted [20, 21]. All or some of the followers are assumed to have access to the motion information of leaders within their sensing range when needed, mostly, position and velocity [22, 23]. Then the followers are steered to maintain desired relative distance and orientation with their corresponding leaders by employing a local control protocol.

However, in a practical application, it is not necessary or even possible to guarantee all individuals informed of leader information, especially for military UAV swarm in a complex electromagnetic environment. In most cases found in nature, only a small fraction of individuals have the knowledge of food source or migration route [24]. Another example is the autonomous synchronicity of applause in a meeting. For a swarm with such small proportion of informed individuals or even without any explicit leader, it is not possible for all individuals to know the global information. That is to say the leaders are implicit for followers and the swarm is leaded unconsciously. Besides these problems, existing protocols are not so reliable in regulating a UAV swarm because the speed of vehicles in an aerial swarm is much faster than that of ground mobile robots, the distance between flying UAVs is

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