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Randomly changing leader-following consensus control for Markovian switching multi-agent systems with interval time-varying delays

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ABSTRACT

This paper considers the problem of leader-following consensus stability and also stabilization for multi-agent systems with interval time-varying delays. The randomly occurring interconnection information of the leader and the Markovian switching interconnection information of the agent are matters of concern in the systems. Through construction of a suitable Lyapunov–Krasovskii functional and utilization of the reciprocally convex approach, new delay-dependent consensus stability and stabilization conditions for the systems are established in terms of linear matrix inequalities (LMIs) which can be easily solved by using various effective optimization algorithms. Two numerical examples are given to illustrate the effectiveness of the proposed methods.

1. Introduction

For the past few years, Multi-agent systems (MASs) have gained considerable attention due to their extensive applications in many fields such as biology, physics, robotics, power grid, and so on [1–8]. The prime concern of these systems is the agreement of a group of agents on the states of their leader by interaction. In other words, this is a consensus problem. Specifically, a consensus problem with a leader is called a leader-following consensus problem or consensus regulation. In recent times, this problem applies to various fields such as vehicle systems [2,3], groups of mobile autonomous agents [4], networked control systems [5], and other applications [6–8]. Also, various problems are studied as research areas of MASs in addition to the consensus problem. These include controllability [9], stability [10,11], boundedness conditions [11], network topology and communication data rate [12], as well as other problems [13].

On a separate note, the overall concept of this work can be explained as follows:

- In a real world situation, environmental change occurs in practical systems. In the case of MASs, taking the group of environment monitoring robot fish in Fig. 1 as an example, the interconnection between the leader and one particular agent can be disconnected because of the environmental change as shown in Fig. 1(b). At this time, in order to follow the leader, this situation shall emphasize the need of switching to another agent. That is, the method of keeping the interconnection between the leader and one of two or more agents according to the environmental change as shown in Fig. 1(c) should be considered.

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Fig. 1. Environment monitoring robot fish: (a) the occurrence of environmental change; (b) disconnection between the leader and the group of agents; (c) switching interconnection between the leader and the other agent.

- As mentioned previously, it is natural to ask the following question, "if the probabilistic concept is added to the interconnection information of the leader, can we consider the effect of environmental change on the leader?". In order to obtain the answer, in the formulated system (5), by the use of a probabilistic sequence, the randomly changing leader was first introduced. Moreover, MASs are being put to use in the consensus problem for time-delay which occurs due to the finite speed of information processing in the implementation of this system.

The main points are as follows:

- It is known that time-delay often causes undesirable dynamic behaviors such as oscillation, performance degradation, and instability of the system. Thus, it is necessary to investigate the problems of various forms of systems with time-delay [14–21]. Since the consensus issue is one of the major topics studied in the applications of MASs, various approaches to the consensus criteria for MASs with time-delay have been investigated in the literature [22–25]. Also, since delay-dependent analysis makes use of information about the size of time delay, delay-dependent analysis has gained more attention compared to the delay-independent one [21]. That is, the former is generally less conservative than the latter.
- During the implementation of many practical systems such as aircraft and electric circuits, there are probabilistic perturbations occasionally. Also, the probabilistic perturbations are as significant as the time-delay as a factor affecting dynamics in the applications of science and engineering. In this sense, the consensus problem for the MASs with both time-delay and switching interconnection topology was considered in [24–27]. However, the aforementioned literature and [13] have mainly addressed the consensus conditions of the MASs with periodic or non-probabilistic switching interconnection topology. Thus, it is more realistic to assume that switching interconnection topology is a probabilistic process. Also, in any other literature, MASs with probabilistic changing leader have not been considered yet.

Therefore, analyzing the consensus problem of the MASs with time-delay and probabilistic switching interconnection topology can be regarded as investigating the stability of MASs. Furthermore, the problem of designing the consensus controller for MASs has not been fully investigated yet.

Motivated by the matters mentioned above, a new delay-dependent consensus problem for MASs with interval time-varying delays and probabilistic information of interconnection topology will be studied in this paper. These sets of information are about the randomly changing leader with Bernoulli trials and Markovian switching agents. Simply put,

- Bernoulli trials are recognized in the experiment as the combination of N identical sub-experiments. To elaborate in detail, let A be the elementary event having one of the two possible outcomes as its element. $\bar{A}$ is the only other possible elementary event. At this time, we shall repeat the basic experiments N times and then determine the probability of A being observed exactly k times out of N trials. Such repeated experiments are called Bernoulli trials [28]. In this regard, referring to [29–31], the problems for various systems with randomly occurring delay, uncertainties and nonlinearities were considered.
- Markovian switching systems are a special sort of hybrid systems, driven by the Markov process, and may undergo unexpected changes within Markovian switching parameters [32–35].

By constructing a suitable Lyapunov–Krasovskii functional and utilizing the reciprocally convex approach [36], a randomly changing leader-following consensus delay-dependent criterion for Markovian switching MASs with interval time-varying delays and a corresponding controller design method are derived in terms of LMIs. As such, this can be solved efficiently by using standard convex optimization algorithms such as interior-point methods [37]. Finally, two numerical examples are included to demonstrate effectiveness of the proposed methods.

Notation: $\mathbb{R}^n$ is the n-dimensional Euclidean space, and $\mathbb{R}^{m\times n}$ denotes the set of all $m\times n$ real matrices. $\mathbb{C}_{n,h} = \mathbb{C}([-h, 0], \mathbb{R}^n)$ denotes the Banach space of continuous functions mapping the interval $[-h, 0]$ into $\mathbb{R}^n$, with the topology of uniform convergence. For symmetric matrices X and $Y, X > Y$ means that the matrix $X - Y$ is positive definite, whereas $X \geq Y$ means that the matrix $X - Y$ is nonnegative. $X^{\perp}$ denotes a basis for the null-space of X. I_n, 0_n and $0_{m\times n}$ denote an $n \times n$ identity matrix, $n \times n$ and $m \times n$ zero matrices, respectively. $\mathbb{E}\{\cdot\}$ stands for the mathematical expectation operator. $\|\cdot\|$