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Noise tolerance leader-following of high-order nonlinear dynamical multi-agent systems with switching topology and communication delay

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Abstract

This paper investigates the leader-following tracking consensus problem for high-order nonlinear dynamical multi-agent systems with switching topology and communication delay under noisy environments. In order to reflect a more realistic situation, we introduce a general multi-agent systems model and also further investigate its robust consensus under noisy environments, the topology of the network is assumed to be in a finite set of arbitrarily stochastic switching, the communication delay is also considered in the tracking control protocols. The mean square consensus sufficient conditions of multi-agent systems are explored via the common stochastic Lyapunov functional stability theory, in other words, can be solved by linear matrix inequality schemes. The mean square consensus condition is derived to provide a rigorous condition for leader-following of high-order nonlinear dynamical multi-agent systems with considerable scale. In particular, we prove that the proposed algorithm is robust against the bounded communication delay in noisy environments. On the other hand, when it involves many multi-agent systems, a more conservative but effective consensus protocol is also raised. The consensus protocols only require low-dimensional matrices, which are independent of the network size. In addition, the consensus criteria of two cases without communication delay or noisy environment are also proposed. A simple optimization program is also developed to determine the maximum allowable communication delay. Finally, in order to demonstrate the effectiveness and feasibility of the consensus protocol obtained in this paper, the numerical examples are given.
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1. Introduction

In the last few years, the consensus problem for multi-agent systems has received much attention from various research communities [1,2], this is mainly due to their wide applications in spacecraft formation flying [3], sensor networks [4], cooperative unmanned air vehicles [5], scheduling of automated highway systems [6], cooperative surveillance [7], and air traffic control [8]. Therefore, the investigation of the consistency issue of multi-agent systems is a hot topic. Recently, research works on the consistency of multi-agent systems have made great progress, for example, the mean square consistency issues of multi-agent systems with the Markov switching topology have been investigated [9]. Consistency conditions of discrete/continuous time multi-agent systems with communication time delay and deterministic topology are given [10].

Note that most existing reports of the consensus issue focus on the case where multi-agent systems are evolved by first-order dynamical model or second-order dynamical model. First-order consensus is to gain with effort iff (if and only if) the fixed network structure has a component with a directed spanning tree [11]. Consensus of second-order linear multi-agent systems can be reached iff the linear multi-agent dynamical system has exactly two zero eigenvalues and the real parts of all other eigenvalues have negative values [12]. However, for a general directed network, even if the network contains a directed spanning tree, the second-order consistency may fail [12]. Some consensus sufficient conditions of second-order multi-agent systems with directed topologies were established in [13], which demonstrated that both the real and imaginary parts of the eigenvalues of the network topology corresponding Laplace matrix had played a decisive role in the consistency problem. Thus, consensus of high-order multi-agent systems has been an interesting topic in recent years.

High-order consensus has been achieved based on dynamic feedback controllers [14]. In addition, the swarm consensus issues for high-order systems were investigated [15], where the consensus condition was obtained by using the eigenvalues analysis and the Lyapunov method. Some necessary and sufficient conditions of observer-type protocols for high-order multi-agent systems were proposed [16]. In addition, two high-order consensus protocols of discrete/continuous-time multi-agent systems were proposed based on a reduced-order observer control scheme [17].

Note that in the above results, the consensus of multi-agent systems without a virtual leader was obtained. In practical applications, however, a virtual leader can denote the final aim of the team, which is significant to the investigation of leader-following consensus. The leader-following consensus problem of the first- and second-order multi-agent systems was addressed based on the observer control scheme [18], in which the results were extended to the case of time-varying communication delays [19], and the case of multiple time delays was investigated [20].

The existing researches on consensus focus mainly on the cases when no inherent dynamics was investigated. However, in many practical systems, inherent nonlinear dynamics often exists for the multi-agent systems. For example, in the synchronization of complex networks [21], to name a few, the dynamics of each node is normally described by the sum of a continuously differentiable function describing the inherent dynamics associated with the node and the coupling item identifying the corresponding connection between the node and the other nodes. Sufficient conditions are given to guarantee first-order consensus of multi-agent systems in the presence of inherent nonlinear dynamics under a directed fixed interaction graph [22]. Second-order consensus algorithm for multi-agent systems with inherent nonlinear dynamics when existing a virtual leader was investigated [23]. Consensus of nonlinear agents without coupling delay can be achieved under a directed network suffering recoverable attack, implying that the topology is changing, the consensus condition is governed by a set of linear matrix inequalities while the sizes of their matrices are related to the network size [24].

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