Chapter 98
Adaptive Swarm Coordination and Formation Control

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ABSTRACT

Swarm coordination and formation control designs focus on multi-agent dynamic system behavior and aim to achieve desired coordinated behavior or predefined geometric shape. They utilize techniques from the control theory and graph theory literature. On the other hand, adaptive control theory is concerned with uncertainties in the system dynamics, and has structured frameworks for various types of plant models. Therefore, in case there are uncertainties in the swarm dynamics, adaptive control methodologies can be utilized to achieve the desired coordinated behavior and there exist remarkable works in this direction. However, connection among swarm coordination, formation control, and adaptive control theory brings some restrictions as well as advantages. Hence adaptive swarm coordination and formation control has been developed in limited aspects. In this chapter, we review some existing works of the adaptive formation control literature along with non-adaptive ones, and discuss the advantages of application of adaptive control frameworks to swarm coordination and formation control.

1. INTRODUCTION

Many creatures in nature behave collectively and exhibit swarm behavior. Inspired by this observation, researchers have tried to set up swarm architectures to be used in the motion control and coordination of multiple mobile robot systems (Bonabeau et al., 1999). Artificial systems composed of multiple interacting agents such as robots, unmanned ground, sea or air vehicles are commonly referred to as

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multi-agent systems (*MAS*), *multi-agent dynamical systems*, or *multi-vehicle systems.* The formation control problem is a swarm coordination problem in which a group of robots are required to acquire and maintain a prescribed geometric shape during their motion from their initial locations to a desired final destination (Bullo et al., 1999), (Ren & Cao, 2010), (Shamma, 2008). Designing agent controllers which achieve such behavior is an important problem considered in the literature widely (Anderson et al., 2008), (Gazi & Passino, 2003), (Das et al., 2002), (Olfati-Saber, 2006), (Olfati-Saber & Murray, 2004), (Tanner et al., 2004), (Ren & Beard, 2008), (Bai et al., 2011), (Desai et al., 1998, 2001), (Fidan et al., 2013), (Dorigo, & Sahin, 2004), (Gazi & Passino, 2011), (Gazi & Fidan, 2007). There are various surveys and monographs on this topic including (Ren & Cao, 2010), (Sahin & Spears, 2005), (Jadbabaie et al., 2003), (Lin et al., 2005). In order to be able to control a dynamic MAS, e.g., to accomplish certain formation control tasks, one needs to consider the dynamics of each individual agent and design an individual controller for that agent, aiming to have the resultant distributed control scheme meet the MAS control goal. There are various agent dynamic models considered in the literature including single integrator, double integrator, non-holonomic, or Lagrange agent models. If the MAS is a homogeneous system, the dynamics of all the agents might be governed by the same model. In contrast, in a heterogeneous MAS, agents with different underlying dynamics can be part of the same system. From control point of view, an MAS can be viewed as a *set* of plant dynamics of the individual agents which are loosely coupled by the mission constraints of the problem under consideration. For example, in the formation control problem, the agent motions are constrained by the distance requirements in the desired geometric shape. Most of the approaches assume known system parameters and no uncertainty in the agent dynamics. Under this assumption various decentralized and distributed control schemes have been developed in the literature.

In real-life applications, the agents are autonomous mobile robots or vehicles with actual dynamics which are indeed more complicated than the single or double integrator models. It is also a common situation in real-life scenarios that exact values of the system parameters like mass and inertia of the vehicle are not known *a priori*, but their approximate values are known. In case the agent dynamics contains uncertainties, there is a need to suppress their effects using robust or adaptive strategies. There have been some attempts in this direction as well, combining the methods and tools of the adaptive and robust control literature with the MAS control algorithms.

Adaptation appears in many different forms in the coordination and control of MASs. One of the instances in which one can utilize adaptive control approaches is the case in which the agent dynamics contains unknown parameters. Since centralized control of MASs is often infeasible or impractical, the formation control approaches have tended to be distributed or decentralized, and adaptive and robust control frameworks are typically practiced to suppress the uncertainties at the agent level (Güler et al., 2013a), (Güler et al., 2013b), (Gazi et al., 2012), (Duran & Gazi, 2010). Techniques from the adaptive control literature can be used also for estimating a certain common target parameter (e.g. desired common velocity synchronization, or desired trajectory for cohesive motion) of the formation at each agent using the sensing capabilities of the agent (Bai et al., 2008, 2009). This approach can be used in hierarchical or leader-follower formation control schemes in the case where only some assigned agents know the common target parameters, while the follower agents need to estimate these target parameters.

In this chapter, we discuss the application of various adaptive control techniques in formation control problems subject to uncertainties in the agent dynamics and/or lack of the common target parameter information in some agents. We first provide a review of key works on formation control in the literature. Then, we review some of the previous works that have connected the adaptive control concepts to the formation control literature, after introducing the key adaptive control tools used in these works. Real-

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