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On pinning group consensus for heterogeneous multi-agent system with input saturation

Guoguang Wen [a], Jun Huang [a,*], Zhaoxia Peng [b], Yujie Yu [a]

[a] Department of Mathematics, Beijing Jiaotong University, Beijing 100044, PR China
[b] School of Transportation Science and Engineering, Beihang University, Beijing 100191, PR China

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ABSTRACT

This paper investigates group consensus of a class of heterogeneous multi-agent systems with input saturation via pinning scheme, in where the heterogeneous multi-agent system is composed of first-order agents and second-order agents. Firstly, based on the fact that the control input of partial first-order integrator agents could be bounded due to the limitation of actuators, a class of control protocols including partial first-order integrator agents with input saturation is proposed to solve the group consensus problem of heterogeneous multi-agent systems. Secondly, to guarantee the states of agents in the same group can converge to one specified consensus state, the group consensus problem of heterogeneous multi-agent systems with some pinned agents who can be first-order or second-order agents is discussed. Then a class of new control protocols with pinning scheme is proposed. By using LaSalle Invariance Principle, matrix theory, algebraic graph theory and Lyapunov stability theory, the rigorous proofs are given and the corresponding sufficient group conditions are also obtained. Finally, simulation results are also provided to illustrate the effectiveness of the obtained results.

1. Introduction

Distributed coordinated control of multi-agent systems has attracted more and more attention of researchers in the past years because of its important applications in the multi-robot formation, satellite formation, wireless sensor networks, and so on [1–5]. Consensus problem is one of the very important issues of distributed coordinated control of multi-agent systems. The aim of consensus control is to design suitable control protocols such that all agents converge to a consistent state. The consensus control problems of multi-agent systems have been extensively investigated recently, as seen in Refs. [6–11], and the references therein.

Among the various consensus problems, there is a particular consensus phenomenon called group consensus. The group consensus means that all agents in the same group can reach a consistent state, but the agents in different groups may reach different consistent states. It is obviously that consensus can be viewed as a special case of group consensus. Especially, for the complicated multi-agents systems, for example the agent systems have some unanticipated situations or any changes in practice, the group consensus is more appropriate approach for studying the coordinated control. Based on the above facts, the group consensus control problems have been extensively investigated recently, and a number of results have been obtained [12,13].

Note that most of the existing literatures study the control of homogeneous multi-agent dynamical systems, in which it is assumed that all agents in the group have the same dynamics. Actually, the dynamics of agents may be different when different kinds of agents share common goals in some practical applications [14]. For instance, because of restrictions and external uncertainty, multi-robot systems with different abilities and shapes is more applicable modeled by heterogeneous dynamics than the homogeneous systems in practice [14]. Therefore, it is of great interest and importance to study the consensus problem about the heterogeneous multi-agent systems. Recently, many researchers throw themselves into the study of heterogeneous multi-agent systems. In [15], the group consensus problems of heterogeneous multi-agent systems with fixed and switching topologies were investigated. The distributed group consensus protocols were designed via its neighbors' information. However, this paper require the strong consensus parameters conditions according to the proposed control protocols. In [16], the consensus problem of heterogeneous multi-agent systems were studied without considering velocity measurement information. Furthermore, in [17], the consensus problem of heterogeneous multi-agent systems consisted of first-order integrator agents, second-order integrator agents and Euler–Lagrange agents was presented and solved.

* Corresponding author.
E-mail address: guoguang.wen@bjtu.edu.cn (J. Huang).

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As we know, the actuator has bounds due to its input in almost physical applications. Thus, it is necessary to study the actuator saturation. This is a changeling problem for achieving consensus of the multi-agent systems with input saturation constraints. In [18], a linear consensus protocol and a saturated consensus protocol were presented for the heterogeneous multi-agent systems which consisted of first-order integrator agents and second-order integrator agents. In [19], the consensus problem of heterogeneous multi-agent systems with saturated consensus protocol were considered. Based on Lyapunov theory, the consensus problems of heterogeneous multi-agent systems are considered with and without velocity measurements, respectively, and saturated consensus protocol is also taken into consideration.

In general, the whole system cannot reach consensus by itself. Therefore, some appropriate control algorithms need to be designed, and applied to drive the whole system to achieve consensus. Of course, it is very costly and literally impractical to add controllers to all nodes. In order to reduce number of controlled nodes, some local feedback controllers may be adopted to a small fraction of the system nodes which is known as pinning control [20–23]. Recently, some results on pinning control have been obtained. For example, Wang et al. [24] addressed a cluster synchronization of nonlinearly coupled complex networks by using the pinning scheme. Hu and Jiang [25] proposed a pinning strategy by means of viewing each community as a whole and according to the information of each community. The community whose in-degrees were bigger than the out-degrees should be preferentially considered to be controlled. Recently, Su et al. [26] proposed a distributed adaptive pinning control scheme for cluster synchronization of undirected topology by using a local adaptive strategy on both feedback gains and coupling strengths, and drew a conclusion that at least one node in each cluster was selected to be pinned in order to reach cluster synchronization. Ma and Lu [27] further investigated the complex networks with directed and weakly connected topology, and some simple criteria were obtained to guarantee the cluster synchronization, and the corresponding pinning scheme was addressed.

