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Consensus for multiple heterogeneous Euler–Lagrange systems with time-delay and jointly connected topologies

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Abstract

In this paper, we consider the consensus problem of multiple agents modeled by Euler–Lagrange (EL) equation, among which two classes of agents are addressed, i.e., some agents with exactly known parameters and the others with parametric uncertainties. We propose a distributed consensus protocol for the heterogeneous EL systems in which both time-delay and jointly connected topologies are taken into consideration. Based on graph theory, Lyapunov theory and Barbalat's lemma, the stability of the controller is proved. A distinctive feature of this work is to investigate the consensus problem of EL systems with heterogeneous dynamics, time-delay and jointly connected topologies in a unified theoretical framework. Simulation results are also provided to illustrate the effectiveness of the obtained results.

1. Introduction

Consensus problems of multi-agent systems have drawn great attention due to their broad applications such as cooperative control of unmanned aerial vehicles, wireless sensor network, and spacecraft formation [1]. Two interesting topics on consensus problem have been extensively studied. One is on how to study the effects of time delay. In practical applications, time delay in

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communication topologies is usually inevitable. Results on time delay of multi-agent systems can be found in [2–7], to name just a few. The other topic is on the effects of the switching communication topology which is very commonplace in practical applications as the interaction between individual agents may change over time [8–12]. It matters because the switching topology may deteriorate the performance of a system and even cause instability, especially when the communication topology is disconnected at some time instants. The aforementioned results mainly concentrate on dealing with one of these two topics separately. However, in practical applications, these two factors may coexist, thus it is worthwhile to study the two problems together. Although there have been some results on this issue (see [13–19] for example), most of those studies focus on the linear single-integrator or double-integrator multi-agent systems.

On the other hand, EL equation can describe lots of physical systems including mechanical and power systems, and the control of EL systems is a classical control problem which has great value in theory and practical significance [20]. The past few years have witnessed the burgeoning interest in synchronization control of multiple EL systems [21–34]. For example, global exponential synchronization and concurrent synchronization of multiple Lagrangian systems are discussed in [21]. In [22], a distributed controller is proposed to tackle the consensus of EL systems, where Matrosov theory and Lyapunov theory are used to demonstrate the stability. Dynamic tracking of networked EL systems is studied in [23,24]. The finite-time coordination control problems of EL systems are addressed in [25,26]. The effects of communication delays in networked Euler–Lagrange systems are studied in [27–30]. The coordination consensus algorithm for multiple Lagrangian systems without using neighbors' velocity information is presented in [31]. Note that these results only consider fixed communication network topologies. The study of switching topologies of multiple mechanical systems includes [32–34]. In [32] the consensus is studied under connected switching network but parametric uncertainties are not taken into consideration. In [33], the results are under the assumption that the switching topologies are balanced and a connected. In [34], time-delay and switching topology are studied separately. However, none of the aforementioned references on multiple EL systems consider the jointly connected topologies, let alone time-delay together with the jointly connected topologies. We hence extend the existing results to a broader application scenario.

In some practical applications, heterogeneous EL agents may coexist in which some agents' parameters are exactly known and others are not. For example, in the multi-robot systems, due to a common goal and dynamic environments, some robots' parameters are exactly known but the others are not, then new coordination protocols need to be developed. Therefore, it is of great interest to study this kind of system in a unified framework. Different from the existing results, in this paper, we study multiple heterogeneous EL systems with both known and unknown parameters. The contributions of this paper are threefold:

(1) Jointly connected topologies are considered for multiple EL systems. The existing results of multiple EL systems require the switching communication topologies to be connected. As commonly known, it is much harder to study consensus problems on jointly connected topologies than on connected topologies.
(2) The communication topology considered is jointly connected and coupled with time-delay. In the existing results, the consensus problems of EL systems are addressed with only switching topologies or time-delay. We consider the two factors together in this paper.
(3) Multiple heterogeneous EL systems are studied. Our consensus protocol is applicable to multiple heterogeneous EL systems composed of agents with both known and unknown parameters.