Applied Mathematics and Computation 337 (2018) 535–544

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Distributed-observer-based output synchronization for heterogeneous double-integral networks

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ARTICLE INFO

Keywords:
Cooperative control
Output synchronization
Adaptive distributed compensator
Second-order Luenberger observer

ABSTRACT

This paper considers the output synchronization for nonidentical second-order integral dynamics with external disturbance. The leader's signal can only be received by parts of the followers, and all the followers have different dynamics. An adaptive distributed compensator is utilized to estimate the leader's signal and system matrix. Since the states' information of the agents can not be measured by the others, a novel distributed reduced-dimension observer is designed to estimate the unmeasurable states. Based on the adaptive distributed compensator and reduced-dimension observer, a dynamic output feedback control law is designed to solve the output synchronization problem. Finally, an example is given to illustrate the validity of the theoretical results.

1. Introduction

In recent years, the coordination control problems have been a hot topic of research in systems and control. The emphasis of the coordination control is on the communication constraints rather than on the individual dynamics, i.e., the agents exchange information with the others according to a communication graph which is not necessarily complete, nor even symmetric or time-invariant. In the area of the cooperative control problems, consensus is an important and fundamental problem [1–5]. The aim of consensus problem is that the trajectories of the agents asymptotic reach to a common value [6–9].

The synchronization of the multi-agent systems is an important and interesting phenomena mostly because the synchronization can well explain many natural phenomena. Therefore, the synchronization of dynamical networks has been actively studied due to its wide applications in physics, biological, and various engineering disciplines [10–15]. Many control schemes such as adaptive control [16–21], pinning control [22–24], input saturation control [25–28], fuzzy control [29–32], and optimal control [33] have been applied to achieve synchronization of complex dynamical networks. Discrete-time multi-agent systems has been considered in [34] and the agents have the same dynamics. Ref. [35] extended the results of [34] to the unmeasurable case and event-triggered output feedback control was considered in [36]. The above references mainly consider the first order case without the disturbance.

Output synchronization is investigated as the process of moving the subsystem outputs onto a common trajectory [37–40]. A finite-time convergent observer is constructed in [37] to estimate the unknown velocity information in a finite time, then an observer-based finite-time output feedback controller is developed in handling finite-time synchronization problem

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https://doi.org/10.1016/j.amc.2018.05.060
0096-3003/

for a class of second-order nonlinear multi-agent systems. The consensus problem of second-order multi-agent systems with exogenous disturbances is investigated in [40] based on a pinning disturbance observer. Double-integrator multi-agent systems with multiple leaders were considered in [41], in which the weighted average of the leaders velocities were estimated by a distributed finite-time observer, and a novel distributed finite-time containment control algorithms was addressed.

The existing results about second-order multi-agent systems usually consider the single dimension variable. Moreover, the results for high-dimension second-order integral dynamics also have been considered by many researchers. The nonlinear dynamics are represented in [42] as

$$\begin{cases} \dot{x}_i(t) = v_i(t), \\ \dot{v}_i(t) = f(t, x_i(t), v_i(t)) + u_i(t), \end{cases}$$

in which $x_i(t), v_i(t), u_i(t) \in R^m$. This is a more general second-order dynamic system, which covers the cases in [43]. A piecewise continuous law and event-triggered control function were designed in [44] to achieve consensus for second-order multi-agent systems.

Different with [42], in this paper, we study output synchronization for second-order multi-agent systems. Since not all the followers could access the signal of the leader, an adaptive distributed compensator is utilized, to each follower, not only the estimation of the leader's system matrix, but also the estimation of reference output. Therefore, each follower can receive the leader's information or the compensator's information directly. In addition, the state information of the agent can not be measured by itself and others directly. A novel distributed reduced-dimension observer is designed to estimate the unmeasurable states. Based on the adaptive distributed compensator and reduced-dimension observer, a dynamic output feedback control law is designed to solve the output synchronization problem for second-order multi-agent systems. Finally, some simulation results are given to illustrate the effectiveness of the proposed results.

