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Group Consensus in Networked Mechanical Systems with Communication Delays

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Abstract

This paper studies the adaptive group consensus problem of networked mechanical systems formulated by Lagrangian dynamics under directed acyclic network topology by the use of adaptive control scheme based on neural networks. A distributed group consensus algorithm is proposed for such networked mechanical systems with communication delays, and then a simple yet generic criterion on the convergence for such algorithm over directed acyclic topology is established. Furthermore, the effect of time delays on the performance of adaptive group consensus are numerically investigated. It is shown that the networked mechanical systems with communication delays can always reach the group consensus if each subgroup has a directed spanning tree. Subsequently, numerical examples illustrate and visualize the effectiveness and feasibility of the theoretical results.

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Keywords: Acyclic graph, neural network, group consensus, lagrangian dynamics, communication delays;

1. Introduction

The distributed coordinated control in networked mechanical systems modeled by Lagrangian dynamics (or networked Lagrangian systems) has recently received significant attention in many engineering fields, including multiple robotic manipulators, formation flying spacecrafts, and autonomous vehicles[1,2,3,4,5,6]. As one type of the extended consensus problems in coordinated control of networked multi-agent systems, group consensus is more suitable to deal with cooperative control of networked mechanical systems in complex and integrated production process, and so it has a wide range of industry applications[7,8,9,10]. For example, in a large-scale production processes, including manufacturing and automotive engineering, a large swarm of robots is required to accomplish a cooperative task of multiple sophisticated subtasks, where the designed group consensus scheme is effectively performed to divide a large swarm of robots into multiple groups such that all agents in different groups can achieve the corresponding sophis-

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ticated subtasks. As a consequence, this has led to a large number of research works on this topic for networked Lagrangian systems from various perspectives[11,12,13,14,15].

Time delays likewise exist in a wide variety of networked multi-agent systems due to a large amount of factors including actuation, control, communication and computation. As a representative type of time delays, communication delays often arise as a consequence of data transmission among agents, and/or packet drop due to the restriction of network communication channels. It is well known that communication delays are usually viewed as one of the key factors, which may affect the performance of multi-agent systems adversely, or even cause the systems instable[3,5,6,16,17]. As a result, many researchers have studied the effects of communication delays on consensus problem for networked Lagrangian systems[5,6]. For instance, Nuño et. al[5] presented an adaptive controller for networked fully-actuated Lagrangian systems subjected to constant communication delays. Wang[6] developed a unified framework for the consensus problem of networked mechanical systems described by Lagrangian dynamics with communication delays. On the other hand, it is widely accepted that neural network (NN) control has been extensively used to deal with nonlinear dynamical systems with uncertain dynamics for its multi-function distinguishing features, including strong learning and concurrent computation ability in NN technology[10,11,12,13,14,15,18]. However, to the authors best knowledge, there has been very little work on group consensus problem for networked Lagrangian systems with communication delays based on neural network strategy.

Motivated by the above comments, in this paper we investigate the group consensus problem of networked Lagrangian systems with uncertain parameters in the presence of communication delays under directed acyclic network topology. A feedforward neural network (FFNN) will be employed to design a distributed group consensus protocol for uncertain networked Lagrangian systems, and a necessary and sufficient condition for solving group consensus problem is then presented. It is demonstrated that the developed group consensus condition is only dependent on the directed network topology with acyclic partition, and so it is easy to verify in practical applications. In addition, the effect of communication delays on group consensus are discussed numerically, and it shown that that communication delays may have the negative effects on group consensus performance for networked Lagrangian systems.

The rest of the paper is organized as follows: Section 2 describes some preliminaries and problem formulation. Section 3 presents the main results of adaptive group consensus of uncertain networked Lagrangian systems with communication delays, and Section 4 provides the corresponding simulation results. Finally, Section 5 gives the conclusions.

2. Preliminaries and problem formulation

2.1. Graph theory

Let the graph $\mathcal{G} = (\mathcal{V}, \mathcal{E}, \mathcal{A})$ be a weighted directed graph of order N with the network topology. The node set $\mathcal{V} = \{1, 2, \cdots, N\}$, the edge set $\mathcal{E} \in \mathcal{V} \times \mathcal{V}$ and a weighted adjacency matrix $\mathcal{A} = [a_{ij}] \in \mathbb{R}^{d\times d}$. The matrix $\mathcal{A}$ is defined as $a_{ij} \neq 0$ if $(j, i) \in \mathcal{E}$, otherwise $a_{ij} = 0$. In addition, it is assumed that $a_{ii} = 0$ for $i \in \mathcal{V}$. A directed path in directed graph $\mathcal{G}$ is a sequence of edges taking the form of (i_1, i_2), (i_2, i_3), $\cdots$, (i_{k-1}, i_k), such that $(i_j, i_{j+1}) \in \mathcal{E}$. A directed graph has a directed spanning tree if there exists at least one agent which has a directed path to any other agent. The Laplician matrix $\mathcal{L} = [l_{ij}] \in \mathbb{R}^{d\times d}$ is defined as $l_{ii} = \sum_{j=1}^{d} a_{ij}$ and $l_{ij} = -a_{ij}$, $i \neq j$. The node set $\mathcal{V} = \{1, \cdots, N\}$ has a partition which takes the form as $\{\mathcal{V}_1, \cdots, \mathcal{V}_k\}$, i.e. $\mathcal{V}_i \neq \emptyset$, $\cup_{l=1}^{k} \mathcal{V}_l = \mathcal{V}$, $\mathcal{V}_i \cap \mathcal{V}_j = \emptyset$, $i \neq j$. For $i \in \mathcal{V}_s$ and $j \in \mathcal{V}_t$, if $s = t$, we state that agents i and j belong to the same group. In addition, $\mathcal{G}_i$ is used to denote the underlying topology of node subset $\mathcal{V}_i$, $i = 1, 2, \cdots, k$. Without loss of generality, the node set of each group is indexed as $\mathcal{V}_l = \{\sum_{j=0}^{l-1} n_j + 1, \cdots, \sum_{j=0}^{l} n_j\}$, $1 \leq l \leq k$, respectively, where $n_0 = 0$ and $\sum_{l=1}^{k} n_l = N$.

2.2. Networked Lagrangian systems

In general, the ith system of networked mechanical systems composed of N Lagrangian systems (i.e., agents) can be described as[6,7,12]

$$M_i(q_i)\ddot{q}_i + C_i(q_i, \dot{q}_i)\dot{q}_i + g_i(q_i) = \tau_i, \qquad i = 1, 2, \cdots, N, \tag{1}$$

where $q_i \in \mathbb{R}^m$ represents the generalized coordinate vector, $M_i(q_i) \in \mathbb{R}^{m\times m}$ represents the symmetric positive definite inertia matrix, $C_i(q_i, \dot{q}_i) \in \mathbb{R}^{m\times m}$ represents the Coriolis and centrifugal matrix, $g_i(q_i) \in \mathbb{R}^m$ represents the gravitational