Available online at www.sciencedirect.com

ScienceDirect

Journal of the Franklin Institute 353 (2016) 4074–4090

Journal of The Franklin Institute

www.elsevier.com/locate/jfranklin

Admissible output consensualization control for singular multi-agent systems with time delays ☆

Jianxiang Xi[a], Ming He[a], Hao Liu[b,*], Jianfei Zheng[a]

[a]High-Tech Institute of Xi'an, Xi'an 710025, PR China
[b]School of Astronautics, Beihang University, Beijing 100191, PR China

Received 27 October 2015; received in revised form 4 April 2016; accepted 30 July 2016
Available online 5 August 2016

Abstract

Admissible output consensus design problems for high-order linear time-invariant singular multi-agent systems with constant time delays are dealt with. Firstly, based on the observability decomposition, a dynamic output feedback consensus protocol is proposed, which makes singular multi-agent systems satisfy some separation principle and can simplify admissible output consensus design problems. Then, LMI criteria for admissible output consensualization are presented, which can guarantee the regular and impulse-free properties of singular multi-agent systems directly. Moreover, an approach to determine the output consensus function is presented on the basis of the first equivalent form and the impacts of initial states of consensus protocols and dynamic agents are determined, respectively. Finally, numerical examples are shown to demonstrate theoretical results.

1. Introduction

By simple local interactions among a group of dynamic agents which is usually called multi-agent systems, complex global behaviors as a whole can be produced. The analysis of how those behaviors emerge is a very interesting research topic which attracted considerable attention from many different fields such as physics [1,2], biology [3,4] and engineering [5–8], etc.

☆This work was supported by the National Natural Science Foundation of China under Grants 61374054, 61503012 and 61263002, also supported by Innovation Foundation of High-Tech Institute of Xi'an under Grants 2015ZZDJJ03.
*Corresponding author.
E-mail address: liuhao13@buaa.edu.cn (H. Liu).

http://dx.doi.org/10.1016/j.jfranklin.2016.07.021
0016-0032/

Consensus is an important type of global behaviors of multi-agent systems, which means that a group of dynamic agents achieve agreement on certain variables of interest via some local rules constructed by information of neighboring agents. It is well-known that the communication delay is a critically important factor for multi-agent systems to achieve consensus. Bliman and Ferrari-Trecate [9] discussed average consensus for first-order multi-agent systems with a single constant time delay and gave necessary and sufficient conditions for average consensus. In [10], leader-following consensus problems for second-order multi-agent systems were dealt with, where time delays can be time-varying. In [11], the impacts of rationally-independent multiple time delays on consensus properties of second-order multi-agent systems were investigated, where both leaderless and leader–follower consensus protocols were applied. In [12], a new network-based leader–follower consensus protocol was proposed by introducing buffers to deal with time delays. Guo et al. [13] proposed an interesting event-triggered transmission strategy for sampled-data consensus. By linear matrix inequality (LMI) techniques, Xi et al. [14] presented consensus analysis and design criteria for high-order multi-agent systems with both time delays and external disturbances and pointed out that it is difficult to give the critical upper bound of time delays for general high-order linear time-invariant multi-agent systems. In aforementioned literatures, the dynamics of each agent is modeled by a normal system.

However, for some practical multi-agent systems, each agent can only be modeled as a singular system rather than a normal one. One example is a type of the transistor circuit shown in [15], which cannot be modeled by a normal system. Moreover, some singular multi-agent systems in practical engineering applications were presented in [16,17]. Xi et al. [16] considered guaranteed-cost consensus problems for singular multi-agent systems with switching topologies, where all state information of neighbors is needed to construct consensus protocols. Yang and Liu [17] presented some interesting results about consensus by static output feedback consensus protocols, where a special rank constraint which may restrict the applications of their results was required. In [18], LMI admissible consensus and consensualization conditions for singular multi-agent systems with state feedback consensus protocols were shown, where an approach was proposed to guarantee the scalability of multi-agent systems. In [16–18], the impacts of time delays on consensus were not dealt with and all the states were required to achieve consensus.

It should be pointed out that output consensus instead of state consensus is required in many practical multi-agent systems. Since outputs are partial states or linear combinations of states, output consensus is more complicated and challenging than state consensus. Output consensus problems for second-order normal multi-agent systems were investigated in [19]. Liu and Jia [20] proposed an H_∞ analysis approach to study output consensus for high-order normal multi-agent systems, where it was supposed that the dynamics of each agent is a high-order integrator. In [21], output consensus for single-input–single-output high-order normal multi-agent systems was discussed via the output regulation theory under the assumption that there do not exist communication delays among agents. By the partial stability method, output consensus analysis and design problems for general high-order linear normal multi-agent systems without time delays were dealt with in [22]. For singular multi-agent systems with each agent modeled as a transistor circuit shown in [15], some current parameter is required to achieve consensus but other parameters do not. This is a typical output consensus problem for singular multi-agent systems. Due to special structure properties of singular systems and the influences of communication delays, the approaches in [19–22] cannot be used to investigate output consensus of singular multi-agent systems. To the best of our knowledge, output consensus analysis and design problems of singular multi-agent systems with time delays are still not comprehensively investigated.