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Distributed adaptive controller for the output-synchronization of networked systems in semi-strict feedback form ☆

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Abstract

In this paper, we investigate the output synchronization of networked SISO nonlinear systems that can be transformed into semi-strict feedback form. Due to parameter uncertainty, the agents have heterogeneous dynamics. Combined backstepping method together with graph theory, we construct an augmented Laplacian potential function for analysis and a distributed controller is designed recursively for each agent such that its output can be synchronized to its neighbors' outputs. The distributed controller of each agent has three parts: state feedback of itself, neighborhood information transmitted through the network and adaptive parameter updaters both for itself and its neighbors. Moreover, distributed tuning function is designed to minimize the order of the parameter updater. It is proved that when the undirected graph is connected, all agents' outputs in the network can be synchronized, i.e., cooperative output synchronization of the network is realized. Simulation results are presented to verify the effectiveness of the proposed controllers.

1. Introduction

Since the start of 21st century, cooperative control of multi-agent system has attracted great attention in control community, such as documented in the reference papers [1,2] and books [3,4].

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Due to the simplicity, earlier results in this area mainly focus on agents with linear dynamics, such as first-order integrator systems [5,6], double-integrator systems [7,8], high-order integrator systems [9], or general linear time invariant (LTI) systems [10]. On the other hand, various controllers have been proposed for the stabilization or asymptomatic tracking problem of single nonlinear system in the past few decades [11,12]. Based on these, cooperative control of networked nonlinear systems comes into researchers' eyes recently, to just name a few, formation control of networked canonical chained systems [13], synchronization of networked first-order nonlinear systems [14], consensus control of networked Euler–Lagrange system [15] and leader-following control of lower-triangular systems [16].

In practice, system may be subjected to uncertainty or disturbance, so the agents in the network may have unknown and heterogeneous dynamics. In that case, synchronizing the full state is sometimes unnecessary and impossible (e.g., the dynamic of agent i is $\dot{x}_{i1} = x_{i2} + \theta_i^T \varphi(x_{i1}); \dot{x}_{i2} = u_i$, it is impossible to synchronize x_{i2} when x_{i1} is synchronized because of different θ_i). Output synchronization of networked linear systems has attracted researcher's attention recently, e.g., output synchronization controllers based on internal model principal for linear agents with identical dynamics in [17], state-feedback controllers for linear but heterogeneous and non-introspective agents in [18] and output consensus controllers for heterogeneous uncertain agents whose dynamics are still linear [19]. In this paper, we investigate the output synchronization problem of networked semi-strict feedback nonlinear systems with parameter uncertainty. Distributed controller is designed recursively for each agent to achieve the control objective. It is proved that under the topological property that the undirected graph is connected, cooperative output synchronization can be realized, i.e., all x_{i1} can be set to the same while other states maintain bounded. Simulation results are provided to verify the effectiveness of the proposed controllers.

The main contributions of our work are:

- The agents investigated in this paper are semi-strict feedback nonlinear systems with unknown parameters. Unlike the "virtual agent tracking" method in existing works with the same problem formulation [16,20], there is no "virtual agent" in our work. We technically construct an augmented Laplacian potential function for analysis. It is proved that control objective can be achieved when the undirected graph is connected. Controller of each agent has three parts: state-feedback of itself, neighborhood information and parameter updaters both for itself and its neighbors. To the best of our knowledge, no other works have solved the problem under these circumstances yet.
- Adaptive parameter updaters are designed for agents to eliminate the effect of unknown parameters in their dynamics. In contrast to traditional updaters in backstepping control, the updaters in our work are distributed.
- Distributed tuning functions are designed to minimize the order of the parameter updaters.

The rest of the paper is organized as follows. Section 2 reviews some basic notions and preliminaries of graph theory which will be used in sequel. Then, in Section 3, we formulate the problem and propose the control object of the paper. In what follows, the main result of this paper is presented in Section 4. Section 5 provides two numerical examples to illustrate the effectiveness of the proposed controllers and Section 6 closes this paper.