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Swarm Coordination Under Conflict and Use of Enhanced Lyapunov Control

We consider hostile conflicts between two multi-agent swarms. First, we investigate the complex nature of a single pursuer attempting to intercept a single evader (1P-1E), and establish some rudimentary rules of engagement. The stability repercussions of these rules are investigated using a Lyapunov-based stability analysis. Second, we extend the modeling and stability analysis to interactions between multi-agent swarms of pursuers and evaders. The present document considers only swarms with equal membership strengths for simplicity. This effort is based on a set of suggested momenta deployed on individual agents. The control of group pursuit is divided into two phases: the approach phase during which the two swarms act like individuals in the 1P-1E interaction, and the assigned pursuit phase, where each pursuer follows an assigned evader. A simple, single-step dissipative control strategy, which results in undesirable control chatter, is considered first. A distributed control logic is then introduced, in order to ameliorate the chatter problems. In this new logic, the dissipative control action is spread out over a time window. A wide range of case studies is tested in order to quantify the parametric effects of the new strategy. [DOI: 10.1115/1.4003213]

1 Introduction

This study addresses the modeling, analysis, and control of multi-agent swarm dynamics. When each agent influences every other agent, the rules of interaction and stability of group dynamics become quite complicated. Most of the earlier investigations that focus on this general theme consider homogeneous swarms, i.e., those composed of alike members [1–7].

Gazi and Passino [2] expanded their pioneering work on swarm coordination by generalizing the stability analysis for a class of attraction/repulsion functions for homogeneous swarms. As a consequence of the homogeneous membership and symmetric characteristics of the momenta, stationary and stable swarm aggregation is achieved. They also propose modifications to account for finite body size of the swarm members. All the members are required to know (or sense) the position of the others. Recently, this work was further expanded by analyzing the second order dynamics of the swarm members [7].

Chu et al. [8,9] addressed the stability analysis of anisotropic (asymmetric behavior) but nonhostile swarms. They proposed aggregation rules for swarms with reciprocal and nonreciprocal interactions between agents. They also point out that the current general understanding is that the swarming behavior results from the interplay between long range attraction and short range repulsion among individuals. For nonreciprocal interaction, a condition of weighted momenta is assumed [8]. In the present paper, we extend the application of asymmetric momenta to hostile swarm interactions, which are poorly studied in literature.

A number of other groups have also expanded the understanding of swarm aggregation by incorporating different dynamic communication topologies. Chen et al. [10] considered cases in which the motion decision of each agent is based only on the information about its own neighbors or the leader. They used algebraic graph theory fundamentals to perform the stability analysis of such swarms and to define a bound in the final swarm aggregate.

Gazi [11] and Yao et al. [12] incorporated sliding mode control and artificial potential functions to ensure swarm aggregation even under uncertainties. In Ref. [12], the swarm in a formation is guided to track a target. In these investigations, the principal aim is the definition of a decentralized formation control to increase robustness in the task taking into account the limited range and angle vision permitted by the sensors.

Kumar and co-workers investigated the dynamic coordination of multiple robots to perform cooperative tasks [13,14]. They used a hybrid systems framework to model the cooperative tasks and dynamic role assignment among multiple robots. The approach coordinates the cooperative execution of the task by considering the individual characteristics of each of the robots in the team. The strategy is also tested using an experimental platform. They proposed an abstraction of the configuration space to define the controllers in a lower dimensional space. This results in improved computational efficiency to command large number of robots (i.e., agents). This same research group used artificial potentials to maintain connectivity and to avoid collisions [15].

We address an understudied the aspect of swarm coordination by including two groups of antagonistic swarm members. In particular, we consider the pursuit of a swarm of "evaders" by a swarm of "pursuers," an operation that includes heterogeneous agents and hostile interactions. Due to the asymmetric governing dynamics, as well as the pursuer/evader assignment policies, the control and stability analysis becomes quite complex. For simplicity, within this study, we consider only the cases with equal numbers of pursuers and evaders along with a simple assignment policy.

We begin by deploying the models of the interactions between a single pursuer and a single evader adopting the momenta similar to those described in Ref. [1] for homogeneous swarms. The major novelty, however, is the introduction of heterogeneity (i.e., two hostile swarms), which is described in Sec. 2. This section treats the antagonistic scenario in two separate phases: approach and

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