Maximizing Search Coverage Using Future Path Projection for Cooperative Multiple UAVs with Limited Communication Ranges

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Abstract. In this chapter, we present Future Path Projection (FPP) as a novel method for multiple Unmanned Aerial Vehicles (UAVs) with limited communication ranges to cooperatively maximize the coverage of a large search area. For multiple cooperative UAVs to perform an effective search mission, the critical status and sensor information collected by each UAV must be shared with all other UAVs in the group. In an ideal environment where there is no communication limitation, all involved UAVs can share the necessary information without any constraints. In a more realistic environment, UAVs must deal with limited communication ranges. The communication range limitation, however, introduces a challenging problem for multiple UAVs to effectively cooperate. In the proposed method, each UAV constructs an individual probability distribution map of the search space which reflects predictions of the future paths of UAVs as they move beyond their communication ranges. The probability distribution map describes the likelihood of detecting targets within the search space. The overall, collective UAV search patterns are governed by decisions made by each UAV within the group, based on each individual probability distribution map. We show that the collective search patterns generated by cooperative UAVs using the proposed method significantly improve the search area coverage when compared to similar search patterns produced by other mitigation strategies designed to overcome the communication range limitation. We validate the effectiveness of the proposed path projection method using simulation results.

Keywords: cooperative, unmanned aerial vehicles, limited communication, future path projection.

1 Introduction

Significant research has been conducted on mobile multi-agent systems directed at solving problems such as target search [1], target observation [2], and cooperative transportation [3]. Of particular interest is the development of multi-agent systems composed of Unmanned Aerial Vehicles (UAVs) capable of covering vast areas using a wide range of sensors. These systems are ideal for applications such as surveillance, reconnaissance, rescue, and emergency site monitoring [4].
For an increasing number of applications, multiple UAV systems provide superior performance compared to single UAV systems by taking advantage of the redundancy, robustness, and cooperation potential of multiple systems. However, to gain the advantages of no centralized control unit, cooperation intrinsically requires some degree of communication between UAVs [5]. In practice, the cooperation potential is often not fully achieved due to restricted communication capabilities, such as limited communication ranges. Moreover, the bigger the volume of information a cooperative algorithm requires to be transferred between UAVs, the greater will be the necessary communication bandwidth. In most protocols, increased bandwidth usage ultimately leads to communication delays. When UAVs operate based on delayed information about the states of other cooperating UAVs, the environment, or the status of the global mission, the entire system performance can be degraded or its stability compromised [6], [7].

Recently, strategies that aim at mitigating the impact of communication limitations on the cooperation performance of multi-agent systems have been the focus of significant research activity. Current efforts can be generally classified into two groups: uninterrupted communication strategies that restrict the mobility of the fully connected cooperating UAVs; and unrestricted mobility strategies that provide the agents with freedom of movement but temporarily increase the volume of information exchanged when two or more UAVs happen to fly within communication range of each other.

An example of an uninterrupted communication strategy can be found in [8], where a formation control framework is applied to a set of multiple agents with the goal of balancing the intent of each unit to contribute to the collective mission and the requirement to maintain a single communication network by restricting any single agent from moving beyond the communication range of the group. Another such strategy is introduced in [9], where occasional non-local interactions determined by an acute angle switching algorithm are shown to generate mobile networks that robustly preserve system-wide connectivity while seeking to cover a number of regions of interest. Approaches such as these have the benefit of allowing agents to operate under a single network. If the volume of exchanged information is not prohibitive, it allows for all agents to share a common knowledge database during the entire mission. However, to achieve and maintain a single network, the mobility of each individual agent becomes limited, which can compromise the performance of the group.

In unrestricted mobility strategies, individual performance is not compromised. However, cooperation performance is generally affected negatively since, for the lack of a system-wide network, the UAVs must operate without access to a common knowledge database. Without such information, the capability of a UAV to effectively cooperate with the team becomes limited. Therefore, unrestricted mobility strategies focus on techniques that provide additional information when communication opportunities occur as two or more UAVs fly within a communication range of each other. Typical approaches involve the sharing of information in the form of past states and/or past sensor readings. In practice, the frequency and duration of such encounters tend to decrease with