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Brief paper

Bounded and inverse optimal formation stabilization of second-order agents☆

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ABSTRACT

This paper formulates and solves a new problem of both bounded and inverse optimal formation stabilization control for a group of second-order dynamic mobile agents with collision avoidance and limited sensing range. The control design is based on new Lyapunov functions, new non-zero convergence and dominating lemmas, new pairwise collision avoidance functions, and forwarding and inverse optimal control design methods. The proposed formation stabilization control design guarantees no collision between any agents, "almost global" asymptotic stability of desired equilibrium points and instability of undesired equilibrium points, an infinite gain margin, bounded controls by a pre-specified constant, and minimization of a cost function that penalizes both stabilization errors and the control inputs without having to solve a Hamilton–Jacobi–Bellman or Hamilton–Jacobi–Isaacs equation.

1. Introduction

Formation control of multiple agents usually involves controlling their states to stabilize them at desired stationary or moving reference values for various applications such as area coverage, cooperative transportation, coastal zone management, and military operations. These reference values can be either pre-specified or computed using measurements from sensors installed on agents. Formation control of multiple agents has received excessive attention from researchers, see Cao, Ren, and Chen (2013), Kamel, Yu, and Zhang (2020), Liu and Bucknall (2018) and Oh, Park, and Ahn (2015) for recent reviews. From a reference value point of view, formation control of mobile agents can be divided into two main classes: (1) pre-specified reference values and (2) computed reference values (e.g., Cortes, Martinez, & Bullo, 2005; Cortes, Martinez, Karatas, & Bullo, 2004; Do, 2007, 2011a, 2011b, 2012a, 2012b, 2014; Ge, Fua, Do, & Lim, 2007; Jonathan, Beard, & Young, 2003; Ogren, Fiorelli, & Leonard, 2002; Roldao, Cunha, Cabecinhas, Silvestre, & Oliveira, 2014; Wang, Huang, Wen, & Fan, 2014). There are three main approaches to the class of pre-specified reference values. The leader–follower approach (e.g., Roldao et al., 2014) uses one or several agents as leaders and others as followers. The behavioral approach (e.g., Jonathan et al., 2003; Khaledyan & de Queiroz, 2019), where each agent locally reacts to actions of its neighbors, is suitable for decentralized control but has difficulties in control design. The virtual structure approach (e.g., Do, 2007, 2012a, 2012b, 2014; Ge et al., 2007; Ogren et al., 2002; Peng, Sun, Guo, & Geng, 2020) treats all agents as a single entity. This approach is amenable to mathematical analysis but has difficulties in controlling critical points. For the class of computed reference values, optimizing cost functions is needed to obtain reference values for the agents to track/stabilize. Gradient climbing was addressed in Do (2011b) and Ogren et al. (2002). Geometric formation based on Voronoi partition was considered in Cortes et al. (2004). Other works belong to this class included Suzuki and Yamashita (1999) on geometric formation, Do (2011a) on flocking, Cortes et al. (2005) on deployment. The main problems with this class include no-foretold final arrangement and local stability. Formation control of second-order (or higher-order) agents was also addressed (e.g., Do, 2014, 2020; Khaledyan & de Queiroz, 2019; Li, Chen, & Liu, 2013; Lu, Austin, & Chen, 2012; Wang, Shen, Song, & Zhang, 2020). The formation control design (with collision avoidance) for second-order agents is usually carried out by a combination of the control design for the first-order agents using the aforementioned approaches and the backstepping method (Krstic, Kanellakopoulos, & Kokotovic, 1995).

Optimal control is much more desirable than control methods that only achieve desired stability of stabilization/tracking errors because it avoids the control effort unnecessarily wasted and yields a large control margin, which is an important robustness property (Sepulchre, Jankovic, & Kokotovic, 1997a). However, (direct) optimal control of nonlinear systems was abandoned due

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