Inspired by the relevant works, this paper investigates group consensus of a class of heterogeneous multi-agent systems with input saturation via pinning scheme, in where the heterogeneous multi-agent system is composed of first-order agents and second-order agents. The contribution of this paper can be stated as follows: firstly, based on the fact that the control input of partial first-order integrator agents could be bounded due to the limitation of actuators, a class of control protocols including partial first-order integrator agents with input saturation are proposed to solve the group consensus problem of heterogeneous multi-agent systems. By applying the algebraic graph theory and LaSalle Invariance Principle, the proposed protocol is proved to reach consensus feasible. Secondly, to guarantee the states of agents in the same group can converge to one specified consensus state, the group consensus problem of heterogeneous multi-agent systems with some pinned agents that can be first-order or second-order agents is discussed. Then a class of new control protocols with pinning scheme is proposed and some sufficient group consensus conditions are also given. Finally, simulation results are also provided to illustrate the effectiveness of the obtained results. Compared with the existing works, this paper has the following advantages: firstly, in contrast of consensus control for homogeneous multi-agent systems [1–5,9,10,12,13] in which all agents have the same dynamics, this paper investigates the group consensus control for heterogeneous multi-agent systems. Secondly, in contrast to the existing results [15–17] in which without considering the input saturation, this paper consider the multi-agent system with input saturation, which can solve the actuator with bounded in practice. Thirdly, in contrast to the existing results [15–19], in this paper the pinning control is used to group consensus control for heterogeneous multi-agent systems such that the agents in the same group can reach their desired consensus state.

The remainder of the paper is organized as follows. In Section 2, some preliminaries are briefly outlined. In Section 3, the main results of pinning group consensus of heterogeneous multi-agent systems are addressed. In Section 4, some simulation examples are presented to illustrate the theoretical results. And conclusions are finally drawn in Section 5.

2. Preliminaries and problem formulation

2.1. Preliminaries

The network topology of a system with n agents is modeled as a weighted undirected graph $\mathcal{G}=(\mathcal{V},\mathcal{E},A)$ where $\mathcal{V}=(v_1,v_2,\dots,v_n)$ is the set of nodes, $\mathcal{E}\subseteq\mathcal{V}\times\mathcal{V}$ is the set of edges, and $A=[a_{ij}]_{n\times n}$ is the weighted adjacency matrix. Denote $a_{ij}>0$ if $e_{ji}\in\mathcal{E}$ and $a_{ij}=0$ if $e_{ji}\neq\mathcal{E}$. An edge $e_{ij}=(v_i,v_j)\in\varepsilon$ shows that node v_j can receive information from node v_i. Suppose $N_i=\{v_j\,|\,e_{ji}\in\mathcal{E}\}$ is the neighbor set of node v_i. The Laplacian matrix $L=[l_{ij}]_{n\times n}$ of graph $\mathcal{G}$ is defined as

$$l_{ij}=\begin{cases}-a_{ij} & \text{if} \quad i\neq j\\ \sum\limits_{j=1,j\neq i}^{n}a_{ij} & \text{if} \quad i=j\end{cases}\quad i,j=1,2,\dots,n.$$

The degree of the node i can be defined as $\deg(i)=\sum_{j=1,j\neq i}^{n}a_{ij}$.

2.2. Problem formulation

Suppose the heterogeneous multi-agent system consists of l first-order agents, $m-l$ first-order agents with input saturation and $n-m$ second-order agents. Each first-order agent has the dynamics as follows

$$\dot{x}_i(t)=u_i(t),\quad i=1,2,\dots,l, \tag{1}$$

where $x_i(t)\in R$, $u_i(t)\in R$ are position vector and control input for the agent i respectively. Each first-order agent with input saturation has the dynamics as follows

$$\dot{x}_i(t)=u_i(t)=f_i(\cdot),\quad i=l+1,l+2,\dots,m, \tag{2}$$

where $f_i(\cdot)$ denotes the continuous function and it holds $|f_i(\cdot)|\leq c$ induced by actuator constraint. $x_i(t)\in R$ and $u_i(t)\in R$ are position vector and control input with input saturation for the agent i respectively. In addition, the dynamics of the second-order agent i is as follows

$$\begin{cases}\dot{x}_i(t)=v_i(t),\\ \dot{v}_i(t)=u_i(t),\end{cases}\quad i=m+1,m+2,\dots,n, \tag{3}$$

where $x_i(t)\in R$, $v_i(t)\in R$ and $u_i(t)\in R$ are position vector, velocity vector and control input for the agent i.

Remark 2.1. In this paper, all agents are supposed in one-dimensional space for convenience i.e., $x_i(t)$, $v_i(t)$, $u_i(t)\in R$. However, all results we have obtained exist in n-dimensional space by using the Kronecker product.

Suppose a multi-agent system consists of k subgroups with $k\geq 2$, and denote $\sigma_i=k$ if agent i belongs to the kth group.

Definition 1. The heterogeneous multi-agent system (1)–(3) is said to be reach k-group consensus ($k\geq 2$) if for any initial condition $x_i(0)$ and $v_i(0)$, we have

$$\lim_{t\to\infty}\|x_i(t)-x_j(t)\|=0,\text{if }\sigma_i=\sigma_j,\quad \forall i,j\in\{1,2,\dots,n\},\forall\sigma_i,$$