Chapter 70
Distributed Control of Robot Swarms: A Lyapunov-Like Barrier Functions Approach

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ABSTRACT

This chapter considers the problem of multi-agent coordination and control under multiple objectives, and presents a set-theoretic formulation which is amenable to Lyapunov-based analysis and control design. A novel class of Lyapunov-like barrier functions is introduced and used to encode multiple control objectives, such as collision avoidance, proximity maintenance and convergence to desired destinations. The construction is based on recentered barrier functions and on maximum approximation functions. Thus, a single Lyapunov-like function is used to encode the constrained set of each agent, yielding simple, gradient-based control solutions. The derived control strategies are distributed, i.e., based on information locally available to each agent, which is dictated by sensing and communication limitations. The proposed coordination protocol dictates semi-cooperative conflict resolution among agents, as well as conflict resolution with respect to an agent (the leader) which is not actively participating in collision avoidance, except when necessary. The considered scenario is pertinent to surveillance tasks and involves nonholonomic vehicles. The efficacy of the approach is demonstrated through simulation results.

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INTRODUCTION

Multi-agent systems have seen increased interest during the past decade, in part due to their relevance to many research domains and real world applications, from large-scale systems, such as power and transportation networks, to complex dynamical systems and multi-vehicle networks. Depending on the global and local/individual objectives, various distributed coordination and control problems have been introduced, namely consensus (also seen as agreement/synchronization/rendezvous), formation, distributed optimization and distributed estimation; for a recent survey on the related topics the reader is referred to Ren, W., & Cao, Y. (2011).

The main concerns when coordinating the motions of multi-vehicle or multi-robot (the terms are used interchangeably) teams include inter-agent collision avoidance, convergence to spatial destinations/regions or tracking of reference trajectories, maintenance of information exchange among agents and avoidance of physical obstacles. Such objectives are encountered in flocking (Jadbabaie, A., & Lin, J., & Morse, A. S. (2003), Tanner, H. G. (2004), Olfati-Saber, R. (2006), Tanner, H. G., Jadbabaie, A., & Pappas, G. J. (2007), Sharma, B., Vanualailai, J., & Chand, U. (2009), Su, H., Wang, X., & Lin, Z. (2009)), and in consensus, rendezvous and/or formation control (Ji, M., & Egerstedt, M. (2007), Olfati-Saber, R., Fax, J. A., & Murray, R. M. (2007), Dimarogonas, D. V., & Kyriakopoulos, K. J. (2008a), Dimarogonas, D. V., & Kyriakopoulos, K. J. (2008b), Mastellone, S., Stipanović, D. M., Graunke, C. R., Intlekofer, K. A, & Spong, M. W. (2008), Zavlanos, M. M., Egerstedt, M. B., & Pappas, G. J. (2011)). Collision avoidance is an unnegotiable requirement in such problems, and is often addressed with potential function methods and Lyapunov-based analysis. For a recent survey on potential function methods in formation control and similar problems see Hernandez-Martinez, E. G., & Aranda-Bricaire, E. (2011). It is worth mentioning that these contributions do not consider all the aforementioned control objectives. In fact, the algorithmic planning and control design in such cases is, to the best of our knowledge, a very challenging, often intractable problem, and still remains an open issue in many respects.

When it comes to multi-vehicle systems in particular, a common ground may be that multiple agents need to work together in a collaborative fashion in order to achieve one or multiple common goals. Lately there has been significant interest in the deployment of robotic networks (or teams) for exploration, surveillance and patrolling of inaccessible, dangerous or even hostile (indoor and outdoor) environments, such as oil drilling platforms and nuclear reactors, see for instance (Cortes, J., Martínez, S., Karatas, T. & Bullo, F. (2004), Hussein, I. I., & Stipanović, D. M. (2007), Berman, S., Halász, A., Hsieh, M. A., & Kumar, V. (2009), Schwager, M., Slotine, J. J., & Rus, D. (2011), Renzaglia, A., Doitsidis, L., Martinelli, A., & Kosmatopoulos, E. B. (2012), Pasqualetti, F., Franchi, A., & Bullo, F. (2012), Panagou, D., & Kumar, V. (2014)). Based on the assumptions on the agents' sensing and communication modeling, as well as on the control objectives, various formulations and solutions have appeared ranging from combinatorial motion planning to optimization-based and Lyapunov-based methods. Coordination and control in such cases is naturally dictated by the available patterns on sensing and information sharing, as well as by physical/ environmental constraints and inherent limitations (e.g., motion constraints, obstacles, unmodeled disturbances, input saturations etc). Therefore, the problem of motion planning, coordination and control has been and still remains an active topic of research within both the robotics and control communities. While it is out of the scope of this chapter to provide an overview of the existing methodologies on these topics, the interested reader is referred to Ren, W., & Cao, Y. (2011), Parker, L. E. (2009), and the references therein.