This paper is organised as follows: In Section 2, some basic knowledge about graph theory and problem formulation are given. Section 3 contains the observer design and the output synchronization problem with output information. Simulation results are presented in Section 4. The conclusion is given in Section 5.

2. Preliminaries

2.1. Algebraic graph theory

The communication topology between agents and the exosystem is represented by a weighted graph $\mathcal{G} = (\mathcal{N}, \mathcal{E}, \mathcal{A})$, where $\mathcal{N} = \{v_0, v_1, v_2, \ldots, v_N\}$ is the set of nodes, and v_0 represents the dynamic of the exosystem. $\mathcal{A} = [a_{ij}]$ is a weighted adjacency matrix, where $a_{ii} = 0$ and $a_{ij} \geq 0$ for all $i \neq j$. $a_{ij} > 0$ if and only if there is an edge from vertex j to vertex i. The set of neighbors of node v_i is denoted by $\mathcal{N}_i = \{v_j \in \mathcal{V} : (v_i, v_j) \in \mathcal{E}\}$. $\mathcal{N}_s = \{v_1, v_2, \ldots, v_N\}$ represents the node set of the subgraph $\mathcal{G}_s = (\mathcal{N}_s, \mathcal{E}_s, \mathcal{A}_s)$. A diagonal matrix $\mathcal{D}_s = \mathrm{diag}\{d_1, d_2, \ldots, d_N\}$, where $d_i = \Sigma_{j=1}^{n} a_{ij}, i = 1, 2, \ldots, N$ is called a degree matrix of $\mathcal{G}_s$. The Laplacian with the directed graph $\mathcal{G}_s$ is defined as $\mathcal{L}_s = \mathcal{D}_s - \mathcal{A}_s$. Moreover, the Laplacian matrix with the directed graph $\mathcal{G}$ is defined as

$$\mathcal{L} = \mathcal{D} - \mathcal{A} = \begin{pmatrix} 0 & \mathbf{0} \\ -\mathcal{A}_0 \mathbf{1}_N & \mathcal{H} \end{pmatrix}, \tag{1}$$

where $\mathcal{D} = diag\{\Sigma_{j=0}^{n} a_{0j}, \mathcal{D}_s\}$ $\mathcal{H} = \mathcal{A}_0 + \mathcal{L}_s$, $\mathcal{A}_0 = diag\{a_{10}, a_{20}, \ldots, a_{N0}\}$ and $\mathcal{L}_s$ is the Laplacian matrix of subgraph $\mathcal{G}_s$.

An edge of $\mathcal{G}$ denoted by $e_{ij} = (v_i, v_j) \in \mathcal{E}$ means that node v_i receives information from node v_j. There is a sequence of edges with the form $(v_i, v_{k_1}), (v_{k_1}, v_{k_2}), \ldots, (v_{k_j}, v_j) \in \mathcal{E}$ composing a direct path beginning with v_i ending with v_j, then node v_j is reachable from node v_i. A node is reachable from all the other nodes of graph, the node is called globally reachable. For more information see [45].

2.2. Problem Formulation

Complex systems have been extensively development in recent years. In such systems, agents communicate with others to perform tasks beyond the ability of individuals. In this paper, we will further study the distributed control problems, and the double-integral dynamics are extended as follows:

$$\begin{cases} \dot{x}_{1i} = x_{2i}, \\ \dot{x}_{2i} = A_i x_{2i} + u_i + \delta_i, i = 1, 2, \ldots N, \\ y_i = C_i x_{1i}, \end{cases} \tag{2}$$

where $x_{1i} \in R^n$, $x_{2i} \in R^n$ are the first- and second-order states, $y_i \in R^n, i = 1, 2, \ldots N$ are the outputs of each agent. $\delta_i = E_i x_0$ is the disturbance which is generated by the following exosystem:

$$\begin{cases} \dot{x}_0 = A_0 x_0, \\ y_{ri} = Q_{i0} x_0, \end{cases} \tag{3}$$